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FACTORS AFFECTING REPRODUCTION AND MIGRATION OF WATERBIRDS ON THE NORTH CAROLINA BARRIER ISLANDS

Final Report

to the

National Park Service

Cape Hatteras and Cape Lookout Seashores

by

Jaime A. Collazo

North Carolina State University
Department of Zoology
Raleigh, NC 27695

Jeffrey R. Walters

Virginia Polytechnic Institute and State University
Department of Biology
Blacksburg, Virginia 24061

and

James F. Parnell

Department of Biological Science
University of North Carolina at Wilmington
Wilmington, North Carolina 28403

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PROJECT SUMMARY

This project was designed to study three aspects of the ecology of aquatic birds in the Outer Banks of North Carolina, namely, (1) to assess the seasonal abundance and distribution of aquatic birds, and for selected shorebird species, assess the relative importance of outer beach habitats on the Outer Banks; (2) study the effects of human disturbance on aquatic species using the outer beach habitats; and (3), study the breeding biology of Piping Plover (Charadrius melodus) and factors affecting their reproductive success. Over 110,000 individuals of 21 species of shorebirds were found during the study, the most abundant being Sanderling, Red Knot, and Willet. Shorebirds were most abundant in May and August and the greatest numbers occurred on North Beach. The annual and seasonal abundances of eight species of shorebirds were examined in detail. For four species (Piping Plover, Whimbrel, Red Knot, and Sanderling), the Outer Banks appear to be an important staging area for the Atlantic Coast populations. Portsmouth Flats and the Core Sound side of North Core Banks were censuses as well. A total of 27 species of shorebirds, 5 species of gulls, and 9 species of terns were detected on censuses. Shorebirds were most numerous on the flats from November to May. Several shorebird species found on the flats in moderate to large numbers (i.e. Greater Yellowlegs, Marbled Godwit, Semipalmated Sandpiper, Western Sandpiper, Dunlin, Short-billed Dowitcher) were scarce on the beaches, probably because these species preferred tidal flats over sandy beaches. Gulls were most numerous on the flats from July to November, though numbers were low compared to beach counts. Laughing Gulls were the most numerous

species, with good numbers of Herring Gulls as well. Gull diversity was similar to that of outer beaches, except that Bonaparte's Gulls did not occur on the flats. Terns were most numerous on the flats from May to October. Most were Forster's and Least terns and Black Skimmers. As with the gulls, they were probably using the flats as a roosting place. On the Core Sound side of North Core, High Hills, Mile 9 and Old Drum Inlet were censused. High Hills was the location where the highest numbers of any aquatic group was recorded. Shorebirds were most abundant during spring. Gulls did not exhibit strong seasonal patterns, with counts ranging from 50 to 100 individuals. Counts were, by and large, evenly distributed among the three count locations. Terns, in contrast, exhibited strong seasonal trends. Highest counts were recorded in spring and fall. Herons also exhibited a strong seasonal patterns of high counts during spring and fall. Additional species observed in the Flats or Core Sound-North Core were the Brown Pelican, Double-crested Cormorant, White Ibis, Canada Goose, American Black Duck, and Clapper Rail.

