The Condor 95:694–705

ABUNDANCE AND DISTRIBUTION OF MIGRANT SHOREBIRDS IN DELAWARE BAY[1]

KATHLEEN E. CLARK AND LAWRENCE J. NILES
Endangered and Nongame Species Program, New Jersey Division of Fish, Game and Wildlife, P.O. Box 236, Tuckahoe, NJ 08250-0236

JOANNA BURGER
Department of Biological Sciences, Rutgers University, Piscataway, NJ 08855

Abstract. Northbound migrant shorebirds (Charadridae and Scolopacidae) were surveyed weekly by air on Delaware Bay beaches on the Atlantic coast of North America in May–June 1986 through 1992. The single day peak count occurred between 26–30 May when an average of more than 216,000 birds was counted. The most abundant species were Semipalmated Sandpiper (*Calidris pusilla*), Ruddy Turnstone (*Arenaria interpres*), Red Knot (*Calidris canutus*) and Sanderling (*Calidris alba*). Our surveys documented high hemispheric counts for each of these species, and established Delaware Bay as the most important spring stopover in the eastern U.S. for these shorebirds. Counts of Sanderlings and Semipalmated Sandpipers declined significantly over the seven years; no trends for other species were detected. Differences among species in distribution along bay beaches were attributable partly to habitat factors. We suggest that a thorough understanding of shorebird abundance and habitat use in Delaware Bay is necessary to develop a conservation strategy for regulatory protection and conservation of migrant shorebirds using this area.

Key words: Shorebirds; migration; Delaware Bay; habitat; stopover; conservation.

INTRODUCTION

Shorebirds spend up to two-thirds of the year in migration and on wintering grounds (Burger 1984a). Environmental conditions and food resources encountered in migration at stopover areas are important for survival and reproduction (Blem 1980, Meier and Fivizzani 1980, Myers 1983). The significance of stopovers in the ecology of long distance migrants has recently gained worldwide attention (Myers et al. 1987). Stopovers are especially important for migratory shorebirds (Charadriiformes: Charadridae and Scolopacidae) that, unlike most neotropical migrants, concentrate in small areas to accumulate energy reserves for continued flight (Morrison 1984, Senner and Howe 1984, Myers et al. 1987).

Because shorebirds travel as much as 30,000 km each year, they must take advantage of seasonally abundant food resources at intermediate stopover areas to build up fat reserves for the next long distance non-stop flight (Morrison and Harrington 1979). Protection of stopover areas is necessary for conservation of food and habitat resources and to manage migrant species dependent on them (Myers et al. 1987, Moore et al. 1990).

[1] Received 4 January 1993. Accepted 13 April 1993.

In this paper, we examine the spring migration and stopover behavior of shorebirds on Delaware Bay over seven years to understand the species, habitat use, and temporal patterns. Delaware Bay in New Jersey (NJ) and Delaware (DE) is a major spring stopover for shorebirds migrating from wintering grounds in South America to breeding grounds on the Arctic tundra (Senner and Howe 1984, Burger 1986, Harrington 1986, Myers et al. 1987). Between 300,000 and 600,000 shorebirds use Delaware Bay on migration (Senner and Howe 1984, Burger 1986), making it the second highest concentration of shorebirds in the Western Hemisphere during spring migration, next to the Copper River Delta on the Alaskan coast, where an estimated 20 million shorebirds pass on spring migration (Isleib 1979).

One reason that shorebirds concentrate on Delaware Bay is the abundant food resources provided by the large number of horseshoe crabs (*Limulus polyphemus*) spawning at the same time (Myers 1986). Horseshoe crabs deposit their eggs in the sandy bay beaches, providing a massive food resource for migrating shorebirds in May and June (Castro et al. 1989). Delaware Bay hosts the largest concentration of horseshoe crab spawning in their Atlantic coastal range (Shuster and Botton 1985, Botton and Ropes 1987).

Although Delaware Bay is recognized as a major stopover area, limited historic data are available on the number of shorebirds using the area. For nearby Atlantic coast sites in 1928–1938, Urner and Storer (1949) listed Semipalmated Sandpipers, Short-billed Dowitchers and Dunlin as abundant or very common, and Sanderlings, Red Knots, Ruddy Turnstones and Least Sandpipers (*Calidris minutilla*) as common or locally abundant in both spring and fall migrations (see Table 1 for scientific names of surveyed shorebirds). Stone (1937) also referred to these species as common in the Cape May region in spring, although he did not explicitly describe Delaware Bay as a major concentration area for migrating shorebirds. Consequently there are no data available on shorebird use of Delaware Bay before 1981 when Wander and Dunne (1981) censused shorebirds weekly from mid-May to mid-June, recording a total of 350,000 shorebirds of four species in one count in late May. In 1982, Burger (1986) surveyed Delaware Bay from April through October: peak daily counts of several individual species ranged from 45,000 to 133,000 in late May. The most abundant species in these studies were Semipalmated Sandpiper, Ruddy Turnstone, Red Knot, Sanderling and Dunlin. Kochenberger (1983) surveyed the bayshore during spring migration in 1983 and confirmed substantial numbers. Burger's (1986) survey was the only one to continue through fall migration. The southbound migration pattern for these species differs: of the most abundant species counted in spring, 3% of Semipalmated Sandpipers, 1% of Red Knots, 5% of Ruddy Turnstones and 63% of Sanderlings (also a winter resident) were counted on the bay July through October.

In 1985, the Endangered and Nongame Species Program of the New Jersey Division of Fish, Game and Wildlife began a yearly survey of all species to determine distribution and population trends as part of a long-term project to protect habitat important to migrating shorebirds on Delaware Bay. In this paper we examine shorebird abundance and distribution, and population trends of shorebirds using Delaware Bay during spring migration from 1986 through 1992. We were particularly interested in aspects of distribution and population trends that would aid in the development of a sound conservation and management strategy, and in determining population trends.

