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Source: Journal of Field Ornithology, 75(3):223-231. 2004.

Published By: Association of Field Ornithologists

DOI: 10.1648/0273-8570(2004)075[0223:PAAHUB]2.0.CO;2

URL:

<http://www.bioone.org/doi/full/10.1648/0273-8570%282004%29075%5B0223%3APAAHUB%5D2.0.CO%3B2>

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Prey abundance and habitat use by migratory shorebirds at coastal stopover sites in Connecticut

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Received 30 May 2003; accepted 23 October 2003

ABSTRACT. Stopover areas are vital for the successful migration of many species of shorebirds, as they, in part, allow individuals to deposit large quantities of fat needed to fuel their northward and southward journeys. While much research has focused on bird migration, few studies closely examine the environmental characteristics of specific stopover areas. For our study, we conducted prey availability surveys and documented shorebird habitat use during northward summer migration for three historically important stopover areas along the Connecticut Long Island Sound coastline in 2000. Coastal Connecticut provides important habitat not only for shorebirds migrating from northern Canada to South America, but also for resident breeding shorebirds (e.g., oystercatchers, plovers, and sandpipers). Our prey availability surveys indicate that all three stopover sites were characterized by some combination of polychaete worms, crustaceans, and mollusks. Polychaete worms of the family Nereididae were the most common prey item at two of the three sites. In addition, the site frequented by the greatest densities of shorebirds also had the greatest density of nereid worms and the greatest diversity of invertebrates. In terms of habitat use, our results indicate that foraging densities tended to be highest on intertidal habitats that were sheltered from coastal wave action and where densities of benthic (burrowing) and epifaunal (surface-dwelling) prey tended to be high. However, some shorebird species, including one breeding resident, the American Oystercatcher (*Haematopus palliatus*) and one migrant, the Ruddy Turnstone (*Arenaria interpres*), both of special management concern, favored foraging on beach-front habitats. In contrast to foraging habitat preferences, shorebirds roosting at high tidal phases showed strong preferences for beach habitats fronting the Long Island Sound. The use of beach-front habitats for both foraging and roosting poses a challenging situation for beach managers.

SINOPSIS. Abundancia de presas y uso de habitat por playeros migratorios en una parada costanera de Connecticut

Las áreas de paradas (stopover) son de vital importancia para el éxito migratorio de muchas especies de playeros (Charadriiformes) ya que las mismas permiten que los individuos se recargen con la cantidad de grasas que estos necesitan, como combustible, en sus viajes o jornadas hacia el norte o hacia el sur. Aunque mucha investigación se ha enfocado en la migración de las aves, muy pocos estudios han examinado las características ambientales de paradas específicas. Durante el 2000, determinamos la disponibilidad de presas y documentamos el uso del habitat por parte de los playeros durante su migración veraniega hacia el norte en tres importantes e históricos lugares de paradas a lo largo de la línea costera de Connecticut. El área costera de Connecticut provee habitat importante no tan solo para los playeros que vienen migrando desde el norte de Canada, sino además para los playeros residentes (ej., ostreros, chorlos y playeritos). Nuestro estudio de disponibilidad de presas indica que los tres lugares de parada se caracterizan por la presencia de poliquetos, crustáceos y moluscos. La presa más común en las tres localidades fueron gusanos de la familia Nereididae. Además la localidad más frecuentada y con mayor densidad de aves, también fue la que contenía la mayor cantidad de gusanos y la mayor diversidad de invertebrados. En términos de uso de habitat, nuestros resultados indican que las densidades de forrajeo tienden a ser mayor en habitats intertidales que están protegidos de las mareas, y en donde la densidad de presas tanto bénticas (que se entierran) como epifaunales (que se encuentran en la superficie) tiende a ser mayor o más alta. Sin embargo, algunos playeros, incluyendo a uno residente (el ostrero) y un migratorio (*Arenaria interpres*) ambas especies con especial preocupación de manejo, favorecen habitats de frentes de playas. En contraste a preferencias en el habitat de forrajeo, los playeros que pernoctaron durante las fases de marea alta, mostraron preferencias por habitats de playas de frente a Long Island Sound. El uso de frentes de playa para actividades de forrajeo como para pernoctar, presentan una situación de reto para los manejadores de playas.

