Factors Limiting Piping Plover Nesting Pair Density and Reproductive Output on
Long Island, New York

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

Doctor of Philosophy
In
Fisheries and Wildlife Sciences

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April 19, 2005
Blacksburg, VA

Keywords: Ornithology, Population Dynamics, Beach Renourishment

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ABSTRACT

Storm-created nesting habitat and low wave energy moist sediment
habitat (MOSH), such as intertidal sandflats, have long been considered
important to the recovery of the piping plover (*Charadrius melodus*), a federally
threatened shorebird. Beach renourishment is a common practice on the U.S.
Atlantic Coast for the protection of human property from storms, but it also
prevents normal MOSH formation. We examined factors limiting piping plover
nesting pair density and reproductive output on Atlantic Barrier Islands, 2001-
2004, including one site that had been breached by a storm in 1992, and
subsequently repaired and renourished by the U.S. Army Corps of Engineers.
We also investigated the short-term impact of beach renourishment at these
sites. Number of pairs at a site increased with beach area. Pair density
increased with MOSH availability at the site level. Home range size increased as
the distance from plover nests to MOSH increased. Home range size was
smaller for plovers with higher foraging rates in the territory-establishment period,
but this effect was most likely independent of distance to MOSH. Reproductive
output was not apparently related to availability of MOSH to adults or broods, and
was limited by predation.   Habitat widths, prey abundance, and brood habitat
selection changed at two of our sites after renourishment. However, similar
changes occurred in reference areas. Other research shows that in addition to

long-term loss of storm-created features, beach stabilization can lead to loss of habitat and low reproductive success due to human development and an increased presence of introduced predators. Management for recovery of this species should thus include permitting natural storm-mediated habitat creation to occur where feasible. However, since we found no direct negative short-term impact of renourishment on prey or habitat availability, habitat restoration via renourishment of eroded beaches could be a viable strategy for plover recovery, if negative indirect short and long-term effects are mitigated. Restoration projects should include restoration or creation of MOSH adjacent to nesting habitat, because MOSH attracts a high density of pairs and to offset long-term loss of storm-created habitat.   Human disturbance and predation must also be controlled at restoration sites.

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14 March 2005
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CHAPTER 1: FACTORS LIMITING PIPING PLOVER NESTING PAIR DENSITY ON LONG ISLAND, NEW YORK

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threatened shorebird. We examined factors limiting piping plover nesting pair

density on Atlantic Barrier Islands, 2001-2004, including one site that had been

breached by a storm in 1992, and subsequently repaired by the U.S. Army Corps

of Engineers. Nesting pair density on 8 beaches in New York and

Massachusetts increased with increasing ratio of area of MOSH within 300 m of

nesting habitat to area of nesting habitat (P = 0.007). At our New York sites,

local density increased and home range sizes decreased as the distance from the nest site to the nearest MOSH and storm-created "large MOSH" decreased. Home range size decreased as percent time spent in MOSH and foraging rate increased. Probability of a focal plover charging at or chasing another plover intruding to within 5 m increased with increasing distance from the plover's nest to the large MOSH, but percent time spent in aggressive behavior was higher for plovers with smaller home ranges than those with larger home ranges. Successfully reproducing birds were more likely to return than failed birds following one year of very poor reproduction, though whether this was due to mortality or emigration of failed birds is unknown. A small sample of second-year birds tended to nest farther from the large MOSH than older birds. Presumed heavy predation in certain habitat patches apparently resulted in territory abandonment, which may have depressed the local population size to below equilibrium density. Habitat creation and restoration plans should focus on creating large areas of nesting habitat, with a high ratio MOSH to nesting habitat. The MOSH should be within 300 m of the nesting habitat. Predators should be controlled at restoration sites. Such plans are currently under consideration by the U.S. Army Corps of Engineers as part of a larger storm-damage protection project covering 130 km of Long Island shoreline.

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The density of wild populations has been modeled as an increasing function of resource quantity and quality on the breeding grounds, and a decreasing function of territorial behavior (Fretwell 1972). Territory size is generally accepted as a proximate factor limiting population density in territorial birds (Newton 1992), where territorial behavior and size are functions of resource availability, level of competition, and individual traits (Hinde 1956, Newton 1992). Food is usually considered to be the primary resource affecting territoriality in wildlife, and food quantity, predictability, distribution, and quality have been the most extensively studied ecological correlates of territorial behavior (Maher and Lott 2000).

We hypothesized that on Westhampton Island, Long Island, NY, the availability of foraging habitat limits the nesting pair density of the piping plover (*Charadrius melodus*), a territorial shorebird that was listed as federally threatened in 1985 (Federal Register 1985). On Atlantic barrier islands with adequate nesting space, piping plovers disproportionately nested along beaches that were adjacent to intertidal mud flats or sand flats, or that contained ephemeral pools (Elias *et al.* 2000). This low wave energy moist sediment habitat (MOSH) provided more arthropod prey for foraging broods than did other cover types (Loegering and Fraser 1995, Elias *et al.* 2000, Houghton *et al.* 2000). Piping plovers also preferred to nest adjacent to MOSH in Maryland (Loegering and Fraser 1995), and foraging adults preferred MOSH to other cover types on

Monomoy Island, Massachusetts in the territory-establishment phase of the breeding season (Keane *et al.* in press).

The MOSH used by foraging plovers on narrow barrier islands is primarily created by storm-mediated sediment transport from the ocean beach to the lower wave-energy shoreline on the opposite side (Dolan *et al.* 1973). This process is interrupted by human stabilization and alteration of the islands (Leatherman and Allen 1985). On Westhampton Island, a peak in the population size of piping plovers from 1940-1942 was attributed to habitat created by the Hurricane of 1938 (Wilcox 1959). The plover population subsequently declined as humans developed the coastline (Wilcox 1959), including the construction of a high concentration of beachfront houses (Schubel *et al.* 1991) and a series of rock groins designed to prevent erosion on the ocean beach (Leatherman 1999). There were no known plover breeding activities at our primary study site, the village of West Hampton Dunes (WHD) on Westhampton Island, from 1983 to 1992 (Downer and Leibelt 1990, Elias-Gerken 1994). Five pairs of piping plovers colonized WHD after storms overwashed and breached the beach in the winter of 1992-93, washing away the road and most of the houses in the eastern half of the village. The birds nested on the newly-cleared backshore, and foraged on storm-deposited sandflats in Moriches Bay. After the the U.S. Army Corps of Engineers (USACE) rebuilt the beach (USACE 1994), the plovers also nested in the expanded ocean backshore and on the dune, and foraged on bayside sandflats along the margin of the reconstructed beach. From 1993 to 2000, the plover population increased to a peak of 39 pairs, after which it began to decline

(Cohen *et al.* 2003). In 2004, the population consisted of 18 pairs. The goal of this study was to determine factors that limited nesting pair density of this population. Such an understanding will aid managers seeking to increase populations of this threatened species (USFWS 1996).

At the landscape scale, we expected that piping plovers would respond to a greater food supply at beaches adjacent to MOSH by defending smaller territories and crowding them more densely. Such a relationship between nesting pair density and proximity to intertidal feeding areas was observed in oystercatchers (*Haematopus ostralegus*) in the Netherlands (Ens *et al.* 1992). We thus predicted that nesting pair density would increase with increasing area of available MOSH (excluding high wave energy ocean intertidal zone, which is relatively uniform in availability along the shore of Westhampton Island). At the scale of the habitat patch, we predicted that territory size would increase and local nesting pair density would decrease as the distance from an individual's nest to MOSH increased, as was also seen in oystercatchers (Ens *et al.* 1992). This relationship could arise either because plovers tolerate being confined to small home ranges by a high number of territorial neighbors in order to be close to a rich food supply, or because plovers range over and defend a larger area when food is scarce than when it is abundant (Hinde 1956). Lastly, we predicted that foraging rate would be higher for adults in MOSH in cover types with the highest prey abundance, as it was for plover chicks in other studies (Loegering and Fraser 1995, Elias-Gerken *et al.* 2000).

We recognized that if the abundance of prey was directly limiting plover populations, one would expect that the primary prey items of adults would be depleted as a result of foraging by plovers and their competitors (Martin 1986). To test whether such depletion was occurring, we performed a cage exclosure study in the MOSH at WHD in 2001 and 2002.

Predation risk also has been proposed as a correlate of territoriality (Maher and Lott 2000, Newton 1992), and as a factor limiting bird populations apart from territoriality (Newton 1994). Predation has impacted the reproductive success of the WHD plover population to varying degrees, sometimes severely (Houghton *et al.* in prep). In wintering shorebirds, predation risk has been shown to decrease spacing and increase anti-predator flocking behavior (Myers 1979, 1980). Myers (1980) acknowledged that predation pressure might instead have led to an increased tendency for individuals to space themselves out, thereby making hunting less profitable for predators. Since piping plovers are highly territorial in the breeding season, we expected that predation would affect nesting pair density in the latter manner, either through increased territory size of plovers that experienced predation, or abandonment of high-risk areas. We thus predicted that local nesting pair density would decline in areas where birds lost nests or broods to predators, and that returning birds that experienced predation the previous year would have larger territories and nest further from their previous year's site than returning successful birds. To summarize our hypotheses:

      1. Nesting pair density is higher at sites that have more MOSH

2. Within a breeding site, local density increases with increasing availability of MOSH

3. Territory size decreases with increasing distance to MOSH, because % time spent in nesting habitat increases, % time spent foraging decreases, and/or foraging rate decreases further from MOSH.

4. Aggressiveness of individual plovers increases with increasing distance to MOSH, and increases with decreasing % time spent foraging and decreasing foraging rate.

5. Benthic prey items are depleted by plovers and their competitors during the breeding season.

6. Successfully reproducing birds are more likely to return the following year than failed birds.

7. Failed birds have larger territories the following year

8. Young birds nest further from MOSH than older birds

STUDY AREA

We studied plover populations at WHD and several reference areas. The reference areas differed from WHD in the quantity of nesting and foraging habitat, and varied in proximity to WHD. The most abundant vegetation in the backshore and dunes at all sites was American beach grass (*Ammophila breviligulata)*, a native plant that is also planted by humans to curtail erosion. Sea rocket (*Cakile edentula*), Dusty Miller (*Senecio cineraria*), seaside goldenrod (*Solidago sempervirens*), and false heather (*Hudsonia tomentosa*) were the next

most common herbaceous plants. Depending on the site, woody vegetation on the dunes and upland portions of the bay shore was predominately beach rose (*Rosa rugosa*), poison ivy (*Rhus radicans*), and/or beach plum (*Prunus maritima*), and late successional areas included pitch pine (*Pinus rigida*), especially in areas of human development, possibly because these areas had the highest elevation..

     West Hampton Dunes.—WHD is located approximately 3 km east of Moriches Inlet on the Westhampton Barrier Island off the south shore of Long Island, New York (40°47' N, 72°43' W, Fig. 1). It is bounded by Moriches Bay to the north and the Atlantic Ocean to the south. The nesting area contained approximately 2.8 km of Atlantic Ocean beach and a 0.5-km long sand spit perpendicular to the island that was created in the 1992 storm. In 1996, the USACE expanded the oceanside backshore through beach nourishment and constructed an artificial dune along the entire length of WHD to prevent future property damage. In 2000, the USACE renourished the entire ocean beach. By 2004, the road and houses at WHD were largely rebuilt. The backshore, foredune, and dune areas were sparsely vegetated and provided nesting habitat for piping plovers. Houses and dense vegetation covered most of the bay backshore (including the sand spit), where most pairs had nested from 1993 until 2000, and no pairs nested in that area in 2004. Most pairs after 2000 nested on the ocean side of the artificial dune.

     Westhampton Beach.—Westhampton Beach (WHB) is located adjacent to WHD to the east (40°48' N, 72°39' W, Fig. 1). WHB was highly developed with

homes, beach clubs, and paved roads. The nesting area in our study contained 3.2 km of ocean beach between groin 7 in the east to groin 15 on the west, at the boundary with WHD. Residences in WHB south of Dune Road are separated from the backshore by a dune. The dune toe, foredune and ocean backshore were sparsely vegetated and provided nesting habitat for piping plovers. The upper dune areas were densely vegetated, and the Moriches Bay side of Dune Road was densely developed and densely vegetated by upland and salt marsh vegetation. A few small (< 1ha) intertidal flats were scattered along the length of the bay shore. In 1997, the USACE renourished the entire WHB study site. In 2000, they renourished the areas between groins 8-10 and 13-15, the eastern and western thirds of the site.

Cupsogue.—Cupsogue County Park (Cupsogue, 40°46' N, 72°45' W, Fig. 1) is located at the western end of Westhampton Island, and is bounded by WHD to the east and Moriches inlet to the west. It has a narrow ocean beach that affords some nesting habitat, backed by steep, vegetated dunes. The bay margin of the western half of the site is fortified with a rock revetment. A broad, flat area of sand covers the rock revetment except at its margin, and this bay backshore area is vegetated by upland plants. However, vegetation was cleared from the backshore (which was then named the "experimental area") in 1999 to create nesting habitat for plovers. Furthermore, three small artificial ephemeral pools were created within the experimental area in 1999 to enhance foraging habitat for broods. The bay side of the eastern half of Cupsogue contains vegetated dunes adjacent to extensive salt marshes and intertidal sandflats and

mudflats. That portion of the site contains a large pile of sand maintained by the

USACE as a reserve for beach nourishment, which often attracts a nesting pair

of plovers.

Shinnecock West.—Shinnecock West County Park (Shinnecock), contains

approximately 1.2 km of barrier beach at the eastern end of Westhampton Island

(40°51' N, 72°30'W, Fig. 1). This site is approximately 15 km east of WHD. The

inlet at Shinnecock was formed by the Hurricane of 1938, and was stabilized with

two jetties in 1956. Several subsequent hurricanes and northeasters moved

sediment along the bay shore and deposited a narrow band of intertidal sandflats

along the western two-thirds of the bay shoreline (Morang 2000). The site

contains nesting space only on the ocean beach, as the Shinnecock Bay side is

overgrown with dense herbaceous and woody vegetation.   The bay side of the

extreme eastern end of the park is a fishing cooperative, including commercial

docks and several restaurants. Beach use by off road vehicles (ORVs) is

prohibited at this site after Memorial Day, but illegal ORV traffic occurred at

Shinnecock on weekends during the plover nesting season, sporadically in 2001

and 2002 but more frequently in 2003.

Democrat Point.—Democrat Point (Democrat, 40°37' N, 73°18' W, Fig. 1)

is a large sandspit at the westernmost section of Robert Moses State Park on

Fire Island (Zadi 1997), west of a rock jetty. It is approximately 50 km west of

WHD. The site had interior sand flats and large tidal pools. Due to low elevation

(approximately 1.5m) the beach was prone to flooding and reshaping by storm

events during this study and over the winters. The nesting habitat consisted

mostly of open sand around the perimeter of the interior sandflats, interspersed with low, grassy dunes. Democrat was subject to recreational ORV traffic during the plover nesting season, until the first nest hatched. ORVs were restricted to a corridor along the ocean intertidal zone and an adjacent 10-20 m of ocean backshore, depending on the year.

South Monomoy Island.—Monomoy Island is an 8.3-km long barrier island in Massachusetts, located between the Atlantic Ocean and Nantucket Sound, approximately 240 km from West Hampton Dunes. The entire island is a National Wildlife Refuge, and is divided by an inlet into South Monomoy and North Monomoy. We included 3 beaches from South Monomoy in certain of our analyses. For further description of these sites, see Keane *et al.* in press.

METHODS

Data collection and processing

Nest density, distribution, and reproductive success.—We searched for plover nests daily from 15 March through 31 July, 2001 through 2003. Locations of all nests in WHD, WHB, and Shinnecock were recorded with a global positioning system (GPS) unit. Researchers observed plover nests daily to determine hatch dates and causes of nest or egg loss. At Democrat, New York State Park personnel and U.S. Fish and Wildlife Service contractors conducted all nest searching and brood monitoring, at least 3 times per week. At Cupsogue, Suffolk County Parks personnel did the same. Data on nest locations and survival were provided to Virginia Tech personnel during and at the end of the breeding season. Nesting pair densities at all sites were estimated by

classifying nesting habitat on true color 1:800 scale scanned aerial photos taken within 1 hour of low tide between April 20 and May 15 (Aerographics Corps., Bohemia, NY), using ArcView Image Analyst software (ESRI, Redlands, CA, 2001) and calculating the number of nesting pairs / unit area of nesting habitat. Aerial photos were georeferenced using rubber sheeting, based on 2001 New York State digital orthophoto quads, with at least 20 ground control points and a root mean-squared error of 5 m or less. We classified habitat by drawing polygons by hand on the georeferenced photos. We considered any open dry sandy or sparsely vegetated areas >5 m from houses to be nesting habitat, but excluded patches we knew from our fieldwork to be unsuitable (e.g., heavily impacted by construction traffic or flooding). In 2002 and 2003, we obtained population data and aerial photos from three beaches on South Monomoy Island, MA, to compare quantity of nesting habitat and MOSH, and population density with our sites. Monomoy National Wildlife Refuge of the USFWS provided us with nest location and survival data. For each site, we calculated chicks fledged / nesting pair.

We also classified MOSH on the aerial photos by drawing polygons by hand, including intertidal sandflats, mudflats, other low-wave energy portions of the bay intertidal zone, and ephemeral pools. We estimated the extent of the MOSH that was available to nesting plovers using data on travel distances between nests and MOSH foraging locations, as follows. In ArcView, we calculated the median distance traveled by each marked male plover from its nest site to MOSH during the 2002 and 2003 breeding seasons. Males were

used because females often abandoned their broods before fledging, after which they spent their time on MOSH far from their nest sites. Since larger beaches tend to have more MOSH, we calculated a "MOSH Index" for each beach as area of MOSH (ha) / area of nesting habitat (ha).

Using ArcView, we created a 600-m radius circular buffer zone around the location of each first nest attempt at WHD and WHB. This buffer distance was chosen based on a quadrat method for spatial pattern analysis (Appendix A, Krebs 1999) that indicated 600 m to be the scale at which plover nests showed the most clustering. Within the circle, we determined the number of neighboring nests and the hectares of nesting habitat. For each nest, we calculated "neighbor density" as no. of neighbors within 600 m (including the focal nest) / quantity of nesting habitat within 600 m. Since measuring territory size for piping plovers is difficult, we used neighbor density as on indicator of territory size, since we expected the number of neighbors within a fixed distance from a focal pair would decrease as territory size increases. In ArcView, We divided the combined WHD-WHB site into 600 m segments, and calculated "local density" in each segment as no. nests / hectares of nesting habitat. We also calculated a MOSH index for each segment, as above.

We calculated the distance from each nest to the nearest shoreline of bayside MOSH, and to the shoreline of the large contiguous area of MOSH created by the storm of 1992 and subsequent breach repair (hereafter "large MOSH", approximately 25 ha).

   Adult habitat use, behavior, and home range.—We captured adult plovers prior to nesting using noose carpets (Mehl *et al.* 2003, Drake *et al.* 2001) and walk-in funnel traps. Funnel traps were constructed of a 76-cm diameter x 61-cm high chickenwire corral with a bird-netting roof, or a 91-cm diameter circle of bird-netting stretched on a wire frame and bent into a funnel shape, and two 7.6-m x 61-cm chickenwire drift fences, formed into a shallow "V" (~ 170° angle) to act as lead lines. During incubation, adult plovers were captured on their nests with box traps (Wilcox 1959) and funnel traps, without the lead lines (Paton 1994).   Birds with nests inside predator exclosures were captured by driving them into a funnel trap facing into the exclosure on one side, with chickenwire drift fences blocking escape on either side of the funnel.

   We applied a single plastic numbered color-band to both tibiotarsi on each bird. Each adult plover was marked with a unique color combination. We captured chicks on hatch day, and in 2002 and 2003 each chick was banded in a similar manner to the adults, except that all members of the same brood were assigned the same color combination, and individuals were identifiable only by band numbers.

   For all returning plovers banded in a previous year, we used an instantaneous sampling method to estimate the % time adults spent in different cover types (Table 1) and behaviors (foraging, resting/preening, courtship, intraspecific aggression, other) prior to nest initiation (Altman 1974, Lehner 1979, Tyler 1979). At WHD, WHB, and Shinnecock, we considered the dune to be the boundary between the ocean and bay zones. At Democrat, "ocean side" cover

types extended from the ocean intertidal zone to the dune line, "interior" cover types extended from the ocean-side toe of the dune line to the bayside toe of the dune line, and "bay side" cover types extended from the bayside toe of the dune to the bay intertidal zone. We recorded cover type and behavior continuously for 5 min on a tape recorder. Later, we sampled cover type and behavior from the tape every 10 s.

We used a continuous sampling method to score the aggressiveness of individual birds (Maxson 2000). During each 5-min behavioral observation, we recorded each "intrusion" (i.e., each instance in which another bird came within 5 m of the focal adult) and recorded the focal adult's reaction (Alertness, Agitation, Charge, Chased Intruder, Chased by Intruder). If a chase occurred, we recorded the chase distance. We calculated aggressiveness as "number of reactions" / "number of intrusions", averaged for each plover during the pre-nesting period. We discerned if the intruder was the focal bird's mate based on courtship behavior and tendency to remain paired despite flock dynamics, and we excluded mates from consideration as intruders.

We used a continuous sampling method to estimate foraging rates for adults (Tyler 1979, Tacha *et al.* 1985) prior to nest initiation. During the 5-min observation, we continuously recorded pecks and worm pulls. We calculated foraging rate (attempts/min) as "number of foraging attempts" (pecks and pulls) / "observation time" (number of 10-s intervals x 10 s x 60^{-1}). Similarly, we calculated the number of worm pulls/min. This foraging rate was based on entire 5-min observations, and thus included time in which the bird was not foraging.

We also calculated a foraging rate "while foraging" as "number of foraging attempts" / "estimated time spent foraging" (number of 10-s intervals in which the bird was foraging x 10 s x 60^{-1}). If a focal bird was seen to peck at the same prey item multiple times, only one attempt was recorded.

We searched for color-marked birds every day in all potential plover habitats from March 15 to August 15, 2002 and 2003. The location of a marked bird was computed by recording the location of the observer using a GPS unit, using a compass to obtain a bearing to the plover, estimating the distance from the observer to the bird, and later calculating the bird's location using Euclidean geometry in the "Distance and Azimuth Tools" extension of ArcView. Field crew members were provided with aerial photos of each field site depicting distances between landmarks visible in the field, as a distance estimation aid. We computed 50% and 95% home ranges using fixed kernel estimates in the Animal Movements Extension (Hooge, Anchorage, AK 1997), for all plovers with ≥ 20 sightings, using least-squares cross-validation (LSCV) to determine the smoothing parameter (h). We chose 20 sightings because a graph of home range size vs. number of sightings indicated that home range size estimates stabilized after 20 sightings. Each home range was overlayed on nesting habitat polygons to calculate the hectares of nesting habitat within the home range. We used 95% and 50% home range sizes as indicators of territory size, since we could not measure territory size directly and we expected that home range size would increase with territory size.

Return rates.—We calculated return rates each year by dividing the number of returning marked birds in year t by the number carrying marks in year t-1. We determined return rates separately for males and females, and for second year (SY, those that hatched in the previous breeding season) and after second year (ASY, those that hatched prior to the previous breeding season) birds.

Sediment characteristics and exclosure cages.— In 2001 and 2002, we placed exclosure cages (1-m x 1 m x 0.3 m iron frame, 1.3-cm mesh plastic bird netting sides attached to frame with plastic cable ties) on 6 randomly chosen plots on the MOSH at WHD. Cages were anchored to 1.3-cm iron rebar at each corner with plastic cable ties. We sampled sediment from the 6 caged plots (10 cm diameter x 2 cm deep PVC core sampler), 6 paired cage control plots (frames only), and 6 paired control plots (no cage or frame), in March as the plovers were arriving. We sampled sediment from each plot again in late May or early June as plover eggs were hatching.

We sorted benthic organisms out of the sediment samples and counted them by the categories of large worm ($\geq$ 2 cm length), small worm, worm tube, worm fragment, insect larva, crustacean, and, tiny organism ($\leq$ 1 mm length), and "other". We then dried each organism sample (= all individuals in a particular category from a particular sediment sample) at 60 °C for 48 h and weighed it (nearest 0.1 mg).

Data analysis

We used regression and correlation to analyze simple linear relationships between continuous variables. Where data did not conform to normality assumptions, we used Spearman rank correlations. For analyses with a spatial component (e.g., relating neighbor density to distance from nests to MOSH), we compared mixed models incorporating an exponential spatially-autocorrelated variance structure (random effect = nest location) to a fixed-effects model with a diagonal variance structure, using Akaike's Information Criterion (AIC). If the $AIC_{fixed} - AIC_{mixed} \geq 2$, (Burnham and Anderson 2002), we used the mixed model to evaluate our main effect.

We hypothesized that distance to MOSH might influence territory size indicators either by affecting foraging rate or habitat use. Thus, we designed a path analysis (Sokal and Rohlf 1980) to model these potential effects and to incorporate correlations among them. We constructed several path models containing the above variables as systems of linear equations. We solved these systems using PROC CALIS in SAS (SAS Institute, Cary, NC 2001) to obtain path coeffiecients (standardized partial regression coefficients, which represent the relative strength of each effect in the model) and goodness-of-fit statistics (Pearson χ^2, which tests the fit of a particular model against that of the global model). We evaluated the probability of a particular model being correct using AIC_c, Δ_{AIC}, and model weights (ω_i, Burnham and Anderson 2002). We computed AIC_c as AIC + $[2 \times K \times (K + 1)] / (n - K - 1)$, where AIC was calculated in PROC CALIS as $\chi^2 - 2df$, and $df = [(p \times (p+1)]/2 - K]$, p = the number of variables in the

model, K = the number of path coefficients and variance parameters being estimated, and n = sample size.   The equation for our global model was:

$$y = \beta_{y1}\, x_1 + \beta_{y2}\, x_2 + \beta_{y3}\, x_3 + e_1,$$

where y = an indicator of territory size (neighbor density or home range size), x_1 = distance from nest to MOSH (m), x_2 = foraging rate (attempts/min), and x_3 = % use of a particular cover type, and the x variables were not assumed to be independent (i.e., we modeled the variance-covariance matrix). We tested the global model against sub-models in which either β_{y2} or β_{y3} was set equal to zero, and against the following structural model in which x_2 and x_3 were considered to be functions of x_1 (after Lea and Webley 1997):

$$y = \beta_{y2}\, x_2 + \beta_{y3}\, x_3 + e_1,$$

$$x_2 = \beta_{21}\, x_1 + e_2,$$

$$x_3 = \beta_{31}\, x_1 + e_3.$$

We also tested sub-models of the above structural model in which either β_{y2} or β_{y3} was set equal to zero, and the equation for the corresponding x variable was not included. Finally, we included an "independence model", or null model, in which the covariance between each pair of variables was set to 0.

RESULTS

Nest Initiation

The first plovers were recorded between 14 March and 19 March at WHD, between 21 March and 1 April at WHB, and between 19 March and 28 March at Shinnecock. Surveys were not conducted frequently enough at Democrat in the arrival period to assess dates, although plovers were always seen on our first

survey between 1 April and 10 April. Nesting commenced between 17 April and

5 May, depending on the site and year (Appendix B).

Nesting pair density and habitat

An exponential distribution ($\theta = 0$, $\sigma = 441.3$) fit the sample of median

distance traveled between nests and MOSH foraging locations of male plovers

(Cramer-von Mises test, $P = 0.18$, $n = 28$). The median of this distribution was

300 m. Accordingly, we used 300 m circle around nesting areas for selecting the

area of MOSH most likely to be visited by plovers. Number of pairs, nesting pair

density, area of nesting habitat (ha), and area of MOSH within 300 m of nesting

habitat (ha) were higher at WHD than the other Long Island sites in all years

(Table 2).   Estimated area of ocean intertidal zone was highest at WHB in all

years (Table 2).

Site nesting pair density and MOSH.—Mean density of piping plover

nesting pairs increased with mean MOSH index for 5 sites on Long Island, NY

(measured each year for 3 years) and 3 sites on Monomoy Island, MA

(measured each year for 2 years, Fig. 2). Pairs/km of nesting beach also

increased with MOSH index ($r^2 = 0.93$, $F_{1,6} = 81.4$, $P < 0.001$). Number of

nesting pairs increased with area of nesting habitat (Fig. 3), but pairs/km of

beach did not ($r^2 = 0.08$, $F_{1,6} = 0.46$, $P = 0.52$). Mean pairs/ha of nesting habitat

and mean pairs/km of beach were correlated ($r = 0.75$, $P = 0.030$, $n = 8$).

Local density and MOSH.—Mean density of piping plover nesting pairs

within 600-m segments of barrier island increased logarithmically with increasing

MOSH index (Fig. 4).

Home range and neighbor density

The statistical LSCV method for selecting h for home range calculations resulted in unrealistically large, ellipsoid home ranges for plovers, probably because the LSCV method was sensitive to outliers in the distribution of bird locations. Therefore we used custom values for h calculated as half the average distance between neighboring first nests (h = 42 m in 2002, 60 m in 2003). These custom h values resulted in home ranges that traced the clusters of plover observations much more closely than those using an h calculated from LSCV. Members of a pair were usually observed together, and thus did not have independent home ranges. We therefore pooled locations for members of the same pair, but deleted duplicate locations, when calculating home ranges. We also averaged behavioral data (activity budget, habitat use, foraging rate) for members of a pair in subsequent analyses. Shinnecock home ranges were not included in the following analyses because we had < 20 observations for all birds from that site. Home range sizes and area of nesting habitat within home ranges were greater in 2003 than in 2002 (Table 3). Because our sample size of home ranges for each year was small, we still desired to pool years in order to increase our sample size for subsequent analyses. In doing so, we also recognized that we were treating 9 birds that were observed in both 2002 and 2003 as different samples from one year to the next. To test the hypothesis of no bird effect, we performed a Monte Carlo permutation test (Manly 1997) to compare the difference in home range size of returning birds to the difference in size between randomly selected home ranges from 2002 and 2003. Of the 9 birds, we used

only the 3 that nested outside of their 95% home range of the previous year to avoid confounding the bird effect with a location effect. We sampled 3 home range size differences from a set of 345, for 1000 replicates. The probabilities for observing the home range difference (or less) of our 3 returning birds was 0.082 for 50% home range, 0.381 for nesting habitat within 50% home range, 0.124 for 95% home range, and 0.349 for nesting habitat within 95% home range. Since all P-values were > 0.05, we were satisfied that there was no significant bird effect. Neighbor density within 600 m of nests was correlated with total (95%) home range (Spearman's ρ = -0.38, P = 0.024, n = 36), and hectares of nesting habitat within 95% home range (Spearman's ρ = -0.63, P < 0.001), 50% home range size (Spearman's ρ = -0.46, P = 0.005), and hectares of nesting habitat within 50% home range (Spearman's ρ = -0.59, P < 0.001).

Distance to foraging areas.—Neighbor density of nests in each year was greater for breeding sites closer to the large MOSH, although the relationship was logarithmic and became less steep as distances to MOSH neared 300 m (Fig. 5). Neighbor density of nests was also higher for breeding sites closer to any MOSH, regardless of MOSH area, in every year (Fig. 6).

AIC values for mixed models of home range size as a function of distance to MOSH were not different than for fixed-effects models, so we used models without spatial autocorrelation. However, analysis of residuals indicated that the normality assumption of linear regression was violated, so we analyzed these relationships with Spearman rank correlations. With years pooled (n = 38 individuals or pairs), 95% home range size was not correlated with distance to

large MOSH (Fig. 7) or distance to nearest MOSH (r = 0.22, P = 0.18). There

was more nesting habitat within the 95% home range in breeding sites far from

the large MOSH (Fig. 7) and far from the nearest MOSH (r = 0.40, P = 0.013).

Fifty percent home range size was greater farther from the large MOSH (Fig. 8),

but was unrelated to distance to nearest MOSH (r = 0.19, P = 0.26). There was

more nesting habitat within 50 % home ranges at sites farther from the large

MOSH (Fig. 8) and the nearest MOSH (r = 0.37, P = 0.024).

Habitat Use.—The amount of nesting habitat within 95% home ranges

was higher for birds that spent a higher % of their time in the ocean backshore

prior to nesting, both within 3 h (where h = hours, not the scale parameter for the

kernel home range estimators) of high tide (Fig. 9) and low tide (Spearman's ρ =

0.53, P = 0.012, n = 22). Amount of nesting habitat within 95% home ranges

was lower for birds that spent more time in the bay intertidal zone within 3 h of

high tide (Fig. 9).

Fifty percent home range size was higher for birds that spent a greater %

of time in the ocean intertidal zone within 3 h of high tide, prior to nesting

(Spearman's ρ = 0.51, P = 0.022) and a smaller % of time in the bay intertidal

zone (Spearman's ρ = -0.46, P = 0.043). Plovers also had more nesting habitat

within the 50% home range the greater % time they spent in the ocean intertidal

zone (Spearman's ρ = 0.52, P = 0.018) and the less % time they spent in the

bay intertidal zone (Fig. 10).

Neighbor density of neighboring nests was greater for birds that spent a

higher % of time in the bay intertidal zone within 3 h of low tide prior to nesting,

in 2003 (mixed-model with spatial autocorrelation, $F_{1,14}$ = 41.89, P < 0.001, n = 16). The relationship was not significant in 2002 ($F_{1,16}$ = 3.99, P = 0.06, n = 21).

Based on daily surveys from the first date a plover was sighted to nest initiation, plovers that nested further from the large MOSH were more commonly observed on their upland breeding site than plovers that nested closer to the large MOSH (Spearman's ρ = 0.44, P = 0.005, n = 39). We found no relationship between any home range size measures and proportion of surveys in which a bird was sighted in its prospective territory prior to nesting. Neighbor density of nesting pairs was lower for plovers that spent a greater proportion of time near the prospective nest site prior to egg-laying in 2003 (regression with spatial autocorrelation, $F_{1,13}$ = 14.1, P = 0.002, β_0 = 0.87±0.11, β_1 = -0.81±0.22, n = 17), but not in 2002 ($F_{1,17}$ = 0.01, P = 0.91, β_0 = 1.03±0.19, β_1 = -0.07±0.56, n = 22).

Activity Budgets.—Birds with smaller 50% home range sizes and less nesting habitat within the 50% home range spent a greater % time in aggressive behavior than birds with larger home ranges (Spearman's ρ = -0.55, P = 0.014, n = 19 for both relationships). There were no other significant correlations between home range size measures and % time adult plovers spent in any behavior.

Neighbor density was lower for birds that spent a higher % of their time foraging prior to nesting in 2002 (regression with spatial autocorrelation, $F_{1,17}$ = 18.1, β_0 = 1.14±0.18, β_1 = -0.66±0.15, P < 0.001, n = 23) but the relationship did not hold in 2003 ($F_{1,14}$ = 1.2, β_0 = 0.58±0.11, β_1 = 0.22±0.20, P = 0.29, n = 18).

Foraging rate.—There was more nesting habitat in the 95% home ranges of birds with lower foraging rates in the pre-laying period (Fig. 11), as well as lower foraging rate while foraging (Fig. 11), fewer worm pulls/min (Spearman's ρ = -0.47, P = 0.025, n = 23), and fewer worm pulls/min while foraging (ρ = -0.44, P = 0.042, n = 22). Fifty % home range size was larger for birds with fewer worm pulls/min (Spearman's ρ = -0.46, P = 0.028, n = 23) and worm pulls/min while foraging (Spearman's ρ = -0.46, P = 0.032, n = 22) in the pre-laying period. There was more nesting habitat within the 50% home ranges of birds with lower foraging rates (Fig. 12), and foraging rates while foraging (Fig. 12) in the pre-laying period. Neighbor density was not related to any foraging rate measures (2002 and 2003 modeled separately, with spatial autocorrelation).

Correlations among explanatory variables.—There were many correlations among % time foraging and resting, foraging rate, and distance to large MOSH and nearest MOSH (Table 4). Plovers that nested further from MOSH spent more time in the ocean backshore and less time in the bay intertidal zone, spent less % of their time foraging and greater % resting, and had lower foraging rates.

Path analysis.—We chose the variables for our path models based on *a priori* hypotheses, but chose the following measures for each variable based on single correlation analyses between *y* and each *x*:

y = neighbor density (pairs/ha within a 600-m of a focal nest), nesting
habitat within 50% and 95% home range

x_1 = ln(distance from first nest to large MOSH)

x_2 = foraging rate while foraging (attempts/min foraging)

x_3 = % use of non-MOSH habitat while foraging

The model that best explained neighbor density included a direct negative effect of distance to MOSH and a direct positive effect of % use of non-MOSH habitat (ω_i = 0.48, Fig. 13). The effect of distance was over 3 times greater than the effect of habitat use. Two other models had some support (Δ_{AIC} < 2, Burnham and Anderson 2002) with a combined ω_i of 0.52 (Fig. 13). We obtained similar results for 50% home range size, except that the best model included a strong direct effect of distance to MOSH and weak direct effect of foraging rate (ω_i = 0.40, Fig. 14). For 95% home range size, the model containing direct effects of distance to MOSH and foraging rate also had the most support (ω_i = 0.40, Fig. 15), but the effect of distance was only 0.25 times that of foraging rate. Three other models also received support with a combined ω_i of 0.50, one of which contained an indirect effect of distance to MOSH via foraging rate (Fig. 15). In that model, the total effect of distance to MOSH was (-0.54 x -0.58) = 0.31, much less than the observed correlation of 0.78.

Aggressive Behavior

Males and females observed > 100 m from their nest were equally likely to exhibit alertness or agitation or to charge at or chase intruding plovers, and were equally likely to be chased by an intruder (Wilcoxon rank-sum tests, all P > 0.1, Table 5). There was no difference in the distance males and females chased intruders, or the likelihood that a male or female would respond to a intruder > 5 m away (Wilcoxon rank-sum tests, all P > 0.1, Table 5). With sexes pooled, plovers were no more likely to exhibit one type of response than any other, and

were as likely to be chased by an intruder as to chase one (Wilcoxon signed-rank

tests, $P > 0.05$ for all comparisons).

Home Range and Neighbor Density.—We found no correlation between

50% and 95% home range measures and responsiveness of plovers to intruding

plovers ($n = 14$). In 2002, probability of responding to an intruder with alertness

or agitation (where those 2 probabilities were summed for each bird) was higher

for birds living in areas with higher neighbor density (regression with

autocorrelation, $F_{1,10} = 27.4$, $\beta_0 = 1.0\pm0.2$, $\beta_1 = -0.7\pm0.1$, $P < 0.001$, $n = 14$).

There was no relationship between neighbor density and other measures of

responsiveness to intruders.

Distance from nests to MOSH.—Birds that nested farther from the large

MOSH were more likely to charge or chase an intruder than birds that nested

closer to the large MOSH, when observed > 100 m from their nest ($r = 0.50$, $P =$

0.04, $n = 18$). There were no other correlations between frequency of behavioral

responses to intruders and distances from the nest to the large MOSH or nearest

MOSH.

Activity budget and foraging rate.—Considering only birds that were > 100

m from their nests when responses to intruders were recorded, birds were more

likely to exhibit alertness when an intruder neared as the % time spent in "other"

behaviors (primarily non-foraging locomotion) increased ($r = -0.55$, $P = 0.02$, $n =$

18). Probability that a plover would charge at an intruder increased with the

mean percent time the plover spent in "other" behaviors or reacting to

disturbance, when these two proportions were summed ($r = 0.50$, $P = 0.03$, $n =$

18). There were no correlations between probabilities of responses to intruders

and any measures of foraging rate (attempts/min or worm pulls/min).

Prey Depletion

There was no evidence that changes in benthic organism abundance

(Table 6) or biomass (Table 7) in exclosed plots between March and June were

significantly different than changes in control plots. Furthermore, there were no

plots in either year in which abundance of a particular category of organism

decreased in the cage control and/or control while increasing or staying at the

same level in the corresponding exclosure.

Nest success, distribution, and nesting pair density

Return rates for marked ASY plovers breeding in the study area (WHD,

WHB, Cupsogue, and Shinnecock pooled) in the previous year were 72.2%

(26/36) in 2002, 51.2% (22/43) in 2003, and 57.4% (27/47) in 2004. These return

rates do not include plovers that were sighted during spring or fall migration but

did not breed in the study area.   Return rates were not significantly different by

year, with sites pooled (χ^2 test, χ^2_2 = 3.7, P = 0.15, n = 126). There were no

differences in site-specific return rate among the sites, with years pooled (χ^2 test,

χ^2_2 = 1.2, P = 0.56, n = 124).

Female and male ASY plovers had statistically similar return rates in 2002

(F = 70.8%, M = 75.0%, n = 24F + 12M, Fisher's Exact Test, P = 1.000), 2003 (F

= 52.0%, M = 50.0%, n = 25F + 18M, P = 1.000), and 2004 (F = 50.0 %, M =

72.7%, n = 22F + 25M, P = 0.386). Therefore, sexes were pooled in subsequent

analyses.

Nest success and return rate.— There was no difference in return rate between ASY plovers that hatched at least 1 egg and those that did not, in any year or with years pooled (WHD, WHB, Shinnecock, and Cupsogue pooled, Table 8). There was no difference in return rate between ASY plovers that fledged at least 1 chick and those that did not, by year or with years pooled (Westhampton Island sites pooled), except birds that successfully fledged a chick in 2003 were more likely to return in 2004 than those that failed (Table 8).

   With years pooled, we found no difference in return rates for plovers that nested successfully after 1 attempt (23/32, 71.9%), plovers that nested successfully after multiple attempts (12/21 = 57.1%), plovers that failed and had only 1 attempt (19/38 = 50.0%) or plovers that failed and had multiple attempts (21/35 = 60.0%, χ^2_3 = 3.5, P = 0.320, Westhampton Island sites pooled).

Interyear movement.—For returning birds, there was no difference in the mean distance between the last nest attempt in 2001 and the first nest attempt in 2002 for plovers that nested successfully in 2001 (228.0±99.8 m, $n = 15$) and those that failed (294.5±133.0 m, $n = 11$, Wilcoxon two sample test, P = 0.72). There was also no difference in distance moved between 2002 and 2003 for plovers that succeeded in 2002 (286.0±99.2 m, $n = 11$) and those that failed (448.5±218.4 m, $n = 11$, P = 0.60). The same result held for distances moved between 2003 and 2004 for birds that succeeded in 2003 (103.7±45.7 m, $n = 9$) and those that failed (282.2±80.9 m, $n = 18$, P = 0.15). No significant differences were found when males and females were considered separately, for any year.

Home range.—Birds that bred successfully in 2002 had a larger 95% home range in 2003, in terms of total area (mean change = 8.3 ± 2.3 ha, $n = 6$, 1 sample t-test, t_5 = 3.7, P = 0.015) and nesting habitat within the home range (mean change = 1.9 ± 0.3 ha, $n = 6$, t_5 = 5.6, P = 0.003). Birds that failed in 2002 did not have significantly larger 95% home ranges in 2003 in terms of total area (mean change = 8.5 ± 3.9 ha, $n = 3$, t_2 = 2.9, P = 0.16) or nesting habitat within 95% home range (mean change = 2.1 ± 1.9 ha, $n = 3$, t_2 = 1.1, P = 0.39). Fifty percent home range size increased significantly between 2002 and 2003 for successful breeders (mean change = 0.95 ± 0.35 ha, $n = 6$, t_5 = 2.5, P = 0.04), but not for failed breeders (mean change = 0.66 ± 0.19 ha, $n = 3$, t_2 = 3.5, P = 0.07). Nesting habitat within 50% home range did not change for successful breeders (mean change = 0.41 ± 0.19 ha, $n = 6$, t_5 = 2.1, P = 0.09) or failed breeders (mean change = 0.65 ± 0.28 ha, $n = 3$, 1 sample t-test, t_2 = 2.3, P = 0.15).

Neighbor density.—Birds that nested successfully in 2001 tended to nest in areas with a higher neighbor density in 2002 (mean change = 0.21± 0.08 pairs/ha within 600 m, $n = 15$, 1 sample t-test, t_{14} = 2.6, P = 0.02). Birds that failed in 2001 nested in areas with similar neighbor density in 2002 (mean change = 0.06 ± 0.07 pairs/ha within 600m, $n = 10$, t_9 = 0.9, P = 0.41). Neighbor density did not significantly change between 2002 and 2003, either for plovers nesting successfully in 2002 (mean change = -0.18± 0.09 pairs/ha within 600 m, $n = 11$, t_{10} = -1.9, P = 0.09) or those that failed (mean change = -0.23± 0.13 pairs/ha within 600 m, $n = 11$, t_{10} = -1.8, P = 0.10).

Age Effects

Of 28 plover fledglings banded in 2002 in WHD and WHB, 3 returned to breed at those sites in 2003, a 10.7% return rate for SY birds. Thus, 3 out of 25 returning plovers were SY birds (12.0%). Of 16 fledglings banded in 2003 in WHD and WHB, 1 returned to breed at those sites in 2004, a 6.2% return rate. Thus, 1 out of 28 returning plovers in 2004 were SY birds (3.5 %). No chicks banded in 2002 were observed in 2004.

Distance to MOSH and neighbor density.—   There was no difference in the distance from the nest to the nearest MOSH between SY and ASY birds in 2003 (Table 9). SY birds nested farther from the large MOSH than ASY birds (Table 9). SY plovers did not nest in areas with different neighbor densities than ASY birds in 2003 (Table 9).

DISCUSSION

We based our hypothesis that MOSH availability affects nesting pair density of piping plovers on studies that identified the presence of MOSH as a factor predicting the presence of plovers at breeding sites (Elias-Gerken *et. al* 2000) and wintering sites (Johnson and Baldassarre 1990), and a demonstrated preference for MOSH by foraging broods in New York (Elias-Gerken *et al.* 2000). A preference for MOSH also has been documented for foraging adults in the territory establishment phase of the breeding period in MA (Keane *et al.* in press) and at our NY sites (Appendix C).

We found evidence at two spatial scales to support our hypothesis. Among breeding beaches, those with a higher MOSH index had a higher pair

density, and within our WHD-WHB site, local density increased with MOSH

index. The MOSH may have differed among sites in other aspects besides area.

At WHD (our New York site with the highest breeding density and largest area of

available MOSH), sediment grain size and chemistry were similar to that at our

other sites, with the exception of P and K concentrations, which were higher at

Democrat (Appendix E). An adjacent golf course at Democrat may explain the

high concentration of those nutrients, as they are common elements in lawn

fertilizer. Density of small (< 2 cm) polychaete worms in Spring at WHD was

lower than at the other sites (Appendix E). However, WHD was the only site

where we found large (≥ 2 cm) polychaetes (Appendix E). A study of energy

intake and the size of polychaete prey taken by plovers at each site would shed

more light on whether MOSH differs among sites in quality as well as quantity.

At the scale of the habitat patch, neighbor density was higher and home

range size smaller closer to MOSH, and this effect was greater when only the

large MOSH was considered.   This was similar to findings for oystercatchers

(*Haematopus ostralegus*) in the Netherlands, which had dense, compressed

territories adjacent to tidal flats, but larger, more diffuse territories 200-500 m

further inland (Ens *et al.* 1992). In contrast, Plissner *et al.* (2000) found no

relationship between home range size and distance to the nearest waterbody

(the shoreline of which provided foraging habitat) for killdeer (*Charadrius

vociferous*) in the Great Basin of the United States, although killdeer also forage

in upland habitat. In non-shorebird species including sparrowhawks (*Accipiter

nisus,* Newton 1997), wild turkeys (*Meleagris gallopavo*, Cobb 1990, Badyaev *et*

al. 1996), and ruffed grouse (*Bonasa umbellus*, Whitaker 2004) home range has been demonstrated to be smaller where food is abundant than where it is scarce.

The benthic organisms in MOSH may be the most abundant prey for plovers when the birds arrive at the start of the breeding season. In March and April, adult arthropods have yet to emerge in appreciable numbers in upland habitat (Houghton *et al.* in prep). We found that in early spring at WHD, grassy upland cover types yielded more adult than other cover types (Appendix D), but the abundance was very low compared to that in all cover types later in the season (Chapter 3). We observed that it is these adult arthropods upon which the plovers feed when they forage within their nesting territory. Furthermore, coleopterans and dipterans were the primary prey items found in the feces of plovers foraging in upland habitat in Quebec (Shaffer and Laporte 1994). However, during behavioral observations it is usually difficult to discern the exact type of prey taken, and whether a particular foraging attempt is successful.