STUDY AREA AND METHODS

Delaware Bay is situated in the mid-Atlantic region of the United States (38°47′, 39°20′ lat. and 74°50′ to 75°30′ long., Fig. 1). Tidal amplitude in the bay is approximately 2.5 m. The lower bay region consists almost entirely of sandy beach, with very little adjacent tidal marsh (*Spartina* spp.). The upper New Jersey region beach is a mixture of sod and sand, with extensive adjacent tidal marsh. Beaches in the upper Delaware region are mostly sandy with considerable areas of adjacent tidal marsh. The upper regions of the bay also contain large river outflows that form sandy deltas. There is sparse development of residential buildings and bulkheads on both shores.

We obtained data on beach habitats from aerial photography, U.S. Geological Survey topographic maps, and aerial observation. We measured slope of the beach (represented by distance to a 2 m depth of water), distance to Delaware Bay salt marsh, and distance to the Atlantic Ocean. We measured the percent of sand on each beach by aerial photography and aerial survey observations. Human accessibility was measured as amount of road access and residential development along the shore.

We surveyed approximately 80 km in New Jersey and 80 km in Delaware. Survey flights were made once per week for six weeks, from 4 May to 12 June, in a Cessna high-wing airplane. We began our flights on the New Jersey side approximately 2 km north of the bay entrance and continued north to Cohansey Point, then to Woodland Beach in Delaware south to Cape Henlopen (Fig. 1). All flights were conducted on the falling tide, 3–4 hr after high tide, a period when birds were feeding on beaches (established by ground surveys). The aircraft was flown at an altitude of approximately 25 m, 30 m offshore and a speed of 110 km/hr. The plane temporarily flushed birds off the beaches as it passed, which facilitated counting and identification.

The survey crew included one biologist who counted birds in each flock, one who estimated the species composition of the flock, and one who recorded the information on U.S.G.S. topographic maps. The majority of shorebirds were identified to species; small birds of the genus *Calidris* were classified as "peep" when species could not be determined.

For each year we had six counts (at one week intervals) of shorebirds (except 1987 and 1988

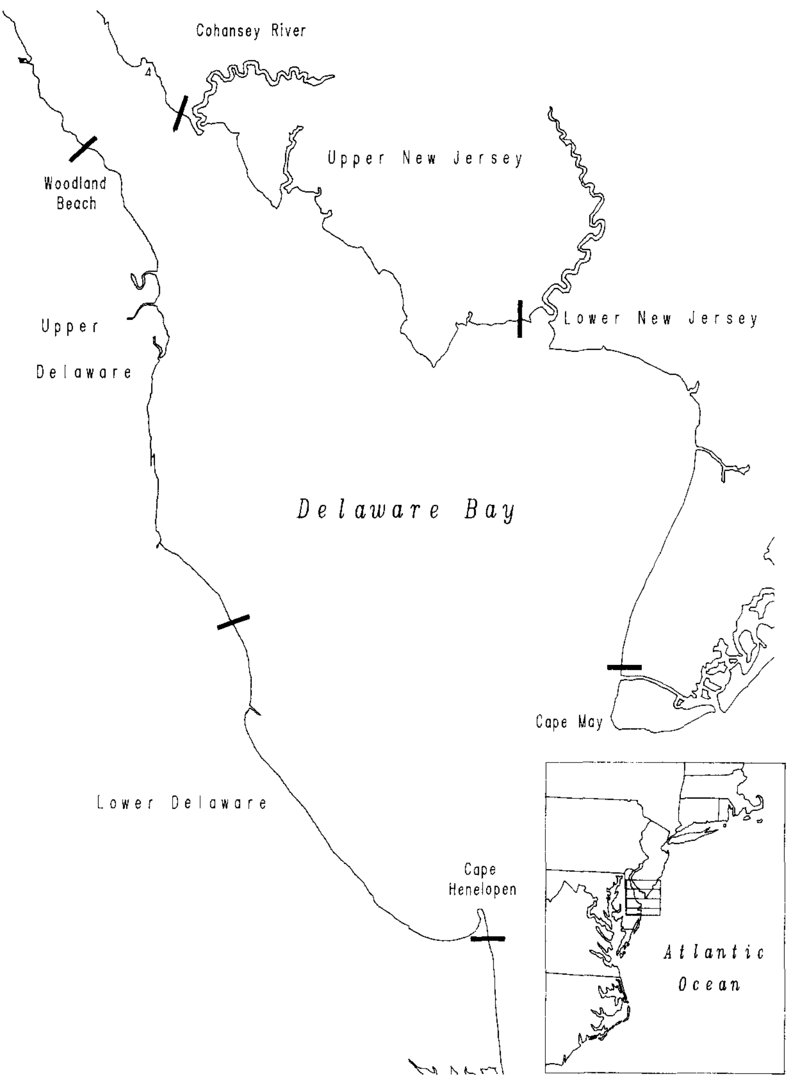

FIGURE 1. Delaware Bay is located between New Jersey and Delaware, on the mid-Atlantic coast. Shown are demarcations for regions of upper and lower New Jersey and Delaware.

when we missed two surveys each year because of inclement weather). We examined the census data for the seven years in three ways: (1) We used analysis of variance (ANOVA) procedures (Zar 1984, SAS Inst. 1985) on log-transformed data to examine the factors affecting species abundance, including year, region (defined as 40 km sections of upper and lower bay in New Jersey and Delaware), and survey (survey week number 1–6). (2) We used a regression procedure to examine trends in species counts over years. (3) We used regression procedures for each species to examine the factors accounting for their distribution along the bay. Factors examined for each beach included distance to marsh, distance to ocean, slope, percent sand, number of individuals of other species present and accessibility to people. Our model included a total R^2 for these species.