Another aspect of the study dealing with shorebirds was an effort to quantify the population dynamics and turnover rates of migrant Sanderlings. This species is one of the most abundant in the Outer Banks but is one exhibiting population declines throughout eastern North America. This information allow us to learn more about the role of the Outer Banks as migratory stopover and where does it fit relative to other stopover sites along the eastern seashore. A total of 964 Sanderlings was individually marked in 1993 to estimate residence probabilities and population size using the Jolly-Seber model. Birds remained on the Outer Banks, on average, about two weeks in spring and for nearly four weeks in fall. Sanderlings of two body mass classes had different residence probabilities in fall, but not in spring. The Sanderling population using the Outer Banks was estimated at 35-40,000 birds, with the majority present during fall. According to the Western Hemisphere Shorebird Reserve Network, the Outer Banks are a site of regional importance. A comparison of population estimates generated from the mark-resight study with those from beach censuses revealed that the mark-resight estimates were consistently higher. Beach counts of Sanderlings, when multiplied by a factor of 1.235, provided reasonable estimates of the number present based on the results of this study. The Outer Banks appear to be an important staging area for Sanderlings. It ranked as the site with the highest peak count during fall migration when compared to seven other sites along the Atlantic Coast. Delaware Bay in New Jersey is the only site to record higher peak counts than those on the Outer Banks. The demographic implications of these results are clear. The Outer Banks of North Carolina provide a critical link in the migratory path of several shorebird species. Significant portions of the Atlantic Coast populations of some species may depend on the Outer Banks to complete their annual migrations. This detailed study of Sanderlings hints at the implications of habitat loss or alteration on the Outer Banks. If such losses were to occur, a significant portion of the Atlantic Flyway population of sanderlings would be negatively impacted, perhaps exacerbating population declines. Other shorebird species could be similarly affected. Given the regional significance of this area, further protection for shorebirds under the guidelines of the Western Hemisphere Shorebird Reserve Network is necessary.

Impacts of human use of barrier island beaches on shorebirds along North Carolina's Outer Banks were determined during a 16-month period (April 1992 - July 1993) by observing shorebird numbers and behavior relative to human activities in six pairs of beach plots. Within each pair, one plot was open to human use and the other was closed to all human traffic. Human beach use peaked in the fall, coinciding with shorebird migration and highest shorebird numbers. Human disturbance levels decreased from time of high tide to low tide. More shorebirds were observed within plots closed to humans than in open areas. Shorebirds were also more abundant during intermediate and low-tide phases than high tide. Shorebirds spent more time foraging during periods of low and intermediate tide than at high tide. Although time spent foraging did not differ significantly between open and closed plots, high levels of human activity may have reduced shorebirds' feeding efficiency by disrupting flocking behavior along the intertidal beach. More time was spent resting on upper beach areas during high tide than during other tide phases. Resting time was reduced by nearly 50 percent in areas open to human activity. Beach closures were effective in increasing resting times and providing uninterrupted foraging areas for of shorebirds. Beach closures were effective in increasing resting times and providing uninterrupted foraging areas for shorebirds.

Colonial waterbirds are doing well at both Cape Hatteras and Cape Lookout. Both parks provide nesting habitat for significant regional populations of nesting colonial waterbirds. Reproductive success appears to be good, and the management strategy of posting colony sites and providing patrol of these sites appears to be effective. Protection of nesting sites has allowed beach nesters to be successful most years in spite of heavy use of beaches by people. This strategy is now being copied by the State of North Carolina at Ft. Fisher and is allowing nesting to be successful there as well. Primary threats to beach nesting within the national seashores appear to be overwash and vegetative encroachment. Predation, especially by mammals such as feral cats (*Felis domesticus*) and raccoons (*Procyon lotor*) may also be important occasionally. Overwash may destroy colonies when it occurs during the nesting season, but will likely be beneficial in the long run, as it helps to maintain the open sandy beach that is used by nesting terns and skimmers. Encroachment of beach nesting sights by plants is a normal part of the succession of overwash communities. Growth is slowed by frequent overwash and now by the action of ORVs. When colony sites are posted throughout the year, vegetation may grow rapidly and the period of use by nesting terns and skimmers will be shortened. Under natural conditions the birds would be expected to move to new bare areas elsewhere up or down the beach or to offshore dredged-material islands. This is much more difficult now that much beachfront is developed and dredging practices no longer result in the regular deposition of new surfaces on islands along dredging channels.