It is generally accepted that bird populations can be limited by food availability (Newton 1994) and proximately by territorial behavior (Newton 1992). We assumed that as a territorial species, territoriality would play a role in limiting piping plover density at our site. We did not find depression of the benthic prey base by foraging plovers and their competitors (although our sample size was small), which is one prerequisite line of evidence that food itself (or food availability) is the proximate factor limiting population density (Martin 1986). The number of worms did drop considerably in the WHD MOSH between Spring and Summer of 2002, but that was also true within our cage exclosures, so it appears

that predation was not the factor causing the decline, unless our exclosures failed in a way we did not detect.

Territory size may become compressed in areas where high food abundance attracts a large population of birds, as was seen with grey plovers (*Pluvialis squatarola*) wintering in South Africa (Turpie 1995). In such a case, territoriality mainly acts to maintain spacing among individuals. Alternatively, birds may calibrate their territory sizes to resource availability regardless of competition. This was demonstrated with oystercatchers (*H. ostralegus*), which defended smaller territories in higher quality than in lower quality habitat, even in the absence of competition (Vines 1979).

Our correlation analyses indicated that our territory size indicators decreased with increasing MOSH availability and increasing foraging rate. Based on our path analysis, only in the case of 95% home range was the effect of foraging rate strong when the effect of distance to MOSH was controlled. Even then, the best model showed foraging rate affecting home range size independently of distance to MOSH. Some factor we did not measure may thus better explain the correlation between distance to MOSH and territory size. Prey availability after the pre-laying period (especially the brood-rearing period) is one possibility, because fitness depends on having an adequate territory to support chick foraging. Food availability has often been considered an ultimate rather than proximate factor in determining avian territory size, having played an evolutionary role in selecting for the compressibility of territories, which should be calibrated for periods of resource scarcity (Tingen 1957, Brown 1964). If the

brood rearing period is the food-limited phase of the breeding cycle, the relationship between MOSH availability and territory size could weaken over time at our sites, because most broods are now restricted to oceanside habitat. In 2003, the relationship between neighbor density and distance to large MOSH was indeed weaker than in 2001 and 2002. Analysis of data from 2004 should shed further light on this subject.

Factors besides food availability might also govern the evolution of minimum territory size. For other bird species, increased efficiency in securing and relocating mates after pair formation, protection of mates from extra-pair copulation, and predator-escape benefits of terrain familiarity all have been suggested and investigated (Hinde 1956, Tinbergen 1957, Moller 1992). A study of how territory size and territorial behavior change during the breeding season might indicate which phase of the breeding cycle was most important, and if mate guarding were a prime determinant (Moller 1990). A study of the degree of extra-pair paternity and or maternity in dense vs. sparse populations would also shed light on the role of territory size in mate-guarding.

At our Westhampton Island sites, a high level of predation may have kept the population below equilibrium density. The ability of intense predation to keep a population from reaching the level that food resources can support has also long been recognized (Newton 1994).   In 2003, reproductive success was particularly bad (0.48 fledglings/pair at WHD, 0.69 at WHB, and 0.33 at Shinnecock). Much of the loss in productivity was due to nest predation, with crows playing a large role (Houghton *et al.* in prep). In the following year, a

higher proportion of successful breeders returned than failed breeders. Thus, adult plovers were either killed when they lost their nests, or abandoned the site due to repeated reproductive failure. Future resightings may shed light on whether the adults that left the site survived. Return rates were higher for successfully breeding semipalmated plovers (*Charadrius semipalmatus*, Flynn *et al.* 1999) and spotted sandpipers (*Actitis macularia*, Oring and Lank 1982) than failed ones, but there was no such relationship for piping plovers in Manitoba (Haig and Oring 1988). Successful bobolinks (*Dolichonyx oryzivorous*) returned at a higher rate than unsuccessful breeders, but only at their "low quality" site and not at their "high quality" site (Gavin and Bollinger 1989). Songbirds nesting in shelterbelts in the Great Plains were more likely to return to sites where reproductive success was higher (Haas 1997), regardless of their own reproductive success. It is thus possible that birds can assess the reproductive success of their neighbors.

We also witnessed that the bay side nesting area at WHD was gradually abandoned over 4 years as reproductive success there declined, despite the fact that pairs there nested closer to MOSH than pairs anywhere else on Westhampton Island. We observed 5 cases in which pairs or individuals relocated permanently from the bayside to the ocean side, either within or between breeding seasons, after losing a clutch or a mate to predators, and there was also one such move by a successful breeder. We observed only one move in the opposite direction following a predation event and one such move by a successful breeder (which moved back to the ocean side after losing its nest to

a predator). In fact, the nesting pair density on the ocean beach at WHD remained relatively constant from 2001-2003 (1.07, 0.98, and 0.98 pairs/ha in 2001-2003), finally declining in 2004 (0.66 pairs/ha).   At the same time, density declined precipitously on the bay side of the site (0.97, 1.25, 0.33, 0.00 pairs/ha in 2001-2004). During this study, only two bayside-nesting pairs out of 17 successfully raised young (Houghton *et al.* in prep). Predation is presumed to have caused almost all of these losses (flooding is known to have caused 2 nest losses), although documenting sources of chick loss usually is not possible.

An apparent lack of reoccupation by bayside territories after abandonment by nesting pairs, either within or among seasons, presents a challenge to the hypothesis that territoriality is limiting density at WHD. Reoccupation is considered a prerequisite in order to conclude that territoriality has an effect (Patterson1980), provided enough time is left in the breeding season. Many bird studies in which territory holders were removed demonstrated immediate reoccupation (Newton 1994), and such an effect was observed in a study on territory abandonment in golden plovers (*Pluvialis apricaria*) in Britain (Parr 1979). We observed rapid reoccupation of abandoned territories in WHB in 2001 and 2003. It may be that the presence of predators, and possibly human disturbance, was so high on the bay side that potential pairs were discouraged from settling. In fact, in 2003 and 2004 we did observe territorial pairs in some abandoned territories, at various times during the breeding season, but they never settled. In one case, an area where a pair was scraping was graded for a driveway. However, it seems more likely that territories on the bayside became

unsuitable in ways that were difficult for us to measure. For instance, we calculated the total ha of nesting habitat, but if such habitat were fragmented by houses and vegetation into patches too small to attract plovers, the patches would not be expected to have been recolonized. The minimum patch size necessary to attract a breeding pair merits further investigation.

We found little evidence that home range size was related to individual quality, as measured by plumage or morphology (Appendix G), although contrary to our prediction, successful plovers in 2002 had larger home ranges in 2003 while failed birds did not.   However, the lack of a statistical difference in home range size between years for returning failed birds was likely a sample size issue (n = 3). Also, SY birds tended to nest at the periphery of our Westhampton site in 2003, farther from the large MOSH than older birds, but due to a small number of observations per bird, we could not measure home ranges of SY birds.

Finally, we did not study the spatial arrangement of nesting habitat in relation to home range size and local density, but it changed drastically over the course of the longer study at our site (Houghton *et al.* in prep). Human construction and vegetation increasingly covered and fragmented the nesting habitat by 2004, so that potential breeding sites became concentrated on the front beach and the north-south axis of potential territories was greatly truncated.

As has often been pointed out since its elucidation by Van Horne (1983), a high population density in an area may not indicate that habitat quality is good (for instance, a high density of juveniles may be forced into substandard habitat by dominant older animals), especially reproduction is impaired. The relationship

between reproductive success, population density, and home range size at our sites will be described elsewhere.

MANAGEMENT IMPLICATIONS

Since the Hurricane of 1938, major storms on Long Island, New York, have been followed by efforts to stabilize the shoreline (Leatherman and Allen 1985). Beach stabilization, including beach nourishment and construction of jetties, groin fields, and seawalls has decreased the impacts of storms on shorelines and facilitated shoreline development (Leatherman and Allen 1985, Schubel *et al.* 1991). This has raised concern that early successional, storm-maintained features such as overwash, sand spits, ephemeral pools, tidal flats, and open vegetation will be prevented from forming and will diminish in abundance along the coast (Dolan *et al.* 1973, Elias-Gerken 1994).

On Long Island, New York, the Fire Island to Montauk Point (FIMP) Reformulation Plan of the USACE provides for storm damage protection, breach prevention, and beach widening over 130 km of shoreline (USACE 1994). The plan consists of beach widening through renourishment, construction or reconstruction of artificial dunes, planting of beach grass, and potentially new groin construction. The importance of overwash-created MOSH as foraging habitat for piping plovers has been recognized since this species' revised Atlantic Coast recovery plan was adopted (USFWS 1996), and this has been supported by several previous studies on habitat selection by adults and broods (Loegering and Fraser 1995, Goldin and Regosin 1998, Elias-Gerken 2000, Keane *et al.* in press).

Mitigation of the potential negative impacts of the FIMP on plover foraging and nesting habitat is of interest to the USACE, and strategies for habitat restoration are currently under consideration (USACE 2001). The WHD site illustrates that piping plovers will colonize artificially-created nesting habitat, and will forage on sandflats that are created as a consequence of beach restoration. Experiments in nesting habitat creation in Massachusetts, in the form of artificial overwash corridors, have been shown to attract breeding pairs (S. Hecker, National Audubon Society, pers. comm), and piping plovers are known to nest on dredged materials (USFWS 1996). We have identified that larger nesting areas attract more birds, and creating a high ratio of MOSH area to nesting habitat area should result in a higher density of piping plovers than if MOSH is absent. Furtthermore, creation of such MOSH within 300 m of the nesting habitat should lead to the desired effect (however, we did not test other distances). Maintaining access to MOSH for broods may be an important strategy for sustaining a high population density.

Furthermore, we have anecdotal evidence that predation leads to territorial abandonment, and may reduce the carrying capacity of breeding beaches. This issue requires further study, and stresses the importance of a predation control element in any habitat restoration plan.

ACKNOWLEDGEMENTS

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Table 1. Cover types recognized in the study.

Cover Type	Description
Ocean Intertidal Zone	Ocean bare sand zone (damp to saturated sand) found between the last high tide and the most recent tide line.
Ocean and Bay Fresh Wrack	Fresh, wet lines of organic materials (usually vegetation) deposited on the seaward edge of the backshore or throughout the intertidal zone at the peak of the last high tide.
Ocean and Bay Backshore	A zone of dry sand, shell, cobble and beach debris (<10% vegetative cover) landward of the mean high water line and shoreward of human structures and the toe of the dune.
Ocean and Bay Old Wrack	Any dry mat of organic matter, usually vegetation, deposited from spring or storm tides. Typically located on the backshore or amid clumps of sparse vegetation.
Ocean and Bay Sparse Vegetation	A zone of vegetation, usually American Beach Grass (*Ammophila breviligulata*), which plover chicks can move through freely. Characteristic of early succession, landward of the ocean backshore, but shoreward of dune toe, cover ranges from 10-90%.
Dune Sparse Vegetation	A zone of vegetation on the dune face or crest, usually American Beach Grass (*Ammophila breviligulata*), which plover chicks can move through freely. Characteristic of early succession, cover 10-90%.
Dense Vegetation	A zone of live or dead, thick and matted vegetation (grasses, forbs, and/or shrubs) too thick for chicks to move through. It is characteristic of mid to late succession. Typically landward of sparse vegetation on the dune or backshore. Cover >90%.
Bay Intertidal Zone (MOSH)	Bayside bare sand zone (damp to saturated sand) between the last high tide and the most recent tide line.
Ephemeral Pools	A mosaic of wetland and moist sandy/muddy habitats that occur in low lying backshore areas or in interdunal corridors. Moisture content fluctuates reflecting changes in groundwater level or the affect of meteorological overwash and breaching events.
Interior Cover Types	Any of the above cover types that occur in the interiors of peninsulas at the ends of barrier islands, and are not clearly associated with either the bay or ocean side.

Table 2. Plover pairs, density and area of MOSH and ocean intertidal zone, West Hampton Dunes, Westhampton Beach, Shinnecock West, Cupsogue,and Democrat Point, Long Island, NY and Monomoy Island, MA 2001-2003.

	Pairs	Length (km)	Nesting habitat (ha)	Density (pairs/ha)	MOSH (ha)[a]	Ocean ITZ (ha)[b]
2001						
WHD	38	2.9	36.3	1.05	24.8	5.3
WHB	15	3.2	29.7	0.51	1.9	8.0
Shinnecock	6	1.5	14.0	0.43	1.6	3.4
Cupsogue	8	2.2	15.9	0.50	1.5	-
Democrat	7	1.4	12.8	0.55	12.0	3.3
2002						
WHD	34	2.9	33.3	1.02	21.3	5.2
WHB	20	3.2	27.3	0.73	1.9	8.7
Shinnecock	6	1.5	13.1	0.46	1.6	4.1
Cupsogue	8	2.2	17.9	0.45	1.8	-
Democrat	10	1.1	12.4	0.81	12.3	2.4
Powder Hole[c]	16	1.9	11.8	1.36	18.0	-
SE Monomoy[c]	7	2.5	19.2	0.36	0.00	-
NE Monomoy[c]	6	0.8	5.9	1.02	10.52	-
2003						
WHD	27	2.9	31.5	0.86	23.5	9.4
WHB	13	3.2	27.5	0.47	1.7	11.6
Shinnecock	8	1.5	9.7	0.82	1.6	4.1
Cupsogue	8	2.2	16.1	0.50	1.6	-
Democrat	7	1.0	9.0	0.78	10.7	4.6
Powder Hole[c]	16	1.9	10.6	1.52	20.1	-
SE Monomoy[c]	9	2.5	19.4	0.46	0	-
NE Monomoy[c]	5	0.8	7.2	0.69	11.0	-

[a]Classified on aerial photos, then selected with 300 m wide buffer zones around nesting habitat.

[b]Estimated as average of mean monthly transect widths measured within 3 hrs of low tide x length of beach ($n = 5$ months at Democrat, 6 months for other sites, not measured at Cupsogue).

[c]Monomoy Island, MA

Table 3. Fixed kernel estimates of home range (HR) sizes (ha) and hectares of nesting habitat within home ranges of piping West Hampton Dunes and Westhampton Beach, Long Island, NY, 2002-2003.

	Year	n^a	$\bar{x}$ HR size (ha)	se	P^b	$\bar{x}$ nesting habitat (ha)	se	P^b
50% HR	2002	23	1.17	0.12		1.02	0.11	
	2003	15	2.25	0.24	< 0.001	1.66	0.21	0.003
95% HR	2002	23	8.97	0.59		4.03	0.33	
	2003	15	16.52	1.47	< 0.001	6.56	0.66	0.005

[a]When a male and a female were part of a pair, we pooled their observations and calculated a single home range

[b]Wilcoxon rank-sum test, H_o: HR size in 2002 = HR size in 2003.

Table 4. Significant correlations among explanatory variables used to model home range size and neighbor density of piping plovers, WHD and WHB, 2002-2003.

Variable 1	Variable 2	*n*	*r*	P
foraging rate (pecks/min)	% time foraging	41	0.79	< 0.001
	% time resting	41	-0.66	< 0.001
ln(distance to large MOSH)	% time foraging	41	-0.55	< 0.001
	% time resting	41	0.46	0.003
	foraging rate	41	-0.52	< 0.001
	% use OBS[a], low tide[b]	37	0.60	< 0.001
	% use BIT[c], low tide	37	-0.59	< 0.001
	% use BIT, high tide[d]	39	-0.58	< 0.001
ln(distance to nearest MOSH)	foraging rate	41	-0.43	0.005
	% use OBS, low tide	37	0.43	0.008
	% use BIT, low tide	37	-0.34	0.039
	% use BIT, high tide	39	-0.32	0.045

[a]ocean backshore

[b]within 3 hours of low tide

[c]bay intertidal zone

[d]within 3 hours of high tide

Table 5. Mean proportion of observations that a focal adult plover exhibited a particular response to an intruding plover within 5 m, mean distance (m) an intruder was chased if a chase occurred, and mean proportion of observations in which a plover responded to an intruder at > 5 m, WHD and WHB, 2002-2003.

	n	alert	se	agi-tated	se	charge	se	chase	se	any	se	was chased	se	chase dist.	se	response at > 5 m	se
M	18	0.34	0.09	0.21	0.08	0.23	0.08	0.19	0.07	0.44	0.08	0.15	0.05	8.10[a]	3.28	0.02	0.01
F	12	0.16	0.09	0.15	0.05	0.13	0.04	0.21	0.06	0.34	0.08	0.19	0.09	7.00	1.43	0.02	0.01

[a]Number of plovers for which chases were observed (n) = 9 females and 8 males

Table 6. Mean abundance of benthic organisms (no. per 79 cm^2 x 2 cm) in experimental cage plots, cage controls, and controls, WHD, 2001-2002. $n = 6$ plots. Spring = March/April (pre-laying period), Summer = June/July (brood period).

	Cage	se	Cage Control	se	Control	se	$F_{2,10}$[a]	P
Small Worms								
2001								
Spring	8.7	2.7	4.3	1.2	7.3	1.6		
Summer	18.8	9.6	12.7	4.0	14.3	3.5		
Change	10.2	10.1	8.3	3.7	7.0	2.0	0.1	0.94
2002								
Spring	109.2	44.8	49.0	27.1	49.2	21.3		
Summer	29.5	16.0	14.8	5.7	25.5	13.6		
Change	-79.7	44.0	-34.2	27.5	-23.7	15.3	0.1	0.40
Large Worms								
2001								
Spring	0.7	0.3	1.7	0.8	0.3	0.2		
Summer	0.7	0.7	0.2	0.2	1.2	0.7		
Change	0.0AB[b]	0.9	-1.5B	0.8	0.8A	0.5	4.1	0.051
2002								
Spring	1.2	0.6	3.8	3.6	0.3	0.3		
Summer	0.7	0.7	1.7	1.5	0.2	0.2		
Change	-0.5	0.6	-2.2	4.2	-0.2	0.2	0.2	0.83
Insect Larvae								
2001								
Spring	1.0	0.4	3.3	1.1	2.2	0.5		
Summer	16.7	9.9	14.7	8.2	1.2	0.8		
Change	15.7	10.0	11.3	9.0	-1.0	1.1	2.3	0.15
2002								
Spring	0.5	0.3	1.0	0.6	4.8	4.8		
Summer	5.5	3.2	5.7	4.1	4.3	3.6		
Change	5.0	2.9	4.7	3.6	-0.5	1.4	1.3	0.31
Crustaceans								
2001								

Spring	0.0	0.0	0.0	0.0	0.2	0.2	
Summer	0.3	0.3	0.5	0.2	0.5	0.5	
Change	0.3	0.3	0.5	0.2	0.3	0.3	0.1 0.89
2002							
Spring	6.5	6.3	4.7	4.7	7.0	5.2	
Summer	3.5	2.1	2.3	2.1	2.3	1.6	
Change	-3.0	5.7	-2.3	2.5	-4.7	3.8	0.4 0.70
Tiny Organisms							
2001							
Spring	28.0	20.6	2.3	1.6	2.3	1.7	
Summer	57.0	32.2	55.0	30.1	22.8	15.7	
Change	29.0	41.5	52.7	30.8	20.5	15.2	0.4 0.68
2002							
Spring	2135.7	2092.4	51.8	16.6	280.0	200.1	
Summer	579.5	318.3	43.7	21.6	88.0	40.3	
Change	-1556.2	2195.0	-8.2	32.0	-192.0	214.5	0.5 0.65

[a]ANOVA, H_o: seasonal change is equal among treatments, controlling for plot as a random effect

[b]Means with the same capital letter are not significantly different

Table 7. Mean biomass of benthic organisms (mg per 79 cm^2 x 2 cm) in experimental cage plots, cage controls, and controls, WHD, 2001-2002. $n = 6$ for all plots in 2001, 6 for cages and cage controls in 2002, 5 for controls in 2002. Spring = March/April (pre-laying period), Summer = June/July (brood period).

	Cage	se	Cage Control	se	Control	se	$F_{2,x}$[a,b]	P
Small Worms								
2001								
Spring	1.0	0.5	2.3	1.0	1.7	0.9		
Summer	6.2	3.3	4.8	2.5	14.2	6.6		
Change	5.2	3.5	2.5	3.1	12.5	5.8	1.1	0.36
2002								
Spring	20.4	10.1	4.1	2.2	21.9	11.6		
Summer	2.9	1.6	2.4	1.7	2.0	0.9		
Change	-17.5	10.1	-1.7	2.7	-9.3	4.9	2.2	0.17
Large Worms								
2001								
Spring	0.3	0.2	1.0	0.6	3.2	2.1		
Summer	12.3	12.3	0.0	0.0	5.2	3.7		
Change	12.0	12.4	-1.0	0.6	2.0	1.6	1.0	0.41
2002								
Spring	11.6	5.8	20.7	18.3	4.3	2.8		
Summer	4.5	4.5	7.8	7.1	1.7	1.7		
Change	-7.1	5.0	-12.9	21.2	-1.4	1.4	0.2	0.83
Insect Larvae								
2001								
Spring	1.0	0.5	1.8	1.0	1.8	0.6		
Summer	0.5	0.3	0.2	0.2	0.7	0.7		
Change	-0.5	0.4	-1.7	1.0	-1.2	1.0	0.3	0.72
2002								
Spring	0.1	0.1	0.3	0.3	1.2	1.2		
Summer	0.1	0.1	0.3	0.1	0.2	0.1		
Change	0.1	0.1	0.0	0.4	-1.2	1.5	0.7	0.55
Crustaceans								
2001								
Spring	0.0	0.00	0.00	0.00	0.2	0.2		

Summer	0.7	0.7	0.2	0.2	0.3	0.3	
Change	0.7	0.7	0.2	0.2	0.2	0.2	0.5 0.65
2002							
Spring	1.4	1.4	1.1	1.1	2.4	1.9	
Summer	3.9	3.2	1.2	1.0	0.0	0.0	
Change	2.5	3.6	0.0	0.3	-0.6	0.6	0.6 0.58
Tiny Organisms							
2001							
Spring	0.5	0.5	0.0	0.0	0.0	0.0	
Summer	0.3	0.3	0.0	0.0	1.5	1.5	
Change	-0.2	0.7	0.0	0.0	1.5	1.5	1.0 0.42
2002							
Spring	0.9	0.7	0.1	0.1	0.4	0.2	
Summer	0.3	0.1	0.1	0.1	0.2	0.2	
Change	-0.5	0.6	-0.1	0.1	-0.1	0.3	0.5 0.65

[a]ANOVA, H_o: seasonal change is equal among treatments, controlling for plot effect.

[b]x = 10 in 2001, 9 in 2002

Table 8. Percent of ASY piping plovers returning to the study area from previous year, that succeeded or failed to a) hatch an egg or b)fledge a chick in the previous year, WHB, WHD, and Shinnecock, NY. Year is when success or failure was recorded.

			Returned		Not Returned			
			n	%	n	%	(P)[a]	P
Hatching Success	2001	Succeeded[b]	21	72.4	8	27.6		
		Failed	5	71.1	2	28.9	0.35	1.000
	2002	Succeeded[b]	15	48.4	16	51.6		
		Failed	7	58.3	5	41.7	0.23	0.736
	2003	Succeeded[b]	12	63.2	7	36.8		
		Failed	15	53.6	13	46.4	0.19	0.561
	2001-03	Succeeded[b]	48	57.4	31	42.6		
		Failed	27	61.4	20	38.6	0.14	0.851
Fledging Success	2001	Succeeded[c]	15	75.0	5	25.0		
		Failed	11	68.8	5	31.2	0.27	0.722
	2002	Succeeded[c]	11	47.8	12	52.2		
		Failed	11	55.0	9	45.0	0.22	0.763
	2003	Succeeded[c]	9	90.0	1	10.0		
		Failed	18	48.7	19	51.3	0.02	0.029
	2001-03	Succeeded[c]	35	66.0	18	34.0		
		Failed	40	54.8	33	45.2	0.07	0.27

[a](P) = table probability for Fisher's Exact Test.

[b]Succeeded = hatched at least 1 egg

[c]Succeeded = fledged at least 1 chick

Table 9. Distance to MOSH and local density of nesting pairs for returning ASY and SY piping plovers, WHD and WHB, NY, 2003.

	ASY			SY			
	n	$\bar{x}$	se	n	$\bar{x}$	se	
Local Density (pairs/ha w/in 600m)	18	0.78	0.04	3	0.54	0.17	$P = 0.14$[a]
Distance from nest to nearest MOSH (m)	18	228.5	18.6	3	260.0	27.8	$P = 0.59$
Distance from nest to large MOSH (m)	18	582.9	151.0	3	2167.0	616.7	$P = 0.028$

[a]Wilcoxon rank-sum test
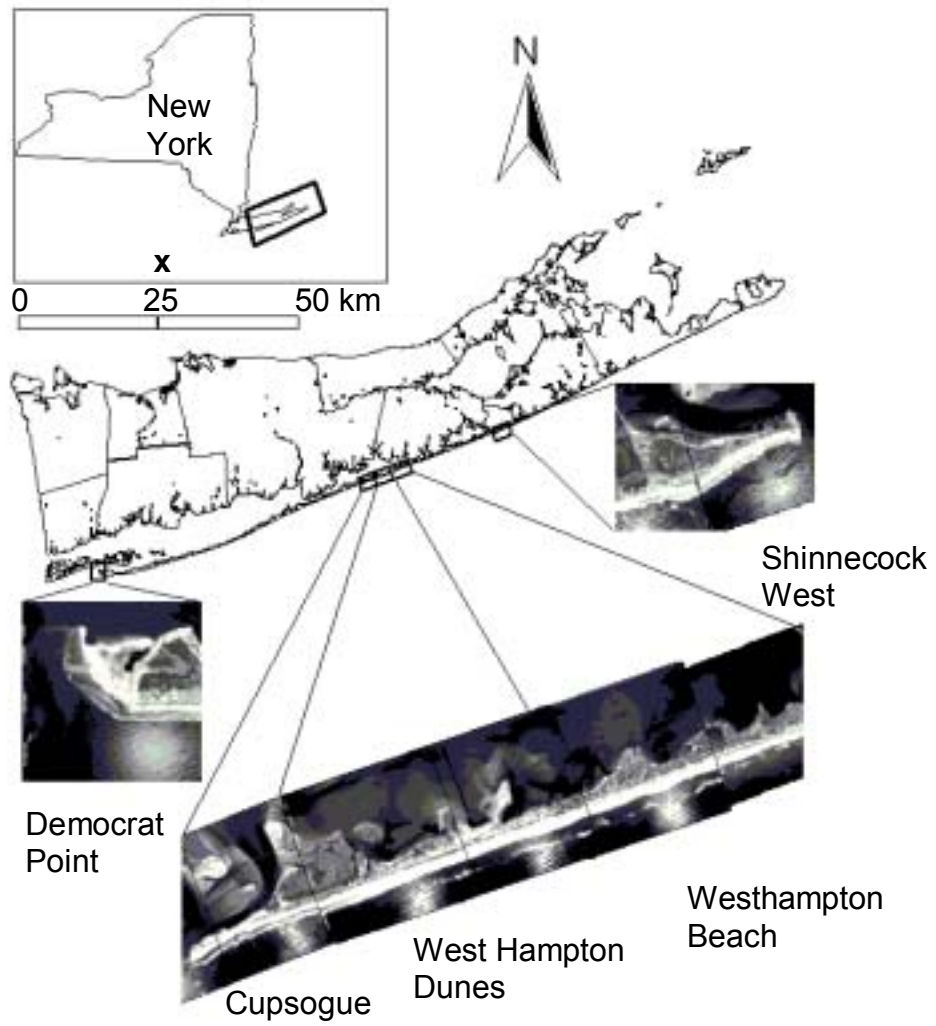
Fig. 1. 2003 aerial photographs of piping plover breeding beaches on Long Island, NY where this study was conducted.
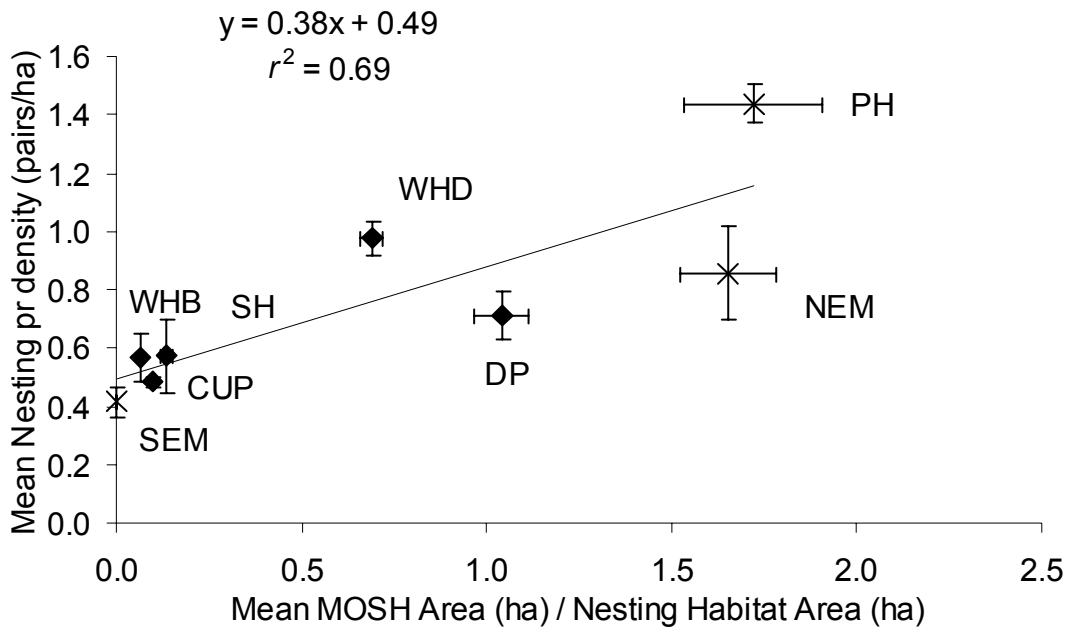
Fig. 2. 2-year (Monomoy) or 3-yr (Long Island) mean nesting pair density of piping plovers vs. 2-year or 3-yr mean hectares of MOSH within 300 m of nesting areas normalized by area of nesting habitat, 2001-2003. Diamond = Long Island, X = Monomoy. Std. error bars shown. Linear regression: $F_{1,6}$ = 16.2, P = 0.007. WHD = West Hampton Dunes, WHB = Westhampton Beach, CU = Cupsogue, SH = Shinnecock West, DP = Democrat, PH = Powderhole, Monomoy, NEM = Northeast Monomoy, SEM = Southeast Monomony.
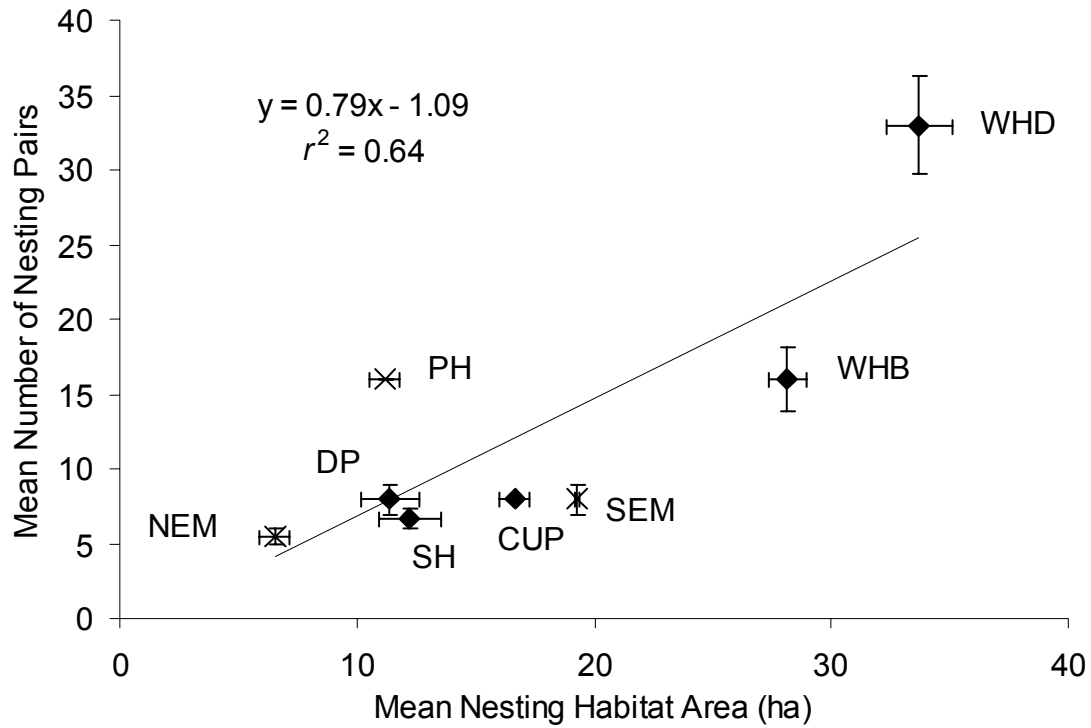
Fig. 3. 2-year (Monomoy) or 3-yr (Long Island) mean no. nesting pairs of piping plovers vs. 2-year or 3-year mean hectares of nesting habitat, 2001-2003. Diamond = Long Island, X = Monomoy. Std. error bars shown. Linear regression: $F_{1,6}$ = 10.7, P = 0.02. WHD = West Hampton Dunes, WHB = Westhampton Beach, CU = Cupsogue, SH = Shinnecock West, DP = Democrat, PH = Powderhole, Monomoy, NEM = Northeast Monomoy, SEM = Southeast Monomony.
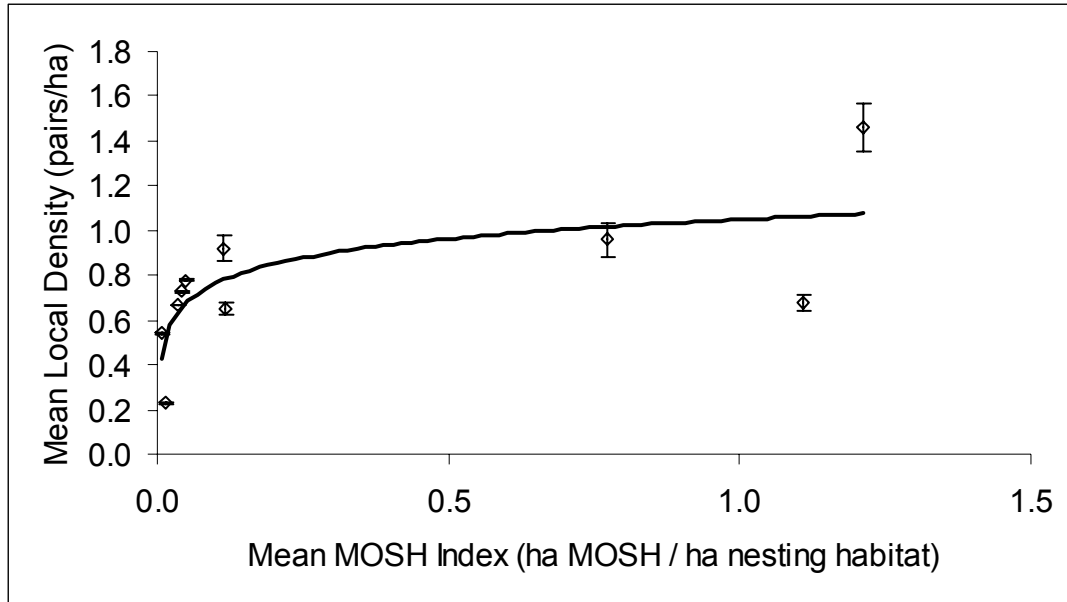
Fig. 4. 3-yr mean local density (pairs/ha/600 m segment) of piping plovers vs. mean MOSH Index per segment, WHD and WHB, 2001-2003. Linear regression results for local density vs. ln(MOSH Index): $r^2 = 0.51$, $F_{1,8} = 8.2$, $P = 0.021$, $n = 10$ segments
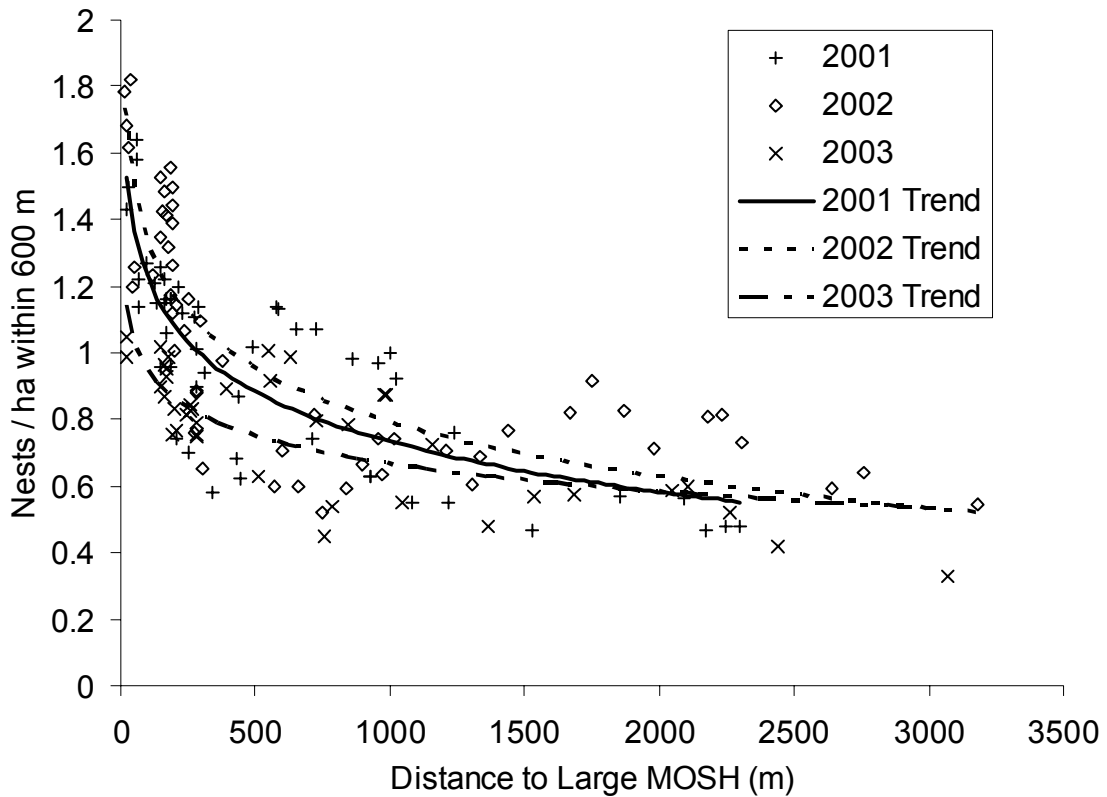
Fig. 5. Neighbor density of nesting pairs of piping plovers within 600 m vs. distance from nest to large MOSH area created by the nor-easter of 1992 and subsequent breach fill. Mixed-model results (with spatial autocorrelation) for 2001: $\beta_0 = 1.77\pm0.14$, $\beta_1 = -0.15\pm0.02$, $F_{1,49} = 10.7$, $P < 0.001$; 2002: $\beta_0 = 1.98\pm0.07$, $\beta_1 = -0.17\pm0.01$, $F_{1,32} = 462.5$, $P < 0.001$; 2003: $\beta_0 = 1.01\pm0.15$, $\beta_1 = -0.05\pm0.02$, $F_{1,37} = 10.6$, $P = 0.002$.
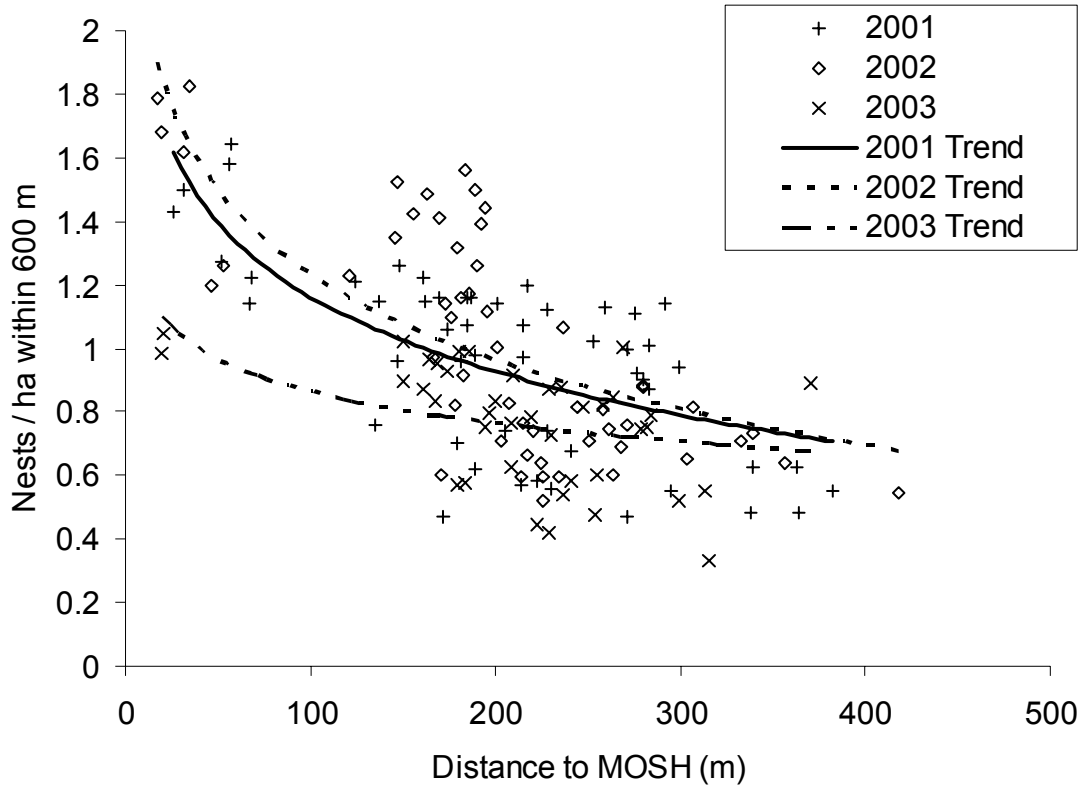
Fig. 6. Neighbor density of nesting pairs of piping plovers within 600 m vs. distance from nest to nearest MOSH. Mixed-model results (with spatial autocorrelation) for 2001: β_0 = 1.52±0.16, β_1 = -0.14±0.02, $F_{1,45}$ = 51.1, P < 0.001; 2002: β_0 = 1.76±0.09, β_1 = -0.17±0.01, $F_{1,38}$ = 509.6, P < 0.001; 2003: β_0 = 0.88±0.16, β_1 = -0.05±0.02, $F_{1,35}$ = 9.6, P = 0.003.
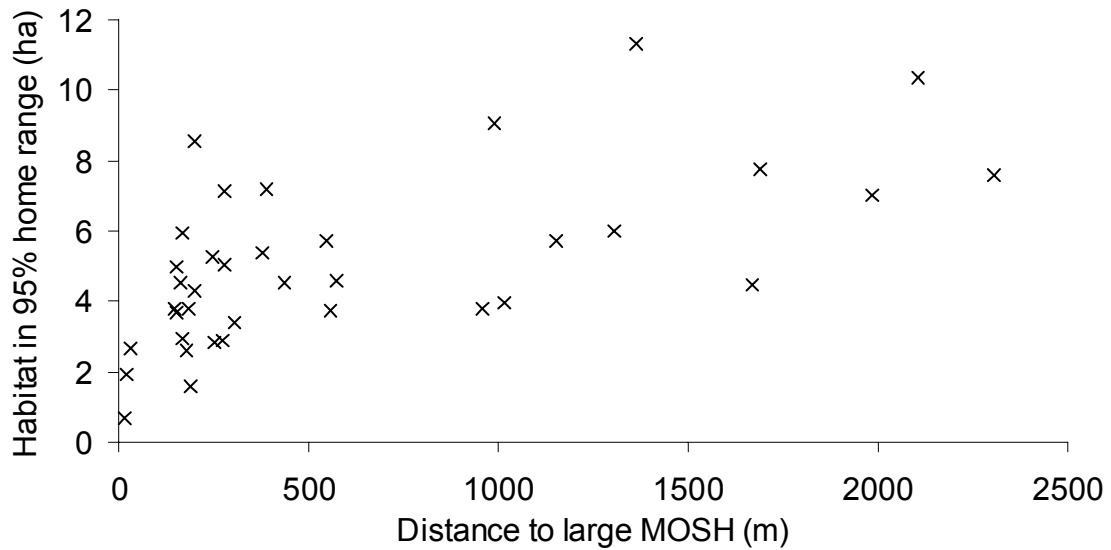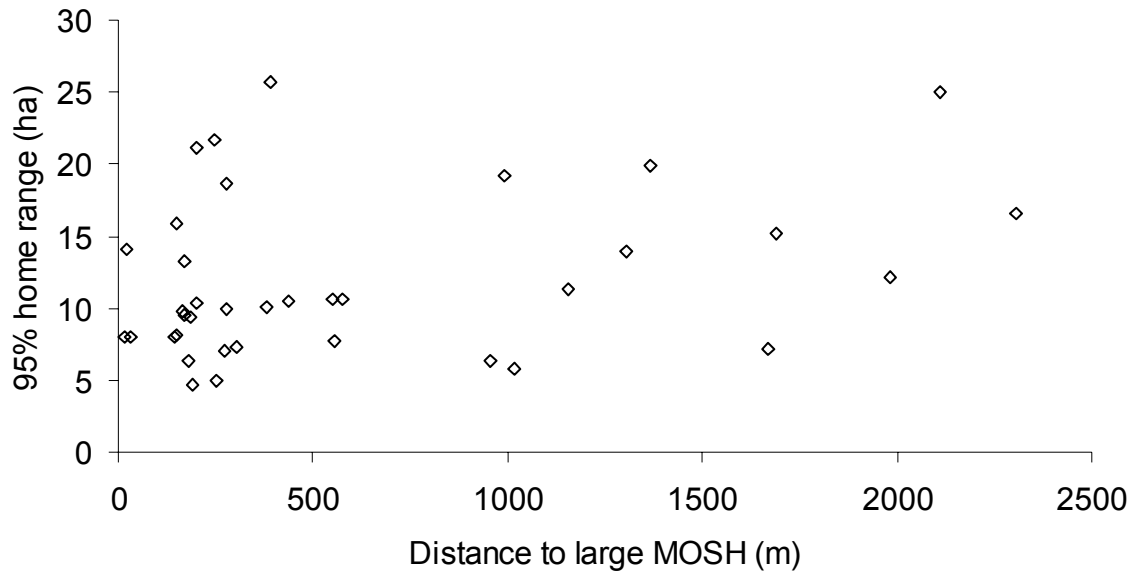
Fig. 7. 95% home range area (ha) and area of nesting habitat in 95% home ranges (ha) of piping plovers vs. distance from nest to large MOSH area created by the nor-easter of 1992 and subsequent breach fill. Rank correlation statistics for total area: Spearman's ρ = 0.27, P = 0.112, n = 37; Nesting habitat: Spearman's ρ = 0.64, P < 0.001, n = 37).
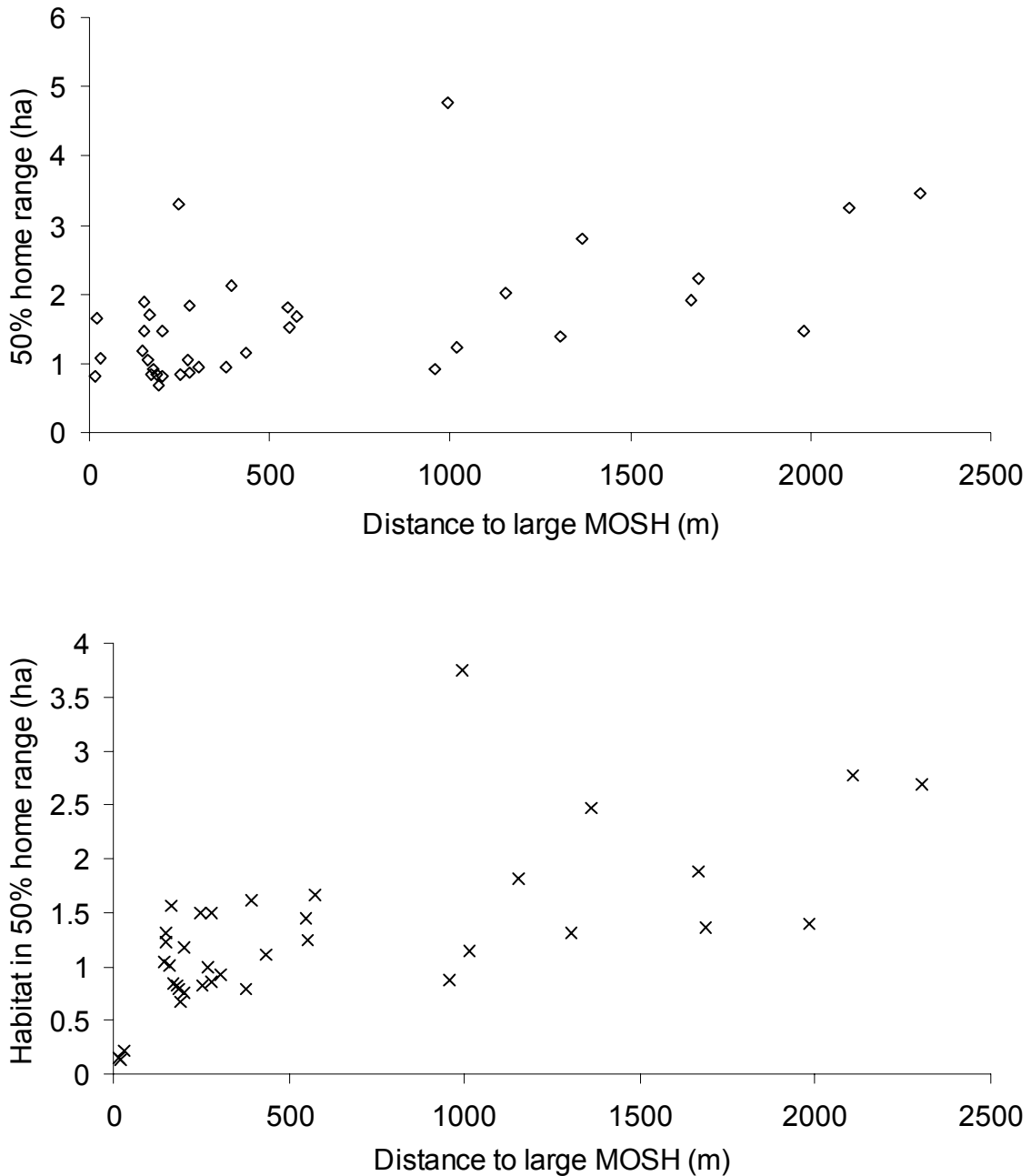
Fig. 8. 50% home range area (ha) and area of nesting habitat in 50% home ranges (ha) of piping plovers vs. distance from nest to large MOSH area created by the nor-easter of 1992 and subsequent breach fill. Rank correlation statistics for Total area: Spearman's ρ = 0.50, P = 0.001, n = 37; Nesting habitat: Spearman's ρ = 0.67, P < 0.001, n = 37).
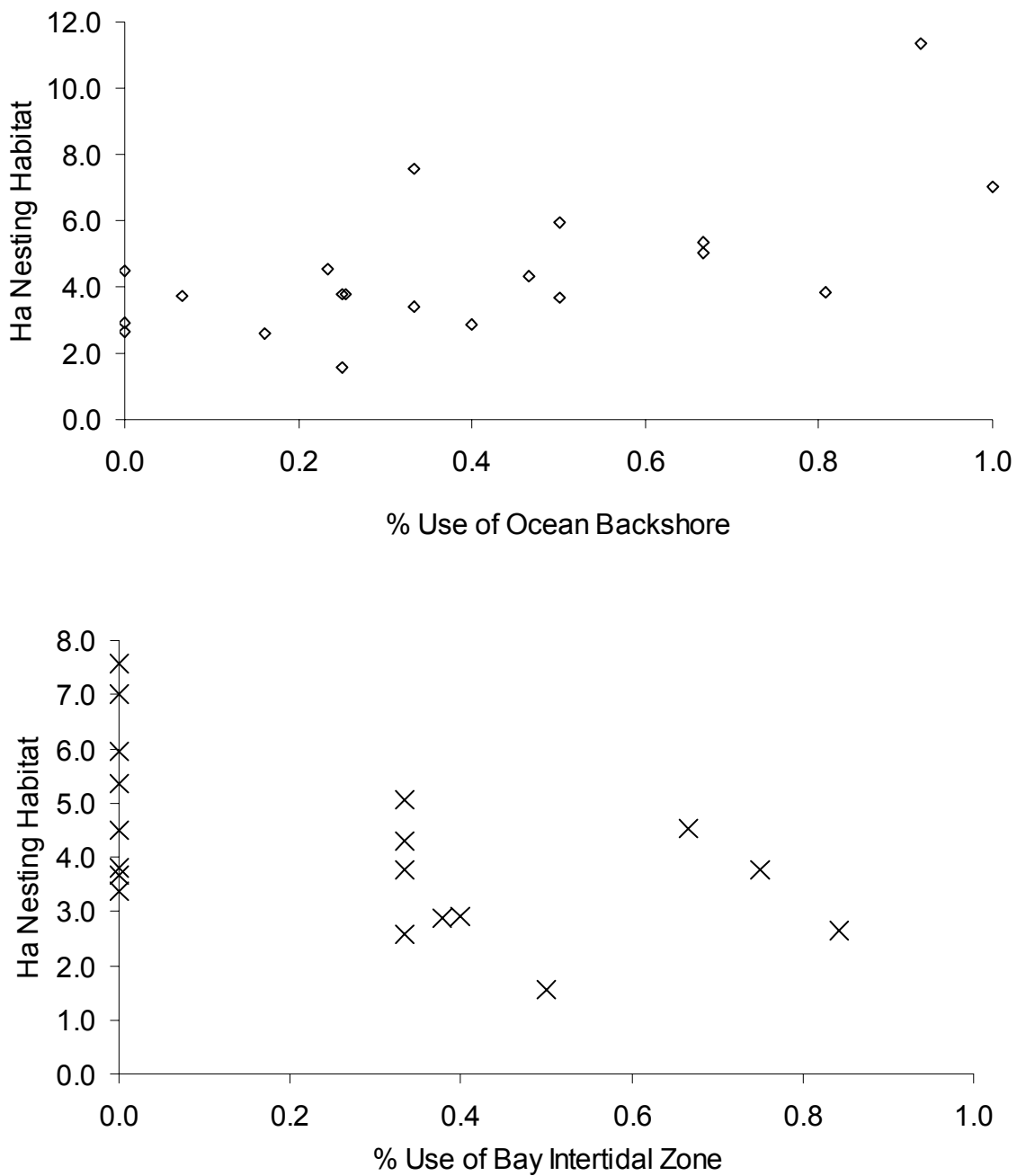
Fig. 9. Area of nesting habitat in 95% home ranges (ha) of piping plovers vs. % use of ocean backshore and bay intertidal zone ± 3 h of high tide in the pre-laying period. Rank correlation statistics for ocean backshore: Spearman's ρ = 0.63, P = 0.003; bay intertidal zone: Spearman's ρ = -0.48, P = 0.031, n = 20.
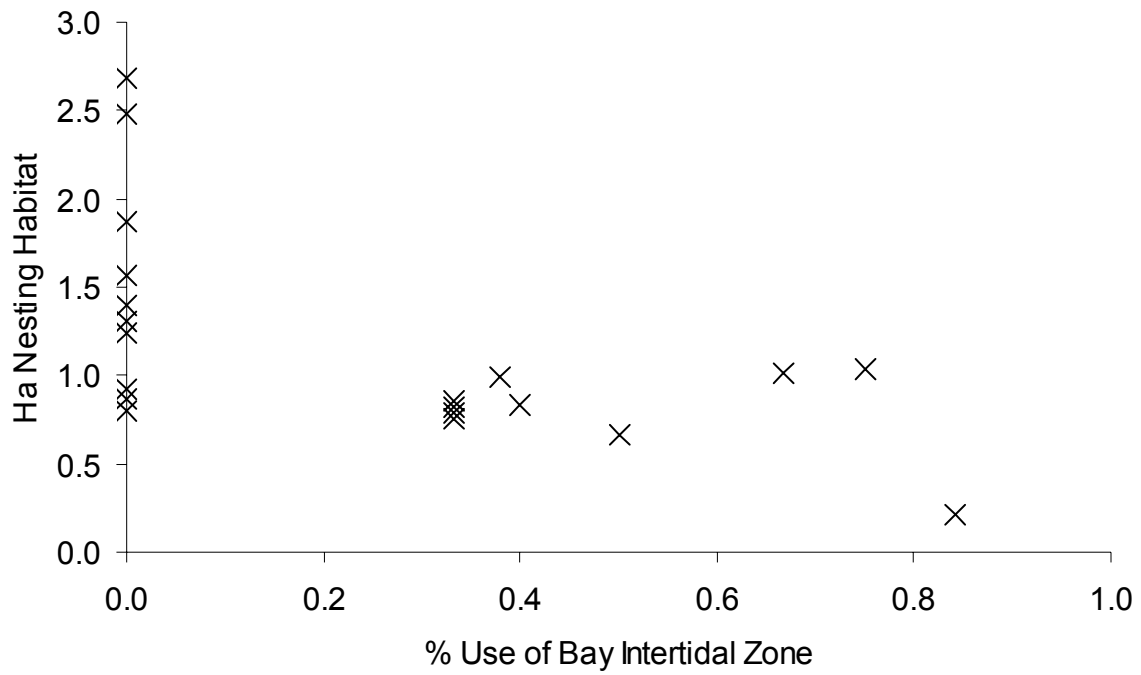
Fig. 10. Area of nesting habitat in 50% home ranges (ha) of piping plovers vs. % use of bay intertidal zone ± 3 h of high tide in the pre-laying period. Rank correlation statistics: Spearman's ρ = -0.58, P = 0.007, n = 20.
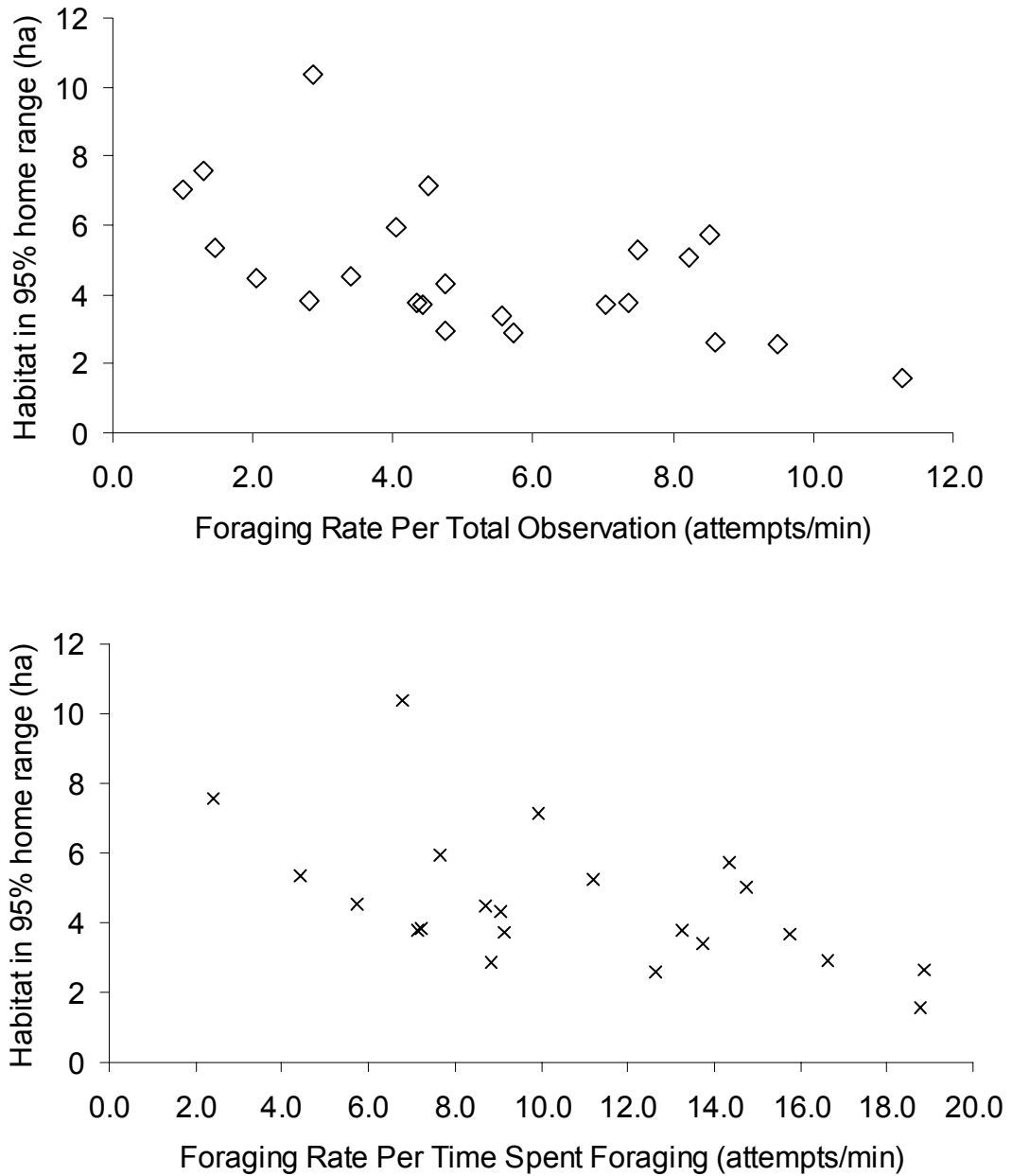
Fig. 11. Nesting habitat in total (95%) home range of piping plovers vs. foraging rate (attempts/min) in the pre-laying period. Rank correlation statistics for foraging rate per total observation: Spearman's ρ = -0.60, P = 0.003, n = 23; time spent foraging: Spearman's ρ = -0.58, P = 0.005, n = 22).
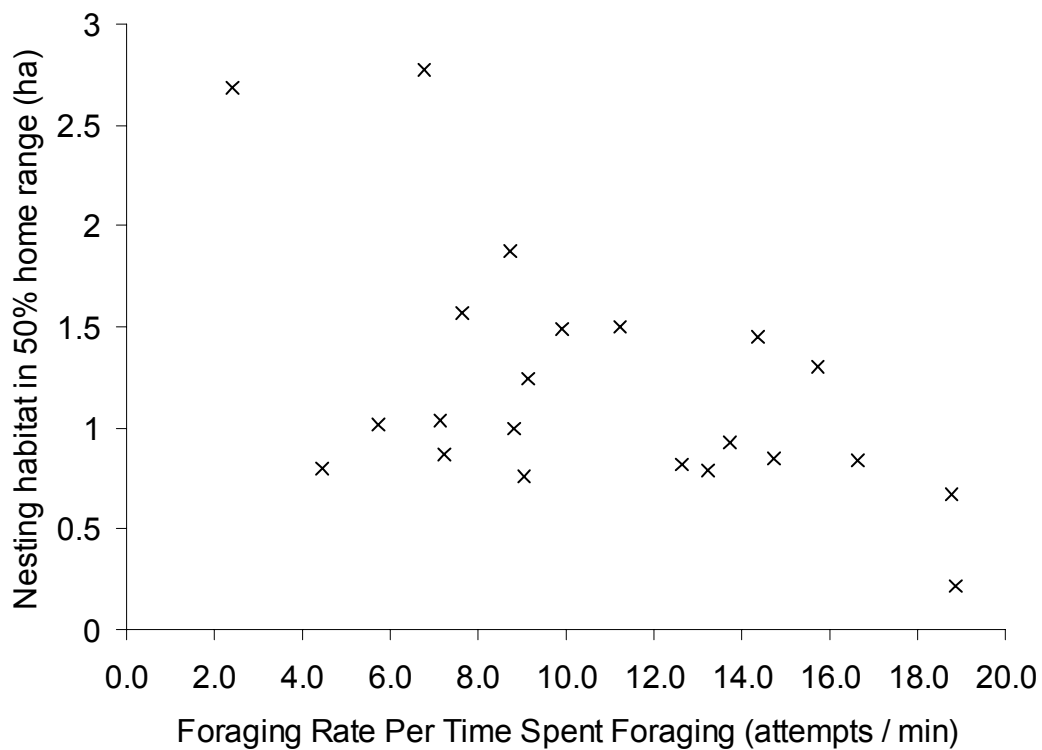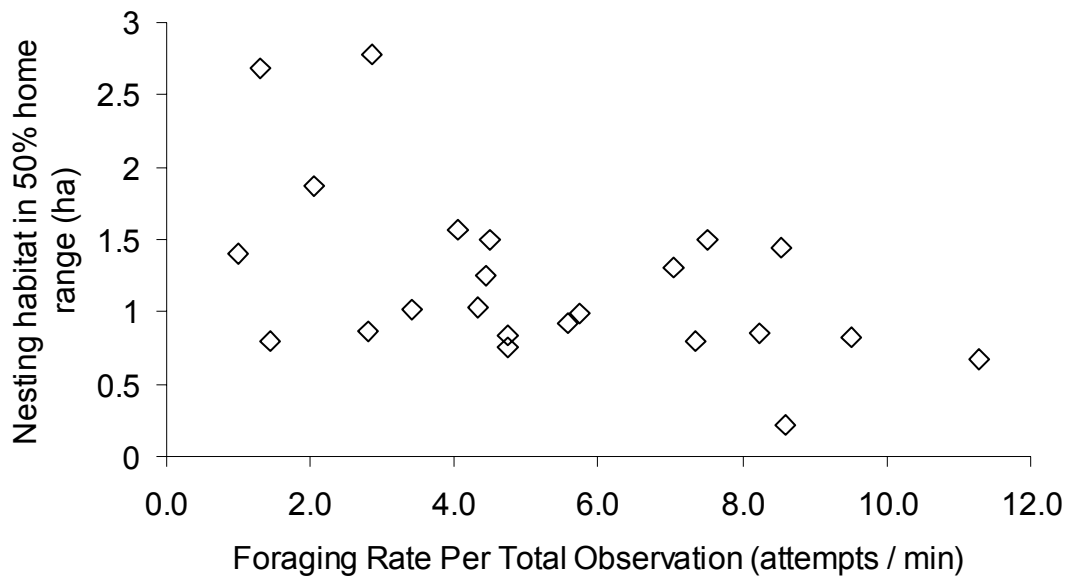
Fig. 12. Nesting habitat in 50% home range of piping plovers vs. foraging rate (attempts/min) in the pre-laying period. Rank correlation statistics for foraging rate per total observation: Spearman's ρ = -0.50, P = 0.016, n = 23; time spent foraging: Spearman's ρ = -0.47, P = 0.029, n = 22).