RESULTS

The most abundant species in our surveys were Semipalmated Sandpiper, followed by Ruddy Turnstone, Red Knot and Sanderling (Table 1).

TABLE 1. Average (of each yearly peak) and range of peak daily counts of six shorebird species in Delaware Bay on May–June, 1986–1992.

Species	Range of peak counts	Average peak count ($\bar{x} \pm$ SE)
Semipalmated Sandpiper (*Calidris pusilla*)	42,630 (1992)–267,348 (1986)	114,533 ± 32,576
Ruddy Turnstone (*Arenaria interpres*)	32,301 (1990)–105,160 (1989)	66,086 ± 9,665
Red Knot (*Calidris canutus*)	25,595 (1992)–94,460 (1989)	46,513 ± 8,888
Sanderling (*Calidris alba*)	5,305 (1991)–33,795 (1986)	14,719 ± 4,355
Dunlin (*Calidris alpina*)	2,474 (1989)–11,245 (1992)	5,870 ± 1,295
Dowitcher (*Limnodromus* spp.)	166 (1986)–6,335 (1992)	1,698 ± 805
Total shorebirds	105,985 (1990)–426,162 (1986)	216,177 ± 44,094

These four species accounted for 97% of shorebirds counted: Dunlin and Short-billed Dowitcher accounted for about 1%. Thus hereafter we consider these six main species.

Peak single day counts of total shorebirds ranged from 105,985 in 1990 to 426,162 in 1986, and averaged 216,177 shorebirds (Table 1).

Temporal and regional variations. We used ANOVA to examine the effect of temporal and regional variables on shorebird numbers in the bay. The models accounted for between 16% and 33% of the variation in shorebird numbers for each species (Table 2). Year, week and region of the bay significantly influenced the total number of shorebirds observed, but the influence was different on individual species (Table 2).

The number of all six species of shorebirds varied significantly over the seven year study period (Fig. 2). A regression analysis to examine trends in the peak counts showed a significant negative trend in Semipalmated Sandpiper and Sanderling. No trend was detected in other species.

As expected, the number of birds varied significantly over the six weeks of the study season. Overall, the peak count was between 27–30 May, when an average of 216,177 shorebirds was counted (Fig. 3). Red Knots, Ruddy Turnstones and Sanderlings peaked 26–30 May. Semipalmated Sandpipers usually peaked later (2–5 June). Dowitcher and Dunlin counts peaked earlier, 12–15 May and 19–22 May, respectively.

Region of the bay influenced all species when we considered all survey data. However, we also examined the distribution of species during their peak counts, when region was significant for only Sanderlings (Fig. 4). Sanderlings, during the peak of migration, were most abundant in the lower New Jersey region. Red Knots were observed evenly throughout the bay. Turnstones were most abundant in lower New Jersey and upper Delaware and Semipalmated Sandpipers were most abundant in upper Delaware, followed by upper New Jersey and lower New Jersey. Dunlin were most abundant in both upper bay regions, and dowitchers were most numerous in upper New Jersey region.

Distribution and habitat. Some beach habitat variables were important in the distribution of some species, with the regression accounting for

TABLE 2. Results of ANOVA test on log-transformed data. Given are *F*-values (df) and significance level, by shorebird species counted in aerial surveys of Delaware Bay beaches, 1986–1992.

	Species					
Variable	Red Knot	Ruddy Turnstone	Semipalmated Sandpiper	Sanderling	Short-billed Dowitcher	Dunlin
Year	3.54 (6)*	5.22 (6)**	27.38 (6)**	7.59 (6)**	17.40 (6)**	5.98 (6)**
Region	6.60 (3)**	7.87 (3)**	46.76 (3)**	32.04 (3)**	19.58 (3)**	9.62 (3)**
Survey	44.07 (5)**	82.53 (5)**	60.44 (5)**	15.26 (5)**	32.98 (5)**	30.12 (5)**
Region × Survey	1.48 (15)NS	2.41 (15)*	6.42 (15)**	3.48 (15)**	9.68 (15)**	3.56 (15)**
Survey × Year	3.82 (26)**	7.48 (26)**	14.49 (26)**	2.80 (26)**	13.82 (26)**	2.64 (26)**
Area × Year	4.77 (18)**	1.23 (18)NS	6.24 (18)**	2.88 (18)**	4.34 (18)**	1.84 (18)*
Model R^2	0.16	0.21	0.33	0.16	0.29	0.15

NS = Not Significant; * = significant at $P < 0.05$; ** = significant at $P < 0.0001$.