Key words: Connecticut, foraging behavior, habitat selection, resource availability, shorebirds, stopover areas, waders

The migration of many shorebird species to their Arctic breeding grounds is constrained to

a narrow window of time (Evans and Pienkowski 1984; Farmer and Parent 1997). If the birds arrive too late, they run the risk of not acquiring a suitable territory, but if they arrive too early, there is the risk of dying due to extreme cold weather or lack of emerging insects (Evans and Pienkowski 1984). In addition,

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these migrations often include long-distance, nonstop flights exceeding thousands of kilometers (McNeil 1969; McNeil and Burton 1977; Alerstam et al. 1990; Piersma and Davidson 1992). To complete these extraordinary flights, shorebirds must accumulate large fuel reserves (Dunn et al. 1988; Harrington et al. 1989; Evans et al. 1991). In many of the 46 more common North American shorebird species, these fuel reserves are accumulated in the form of fat and protein at food-rich staging and stopover areas (Myers et al. 1987), but there are few areas that have the right combination of resources (Morrison and Harrington 1979). In some cases, between 50% and 80% of entire migrating populations of shorebirds (i.e., all individuals of a species migrating from a specific geographic region) use a single site (Morrison and Harrington 1979), indicating that any loss of critical stopover areas could reduce hemispheric shorebird numbers. Since many stopover areas are relatively restricted in area and are particularly vulnerable to various forms of development and industrialization (e.g., coasts and estuaries), research on the geographic distributions and migration patterns of shorebirds that use these areas has steadily increased in the last 50 yr (e.g., Brown et al. 2001). However, determining the environmental characteristics of stopover areas (e.g., resource availability, predator pressures, habitat use) has not been examined as often or as extensively.

Our study focuses on characterizing several of these food-rich stopover areas along the Connecticut coast by determining both the resource availability and shorebird use of these areas. Since the ecologies of shorebirds are closely tied to the distribution and abundance of food resources, especially of benthic invertebrates (Safran et al. 1997), we focused mainly on prey abundance, as it is likely that it is one of the most important characteristics of a frequently used stopover area. In fact, positive correlations between waterbirds and benthic invertebrate populations is common (e.g., Murkin and Kadlec 1986; Colwell and Landrum 1993; Safran et al. 1997). In addition, both foraging and roosting habitat may be required, as migrating flocks may spend several days at any one particular stopover area (e.g., Warnock and Bishop 1998; Fernandez et al. 2001). Therefore, we also examined the foraging and roosting behavior of the shorebirds at our sites, as well as

shorebird habitat use during foraging and roosting. The overall goal of our study was to provide natural history data on the prey composition and shorebird habitat use of several stopover areas.

METHODS

Study area. One-hectare plots were established at three locations in coastal Connecticut that included representative shorebird habitats and were known to be frequented by both migrating and resident shorebird species. Four plots were located in Stratford, Fairfield County (Lordship Marsh), six in Milford, New Haven County at Wheeler National Wildlife Refuge salt marsh at Milford Point, and three in West Haven, New Haven County (Sandy Neck). All three locations are on the coast of Long Island Sound and are characterized by both beach-front habitat and backwater marshes.

All plots were on open, tidal flats essentially free of standing vegetation. Two major habitat categories were represented: (1) plots located in relatively sheltered waters (e.g., lagoons and salt marsh bays behind barrier beaches) and having a high mud content, and (2) plots characterized by having higher wave energy, high sand, and low mud content. Category (1) and (2) plots are referred to as backwater and bayfront plots, respectively.

Invertebrate sampling. Invertebrate sampling was carried out from late May to early June 2000, shortly before northward shorebird migration commenced. Two sets of seven grab samples were collected from a 6-m² area randomly situated at each study plot. Grab sampling entailed collecting a handful (ca. 300 ml) of the first 10–15 cm of substrate (e.g., mud, sand) from the plot being sampled. Samples were collected on site, sieved in the field with a 1.0 mm Newark Standard Screen, washed with saltwater into suitable containers, marked for date and location, and refrigerated. All invertebrate sampling was completed during low tides to control for tidal differences in prey availability and abundance (e.g., de Vlas et al. 1996), and because this was the time in which shorebirds typically foraged at our sites (see below). Sorting, identification, and counting were completed within 24 h. All invertebrates were identified using field guides (Gosner 1978; Weiss 1995). Gastropods and bivalves were

identified to genus, or more often, to species level. Amphipods and polychaetes were identified to family. Shrimp were identified to genus, crabs to genus, insects and spiders to order, and scarce invertebrates (i.e., occurrence <5% by individual count) to class. Voucher specimens were verified by C. Cuomo (pers. comm.).