Model	K	AICc	Δ_{AIC}	ω_I
1	7	19.73	11.93	0.001
2	7	18.20	10.40	0.003
3	8	23.07	15.28	0.000
4	*8*	*9.03*	*1.23*	*0.259*
5	**7**	**7.80**	**0.00**	**0.479**
6	10	20.00	12.21	0.001
7	*8*	*9.05*	*1.25*	*0.256*
Null	4	30.02	22.23	0.000
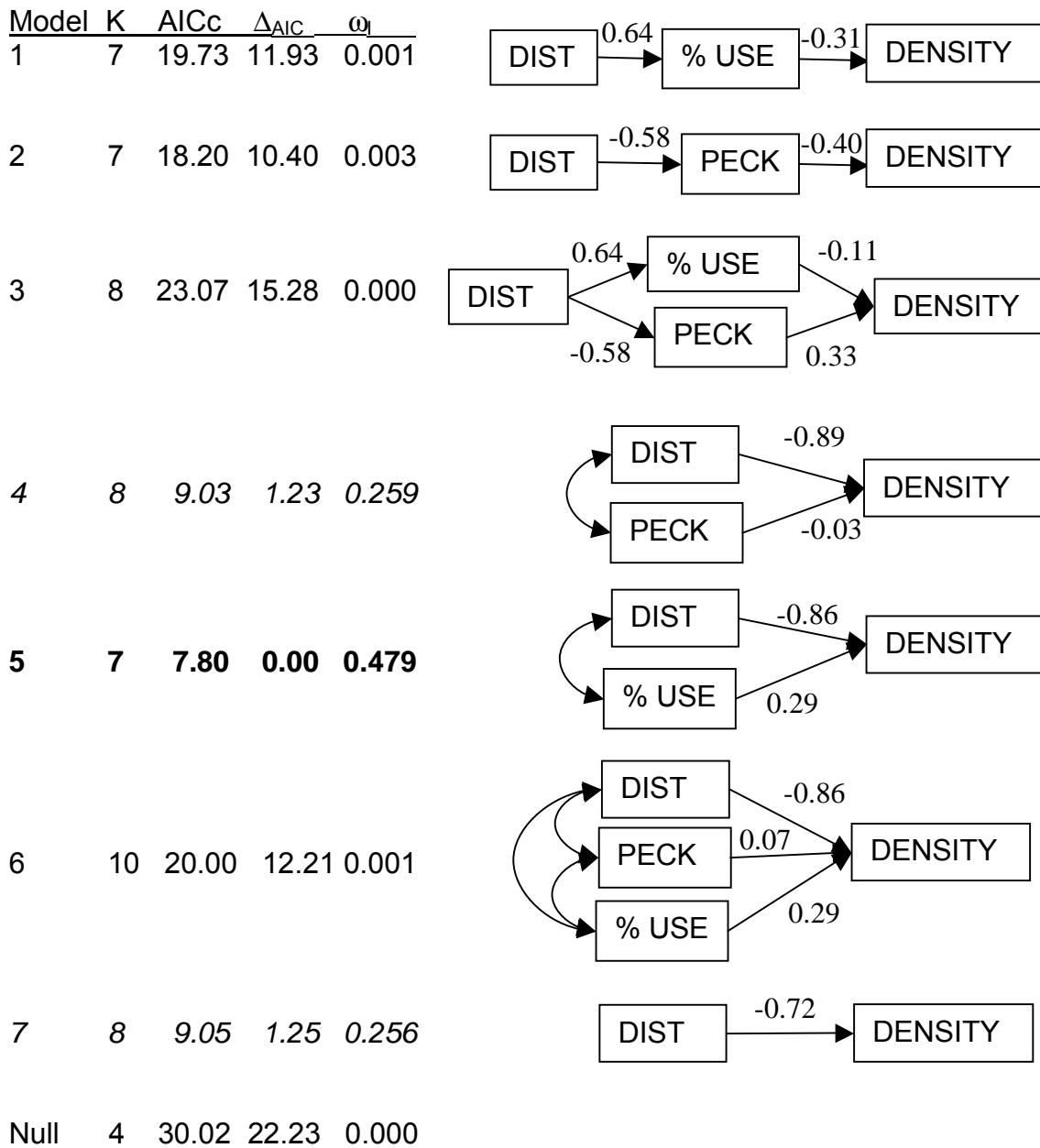
Fig. 13. Path analysis of relationships between neighbor density of piping plovers (DENSITY), foraging rate (PECK, attempts/minute foraging) in the pre-laying period, % use of cover types other than MOSH by foraging birds (% USE), and ln-transformed distance from the first nest attempt to the large MOSH (DIST), WHD and WHB, Long Island, NY, 2002-2003 ($n = 22$ birds or pairs). Path coefficients are standardized partial regression coefficients. Double arrows indicate correlation between two variables (*r* not shown). *K* = No. of estimated

parameters. Error terms not depicted. Best model (5) is bold-faced, competing
models (4,7) are italicized.

Model	K	AICc	Δ_{AIC}	ω_I
1	7	10.79	11.65	0.001
2	7	17.79	10.64	0.002
3	8	21.19	14.05	0.000
4	**8**	**7.14**	**0.00**	**0.407**
5	*7*	*7.79*	*0.65*	*0.294*
6	10	20.00	12.86	0.001
7	*7*	*7.79*	*0.65*	*0.294*
Null	4	33.24	26.10	0.000
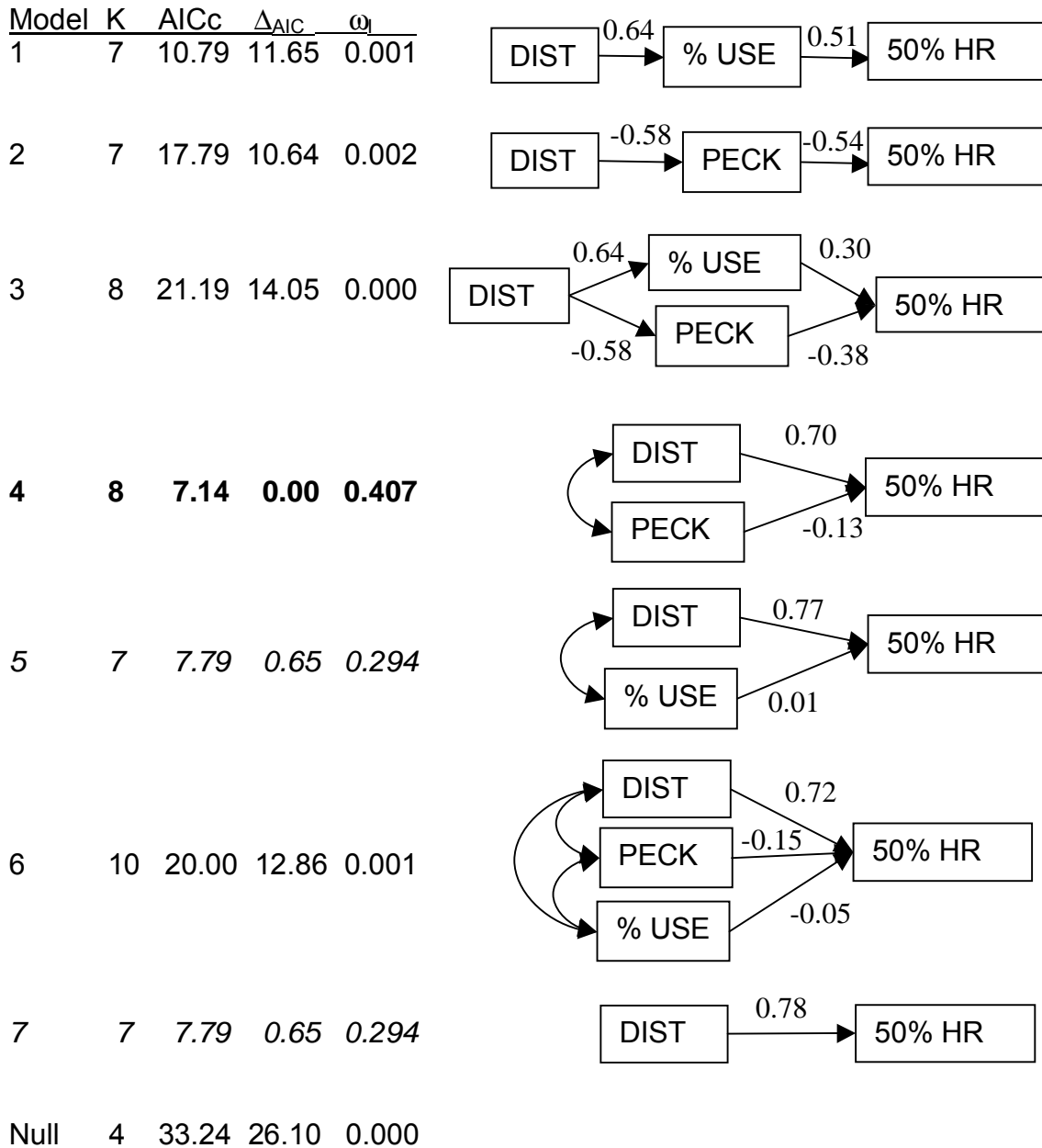
Fig. 14. Path analysis of relationships between nesting habitat in 50% home
range (50% HR) of piping plovers, foraging rate (PECK, attempts/minute
foraging) in the pre-laying period, % use of cover types other than MOSH by
foraging birds (% USE), and ln-transformed distance from the first nest attempt to
the large MOSH (DIST), WHD and WHB, Long Island, NY, 2002-2003 ($n = 22$
birds or pairs). Path coefficients are standardized partial regression coefficients.
Double arrows indicate correlation between two variables (r not shown). K = No.

of estimated parameters. Error terms are not depicted. Results for the model with the most support are bold-faced (4), and competing models are italicized (5,7).

Model	K	AICc	Δ_{AIC}	ω_i
1	7	15.96	7.40	0.011
2	7	10.33	1.76	0.191
3	8	15.39	6.83	0.015
4	**8**	**8.56**	**0.00**	**0.461**
5	7	10.53	1.97	0.172
6	10	20.00	11.43	0.001
7	7	10.83	2.27	0.148
Null	4	26.43	17.87	0.000
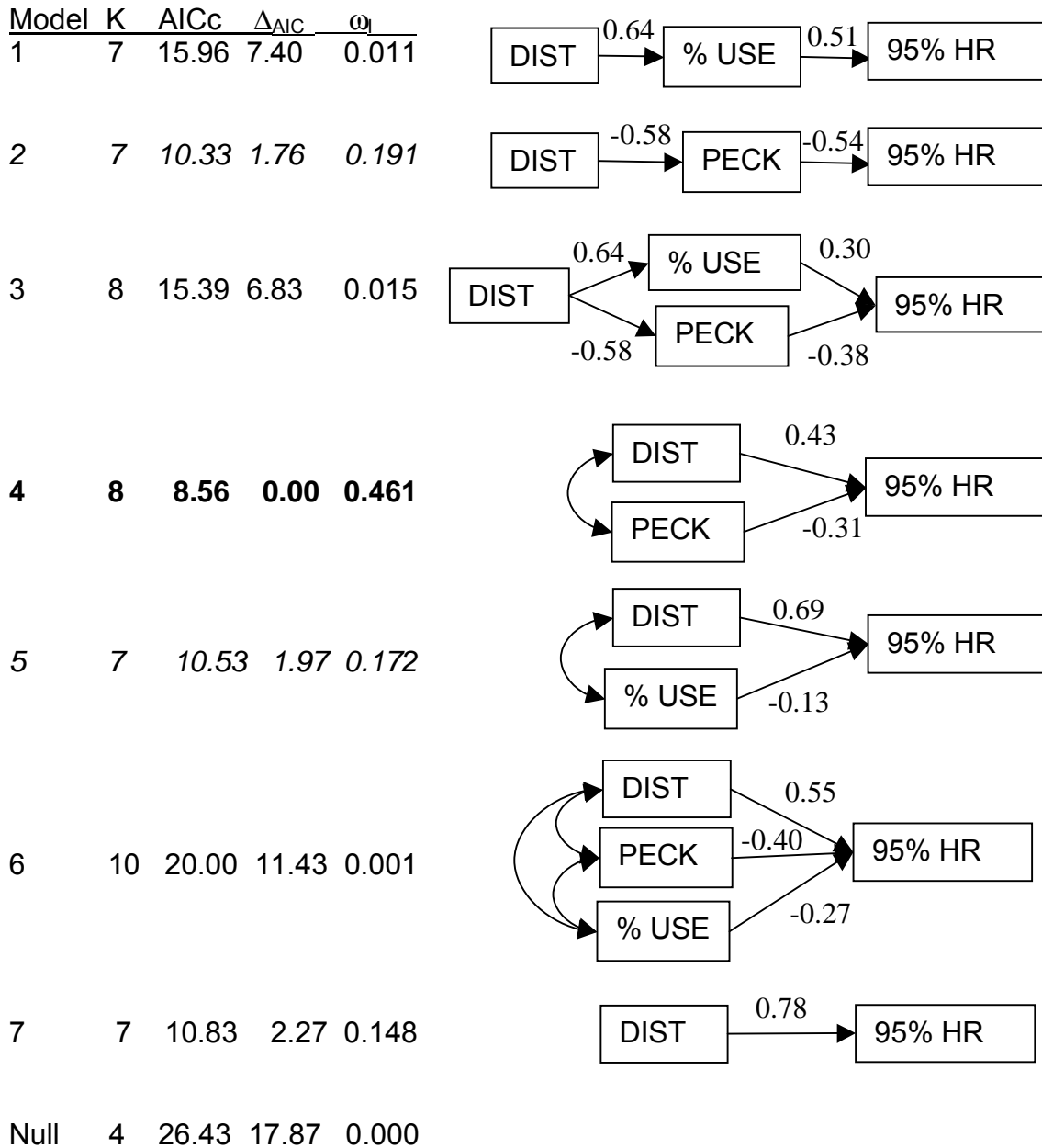
Fig. 15. Path analysis of relationships between nesting habitat in 95% home range (95% HR) of piping plovers, foraging rate (PECK, attempts/minute foraging) in the pre-laying period, % use of cover types other than MOSH by foraging birds (% USE), and ln-transformed distance from the first nest attempt to the large MOSH (DIST), WHD and WHB, Long Island, NY, 2002-2003 (n = 22 birds or pairs). Path coefficients are standardized partial regression coefficients. Double arrows indicate correlation between two variables (r not shown). K = No. of estimated parameters. Error terms are not depicted. Results for the model

with the most support are bold-faced (4), and competing models are italicized (2,5).

14 March 2005
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RH: Piping Plover Productivity Limitation • *Cohen and Fraser*

CHAPTER 2: FACTORS LIMITING PIPING PLOVER REPRODUCTIVE

OUTPUT ON LONG ISLAND, NEW YORK

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Abstract: Availability of moist sediment foraging habitat (MOSH), such as

intertidal sandflats, has been demonstrated to improve survival of piping plover

chicks (*Charadrius melodus*), a federally threatened shorebird. We examined

whether MOSH availability limited piping plover reproductive success on a barrier

island on Long Island, NY, 2001-2004. Fledgling production (fledges/ha) was

related to MOSH area ($P = 0.002$) and nesting pair density ($P = 0.005$) at 5 sites

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in NY and 3 reference sites in MA.   Most nest losses were due to predation or predator-induced abandonment. Brood survival and number of chicks fledged increased with home range size in some years, but was not dependent on measures of female quality, clutch weights, chick growth rates, or chick size at any given age. Wing chord growth rate was higher for 2 broods that foraged in MOSH than 17 broods that did not ($P = 0.041$). Loss of chicks that had access to MOSH, presumably due to predation, made any direct effect of foraging habitat availability on survival difficult to detect.

For threatened piping plovers (*Charadrius melodus*) breeding on the Atlantic Coast, limitations to reproductive output are fairly well understood, and management for increased reproductive output has played a major role in the recovery of this species to date (Plissner and Haig 2000). Predation often is a primary determinant of nest success for piping plovers (Loegering and Fraser 1995, Mayer and Ryan 1991, Patterson *et al.* 1991, Prindiville Gaines and Ryan 1991). Other factors that have been identified include human disturbance (Burger 1989, Flemming *et al.* 1988), inclement weather (Burger 1989), and nutrition (Loegering and Fraser 1995). Access by broods to high quality foraging habitat, such as intertidal mud flats and ephemeral pools, has been found to

increase fledging success at several sites along the Atlantic Coast (Loegering and Fraser 1995, Goldin and Regosin 1998, Elias *et al.* 2000). In addition to providing food, such low wave-energy moist-sediment habitat (MOSH) also may provide refuge from human disturbance (Goldin and Regosin 1998).

In contrast to studies that showed a link between access to MOSH and higher piping plover chick survival, a long-term study on Long Island, NY did not demonstrate a benefit to chick survival for chicks foraging in MOSH compared to those foraging in other cover types (Houghton *et al.* in prep). In fact, in later years of the study, chicks with access to MOSH had lower survival than those that did not, probably because the bay side of the island became more developed by humans and more densely vegetated. High predation rates may have masked any beneficial effect of access to good foraging habitat. In that study, nest and brood survival were found to be linked to predator-control measures, such as nest exclosures and trapping. Examination of subtler responses to habitat quality, such as chick growth, may reveal habitat-related differences that could influence survival. Cairns (1982) found that piping plover chicks that failed to obtain 60% of "normal" (we interpret this to mean "average") body mass by 12 days were less likely to survive than heavier chicks.

The role of adult quality and nutrition in limiting breeding success of piping plovers is less well understood. In other bird species, fledging success has been linked to quality of one or both parents (Wendeln and Becker 1999, Risch and Rohner 2000, Yerkes 2000, Ferns and Lang 2003). Measures of quality in other species include body mass (Wendeln and Becker 1999), wing chord or tarsus

length (Bart and Earnst 1999), plumage characteristics (Senar *et al.* 2002, Ferns and Lang 2003), or egg mass and laying date (Nisbet *et al.* 1998, Risch and Rohner 2000). The environmental and genetic bases of such traits can be difficult to distinguish, especially for body mass which has components of both condition and structural size (Gebhardt-Henrich and Richner 1998). Adults foraging in high quality habitat may be in better condition than adults in poorer habitat, regardless of genetically-based differences among the adults; also possible is that adults that are innately superior may be better able to establish and defend territories in the best habitat. In either case, adults in better condition may produce heavier eggs and chicks, and be better at defending their offspring.

After more than doubling in the first 16 years following being listed as threatened, the Atlantic Coast population trajectory of piping plovers declined slightly between 2002 and 2004 (from 1690 to a preliminary estimate of 1668, USFWS 2004), and is 330 pairs short of the recovery goal of 2000 pairs (USFWS 1996), despite intense efforts to manage predation and human disturbance. In continuing to manage piping plovers, it will be important to determine whether other factors that have received less attention (such as foraging habitat availability) affect breeding success.

In 1992, a storm breached and overwashed Westhampton Island, Long Island, NY in what was to become the village of West Hampton Dunes (WHD). Between the storm and the addition of new beach by the U.S. Army Corps of Engineers (USACE) as they repaired the breaches (USACE 1994), approximately 25 ha of new MOSH was created in the form of bay side intertidal

sandflats (Chapter 1). This provided an opportunity to compare reproductive success of pairs with broods that used MOSH and broods that did not at WHD and other nearby sites. In this study, our goal was to determine factors affecting piping plover reproductive output. We attempted to relate survival of eggs and chicks to use of MOSH by pre-laying adults and foraging broods. We predicted that nest survival, brood survival, egg weights, and chick growth rates would be higher for adults of greater quality as measured by morphology and plumage traits. We further predicted that measures of parental quality would be dependent on use of MOSH for foraging in the pre-laying period. Finally, we predicted that chick growth rate would be dependent on chick access to MOSH for foraging, and that survival to fledging would be correlated with growth rate. To summarize the hypotheses we tested:

1. Sites with more MOSH have higher reproductive output than sites with less MOSH

2. Sites with more MOSH have higher hatching success and fledging success than sites with less MOSH

3. High quality adults (larger body size, darker plumage bands) lay heavier eggs, have chicks with higher growth rates, and fledge more young than lower quality adults

4. Adults that spend more time in MOSH and have high foraging rates in the territory establishment period lay heavier eggs, have chicks with higher growth rates, and fledge more young than adults that use MOSH less and have lower foraging rates.

5. Chicks with access to MOSH grow faster and survive better than
   chicks without access to MOSH

STUDY AREA

West Hampton Dunes (WHD) is a barrier island village, located approximately 3 km east of Moriches Inlet on the Westhampton Barrier Island off the south shore of Long Island, New York (40°47' N, 72°43' W).   This site contains extensive intertidal sandflats created during a storm-related breach in 1992, and augmented by the U.S. Army Corps of Engineers (USACE) beach rebuilding effort that occurred thereafter (USACE 1994). There are approximately 3.3 km of nesting beaches, including a sandspit extending northward into Moriches bay. The ocean front is separated from the bay shore by an artificially-constructed dune, dense vegetation, and houses. Many of the buildings have been added since the 1992 storm, which destroyed part of the village (USACE 1994).   Most of the broods that hatched on the bay side or on the eastern half of the ocean beach were able to access the bayside MOSH for foraging, although the number doing so decreased as the bayside became developed by humans and revegetated (Houghton *et al.* in prep).

We examined plover populations at several areas that differed from WHD in the quantity of nesting and foraging habitat, and which varied in proximity to WHD. The first such site was Westhampton Beach (WHB). This site is adjacent to WHD on the east (40°48' N, 72°39' W), and contains approximately 3.2 km of nesting beach, separated from the bay side of the island by dense vegetation and human construction. The bayside contains a few small marginal intertidal

sandflats (<1.5 ha in total), to which adults have access but the flightless chicks do not.   We collected data at 3 smaller NY sites (Shinnecock West County Park, Cupsogue County Park, and Democrat Point at Robert Moses State Park) and 3 sites on Monomoy Island, MA for various purposes. For descriptions of the New York sites, see Chapter 1. For descriptions of Monomoy sites, see Keane et al. in press.

METHODS

DATA COLLECTION AND PROCESSING

Nesting pair density and vital rates.—We searched for plover nests daily, 15 March through 25 July, 2001 through 2003. Locations of all nests in WHD, WHB, and Shinnecock were recorded with a global positioning system (GPS) unit. Researchers observed plover nests daily to determine hatch dates and causes of nest or egg loss. At Democrat Point, Robert Moses State Park personnel and U.S. Fish and Wildlife Service contractors conducted all nest searching and brood monitoring, at least 3 times per week. At Cupsogue County Park, Suffolk County Parks personnel collected the data. Data on pair locations and productivity for Monomoy were provided by the U.S. Fish and Wildlife Service, Monomoy National Wildlife Refuge.

Densities at all sites were estimated by classifying nesting habitat on scanned 1:800 scale true color aerial photos (Aerographics Corp., Bohemia, NY) for WHD, WHB, Shinnecock West, Democrat Point, and 3 beaches on Monomoy Island, Massachusetts (Powderhole, Northeast, and Southeast), using ArcView Image Analyst software (ESRI, Redlands, CA, 2001, see Chapter 1 for details).

We then calculated the number of nests per unit area of nesting habitat. Chick production was calculated as fledglings / ha of nesting habitat. Reproductive output was calculated as fledglings / pair. On the same aerial photos, we determined the area of MOSH within 300 m of nesting habitat (see Chapter 1 for explanation of the 300 m distance). We calculated a "MOSH Index" as "MOSH within 300 m of nesting habitat (ha)" / "nesting habitat (ha)", because larger beaches tend to have more MOSH.

For each nest, we calculated the density of neighboring nests experienced by each bird as no.neighbors within 600 m / nesting habitat within 600 m (ha). The 600 m distance was chosen based on a spatial pattern analysis (Krebs 1999), which indicated this to be the scale at which plover pairs displayed the most aggregation (Chapter 1). The distance from each nest to the nearest MOSH (regardless of size) and to the large contiguous area of MOSH created by the storm of 1992 and subsequent breach repair by the USACE (hereafter "large MOSH"), were calculated in ArcView.

Since we conducted complete censuses each day at our site, or obtained data from collaborators who performed such censuses, we believe that our raw survival data were relatively free of bias stemming from detection rate (Houghton et al. in prep). Therefore, we performed our analyses on raw survival rather than Mayfield-type estimators (Mayfield 1975).   At each site, we calculated observed nest survival as number of nests that hatched ≥ 1 egg / number of nests in which eggs were laid.   We calculated observed egg success as number of eggs hatched / number of eggs laid.

After the eggs hatched, we attempted to observe each brood daily until it fledged. We observed broods from a distant or concealed location so that brood movements were unaffected. If brood behavior appeared to be affected by the presence of the observer, the observation was discarded. A chick was considered to have fledged if we observed sustained flight for 15 m or if it reached 25 days of age. If chicks were missing from a brood, we searched the immediate area for at least one half hour. If the chicks failed to reappear over the course of the pre-fledging period, they were presumed to have died. We calculated brood and chick survival as the number of broods or chicks fledged/number of broods or chicks hatched.

Plover capture and measurement.— Adult plovers were captured prior to nesting by driving them onto noose carpets (Drake *et al.* 2001, Mehl *et al.* 2003) and into walk-in funnel traps (Chapter 1). During incubation, adult plovers were captured on their nests with box traps (Wilcox 1959) and funnel traps (Paton 1994, Cairns 1982).   Birds with nests inside predator exclosures were captured by flushing them into a funnel trap facing into the exclosure on one side, with lead lines blocking escape on either side of the funnel.

A single plastic numbered color-band was applied to each tibiotarsus. Each adult plover was marked with a unique color combination. Body weight (nearest 0.1g), culmen, tarsus, and wing chord length (nearest 0.1 mm), and indices of plumage pattern (1 = complete neck or forehead band, 0 = incomplete band) and coloration (1 = black bands, 0 = gray or brown bands) and bill coloration (1 = "≤ 25% black", 0 = "> 25% black") were recorded.

We weighed clutches at WHD, WHB, and Shinnecock on the day of clutch completion where possible, but no more than 7 days after completion. Eggs were placed singly in drawstring bags and weighed (nearest 0.1 g) with a hanging spring balance. Eggs were replaced in their original position and orientation within 5 min of approaching the nest.

One researcher participated in chick capture for each chick in a brood. Chicks were captured by hand, placed individually into drawstring bags, and weighed (nearest 0.1 g) with a hanging spring balance (Cairns 1982, Loegering *et al.* 1995). Wing chord of the right wing was measured (nearest 0.1 mm) with a wing rule. For young chicks, we measured wing chord to the end of the fleshy wing stub, rather than the down feathers. Wherever possible, all members of a brood were caught and released together. Chicks were captured on hatch day and in 2002 and 2003 each chick was banded in a manner similar to the adults, except that all members of the same brood were assigned the same color combination. Individuals were identifiable only by band number.   At WHD and WHB, we attempted to capture and re-measure chicks from marked broods every 3 days in 2001, and every 7 days in 2002-2003, including fledge day (25 days of age). At Shinnecock, Cupsogue, and Democrat Point, we did not individually mark broods. We attempted to capture and measure broods at each of the latter sites on each of 2 visits, at least 1 month apart.

Adult and chick behavior.— We used an instantaneous sampling method to estimate time adults spent in different cover types and behaviors prior to nest initiation (Altman 1974, Lehner 1979, Tyler 1979). We recorded cover type and

behavior of banded adults continuously for a 5-min period on a tape recorder. We sampled the tape, recording cover type and behavior every 10 s.

We used a continuous sampling method to estimate foraging rates for adults prior to nest initiation (Tyler 1979, Tacha *et al.* 1985). During the same 5-min observation, we continuously recorded pecks and worm pulls in order to determine foraging rate. We calculated foraging rate as number of foraging attempts (pecks and worms) / number of 10-s intervals x 10 x 60^{-1}. We calculated a foraging rate "while foraging" as number of foraging attempts / number of 10-s in which the bird was foraging x 10 x 60^{-1}. If a focal bird was seen to peck at the same prey item multiple times, we only recorded one peck.

After chicks hatched, we recorded activity budget, cover type use, and foraging rate of broods in a manner similar to adults, using a "focal chick" method and 5-min observations. If a brood went out of view then returned to view during a 5-min observation, a new focal chick was chosen to complete the observation.

Adult home range.— We searched for color-marked birds daily in all potential plover habitats from 15 March to 15 August, 2002 and 2003. The location of all marked birds seen was computed by first recording the location of the observer using a GPS unit, using a compass to obtain a bearing to the plover, estimating the distance from the observer to the bird, and then using Euclidean geometry to plot the plover's location. All such observations were entered into ArcView GIS 3.2 (ESRI, Redlands, CA 2001). Both 50% and 95% home ranges were calculated using fixed kernel estimates in the Animal Movements Extension (Hooge, Anchorage, AK 1997) for all plovers with ≥ 20

sightings, using Least-Squares Cross-Validation (LSCV) to determine the smoothing parameter (h). Each home range was intersected with nesting habitat polygons, to calculate the hectares of nesting habitat within the home range.

DATA ANALYSES

We used standard parametric or nonparametric tests to analyze most relationships. To reduce the morphological data to a few uncorrelated variables that represented most of the variance in body size, we performed a principal components analysis (PCA) on morphological measurements of adult plovers, by year and sex. Before conducting the PCA, each measurement was standardized by the mean and standard deviation for the appropriate year and sex. We included the first two principal components in all analyses involving morphological measurements.