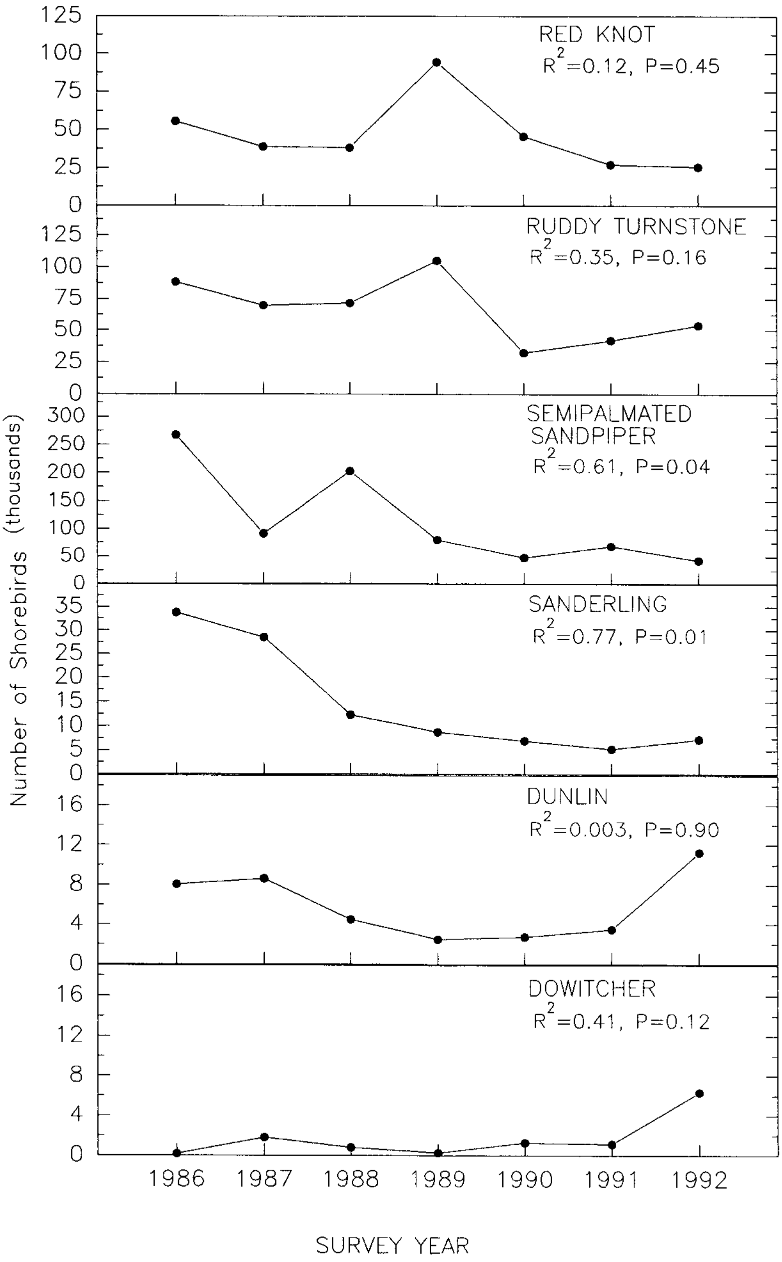

FIGURE 2. Peak single day counts of migrating shorebirds by year, from aerial surveys of Delaware Bay beaches, May–June 1986–1992. Regression statistics R^2 and P are given.

between 35% and 78% of the variation in distribution (Table 3). In New Jersey, greater numbers of knots were associated with shorter distance to Delaware Bay salt marsh, while more Sanderlings were associated with beaches farther from salt marsh. Semipalmated Sandpipers were associated with beaches farther from the Atlantic Ocean. Dowitchers were associated with low slope beaches. Dunlin were the only species negatively related to greater human access beaches. Knots

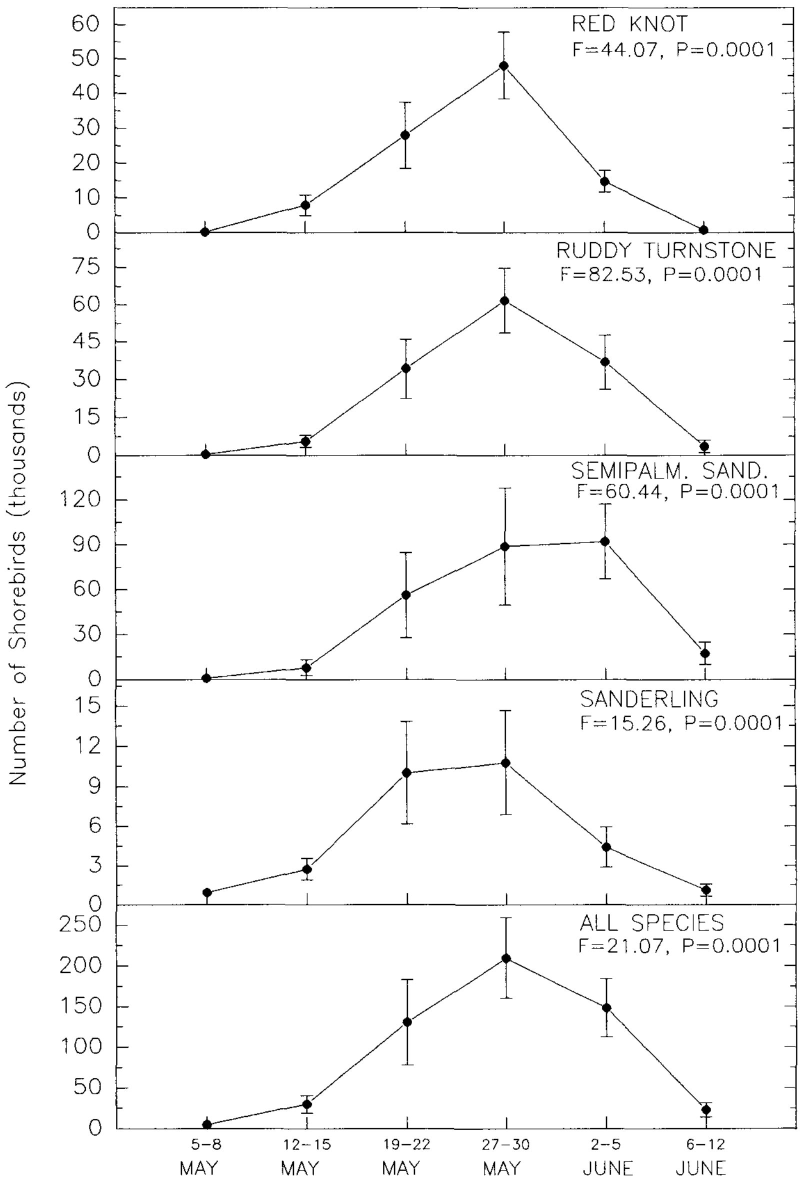

FIGURE 3. Peak single day counts of migrating shorebirds by week in aerial surveys of Delaware Bay beaches, May–June 1986–1992.

were associated with beaches higher in sand. All species showed a positive relationship with beaches having other species of birds present.