Bird censuses. Shorebird censuses were conducted approximately four times weekly on each plot during late May/early June through August 2000 during northward migration. As is typical of coastal locations, tidal flux varied with relative earth/sun/moon positions, and since tide is a major factor influencing the distribution, abundance, and behavior of shorebirds and their prey (e.g., Burger and Olla 1984), censuses were conducted at both "low" and "high" tides to further understand stopover area habitat use. We defined "high tides" as those when substrates of one or more study plots at a particular location were inundated, and "low tides" as those when plots were exposed. Attempts were made to complete surveys at the peak of both high and low tidal phases, but if surveys were conducted as tides were still falling or rising, we aggregated them with our low and high data, respectively. A total of 36 censuses were conducted at each plot throughout the course of the study with half being conducted at high tide and half at low tide. During censuses, shorebirds were counted using a 20× telescope from points at least 100 m away so as to ensure that the researcher's presence did not affect bird numbers (de Boer and Longman 1996). We did not count shorebirds under extreme weather conditions (windy and/or rainy days) because of possible adverse effects on bird activity (Conner and Dickson 1980).

Data analysis. For the invertebrate data, the density of polychaetes, crustaceans, mollusks, and other invertebrates were compared between backwater and bayfront plots at each of the three sites using mixed-model ANOVAs. Initially, the independent variables included in each model consisted of site, plot location, and a term for the interaction between site and plot location; however, if the interaction term was not significant, it was removed from the model. In addition, the densities of specific prey items (i.e., at the family, genus, or species level) were also compared in this manner. If an ANOVA indicated that treatment levels of the independent variables resulted in significant differences

in invertebrate densities, Tukey-Kramer multiple-comparison tests were employed to determine pair-wise differences. Since species diversity is often linked to stable ecosystems, Shannon-Weiner diversity indices (H) and evenness indices (J) were also calculated, using the natural log (Legendre and Legendre 1998), for all invertebrates collected at each of the three sites and for the subset of invertebrates considered to be potential shorebird prey (Kent and Coker 1997).

Mixed-model ANOVAs were employed to detect differences in shorebird densities between the three sites and different plot locations at both low and high tides. Independent variables consisted of site, plot location, tidal phase, species, and interactions between them. If an interaction term was not significant, it was dropped from the model. In addition, since shorebird surveys were conducted from May to August, we investigated temporal trends in shorebird densities across sites and plots via repeated-measures mixed-model ANOVAs. If our ANOVAs indicated that the levels of our independent variables resulted in significant differences in shorebird densities, Tukey-Kramer multiple-comparison tests were used to detect significant pair-wise differences. All invertebrate and shorebird data were normalized via log transformations, and alpha (α) was set at 0.05 for all statistical analyses. Results are presented as mean \pm 1 SE.

RESULTS

Prey availability. At all sites, the mud snail (*Nassarius* sp.) was the dominant invertebrate and representatives of the phyla Annelida, Arthropoda, and Mollusca were common, with no significant differences in invertebrate densities attributed to a site effect. In addition, since there was no significant interaction between site and plot location, we pooled our invertebrate data to examine plot type. When controlling for site, some groups of invertebrates were found to differ as a result of plot type (Fig. 1). Polychaete ($F_{3,9} = 5.60, P = 0.04$) and crustacean ($F_{3,9} = 8.94, P = 0.02$) mean densities were greater in backwater plots than bayfront plots, while mollusks ($F_{3,9} = 0.0049, P = 0.95$) and other invertebrates ($F_{3,9} = 1.02, P = 0.24$) did not differ significantly between plot type.