We used sample-size-corrected information-theoretic variable selection criteria (Akaike's Information Criterion, AIC_c, (Burnham and Anderson 2002)) with multiple linear regression, to select the model, if any, that best explained mean egg weights in a clutch based on morphological characteristics of adult females and their principal components. We compared the model with the best AIC_c to a null model with no explanatory variables, to determine if any model adequately described the observed pattern in mean egg weights. Similarly, we used AIC_c as a variable selection method to determine if models based on morphological measurements of adults adequately explained number of chicks fledged, and whether chick behavior (peck rate, % time in different behaviors) could explain average brood growth rates in body mass and wing chord. We used AIC_c with all

possible logistic regressions to identify morphological traits of adults that could best explain patterns in nest survival and brood survival. We used Poisson regression to examine the relationship between number of chicks fledged from a brood and the average growth rate of in body mass (g) and wing chord (mm) of the brood.

We used a graphical technique (Ricklefs 1967) to determine whether exponential, logistic, Gompertz, or von Bertalanffy curves best fit the plots of chick age and wing chord vs. chick age. After choosing the best curve, we linearized the data using the appropriate transformation (Ricklefs 1967), and calculated growth rate as the slope of the resultant line, from Day 0 to Day 15 and from Day 0 to fledge (Day 25).

RESULTS

At the 4 Long Island sites other than Cupsogue, vital rates differed among sites and/or years (Table 1). Cupsogue was not included in our analyses of site and year differences in vital rates because nest and brood-specific success data were not available. Chicks fledged / pair at Cupsogue was 0.50, 1.13, and 0.38 in 2001, 2002, and 2003, respectively. Chicks fledged / ha nesting habitat was 0.29, 0.54, and 0.19 in those years.   At WHD, 87-100% of the nest losses for unexclosed nests (no predator exclosures used) were due to predation, depending on the year (Appendix K). At WHB, 50-84% of the unexclosed nest losses were due to predation (Appendix K).   In addition to direct predation, most of the nest abandonments in Appendix K were presumable due to predators harassing or killing adults at exclosure cages. One adult at WHD was know to

have been killed by a cat in 2002, and another adult was killed by an unidentified predator at Shinnecock in 2003. Chick losses were usually to unknown sources, but were presumably due to predators if they did not occur after severe weather events and the chicks were not seen to be moribund before they were lost. The carcass of one chick was found in 2001 at WHD with puncture wounds. In 2002 at WHB, one carcass was found that had been partially eaten by a mammalian predator. In 2003 at WHD, a wounded living chick was observed, and the chick disappeared by the next day.

VITAL RATES AND REPRODUCTIVE OUTPUT

Site-level effects.—Mean chicks fledged / ha increased with increasing mean MOSH index (Fig. 1). There were no other correlations between vital rates and mean MOSH index or area of nesting habitat (Table 2). Mean chicks fledged / ha increased with increasing nesting pair density ($r = 0.87$, $P = 0.005$, $n = 8$), but there were no other correlations between reproductive success variables or vital rates and nesting pair density ($\alpha = 0.05$). Mean chicks fledged / ha was not correlated with mean chicks fledged / pair ($r = 0.66$, $P = 0.08$). Chicks fledged/pair increased with increasing brood survival ($r = 0.86$, $P = 0.014$), but not nest survival ($r = -0.09$, $P = 0.84$). Chicks fledged/ha was not correlated with any vital rates.

Distance to MOSH.—Nest success of a pair (probability of a pair hatching eggs from at least one nest) was not related to distance from the first nest attempt to the large MOSH or distance to nearest MOSH (Table 3). Brood success (probability of fledging at least 1 chick) increased with increasing

distance from the large MOSH and nearest MOSH in 2001 and 2002, but the

effect was not significant in 2003 (Table 3). In 2002, number of chicks fledged

increased with increasing distance to large MOSH (Spearman's r = 0.31, P =

0.0192, n = 55) and nearest MOSH (r = 0.33, P = 0.0106, n = 61). In 2001 and

2003 the values of r were all between -0.10 and 0.13, with all P > 0.05.

Neighbor density.—Probability of a pair hatching eggs in at least one nest

increased with increasing neighbor density in 2001, but not 2002 or 2003, for

WHD, WHB, and Shinnecock (Table 4). Probability of fledging at least one chick

from a successful nest was lower in areas of high neighbor density than low

neighbor density in 2001 and 2002, but the effect was not significant in 2003,

(Table 4). Number of chicks fledged / pair was low in areas with high neighbor

density in 2002 (Spearman's r = -0.28, P = 0.027, n = 61), but not in 2001 (r = -

0.04, P = 0.79, n = 58) or 2003 (r = -0.18, P = 0.42, n = 49).

Home range size.— The LSCV method for selecting h for home range

calculations resulted in unrealistically large, ellipsoid home ranges for plovers.

Therefore we used custom values for h defined as half the average distance

between neighboring first nests (h = 42 m in 2002, 60 m in 2003). These custom

h values resulted in home ranges that traced the clusters of plover observations

much more closely than those using an h calculated from LSCV.

Nest success was not related to any measure of 50% or 95% home range

size (Table 5), and the same was true for brood success (Table 6). In 2002,

number of chicks fledged increased with increasing 50% home range size

(Spearman's r = 0.42, P = 0.049, n = 23) and ha of nesting habitat within 50%

home range (r = 0.49, P = 0.017, n = 23). In 2003, these correlations were 0.35

(P = 0.21) and 0.10 (P = 0.72), respectively (n = 15). There were no significant

correlations at the α = 0.05 level between number of chicks fledged and

measures of 95% home range size, in either year.

    Adult morphology.— Probability of hatching at least one egg was not

related to morphological characteristics (body mass, culmen, tarsus, and wing

chord lengths) or their principal components of either sex in any year (all possible

logistic regressions, Δ_{aic} for null model ≤ 2, n(males/females) = 14/22, 15/22,

17/20, in 2001, 2002, and 2003, respectively). Similarly, we found no useful

models of probability of fledging at least one chick from a successful nest, based

on morphological variables, n(males/females) = 11/18,12/18, 9/9, in 2001, 2002,

and 2003 respectively. Furthermore, models incorporating morphological

measurements did not explain the numbers of chicks fledged by an adult better

than a null model, for either sex (all possible linear regressions).

    Adult plumage.—Nest survival was not related to any plumage pattern or

pigment scores, or bill pigment score, for either sex in any year (Fisher's exact

test, P > 0.1 for all tests). Females in 2002 with incomplete forehead bands were

more likely to fledge at least one chick (100%, n = 8) than females with complete

forehead bands (50%, n = 10, Fisher's exact test, P = 0.036). In 2002, females

with incomplete forehead bands fledged more chicks (2.4±0.4, n = 8) than those

with complete forehead bands (0.5±0.2, n = 14, P = 0.003).

    Adult behavior and habitat use.—Nest success was not related to male or

female pre-laying peck rates, percent time spent foraging, resting, or disturbed,

or percent use of ocean backshore or bay intertidal zone at high or low tide,

WHD and WHB, 2002-2003 (One-variable Logistic regression, Wald's χ^2 for all

tests < 3, P > 0.1). Sample sizes for 2002 and 2003 (M/F) were 10/18 and 11/13.

Egg mass.—Nest survival was unrelated to mean egg mass (each sample

= average for a clutch) in any year (logistic regression, Wald's χ^2 for all tests < 1,

P > 0.1, n = 33, 48, and 36 in 2001, 2002, and 2003, respectively). This was also

true for brood survival (n = 19, 28, and 10 in 2001, 2002, and 2003, respectively).

Number of chicks fledged was uncorrelated with mean egg mass in any year,

with Spearman's r ranging from -0.04 to 0.08 and all P > 0.1. Survival of broods

to 7 days of age was also unrelated to mean egg mass within clutches in 2001

(logistic regression, χ^2_1 = 0.01, P = 0.92, n = 18) or 2002 (logistic regression, χ^2_1

= 0.81, P = 0.37, n = 27). In 2003, all broods for which we obtained egg weight

measurements survived to 7 days.

Chick growth rates.— For all broods that we measured at least 3 times by

Day 15, body mass and wing chord grew exponentially from Day 0 to Day 15 (r^2

for the linearized relationships ranged from 0.75 to 1.0 for body mass, 0.78 to 1.0

for wing chord). Thus, we calculated growth rate to Day 15 as the slope of the

relationship between ln(body mass or wing chord) and age. All broods that we

weighed at least 3 times before 15 days of age fledged at least one chick.

Number of chicks fledged was not correlated with average growth rate in body

mass to 15 days (Poisson regression, Wald χ^2_1 = -0.86, P = 0.35, n = 27) or wing

chord (Poisson regression, Wald χ^2_1 = 0.37, P = 0.54, n = 18). Furthermore,

number of chicks fledged was not related to the brood average body mass or

wing chord length at or just after hatch (0 to 2 days), or at ages 5-7 days, 9-11

days, 12-15 days, 18-21 days or 22-25 days (Wald χ^2_1 ranged from 0.0 to 1.1, all

$P > 0.1$).

Individual chicks also grew exponentially (r^2 for the linearized relationship

ranged from 0.73 to 1.00 for body mass, 0.66 to 1.00 for wing chord). We

therefore estimated growth rate of individual chicks in a similar manner to that

used for brood average growth rates. Only 3 of 30 chicks that we weighed at

least 3 times from hatch to age 15 days failed to survive. In one brood, we were

not certain which of 2 broodmates survived, leaving a sample size of 28 chicks of

known fate (26 survived). There was no relationship between the probability of

survival and body mass or wing chord measured at any of the age categories

mentioned above (logistic regression, all Wald $\chi^2 \leq 2.0$, all $P > 0.1$).

EGG MASS

There were no differences in average mass of eggs (each sample =

average egg mass within a clutch) among years or sites, or between first nest

attempts and renests (ANOVA, $F_{5,112} = 0.94$, $P = 0.46$, Table 7). With sites and

years pooled, the average egg mass of first nest attempts was 10.0±0.1 g ($n =$

86), and the average mass of renests was the same ($n = 32$). Mean egg mass of

a clutch was not related to clutch size or nest initiation date, in days after Jan 1

(multiple linear regression, $F_{3,108} = 0.08$, $P = 0.970$).

Neighbor density and home range.—There were no correlations between

average egg mass of first nest attempts and neighbor density with sites pooled,

in 2001 (Spearman's $r = 0.18$, $P = 0.35$, $n = 30$), 2002 ($r = -0.17$, $P = 0.34$, $n =$

34), or 2003 (r = -0.03, P = 0.91, n = 23). There were no correlations between average egg mass and distance to large MOSH (r = -0.09, P = 0.40, n = 82) or nearest MOSH (r = 0.06, P = 0.61, n = 87), with site and year pooled. There were no correlations between mean egg mass and 50% or 95% home range size, or area of nesting habitat within home ranges (r ranged from -0.23 to 0.15, P > 0.1).

Female behavior.— Mean egg mass of first clutches was not generally related to female pre-laying peck rates, percent time spent foraging, resting, or disturbed, WHD and WHB, 2002-2003 (Spearman's r ranged from -0.21 to 0.22, all P > 0.1, n = 24). Mean egg mass increased with % use of bay intertidal zone at low tide by pre-laying females (Fig. 2).

Female morphology.—Based on best subsets regression and AIC_c, no models containing female morphological measurements or their principal components adequately explained patterns in mean egg mass of first clutches (Δ_{aic} of the null model ≤ 2) in 2001 (n = 11), or 2002 (n = 21). In 2003, however, several models explained mean egg mass better than a null model, but one model was clearly the best ($AIC_{c\text{-null}}$ = -2.1, $AIC_{best\ model}$ = -6.4, ω_i = 0.68, n = 8, Fig. 3), since the Δ_{AIC} for all others was > 2.0.

CHICK GROWTH

Plover chicks grew exponentially from hatch until 25 days of age, when they are considered to be fledged (Fig. 4, 5). One brood on the western border of WHD in 2003 had lower than average growth rates of both body mass and wing chord (Fig. 4, 5). The chicks of that brood were not capable of flight by age

30, but did not appear moribund. Average brood growth rates of body mass and

wing chord were uncorrelated (r = 0.15, P = 0.53, n = 19), but these rates were

correlated for individual chicks, (r = 0.59, P = 0.001, n = 30).

Mean brood body mass at hatch increased with mean egg mass of the

clutch (Spearman's r = 0.47, P = 0.013, n = 27). There were no differences

among years or sites in body mass at hatching or fledging (Table 8). Mean body

mass at fledging was approximately 67% of mean adult body mass during

incubation, and mean wing chord at fledging was approximately 64% of adult

wing chord, although there was much variability. Hatchlings from Shinnecock

West had smaller wing chords than those from WHD or WHB (Table 9).   Mean

brood hatch mass was 3.1±0.1 g less than mean egg mass. There were no

differences in fledgling wing chords among sites or years, although we did not

capture any fledglings at Shinnecock (Table 9). Average brood growth rate was

not related to hatch date, but was greater for small broods than for large ones

(multiple linear regression, $F_{1,27}$ = 6.6, r^2 = 0.20, P = 0.016, growth rate =

0.09±0.01 – 5.69E-3±2.21E-3(brood size), n = 28).   Growth of the wing chord

was not related to hatch date and initial brood size ($F_{2,16}$ = 1.14, r^2 = 0.12, P =

0.34, n = 18).

Neighbor density and home range.—Brood average growth rate was not

related to neighbor density or any measures of home range size (Spearman rank

correlations, all P > 0.07). Individual chick growth rate in body mass from hatch

to fledge decreased with increasing neighbor density of nesting pairs in 2002

(Spearman's r = -0.59, P = 0.001, n = 29). The same was true for growth rate of

the wing chord (r = -0.44, P = 0.016, n = 29), but there were no relationships in

2003. With years pooled, there was no correlation between body mass or wing

chord growth rates and distance to large MOSH or nearest MOSH (r ranged from

-0.09 to 0.22, all P > 0.1, n = 44). Growth rate in body mass (n = 38) increased

with increasing 50% home range size (r = 0.33, P = 0.040), 95% home range

size (r = 0.45, P = 0.004), and nesting habitat within 95% home range size (r =

0.36, P = 0.026).   Wing chord growth rate was correlated only with 95% home

range size (r = 0.34, P = 0.040).

In 2001, 2002, and 2003, the number of marked broods that were

observed foraging on MOSH in the bay intertidal zone was 5, 1, and 1. Average

brood body mass growth rate (2001-2003) was not different between broods that

foraged at least part of their lives on MOSH (n = 7) and those that did not

(Wilcoxon rank-sum test, P = 0.50, n = 22). Average wing chord growth rate

(2002-2003) was greater for broods with access to MOSH (n = 2) than those

without access (P = 0.041, n = 17).

With years and sites pooled, mean body mass was higher for 8-11 day old

chicks with access to MOSH than those without, but there were no differences for

other age categories (Table 10). Mean wing chord length was longer for 12-15

day old chicks with access to MOSH than those without, but there were no

differences for other age categories (Table 10).

Brood behavior.— Based on best subsets regression and AIC$_c$, no models

containing mean brood peck rate (attempts/min), % time foraging, % time resting,

or % time disturbed adequately explained mean brood growth rate of body mass

from hatch to fledge (Δ_{AIC} for null model ≤ 2, n = 25 broods). The same was true

for growth rate of the wing chord (n = 15).

CORRELATIONS AMONG EXPLANATORY VARIABLES

Neither foraging rate nor percent time spent in different behaviors was

correlated with neighbor density in any year, 2001-2003 (Spearman rank

correlation, all P > 0.07). With years pooled, percent time chicks spent resting

decreased with increasing distance from large MOSH (Spearman's r = -0.28, P =

0.021, n = 67), but there were no other correlations with distance to large MOSH

or nearest MOSH (all P > 0.1). Percent time spent in "other" activities besides

resting, foraging, or reacting to disturbance (primarily non-foraging locomotion)

increased with increasing ha of nesting habitat within 95% home range (r = 0.55,

P = 0.010).

POST-FLEDGING

We found no difference in brood average body mass or wing chord

lengths at fledging (Day 22-26) between broods that we know had at least one

chick return to our sites the following year (whether they bred or not, mass =

39.7±2.6, wing = 71.4±3.5, n = 5) and those that did not return (mass = 36.0±1.8,

wing = 74.5±3.9, n = 11). We also found no difference between broods for which

we know at least one chick returned and nested at our sites (mass = 37.1±2.5,

wing = 70.6±6.2, n = 3) and those that did not (mass = 37.1±1.8, wing =

74.2±3.3, n = 13, Wilcoxon rank-sum tests, all P > 0.2).

DISCUSSION

We found little evidence that access to MOSH benefits reproduction and chick growth at WHD and WHB. In fact, during our study, brood survival was especially poor for chicks that had access to MOSH in WHD from 2001-2003. This may have been due to density-independent factors, especially high predation by cats, which was likely correlated with a growing human population on the bay side of the island (Houghton et al. in prep). Houghton *et al.* (in prep) found that piping plover egg and brood survival at WHD and WHB from 1993 to 2003 were correlated with number of predators removed by trapping, mean minimum monthly temperature, and total rainfall.   Furthermore, the use of predator exclosures improved nest survival in many years.   Brood survival also was positively related to foraging rate and percent time a brood spent resting. That weather and brood foraging rate were demonstrated to impact survival does imply that energetics plays a role in limiting reproductive success, but the link was not apparent in our years except that chicks reared closer to MOSH spent more time resting than chicks farther away. High predation may have masked our ability to detect a relationship between foraging habitat use and growth and survival. Mammalian predators were removed from WHD by trapping from 1996-2000, but trapping efforts diminished in 2001 and ceased in 2002.

Chick growth rates of piping plovers in our study were greater than those found in the same study area by Wilcox (1959), and lower than those found at Cadden Beach, Nova Scotia (Cairns 1982) and the Great Plains (D. Le Fer, Virginia Tech Dept. Fisheries and Wildlife Sciences, unpublished data), and

much lower than for captive reared chicks, which were fed *ad libitum* (U.S. Army Corps of Engineers, unpublished data). The reason for our discrepancy with the previous Long Island study is unclear, especially since egg mass and hatchling masses were comparable with our study. Wilcox (1959) found much greater hatching success than in our years (91%), but did not report overall reproductive success, or the intensity of his search effort. The differences in growth rate between our study and those conducted in Canada and the Great Plains may be a result of the difference in breeding season length among these locales, which has been demonstrated to explain differences in interspecific growth rates in Charadriiform birds (Beintema and Visser 1989). Peak nest hatching at Cadden Beach occurred during the second and third week of June (Cairns 1982), while at our sites, the peak hatch was between the first and second week of June (Houghton *et al.* in prep). In Canada, the peak occurrence of plovers in pre-migratory flocks on the intertidal flats was the second week of July (Cairns 1982), which coincided with the peak fledging dates at our sites (Houghton *et al.* in prep) This implies that the breeding season was at least 1 to 2 weeks longer in New York than in Canada. However, at Cadden beach most broods also had access to MOSH for foraging (Cairns 1977). Plovers in North Dakota were observed to begin laying on 19 May and 6 May in 2 consecutive years, and successful breeders began leaving in late July (Prindiville Gaines and Ryan 1988). By comparison, nest initiation at WHD and WHB began as early as April 17, and peaked in the first week of May (Houghton *et al.* in prep), indicating a shorter breeding season in the former study.

Slower-growing chicks may more vulnerable to predation, but less vulnerable to starvation, than faster growing chicks (Gebhardt Henrich and Richner 1998). If chick growth rates are slower at WHD than other sites as an adaptation to lower prey abundance, then broods at WHD may not be well-suited to cope with intensified predation from introduced predators such as cats. At our sites, reproductive output (0.48 to 1.3 fledglings / pair at WHD, 0.69 to 1.67 at WHB) was lower in general than that measured at Cadden Beach (1.3 – 2.1 fledglings per pair, Cairns 1982), where chick growth rates were higher. However, in the current study we were unable to demonstrate that survival was related to egg weights, chick growth rate (although by measuring growth every 5-7 days we may have missed effects due to poor growth very early on), or chick size at different ages, or that brood behavior affected growth rate. This contrasts with findings for piping plovers in Nova Scotia (Cairns 1982) where individuals that were heavier at 12 days of age were more likely to survive than lighter chicks, as well as findings for other nidifugous species. Survival of golden plover chicks (*Pluvialis apricaria)* to 1 week was dependent on weight gain by 2 days of age, and chicks with longer bills survived better than those with shorter bills (Pearce-Higgins and Yalden 2002). In Sandwich tern chicks (*Sterna sandvicensis*), survival to fledging increased with growth rate (Stienen and Brenninkmeijer 2002), and the same was true for oystercatchers (*Haematopus ostralegus*, Kersten and Brenninkmeijer 1995), and a variety of other precocial and altricial species (Gebhardt Henrich and Richner 1998).

We found no correlation between chick growth and survival and MOSH availability, except a higher growth rate of the wing primaries (albeit with a sample size of only 2) and a larger body size at about 1/3 to 1/2 of the way between hatching and fledging for broods with access to MOSH, a trend that disappeared before fledging. We found no relationship between MOSH availability and body mass in the first week, which contrasts findings for piping plover chicks in Maryland (Loegering and Fraser 1995), which weighed more at 4-5 days of age and were more likely to survive if they had access to MOSH. In that study, chicks without access to MOSH apparently were starving.

Oystercatchers (*Haematopus ostralegus*) nesting adjacent to intertidal foraging habitat produced larger clutches, heavier eggs and fledglings, and fledged more broods than individuals nesting far from foraging areas, especially in years of low prey abundance (Heg and van der Velde 2001). Bradbury *et al.* (2003) found very weak links between foraging habitat availability and nestling body condition and survival in 4 species of farmland-nesting passerines. They posited that either food was not limiting, or that parents were absorbing the entire cost when food resources were poor, which would be evident if parental quality and survival were measured. For precocial species, the later is unlikely, and in the case of piping plovers at our study sites, competition between adults and juveniles was reduced because parents foraged on MOSH, away from the brood-rearing territory. Reynolds *et al.* (2003) found that supplementing Florida scrub jay (*Aphelocoma coerulescens*) territories with food increased chick growth and survival in one year relative to control territories, but not in the following year.

They noted that chick survival within both types of territory increased significantly between the two years. This implies that food was limiting in some years but not others. At WHD, insect abundance in the brood rearing months of 2003 was equal to or greater than abundance in years with far better reproductive success (Chapter 3). Food also was discounted as a factor limiting growth and reproductive success of ringed plovers (*Charadrius hiaticulata*) in Greenland and England (Pienkowski 1984), and predation was implicated instead.

We found little effect of parental quality, as measured by morphological and plumage variables, on growth rates or survival. High female quality, as measured either by egg mass or female morphology, has been demonstrated to increase chick survival in common terns (*Sterna hirundo*, Wendeln and Becker 1999), herring gulls (*Larus argentatus*, Risch and Rohner 2000), and redheads (*Aythya americana*, Yerkes 2000), although the former two feed their young. Male shelducks (*Tadorna tadorna*) with more "immaculate" plumage" (less wear on the edges of the chestband) were more likely to produce fledglings than males with lesser quality plumage (Ferns and Lang 2003). In an experiment in which nestlings were artificially redistributed among broods after hatch, higher quality female shags (*Phalacrocorax aristotelis*, Amundsen and Stokland 1990), as measured by mean clutch volume, raised chicks with longer wing lengths at age 17 than lower quality females. In a similar experiment, survival of lapwing chicks (*Vanellus vanellus*) was also a function of female body mass and egg weight (Blomqvist *et al.* 1997). Furthermore, tarsus length of blue tit chicks (*Parus*

caeruleus) was related to the yellowness of the plumage of the foster male parent in a cross-fostering experiment.

We observed that females that spent more time in MOSH prior to laying had heavier clutches than those that spent less time in MOSH, and that egg mass increased with increasing female wing chord length in 2003. The pre-laying period was particularly wet and cold in 2003 compared to the previous two years (Houghton *et al.* in prep). We found that at two of our sites (WHB and Shinnecock), arthropod abundance in ocean intertidal zone and fresh wrack was lower in 2003 than in 2002 (Appendix D). Thus, habitat use and body condition may have influenced egg mass more than in prior years. However, we did not detect a direct effect of low egg mass on fitness. Breeding success has been found to increase with increasing egg weight in other species, where hatchlings from heavier eggs survive food deprivation longer, grow at a faster rate, and reach fledging sooner than hatchlings from lighter eggs (Parsons 1970, Ankney 1980, Quinn and Morris 1986). In our study, hatchability of eggs that survived the incubation period without being depredated was lower in 2003 at WHD and WHB than in any year since 1996 (which also had a cool, wet spring, Houghton *et al.* in prep). Reproductive success for the WHD and WHB plover population was low in 2003 (0.48 and 0.69 chicks fledged/pair, respectively), primarily due to nest depredation by crows. This may have prevented us from observing any potential variability in fledging rate due to early-season differences in adult female quality or behavior, or egg mass. The general consequence of predation

was to mask or weaken any effect we might have observed of food availability on reproductive output.

Average vital rates were not impacted by quantity of MOSH or nesting pair density among the 8 sites we examined, but within our WHD and WHB site, fledging rate was positively related to home range size and negatively related to neighbor density, in some years. Chick growth rates also were higher in larger home ranges in some years. This agrees with findings for great tits (*Parus major*) when density was manipulated by removal of territorial pairs (Both and Visser 2000).   However, in our study the relationship may simply be due to high predation rates on chicks on the densely-vegetated bay side of WHD, where home ranges happened to be smaller, rather than any intraspecific competition effect.   Alternatively, predators may have targeted the denser population on the bay side. More study is needed where predation is strictly controlled to distinguish these possibilities.

Although presumed predation of chicks reared adjacent to what we hypothesized to be the most profitable foraging areas at WHD hindered our ability to detect direct relationships between habitat quality and chick growth and survival, we saw little evidence of starvation on the ocean beaches. Broods on the ocean side appeared to grow normally, to be in good body condition, and to exhibit normal behavior. One oceanside brood in WHD 2003 grew much slower than expected, indicating that food may have been locally scarce, but a neighboring brood grew normally. The slow-growing brood hatched adjacent to Cupsogue County Park and was often found within the park, which receives

hundreds of visitors during the brood-rearing months, so human disturbance may have interfered with foraging. However, a brood reared in the same part of Cupsogue in 2002 grew normally and fledged on time. It is also possible that the slow growth rate was genetic.

On Assateague National Seashore in MD, broods were evidently starving (growing slowly and dying in poor body condition) if they lacked access to MOSH (Loegering and Fraser 1995). The Maryland beaches lacked an appreciable wrack line and sparse vegetation zone (Loegering and Fraser 1995), both of which provide foraging habitat for chicks in New York (Elias *et al.* 2000). During our study, brood and chick survival at WHB, where no chicks had access to MOSH, were the same as at Democrat Point, where all chicks foraged on MOSH. Reproductive output at Democrat Point was generally much higher than at WHB, but this was due to higher nest survival.

Ultimately, we are interested in whether energetics and chick growth impact post-fledging survival and recruitment. Prefledging condition has been shown to impact subsequent survival in many altricial and some precocial birds, but there have been several exceptions (Gebhardt-Henrich and Richner 1998). Lack of an effect on post-fledging survival in species that are still fed by their parents after fledging has been attributed to a high food abundance in the post-fledging period (Newton and Moss 1986) and ability of fledglings to move closer to the food supply (Steinen and Brenninkmeijer 2002).

One would expect fledgling survival of a self-feeding migratory bird such as the piping plover to be sensitive to pre-migration food supply. We observed

that fledged chicks remained on their territory, accompanied by at least the male parent, until they were approximately 40 days old, at which time they began to appear independently in the MOSH zones. Once there, we observed them foraging on polychaetes. We did not record data on fledgling survival after Day 25, so we are not certain of the mortality rate between Day 25 and the time the fledglings appeared in the MOSH. It seems unlikely that food would be limiting once the fledglings began to use the most profitable habitat, prior to migration.

Having only obtained 2 years of data on return rates of banded juveniles, our evidence is insufficient at this time to address the question of fledgling survival rates in relation to body condition. Further research concentrating on chick growth, survival and dispersal in the post-fledging period, and recruitment are needed to understand the role that habitat quality and energetics may play in this aspect of piping plover demographics. It would be especially instructive to mark and follow chicks at breeding sites where no MOSH is readily available, even to independent fledglings.

MANAGEMENT IMPLICATIONS

Habitat restoration efforts have been proposed for Long Island that are intended to mitigate the effects of beach alteration for storm damage protection, to attract piping plovers to new areas, and to increase the size of existing populations (USACE 2001). Based on our research and that conducted on plovers in North Dakota (Murphy *et al.* 2001), attracting a high nesting density of nesting pairs should not adversely affect reproduction. In fact, in our study, fledgling production increased greatly with increasing nesting pair density.

Furthermore, reproductive output and vital rates were not correlated with site-level density (although in some years fledging success was higher in patches with lower neighbor density). Regardless, restoration projects should incorporate a plan to monitor the impact of nesting pair density on reproductive output.

Predation remains the primary limiting factor to reproductive success at our sites, as it has been in many parts of the range of the piping plover (USFWS 1996). Many of the predators that currently are impacting plover reproduction are either non-native to North American barrier islands, such as red foxes (*Vulpes vulpes*, Kamler and Ballard 2002) and feral cats (*Felis domesticus*), or have likely increased in prevalence due to the presence of humans, such as crows (*Corvus* spp.) and gulls (*Larus* spp.). Predator control, especially the use of exclusion devices such as nest exclosures (Rimmer and Deblinger 1990) and electric fences (Mayer and Ryan 1991) have been successful in increasing productivity in piping plovers. Our results lend further support to the notion that habitat management must include a predator-control component if a project is to be successful in producing recruits. Predator exclosures have their own risks, including potential for increased adult and nest mortality via attraction of certain types of predators (Neuman *et al.* 2004). Furthermore, exclosures do not promote self-sustaining populations in the long term, but are an important tool for protecting species at particular sites in the short term (Johnson and Oring 2002). Predator removal can be successful in reducing chick mortality (Houghton et al. in prep), but avian predation on juveniles is more difficult to control and may counteract effects of mammalian predator trapping (Neuman *et al.* 2004).

Predator removal takes on special importance in light of our finding that reproductive output was correlated with brood survival rather than nest survival, since exclosures do little to protect broods. We recommend a mix of exclusion and removal strategies, as well as public education regarding the negative consequences of feeding and otherwise maintaining feral cat populations, which is a common practice at our sites. Furthermore, enforcing restrictions on trash disposal and wildlife feeding on beaches may help to reduce the presence of avian and mammalian predators.

ACKNOWLEDGEMENTS

for, and data from Democrat Point. We thank Suffolk County Parks, especially

Bill Sickles and Nick Gibbons, for providing access to their sites and data on

Cupsogue County Park. We thank the towns of Southampton and Westhampton

Beach for providing logistical support. We also are grateful for assistance from

the Long Island Chapter of The Nature Conservancy, especially Joe Jannsen,

Sarah Over, Caitlin Robinson, Alan Bettler, Julie Marik, and Amanda Cluck.

Special thanks to Jed Hayden, Emilie Masiello, Stephen Hartsfield, Amy Alsfeld,

Dawn Romaine, Sarah Gibson, Melissa Neely, Beth Forbus, Donald Wardwell,

Ellen Creveling, Bradley Pickens, Elizabeth Wunker, and Dawn Wiley for data

collection and entry.

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Table 1. Vital rates of piping plovers and chicks fledged/ha of nesting habitat, West Hampton Dunes, Westhampton Beach, Shinnecock West, and Democrat Point, Long Island, NY, 2001-2003. If global model was significant, main effects are shown, and interaction where appropriate.

	WHD[a]			WHB			Shinnecock West			Democrat Point			Sites Pooled		
	n	$\bar{x}$	se	n	$\bar{x}$	se	n	$\bar{x}$	se	n	$\bar{x}$	se	n	$\bar{x}$	se
Chicks fledged/pair[b]															
2001	38	1.03	0.20	15	1.67	0.37	6	0.00	0.00	7	1.29	0.61	66	1.11XY[c]	0.16
2002	34	1.32	0.24	20	1.30	0.27	6	0.83	0.40	10	1.30	0.37	70	1.27X	0.15
2003	27	0.48	0.15	13	0.69	0.38	8	0.38	0.38	7	2.00	0.44	55	0.71Y	0.15
2001-03	99	0.98A[d]	0.12	48	1.25A	0.20	20	0.40B	0.20	24	1.50A	0.26			
Chicks fledged/ha															
2001	38	0.98	-	15	0.82	-	6	0.00	-	7	0.41	-			
2002	34	1.26	-	20	0.98	-	6	0.30	-	10	1.23	-			
2003	27	0.46	-	13	0.32	-	8	0.32	-	7	1.28	-			
Nests hatched / nests laid[e]															
2001	49	0.63 A	0.07	19	0.53 A	0.12	10	0.1 B	0.10	11	0.36 A	0.15	89	0.52	0.05
2002	50	0.54 AB	0.07	29	0.45 AB	0.09	9	0.56 AB	0.18	13	0.54 A	0.14	101	0.51	0.05
2003	49	0.24 B	0.06	24	0.13 B	0.07	11	0.64 A	0.15	10	0.60 A	0.16	94	0.30	0.05
2001-03	148	0.47	0.04	72	0.36	0.06	30	0.43	0.09	34	0.50	0.09			
Eggs hatched / eggs laid[f]															
2001	177	0.52 A	0.07	73	0.47 A	0.11	32	0.1 B	0.10	41	0.27 A	0.14	323	0.43	0.05
2002	182	0.49 A	0.07	98	0.43 A	0.09	35	0.46 AB	0.15	40	0.44 A	0.12	355	0.47	0.05
2003	176	0.2 B	0.05	82	0.1 B	0.06	40	0.59 A	0.14	33	0.58 A	0.16	331	0.26	0.04
2001-03	535	0.40	0.04	253	0.33	0.05	107	0.39	0.08	114	0.42	0.08			

Broods fledged / broods hatched[g]

Year	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE
2001	31	0.65	0.09	10	1.00	0.00	1	0.00	-	4	1.00	0.00	46	0.74	0.07
2002	27	0.74	0.09	13	0.92	0.08	5	0.60	0.24	7	1.00	0.00	52	0.61	0.06
2003	12	0.67	0.14	3	1.00	0.00	7	0.14	0.14	6	1.00	0.00	28	0.84	0.09
2001-03	70	0.69B	0.06	26	0.96A	0.04	13	0.31C	0.13	17	1.00A	0.00			

Chicks fledged / chicks hatched[h]

Year	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE
2001	92	0.42	0.07	34	0.78	0.09	2	0.00	-	12	0.67	0.22	140	0.51	0.06
2002	96	0.50	0.08	45	0.62	0.08	16	0.28	0.13	23	0.60	0.12	185	0.52	0.05
2003	34	0.40	0.11	10	0.89	0.11	24	0.11	0.11	20	0.75	0.13	88	0.46	0.08
2001-03	212	0.45B	0.05	89	0.71A	0.06	42	0.17C	0.08	55	0.67A	0.08			

[a]WHD = West Hampton Dunes, WHB = Westhampton Beach

[b]ANOVA on ranks: Year: $F_{2,185} = 3.48$, $P = 0.033$, Site: $F_{3,185} = 3.50$, $P = 0.017$

[c] Year means with same capital letter are not significantly different, $\alpha = 0.05$

[d] Site means with same capital letter are not significantly different, $\alpha = 0.05$

[e]Year: $\chi^2_2 = 3.42$, $P = 0.18$ Site: $\chi^2_3 = 3.41$, $P = 0.33$ Year x Site: $\chi^2_6 = 18.51$, $P = 0.005$

[f] ANOVA on ranks: Year: $F_{2,269} = 1.02$, $P = 0.36$, Site: $F_{3,269} = 0.56$, $P = 0.64$, Year x Site: $F_{6,269} = 3.93$, $P = 0.001$

[g]Year: $\chi^2_2 = 2.62$, $P = 0.27$, Site: $\chi^2_3 = 26.69$, $P < 0.001$

[h]ANOVA on ranks: Year: $F_{2,116} = 0.02$, $P = 0.98$, Site: $F_{3,116} = 8.78$, $P < 0.001$

Table 2. Pearson correlations between mean values of reproductive variables of piping plovers and mean values of habitat variables, West Hampton Dunes, Westhampton Beach, Shinnecock, and Democrat Point, Long Island, NY, 2001-2003, and 3 sites on Monomoy Island, MA, 2002-2003.

Reproductive Variable	Habitat Variable	n	r	P
fledglings/pair	MOSH Index[a]	8	0.52	0.19
	Nesting habitat (ha)	8	0.15	0.72
fledglings/ha	MOSH Index	8	0.91	0.012
	Nesting habitat (ha)	8	0.22	0.59
egg success	MOSH Index	7	-0.21	0.65
	Nesting habitat (ha)	7	0.08	0.87
nest success	MOSH Index	7	-0.39	0.38
	Nesting habitat (ha)	7	0.26	0.58
chick success	MOSH Index	7	0.01	0.98
	Nesting habitat (ha)	7	0.20	0.67
brood success	MOSH Index	7	0.07	0.88
	Nesting habitat (ha)	7	0.20	0.67

[a]MOSH within 300 m of nesting habitat (ha) / nesting habitat (ha)

Table 3. Logistic regression modeling results for probability of piping plovers hatching at least one egg and fledging at least one chick from a successful nest as a function of distance to large MOSH and nearest MOSH, West Hampton Dunes, Westhampton Beach, and Shinnecock West, Long Island, NY 2001-2003.

		Year	n	Intercept	β_1	Wald χ^2_1	P	%C	%D	%T
Nest Survival	Distance to	2001	52	-4.5±2.1	-0.5±0.3	2.7	0.10	66.9	32.7	0.4
	Large MOSH	2002	55	0.3±1.4	0.1±0.2	0.2	0.64	51.8	46.2	2.0
		2003	41	1.7±1.8	-0.4±0.3	1.6	0.21	62.3	37.2	0.5
	Distance to	2001	58	3.6±3.1	-0.5±0.6	0.8	0.38	59.7	38.7	1.6
	Nearest MOSH	2002	61	-1.4±2.2	0.5±0.4	1.3	0.26	54.3	44.4	1.3
		2003	49	1.3±2.9	-0.3±0.6	0.3	0.60	55.4	42.3	2.4
Brood Survival	Distance to	2001	40	-4.8±2.5	1.1±0.5	5.1	0.023	73.7	26.0	0.3
	Large MOSH	2002	40	6.7±3.2	1.5±0.6	5.9	0.015	84.8	14.8	0.4
		2003	15	-3.7±3.6	0.8±0.7	1.6	0.20	65.9	34.1	0.0
	Distance to	2001	41	-7.6±4.0	1.7±0.8	4.7	0.030	67.9	32.1	0.0
	Nearest MOSH	2002	45	-19.7±10.6	4.0±2.0	4.0	0.046	80.3	19.4	0.3
		2003	22	-12.6±9.7	2.4±1.8	1.8	0.18	71.7	28.3	0.0

[a]%C = % Concordant, %D = % Discordant, %T = % Ties

Table 4. Logistic regression model results for probability of piping plovers hatching at least one egg and probability of fledging at least one chick from a successful nest as a function of neighbor density (pairs/ha within 600 m of focal nest), West Hampton Dunes, Westhampton Beach, and Shinnecock West, Long Island, NY 2001-2003.

	Year	n	β_0	β_1	Wald χ^2_1	P	%C[a]	%D	%T
Nest survival	2001	58	-0.9±0.8	2.1±1.0	4.7	0.031	70.2	29.1	0.7
	2002	61	1.7±0.8	-0.7±0.8	0.7	0.40	54.7	44.2	1.1
	2003	49	-0.9±0.8	2.1±1.0	2.1	0.15	60.6	38.7	0.7
Brood survival	2001	41	5.1±2.1	-4.0±1.9	4.5	0.035	76.4	23.3	0.3
	2002	45	4.2±1.3	-2.9±1.1	6.4	0.012	71.4	28.0	0.6
	2003	22	5.3±3.0	-6.1±3.5	3.1	0.08	72.5	27.5	0.0

[a]%C = % Concordant, %D = % Discordant, %T = % Ties

Table 5. Logistic regression modeling results for probability of piping plovers hatching at least one egg as a function of 50% home range (HR) size (ha), nesting habitat within 50% home range, 95% home range size, and nesting habitat within 95% home range, West Hampton Dunes and Westhampton Beach, Long Island, NY 2001-2003.

		n	Intercept	β_1	Wald χ^2_1	P	%C[a]	%D	%T
50% HR	2002	23	0.8±2.1	1.0±1.9	0.24	0.63	48.3	50.0	1.7
	2003	15	-0.5±1.7	0.6±0.8	0.51	0.57	66.0	34.0	0.5
Nesting habitat in	2002	23	0.0±1.6	2.2±1.9	1.39	0.24	61.7	38.3	0.0
50% HR	2003	15	0.9±1.3	-0.1±0.7	0.02	0.88	54.0	42.0	4.0
95% HR	2002	23	0.5±2.2	0.2±0.3	0.40	0.53	58.3	36.7	5.0
	2003	15	0.3±1.7	0.0±0.1	0.06	0.80	56.0	44.0	0.0
Nesting habitat in	2002	23	1.2±1.7	0.2±0.4	0.19	0.66	55.0	41.7	3.3
95% HR	2003	15	0.1±0.5	0.1±0.2	0.17	0.68	56.0	42.0	2.0

[a]%C = % Concordant, %D = % Discordant, %T = % Ties

Table 6. Logistic regression modeling results for probability of piping plovers fledging at least one chick from a successful nest as a function of 50% home range (HR) size (ha), nesting habitat within 50% home range, 95% home range size, and nesting habitat within 95% home range, West Hampton Dunes and Westhampton Beach, Long Island, NY 2001-2003.

		n	Intercept	β_1	Wald χ^2_1	P	%C[a]	%D	%T
50% HR	2002	20	-21.3±15.9	28.1±19.8	2.01	0.16	94.4	5.6	0.0
	2003	10	-8.0±10.5	5.6±6.2	0.80	0.37	88.9	11.1	0.0
Nesting habitat in	2002	20	-33.0±53.7	49.5±77.1	0.41	0.52	97.2	2.8	0.0
50% HR	2003[b]	10							
95% HR	2002	20	-2.8±3.3	0.6±0.5	1.84	0.17	83.3	16.7	0.0
	2003	10	-1.1±4.6	0.2±0.3	0.49	0.49	77.8	22.2	0.0
Nesting habitat in	2002[c]	20							
95% HR	2003[b]	10							

[a]%C = % Concordant, %D = % Discordant, %T = % Ties

[b]Inestimable. The smallest home range contained the only failed brood.

[c]Inestimable. The 2 smallest home ranges contained the only 2 failed broods.

Table 7. Mean egg mass (g) of piping plovers for first nest attempts and renests West Hampton Dunes, Westhampton Beach, and Shinnecock West, Long Island, NY 2001-2003. Each sample is the mean mass of 1 to 4 eggs (mode = 4 eggs) weighed within 7 days of incubation commencement. Global ANOVA of site, year, and first nest/renest not significant at $\alpha = 0.05$.

		WHD[a]			WHB			Shinnecock West		
		n	$\bar{x}$	se	n	$\bar{x}$	se	n	$\bar{x}$	se
First Nests	2001	22	10.2	0.1	8	9.9	0.1	-	-	-
	2002	21	9.8	0.1	9	10.1	0.1	3	9.7	0.1
	2003	16	10.0	0.2	5	10.0	0.3	2	9.9	0.0
	2001-03	59	10.0	0.1	22	10.0	0.1	5	9.8	0.1
Renests	2001	3	10.0	0.5	1	10.3		-	-	-
	2002	10	10.1	0.2	3	9.6	0.5	2	9.5	0.7
	2003	5	9.8	0.3	6	10.4	0.2	2	9.9	0.3
	2001-03	18	10.0	0.1	10	10.1	0.2	4	9.7	0.3

[a]WHD = West Hampton Dunes, WHB = Westhampton Beach

Table 8. Mean body mass (g) of piping plover hatchlings, age 0 to 2 days, and fledglings, age 22 to 30 days West Hampton Dunes, Westhampton Beach, Shinnecock West, and Democrat Point, Long Island, NY 2001-2003.   Global ANOVA on ranks of site and year effects not significant at α = 0.05 for hatch mass or fledge mass.

		WHD[a]			WHB			Other Site[b]		
		n	$\bar{x}$	se	n	$\bar{x}$	se	n	$\bar{x}$	se
Hatchlings	2001	31	7.2	0.1	12	6.5	0.3	2	6.5	0.0
	2002	36	7.0	0.2	18	6.9	0.2	-	-	-
	2003	21	6.7	0.2	5	7.3	0.3	3	7.2	0.2
	2001-03	88	7.0	0.1	35	6.8	0.2	5	6.9	0.2
Fledglings	2001	8	38.2	1.6	6	39.9	1.4	1	35.0	-
	2002	16	37.2	0.6	9	37.9	1.5	3	31.7	5.6
	2003	8	33.8	4.2	2	36.5	0.5			
	2001-03	32	36.6	1.2	17	38.4	0.9	4	32.5	4.1

[a]WHD = West Hampton Dunes, WHB = Westhampton Beach

[b]Other Site = Shinnecock West for hatchlings, Democrat Point for fledglings

Table 9. Mean wing chord (mm) of piping plover hatchlings, age 0 to 2 days, and fledglings, age 22 to 30 days, West Hampton Dunes, Westhampton Beach, and Shinnecock West, and Democrat Point, Long Island, NY 2001-2003. Where Global ANOVA on ranks was significant, year and site effects are shown.

		WHD[a]			WHB			Other Site[b]		
		n	$\bar{x}$	se	n	$\bar{x}$	se	n	$\bar{x}$	se
Hatchlings	2002	36	11.2	0.3	18	11.3	0.4			
	2003	21	10.5	0.4	5	11.8	1.0	3	7.3	0.7
	2002-03[c]	57	11.0A[d]	0.2	23	11.4A	0.4	3	7.3B	0.7
Fledglings	2002	16	73.5	2.1	9	75.1	3.5	3	67.8	3.7
	2003	8	62.1	6.9	2	84.0	0.0	-	-	-
	2002-03	24	69.7	2.8	11	76.7	3.0	3	67.8	3.7

[a]WHD = West Hampton Dunes, WHB = Westhampton Beach

[b]Other Site = Shinnecock West for hatch wing chord, Democrat Point for fledge wing chord

[c] $F_{1,79}$(Year) = 0.8, P = 0.38, $F_{2,79}$(Site) = 3.6, P = 0.033

[d]Means with same capital letter are not significantly different

Table 10. Mean body mass (g) and wing chord length (mm) of piping plover chicks in different age categories, observed using MOSH and not observed using MOSH, West Hampton Dunes, Westhampton Beach, Cupsogue, Shinnecock West, and Democrat Point, Long Island, NY 2001-2003.