In Delaware, few habitat variables were significantly related to number of shorebirds (Table 3). More turnstones were associated with beaches of diminished sand composition. All species except Sanderlings and dowitchers were associated with beaches having other species of shorebirds present; dowitchers showed a negative relationship with those beaches. Sanderlings showed no significant relationship.

DISCUSSION

Methodological considerations. The costs of aerial surveys preclude daily counts, and in this

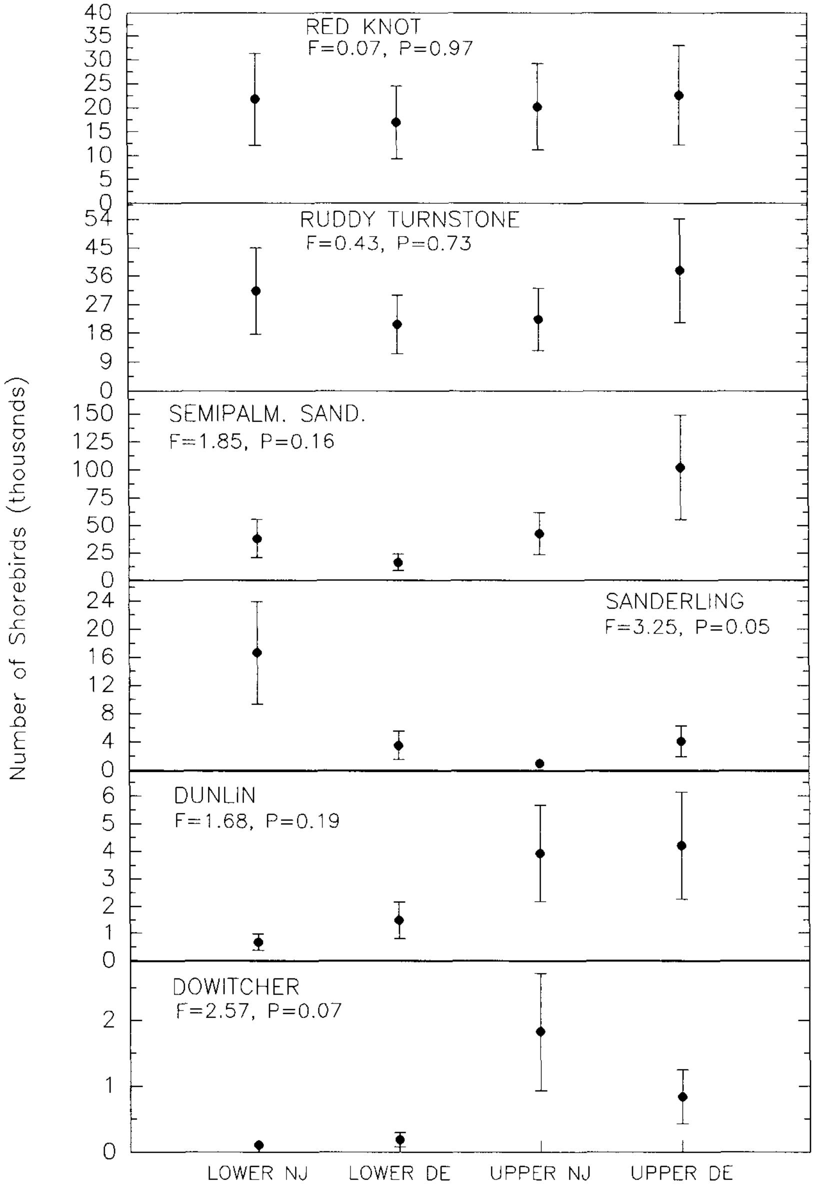

FIGURE 4. Mean peak count of shorebirds in four regions of Delaware Bay beaches, and ANOVA *F*-value and significance level, from aerial surveys May–June 1986–1992.

study we made weekly counts. Thus it was possible that we missed the absolute peak number of birds. However, since we expect that most shorebirds remain in the area for at least a week to build up adequate fat reserves (Hicklin 1987), our numbers should be fairly accurate.

In two of the seven years we were unable to survey during the third week (19–22 May) because of several days of bad weather. This would bias our estimates if the peak for any species consistently fell during this week, and if the individuals of this species remained in the bay for less than a week. As is clear from Figure 3, most species peaked in weeks 4 or 5. Only Sanderling peaked in week 3 in four of the five years when these data were available. Since we averaged our weekly counts only for the years available, this should not have biased our findings. Further, if

TABLE 3. Variables contributing significantly to the distribution of migrating shorebirds on Delaware Bay beaches. Given are the parameter estimates (probability levels) of each variable. Variable definition: Distance to marsh = distance to Delaware Bay salt marsh; Distance to ocean = distance to Atlantic Ocean; Slope = slope of beach as distance to 2 m water depth; Human access = level of human access, 0–6; % sand = surface sand composition; Other species = number of shorebirds of other species present.

	Distance to						Model	
Species	Marsh	Ocean	Slope	Human access	% sand	Other species	R^2	P
NJ								
Red Knot	−0.32 (0.0005)				0.01 (0.04)	0.13 (0.01)	0.45	0.0003
Ruddy Turnstone						0.29 (0.0001)	0.65	0.0001
Semipalmated Sandpiper		−0.37 (0.06)				0.24 (0.06)	0.28	0.03
Sanderling	0.33 (0.0002)					0.09 (0.02)	0.58	0.0001
Dowitcher			−0.01 (0.004)				0.40	0.001
Dunlin				−0.03 (0.02)		0.01 (0.06)	0.35	0.005
DE								
Red Knot						0.19 (0.001)	0.52	0.005
Ruddy Turnstone					−0.02 (0.01)	0.17 (0.001)	0.63	0.0001
Semipalmated Sandpiper						0.46 (0.05)	0.35	0.06
Sanderling							0.14	0.65
Dowitcher						−0.01 (0.05)	0.43	0.02
Dunlin						0.03 (0.0001)	0.78	0.0001

our data are biased by the missing data, they are an underestimate, rather than an overestimate.