When examining the invertebrate composi-

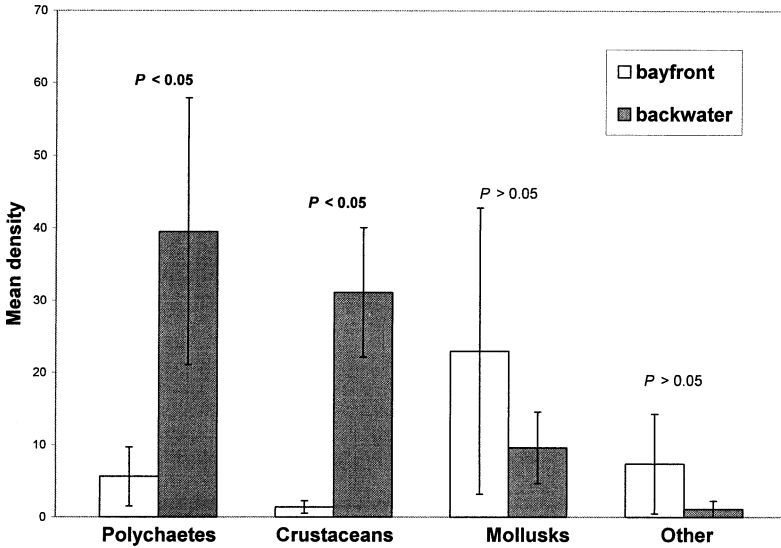


Fig. 1. Mean invertebrate densities (± 1 SE) observed on bayfront ($N = 5$) and backwater ($N = 8$) plots from three coastal Connecticut sites in 2000. P -values, derived from mixed-model ANOVAs after controlling for site effects, are indicated above bars (those significant in bold).

tion of the three sites at the level of class or below, substantial differences occurred (Table 1). Excluding *Nassarius* sp., Milford samples were dominated by marine worms (polychaetes) and crustaceans (mostly gammarid amphipods), West Haven samples were dominated by marine worms and mollusks, and the Stratford macroinvertebrate fauna was dominated by

crustaceans and mollusks. However, only the density of the crangonid shrimp, *Crangon* sp., differed significantly among sites ($F_{5,7} = 12.85$, $P < 0.01$), being more common at Stratford than at either Milford or West Haven. In addition to qualitative and quantitative differences in the abundance of invertebrates at each site, the diversity of invertebrates differed among

Table 1. Mean density (± 1 SE) of invertebrates collected from bayfront and backwater plots at Milford ($N = 6$), West Haven ($N = 3$), and Stratford ($N = 4$), Connecticut, in 2000. When only one of either plot type was sampled for a particular site, a count is given rather than a mean.

Invertebrate (Phylum, Class)	Milford		West Haven		Stratford	
	Bayfront ($N = 3$)	Backwater ($N = 3$)	Bayfront ($N = 2$)	Backwater ($N = 1$)	Bayfront ($N = 1$)	Backwater ($N = 3$)
Annelida						
Polychaeta	9.33 \pm 6.17	80.33 \pm 28.24	4.0 \pm 4.0	57.0	0	3.0 \pm 1.53
Arthropoda						
Crustacea	2.33 \pm 1.20	27.0 \pm 12.22	1.0 \pm 1.0	3.0	0	54.0 \pm 6.66
Insecta	0.67 \pm 0.67	0	0	0	1.0	0
Merostomata						
<i>Limulus</i> eggs	6.67 \pm 6.67	0	4.5 \pm 4.5	0	0	0
Mollusca						
Bivalvia	3.67 \pm 2.33	0.67 \pm 0.33	4.5 \pm 4.5	41.0	1.0	12.0 \pm 4.0
Gastropoda	209.0 \pm 104.79	54.33 \pm 5.36	120.0 \pm 20.0	350.0	251.0	301.0 \pm 29.74
Nematoda	4.67 \pm 4.18	0	0	0	0	0

sites, with 16, 15, and 11 families represented at Milford, Stratford, and West Haven, respectively. These differences in invertebrate diversity and abundance were supported by Shannon-Weiner diversity indices calculated for each site; Milford exhibited the greatest diversity ($H = 1.16$) followed by Stratford ($H = 0.91$) and then West Haven ($H = 0.80$). Evenness indices for the three sites indicated that the families represented at Milford ($J = 0.42$) were more evenly distributed than those represented at Stratford ($J = 0.33$) or West Haven ($J = 0.32$).

Although *Nassarius* sp. was the dominant invertebrate at all three sites, its adult size prevented predation by most shorebirds, and shorebirds were not seen taking it as prey; therefore, this genus was excluded from further analysis. Similarly, all softshell clams (*Mya* spp.) were too large to be food for most shorebirds (except possibly for American Oystercatchers), and they were also excluded. Other prey items excluded from analysis include hermit crabs (Paguridae) and all other mollusks (i.e., *Anomia* spp., *Gemma* spp., *Mercenaria* spp., *Crepidula* spp., and *Littorina* spp.), as these invertebrates are either unknown as shorebird prey (Skagen and Oman 1996), too large or bulky to be taken by shorebirds (Botton 1984).