		Observed in MOSH[a]			Not observed in MOSH[b]			
	age (days)	n	$\bar{x}$	se	n	$\bar{x}$	se	P^c
Body Mass	0-2	56	7.0	0.1	72	6.9	0.1	0.99
	5-7	17	14.9	2.1	70	11.6	0.5	0.91
	9-11	10	16.6	0.9	7	13.6	0.5	0.029
	12-15	8	23.1	2.0	50	19.8	0.4	0.15
	18-21	10	31.8	1.7	37	30.7	0.7	0.43
	22-25	16	36.2	0.8	37	36.5	0.9	0.48
Wing Chord	0-2	25	11.4	0.4	58	10.8	0.3	0.18
	5-7	5	15.0	1.3	52	14.6	0.3	0.74
	9-11	0			3	15.7	1.2	-
	12-15	5	43.2	6.4	39	30.6	1.2	0.037
	18-21	6	63.4	5.7	32	56.5	1.7	0.11
	22-25	7	72.3	5.0	31	71.7	2.1	0.82

[a]Some WHD broods, all Democrat Point broods, 1 Cupsogue brood

[b]Some WHD broods, all WHB and Shinnecock broods, some Cupsogue broods

[c]Wilcoxon rank-sum test
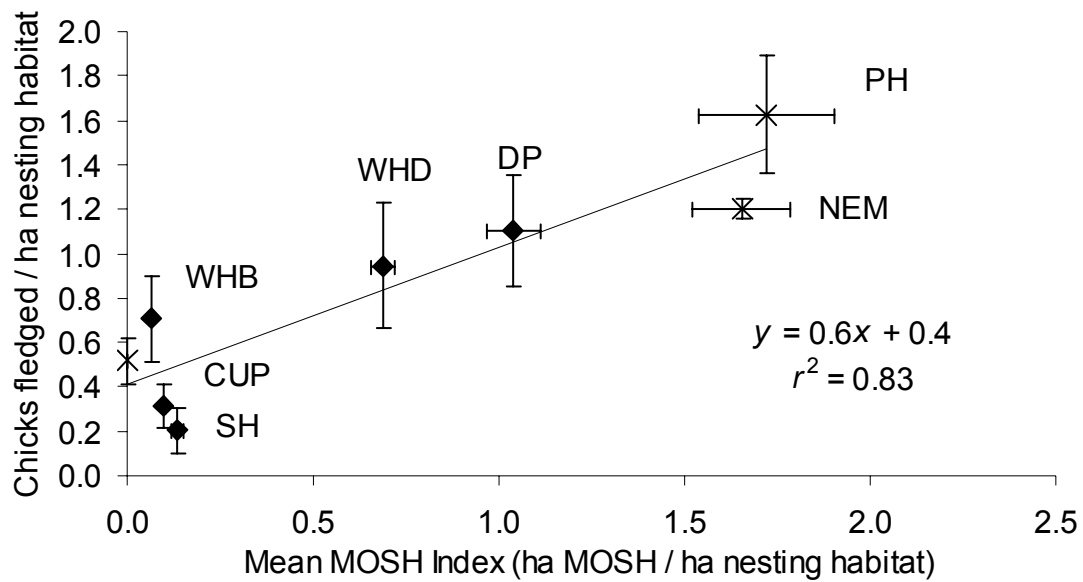
Fig. 1. Mean piping plover chicks fledged/ha nesting habitat vs. mean MOSH index (ha MOSH within 300 m of nesting habitat / ha of nesting habitat). Linear regression: $F_{1,6}$ = 29.7, P = 0.002. ♦ = Long Island, NY site, x = Monomoy Island, MA site. WHD = West Hampton Dunes, WHB = Westhampton Beach, CU = Cupsogue, SH = Shinnecock West, DP = Democrat Point, PH = Powderhole, Monomoy, NEM = Northeast Monomoy. Unlabelled point is Southeast Monomoy. Each point represents a 3-y (Long Island sites) or 2-y (Monomoy sites) mean on both axes.
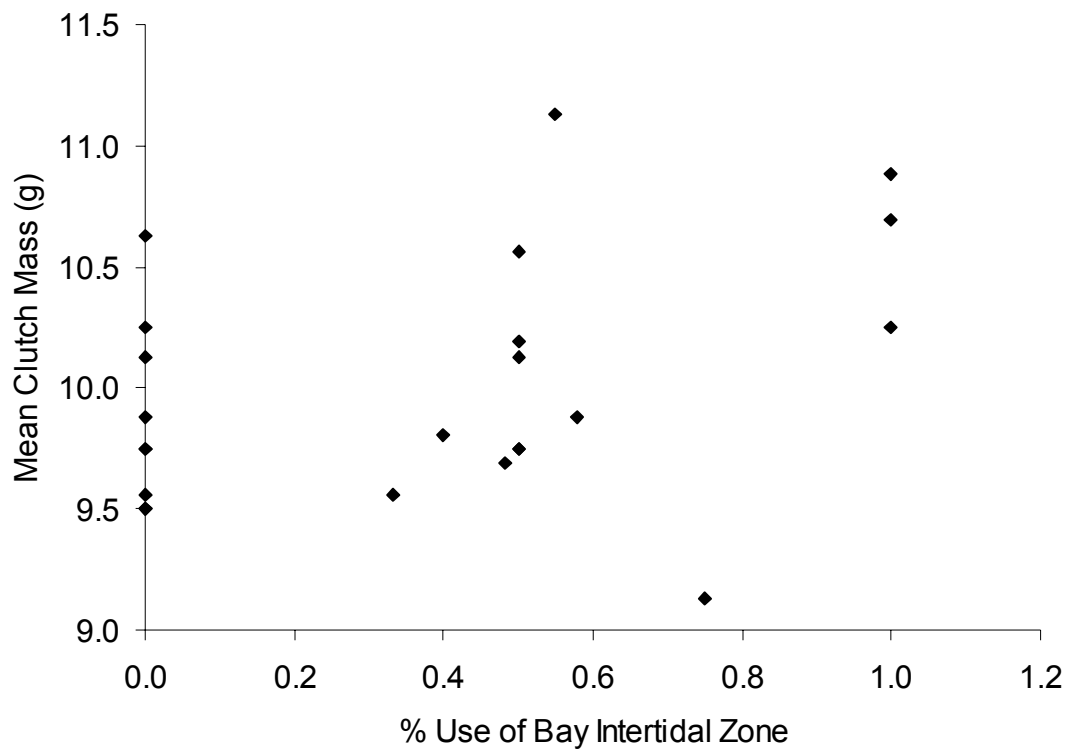
Fig. 2. Mean egg mass (g) in piping plover first nests vs. % use of bay intertidal zone at low tide by adult females in the pre-laying period, WHD and WHB, NY, 2002-2003 (n = 24). Spearman's r = 0.41, P = 0.048.
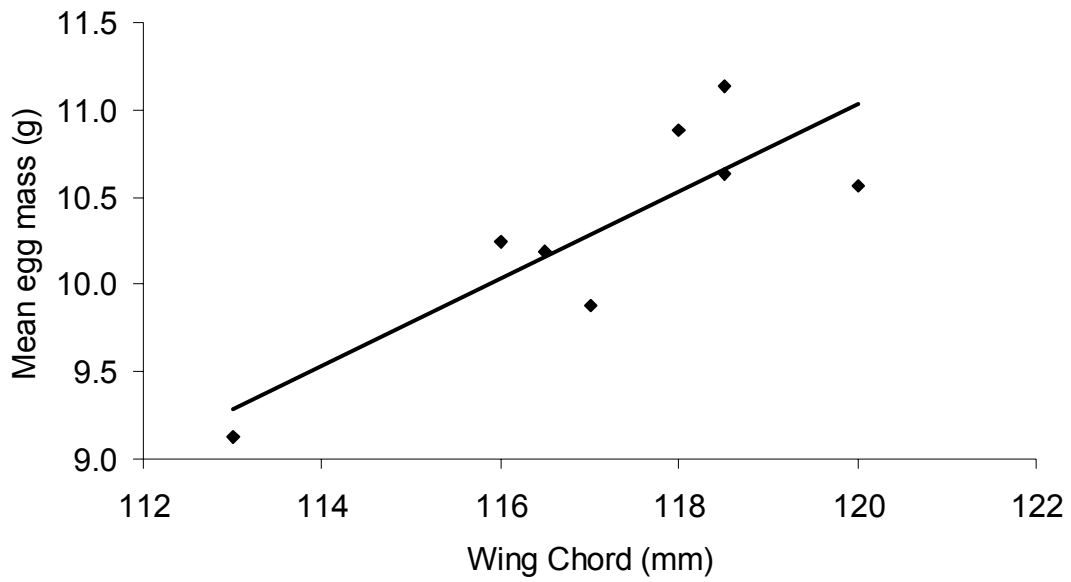
Fig. 3. Mean egg mass (g) in piping plover first nests vs. adult female wing chord length (mm), WHD and WHB, NY, 2003. Linear regression: mean egg mass = (-18.9±7.6) + (0.25±0.07)wing chord, $r^2 = 0.71$, $F_{1,6} = 14.6$, $P = 0.009$, $n = 8$.
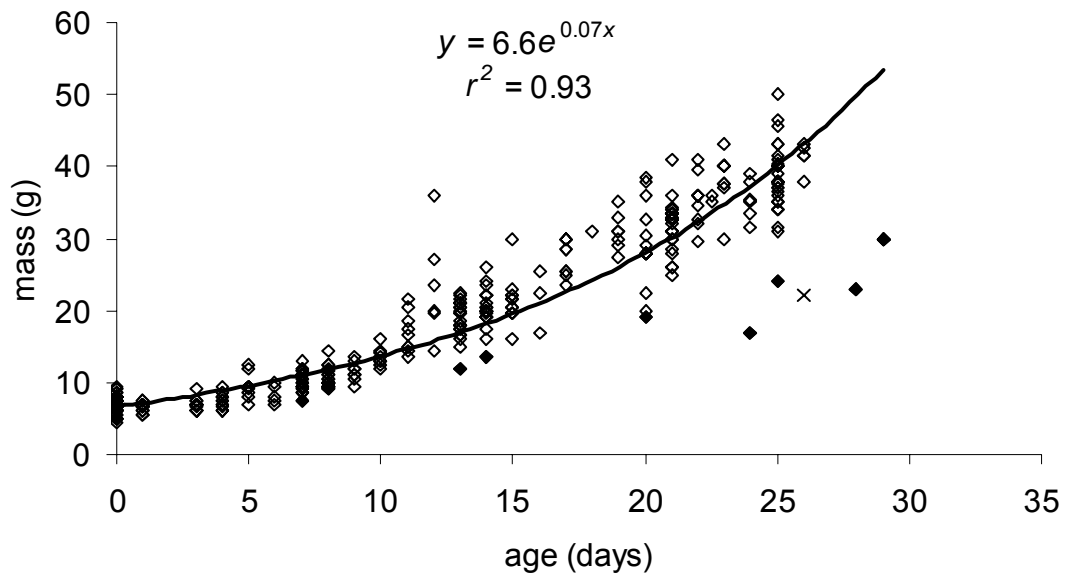
Fig. 4. Body mass (g) growth of piping plover chicks, WHD, WHB, Shinnecock, Cupsogue, and Democrat Point, NY, 2001-2003 (*n* = 426 chicks, from 65 broods).   The solid points are all from WHD brood 20B, in 2003. The x is a chick from Democrat Point in 2002.

$$y = 9.9e^{0.08x}$$
$$r^2 = 0.90$$
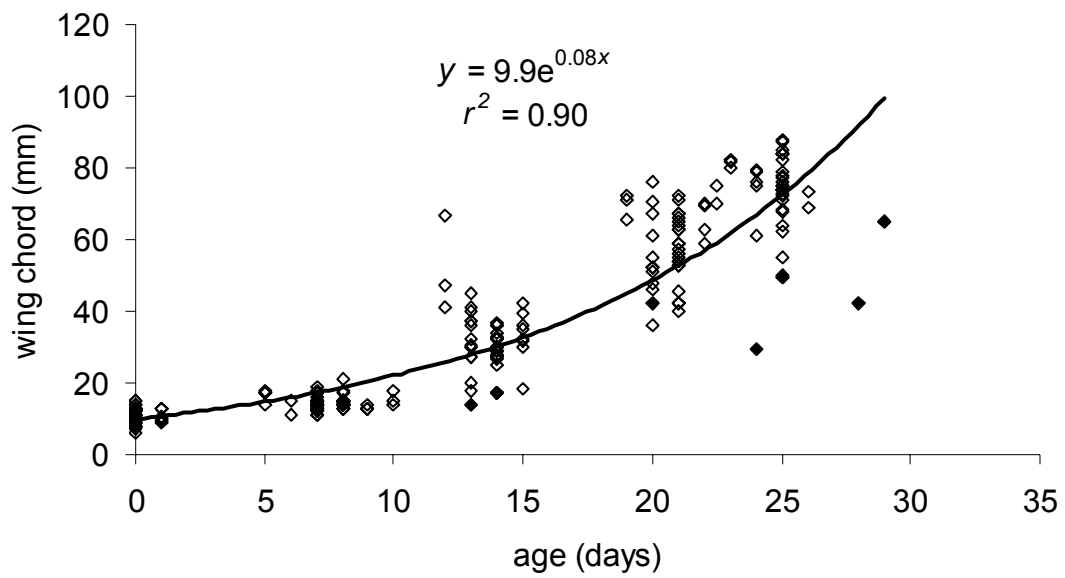
Fig. 5. Wing chord (mm) growth of piping plover chicks, WHD, WHB, Shinnecock, Cupsogue, and Democrat Point, NY, 2002-2003 (n = 268 chicks, from 44 broods). The solid points are all from WHD brood 20B, in 2003.

14 March 2005
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RH: Plovers and Beach Stabilization • *Cohen and Fraser*

CHAPTER 3: THE IMPACT OF BEACH NOURISHMENT ON PIPING PLOVER

NESTING AND FORAGING HABITAT ON LONG ISLAND, NEW YORK

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Abstract: Beach renourishment is a common practice on the U.S. Atlantic Coast

aimed at the protection of human interests from storms. The potential short- and

long-term consequences for beach-nesting wildlife have long been recognized.

We investigated the short-term impact of beach renourishment on Long Island,

New York on the piping plover, a threatened shorebird. We compared

characteristics of nesting and foraging habitat before and after renourishment. At

one site in which the entire ocean beach was renourished, the ocean backshore,

which provides nesting habitat, was widest 1 breeding season after

renourishment, and declined in width thereafter ($P < 0.001$). The ocean intertidal

zone increased in width by March of the third breeding season after

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renourishment ($P < 0.001$), as the backshore eroded into the sea. At a second site at which approximately 66% of the beach was renourished, the ocean beach was wider one breeding season after renourishment than before renourishment in untreated areas, but narrower after renourishment in treated areas two and three breeding seasons after renourishment in June ($P = 0.043$) and July ($P = 0.004$). At the fully-renourished site, July arthropod abundance was lower post-renourishment than before renourishment in ocean side cover types, but also in bayside cover types that received no sand ($P = 0.013$). At the partially renourished site, March arthropod abundance was greater in the ocean intertidal zone three breeding seasons post-renourishment than before renourishment, in treated areas only ($P = 0.023$). We observed no short-term effect of beach nourishment on habitat selection by chicks. Beach renourishment may have contributed to localized erosion of nesting habitat at the partially-renourished site, but did not appear to directly negatively affect other habitat characteristics important to piping plover reproduction and survival. Renourishment may partially mitigate habitat loss due to human development and vegetation growth, and can be used to create or restore nesting habitat. However, there is the potential for negative indirect effects through the attraction of a larger human population and its commensal domestic and wild animals. Furthermore, long-term habitat loss due to the prevention of normal storm-mediated sediment transport must be mitigated if renourishment is used as a restoration tool.

Key words: beach, *Charadrius melodus,* foraging, habitat, home range,

intertidal, nesting, New York, overwash, piping plover, stabilization, territoriality.

Beach renourishment, which entails dredging sand from offshore sites and

depositing it on the shoreline, currently is commonly used to protect coastal

development from storms (Finkl 1996). By widening beaches, renourishment can

increase recreational use and attract economic activity (Silberna and Klock

1988). Total annual costs of renourishment have been estimated to be

$100,000,000 / yr in the United States, excluding the Pacific Coast (Trembanis *et

al.* 1999). Most beach renourishment and other storm damage protection

measures in the U.S. have occurred on Atlantic Coast barrier islands (Trembanis

et al. 1999). Atlantic barrier islands are narrow (often < 500 m wide) islands

bounded by the Atlantic Ocean on one side and a lower wave energy water body

such as a shallow bay on the other. The islands are characterized by several

parallel zones that differ in slope, elevation, and floral characteristics

(Leatherman 1982, Table 1, Chapter 1).

Beach nourishment alters habitat used for breeding by sea turtles,

shorebirds, and other wildlife (ASFMC 2002). It results in higher, wider beaches

that are less prone to flooding, and thus can lead to a short-term increase in the

total area of breeding habitat for some beach-nesting species (Melvin *et al.* 1991,

Steinitz *et al.* 1998). However, beach erosion can erase net gains to breeding

habitat within a few years of renourishment (Steinitz *et al.* 1998). Renourishment

also may destroy beach vegetation, which can take several years to recover

(Looney and Gibson 1993). This could benefit open-nesting species, but might be detrimental to those that require vegetative cover.

Renourishment prevents the overwash and breaching of Atlantic Coast barrier islands by storms, thereby interrupting normal sediment transport from the front to the back of the islands. Sand deprivation on the bay side leads to a higher rate of erosion and eventually loss of tidal marshes and sand flats (Dolan *et al.* 1973).   Moreover, open flats may succeed to densely vegetated marsh if wave energy reaching the marsh is decreased by coastline stabilization (Eertman *et al.* 2002). Wildlife managers and researchers have predicted a negative impact of beach stabilization on the federally-threatened piping plover (*Charadrius melodus*), through the prevention of storm-maintained features (e.g., sand spits, ephemeral pools, tidal flats, and open vegetation, Loegering and Fraser 1995, USFWS 1996,, Goldin and Regosin 1998, Elias *et al.* 2000).

A storm in December 1992 breached Westhampton Barrier Island, Long Island, NY, in 2 places. The breaches created two intertidal sandflats in Moriches Bay and destroyed many houses and parts of Dune Road, the primary artery of the site. Subsequently, the breaches were repaired by the US Army Corps of Engineers (USACE). Between 1996 and 2005 the beach was renourished 3 times, and an artificial dune was constructed along the length of the site and planted with beach grass (*Ammophila breviligulata*). The new village of West Hampton Dunes (WHD) was incorporated, the road was rebuilt, and most of the houses were replaced. There were no known breeding pairs of piping plovers in WHD between 1983 and 1990 (Downer and Leibelt 1990). In

1993, 5 pairs were discovered there.   From 1993 to 2000, the plover population increased to 39 pairs, then declined to 18 pairs from 2000 to 2004 (Houghton *et al.* in prep.). Furthermore, from 2000 – 2004 the distribution of nests shifted from being largely on the bay side to being entirely on the ocean side.

        We studied the short-term effects of beach renourishment on piping plover habitat at WHD and the adjacent village of Westhampton Beach (WHB). Our objectives were to compare habitat availability and prey abundance before and after renourishment, and to examine changes in habitat selection by broods after renourishment. Our hypotheses were:

1. Widths of ocean side cover types changed as a direct result of beach renourishment at WHD and WHB

2. Prey abundance was lower in ocean side cover types at WHD and WHB as a direct result of renourishment

3. Selection of ocean side habitat by plover chicks changed as a direct result of beach renourishment at WHD and WHB

STUDY AREA

        West Hampton Dunes (40°47' N, 72°43' W) begins approximately 3 km east of Moriches Inlet on the Westhampton Barrier Island off the south shore of Long Island, New York, and extends for 2.8 km to the east. The nesting area consisted of the ocean-side beach and a 0.5 km-long sand spit perpendicular to the island and extending north into Moriches Bay.   All oceanside houses in WHD were separated from the beach by an artificial dune. The ocean backshore, foredune, and dune areas were sparsely vegetated and provided nesting habitat

for piping plovers. The bay backshore between the dune and Moriches Bay (including the sand spit), where most pairs had nested from 1993 until 2000, was largely covered by houses and dense vegetation, and no pairs nested in that area in 2004. After 2000, most pairs nested on the ocean side of the artificial dune.

Westhampton Beach (WHB, 40°48' N, 72°39' W) differed from WHD in the extent of beach restoration by the USACE. The site is located adjacent to and directly east of WHD along Dune Road, and the portion we studied extends 3.2 km to the east of WHD.   This site contained a series of 15 parallel rock groins perpendicular to the beach built in the late 1960's as erosion-control structures. WHB was not overwashed by the 1992 storm. All residences and clubs in WHB south of Dune Road were separated from the beach by an artificial dune. The dune was densely vegetated, and the Moriches Bay side of Dune Road was covered by houses and dense upland and salt marsh vegetation, with a few small (< 1ha) intertidal flats. The foredune and backshore were sparsely vegetated and provided nesting habitat for piping plovers.   In Winter of 1996/1997, the USACE tapered the seaward ends of the westernmost 2 groins (groins 14 and 15) in WHB and added a third shorter groin (groin 14b) to increase sand flow into WHD. In Winter of 1997/1998, the USACE renourished all groinfield compartments in WHB. In the Winter of 2000/2001, they renourished the areas between groins 8-10 (the eastern third of our study site) and 13-15 (the western third of our site), approximately 66% of the ocean beach.

METHODS

DATA COLLECTION AND PROCESSING

Habitat width.— We established 6 transects in WHD, and 6 in WHB, each perpendicular to the ocean shoreline. In WHD, the first transect was randomly placed near the west end of the site and the remaining transects were located at 420 meter intervals eastward. In Westhampton Beach, the transects were located midway between each pair of groins, approximately 500 m apart.

Monthly, beginning between 0645 and 1000, March-August 2001-2003, we paced transects from the ocean tide line to dense vegetation or the bay tide line. At WHD, the dune divided the ocean- and bayside habitats. At WHB, there only were ocean-side transects, which ended at dense vegetation or the start of human development. We recorded the number of paces along each transect in each cover type. Fresh wrack and old wrack were measured with a measuring tape. In 2002 and 2003, we remeasured the width of the intertidal zones 6 hours after the first measurements were collected, to account for tidal change in the availability of such cover types. We converted paces to meters based on each researcher's pace length. We classified all intertidal zone measurements taken within 3 hours of low tide as "low tide" and within 3 hours of high tide as "high tide".   In 2000, data were collected weekly instead of monthly; we thus used monthly means from 2000 in our analyses.

Chick habitat availability and use.—We calculated habitat availability as the mean % transect width in each cover type. We averaged % availability across the brood-rearing period (May-August). After chicks hatched, we

searched for each brood daily to record the number of surviving chicks. We used an instantaneous focal chick sampling method to estimate time broods spent in different cover types. We recorded cover type used by the focal bird continuously for a 5-min period on a tape recorder (Altman 1974, Lehner 1979, Tyler 1979). If a brood went out of view then returned to view during a 5-min observation, a new focal chick was chosen to complete the observation. Later, we sampled the tape, recording cover type every 10 s. We calculated the percent of 10-s intervals in each cover type.

     Arthropod abundance.—Monthly from March - July, 2001-2003, we collected arthropod samples along the transects. We sampled for 3 h beginning between 0645-1000 (Elias *et al.* 2000). We coated paint stirrers, except for the handles, with Tanglefoot Insect Trap Coating (Tanglefoot, Grand Rapids, MI). We placed one pair of paint stirrers in the middle of each cover type, except for the intertidal zones, where we put them 1-2 m from the backshore to avoid splashing and submergence. We placed one stirrer vertically in the sand with the uncoated handle buried and the flat surface facing the water's edge. The other stirrer was horizontal on the ground 10 cm south of the vertical stick, with its long axis parallel to the water's edge. The area exposed was 64.5 cm^2 (21.5 cm x 3 cm) for the horizontal stick (coated on the upper side) and 129 cm^2 for the vertical stick (coated on both sides, cf. Loegering et al. 1995). At the end of 3 h, organisms were counted by taxonomic order.   We calculated an arthropod index as the sum of all arthropods captured on a pair of sticks.

Data in 2000 were collected similarly, except only the 2 westernmost transects were used after March in WHB to avoid human interference with sticky sticks, and data were collected weekly.   We used monthly means from 2000 in our analyses.

DATA ANALYSIS

To examine the effect of the Winter 2000/2001 renourishment on cover type widths and prey abundance at WHB, we performed a before-after case-control repeated measures ANOVA, for each month and cover type separately, where each transect was considered a subject and renourishment was considered the treatment. If we found a significant treatment x year interaction (α = 0.05), we used paired contrasts to determine if habitat width or arthropod index in 2000 (before renourishment) was different than in any subsequent year, for treated and untreated areas separately.

To examine the effect of renourishment on arthropod abundance at WHD, we performed a case-control before-after repeated measures ANOVA, with paired subjects. We considered the bay side to be the control since it received no renourishment sand, and we considered fresh wrack, backshore, old wrack, and sparse vegetation to be the subjects, and ocean side and bay side to be the main effect of interest. Intertidal zone was not included because the sloping high wave energy ocean intertidal zone and the flat low wave energy bay intertidal zone were qualitatively different. If we found a significant side x year interaction (α = 0.05), we used contrasts to determine if arthropod index in 2000 (before

renourishment) was different than in any subsequent year, for the ocean and bay side separately.

We used compositional analysis (Aebsicher *et al.* 1993) to test whether habitat use by oceanside-dwelling broods at WHD was different than expected based on availability. We performed an ANOVA on ranks of the effect of year on %use/% availability, for each cover type separately.

RESULTS

Cover Type Widths At WHD

Ocean intertidal zone.— In the first two breeding seasons after renourishment (2001 and 2002), the ocean intertidal zone measured within 3 h of low tide was narrower than or not significantly different than it was in the year before renourishment (2000), in most months (Fig. 1). However in the third breeding season after renourishment (2003), the ocean intertidal zone was wider in most months than in any previous year (Fig. 1).

Fresh wrack.—In March and June-August, the ocean fresh wrack was wider in at least one of the three breeding seasons following renourishment than before renourishment (Fig. 2).

Backshore.—In all months, the ocean backshore was wider in the first breeding season after renourishment (60.0±3.7– 83.9±4.4 m) than before renourishment (39.4±3.3 – 47.8±3.8 m, Fig. 3). By the third breeding season after renourishment, the backshore was significantly narrower than before renourishment in all months except July (16.9±3.9 – 28.0±3.7 m, Fig. 3).

Old wrack.—The mean width of ocean old wrack before renourishment and one breeding season after was extremely small, and there were no differences between these 2 breeding seasons. Except in July, the old wrack was narrower in these 2 breeding seasons than in one or both subsequent breeding seasons, depending on the month (Fig. 4).

Sparse vegetation.—The mean width of the ocean sparse vegetation did not generally differ among years. The exceptions were in May and August, when this cover type was wider in one or both of the last two breeding seasons than in the season before renourishment or the first season after (Fig. 5).

Cover Type Widths At WHB

The ocean intertidal zone in the treated portion of whb was wider three breeding seasons after renourishment than before renourishment, while in the untreated portion the ocean intertidal zone was greater one breeding season after renourishment than before renourishment (table 1). The fresh wrack zone was wider one and two years after renourishment than before renourishment, but only in treated portions of the site (Table 1). The ocean backshore in june was narrower two and three breeding seasons after renourishment than before renourishment in treated areas, but wider one breeding season post-renourishment than before renourishment in untreated areas (Table 1). The ocean backshore in july was narrower three breeding seasons post-renourishment than before renourishment in treated areas, but wider one and two seasons post-renourishment than before renourishment in untreated areas (table 1).

Arthropod Abundance

In most cover types, dipterans made up the largest proportion of the arthropods we captured (Table 2). Amphipods were the next most abundant organisms in intertidal zone and fresh wrack cover types, while in upland cover types our remaining arthropod catch was more evenly distributed among different terrestrial orders (Table 2).

West Hampton Dunes.—In July, arthropod index on the ocean side was lower in all years post-renourishment than before renourishment, and on the bay side arthropod index was lower two years post-renourishment than before renourishment (repeated measures ANOVA, ocean side contrasts: 2001 vs. 2000: $F_{1,17} = 11.3$, $P = 0.004$; 2002 vs. 2000: $F_{1,17} = 10.7$, $P = 0.004$; 2003 vs. 2000: $F_{1,17} = 22.0$, $P < 0.001$; bay side contrast: 2002 vs. 2000: $F_{1,17} = 4.6$, $P = 0.046$). Arthropod index in the backshore and fresh wrack appeared to contribute to these differences, while arthropod index in the old wrack and sparse vegetation did not (Figs 6-13). Although we did not include intertidal zones in the ANOVA, there did not appear to be a difference among years in July arthropod abundance in either bay or oceanside intertidal zone (Figs. 14– 15).

Westhampton Beach.—With the exception of March, only 2 transects of sticky sticks were used at WHB in 2000. Both transects were in renourished portions of the site. Thus, we examined renourishment effects in March only. Arthropod index in the ocean intertidal zone was greater three years after renourishment than before renourishment, in the treated portion of the site only (Table 3).

Habitat Selection

Oceanside-only broods observed within 3 hours of high tide in 2000 preferred ocean old wrack, and were least likely to use dune sparse vegetation in relation to its availability (Table 4). In 2002, there were no differences among cover types except that broods were still least likely to use dune sparse vegetation, and ocean fresh wrack was less likely to be selected than several other cover types.

Broods observed within 3 hours of low tide in 2000 preferred old wrack, were less likely to select fresh wrack and ocean sparse vegetation, and least likely to select dune sparse vegetation (Table 5). In 2001, differences in cover type preference were less pronounced, although fresh wrack and dune sparse vegetation were still used least.   In 2002, ocean fresh wrack was among the preferred cover types, while dune sparse vegetation remained the least used in relation to availability.

Within 3 h of high tide, broods selected old wrack more strongly before renourishment than two breeding seasons after renourishment (ANOVA on ranks of use/availability, $F_{1,30}$ = 13.5, P < 0.001). Within 3 h of low tide, broods selected ocean intertidal zone less strongly before renourishment than two breeding seasons after ($F_{1,42}$ = 8.2, P = 0.007), and the same was true of fresh wrack ($F_{1,42}$ = 6.7, P = 0.013). They selected old wrack more strongly before renourishment than 2 breeding seasons after ($F_{1,42}$ = 21.7, P < 0.001).

DISCUSSION

The width of the ocean backshore, which provides nesting habitat for piping plovers, and the ocean intertidal zone, which provides foraging habitat, showed predictable patterns at WHD in relationship to renourishment. The backshore was wide immediately after renourishment, and three years later was narrower, while the ocean intertidal zone widened as the placed sediment moved offshore. Such offshore movement of sand often is expected after renourishment (Finkl *et al.* 1988), and the widening intertidal zone (and presumably, subtidal sand bars) provides storm damage protection for human development on the barrier beach (Finkl *et al.* 1988). Other cover types used for nesting and foraging did not show any width trend in relation to renourishment at WHD.

At WHB, the ocean backshore widened after renourishment in untreated areas, but the opposite occurred in treated areas, which is counterintuitive. Renourished beaches present a steeper profile to wave action than natural beaches, which increases erosion rates (Dolan *et al.* 1973, Leatherman and Allen 1985). It is possible that the renourished portions of WHB eroded at a faster rate than the untreated portions, and that the eroded sand was deposited at the untreated areas. The nonrenourished section of WHB was downstream in the longshore current from one of the two renourished areas, from which it could have received sand. This hypothesis also is supported by our observation that the ocean intertidal zone was wider in untreated areas one year post-renourishment, while widening was not apparent in treated areas until 3 breeding seasons post-renourishment.

Prey in ocean side cover types may have been affected by renourishment, We found that arthropod abundance was lower in July in all years post-renourishment on the ocean side. However, we also observed this effect in July on the bay side two years post-renourishment, and the bay side did not receive renourishment sand. Thus, the ocean side decline in July arthropod abundance post-renourishment may have simply reflected annual variation, with 2000 being a particularly high year. March arthropod abundance at WHB did not appear to be adversely affected by renourishment. Houghton *et al.* (in prep.) found no effect of renourishment on arthropod abundance during the brood-rearing period following 2 renourishment events at WHB and WHD 1994-2003. At our sites, June and July arthropod index in most ocean side cover types was generally greater (3 – 50) than that observed at Assateague National Seashore, Maryland (2.4 – 18), where chicks on the ocean beach failed to thrive and died of starvation (Loegering and Fraser 1995). They used a 0.5-h sampling period, so we assumed a linear rate of catch on the sticky sticks and extrapolated their findings to a 3 h period to be comparable with our results. Our fresh wrack arthropod indices were greater and our backshore and sparse vegetation indices lower than those found at other New York sites in the brood-rearing period of 1992-93 (Elias *et al.* 2000). We did not see evidence of starvation when we measured chick growth rates (Chapter 2).

Habitat selection by broods apparently changed over time on the ocean side of WHD, with selection of ocean intertidal zone and fresh wrack increasing and old wrack decreasing by two breeding seasons after renourishment.

However, this may have been a year effect and not a renourishment effect. Ocean fresh wrack and intertidal zone have been shown to be the most prey-rich cover types on the ocean side at WHD, while ocean old wrack has been shown to be one of the most depauperate (Houghton *et al.* in prep.). Since it appears that 2002 was a year of lower insect abundance than 2000, regardless of renourishment, selection of the best cover types would be expected to be higher in 2002. Houghton *et al.* (in prep.) demonstrated that chick foraging rates and survival on the front beach at WHD and WHB did not change after renourishment.

We did not detect short-term negative direct consequences of renourishment to piping plovers. Although the 2000/2001 renourishment may have led to localized nesting habitat loss in portions of WHB, habitat accreted in adjacent areas. At WHD, Houghton *et al.* (in prep.) observed that the renourishment of 1996 increased the area of nesting habitat, which was one factor that allowed the plover population to grow to a size rarely seen elsewhere. This potential advantage to renourishment was recognized by plover managers soon after the species was listed (Melvin *et al.* 1991). However, at that time possible pitfalls of beach stabilization were outlined, including habitat loss due to human development, increasing disturbance of nesting birds by humans, and higher predation rates as humans introduced domestic animals to barrier beaches and human litter attracted more predatory wildlife. All of these negative consequences of beach stabilization appear to have been realized at WHD (Houghton *et al.* in prep.), and the population has been in a serious decline due

to several years of low reproductive success and habitat loss.   Since back-bay nesting habitat has been nearly eliminated by revegetation and home construction, persistence of plovers at the site may now depend on continued periodic renourishment of the front beach, a pattern that was also seen with a population of sea turtles nesting on a nourished beach in Florida, which fluctuated with cycles of renourishment and erosion (Steinitz *et al.* 1998). However, renourishment is only performed at WHD every 4 to 5 years, while the severe erosion we witnessed occurred in the third year after renourishment.

The potential long-term effects of renourishment on plover habitat and population dynamics bears further study. Renourishment delays the natural landward migration of barrier islands by preventing breaches and overwash. Ultimately, this can accelerate barrier island erosion, as sediment is no longer transported to the back bay area behind the primary dune line, where it normally accretes during storm events (Dolan *et al.* 1973, Leatherman and Allen 1985). Bayside salt marshes, which absorb storm energy originating on their side of barrier islands, also may become sediment deprived and begin to erode (Dolan *et al.* 1973). Protected from the effects of salt spray by artificially-elevated beaches, bay side vegetation tends to succeed to dense, woody plants, thereby precluding normal barrier island plant and animal communities (Dolan *et al.* 1973, Leatherman and Allen 1985). If hydrologic conditions permit, the eventual succession of sandflats and mudflats into marsh would likewise be predicted, which would preclude foraging by shorebirds that rely on open habitat, as was seen in a storm-created mudflat in the Netherlands that succeeded into marsh

(Eertman *et al.* 2002). Thus, the long-term consequence of periodic beach renourishment to piping plovers is likely to be a loss of both nesting and foraging habitat. The exact time scale over which such effects will occur remains to be seen. However, Leatherman and Allen (1985) predicted that after 75 years of stabilization, eastern Long Island barrier islands will undergo dramatic narrowing, accompanied by overwash and frequent uncontrollable breaches.

MANAGEMENT IMPLICATIONS

The widening of a beach via renourishment should be seen as partially mitigating the negative indirect impacts of stabilization (loss of habitat due to house construction and revegetation) on piping plover populations in the short term rather than as a recovery strategy *per se*. Although the long-term effects of renourishment on plover habitat have not been studied, they are potentially severe. Strategies to offset long-term nesting and foraging habitat loss should be considered. These may include identification of sites where natural storm-processes can be allowed to occur without endangering human interests, restoration of potential or historical habitat through sand and vegetation management, or artificial habitat creation (USACE 2001). An experiment at Cupsogue County Park, which is adjacent to WHD to the west, demonstrated that artificial ephemeral pools can be created that successfully produce prey for plovers, at least on a small scale (Appendix I). However, one of the artificial ephemeral pools we studied there produced few insects even when wet, so the factors leading to variability in prey production at artificial pools should be examined. Furthermore, when habitat is artificially enhanced to allow plovers to

nest within an urbanized system, intensive control of human disturbance and predation will have to be a perennial part of any management plan.

ACKNOWLEDGEMENTS

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Table 1. Mean cover type widths (m) in renourished and nonrenourished portions of WHB, NY, before renourishment (2000), and one, two and three breeding seasons (bs) after (2001, 2002, and 2003, respectively). n = 4 transects per portion in 2000, 3 transects thereafter. Significant findings are bold-faced.

	Renourished								Not Renourished							
	Before		1 bs after		2 bs after		3 bs after		Before		1 bs after		2 bs after		3 bs after	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Ocean Intertidal Zone[a]																
March	26.9	4.0	26.3	8.6	26.9	3.0	51.3	4.2	21.0	4.6	15.9	5.3	25.6	2.1	58.1	4.1
April	29.7	3.2	9.5	3.1	29.6	8.1	25.3	3.8	25.0	1.1	11.6	2.7	30.4	12.9	27.7	3.7
May	17.2	0.5	18.9	5.3	24.5	2.8			22.4	2.4	12.5	2.6	28.8	2.9		
June	27.6	3.2	29.8	6.5	26.8	3.4	35.2	0.0	30.2	2.7	16.6	2.0	26.6	1.2	37.5	0.9
July	21.6	3.4	19.9	1.5	25.4	2.2	**39.8[b]**	**0.6**	17.2	1.8	**32.7[c]**	**15.6**	20.5	2.9	25.5	1.2
August	27.2	2.8	26.2	3.9	24.1	1.4	26.3	2.2	28.5	1.3	27.7	1.9	21.3	1.3	28.2	4.6
Ocean Fresh Wrack																
March	2.2	1.4	0.3	0.2	1.4	0.5	0.5	0.2	0.6	0.5	0.1	0.0	0.7	0.4	0.3	0.2
April	0.3	0.1	0.8	0.8	0.2	0.2	0.0	0.0	0.6	0.2	1.3	1.2	0.2	0.2	0.0	0.0
May	0.5	0.1	2.5	1.0	0.2	0.2			0.4	0.1	1.1	0.5	0.1	0.1		
June	0.6	0.2	**3.6[d]**	**0.7**	**1.8[e]**	**0.4**	0.5	0.1	0.8	0.2	1.1	0.2	0.8	0.4	0.4	0.2
July	0.6	0.4	0.6	0.3	2.2	0.6	0.6	0.3	0.3	0.0	0.9	0.7	2.3	0.2	0.6	0.1
August	0.1	0.0	3.2	0.6	5.5	0.5	0.8	0.5	0.0	0.0	1.9	0.5	5.0	0.8	0.7	0.3
Ocean Backshore																
March	22.2	7.5	58.5	9.4	27.0	2.8	7.7	2.9	20.7	3.8	51.6	2.5	43.2	9.7	7.3	0.8
April	33.5	2.2	52.1	6.0	15.2	7.0	12.4	4.4	30.1	3.9	48.0	2.1	32.3	6.2	19.7	2.9
May	37.1	2.3	43.3	3.7	23.2	0.8			31.2	5.7	40.9	2.3	36.0	7.4		

June	43.8	1.4	41.9	4.6	**20.5**[f]	**5.9**	**17.5**[g]	**2.8**	28.5	4.3	**51.1**[h]	**4.3**	26.4	6.2	17.8	3.1
July	40.0	3.8	49.5	4.9	25.1	2.4	**20.5**[i]	**7.6**	34.6	6.9	**55.6**[j]	**12.6**	**49.7**[k]	**11.8**	15.4	4.8
August	39.0	3.5	37.0	4.7	29.5	3.8	29.4	1.1	30.3	3.0	35.2	7.3	37.7	2.6	27.7	5.1
Ocean Old Wrack																
March	0.0	0.0	0.0	0.0	1.4	0.8	0.7	0.4	0.0	0.0	0.0	0.0	3.1	1.4	0.3	0.1
April	0.0	0.0	0.0	0.0	1.0	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.8	0.3	0.5	0.0
May	0.0	0.0	0.0	0.0	0.9	0.5			0.0	0.0	0.0	0.0	1.1	0.9		
June	0.0	0.0	0.0	0.0	1.6	0.5	0.1	0.1	0.0	0.0	0.0	0.0	1.4	0.7	0.4	0.1
July	0.0	0.0	0.0	0.0	1.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	1.3	0.3	1.1	0.2
August	0.0	0.0	0.0	0.0	1.3	0.4	0.4	0.0	0.0	0.0	0.0	0.0	1.2	0.7	0.7	0.3
Ocean Sparse Vegetation																
March	23.1	2.2	12.5	7.6	38.2	10.6	21.8	10.3	20.3	3.3	19.2	10.3	28.1	4.3	16.1	8.4
April	20.3	2.1	15.4	2.3	37.1	10.3	36.7	7.3	19.8	3.9	17.8	4.7	27.2	5.3	23.8	3.2
May	17.9	3.3	19.9	4.3	39.5	13.9			18.1	3.2	23.2	2.7	36.0	1.2		
June	17.7	3.0	18.9	4.1	22.6	13.6	19.5	0.6	18.7	2.6	27.2	5.5	26.6	7.0	30.7	5.5
July	17.5	3.0	29.6	1.7	31.2	0.0	24.2	2.2	17.2	2.0	34.4	16.7	14.2	7.2	27.1	4.5
August	20.4	3.5	20.3	2.4	31.2	2.2	25.8	2.8	21.3	2.1	29.8	6.2	34.4	3.1	27.7	2.8

[a]Measured within 3 h of low tide

[b]In renourished area, mean in 2003 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,10} = 12.7$, $P = 0.005$

[c]In renourished area, mean in 2001 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,10} = 5.9$, $P = 0.035$

[d]In renourished area, mean in 2002 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,11} = 16.4$, $P < 0.001$

[e]In renourished area, mean in 2003 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,11} = 6.7$, $P = 0.025$

[f]In renourished area, mean in 2002 < mean in 2000, Repeated measures ANOVA contrast, $F_{1,11} = 16.4$, $P = 0.002$

[g]In renourished area, mean in 2003 < mean in 2000, Repeated measures ANOVA contrast, $F_{1,11} = 21.0$, $P = 0.001$

[h]In nonrenourished area, mean in 2001 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,11} = 15.9$, $P = 0.002$

[i]In renourished area, mean in 2003 < mean in 2000, Repeated measures ANOVA contrast, $F_{1,10} = 5.6$, $P = 0.040$

[j]In nonrenourished area, mean in 2001 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,10} = 62.2$, $P < 0.001$

[k]In nonrenourished area, mean in 2002 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,10} = 43.3$, $P < 0.001$

Table 2. Mean percent abundance of arthropods captured on sticky sticks, WHD and WHB, Long Island, NY, 2000-2003. n = 4 months, where each sample is the mean of 12 transects

Cover type	Diptera		Coleoptera		Hymenoptera		Homoptera		Amphipods		Other	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Ocean Side												
intertidal zone	61.4	9.8	4.2	2.2	2.1	1.3	0.6	0.3	31.3	10.3	0.3	0.2
fresh wrack	68.2	11.6	2.8	1.0	1.6	0.6	0.3	0.2	26.9	13.1	0.3	0.2
backshore	86.0	3.7	4.6	2.6	1.3	0.7	0.2	0.1	5.8	3.4	2.0	1.8
old wrack	79.8	8.4	11.7	5.8	2.1	0.7	0.3	0.1	6.0	3.7	0.1	0.1
sparse vegetation	90.1	1.5	2.6	0.6	1.6	0.4	1.6	0.5	2.1	1.2	2.0	0.8
dune sparse vegetation	86.2	1.2	3.8	2.1	5.6	2.0	1.3	0.5	0.6	0.5	2.5	0.6
Bay Side												
sparse vegetation	80.8	3.2	2.3	1.6	6.0	1.1	2.8	1.2	3.0	2.2	5.0	2.0
old wrack	76.8	2.0	6.4	2.0	2.1	1.2	0.9	0.9	10.6	5.1	3.1	1.6
backshore	77.2	8.4	11.1	5.0	1.9	0.6	0.8	0.3	3.0	1.5	6.1	4.9
fresh wrack	67.4	3.2	9.9	3.8	0.6	0.4	1.1	0.6	20.2	1.5	0.8	0.3
intertidal zone	70.8	7.4	5.8	1.8	0.6	0.3	1.2	1.2	19.7	4.7	1.9	1.2

[a]Hemiptera, Odonata, Neuroptera, Orthoptera, arachnids, and unidentified specimens

Table 3. Mean arthropod catch in renourished and nonrenourished portions of WHB, NY before renourishment (2000), and one, two and three breeding seasons (bs) after (2001, 2002, and 2003, respectively). n = 4 transects in 2000, 3 transects thereafter. Significant findings are bold-faced.

	Renourished								Not Renourished							
	Before		1 bs after		2 bs after		3 bs after		Before		1 bs after		2 bs after		3 bs after	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Ocean Intertidal Zone																
March	0.8	0.5	0.0	0.0	0.7	0.3	**6.7**[a]	**1.7**	0.0	0.0	0.3	0.3	2.7	1.5	1.3	0.7
April			0.5	0.5	0.0	0.0	0.0	0.0			1.0	0.0	0.7	0.7	0.0	0.0
May			26.7	5.5	1.7	0.3					26.3	5.8	6.7	4.7		
June			15.0	-	9.0	-	8.5	0.5			32.3	4.6	11.0	-	7.7	0.7
July			28.0	8.0	21.0	-	21.3	2.3			31.3	11.3	44.0	-	35.5	18.5
Ocean Fresh Wrack																
March	1.5	1.5	0.0	0.0	4.7	2.7	1.7	0.3	0.0	-	0.3	0.3	2.0	-	3.3	1.5
April			0.7	0.7	0.5	0.5	0.0	0.0			1.7	0.9	0.0	0.0	0.3	0.3
May			20.0	11.0	6.0	1.5					46.7	14.5	9.3	3.0		
June			35.0	-	6.0	-	15.5	4.5			23.7	7.4	6.0	-	17.3	6.1
July			24.0	11.0	4.0	2.0	43.0	6.7			31.3	14.4	11.0	-	49.0	11.9
Ocean Backshore																
March	0.0	0.0	0.0	-	0.3	0.3	0.7	0.7	0.0	0.0	0.0	0.0	1.3	1.3	1.7	0.7
April			1.0	0.6	0.0	0.0	0.3	0.3			0.7	0.3	0.0	0.0	1.3	0.3
May			4.0	1.5	4.7	1.8					4.7	2.2	2.0	0.0		
June			0.0	-	2.0	-	4.0	2.0			6.0	1.2	3.0	-	3.3	1.2
July			0.5	0.5	1.0	1.0	16.3	2.7			2.7	0.7	1.0	-	13.7	0.9

Ocean Old Wrack

March	0.0	0.0	0.0	-	0.7	0.3	2.7	2.2	0.0	0.0	0.0	-	0.0	0.0	0.3	0.3
April					0.3	0.3	0.3	0.3			1.0	-	0.7	0.3	0.0	0.0
May			5.0	4.0	2.7	0.9					19.3	10.3	1.0	0.6		
June			17.0	-	4.0	-	4.0	0.0			2.7	0.9	1.0	-	4.0	1.2
July			3.0	0.0	2.5	1.5	21.3	2.0			7.5	0.5	2.0	-	24.0	8.7

Ocean Sparse Vegetation

March	0.0	0.0	0.7	0.3	0.3	0.3	0.3	0.3	0.0	-	0.0	0.0	0.0	0.0	0.7	0.3
April			1.3	0.7	7.3	6.4	2.7	2.7			1.3	0.9	14.0	1.2	2.7	0.9
May			2.0	1.2	4.3	1.7					1.7	0.7	3.0	1.2		
June			9.0	-	6.0	-	4.0	0.0			4.3	1.5	4.0	-	8.7	1.8
July			2.5	0.5	4.0	3.0	19.3	5.2			2.3	0.9	10.0	-	18.7	2.7

[a]In nonrenourished area, mean in 2003 > mean in 2000, Repeated measures ANOVA contrast, $F_{1,7} = 26.9$, $P < 0.001$

Table 4. Selection of ocean side cover types by plover broods, within 3 hrs of high tide, WHD and WHB, NY, 2000 and 2002, based on compositional analysis.