Finally, since we do not know how long individuals remain in the bay, or whether the length of stay varies among species, we cannot accurately determine total populations for any species using the bay. Instead we use the total counted on all our censuses as an index of total abundance, and peak single day counts to compare among years.

Importance of Delaware Bay. Our surveys substantiate the importance of Delaware Bay as a migratory stopover for shorebirds. Peak single day counts averaged 216,000 shorebirds, with a high of over 426,000 shorebirds counted on one day in 1986. Peak day counts ranged between 106,000 and 426,000 for all species combined. Yearly total of shorebirds ranged between 624,000 in 1986 to 228,000 in 1991. Although we cannot estimate how many individual shorebirds these counts represent without knowing length of stay, our surveys place Delaware Bay among the ten largest staging sites in the Western Hemisphere, and second largest in spring (Senner and Howe 1984).

Another determinant of stopover importance is the portion of a species population in one location at one time (Senner and Howe 1984, WHSRN 1990). Our data suggest that major portions of Red Knot and Sanderling populations use Delaware Bay during the spring migration. We observed up to 94,460 Red Knots in a single count in 1989, 52% of the estimated 180,000 knots (Morrison and Harrington 1992) in the North American population. This corroborates Harrington's (1986) estimate that Delaware Bay hosts more knots than any other site in the Western Hemisphere. Almost 33,800 Sanderlings were counted in one day in 1986, 31% of the wintering population surveyed in South America (Morrison and Ross 1989). Hence Delaware Bay is significant for the northbound migration of at least four species, and especially significant for Red Knots and Sanderlings.

TRENDS

Peak counts of Semipalmated Sandpipers and Sanderlings showed significant declining trends over the seven year study period. The International Shorebird Survey (ISS), which surveys shorebirds on migration areas, also documented a decline in Sanderlings between 1975 and 1983, but not in Semipalmated Sandpiper (Howe et al. 1989). The ISS did document a significant decline in Short-billed Dowitcher, which we did not find in our surveys. However, dowitchers comprised a minor proportion of shorebirds surveyed on Delaware Bay beaches.

Counts of Red Knots and Ruddy Turnstones reflected substantial annual variation. Possible causes of variation include abiotic factors such as weather-related variables. A cool spring may delay horseshoe crab spawning, reducing spring food availability and limiting areas of shorebird concentration. Thus, birds are more widely dispersed along the bay and Atlantic coast in cool springs. Unusual wind and rain conditions may also affect distribution and length of stay, causing variations in shorebird activity and habitat selection (Burger 1984b). Annual fluctuations in conditions in other areas of the Atlantic coast, such as nutrient fluctuations, might result in unusually high food resources for shorebirds elsewhere, and lead to a reduction in the numbers stopping over in Delaware Bay. Thus differences in the number of birds on the bay may reflect stopover patterns rather than population trends of North American populations. Nonetheless, a consistent downward trend such as occurred for Sanderlings is worrisome, particularly since it was not reflected in other species.

The birds' body condition (fat reserves) may diminish the necessity of stopping on the bay or of stopping for very long. For example, some Red Knots stop over in the southern Atlantic Coast when resources are available (Harrington, pers. comm.), which may reduce the number of knots stopping on Delaware Bay. However, there is no evidence of other major stopover areas for spring migrants along the Atlantic coast, so most birds arriving on Delaware Bay have made journeys of 2,800–3,200 km, and generally are in low body condition. Dunn et al. (1988) found that length of stay of Semipalmated Sandpipers in eastern Maine was related to body fat content, but beyond some body fat threshold other factors, such as weather, became more likely determinants of migratory flight. On Delaware Bay, most shorebirds require a stopover to regain mass, both to complete the northward migration and maintain suitable body condition for breeding. We have found masses of Red Knots and Semipalmated Sandpipers to be generally low early in the period (e.g., May 15–20) and high toward the end (e.g., May 27–30) (Clark and Niles, unpubl. data). This argues for individuals remaining for some period.

DISTRIBUTION WITHIN THE BAY

Tide cycles influence the distribution of shorebirds in many beach and marsh environments as they alter habitat availability (Burger et al. 1977, Connors et al. 1981, Fleischer 1983, Burger 1984a, 1984b, Burger and Gochfeld 1991). We controlled for tide and beach area availability by beginning surveys near low tide, but shorebird distribution on the bay may also be influenced by proximity of particular beaches to other habitats. Adjacent tidal marshes may provide alternate feeding and resting areas as tidal waters limit beach area, or for species that prefer marsh over beach. The distribution of marsh may influence the distribution of species such as Semipalmated Sandpiper, Dunlin and dowitcher, which feed in marsh-mudflat habitats throughout their range (Urner and Storer 1949, Weir and Cooke 1976, Schneider and Harrington 1981, Connors et al. 1979). Red Knots and Ruddy Turnstones, less associated with mudflat in other parts of their range, were found evenly along the bay beaches. Knots and turnstones may not be as limited by location of salt marsh for roosting and resting when beach size is reduced by high tide, and could use either bay or Atlantic coastal marshes equally. Our data showed that proximity to salt marsh in New Jersey was important for Semipalmated Sandpipers and knots. Sanderlings were more abundant at beaches distant from marsh, and thus closer to Atlantic Ocean beaches. No relationship to marsh was found for birds on the Delaware side of the bay, which was expected because most beaches there are adjacent to marsh, and distant from Atlantic coast beaches.