Qualitatively, the prey base at Milford consisted mostly of marine worms and crustaceans, while the Stratford site was characterized by large numbers of crustaceans and the West Haven site by large numbers of marine worms. In addition, although Milford, Stratford, and West Haven were represented by 12, 9, and 8 families of potential prey items, respectively, West Haven ($H = 1.40$) exhibited the greatest Shannon-Weiner diversity index followed closely by Milford ($H = 1.37$) and Stratford ($H = 1.01$). Evenness indices for potential prey items from the three sites indicate that prey were more evenly distributed at West Haven ($J = 0.67$) followed by Milford ($J = 0.55$) and Stratford ($J = 0.49$).

Shorebird counts. Site differences in the mean density of specific shorebird species were not significant ($F_{1,108} = 1.88$, $P = 0.06$), so all species counts were combined for each site in testing for an overall site effect on the mean densities of shorebirds. The mean number of shorebirds per plot was significantly higher at Milford (926.14 ± 325.00) than at Stratford (53.83 ± 14.53) or West Haven ($71.43 \pm$

19.94 ; $F_{2,24} = 3.83$, $P = 0.04$), but bird densities at Stratford and West Haven did not differ from each other. The large Milford counts were most likely influenced by birds coming to roost at this site during high tides. Significantly greater densities of shorebirds were observed at Milford (1576.20 ± 584.37) during high tides than at either Stratford (16.0 ± 6) or West Haven (134.33 ± 70.48 ; $F_{2,12} = 6.69$, $P < 0.05$). Observations made during low tides indicate that there were significant differences in shorebird densities between the three sites, with greater densities of shorebirds at Milford (422.2 ± 99.29) compared to both Stratford (29.13 ± 14.57) and West Haven (115.78 ± 66.84 ; $F_{2,12} = 7.82$, $P = 0.013$).

When controlling for site effects, shorebirds used the bayfront locations most intensively during high tidal periods (as foraging and roosting locations) and backwater locations (as foraging locations only) during low tidal periods. This pattern resulted in significantly higher counts per plot in the bayfront locations during high (1124.59 ± 420.46) versus low tides (24.07 ± 6.12 ; $F_{1,12} = 8.73$, $P < 0.001$). High/low tide comparisons were not possible in backwater locations because they were inundated well before (about 3 h) high tides.

Foraging habitat use. Controlling for site effects, significantly more shorebirds per plot were observed foraging in backwater plots (98.09 ± 21.86) during low tides than in bayfront plots (26.97 ± 7.72 ; $F_{1,13} = 5.67$, $P < 0.001$); however, a significant interaction between species and plot location indicates that this trend varied slightly from species to species ($F_{11,23} = 5.03$, $P < 0.001$; Table 2). While there were always significantly greater numbers of Black-bellied Plovers (*Pluvialis squatarola*), Greater Yellowlegs (*Tringa melanoleuca*), Least Sandpipers (*Calidris minutilla*), Semipalmated Sandpipers (*C. pusilla*), Semipalmated Plovers (*Charadrius semipalmatus*), and Willets (*Catoptrophorus semipalmatus*) foraging in backwater plots than in bayfront plots, the opposite was true for American Oystercatchers and Ruddy Turnstones. In addition, Piping Plovers (*Charadrius melodus*), Sanderlings (*Calidris alba*), Short-billed Dowitchers (*Limnodromus griseus*), and Spotted Sandpipers (*Actitis macularia*) did not significantly differ in their use of either bayfront or backwater plots while foraging.

Temporal trends. When examining

Table 2. Low tide comparisons of mean density (± 1 SE) of shorebirds on bayfront and backwater plots from three coastal Connecticut sites. A total of 54 low-tide censuses were conducted on both plot types at all three sites combined. Species marked with an asterisk differ significantly in mean density between bayfront and backwater plots when controlling for site effects, Tukey-Kramer multiple comparison tests ($P < 0.05$).