Cover Type	n^a	$\bar{x}$ % use	se	n^b	$\bar{x}$ % available	se	
2000							
ocean intertidal zone	23	19.5	5.1	6	17.0	2.9	B[c]
ocean fresh wrack	23	7.5	2.4	6	0.3	0.1	B
ocean backshore	23	30.9	6.3	6	45.1	1.7	B
ocean old wrack	23	25.1	4.0	6	0.0	0.0	A
ocean sparse veg	23	7.8	2.2	6	3.7	1.2	B
dune sparse veg	23	9.3	4.6	6	33.8	1.3	C
2002							
ocean intertidal zone	9	23.8	6.2	6	11.4	2.0	A
ocean fresh wrack	9	8.4	5.6	6	1.5	0.5	B
ocean backshore	9	32.9	7.3	6	45.0	3.9	A
ocean old wrack	9	8.9	3.4	6	1.0	0.2	AB
ocean sparse veg	9	26.0	6.6	6	14.1	2.8	A
dune sparse veg	9	0.0	0.0	6	27.0	1.7	C

[a]n = number of broods

[b]n = number of transects

[c]Within years, cover types with the same capital letter are not more or less likely to be selected

Table 5. Selection of ocean side cover types by plover broods, within 3 hrs of low tide, WHD and WHB, NY, 2000-2002, based on compositional analysis.

Cover Type	n^a	$\bar{x}$ % use	se	n^b	$\bar{x}$ % available	se	
2000							
ocean intertidal zone	23	18.3	3.2	6	20.1	1.4	BC[a]
ocean fresh wrack	23	3.9	1.9	6	0.6	0.2	C
ocean backshore	23	34.4	5.6	6	40.8	1.2	B
ocean old wrack	23	27.1	4.9	6	0.0	0.0	A
ocean sparse veg	23	9.1	2.6	6	8.5	0.8	C
dune sparse veg	23	7.2	2.9	6	30.0	0.6	D
2001							
ocean intertidal zone	12	20.9	8.2	6	14.9	1.4	BC
ocean fresh wrack	12	2.9	1.8	6	0.7	0.2	BC
ocean backshore	12	38.8	7.0	6	48.7	2.3	B
ocean old wrack	12	30.3	8.2	6	0.0	0.0	AB
ocean sparse veg	12	5.8	2.9	6	6.9	1.3	BC
dune sparse veg	12	1.4	1.4	6	28.8	1.7	C
2002							
ocean intertidal zone	10	33.4	6.0	6	15.0	1.5	B
ocean fresh wrack	10	18.9	6.2	6	1.4	0.4	A
ocean backshore	10	26.6	4.8	6	43.1	3.2	AB
ocean old wrack	10	8.8	5.7	6	1.0	0.2	AB
ocean sparse veg	10	12.3	5.7	6	13.5	2.7	B
dune sparse veg	10	0.0	0.0	6	26.1	1.8	C

[a]n = number of broods

[b]n = number of transects

[c]Within years, cover types with the same capital letter are not more or less likely to be selected
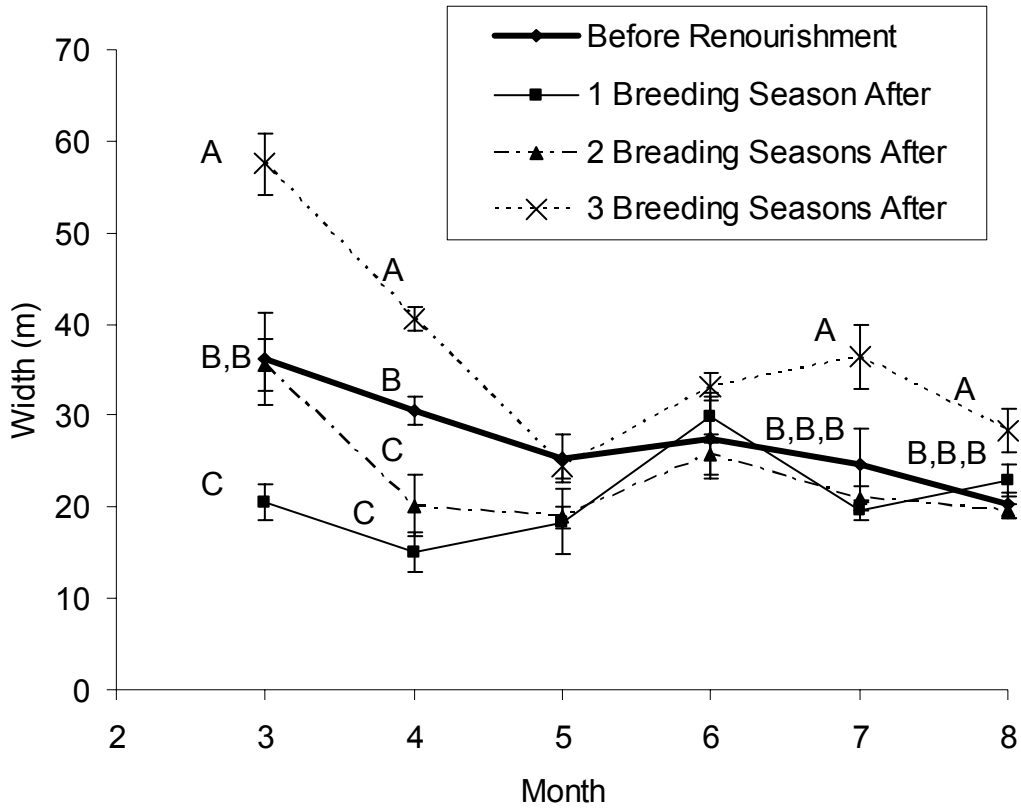
Fig. 1. Monthly mean±se width of the ocean intertidal zone within 3 hours of low tide, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for March: $F_{3,18}$ = 26.9, P < 0.001, n = 22; April: $F_{3,20}$ = 28.6, P < 0.001, n = 24; July: $F_{3,20}$ = 6.5, P = 0.003, n = 24; August: $F_{3,20}$ = 6.6, P = 0.003, n = 24. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
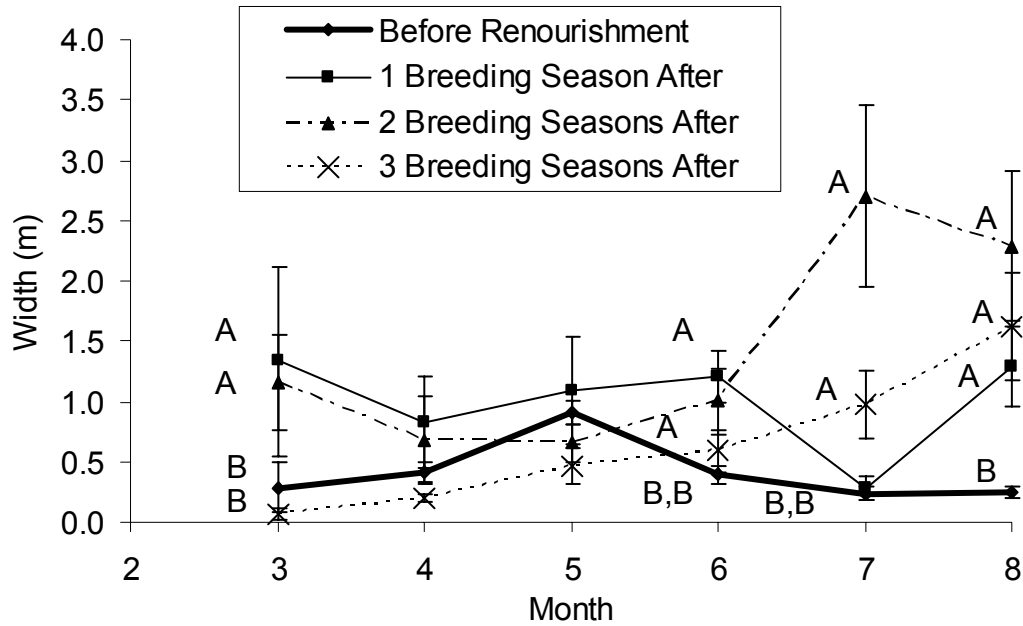
Fig. 2. Monthly mean±se width of the ocean fresh wrack, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season.   ANOVA on ranks results for March: $F_{3,20} = 6.1$, $P = 0.004$, $n = 24$; June: $F_{3,20} = 5.7$, $P = 0.006$, $n = 24$; July: $F_{3,20} = 10.7$, $P < 0.001$, $n = 24$; August: $F_{3,20} = 9.9$, $P < 0.001$, $n = 24$. For all other months, $P > 0.05$. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
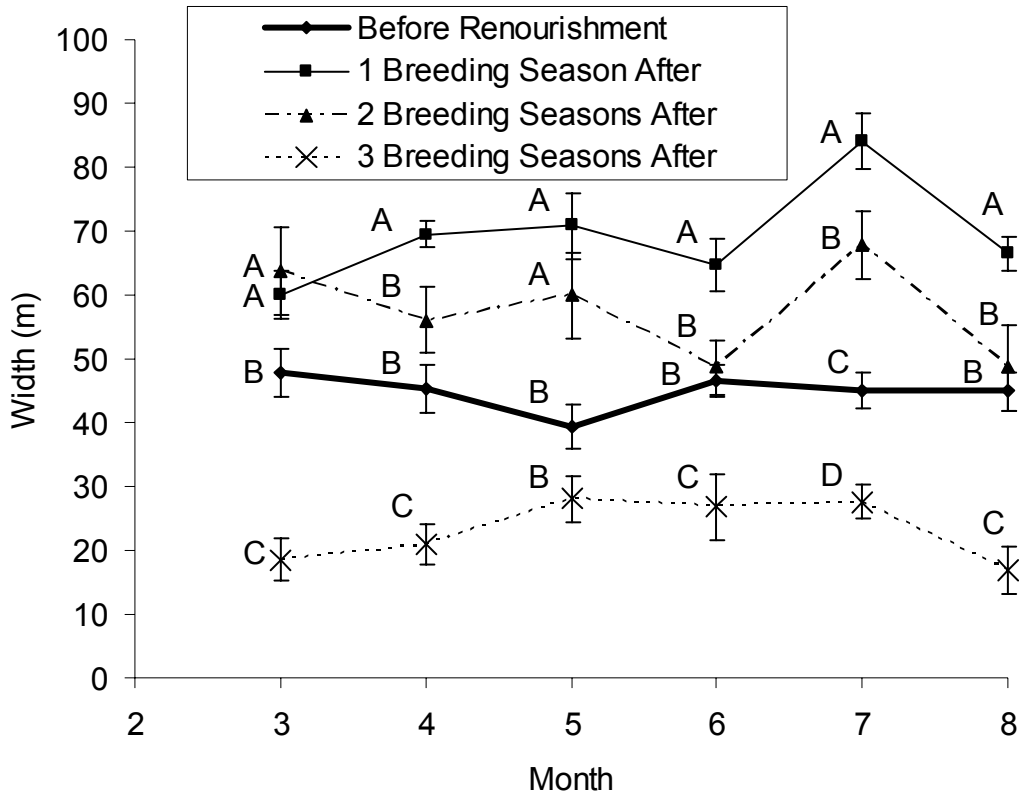
Fig. 3. Monthly mean±se width of the ocean backshore, WHD, 2000-2003.
Renourishment occurred after the 2000 breeding season.   ANOVA on ranks
results for March: $F_{3,20}$ = 14.3, P < 0.001, n = 24; April: $F_{3,20}$ = 30.8, P < 0.001, n
= 24; May: $F_{3,20}$ = 15.5, P < 0.001, n = 24; June: $F_{3,20}$ = 13.4, P < 0.001, n = 24;
July: $F_{3,20}$ = 52.3, P < 0.001, n = 24; August: $F_{3,20}$ = 21.5, P < 0.001, n = 24.
Within months, means with the same capital letter are not significantly different.
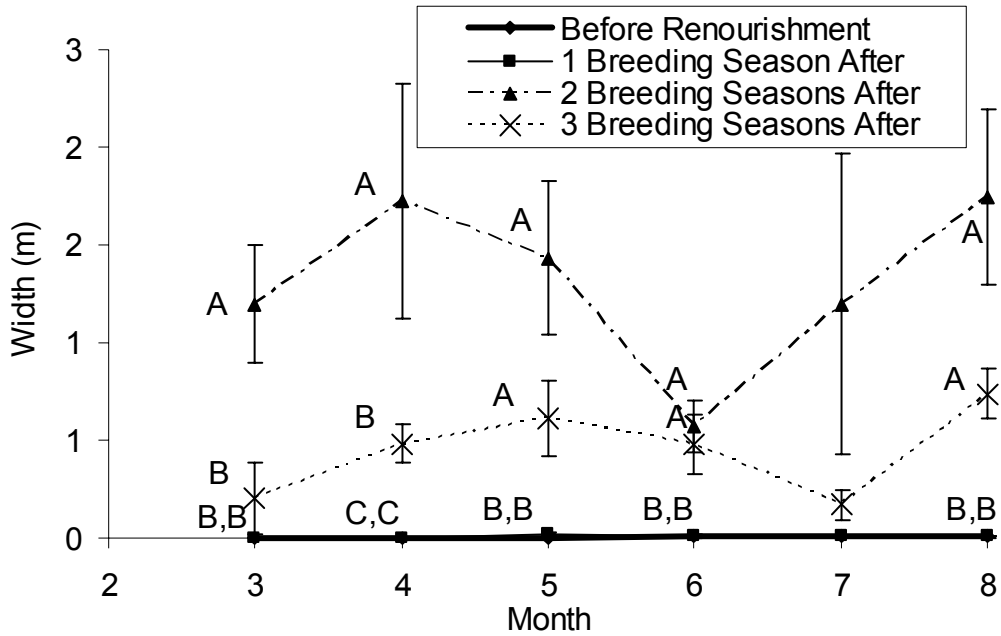
Fig. 4. Monthly mean±se width of the ocean old wrack, WHD, 2000-2003.
Renourishment occurred after the 2000 breeding season.   ANOVA on ranks
results for March: $F_{3,20}$ = 8.5, P = 0.001, n = 24; April: $F_{3,20}$ = 43.1, P < 0.001, n =
24; May: $F_{3,20}$ = 29.9, P < 0.001, n = 24; June: $F_{3,20}$ = 3.7, P = 0.028, n = 24;
August: $F_{3,20}$ = 8.3, P = 0.001, n = 24. For all other months, P > 0.05. Within
months, means with the same capital letter are not significantly different. If no
capital letters are given, there was no difference among years.
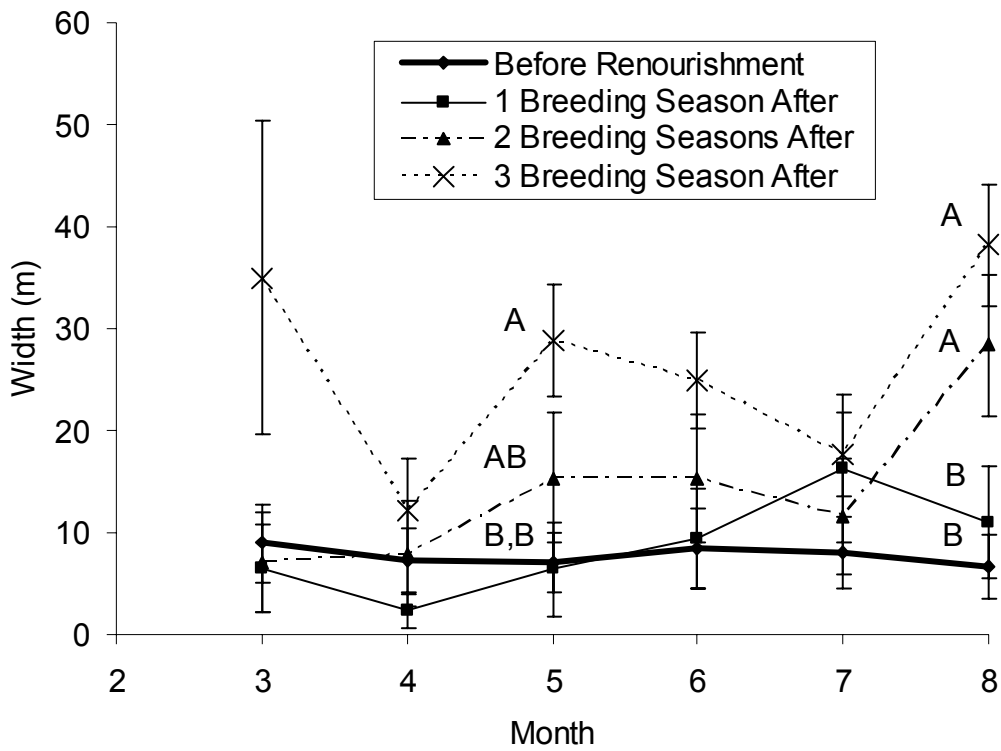
Fig. 5. Monthly mean±se width of ocean sparse vegetation, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for May: $F_{3,20}$ = 4.4, P = 0.015, n = 24; August: $F_{3,20}$ = 6.6, P = 0.003, n = 24. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
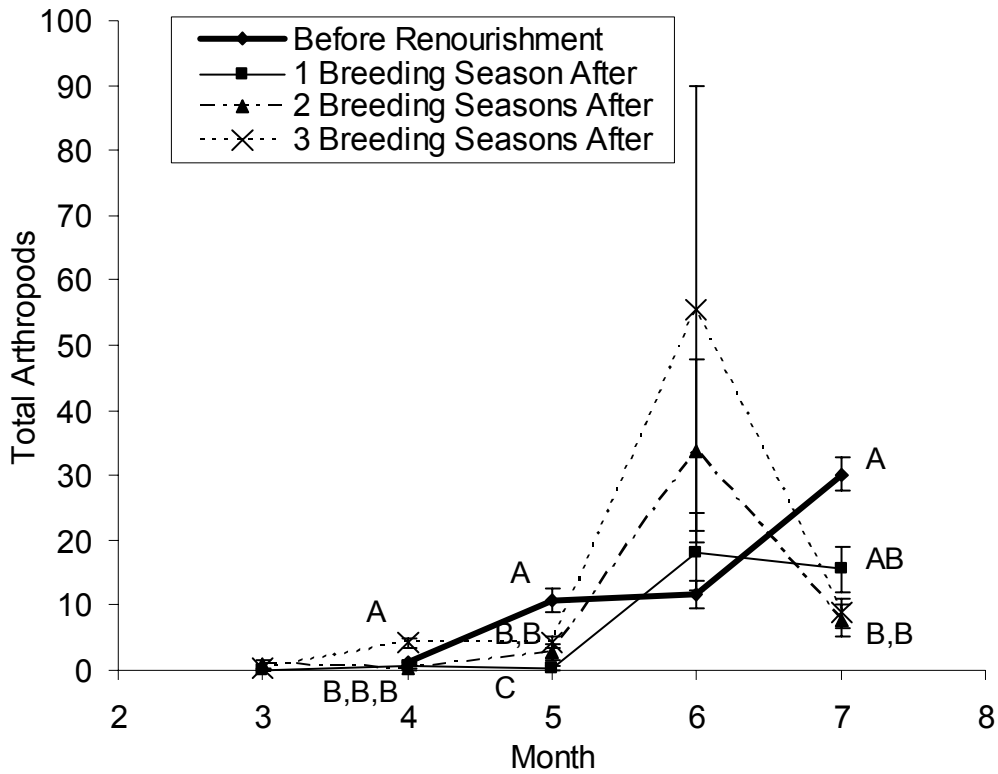
Fig. 6. Monthly mean±se arthropod index in the ocean fresh wrack, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for April: $F_{3,19}$ = 7.4, P = 0.002, n = 23; May: $F_{3,16}$ = 11.6, P < 0.001, n = 20; July: $F_{3,16}$ = 8.4, P = 0.002, n = 17. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
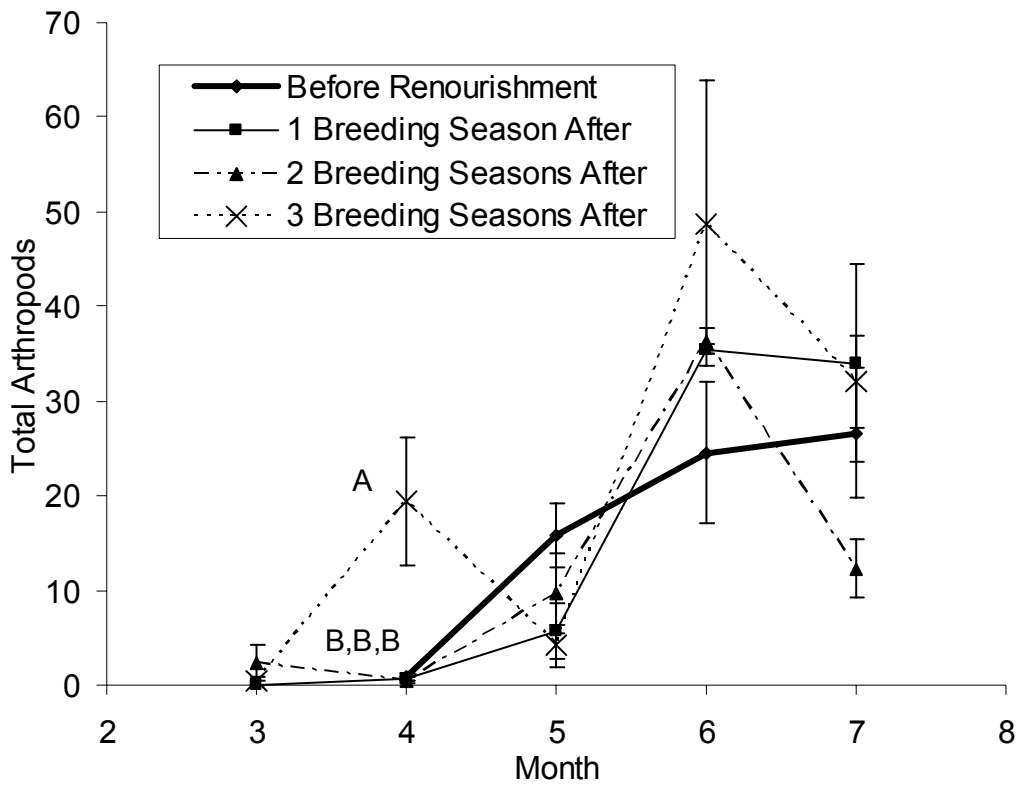
Fig. 7. Monthly mean±se arthropod index in the bay fresh wrack, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for April: $F_{3,15}$ = 14.6, P < 0.001, n = 19. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
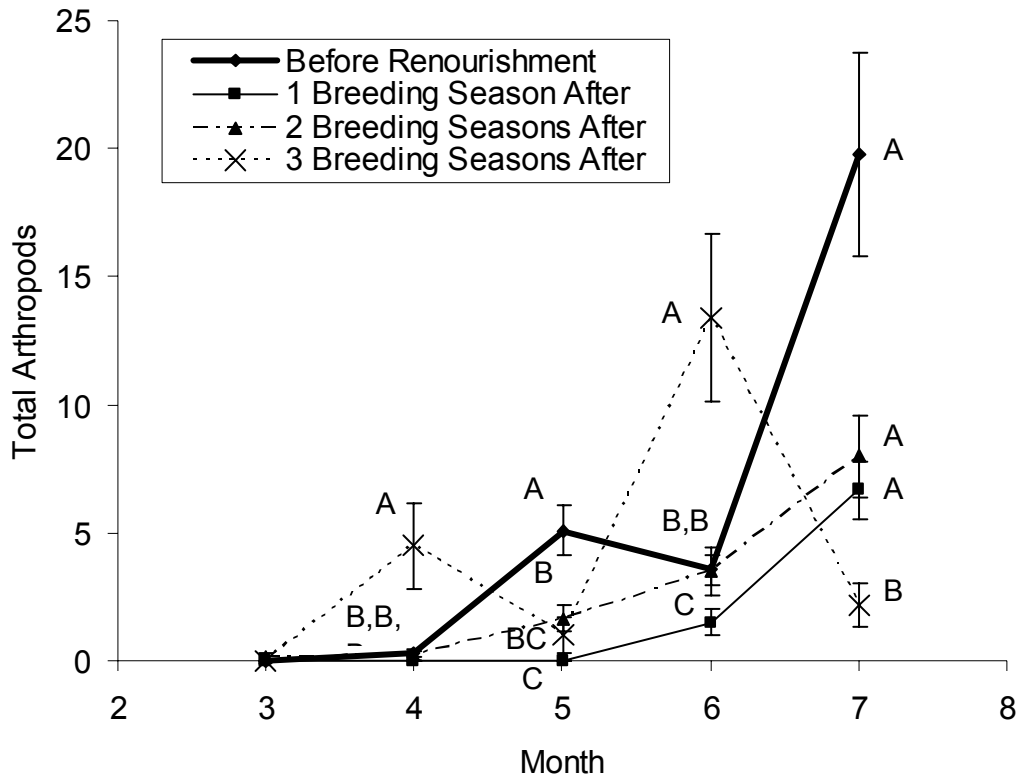
Fig. 8. Monthly mean±se arthropod index in the ocean backshore, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for April: $F_{3,19}$ = 15.7, P < 0.001, n = 23; May: $F_{3,19}$ = 13.2, P < 0.001, n = 23; June: $F_{3,14}$ = 10.9, P = 0.001, n = 18; July: $F_{3,18}$ = 12.6, P < 0.001, n = 22. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
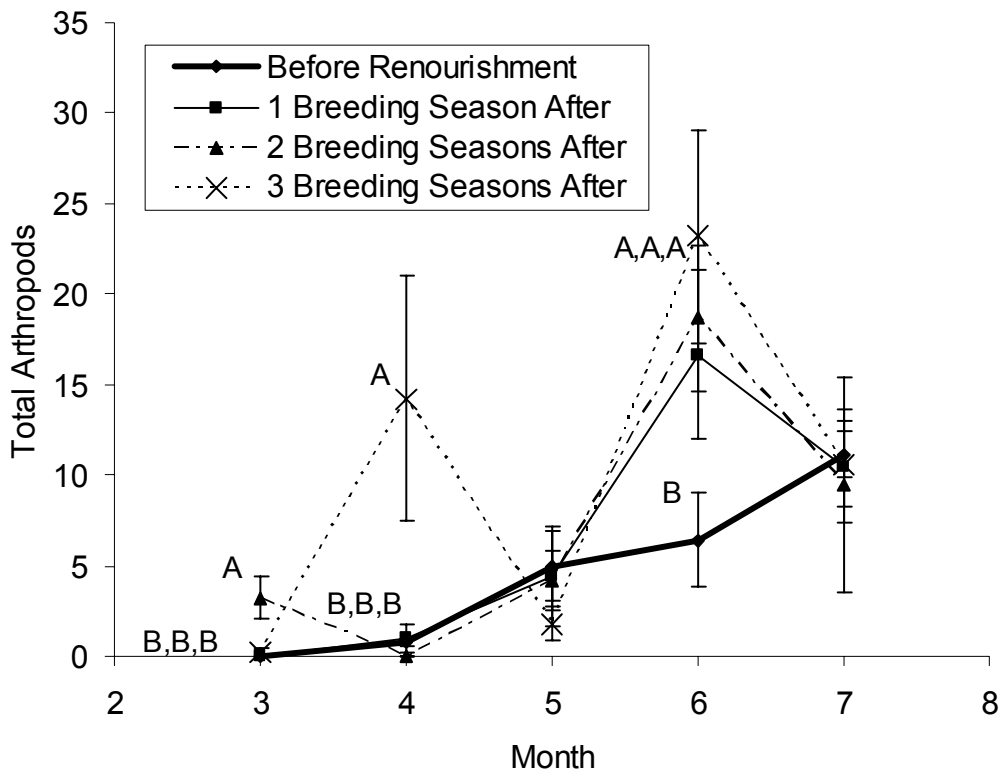
Fig. 9. Monthly mean±se arthropod index in the bay backshore, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for March: $F_{3,13}$ = 7.4, P = 0.004, n = 17; April: $F_{3,13}$ = 4.1, P = 0.031, n = 17; June: $F_{3,13}$ = 4.2, P = 0.027, n = 17. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
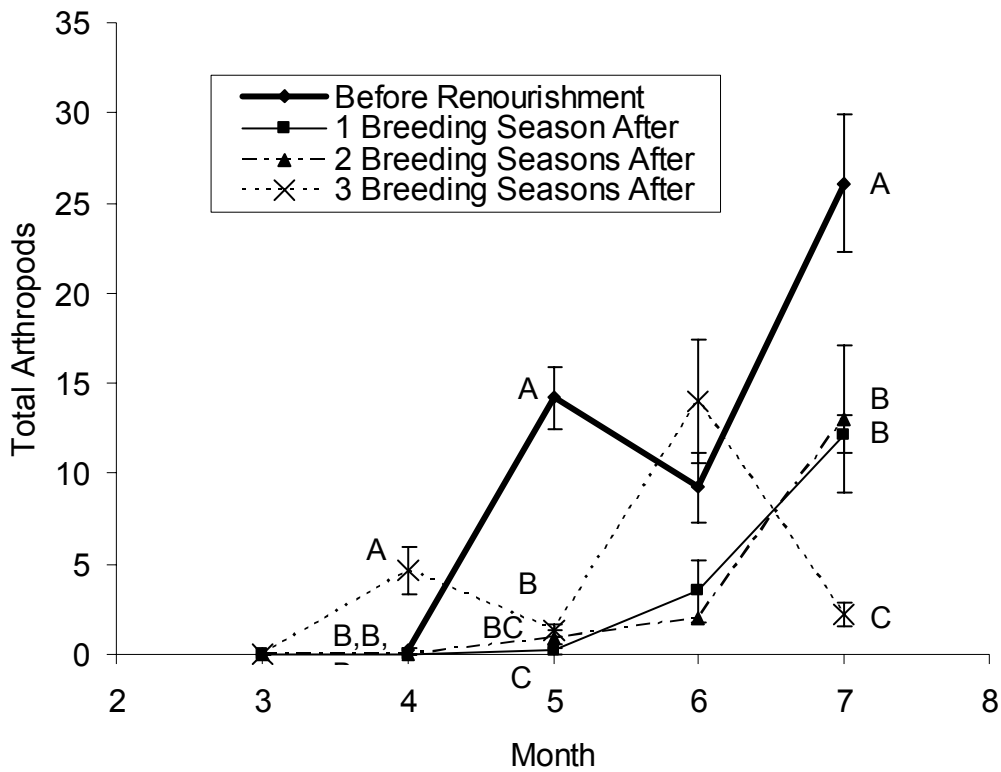
Fig. 10. Monthly mean±se arthropod index in the ocean old wrack, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for April: $F_{3,15} = 37.0$, $P < 0.001$, $n = 19$; May: $F_{3,18} = 27.1$, $P < 0.001$, $n = 22$; July: $F_{3,17} = 19.6$, $P < 0.001$, $n = 21$. For all other months, $P > 0.05$. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
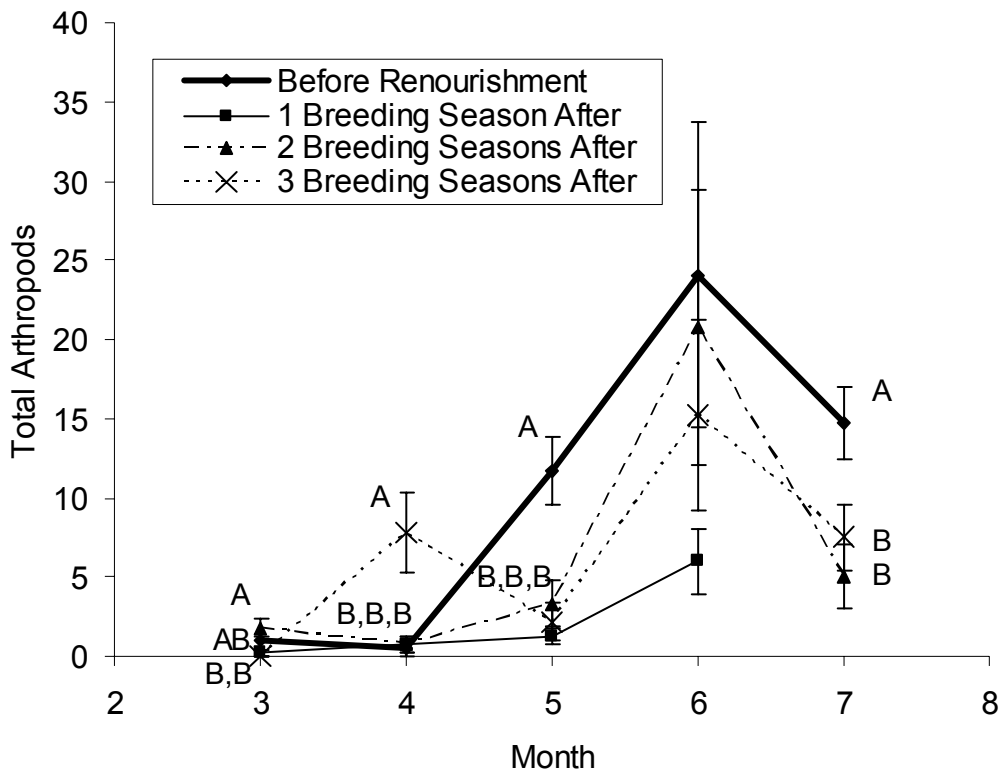
Fig. 11. Monthly mean±se arthropod index in the bay old wrack, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for March: $F_{3,12} = 5.6$, $P = 0.012$, $n = 16$; April: $F_{3,14} = 8.2$, $P < 0.001$, $n = 18$; May: $F_{3,13} = 7.6$, $P = 0.004$, $n = 17$; July: $F_{3,11} = 6.8$, $P = 0.012$, $n = 14$. For all other months, $P > 0.05$. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years. Bay old wrack was not sampled in July 2001.
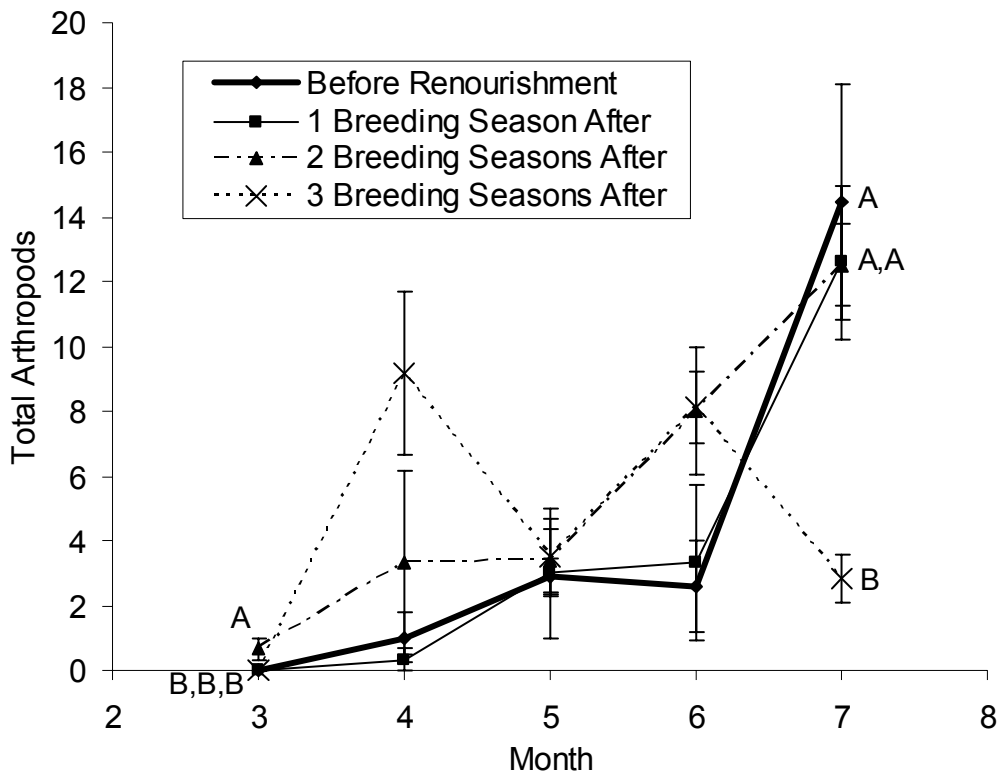
Fig. 12. Monthly mean±se arthropod index in the ocean sparse vegetation, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for March: $F_{3,9}$ = 4.6, P = 0.003, n = 19; July: $F_{3,17}$ = 7.7, P = 0.002, n = 21. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
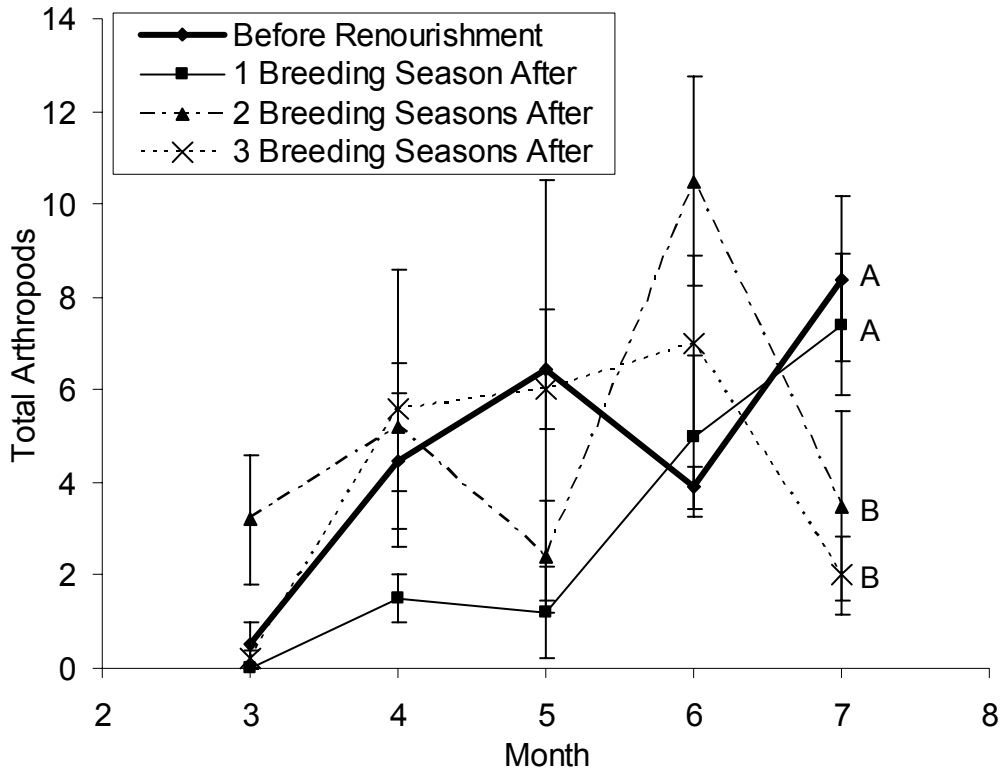
Fig. 13. Monthly mean±se arthropod index in the bay sparse vegetation, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for July: $F_{3,16}$ = 4.9, P = 0.013, n = 20. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
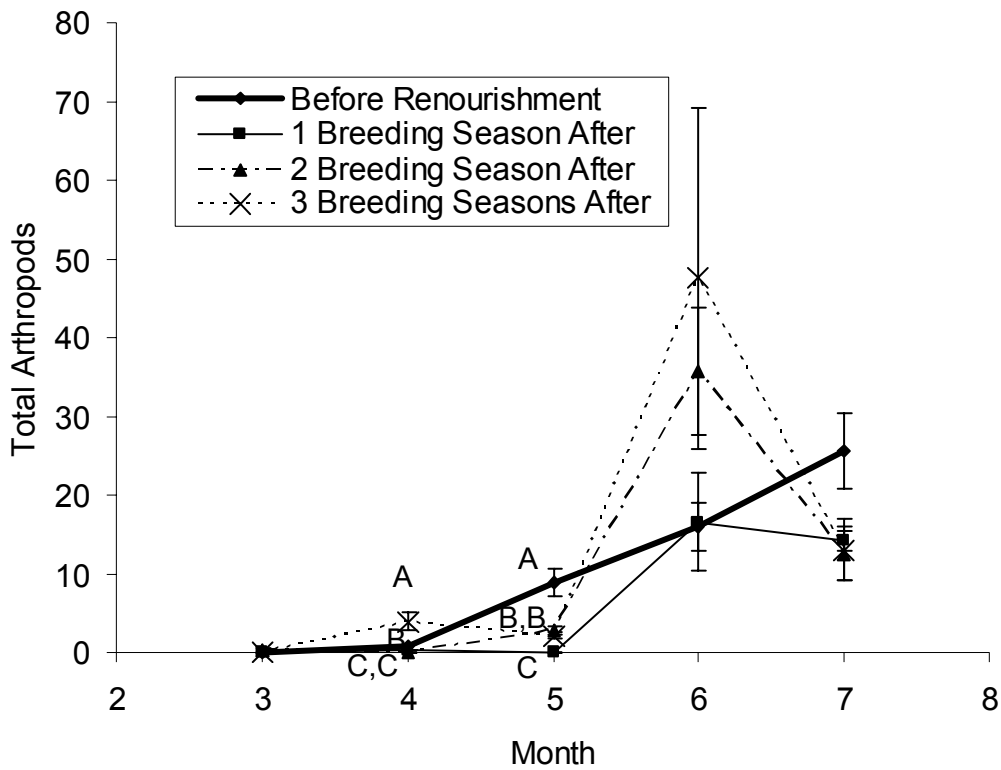
Fig. 14. Monthly mean±se arthropod index in the ocean intertidal zone, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for April: $F_{3,20}$ = 15.4, P < 0.001, n = 24; May: $F_{3,20}$ = 40.5, P < 0.001, n = 24. For all other months, P > 0.05. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.
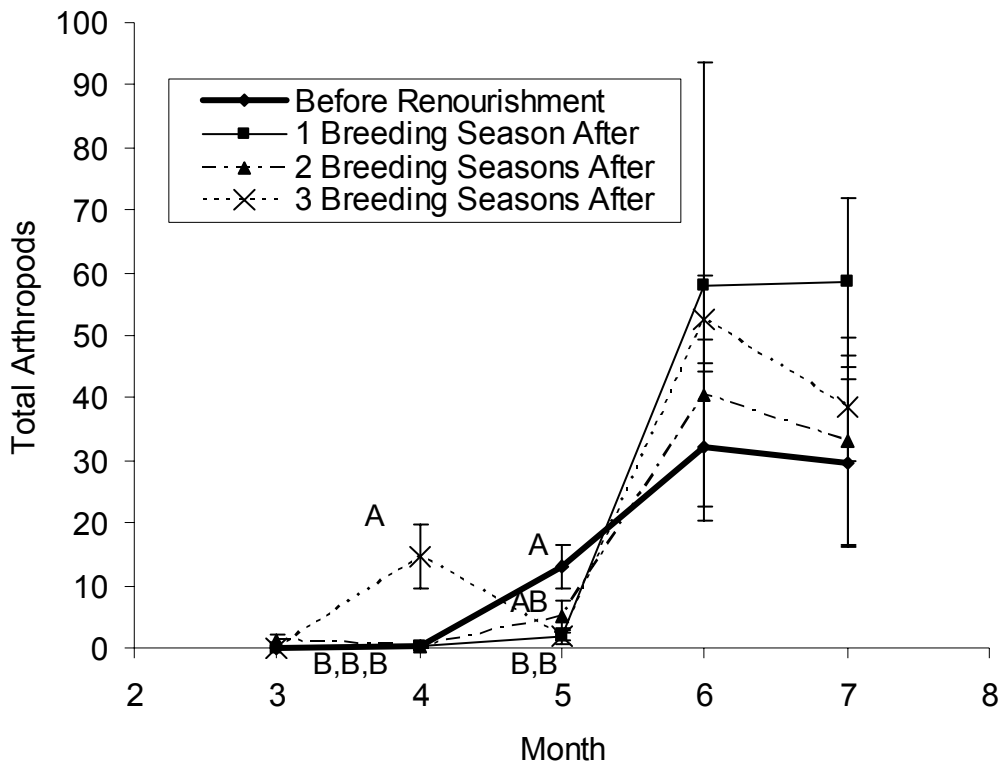
Fig. 15. Monthly mean±se arthropod index in the bay intertidal zone, WHD, 2000-2003. Renourishment occurred after the 2000 breeding season. ANOVA on ranks results for April: $F_{3,16} = 14.0$, $P < 0.001$, $n = 20$; May: $F_{3,17} = 4.7$, $P = 0.016$, $n = 21$. For all other months, $P > 0.05$. Within months, means with the same capital letter are not significantly different. If no capital letters are given, there was no difference among years.

APPENDIX A. SPATIAL PATTERN ANALYSIS
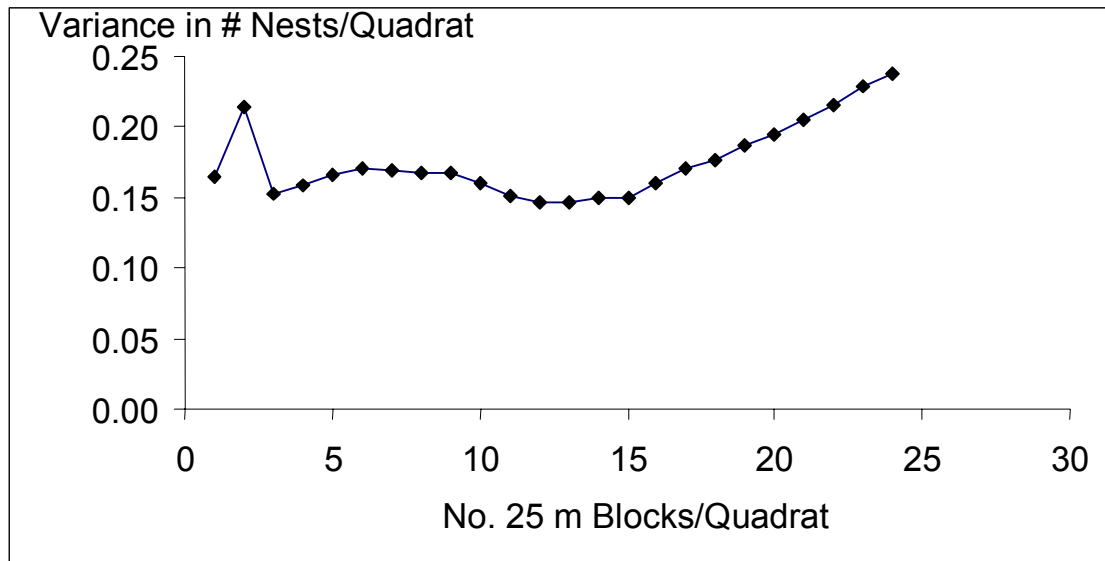
Fig. 1. Spatial pattern analysis to determine scale at which piping plover (C. melodus) nests cluster. For this analysis, we superimposed a rectangle over the nesting area, and divided the rectangle into a single row of 25-m wide blocks. We calculated the variance in number of first nest attempts within each block, then aggregated the blocks into successively larger quadrats, and recalculated the variance. We continued to form larger quadrats up to the maximum practicable quadrat width for our study area (600-m wide quadrats composed of 24 blocks ≈ our study site length of 6000 m/ 10, Krebs 1999) and plotted variance vs. number of blocks per quadrat. A peak in variance, if any, indicates the scale at which clustering occurs.   Based on this analysis, it seems that the clustering of plover pairs in our population occurs at a larger scale than we were able to measure with our study site length, but we used the largest scale available to us (600 m) from this quadrat method in subsequent analyses of local density.