It is likely that the counts of Semipalmated Sandpipers, Dunlin and dowitcher are underestimated by our surveys of beach habitat only. Shorebird counts in Delaware Bay salt marsh by helicopter in May 1992 indicated that an additional 15–20% Semipalmated Sandpipers may be using marshes and are not counted on beaches (Clark and Niles unpubl. data). Similarly, an estimated 30% more Dunlin were observed in salt marsh habitat, and dowitchers were estimated at 10 to 20 times the count from beach surveys. These species may be numerous on the marshes of Delaware Bay due to their preference for tidal mudflats and salt marshes (Urner and Storer 1949, Weir and Cooke 1976, Myers et al. 1979, Connors et al. 1979, Hicklin 1987).

The beach variables measured (slope and percent sand) did not consistently influence the distribution of shorebirds. Human access, measured as road access and residential development, did not influence the distribution of shorebirds except for Dunlin in New Jersey. This may be because road access is not well correlated with human use of beaches.

Another variable that could influence distribution of any species is the number of birds of other species present. However, Recher (1966) indicated shorebirds on migration have greater tolerance to reduce competitive exclusion. For most species in this study, abundance of one species was positively related to abundance of other species, indicating that certain beaches held resources that concentrated several species. This was the case for all species except dowitcher in New Jersey, and all species except Sanderling and dowitcher in Delaware. The relationships we observed did not indicate exclusion of species, but this was not studied directly.

CONSERVATION OF MIGRANT SHOREBIRDS ON DELAWARE BAY

Our study corroborates earlier findings that Delaware Bay ranks as one of the most important shorebird stopover areas in the Western Hemisphere. Delaware Bay is also one of the largest shipping ports and one of the most densely populated areas in the United States (Karish 1988, Mangone 1988). There are severe threats to habitats and resources in Delaware Bay that are critical to shorebirds during migration, including horseshoe crab over harvest, direct development, human disturbance, and the potential effects of toxic accidents. Human disturbance is a serious problem to migrating shorebirds, often displacing shorebirds from prime foraging areas (Burger 1986, Burger and Gochfeld 1991, Clark et al. 1986). An oil spill prior to or during the migration period would not only kill some birds, but would make food unavailable, and might cause birds to suspend further migration. Toxic materials could cause direct mortality to large numbers of birds. Habitat degradation (e.g., salt marsh modification) or loss by development would cause reduction in feeding and roosting areas.

We suggest that conservation of critical Delaware Bay resources requires bay-wide coordination and management for the long term protection of shorebirds. Issues to be addressed include spill response planning, protection of shorebirds from disturbance, habitat acquisition and protection, and nonconsumptive user management.

ACKNOWLEDGMENTS

This was a cooperative study between New Jersey Division of Fish, Game and Wildlife, Endangered and Nongame Species Program and Delaware Division of Fish and Wildlife, Nongame and Endangered Species Program. We thank L. Gelvin-Innvaer, J. Dowdell, P. Dunne, and J. Thomas for assistance in field work, and L. Gelvin-Innvaer for funding assistance. We thank R. Trout for valuable statistical advice, and S. Paul for map preparation. Funding for this study was provided through New Jersey Natural Lands Trust, New Jersey Division of Fish, Game and Wildlife and Delaware Fish and Wildlife.

LITERATURE CITED

BLEM, C. R. 1980. The energetics of migration, p. 175–224. *In* S. A. Gauthreaux, Jr. [ed.], Animal migration, orientation, and navigation. Academic Press, New York.

BOTTON, M. L., AND J. W. ROPES. 1987. Populations of horseshoe crabs, *Limulus polyphemus,* on the northwestern Atlantic continental shelf. Fish. Bull. 85:805–812.

BURGER, J. 1984a. Shorebirds as marine animals, p. 17–81. *In* J. Burger and B. L. Olla [eds.], Behavior of marine animals, vol. 5: Shorebirds: breeding behavior and populations. Plenum Press, New York.

BURGER, J. 1984b. Abiotic factors affecting migrant shorebirds, p. 1–72. *In* J. Burger and B. L. Olla [eds.], Behavior of marine animals, vol. 6: Shorebirds: migration and foraging behavior. Plenum Press, New York.

BURGER, J. 1986. The effect of human activity of shorebirds in two coastal bays in Northeastern United States. Environ. Conserv. 13:123–130.

BURGER, J. AND M. GOCHFELD. 1991. Human activity influence and diurnal and nocturnal foraging of sanderlings (*Calidris alba*). Condor 93:259–265.

BURGER, J., M. A. HOWE, D. C. HAHN, AND J. CHASE. 1977. Effects of tide cycles on habitat selection and habitat partitioning by migrating shorebirds. Auk 94:743–758.

CASTRO, G., J. P. MYERS, AND A. R. PLACE. 1989. Assimilation efficiency of Sanderlings (*Calidris alba*) feeding on horseshoe crab (*Limulus polyphemus*) eggs. Physiol. Zool. 62:716–731.

CLARK, K. E., L. NILES, AND P. D. MCLAIN. 1986. Determining management needs of migrating shorebirds on Delaware Bay, New Jersey (abstract). Transactions of Northeast Section, The Wildlife Society 41:218.

CONNORS, P. G., J. P. MYERS, AND F. A. PITELKA. 1979. Seasonal habitat use by Arctic Alaskan shorebirds, p. 101–111. *In* F. A. Pitelka [ed.], Stud. Avian Biol. No. 2.

CONNORS, P. G., J. P. MYERS, C. S. W. CONNORS, AND F. A. PITELKA. 1981. Interhabitat movements in Sanderlings in relation to foraging profitability and the tidal cycle. Auk 98:49–64.

DUNN, P. O., T. A. MAY, AND M. A. MCCOLLOUGH. 1988. Length of stay and fat content of migrant Semipalmated Sandpipers in eastern Maine. Condor 90:824–835.