Species	Bayfront	Backwater
American Oystercatcher*	2.80 \pm 0.86	0
Black-bellied Plover*	5.35 \pm 2.23	12.62 \pm 2.66
Semipalmated Plover*	2.19 \pm 0.87	24.30 \pm 8.28
Piping Plover	2.57 \pm 1.39	0.43 \pm 0.30
Greater Yellowlegs*	1.74 \pm 0.59	10.04 \pm 1.85
Willet*	0.17 \pm 0.11	1.75 \pm 0.57
Spotted Sandpiper	1.17 \pm 0.48	0.67 \pm 0.21
Ruddy Turnstone*	5.56 \pm 1.80	0
Sanderling	9.67 \pm 5.58	0.67 \pm 0.49
Semipalmated Sandpiper*	28.68 \pm 18.26	40.21 \pm 4.52
Least Sandpiper*	1.94 \pm 1.16	17.00 \pm 9.18
Short-billed Dowitcher	6.56 \pm 2.68	17.00 \pm 0.21

shorebird densities across June, July, and August, a repeated-measures mixed-model ANOVA indicated significant differences from month to month ($F_{2,108} = 20.88$, $P < 0.001$). Specifically, at all three sites, shorebird densities steadily increased from June to August with significantly greater densities of birds being observed in August (441.72 ± 364.22) versus July (127.31 ± 92.27) and June (0.67 ± 0.32). In addition, greater shorebird densities were observed in July as compared to June. This trend was the same for all three sites and for all 12 species with no species \times site interaction being detected ($F_{22,108} = 0.80$, $P = 0.72$); however, differences in the mean densities of species varied within months ($F_{11,108} = 2.62$, $P < 0.01$). For example, there were always greater densities of Semipalmated Sandpipers at each site than of any other species ($P < 0.05$).

DISCUSSION

Resource availability. Relatively small differences in prey abundance existed between our three sites (Table 2); however, polychaete density was higher than all other invertebrate densities at the Milford and West Haven locations, with polychaete densities being significantly greater than any other potential prey at the Milford site. Studies of shorebird diets from diverse locations across the globe indicate that polychaetes are one of the primary prey items taken by shorebirds while foraging (e.g., Halliday et al. 1982; Weber and Haig 1997). This

may explain why significantly greater densities of shorebirds were observed foraging at the Milford site during low tides than at either Stratford or New Haven.

Shannon-Weiner diversity indices indicate that Milford and West Haven are more diverse than Stratford in both all invertebrates and potential invertebrate prey only. In addition, West Haven and Stratford were characterized by low evenness indices for all invertebrates and potential invertebrate prey only, indicating that only a few of the total species occur in large numbers at each site. Milford had the greatest overall invertebrate diversity, the second greatest diversity of potential prey, the highest evenness index for all overall invertebrate diversity, and the second highest evenness index for potential prey. These characteristics indicate that foraging sites with both a greater abundance and diversity of invertebrates and with more evenly distributed invertebrates may support greater numbers of shorebirds. This potential relationship deserves further attention.

Shorebird habitat use. In general, shorebird abundance and habitat use were both greatly influenced by tidal conditions and plot location. Specifically, most shorebirds at the three sites used backwater plots to forage during low tides and bayfront plots to roost during high tides, much as Burger et al. (1977) found in New Jersey, and has been seen commonly elsewhere. Significantly greater densities of shorebirds forage and roost at the Milford site than at either the Stratford or West Haven site.

We believe more shorebirds forage at the Milford site because of a greater abundance of polychaetes, although our analyses did not detect significant differences in polychaete abundance between sites despite substantial mean differences. Why more shorebirds roost at Milford than at the other two locations is not known and was not specifically examined in our study. One possible reason is that at the Milford site, shorebirds roosted on several sandbars located in Long Island Sound that had no connections to the mainland during high tides, whereas the West Haven and Stratford sites lacked such sandbars. Shorebirds roosting at either West Haven or Stratford were in contact with the mainland at all times, and this may have led to increased chances of roosting birds being disturbed either accidentally or by potential predators.

Some shorebirds foraged in backwater habitats (sheltered waters behind spits and barrier beaches) more often than in bayfront habitats. For example, six species foraged significantly more in backwater plots, two species foraged significantly more in bayfront plots, and five species did not differ in their use of backwater and bayfront plots while foraging. Given that invertebrate abundance appeared to be greater in the backwater plots and that these plots were characterized by softer substrates, which tend to result in significantly higher rates of food intake compared to sandy substrates (e.g., Burger and Olla 1984), we expected to see the majority of shorebirds foraging in those areas, but our sample sizes may have been too low to statistically detect differences.