APPENDIX B. NEST INITIATION DATES

Nesting began on 21 April 2001, 17 April 2002, and 1 May 2003 at WHD, 28 April 2001, 21 April 2002, and 1 May 2003 at WHB, 2 May 2001, 27 April 2002, and 5 May 2003 at Shinnecock, and 3 May 2001, 21 April 2002, and 4 May 2003 at Democrat (Fig. 2). Initiation dates of first nest attempts were later in 2003 than in 2001 or 2002 (ANOVA on ranks, $F_{2,161} = 5.3$, P = 0.006), and later at Democrat and Shinnecock than at WHD and WHB ($F_{3,161} = 4.5$, P = 0.005). Variance in initiation date (in days after Jan. 1) did not differ among sites in any given year, with one exception.   In 2003, variance in first nest initiation date was greater at Shinnecock (361.6, $n = 8$) than at WHD (127.5, $n = 26$, Folded F-test, $F_{7,25} = 2.8$, P = 0.051).
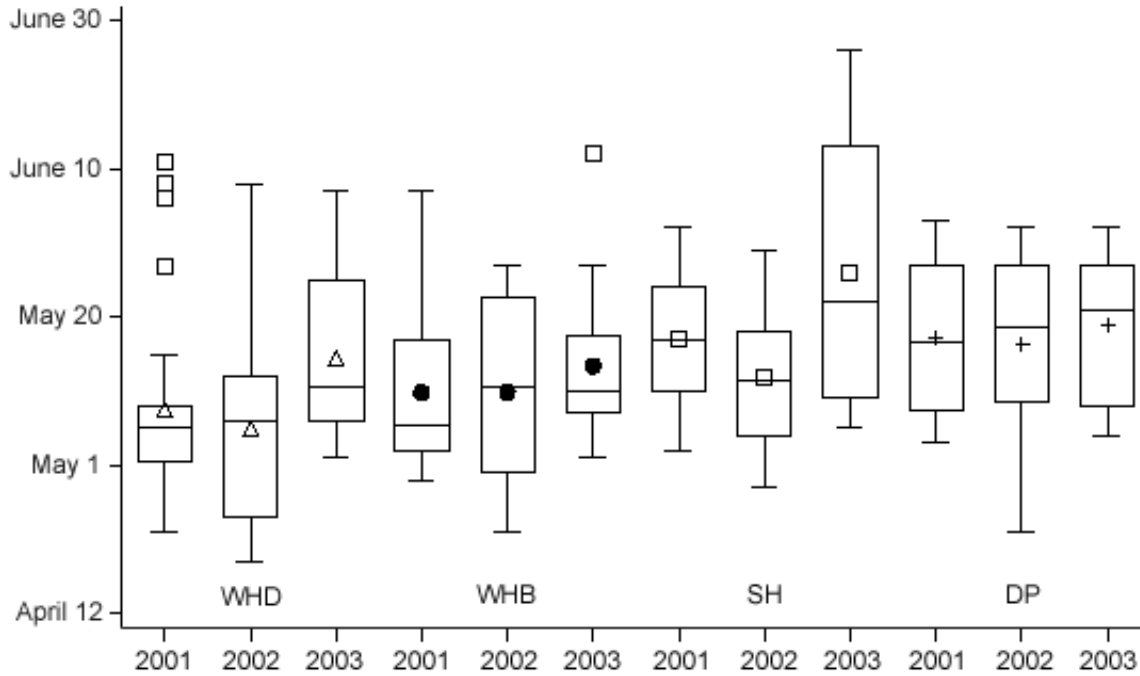
Fig. 2. Boxplots of "first nest attempt" initiation dates of piping plovers (C. melodus) for WHD, WHB, Shinnecock (SH) and Democrat (DP), NY, 2001-2003. Each box covers the interquartile range (IQR) from the 25th to the 75th percentile of initiation dates, with a central line at the median and a geometric symbol at the mean. The whiskers extend to ±(1.5 x IQR) and geometric symbols above or below the ends of the whiskers are considered outliers.

APPENDIX C. HABITAT USE VS. AVAILABILITY

Methods

Habitat availability.—We used transects for habitat data collection. We established 8 transects in WHD (2 of which were on the sand spit), 6 in WHB, 5 at Shinnecock, and 3 at Democrat, each perpendicular to the long axis of the island. At each site except WHB, we randomly located the first transect within 100 m of one border, and evenly spaced out the rest (every 420 m at WHD, every 300 m at Shinnecock and Democrat). On the WHD sandspit, the first transect was randomly located in the southern half of the spit, and the second was randomly located in the northern half. At WHB, transects were located halfway between each pair of groins, starting at the westernmost pair, and were approximately 500 m apart.

Once per month in the morning (starting between 0645 and 0730), from March through August, we paced transects from the waters' edge on the ocean side to the dense vegetation or the waters' edge on the bay side. We recorded the total number of steps (i.e., toe hits) on each transect for each cover type. Fresh wrack and old wrack were measured with measuring tape to the nearest cm. In 2002 and 2003, we repaced the intertidal zones starting 6 hours after the morning measurements began, to account for tidal change in the availability of these cover types. After converting from steps to meters, we calculated an index to percent availability of cover types as "width of cover type" / "width of transect". We classified all measurements taken within 3 hours of low tide as "low tide" and within 3 hours of high tide as "high tide".

We believe transects to be the best method for collecting availability data in certain dynamic coastal sites where cover type zones are rectangular and parallel to each other and sparse vegetation is impossible to discern on aerial photos. Furthermore, the continually changing extent of intertidal areas makes the use of random points infeasible.   At our sites, we found that only MOSH (i.e., bay intertidal zone) cover types were not approximately rectangular and parallel to the other cover types.   Therefore, we modified our transect-based approach at sites with irregularly-shaped MOSH (WHD and Shinnecock).

We calculated the area of a rectangle representing the non-MOSH cover types by multiplying the average total transect width in a particular month (excluding the portion of the transect in MOSH) times the length of the site. We added the area of this rectangle to the area of MOSH as measured on aerial photos, and calculated % availability of MOSH. We then calculated the mean % availability of each non-MOSH cover type as "mean % width of cover type" x "% of the total habitat represented by the rectangle". Since our photos were taken at low tide, we had to modify this approach still further to calculate % availability for measurements taken within 3 hours of high tide. Using the MOSH transects collected at different tidal stages, we found that within 3 hours of high tide, an average of 70% of the MOSH area was still exposed. Thus, for high tide data, we adjusted the area of MOSH downward by 30%, and recalculated availability of all cover types. Finally, we estimated the area of ocean intertidal zone at each site by creating a rectangle based on the average transect width in that zone, for high and low tide separately.

We determined whether plover used cover types in proportion to their availability by compositional analysis (Aebischer *et al.* 1993).

Results

In the pre-laying period at WHD, foraging adult plovers preferred bay intertidal zone, followed by ocean fresh wrack, within 3 h of both high and low tide (years pooled, Table 1). We did not assess preference at WHB because of low sample size of foraging birds (n = 2 birds for both tidal stages).

Literature Cited

AEBISCHER, N.J., P.A. ROBERTSON, AND R.E. KENWARD. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313-1325.

Table 1. Mean % use and % availability and compositional analysis results for cover type selection by foraging adult piping plovers, WHD and WHB, March-May, 2002 and 2003. For availability, $n = 3$ months (subsamples = 8 transects per month at WHD, 6 at WHB).

		2002				2003				
		$\bar{x}\,\%$		$\bar{x}\,\%$		$\bar{x}\,\%$		$\bar{x}\,\%$		
Tide	Cover type	use	se	avail	se	use	se	avail	se	
High[a]	ocean intertidal zone	5.6	2.5	7.8	0.9	10.0	6.1	12.4	2.0	CD[b]
	ocean fresh wrack	2.1	1.7	0.4	0.1	0.0	0.0	0.1	0.0	B
	ocean backshore	10.8	6.5	27.5	5.6	8.8	8.7	9.9	1.0	DE
	ocean old wrack	3.1	2.2	0.7	0.2	0.0	0.0	0.2	0.0	BC
	ocean sparse vegetation	0.0	0.0	4.4	1.3	18.7	12.0	11.0	1.2	D
	dune sparse vegetation	0.0	0.0	13.5	0.4	0.0	0.0	11.0	3.0	E
	bay sparse vegetation	0.0	0.0	13.3	5.6	0.0	0.0	22.1	4.7	E
	bay old wrack	1.1	1.1	0.4	0.2	0.0	0.0	0.3	0.1	C
	bay backshore	0.2	0.2	5.5	0.8	0.0	0.0	1.2	0.1	D
	bay fresh wrack	0.0	0.0	0.4	0.2	0.0	0.0	0.2	0.1	C
	bay intertidal zone	77.1	7.2	26.1	0.1	62.5	12.0	31.7	0.5	A
Low	ocean intertidal zone	0.0[c]	0.0	7.5	0.5	9.9	5.0	15.3	2.3	EF[b]
	ocean fresh wrack	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.1	B
	ocean backshore	7.1	3.4	22.1	1.7	2.5	2.5	9.2	2.4	DEF
	ocean old wrack	0.0	0.0	0.6	0.1	0.0	0.0	0.2	0.1	BC
	ocean sparse vegetation	2.4	2.4	4.1	1.5	0.0	0.0	9.2	1.4	EF
	dune sparse vegetation	1.5	1.5	13.8	1.4	0.0	0.0	10.1	2.0	EF
	bay sparse vegetation	0.0	0.0	13.1	5.9	0.0	0.0	14.1	2.6	F
	bay old wrack	0.0	0.0	1.2	0.6	0.3	0.3	0.4	0.3	CD

bay backshore	0.0	0.0	6.7	2.1	0.2	0.2	1.5	0.7 E
bay fresh wrack	0.0	0.0	0.7	0.5	2.2	2.1	0.1	0.1 B
bay intertidal zone	89.0	4.2	30.1	1.2	84.9	5.4	39.8	0.6 A

[a] n = 16 birds in 2002, 3 in 2003

[b]Cover types with the same capital letter are equally likely to be selected by piping plovers (compositional analysis, years pooled)

[c] n = 12 birds in 2002, 8 in 2003

APPENDIX D. ARTHROPOD ABUNDANCE SUMMARY STATISTICS AND RELATIONSHIP TO FORAGING RATE

METHODS

Once per month from March to July, we collected arthropod samples on the transects. We used a 3-h sampling period for each transect. Sampling of all transects began between 0645-1000. The 3-h sampling period was based on previous work on Long Island (Elias-Gerken *et al.* 2000) and was long enough to allow us to capture a sufficient number of arthropods for analysis, even in cover types with few arthropods. We coated paint stirrers, except for the handles, with Tanglefoot Insect Trap Coating (Tanglefoot, Grand Rapids, MI) on each transect. We placed one pair of paint stirrers in the middle of each zone, except in the intertidal zones, where we placed them 1-2 m from the tideline to avoid splashing and submergence. We placed one stirrer vertically in the sand with the uncoated handle buried and the flat surface facing the water's edge. The other stirrer was horizontal on the ground 10 cm south of the vertical stick, with its long axis parallel to the water's edge. The area exposed was 64.5 cm^2 (21.5 cm x 3 cm) for the horizontal stick (coated on the upper side) and 129 cm^2 for the vertical stick (coated on both sides, cf. Loegering et al. 1995). At the end of 3 h, organisms were counted by taxonomic order. Since we cannot be certain of the area sampled by our sticky sticks, we considered these counts to be indices of abundance (i.e., total arthropods counted = "Arthropod Index").

We tested the effect of cover type on Arthropod Index using repeated measures ANOVA, where the fixed-location transects were the subjects, and with pairwise least-squares means comparisons. We performed a simple linear regression between Arthropod Index and foraging rate, for each plover that was observed foraging in at least 3 cover types. We then performed a one-sample t-test on the resulting regression coefficients to see if they differed from 0 (Olsson *et al.* 2002).

RESULTS

Arthropod abundance.—At each site, mean Arthropod Index differed among years in some cover types but not others (Table 2). With years pooled, Arthropod Index in the ocean intertidal zone was higher at WHB than the other sites (Table 4). In March 2001, amphipods (*Orchestia* spp.) were caught in the ocean intertidal zone at WHB while no arthropods were caught at WHD or Shinnecock (Democrat was not sampled in March).

March-May Arthropod Index at WHD was higher in bay sparse vegetation than all other cover types except ocean and dune sparse vegetation and bay fresh wrack, with which it was tied (Repeated measures ANOVA, $F_{10,24}$ = 3.4, P = 0.007). At WHB, Arthropod Index was higher in ocean fresh wrack than every cover type except ocean intertidal zone, with which it was tied ($F_{5,30}$ = 4.8, P = 0.002). At Shinnecock, Arthropod Index was higher in ocean fresh wrack than in all ocean side cover types except dune sparse vegetation with which it was tied, and was tied with Arthropod Index in all bay side cover types ($F_{10,34}$ = 2.3, P =

0.031). At Democrat we detected no difference among cover types in March-

May Arthropod Index ($F_{7,22}$ = 1.4, P = 0.24).

There was no relationship between foraging rate and Arthropod Index in

particular cover types (t-test of H_o: $\bar{\beta}_1$ = 0, where $\bar{\beta}_1$ is the mean slope of the

regressions of foraging rate on Arthropod Index performed for each adult plover =

1.1±0.6, t_{43} = 1.8, P = 0.08, $n = 44$). However, foraging rate while foraging was

higher in cover types with a higher Arthropod Index ($\bar{\beta}_1 = 2.1±0.9$, t_{18} = 2.4, P =

0.028, $n = 19$).

Table 2. Mean "total arthropod" catch, WHD, WHB, Shinnecock, and Democrat, March-May, 2001-2003. n_t = number of transects, n_m = number of months. Statistical results are for repeated measured ANOVA.

Cover Type	Site	n_t	n_m	2001 $\bar{x}^a$	se	2002 $\bar{x}^a$	se	2003 $\bar{x}^a$	se	F (Year)	P (Year)	2001-2003 $\bar{x}^b$	se
ocean itz	WHD	6	3	0.10B	0.2	1.0A	0.2	1.0A	0.2	$F_{2,7}$ = 6.5	0.025	0.8X[c]	1.0
	WHB	6	3	8.9A	1.1	1.8AB	1.0	1.9B	1.5	$F_{2,15}$ = 13.6	< 0.001	5.1W	0.7
	Shinnecock	5	3	3.0A	0.7	2.1A	0.7	1.3A	0.8	$F_{2,12}$ = 1.5	0.27	2.1X	0.7
	Democrat	3	2	2.6A	1.0	3.3A	1.0	0.5A	1.3	$F_{2,9}$ = 1.5	0.27	2.2BX	0.9
ocean fresh wrack	WHD	6	3	0.6A	0.7	1.1A	0.7	3.1A	0.8	$F_{2,7}$ = 2.9	0.12	1.5W[d]	1.7
	WHB	6	3	12.3A	1.8	3.6AB	1.9	2.0B	3.0	$F_{2,15}$ = 7.3	0.006	6.8W	1.2
	Shinnecock	5	3	5.4A	1.6	7.2A	1.7	2.2B	1.9	$F_{2,12}$ = 2.0	0.18	4.7W	1.2
	Democrat	3	2	5.4A	2.2	2.0A	4.0	2.9A	2.9	$F_{2,7}$ = 0.3	0.73	4.5W	1.8
ocean backshore	WHD	6	3	0.0A	0.3	0.5A	0.3	1.3A	0.4	$F_{2,6}$ = 4.4	0.07	0.5W[e]	0.5
	WHB	6	3	1.4A	0.3	1.3A	0.3	1.8A	0.6	$F_{2,15}$ = 0.5	0.61	1.5W	0.3
	Shinnecock	5	3	1.4A	0.4	1.2A	0.4	1.2A	0.4	$F_{2,12}$ = 0.1	0.90	1.3W	0.3
	Democrat	3	2	0.4B	1.7	6.1A	0.4	0.7B	1.8	$F_{2,9}$ = 9.4	0.006	1.8W	0.5
ocean old wrack	WHD	6	3	-	-	0.6A	0.2	1.3A	0.3	$F_{2,5}$ = 2.5	0.18	0.6W[f]	1.1
	WHB	6	3	4.9A	1.3	0.7B	0.6	1.2AB	1.5	$F_{2,14}$ = 4.5	0.031	2.4W	0.6
	Shinnecock	5	3	6.6A	1.4	3.5AB	0.8	1.2B	0.6	$F_{2,10}$ = 6.5	0.015	2.6W	0.7

ocean sparse veg	WHD	6	3	0.3B	1.0	1.7B	0.9	6.1A	0.9	$F_{2,6}$ = 10.9	0.010	2.1W[g]	0.9
	WHB	6	3	1.3B	0.8	4.6A	0.8	3.6AB	1.3	$F_{2,15}$ = 4.9	0.023	2.9W	0.5
	Shinnecock	5	3	1.3A	1.3	3.6A	0.9	0.8A	0.9	$F_{2,11}$ = 2.6	0.12	2.1W	0.6
dune sparse veg	WHD	6	3	0.7B	0.7	3.5A	0.6	3.5A	0.7	$F_{2,6}$ = 5.4	0.044	2.6W[h]	0.9
	WHB	6	3	0.7B	1.0	5.3A	1.0	3.0AB	1.8	$F_{2,15}$ = 5.7	0.014	3.1W	0.6
	Shinnecock	5	3	2.1A	0.9	4.4A	0.8	3.0A	0.8	$F_{2,12}$ = 2.1	0.16	3.2W	0.6
bay sparse veg	WHD	5	3	1.2A	2.2	3.8A	1.6	2.4A	1.7	$F_{2,5}$ = 0.5	0.63	4.2W[i]	1.6
	Shinnecock	2	3	0.8A	2.6	7.1A	2.4	1.0A	3.2	$F_{2,2}$ = 2.0	0.34	3.5W	1.6
	Democrat	3	2	1.0A	1.5	5.0A	1.1	0.2A	1.6	$F_{2,7}$ = 3.8	0.07	2.7W	1.4
bay old wrack	WHD	5	3	1.0A	0.8	1.7A	0.8	2.3A	0.8	$F_{2,6}$ = 0.6	0.58	1.4W[j]	1.0
	Shinnecock	2	3	3.8A	2.2	1.8A	2.6	2.0A	2.4	$F_{2,5}$ = 0.2	0.84	2.4W	1.1
	Democrat	3	2	0.8A	4.1	7.4A	3.1	1.6A	4.0	$F_{2,5}$ = 1.2	0.37	4.1W	1.1
bay berm	WHD	5	3	0.8A	1.5	3.3A	1.3	3.2A	1.4	$F_{2,5}$ = 0.9	0.45	2.2W[k]	0.9
	Shinnecock	2	3	3.3A	1.4	5.5A	1.7	0.9A	1.5	$F_{2,5}$ = 2.1	0.22	3.3W	1.0
	Democrat	3	2	3.2A	1.2	5.5A	1.0	0.7A	1.9	$F_{2,7}$ = 2.7	0.14	3.6W	0.8
bay fresh wrack	WHD	5	3	2.3A	1.9	5.7A	2.1	3.8A	2.5	$F_{2,6}$ = 0.7	0.53	3.5W[l]	1.2
	Shinnecock	2	3	6.0A	2.4	4.9A	2.2	2.6A	2.1	$F_{2,6}$ = 0.8	0.50	4.7W	1.2

	Democrat	3	2	3.1A	1.8	8.2A	2.2	4.6A	3.0	$F_{2,6}$ = 1.6	0.27	5.3W	1.1
MOSH (bay itz)	WHD	5	3	0.2A	0.5	1.6A	0.5	2.7A	0.6	$F_{2,5}$ = 5.2	0.06	1.2W[m]	0.7
	Shinnecock	2	3	1.3A	1.0	2.3A	1.0	0.9A	1.0	$F_{2,6}$ = 0.3	0.74	1.7W	0.6
MOSH (interior itz)	Democrat	3	2	4.1A	0.9	5.7A	1.2	1.0A	1.6	$F_{2,8}$ = 2.9	0.11	3.6W	0.6

[a]Within study sites, means with the same capital letter are not significantly different (read across rows only).

[b]Within cover types, means with the same capital letter are not significantly different (read down columns).

[c]$F_{3,15}$ = 6.2, P = 0.001

[d]$F_{3,15}$ = 2.2, P = 0.13

[e]$F_{3,14}$ = 1.6, P = 0.24

[f]$F_{2,11}$ = 1.2, P = 0.33

[g]$F_{2,11}$ = 0.5, P = 0.63

[h]$F_{2,11}$ = 0.2, P = 0.84

[i]$F_{2,7}$ = 0.3, P = 0.78

[j]$F_{2,6}$ = 1.6, P = 0.27

[k]$F_{2,7}$ = 0.8, P = 0.48

[l]$F_{2,6}$ = 0.6, P = 0.57

[m]$F_{2,7}$ = 4.5, P = 0.054

APPENDIX E. SEDIMENT CORE SAMPLE SUMMARY STATISTICS

METHODS

In June 2002, we collected a sediment core (10 cm diameter x 2 cm deep) from each of 6 randomly selected plots of MOSH at WHD, Democrat, and Shinnecock, placed them plastic resealable bags, and air dried them for physico-chemical analysis. Physico-chemical analyses were conducted by A&L Eastern Agricultural Laboratories, Inc., Richmond, VA. Measured variables comprised % organic matter, estimated nitrogen release, Bray 1 phosphorous (P_1, which determines the level of P in the soil that is readily available to plants), Bray 2 phosphorous (P_2, which determines the amount of readily available P in the soil plus part of the active reserve levels), potassium (K), magnesium (Mg), and calcium (Ca) concentration, and % sand, silt and clay.

In 2003, we collected 2 randomly-selected sediment cores from each of 9 sections of MOSH at WHD, in March as the plovers were arriving and again in June as plover eggs were hatching. Six core samples were also collected at Democrat and Shinnecock in April and June. All samples were stored in 1 L Nalgene jars (Nalge Nunc Intenational, Rochester, NY) filled with 100% ethanol. We sorted benthic organisms out of the sediment samples, and counted organisms by the categories of large worm (≥ 2 cm length), small worm, worm tube, worm fragment, insect larva, crustacean, and, tiny organism (≤ 1 mm length), and "other".   We then dried each organism sample at 60 °C for 48 h and weighed it.

Results

Sediment grain size and chemistry.—In 2002, there were no differences among the sites in grain size or percent organic matter (Table 3). Sediment at all sites primarily was sand with low organic content. Sediment from Democrat had higher P and K concentrations than WHD and Shinnecock (Table 4).

Benthic invertebrate abundance and biomass.—In 2003, small polychaetes (<2 cm) were more abundant at Shinnecock and Democrat than at WHD in the Spring, but not in the Summer (Table 5).   Large polychaetes were only found at WHD (Table 5). Fewer polychaete tubes were found at WHD in the Spring than the other sites, but an even larger difference among means was not significant in the Summer (Table 5).   There were more insect larvae in cores from Democrat than Shinnecock in the Spring, and more at Democrat than both other sites in the Summer (Table 5).   Shinnecock had the lowest abundance of

crustaceans in the Spring, and had fewer crustaceans (primarily amphipods and isopods) than WHD in the Summer (Table 5). Democrat had more tiny organisms than both other sites in the Spring (Table 5). WHD had a lower biomass of polychaete tubes than the other 2 sites in Spring, and this was the only difference detected among the sites in any organism category (Table 6).

At WHD, there were no differences among years in Spring abundance of small worms or large worms (bare control plots only, Table 7). Spring abundance of insect larvae was highest in 2001, Spring abundance of crustaceans was highest in 2003, and Spring abundance of tiny organisms was highest in 2001 (Table 7). There was no difference among years in Summer abundance of large worms or insect larvae (Table 7). Summer abundance of small worms was highest in 2003, as was Summer abundance of crustaceans, and tiny organisms (Table 7).

There was no difference among years in Spring biomass of small worms, large worms, insect larvae, or crustaceans (Table 8). Spring biomass of tiny organisms was highest in 2001 (Table 8). There was no difference among years in Summer biomass of small worms, insect larvae, or tiny organisms (Table 8). Summer biomass of large worms was higher in 2003 than in 2002 (Table 8). Summer biomass of crustaceans was highest in 2003 (Table 8).

Table 3. Physical characteristics of sediment samples from MOSH, WHD, Shinnecock, Democrat, NY, June 2002. $n = 6$ 79-cm^2 x 2-cm cores per site.

	$\bar{x}$ % organic matter	se	$\bar{x}$ % sand	se	$\bar{x}$ % silt	se	$\bar{x}$ % clay	se
WHD	0.37[a]	0.08	92.60[b]	0.86	1.20[c]	0.25	6.47[d]	0.80
Shinnecock	0.33	0.05	91.60	1.03	2.07	0.52	6.47	0.80
Democrat	0.45	0.02	91.93	0.33	1.53	0.48	6.80	0.73

[a]ANOVA on ranks, study site effect: $F_{2,15}$ = 1.2, P = 0.32

[b]$F_{2,15}$ = 0.4, P = 0.67

[c]$F_{2,15}$ = 1.0, P = 0.39

[d]$F_{2,15}$ = 0.1, P = 0.93

Table 4. Chemical characteristics of sediment from MOSH, WHD, Shinnecock, Democrat, June 2002. $n = 6$ 79-cm^2 x 2-cm cores per site.

	$\bar{x}$ N[a] (kg/ha)	se	$\bar{x}$ P$_1$[b] (ppm)	se	$\bar{x}$ P$_2$[c] (ppm)	se	$\bar{x}$ K (ppm)	se	$\bar{x}$ Mg (ppm)	se	$\bar{x}$ Ca (ppm)	se	$\bar{x}$ pH	se
WHD	57.0A[d,e]	1.7	21.0B[f]	2.4	28.0B[g]	3.2	157.0B[h]	10.0	337.3A[i]	34.5	261.7A[j]	40.2	7.0A[k]	0.2
Shinnecock	55.9A	1.5	24.8B	3.5	31.8B	3.8	173.7B	11.0	372.3A	45.5	248.3A	21.2	7.1A	0.1
Democrat	56.8A	0.5	55.2A	2.9	63.8A	3.0	242.8A	17.0	423.2A	34.3	343.3A	21.9	7.2A	0.0

[a]Estimated nitrogen release

[b]Bray 1 phosphorous (measures level of P in soil that is readily available to plants)

[c]Bray 2 phosphorous (measures readily available P plus part of active reserves)

[d]ANOVA on ranks, study site effect: $F_{2,15} = 0.2$, $P = 0.81$

[e]Means with the same capital letter are not significantly different

[f]$F_{2,15} = 16.4$, $P < 0.001$

[g]$F_{2,15} = 40.0$, $P < 0.001$

[h]$F_{2,15} = 12.2$, $P = 0.001$

[i]$F_{2,15} = 1.3$, $P = 0.31$

[j]$F_{2,15} = 3.1$, $P = 0.07$

[kj]$F_{2,15} = 1.3$, $P = 0.30$

Table 5. Mean benthic invertebrate abundance/79 cm2 x 2 cm in MOSH, WHD, Shinnecock, Democrat, NY, 2003. Spring = March or April (pre-laying period), Summer = June or July (brood-rearing period).

Period	Site	n[a]	small worms[b] $\bar{x}$	se	large worms $\bar{x}$	se	tubes $\bar{x}$	se	insect larvae $\bar{x}$	se	crustaceans $\bar{x}$	se	tiny organisms $\bar{x}$	se
Spring	WHD	9	8.7B[c,d]	2.0	0.2[e]	0.1	0.0B[f]	0.0	0.7AB[g]	0.3	126.1A[h]	87.3	981.7B[i]	166.9
	Shinnecock	6	66.8A	20.4	0.0	0.0	4.2A	2.1	0.2B	0.2	2.5B	1.1	2498.5B	912.8
	Democrat	6	98.0A	64.9	0.0	0.0	3.7AB	2.4	1.3A	0.4	69.7A	45.6	4944.8A	1306.2
Summer	WHD	9	91.3A[j]	13.1	0.3[e]	0.2	9.7A[k]	3.7	0.7B[l]	0.3	36.4A[m]	8.30	1432.9A[n]	194.0
	Shinnecock	6	72.7A	46.5	0.0	0.0	4.2A	2.0	0.8B	0.7	10.3B	2.39	2688.5A	454.4
	Democrat	6	265.2A	101.4	0.0	0.0	88.7A	61.1	18.0A	9.9	29.0AB	13.2	6142.0A	3241.4

[a]At WHD, sample size is the number of core locations, from which 2 cores were collected (n = 18) and the results averaged. At all other sites, n = number of cores.

[b]Small worms were < 2 cm, large worms were ≥ 2 cm, Tubes were unoccupied polychaete tubes, Tiny organisms were any organisms < 1 mm, counts do not include fragments from organisms of unknown length

[c]ANOVA on ranks, study site effect: $F_{2,18}$ = 6.2, P = 0.009

[d]Means with the same capital letter are not significantly different. Compare within period only.

[e]$F_{2,18}$ = 2.6, P = 0.11

[f]$F_{2,18}$ = 4.6, P = 0.024

[g]$F_{2,18}$ = 4.1, P = 0.034

[h]$F_{2,18}$ = 8.8, P = 0.002

[i]$F_{2,18} = 9.8$, $P = 0.001$

[j]$F_{2,18} = 2.1$, $P = 0.14$

[k]$F_{2,18} = 0.5$, $P = 0.61$

[l]$F_{2,18} = 14.2$, $P < 0.001$

[m]$F_{2,18} = 5.7$, $P = 0.012$

[n]$F_{2,18} = 2.0$, $P = 0.17$

Table 6. Mean benthic invertebrate dry mass (mg/79 cm2 x 2 cm) in MOSH, WHD, Shinnecock, Democrat, NY, 2003. Spring = March or April (pre-laying period), Summer = June or July (brood-rearing period).

Period	Site	n[a]	small worms[b] $\bar{x}$	se	large worms $\bar{x}$	se	tubes $\bar{x}$	se	insect larvae $\bar{x}$	se	crustaceans $\bar{x}$	se	tiny organisms $\bar{x}$	se
Spring	WHD	9	5.3A[c,d]	3.1	3.6A[e]	2.6	0.0B[f]	0.0	0.4A[g]	0.2	0.5A[h]	0.2	1.2A[i]	1.1
	Shinnecock	6	4.5A	1.5	0.0A	0.0	2.6A	2.3	0.0A	0.0	0.1A	0.1	0.7A	0.5
	Democrat	6	3.3A	2.0	0.0A	0.0	3.8A	2.5	0.0A	0.0	0.1A	0.1	2.5A	1.5
Summer	WHD	9	13.7A[j]	8.3	26.1B[k]	12.8	9.1[l]	4.0	0.5A[m]	0.3	1.2A[n]	0.2	0.2A[o]	0.0
	Shinnecock	6	40.5A	24.4	0.0A	0.0	0.3	0.2	0.6A	0.5	1.2A	0.8	0.7A	0.2
	Democrat	6	10.7A	3.7	0.0A	0.0	57.6	48.8	4.0A	2.1	0.8A	0.5	9.1A	6.0

[a]At WHD, sample size is number of core locations, from which 2 cores were collected (n = 18) and the results averaged. At all other sites, n = number of cores.

[b]Small worms were < 2 cm, large worms were > 2 cm, tubes were unoccupied polychaete tubes, tiny organisms were any organisms < 1 mm, masses do not include fragments from organisms of unknown length

[c]ANOVA on ranks, study site effect: $F_{2,18}$ = 0.3, P = 0.77

[d]Means with the same capital letter are not significantly different. Compare within period only.

[e]$F_{2,18}$ = 2.5, P = 0.11

[f]$F_{2,18}$ = 5.5, P = 0.014

[g]$F_{2,18}$ = 1.3, P = 0.29

[h]$F_{2,18}$ = 2.5, P = 0.11

$^{i}F_{2,18} = 1.2, P = 0.32$

$^{j}F_{2,18} = 0.4, P = 0.67$

$^{k}F_{2,18} = 6.2, P = 0.009$

$^{l}F_{2,18} = 1.4, P = 0.28$

$^{m}F_{2,18} = 3.1, P = 0.07$

$^{n}F_{2,18} = 0.9, P = 0.41$

$^{o}F_{2,18} = 1.1, P = 0.34$

Table 7. Mean benthic invertebrate abundance (no. per 79 cm2 x 2 cm), WHD, NY, 2001-2003. n = 6 plots per year.

Year	Period	small (< 2cm) worms		large worms		insect larvae		crustaceans		tiny (< 1 mm) organisms	
		$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
2001	Spring	7.3A[a,b]	1.6	0.3A[c]	0.2	2.2A[d]	0.5	0.2B[e]	0.2	2.3C[f]	1.7
2002	Spring	49.2A	21.3	0.3A	0.3	4.8B	4.8	7.0B	5.2	280.0B	200.1
2003	Spring	10.7A	2.2	0.3A	0.2	0.4B	0.1	37.4A	11.1	907.2A	159.1
2001-03		22.4	13.4	0.3	0.0	2.5	1.3	14.9	11.4	396.5	267.6
2001	Summer	14.3B[g]	3.4	1.2A[h]	0.7	1.2A[i]	0.8	0.5B[j]	0.5	22.8B[k]	15.7
2002	Summer	25.5B	13.6	0.2A	0.2	4.3A	3.6	2.3B	1.6	88.0B	40.3
2003	Summer	100.7A	18.3	0.4A	0.2	1.0A	0.3	39.1A	12.3	1417.8A	288.7
2001-03		46.9	27.1	0.6	0.3	2.2	1.1	14.0	12.6	509.6	454.5

[a]ANOVA on ranks, $F_{2,15}$ = 1.5, P = 0.25

[b]Within periods, means with the same capital letter are not significantly different

[c]$F_{2,15}$ = 0.3, P = 0.76

[d]$F_{2,15}$ = 6.9, P = 0.007

[e]$F_{2,15}$ = 15.3, P < 0.001

[f]$F_{2,15}$ = 21.2, P < 0.001

[g]$F_{2,15}$ = 11.2, P = 0.001

[h]$F_{2,15}$ = 0.5, P = 0.59

[i]$F_{2,15}$ = 0.1, P = 0.87

[j]$F_{2,15} = 23.4,\ P < 0.001$
[k]$F_{2,15} = 17.0,\ P < 0.001$

Table 8. Mean benthic invertebrate dry mass (mg per 79 cm2 x 2 cm), WHD, NY, 2001-2003. *n* = 6 plots per year (5 plots Summer 2002).

Year	Period	small (< 2cm) worms		large worms		insect larvae		crustaceans		tiny (< 1 mm) organisms	
		$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
2001	Spring	1.7A[a,b]	0.9	3.2A[c]	2.1	1.8A[d]	0.6	0.2A[e]	0.2	0.0B[f]	0.0
2002	Spring	21.9A	11.6	4.3A	2.8	1.2A	1.2	2.4A	1.9	0.4A	0.2
2003	Spring	7.9A	4.3	5.4A	3.7	0.4A	0.3	0.2A	0.1	1.8A	1.7
2001-03		10.5	6.0	4.3	0.6	1.1	0.4	0.9	0.7	0.7	0.5
2001	Summer	14.2A[g]	6.6	5.2AB[h]	3.7	0.7A[i]	0.7	0.3B[j]	0.3	1.5A[k]	1.5
2002	Summer	2.0A	0.9	1.7B	1.7	0.2A	0.1	0.0B	0.0	0.2A	0.2
2003	Summer	18.4A	12.2	39.1A	17.0	0.7A	0.5	1.4A	0.2	0.2A	0.1
2001-03		11.5	4.9	15.3	11.9	0.5	0.2	0.6	0.4	0.6	0.4

[a]ANOVA on ranks, $F_{2,15}$ = 2.7, P = 0.09

[b]Within periods, means with the same capital letter are not significantly different

[c]ANOVA on ranks, $F_{2,15}$ = 0.1, P = 0.92

[d]ANOVA on ranks, $F_{2,15}$ = 2.4, P = 0.13

[e]ANOVA on ranks, $F_{2,15}$ = 0.8, P = 0.49

[f]ANOVA on ranks, $F_{2,15}$ = 5.7, P = 0.01

[g]ANOVA on ranks, $F_{2,14}$ = 2.0, P = 0.17

[h]ANOVA on ranks, $F_{2,14}$ = 4.2, P = 0.04

[i]ANOVA on ranks, $F_{2,14}$ = 0.4, P = 0.48

[j]ANOVA on ranks, $F_{2,14}$ = 8.5, P = 0.004

[k]ANOVA on ranks, $F_{2,15}$ = 1.4, P = 0.28

APPENDIX F. FORAGING RATE AND ACTIVITY BUDGET SUMMARY

STATISTICS

Methods

We used Multiresponse Randomized Block Procedure (MRBP) in Blossom (Cade and Richards 1999), where each bird was treated as a block, to determine whether time spent in different behaviors differed between tidal stages and among cover types. We used Multiresponse Permutation Procedure (MRPP) to determine if time spent in different behaviors differed among years, within tidal stage. We also used MRBP and MRPP in a similar manner to determine whether foraging rate differed among tidal stage, year, and cover type. If we detected a difference among treatment levels using MRBP, we compared specific treatment levels by their multivariate median (Cade and Richards 1999). The multivariate median is a measure of center that accounts for dependence between variables in a multivariate system. In this case, the dependence arises from using birds as the sampling units.

Results

Adult foraging rates and activity budgets.—There was no difference between peck rates at high and low tide, either based on entire observations (Multiresponse Randomized Block Procedure, MRBP tidal stage x bird, P = 0.88, n = 58), or while birds were foraging (P = 0.45, n = 23). Adult foraging rates (attempts/min observed) were highest in the bay intertidal zone, marsh, bay fresh wrack, and ocean fresh wrack (Table 9).   Marsh (vegetated bay intertidal zone) was rarely used, but 3 plovers were observed foraging there in 2003. Adult

foraging rates while foraging were highest in the above cover types plus ocean intertidal zone and ocean sparse vegetation (Table 9). There was no difference in worms pulled/min between the ocean intertidal zone (0.1 ± 0.1 pulls/min) and bay intertidal zone (0.4 ± 0.1 pulls/min, ANOVA, $F_{1,16}$ = 3.9, P = 0.06, n = 63), or between worms pulled/min foraging in the bay intertidal zone (0.4 ± 0.1 pulls/min) and ocean intertidal zone (0.1 ± 0.1 pulls/min, $F_{1,14}$ = 4.4, P = 0.054, n = 63).

Time spent in different behaviors prior to egg-laying did not differ between tidal stages (MRBP tidal stage x bird, P = 0.10) or between years within tidal stages (low tide: MRPP, P = 0.44; high tide: MRPP, P = 0.22). With tidal stage and years pooled, plovers spent 34.0 ± 2.4% of their time foraging, 56.4 ± 2.4% of their time resting, 1.9 ± 0.5% of their time in agonistic interactions, 0.7 ± 0.2% of their time courting, 2.1 ± 0.6% of their time reacting to disturbance, and 4.6 ± 0.7% of their time engaging in other behaviors (n = 58). Activity budgets differed between the ocean backshore and bay intertidal zone (MRBP cover type x bird, P = 0.005, n = 14), the only pair of habitats used by a big enough sample of birds to allow for testing. Plovers were more likely to forage in the bay intertidal zone (multivariate median = 86.5% of the time) than the ocean backshore (multivariate median = 10.1%), and to rest in the ocean backshore (multivariate median = 76.5 %) than the bay intertidal zone (multivariate median = 7.8 %).

Literature Cited

CADE, B.S, AND J. RICHARDS. 1999, User Manual for Blossom Statistical Software: Fort Collins, CO, U.S. Geological Survey, 107 pp.

Table 9. Foraging rates (attempts/min) of adult piping plovers in the pre-laying period, WHD and WHB, 2002-2003.

	attempts/min			attempts/min foraging		
	n^a	$\bar{x}$	se	n^a	$\bar{x}$	se
ocean intertidal zone	31	4.6B[b,c]	0.8	26	7.5A[d]	1.4
ocean fresh wrack	15	10.9A	2.3	11	10.9A	2.1
ocean backshore	51	0.2C	0.6	17	3.8B	1.7
ocean old wrack	33	0.5C	0.8	9	4.3B	2.2
ocean sparse veg	33	0.4C	0.8	5	7.9A	3.0
bay old wrack	3	2.3BC	2.6	2	2.7B	5.2
bay berm	12	1.6C	1.3	3	3.6B	4.1
bay fresh wrack	4	10.6A	2.2	3	12.4AB	4.1
bay intertidal zone	49	9.9A	0.6	49	12.4A	0.9
marsh	3	10.9A	2.7	3	15.5A	4.1

[a]n = no. of birds observed in a cover type. There were 72 bird*year combinations in this analysis.

[b]ANOVA, effect of cover type: $F_{9,153}$ = 31.4, P < 0.0001

[c]Least squares means with the same capital letters are not significantly different.

[d]ANOVA, effect of cover type: $F_{9,57}$ = 3.69, P = 0.001

APPENDIX G. MORPHOLOGY, HOME RANGE, AND NEIGHBOR DENSITY

METHODS

When plovers were in the hand, we measured body mass (nearest 0.1 g), culmen, tarsus, and wing chord length (nearest 0.1 mm). We scored indices of plumage pattern (1 = complete neck or forehead band, 0 = incomplete band) and coloration (1 = black bands, 0 = gray or brown bands) and bill coloration (1 = "≤ 25% black", 0 = "> 25% black") were recorded.

To reduce the dimensionality of the morphological data and to attempt to create a few variables that would distinguish "large" plovers from "small" plovers, we performed a principal components analysis (PCA) on morphological measurements of adult plovers, by year and sex. Before conducting the PCA, each measurement was standardized by the mean and standard deviation for the appropriate year and sex. We included the first two principal components in all analyses involving morphological measurements.

MORPHOLOGY

Female plovers had greater body mass and smaller culmen lengths than males (Table 10). Body mass was lower in 2002 than in the other two years, and tarsus length was shorter in 2002 than in 2001 (Table 10). There were no significant sex*year interactions. Since some morphological measurements differed by sex and year while others did not, we performed the following analysis by sex and year, and with sex and year pooled. When sex and year were pooled, we used the average morphological measurements for plovers that were

paired, since both birds would have same distance from nest to MOSH and home range measures.

Principal Components Analysis.—With sexes and years separate, the first two principal components (PC) of the standardized morphological measurements explained 66 to 79% of the variation (Table 11). However, the loadings of the first two PCs varied greatly among sexes and years. For females in 2001 and 2002, the first PC contained all positive loadings, while the second PC contained all positive loadings for males (Table 11). Large values for such PC's would thus represent larger plovers. In 2003, neither of the first 2 PC's contained all positive loadings for either sex, and the same was true when years and sexes were pooled (Table 26). In those cases, correlations between PC's and ecological factors would be more difficult to interpret.

Distance to MOSH.—When sexes and years were separated, the only significant relationship between distance to nearest MOSH and a morphological measurement or principal components of morphological measurements was a weak correlation with tarsus length in females in 2003 (r = 0.48, P = 0.032, n = 20). There were no correlations with morphological measurements or their principal components and distance to large MOSH. With sexes and years pooled, there were no significant correlations with either measure of distance to MOSH and any morphological measurements or principal components (n = 96 individuals or pairs for which distance to nearest MOSH was measured, 88 individuals or pairs for which distance to large MOSH was measured).

Neighbor density.—There were no correlations between neighbor density and morphological measurements or their principal components when sex and year were considered separately. This was also true when sexes and years were pooled ($n = 95$ individuals or pairs), 2001-2003.

Home range.—Total 95% home range size, area of nesting habitat within 95% home range, and area of MOSH within 95% home range were correlated with several different morphological measurements and with PC 1, which increases with increasing body size, for female plovers in 2002 (Table 12). There were no such correlations for males in that year. Fifty % home range area, nesting habitat within 50% home range, and nesting habitat within 95% home range were negatively correlated with several morphological measures and PC 2 for males in 2003 (Table 12).   Area of MOSH within 95% home range was positively correlated with tarsus length and negatively correlated with body mass and PC1 for males in 2003 (Table 12). There were no such correlations for females in that year. There were no correlations between any measures of home range size and morphological measures when sexes and years were pooled (n =50 individuals or pairs).

Adult Plumage and Bill Pigment Indices

Males and females had similar scores for neckband pattern (Table 13), but differed in forehead band pattern (Table 13). Forehead and neckband pigment scores were highly correlated for males (Spearman's ρ = 0.76, P < 0.001) and females (Spearman's ρ = 0.91, P < 0.001), so we used neckband pigment score as the only index of plumage pigment. Plumage and bill pigment scores were

different between males and females (Table 13).   The latter result is somewhat

trivial, since we used both pigment scores to sex the birds in the hand, but most

sex designations were confirmed by subsequent observations of behavior.

   Distance to MOSH.—With years pooled, there was no difference in

distance to nearest MOSH based on neckband pattern scores for females

(Wilcoxon 2-sample test, P = 0.47, n = 65) or males (P = 0.06, n = 46). There

was also no difference based on forehead band pattern scores for females (P =

0.3034) or males (P = 0.29). The same was true for a comparison of band

pigment scores for females (P = 0.58) and males (P = 0.92), and for a

comparison based on bill pigment scores for females (P = 0.66) and males (P =

0.81).

   With years pooled, there was no difference in distance to large MOSH

based on neckband pattern scores for females (Wilcoxon 2-sample test, P =

0.61, n = 60) or males (P = 0.08, n = 42). There was no difference based on

forehead band pattern scores for males (P = 0.53), but females with complete

forehead bands nested closer to MOSH (417.6±77.7 m, n = 45) than those with

incomplete forehead bands (843.0±246.1 m, n =15, P = 0.038). There was no

difference based on band pigment score for females (P = 0.95) or males (P =

0.13). Finally, there was no difference based on bill pigment score for females (P

= 0.78) or males (P = 0.47).

   Neighbor density.—With years pooled, there was no difference in neighbor

density of nesting pairs based on neckband pattern scores for females (Wilcoxon

2-sample test, P = 0.65, n = 65) or males (P = 0.45, n = 46). The same was

true for a comparison based on forehead band pattern scores for females (P =

0.14) and males (P = 0.91). There was also no difference in neighbor density

based on band pigment index for females (P = 0.70) or males (P = 0.43), or for

comparisons based on bill pigment index for females (P = 0.30) or males (P =

0.17).

Home range.— With years pooled, there were no significant effects of

plumage or bill pattern or pigment scores on any measure of 50% home range

size (Wilcoxon 2-sample tests, n = 26 F, 19 M) at the α = 0.05 level. The same

was true for 95% home range size.

Table 10. Morphological measurements of male and female piping plovers, WHD, WHB, Cupsogue, and Shinnecock, NY, 2001-2003.

Measurement	Year	Females			Males			Sexes Pooled		
		n	$\bar{x}$	se	n	$\bar{x}$	se	n	$\bar{x}$	se
Mass (g)[a]	2001	22	58.3	0.5	14	55.7	0.7	36	57.2A[b]	2.8
	2002	23	56.1	0.5	15	54.	0.6	38	55.3B	2.6
	2003	20	56.7	0.7	17	56.	1.0	37	56.7A	3.6
	2001-03	65	57.0	0.4	46	55.6	0.5			
Culmen (mm)[b]	2001	22	12.2	0.2	14	12.5	0.2	36	12.3B	0.9
	2002	23	12.5	0.1	15	13.3	0.3	38	12.8A	1.0
	2003	20	12.5	0.2	17	12.8	0.2	37	12.6AB	0.8
	2001-03	65	12.4	0.1	46	12.9	0.1			
Tarsus (mm)[c]	2001	22	19.4	0.4	14	20.4	0.4	36	19.8A	1.7
	2002	23	18.7	0.3	15	19.3	0.4	38	18.9B	1.6
	2003	20	19.3	0.3	17	19.5	0.3	37	19.4AB	1.2
	2001-03	65	19.1	0.2	46	19.7	0.2			
Wing Chord (mm)[d]	2001	22	118.1	0.7	14	119.6	0.6	36	118.7A	3.1
	2002	23	118.1	0.6	15	116.6	0.7	38	117.5A	2.7
	2003	20	116.8	0.6	17	118.5	0.5	37	117.6A	2.9
	2001-03	65	117.7	0.4	46	118.2	0.4			

[a]ANOVA. Year: $F_{2,107} = 4.40$, $P = 0.015$. Sex: $F_{1,107} = 5.88$, $P = 0.017$

[b]Years with the same capital letter are not significantly different.