FLEISCHER, R. C. 1983. Relationships between tidal oscillations and Ruddy Turnstone flocking, foraging, and vigilance behavior. Condor 85:22–29.

HARRINGTON, B. A. 1986. Red knot, p. 870–886. *In* R. L. DiSilvestro [ed.], Audubon wildlife report 1986. National Audubon Society, New York.

HICKLIN, P. W. 1987. The migration of shorebirds in the Bay of Fundy. Wilson Bull. 99:540–570.

HOWE, M., P. H. GEISSLER, AND B. A. HARRINGTON. 1989. Population trends of North American shorebirds based on the International Shorebird Survey. Biol. Conserv. 49:185–199.

ISLEIB, M. E. 1979. Migratory shorebird populations on the Copper River Delta and eastern Prince William Sound, Alaska, p. 125–129. *In* F. A. Pitelka [ed.], Stud. Avian Biol. No. 2.

KARISH, J. F. 1988. Outdoor recreation along the Delaware River, p. 360–378. *In* S. K. Majumdar, E. W. Miller, and L. E. Sage [eds.], Ecology and restoration of the Delaware River basin. Pennsylvania Academy of Science. Philadelphia.

KOCHENBERGER, R. 1983. Survey of shorebird concentrations along the Delaware Bayshore, spring 1983. Peregrine Observer, Fall 1983:3–4.

MANGONE, G. J. 1988. Ports and terminals in the Delaware River basin, p. 273–285. *In* S. K. Majumdar, E. W. Miller, and L. E. Sage [eds.], Ecology and restoration of the Delaware River Basin. Pennsylvania Academy of Science. Philadelphia.

MEIER, A. H., AND A. J. FIVIZZANI. 1980. Physiology of migration, p. 225–282. *In* S. A. Gauthreaux, Jr. [ed.], Animal migration, orientation, and navigation. Academic Press, New York.

MOORE, F. R., P. KERLINGER, AND T. R. SIMONS. 1990. Stopover on a Gulf Coast barrier island by spring trans-gulf migrants. Wilson Bull. 102:487–500.

MORRISON, R. I. G. 1984. Migration systems of some New World shorebirds, p. 125–202. *In* J. Burger and B. L. Olla [eds.], Behavior of marine animals, vol. 6: Shorebirds: migration and foraging behavior. Plenum Press, New York.

MORRISON, R. I. G., AND B. A. HARRINGTON. 1979. Critical shorebird resources in James Bay and eastern North America. Trans. N. Am. Wildl. Conf. 44:498–507.

MORRISON, R. I. G., AND R. K. ROSS. 1989. Overview, p. 27–71. *In* R. I. G. Morrison and R. K. Ross [principal authors], Atlas of nearctic shorebirds on the coast of South America (Vol. 1). Can. Wildl. Serv., Ottawa.

MORRISON, R. I. G., AND B. A. HARRINGTON. 1992. The migration system of the Red Knot (*Calidris* *canutus*) in the New World, p. 71–84. *In* T. Piersma and N. Davidson [eds.], The migration of Knots. Wader Study Group Bulletin 64 Supplement.

MORRISON, R. I. G., R. K. ROSS, AND B. DE JONG. 1989. The Guianas, p. 167–177. *In* R. I. G. Morrison and R. K. Ross [principal authors], Atlas of nearctic shorebirds on the coast of South America (Vol. 2). Can. Wildl. Serv., Ottawa.

MYERS, J. P. 1986. Sex and gluttony on Delaware Bay. Nat. Hist. 95:68–77.

MYERS, J. P. 1983. Conservation of migrating shorebirds: staging areas, geographic bottlenecks, and regional movements. Am. Birds 37:23–25.

MYERS, J. P., R. I. G. MORRISON, P. Z. ANTAS, B. A. HARRINGTON, T. E. LOVEJOY, M. SALABERRY, S. E. SENNER, AND A. TARAK. 1987. Conservation strategy for migratory species. Am. Sci. 75:18–26.

MYERS, J. P., P. G. CONNORS, AND F. A. PITELKA. 1979. Territoriality in non-breeding shorebirds, p. 231–246. *In* F. A. Pitelka [ed.], Stud. Avian Biol. No. 2.

RECHER, H. F. 1966. Some aspects of the ecology of migrant shorebirds. Ecology 47:393–407.

SAS INSTITUTE. 1985. SAS user's guide: statistics, Version 5th Ed. Cary, NC.

SCHNEIDER, D. C., AND B. A. HARRINGTON. 1981. Timing of shorebird migration in relation to prey depletion. Auk 98:801–811.

SENNER, S. E., AND M. A. HOWE. 1984. Conservation of nearctic shorebirds, p. 379–421. *In* J. Burger and B. L. Olla [eds.], Behavior of marine animals, vol. 5: Shorebirds: populations and breeding behavior. Plenum Press, New York.

SHUSTER, C. N., AND M. L. BOTTON. 1985. A contribution to the population biology of horseshoe crabs, *Limulus polyphemus* (*L.*), in Delaware Bay. Estuaries 8:363–372.

STONE, W. 1937. Bird Studies at Old Cape May, Vol. 1. Dover Publishing, New York.

URNER, C. A., AND R. W. STORER. 1949. The distribution and abundance of shorebirds on the north and central New Jersey coast, 1928–1938. Auk 66: 177–194.

WEIR, R. D., AND F. COOKE. 1976. Autumn migration of shorebirds in the Kingston area of Ontario, 1964–1974. Can. Field-Nat. 90:103–113.

WANDER, W., AND P. DUNNE. 1981. Species and numbers of shorebirds on the Delaware Bayshore of New Jersey—Spring 1981. Occas. Paper No. 140. Records of New Jersey Birds 7(4):59–64.

WHSRN. 1990. Western Hemisphere Shorebird Reserve Network. Manomet, MA.

ZAR, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, NJ.