Migrant shorebirds used different habitats (bayfront versus backwater) for roosting and feeding. Most species roosted on beaches and sandbars fronting on Long Island Sound, but foraged in nearby backwater lagoons and salt marsh tidal flats. In contrast, one important locally nesting species, the American Oystercatcher, and one migrant species, the Ruddy Turnstone, principally used beaches and flats on Long Island Sound for foraging and roosting. These differences may be due, in part, to the feeding ecology of the shorebirds examined in this study. While many shorebird species are generalist predators feeding on a wide variety of invertebrate prey, some are considered specialists. For example, the Red Knot (*Calidris canutus*) is known to feed heavily on horseshoe

crab eggs during its northward migration (Botton et al. 1994). The only horseshoe crab eggs detected in our invertebrate surveys were from bayfront plots (Fig. 1); therefore, Red Knots may have foraged more heavily in bayfront plots as an influence of preferred prey availability and feeding ecology. American Oystercatchers often specialize on mollusks (de Vlas et al. 1996), as their beaks are adapted to pry open the shells of such prey; however, mollusk densities did not differ between backwater and bayfront. American Oystercatchers may forage more often in bayfront plots for other reasons (e.g., proximity to nesting sites or competition) not examined in our study.

Temporal trends. As the summer progressed, significantly more shorebirds were observed using each of the three sites, with the greatest densities being documented in August. This trend of increasing densities from June to August was the same for all 12 species of shorebirds we observed. In the Atlantic flyway, most shorebirds complete their northward migration between June and September with no substantial reduction in prey availability being detected before September (Schneider and Harrington 1981). Our data may explain the significant reduction in prey availability detected in September, as we found the largest influxes of migrating shorebirds to occur during August. Unfortunately, we were unable to examine temporal trends in invertebrate diversity, as invertebrate sampling occurred only once or twice per site prior to the arrival of migrating shorebirds. Future work should include such surveys.

Conservation implications. Based on our prey availability surveys, it appears that stopover areas along the Long Island Sound of Connecticut are characterized by some combination of polychaetes, mollusks, and crustaceans, with polychaete densities being greater than other invertebrate densities at two of the three sites. In addition, larger mean densities of foraging shorebirds were observed at Milford, which was characterized by the greatest densities of polychaetes and the greatest diversity of invertebrates. Therefore, conservation biologists and restoration ecologists should take into account the density and diversity of potential shorebird prey when designing reserves or restoring natural stopover areas.

From a spatial perspective, the nature of shorebird coastal habitat requirements pose

some management and conservation challenges. Virtually all coastal habitats are experiencing rapidly increasing numbers of human recreationalists, with coastal birds sometimes being chronically disturbed (Pfister et al. 1992). According to the United States Shorebird Conservation Plan (Brown et al. 2001), controlling chronic disturbance to shorebirds in coastal habitats is an important management goal. During low tides, six species of shorebirds in this study spread principally over backwater, intertidal habitats that typically are muddy and unattractive for human recreational uses. None of these six taxa are in the highest two conservation priority categories of the Shorebird Conservation Plan (Brown et al. 2001). In contrast, both species that favor foraging on the bayfront habitats, which are more popular for human recreational activities, are in the two highest conservation priorities of the Plan; this includes the locally breeding American Oystercatcher. During high tides, whether day or night, tidal flooding of foraging habitats causes virtually all shorebirds to gather on spatially restricted, beachfront habitats. This happens at tidal stages when space available to birds and humans alike is limited. Significantly, in New England (as elsewhere in the United States) the peak times of northward (late May) and of southward shorebird migration (late July and early August) are the primary seasons for human beach recreation. Inevitably, in areas popular to humans, chronic disturbance to the birds occurs and renders the sites less suitable as a migration staging area (Pfister et al. 1992).

ACKNOWLEDGMENTS

We thank Mike Seider and Nils Warnock for providing critical comments on the manuscript. We are grateful to Milan Bull and Barbara Milton for logistical assistance, to the U.S. Fish and Wildlife Service staff of the Stewart B. McKinney National Wildlife Refuge for their help, to Manomet Center for Conservation Sciences (our sponsoring organization), and to Carmela Cuomo for verification of our invertebrate animal identifications. Finally, we are grateful to the State of Connecticut Long Island Sound License Plate Program for support of this project and in particular to Patricia Hughes and Lori Benoit for their help throughout.

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