[c]ANOVA. Year: $F_{2,107} = 3.31$, $P = 0.040$. Sex: $F_{1,107} = 8.85$, $P = 0.004$

[d]ANOVA. Year: $F_{2,107} = 3.12$, $P = 0.048$. Sex: $F_{1,107} = 3.40$, $P = 0.07$

[e]ANOVA. Year: $F_{2,107} = 1.87$, $P = 0.16$. Sex: $F_{1,107} = 0.87$, $P = 0.35$

Table 11. Principal components (PC) analysis of standardized morphological measurements of piping plovers, WHD, WHB, Cupsogue, and Shinnecock, NY, 2001-2003. Table entries are PC loadings.

Year	Measurement	Females		Males	
		PC 1	PC 2	PC 1	PC 2
2001	Mass (g)	0.49	0.02	0.69	0.11
	Culmen (mm)	0.55	-0.07	0.53	0.19
	Tarsus (mm)	0.50	-0.63	0.14	0.75
	Wing Chord (mm)	0.45	0.77	-0.46	0.62
	Proportion of Variance Explained	0.59	0.20	0.37	0.35
2002	Mass (g)	0.65	-0.23	-0.34	0.43
	Culmen (mm)	0.17	0.76	0.70	0.22
	Tarsus (mm)	0.39	0.53	0.40	0.66
	Wing Chord (mm)	0.63	-0.30	-0.49	0.57
	Proportion of Variance Explained	0.41	0.28	0.35	0.31
2003	Mass (g)	0.68	0.20	0.39	-0.53
	Culmen (mm)	-0.14	0.72	0.41	0.68
	Tarsus (mm)	-0.23	-0.62	-0.50	0.45
	Wing Chord (mm)	0.68	-0.25	0.65	0.23
	Proportion of Variance Explained	0.40	0.33	0.46	0.31
2001-03[a]	Mass (g)	0.53	0.40		
	Culmen (mm)	0.36	-0.80		
	Tarsus (mm)	-0.57	0.21		
	Wing Chord (mm)	0.51	0.38		
	Proportion of Variance Explained	0.42	0.25		

[a]Sexes pooled

Table 12. Significant correlations between measures of home range and morphological measures of adult piping plovers, WHD and WHB, NY, 2002-2003.

Year	Sex	n	HR Measure	Morphology	r	P
2002	F	17	95% HR	Mass	0.57	0.016
			95% HR	Tarsus	0.48	0.051
			95% HR	PC 1[a]	0.68	0.003
			Nesting Habitat in 95% HR	Tarsus	0.53	0.028
			MOSH in 95% HR	Mass	0.73	0.001
			MOSH in 95% HR	PC 1[a]	0.66	0.004
	M	11	No significant correlations	-	-	-
2003	F	9	No significant correlations	-	-	-
	M	8	50% HR	Tarsus	-0.75	0.034
			Nesting Habitat in 50% HR	Tarsus	-0.70	0.054
			Nesting Habitat in 95% HR	Culmen	-0.73	0.041
			Nesting Habitat in 95% HR	Tarsus	-0.78	0.021
			Nesting Habitat in 95% HR	PC 2[b]	-0.74	0.037
			MOSH in 95% HR	Mass	-0.83	0.011
			MOSH in 95% HR	Tarsus	0.73	0.039
			MOSH in 95% HR	PC 1[c]	-0.73	0.041

[a]Principal Component 1, 2002. As this PC increases, all morphological measurements increase

[b]Principal Component 2, 2003. As this PC increases, body mass decreases while culmen, tarsus and wing chord lengths increase.

[c]Principal Component 1, 2003. As this PC increases, tarsus length decreases while body mass and culmen and wing chord length increase.

Table 13. Plumage indices of adult piping plovers, WHD, WHB, Cupsogue, and Shinnecock, NY, 2001-2003. These indices were used to sex the plovers. Sex determination was later confirmed by behavioral observations.

	Females		Males		
	n	%	*n*	%	P^a
Neckband complete	30	46.1	24	52.2	
Neckband broken/absent	35	53.9	22	47.8	0.57
Bands black	32	49.2	41	89.1	
Bands gray/brown	33	50.8	5	10.9	< 0.001
Headband complete	48	73.9	43	93.5	
Headband broken/absent	17	26.1	3	6.5	0.011
Bill < 25% black	10	15.4	40	87.0	
Bill > 25% black	55	84.6	6	13.0	<0.001

[a]Fisher's exact test of sex effect

APPENDIX H. ECOLOGY OF BAYSIDE INTERTIDAL SANDFLATS AT WHD

The incursion of the salt marsh into the sandflats at WHD has occurred much slower than managers predicted after the initial breach repair. To gain some understanding of the possible long-term effects of beach stabilization on bayside intertidal sandflats, we examined the rate of marsh vegetation growth into the flats.   Furthermore, we compared sediment physico-chemical characteristics among bare flats, algal mats, and marsh to determine if these factors might be limiting marsh growth.

METHODS

Bay intertidal zone cover type widths.—To determine the rate of encroachment of algal mat and saltmarsh vegetation onto the sandflats, we established 6 transects in the bay intertidal zone at WHD, beginning at the most recent high water line, passing through *Spartina alterniflora* marsh, and extending onto the sandflats, perpendicular to the long axis of the island or sand spit. We used a GPS unit to record the starting point of each transect. In April and August 2002 and March and August 2003, we paced the width of the *S. alterniflora* zone and the algal mat zone, giving precedence to *S. alterniflora* in our zone designation in those areas where grass was growing up through the algal mat.   Paces were converted to meters based on the stride length of the researcher.

*Sediment characteristics***.**—In June 2002, one sediment sample was collected in each of 3 cover types (*S. alterniflora* marsh, algal mat, bare sediment) from 6 plots in the bay intertidal zone of WHD (10 cm diameter x 2 cm

deep core sampler). Each sample was placed in a plastic resealable bag, and air dried for physico-chemical analysis. Physico-chemical analyses were conducted by A&L Eastern Agricultural Laboratories, Inc., Richmond, VA. Measured parameters included % organic matter, estimated nitrogen release (ENR, in kg/ha), Bray 1 phosphorous (P_1, which determines the level P in the soil that is readily available to plants, in ppm), Bray 2 phosphorous (P_2, the extraction of which uses stronger acids than in the extraction of P_1 and which determines the amount of readily available P in the soil plus part of the reserve levels, in ppm), potassium (K), magnesium (Mg), and calcium (Ca) concentrations in ppm, pH, and % sand, silt and clay.

RESULTS

The saltmarsh cordgrass (*Spartina alterniflora*) zone at WHD did not change in width significantly within or between growing seasons (Table 14). Among the 6 transects, variation in the change in zone width was great, with 3 of the 6 showing little intra- or interyear growth (Fig. 2). Mean width of the algal mat zone likewise did not change significantly within or between growing seasons (Table 14). Among-transect variation was great, and the algal mat zone disappeared by the summer on some transects (Fig. 3).

Sediment in the algal mat zone had a higher organic matter content than the marsh or bare zones, while marsh samples had a greater sand and lower clay content, and bare sediment had a lower silt content (Table 15). However, all samples were classified as "sand" by the analytical laboratory. Algal mat

samples had a higher K concentration than marsh or bare sediment samples, and marsh samples had a higher pH than the other cover types (Table 16).

DISCUSSION

We did not observe any significant short-term vegetation growth in the bayside intertidal zone at WHD that could be traced to beach stabilization. The growth of the marsh at WHD has been very slow, and when we measured the intrusion of *S. alterniflora* into the sandflats we found virtually no change between years. Future study is needed of common influences on marsh development, especially duration-of-inundation (Seneca *et al.* 1985), which might underlie the slow growth of the marsh at our site. Sediment physico-chemistry was largely similar between sandflat and developing marsh substrates, so it is unlikely that the spread of the marsh is being hampered by limitation of the nutrients we measured. Other factors, such as storm and wave action and degree of sediment disturbance by human activities (e.g., recreational clamming) should be examined.

LITERATURE CITED

SENECA, E.D., S.W. BROOME, AND W.W. WOODHOUSE, JR. 1985. The influence of duration-of-inundation on development of man-initiated *Spartina alterniflora* Loisel. marsh in North Carolina. J. Exp. Mar. Biol. Ecol. 94:259-268.

Table 14. Mean change in width (m) of Spartina alterniflora and algal mat zones in the bay intertidal zone, WHD, NY, 2002-2003. n = 6 transects

Time Period	$\bar{x}$	se	P^a
S. alterniflora Zone			
April 2002 to August 2002	9.2	4.3	0.08
August 2002 to March 2003	-8.3	4.5	0.12
March 2003 to August 2003	7.4	3.6	0.10
Algal Mat Zone			
April 2002 to August 2002	2.7	4.6	0.59
August 2002 to March 2003	7.9	8.2	0.38
March 2003 to August 2003	-20.9	11.3	0.12

[a]1 sample t-test, $df = 5$, H_o: mean change in width $\neq 0$.

Table 15. Sediment % organic matter and grain size in bay intertidal zone cover types, WHD, 2002. n = 6 transects, 10 cm diameter x 2 cm cores.

Cover Type	$\bar{x}$ % Organic Matter	se	$\bar{x}$ % Sand	se	$\bar{x}$ % Silt	se	$\bar{x}$ % Clay	se
Marsh	0.33B[a,b]	0.04	95.3A[c]	0.3	2.7A[d]	0.7	2.2B[e]	0.8
Algal Mat	0.63A	0.10	91.3B	0.6	3.2A	0.7	5.8A	0.4
Bare Sediment	0.37B	0.08	92.6B	0.9	1.2B	0.2	6.5A	0.8

[a]ANOVA on ranks, blocked by transect: $F_{2,10}$ = 5.8, P = 0.021

[b]Means with the same capital letter are not significantly different

[c]$F_{2,10}$ = 16.7, P = 0.001

[d]$F_{2,10}$ = 6.1, P = 0.019

[e]$F_{2,10}$ = 14.8, P = 0.001

Table 16. Sediment chemistry in bay intertidal zone cover types, WHD, 2002. n = 6 transects, 10 cm diameter x 2 cm cores.

Cover Type	ENR (kg/ha)	se	P$_1$ (ppm)	se	P$_2$ (ppm)	se	K (ppm)	se	Mg (ppm)	se	Ca (ppm)	se	pH	se
Marsh	50.0A[a,b]	0.9	15.3A[c]	2.0	22.2A[d]	3.4	142.7B[e]	22.0	326.8A[f]	56.5	303.3A[g]	77.8	7.62A[h]	0.15
Algal Mat	50.7A	1.5	22.0A	3.1	32.2A	4.3	201.3A	20.0	442.5A	48.5	278.3A	28.1	6.15B	0.52
Bare Sediment	50.8A	1.5	21.0A	2.4	28.0A	3.2	157.0B	10.0	337.3A	34.5	261.7A	40.2	7.03B	0.21

[a]ANOVA on ranks, blocked by transect: $F_{2,10}$ = 0.0, P = 0.98

[b]Means with the same capital letter are not significantly different.

[c]$F_{2,10}$ = 2.0, P = 0.16

[d]$F_{2,10}$ = 2.9, P = 0.10

[e]$F_{2,10}$ = 7.4, P = 0.011

[f]$F_{2,10}$ = 0.9, P = 0.43

[g]$F_{2,10}$ = 0.02, P = 0.98

[h]$F_{2,10}$ = 10.4, P = 0.004
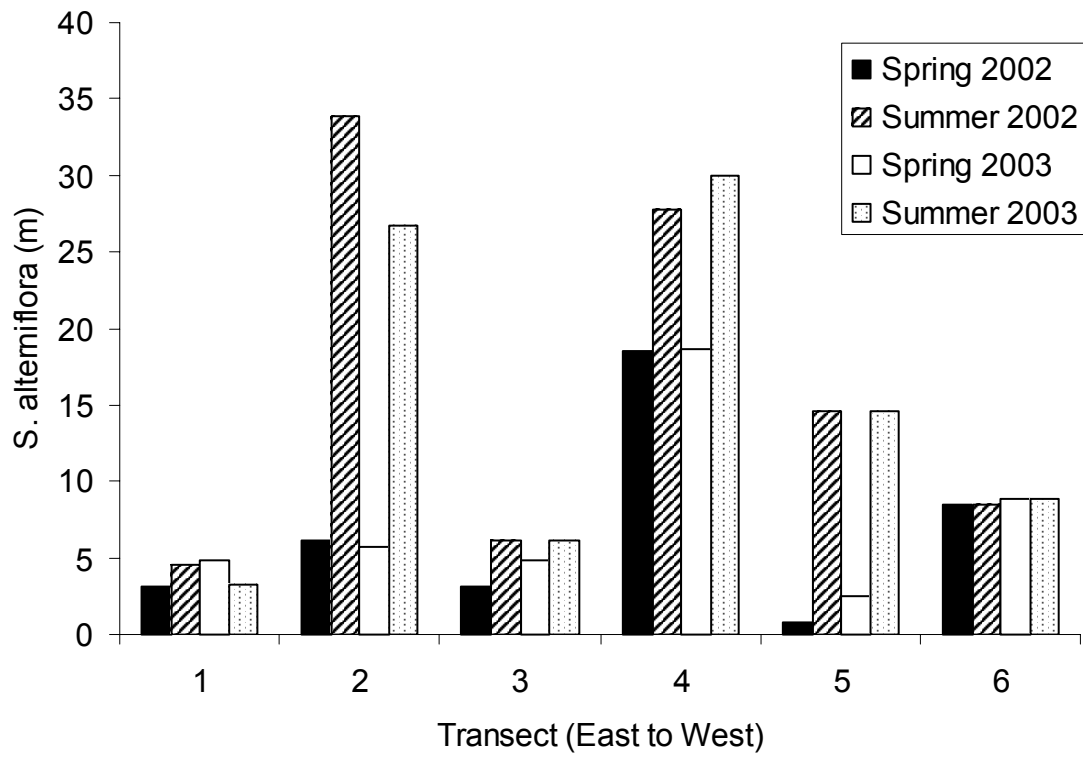
Fig. 3. Marsh cordgrass (Spartina alterniflora) zone width on 6 transects, WHD bay intertidal zone, 2002-2003.
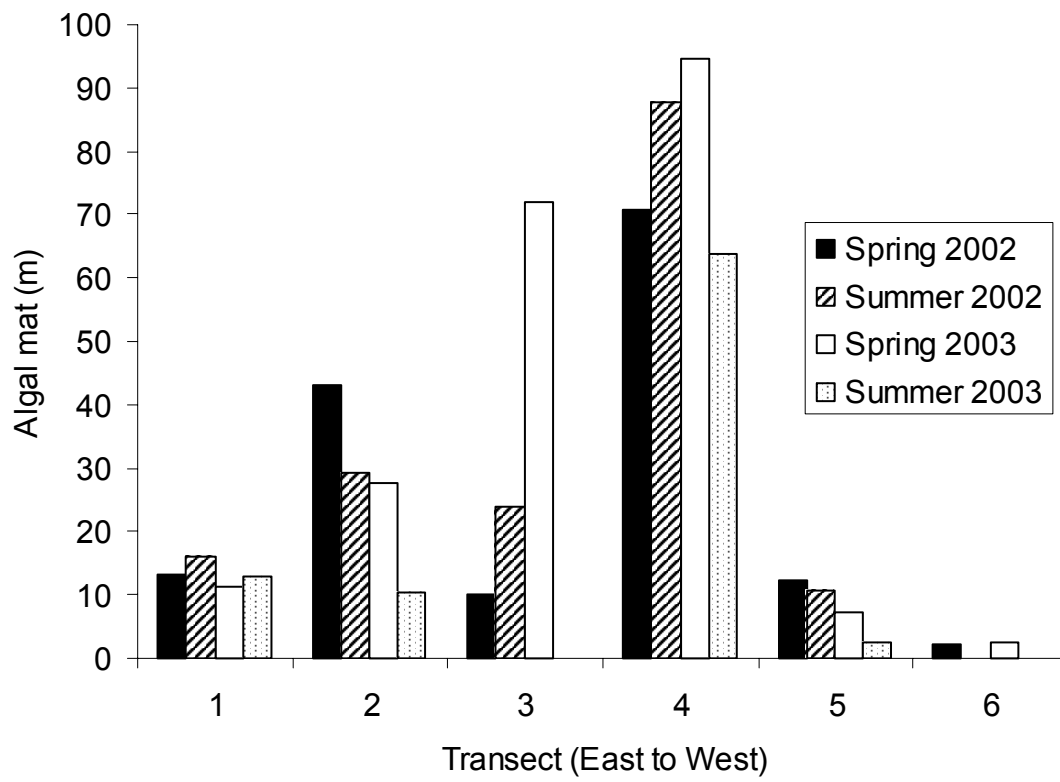
Fig. 4. Algal mat zone width on 6 transects, WHD bay intertidal zone, 2002-2003.

APPENDIX I. ARTIFICIAL EPHEMERAL POOLS AT CUPSOGUE COUNTY

PARK

In light of recent interest in habitat restoration to mitigate negative impacts of storm-damage protection on wildlife (USACE 2001), we studied the efficacy of artificial ephemeral pools in producing arthropod prey for piping plovers. We collected arthropod abundance data at Cupsogue County Park (40°46' N, 72°35' W), which is adjacent to WHD to the west, along Dune Road. The bay margin of the western half of the site is fortified with a rock revetment. A broad, flat area of sand covers the rock revetment except along its bayward margin, and this area is vegetated by upland barrier island plants. However, vegetation removal in 1998 to create plover nesting habitat on the bay side has attracted nesting pairs to the site. Furthermore, three small artificial ephemeral pools were created in 1998 within the cleared area to enhance foraging habitat for broods. The pools were lined with plastic covered by sand. Pool 1 was rectangular, 40 m^2 in area, and approximately 0.25 m deep, pool 2 was rectangular, 8 m^2 in area, approximately 0.25 m deep with emergent vegetation, and pool 3 was circular, 34 m^2 in area, and approximately 0.5 m deep.

Five transects were established in the experimental area at Cupsogue County Park to sample arthropod abundance at the edge of the artificial pools and to compare it to arthropod abundance in other cover types. The transects started at Dune Road and ended at the bay intertidal zone. One transect passed through each of the 3 artificial pools, and one transect passed halfway between

each pair of pools. Cover types included "pool edge" (with the sub-types "wet pool" and "dry pool"), open sand, sparse vegetation, and moist sand (exposed patches of bare sediment among the rocks of the revetment, in the bay intertidal zone). We visited Cupsogue monthly to perform sticky stick sampling, but did not sample if plover broods, terns, or other nesting birds were at risk of being caught.

RESULTS

In 2001, at least some of the Cupsogue artificial pools were holding water during our visits in March (all 3 pools), April (pool # 3), and June (pool # 3). Nest and brood survival in the experimental area were too low for us to have a chance to observe chicks using the pools. Although statistical comparisons were not possible, in April the arthropod index in the wet pool appeared similar to that in other cover types in the experimental area (Fig. 4). We caught many more insects at the edge of the wet pool in June (116) than in any other cover type, including the 2 dry pools. Compared to cover types at the other sites in June 2001, this was second only to the average arthropod index in the bay intertidal zone at WHD (129).

In 2002, Pool 3 was holding water during our April and May visits, but no other pools were wet. One brood used the area, and fledged one chick. We did not sample in June because of the risk of catching plover broods on the sticky sticks. Arthropod index at the edge of the wet pool was similar to other cover types in the experimental area, in the months for which we have data (Fig. 5).

In 2003, we sampled only in April, when Pool 2 and 3 were wet, and June, when all pools were wet. One brood used the experimental area, but did not

survive. In April, arthropod index at the edge of wet pools was similar to that in other cover types, while in June it was greater at the edge of wet pools than other cover types (Fig. 6). However, in June the arthropod index was high only in pools 2 (15 arthropods) and 3 (58 arthropods), and we only caught 2 arthropods at Pool 1 even though it was wet. The catch at Pool 3 in June was less than the mean catch at WHD in the ocean intertidal zone (112), ocean fresh wrack (158), bay intertidal zone (76), and bay fresh wrack (96), but was greater than the mean catch in all other cover types at the other sites, all of which were < 50.

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Fig. 5. Mean±se total arthropod index in the experimental area of Cupsogue, 2001. Pools were artificially created to breed insects for plovers. Moist sand refers to damp sand among the rocks of the revetment along the bay intertidal zone.
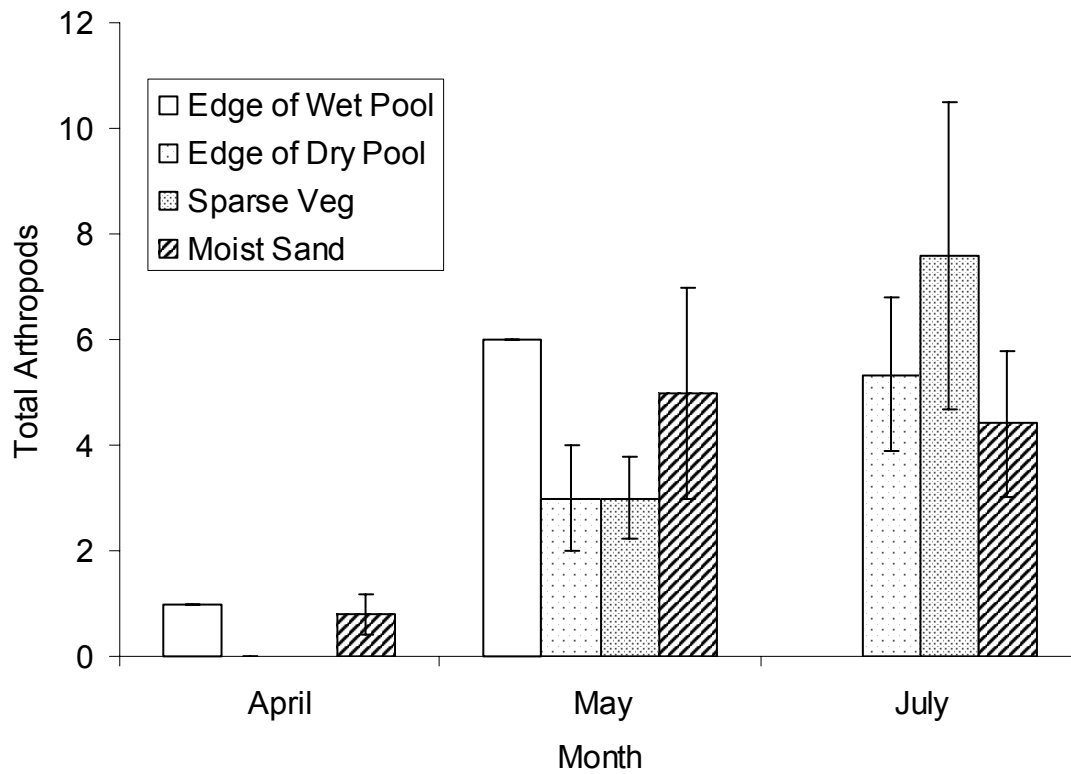
Fig. 6. Mean±se total arthropod index in the experimental area of Cupsogue, 2002. Pools were artificially created to breed insects for plovers. Moist Sand refers to damp sand among the rocks of the revetment along the bay intertidal zone.
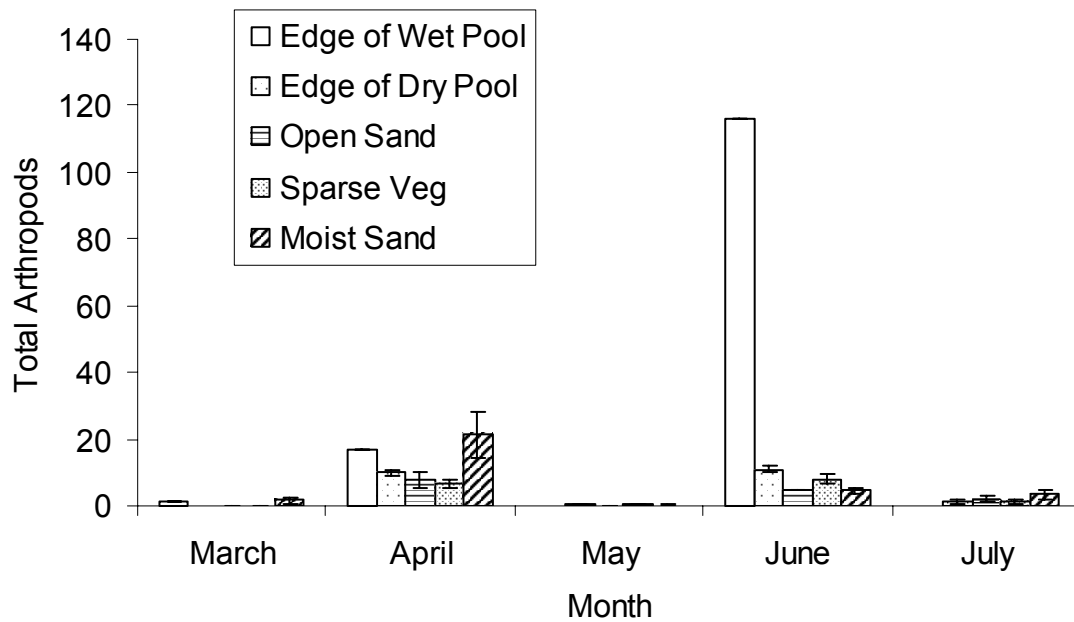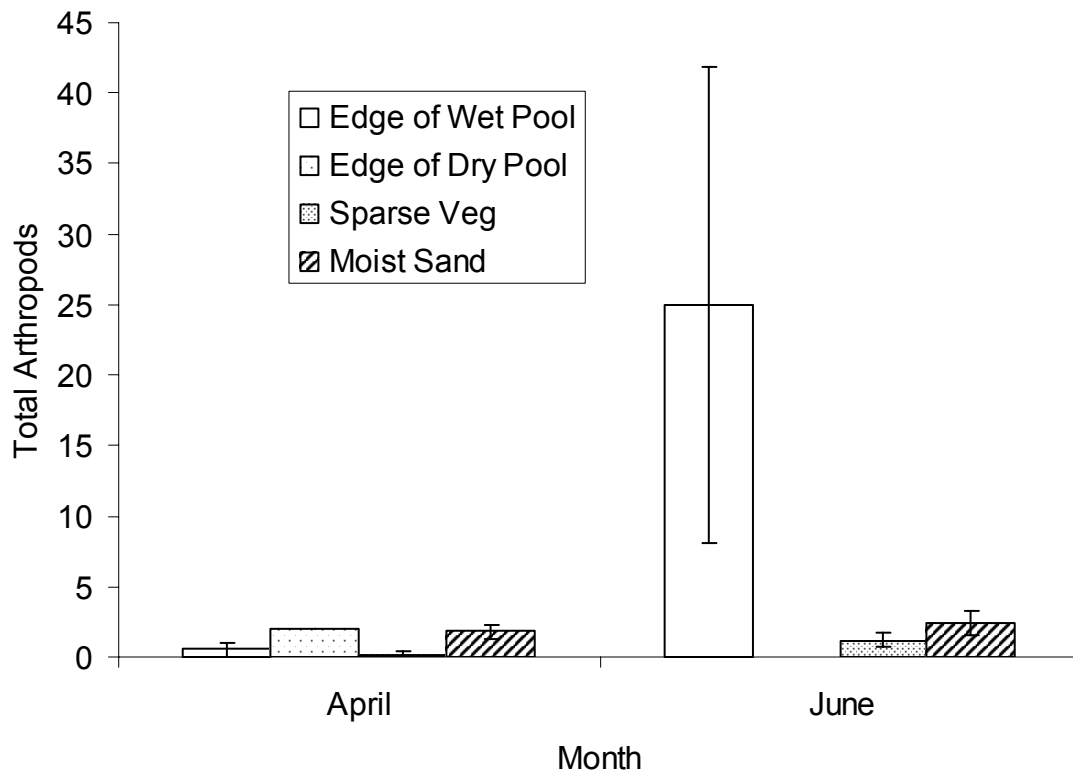
Fig. 7. Mean±se total arthropod index in the experimental area of Cupsogue, 2003. Pools were artificially created to breed insects for plovers. Moist Sand refers to damp sand among the rocks of the revetment along bay intertidal zone.

APPENDIX J. INSECT COLLECTION, WEST HAMPTON DUNES,

WESTHAMPTON BEACH, SHINNECOCK WEST, AND DEMOCRAT POINT,

2002

Specimens were collected by sweepnet or by hand. Collection is stored in 118 Cheatham Hall, Virginia Tech University, Blacksburg, VA.

Date	Order	Family	Site	Habitat
06/29/02	Coleoptera	Carabidae	WHD	Bay ITZ, under *Limulus* carapace?
07/09/02	Coleoptera	Carabidae	Groinfield	Lashley parking lot
07/31/02	Coleoptera	Carabidae	Democrat Pt.	Interior ITZ
07/17/02	Coleoptera	Chrysomelidae	Shinnecock	Bay dense veg
07/20/02	Coleoptera	Chrysomelidae	Groinfield	Bay dense veg
07/31/02	Coleoptera	Chrysomelidae	Democrat Pt.	Ocean fresh wrack
06/29/02	Coleoptera	Cicindellidae	WHD	Sand spit, open moist sand
07/31/02	Coleoptera	Cicindellidae	Democrat Pt.	Interior ITZ
07/07/02	Coleoptera	Coccinelidae	WHD	Flowers by parking lot
07/07/02	Coleoptera	Curculionidae	WHD	Bay sparse veg (by parking lot)
07/17/02	Coleoptera	Curculionidae	Shinnecock	Bay dense veg
07/25/02	Coleoptera	Curculionidae	Groinfield	Dune sparse vegetation
07/20/02	Coleoptera	Dermestidae	Groinfield	Bay veg, under *Limulus* carapace
06/29/02	Coleoptera	Elateridae	WHD	Bay ITZ, under *Limulus* carapace
07/06/02	Coleoptera	Histeridae	WHD	Bay backshore
06/29/02	Coleoptera	Melyridae	WHD	Bay sparse vegetation
06/29/02	Coleoptera	Scarabeidae	WHD	Bay sparse vegetation
06/29/02	Coleoptera	Staphylinidae	WHD	Bay ITZ, under *Limulus* carapace?
06/29/02	Coleoptera	Tenebrionidae	WHD	Bay sparse vegetation
06/30/02	Collembola	Poduridae	WHD	Bay fresh wrack
07/25/02	Diplura	Campodeidae	Groinfield	Marsh, under board in wrack
06/29/02	Diptera	Asilidae	WHD	Bay backshore
07/26/02	Diptera	Bombyliidae	Shinnecock	Marsh vegetation
06/29/02	Diptera	Calliphoridae	WHD	Bay ITZ, on *Limulus* carapace
08/13/02	Diptera	Ceratopogonidae	WHD	Bay sparse vegetation
07/31/02	Diptera	Chloropidae	Democrat Pt.	Ocean sparse veg?
07/31/02	Diptera	Coelopidae	Democrat Pt.	Interior ITZ
08/06/02	Diptera	Coelopidae	WHD	Bay side ITZ/ fresh wrack- superabundant
07/19/02	Diptera	Culicidae	WHD	Dune road
06/29/02	Diptera	Dolichopodidae	WHD	Bay intertidal zone
06/30/02	Diptera	Dolichopodidae	WHD	Bay ITZ/Marsh
07/06/02	Diptera	Dolichopodidae	WHD	?
07/17/02	Diptera	Dolichopodidae	Shinnecock	Bay dense veg
07/26/02	Diptera	Dolichopodidae	WHD	Bay sparse veg
07/31/02	Diptera	Dolichopodidae	Democrat Pt.	Interior ITZ
08/06/02	Diptera	Dolichopodidae	WHD	Bay side
06/29/02	Diptera	Empididae	WHD	Bay sparse vegetation?
06/30/02	Diptera	Empididae	WHD	Marsh vegetation
07/20/02	Diptera	Ephydridae	Groinfield	Marsh vegetation
08/06/02	Diptera	Ephydridae	WHD	Ocean sparse vegetation

07/29/02	Diptera	Heliomyzidae	Shinnecock	Roadside flowers
07/17/02	Diptera	Muscidae	Shinnecock	Bay backshore/fresh wrack
07/31/02	Diptera	Muscidae (1)	Democrat Pt.	Ocean fresh wrack
07/31/02	Diptera	Muscidae (2)	Democrat Pt.	Interior sparse veg
07/31/02	Diptera	Muscidae (3)	Democrat Pt.	Ocean backshore
07/20/02	Diptera	Otitidae	Groinfield	Marsh vegetation
08/06/02	Diptera	Otitidae	WHD	Marsh
07/26/02	Diptera	Piophilidae	WHD	Bay sparse veg
06/30/02	Diptera	Sarcophagidae	WHD	Bay ITZ/Fresh wrack
07/25/02	Diptera	Sarcophagidae	Groinfield	Dune sparse vegetation
07/26/02	Diptera	Scathophagidae	WHD	Bay fresh wrack
06/29/02	Diptera	Syrphidae	WHD	Bay sparse vegetation
07/25/02	Diptera	Syrphidae	Groinfield	Flowers by parking lot
07/17/02	Diptera	Tabanidae	Shinnecock	Parking lot
07/07/02	Hemiptera	Lygaeidae	WHD	Bay sparse veg (by parking lot)
07/18/02	Hemiptera	Lygaeidae	Groinfield	Ocean fresh wrack
07/31/02	Hemiptera	Lygaeidae (1)	Democrat Pt.	Interior sparse veg
07/31/02	Hemiptera	Lygaeidae (2)	Democrat Pt.	Interior sparse veg
06/30/02	Hemiptera	Miridae	WHD	Marsh vegetation
07/18/02	Hemiptera	Pentatomidae	Groinfield	Ocean fresh wrack
06/30/02	Hemiptera	Saldidae	WHD	Bay intertidal zone
07/07/02	Hemiptera	Tingidae	WHD	Bay sparse veg
06/29/02	Homoptera	Aphididae	WHD	Marsh vegetation
07/25/02	Homoptera	Cercopidae	Groinfield	Dune dense vegetation
06/29/02	Homoptera	Cicadelidae	WHD	Marsh vegetation
07/29/02	Hymenoptera	Apidae	Shinnecock	Roadside flowers
07/31/02	Hymenoptera	Braconidae	Democrat Pt.	Interior sparse veg
06/29/02	Hymenoptera	Formicidae (1)	WHD	Bay backshore
06/29/02	Hymenoptera	Formicidae (2)	WHD	Bay backshore/sparse vegetation
07/17/02	Hymenoptera	Halictidae	Shinnecock	Bay dense veg
07/29/02	Hymenoptera	Halictidae (1)	Shinnecock	Roadside flowers
07/29/02	Hymenoptera	Halictidae (2)	Shinnecock	Roadside flowers
06/30/02	Hymenoptera	Ichneumonidae	WHD	Marsh vegetation
07/07/02	Hymenoptera	Ichneumonidae	WHD	Flowers by parking lot
06/29/02	Hymenoptera	Pompilidae	WHD	Bay sparse vegetation
06/29/02	Hymenoptera	Sphecidae	WHD	Bay intertidal zone
07/06/02	Hymenoptera	Sphecidae	WHD	Marsh vegetation
07/31/02	Hymenoptera	Sphecidae	Democrat Pt.	Interior sparse veg
07/29/02	Lepidoptera	Danaidae	Shinnecock	Roadside flowers
08/02/02	Lepidoptera	Hesperiidae	Groinfield	Reed marsh
07/26/02	Lepidoptera	Nymphalidae	WHD	Bay dense veg
06/29/02	Lepidoptera	Pieridae	WHD	Bay sparse vegetation
07/07/02	Lepidoptera	Pieridae	WHD	Bay dense veg
06/29/02	Lepidoptera	Pyralidae	WHD	Bay sparse vegetation
07/29/02	Lepidoptera	Pyralidae	Shinnecock	Roadside flowers
07/20/02	Mantodea	Mantidae (nymph)	Groinfield	Marsh vegetation
07/07/02	Neuroptera	Myrmeleontidae	WHD	Bay dense veg
07/26/02	Odonata	Coenagrionidae	Groinfield	Ocean sparse vegetation
06/29/02	Odonata	Libellulidae	WHD	Marsh vegetation
07/20/02	Odonata	Libellulidae	Groinfield	Bay dense veg

07/06/02	Orthoptera	Acrididae	WHD	Bay sparse vegetation
07/25/02	Orthoptera	Acrididae	WHD	Bay sparse veg
07/31/02	Orthoptera	Acrididae	Democrat Pt.	Interior sparse veg
07/26/02	Orthoptera	Gryllidae	Shinnecock	Marsh vegetation

APPENDIX K. SOURCES OF NEST LOSS, WHD AND WHB, 2001-2003

Site	Year	Nests Laid	Nests Lost	Number Lost to Specific Source										
				Cat	Crow spp.	Dog	Fox	Icterid[a]	Gull spp.	Raccoon	Abandoned	Flood	Peds[b]	Unid[c]
WHD, exclosed[d]	2001	49	18	1	0	0	2	0	2	0	1	1	0	11
	2002	50	23	5	0	0	9	0	1	0	3	0	0	5
	2003	41	36	1	10	2	0	2	0	0	0	0	0	21
WHD, unexclosed	2001	0	-	-	-	-	-	-	-	-	-	-	-	-
	2002	0	-	-	-	-	-	-	-	-	-	-	-	-
	2003	8	1	0	0	0	0	0	0	0	1	0	0	0
WHB, exclosed	2001	8	4	0	0	0	0	0	0	0	0	2	0	2
	2002	28	15	3	2	0	2	1	0	0	1	3	0	3
	2003	21	19	3	3	0	0	0	0	0	3	0	0	10
WHB, unexclosed	2001	11	5	0	0	0	0	0	0	0	5	0	0	0
	2002	1	1	0	0	0	0	0	0	0	1	0	0	0
	2003	3	2	0	0	0	0	0	0	0	1	1	0	0

[a] unidentified blackbird (Icteridae)
[b] peds = pedestrians
[c] unid = unidentified predators
[d] exclosed = predator exclosure installed around nest

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EDUCATION

Ph.D. Fisheries and Wildlife Sciences, Virginia Tech University, GPA 4.0, 26 sem. hrs.
Expected March 2005
M.S. Renewable Natural Resources, University of Connecticut, GPA 3.8, May 1998, 25
sem. hrs.
B.S. Natural Resources, Cornell University, GPA 3.7, May 1994, 144 sem. hrs.

RESEARCH EXPERIENCE

Graduate Research Assistant, Ph.D.   August 2000 – Present   Virginia Tech
University – Blacksburg, VA
Supervisor: James Fraser, 540-231-6064, Mail Code 0321, Virginia Tech, Dept. Fisheries
and Wildlife Sciences,
Blacksburg, VA 24061-0321, 40 h / week
Dissertation: "Factors limiting piping plover nesting density and reproductive success on
Long Island, New York"

- Nest searching and monitoring of reproductive success
- Habitat measurements (vegetative cover, terrestrial arthropod abundance, benthic invertebrate abundance and biomass)
- Trapping, banding, and morphological measurement of adult and juvenile plovers
- Collection of plover home range and behavioral data
- Surveys of other shorebird and seabird species
- Registration of and habitat classification on digitized aerial photos
- Videography of nesting plovers, including overnight time-lapse infrared videography
- Cooperated and coordinated activities with federal, state, and local agencies and landowners
- Public outreach, including preparation of informational brochures regarding my research
- Supervised three field technicians

Biological Technician GS-7   August 1998 – June 2000   Patuxent Wildlife Research Center – Laurel, MD
Supervisor: Barnett Rattner, 301-497-5671, Mail Code 0321, USGS Patuxent Wildlife Research Center, Beltsville Lab c/o BARC-East, Building 308, 10300 Baltimore Avenue, Beltsville, MD 20705
Developed a geographic information system to analyze contaminant exposure and effects data for terrestrial vertebrates inhabiting estuarine and coastal habitat on the Atlantic Coast

- Co-authored internet-based species accounts detailing natural history and toxicological exposure and effects data for greater scaup and clapper rail
- Co-authored an internet-based JavaScript program to calculate an index of suitability of terrestrial vertebrate species as biomonitors of environmental contamination, and vulnerability of such species to contaminants
- Assisted in a lead exposure experiment in free-ranging black-crowned night-heron nestlings
- Assisted in contaminant exposure and effects studies in wild ospreys and wading birds
- Assisted in a laboratory experiment on mercury exposure in kestrels
- Assisted in a mark-recapture population study of wood frogs and spotted salamanders

Coastal Waterbird Intern   April 1998 – August 1998   Massachussetts Audubon Society – Duxbury, MA
Supervisor: Scott Hecker, 781-934-8905, National Audubon Society, 33 Railroad Ave, Duxbury, MA 02332

- Monitored piping plover and least tern nests and broods in barrier beach environment
- Conducted public outreach to educated beach-goers regarding piping plovers

Graduate Research Assistant, M.S.   Sept. 1995 - April 1998   UConn Dept. of Natural Resources - Storrs, CT
Supervisor: John Barclay, 860-486-0143, University of Connecticut, Dept. Natural Resource Management and Engineering, Young Building, Unit 4087, Storrs, CT 06269-4087, 40h / week, $19,000 / yr

- Thesis: "Greater scaup as bioindicators of contaminants on Long Island Sound"
- Coordinated collection of greater scaup specimens by federal and state personnel in four states
- Collected samples of sediments, plankton, and benthic organisms for contaminants analysis
- Performed necropsies of greater scaup specimens and analyzed gastrointestinal contents
- Prepared and extracted samples for pesticide and PCB analysis
- Organized volunteer network for waterfowl ground surveys in four states
- Participated in aerial waterfowl surveys

- Created logistic regression model for greater scaup winter habitat selection based on GIS data

MAPS Intern   May 1995 - August 1995   Inst. for Bird Populations - St. Mary's County, MD
Supervisor: James Sarraco, 907- 697-2777, Institute for Bird Populations, P.O. Box 1346; Point Reyes Station, CA 94956-1346

- Performed mist-netting and banding of passerines
- Collected data on forest vegetation composition and % cover
- Participated in point counts of breeding passerines

Naturalist Intern   Sept. 1994 - April 1995   Northwest Park Nature Center - Windsor, CT
Supervisor: Kathy Perillo, current contact info. unknown. Contact info. for Northwest Park: 860-285-1886, 145 Lang Road, P.O. Box 773, Windsor, CT 06095
- Planned and conducted nature-related programs for the public
- Designed and built nature-related exhibits for public education
- Assisted with radio-telemetry study of dispersal in spotted turtles
- Cared for captive mammals, reptiles, amphibians

TEACHING EXPERIENCE

Aug. 1995 - Dec. 1996   Teaching Assistant, University of Connecticut - Storrs, CT - Environmental Science
Jan. 1994 - May 1994   Teaching Assistant, Cornell University – Ithaca, NY - Intro. Biology; Wildlife Ecology

RELATED WORK EXPERIENCE

Sept. 1993 - May 1994   Curatorial Assistant - Paleontological Research Institute, Ithaca, NY
June 1989 – August 1989 Research Apprentice - University of CT Dept. Plant Science, Storrs, CT

PROFESSIONAL ACTIVITIES

- Graduate Student Computer Lab Committee Chair, Virginia Tech Dept. of Fisheries and Wildlife Sciences, 2002
- The Wildlife Society
    - Member (1992-Present) and Associate Certification (1999)
    - Legislative Review Committee Chair, Maryland-Delaware Chapter, 1999-2000
    - President, University of Connecticut Student Chapter, 1996-97
    - Member, Cornell Student Chapter, 1992-94

REFEREED PUBLICATIONS

Cohen, JB, Rattner, BA, Golden, NH. 2003. Use of retrospective data to assess ecotoxicological monitoring needs for terrestrial vertebrates residing in Atlantic Coast estuaries. Ecotoxicology 12:365-375

Sheffield SR, Sawicka-Kapusta K, **Cohen JB**, Rattner BA. 2001. Rodentia and Lagomorpha. Pp. 215-314 <u>In</u> Shore, R.F. and B.A. Rattner (eds.), Ecotoxicology of Wild Mammals. John Wiley & Sons, Chichester.

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PROFESSIONAL PRESENTATIONS

2004 – Piping plover population regulation on a storm-destroyed and rebuilt barrier island. 10th Annual Meeting of The Society for Conservation Biology, New York, NY

2003 – Factors limiting piping plover nesting pair density in New York. 10th Annual Conference of The Wildlife Society, Burlington, VT

2003 – Long Island Plover Project. Long Island Colonial Waterbird Association Meeting, Quogue, NY

2003 – Long Island Piping Plover Project - 2003 Results - U.S. Army Corps. of Engineers Long Island Piping Plover Project Meeting, Westhampton Beach, NY

2002 – Long Island Piping Plover Project - 2002 Results - U.S. Army Corps. of Engineers Long Island Piping Plover Project Meeting, Westhampton Beach, NY

2002 - Limiting Factors of Piping Plover Nesting Pair Density and Productivity - North American Piping Plover Conference, Ann Arbor, MI

2001 – Long Island Piping Plover Project - 2001 Results - U.S. Army Corps. of
Engineers Long Island Piping Plover Project Meeting, West Hampton Dunes, NY

2001 - Piping Plover Research on Long Island - Atlantic Coast Piping Plover Recovery
Team Meeting, Shepherdstown, VA

1999 – The Contaminant Exposure and Effects - Terrestrial Vertebrates Database -
Society of Environmental Toxicology and Chemistry Annual Conference,
Washington, D.C.

1999 – Spatial Data Gaps for Contaminant Exposure of Terrestrial Vertebrates Residing
in Atlantic Coast Estuaries - Patuxent Wildlife Research Center Annual Meeting,
Laurel, MD

1997 – Greater Scaup as Bioindicators of Heavy Metal Contamination in National
Wildlife Refuges - Society of Environmental Toxicology and Chemistry Annual
Conference, San Francisco, CA

1996 – Effectiveness of GIS for Modeling Greater Scaup Habitat Selection - First Annual
Duck Symposium, Baton Rouge, LA

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utility in biomonitoring and vulnerability to environmental contaminants. U.S.
Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland.
Available from: http://www.pwrc.usgs.gov/ceetv/

AWARDS AND HONORS
Feb. 2001   Phi Sigma National Honor Society in the Biological Sciences
Feb. 2000   U.S. Geological Survey Star Award for Employee Excellence
May 1998   Standard Bearer at Graduation Commencement Ceremony - Storrs, CT

Aug. 1995   Bishop-Carder Scholarship, University of Connecticut - Storrs, CT
April 1994   Henry Morgentheau Scholarship, Cornell University - Ithaca, NY
April 1994   Arthur H. and Karin A. Nelson Scholarship, Cornell University - Ithaca,
NY
May 1994   Phi Kappa Phi National Honor Society
May 1994   Golden Key National Honor Society
May 1994   Gamma Sigma Delta National Honor Society
May 1994   Ho-Nun-De-Kah (Cornell Agriculture Undergraduate Honor Society)

FIELD AND LABORATORY SKILLS
- Identification of birds, reptiles, amphibians, mammals, woody and herbaceous plants, insects, estuarine invertebrates and plankton
- Trapping, banding, handling of shorebirds, passerines, juvenile wading birds and raptors
- Collection of invertebrate specimens (terrestrial, benthic, planktonic)
- Quadrat and transect methods for vegetative percent cover measurement
- Avian necropsy
- Avian gastrointestinal tract content analysis
- Handling and preparation of sediment, plant, and animal tissue samples for toxicological analysis
- Radio telemetry
- Off-road vehicle operation
- Shorebird nest photography
- Infrared videography of nesting shorebirds
- Care and feeding of captive reptiles, amphibians, small mammals

COMPUTER/TECHNICAL SKILLS
- GIS/Remote Sensing (ARC / INFO 3.5, ArcView 3.2, Idrisi for Windows 2.0, ERMapper 5.2, Arcview Image Analyst)
- Home Range (ArcView Animal Movements Extension, ArcView Home Range Extension)
- GPS (Garmin 12, Trimble GeoExplorer, Pfinder, Quickplan)
- Word Processing, Spreadsheets, Databases, HTML, JavaScript, Windows 2000, MacIntosh
- Statistical Software (SAS, Systat, MiniTab, DataDesk)

STATISTICAL SKILLS
- Experimental design and hypothesis testing
- Information-theoretic criteria (AIC) and model selection
- Linear, logistic, Poisson, and nonlinear regression and stepwise model selection
- Path analysis
- Nonparametrics
- Principal components analysis
- Compositional analysis
- Multiresponse permutation procedure (MRPP)