To assure that important sites where nesting birds are successful and where management is possible, we recommend that ORV traffic be allowed in such key colony sites as Cape Point, Hatteras Inlet, Power Squadron Spit, and the west end of Shackleford Island during the fall and winter to assist in maintaining the bare or nearly bare upper beach habitat necessary for nesting terns and skimmers. Terns and skimmers that nest on bare or nearly bare sites need the most assistance. Laughing Gulls, nesting in dense *Spartina patens* meadows on islands along the sound are in habitat that is abundant and that will persist for relatively long periods. These are also areas little used by people and so human disturbance is less frequent. We do recommend that such sites be posted and visited occasionally by park personnel. Herons and egrets usually nest in dense thickets along the back side of the barrier island or on old offshore islands where thickets have developed. There appears to be sufficient habitat, and such sites may be utilized for many years by nesting birds. Human disturbance is most unlikely as such places are decidedly inhospitable. Such sites should, however, be posted. The exception to the natural safety of such sites is when a site is a potential target for development as is the case for the colony near Ocracoke Village.

Because of its threatened status on the East Coast, the piping plover and its breeding success was of special interest to our study of shorebirds in CAHA and CALO. CAHA and CALO certainly represent the principal breeding sites for piping plovers in North Carolina, where productivity historically has been low. Being at a lower latitude and along the edge of the species' breeding range, habitat and conditions for piping plovers breeding in North Carolina are different than those experienced by birds in northern regions, where most previous piping plover research has been conducted. These previous studies have determined major factors that affect reproductive success in northern regions such as human disturbance, habitat loss and predation. A major goal of our study was to determine how these and other possible factors may be influencing production by piping plovers on North Carolina seashores.

We surveyed breeding population size from 1992-1994. The number of breeding pairs increased slightly at CALO and remained steady at CAHA. Reproductive success for the two seashores was quite low and was lower than the average for Atlantic coast plovers. We monitored a total of 196 piping plover nests on CAHA and CALO from 1992-1994. Of these nests, 132 (67%) did not hatch, 47 (24%) produced fledglings, and 17 (9%) hatched but fledged no chicks. Of all hatched nests, 73% fledged at least one chick. These general statistics illustrate that on CAHA and CALO, piping plover reproductive success is most strongly affected by factors reducing hatching success.

A major factor affecting hatching success was predation. Over the three years of our study, predation accounted for 34% of nest losses on CAHA and CALO. We employed predator exclosures experimentally on CALO during the 1993 and 1994 breeding seasons, and on CAHA during the 1994 breeding season. Of 46 exclosed nests, 25 (54%) hatched, and of 76 control nests, 14 (18%) hatched, which was a significant difference ($X^2 = 18.88$, $p<.0001$, df=1). Depending on prevailing weather pattern during the breeding season, flooding was an additional factor affecting hatching success, especially on CALO. In 1994, 37% of the nests found in both parks were lost due to flooding. Flooding of piping plover nesting areas is particular to North Carolina (storms of this nature are much less common in more northern areas [George Lemon, NWS; pers. com.]), and may help explain why piping plover productivity is usually low.

Observations of breeding pairs were conducted to better understand the factors of human disturbance, temperature, foraging habitat use and predation in terms of their possible effect on productivity. We also investigated the nature of interactions between adults and chicks during brood rearing in detail, in order to better understand the determinants of successful reproduction. Through our observations of incubating adults and adults tending chicks, we found that piping plovers are only rarely disturbed by encounters with vehicles, planes or humans on foot. More consequential disturbances were caused by interactions with natural predators and competitors. Due to the nature of the piping plover habitat in these two parks (containing interior washover areas which are preferred by piping plovers for nesting and foraging), interaction between humans and piping plovers is slight. At this present level of park use, park closures would likely have minimal effect on piping plover reproductive success.

Over our three year study, piping plovers in North Carolina exhibited an interesting demographic pattern: reproductive success was very low while the population numbers increased slightly. To understand this pattern, basic information on population dynamics must be ascertained. We discuss the possibilities and information needed to know how the population of piping plovers is regulated in North Carolina. Determining how the population is regulated, including and understanding of differences in biology related to an extreme southern and peripheral location, is the key to devising appropriate management.

Our brief study of piping plover breeding biology has revealed that factors affecting reproductive success in North Carolina are different than those in northern regions. Being along the edge of the piping plover's breeding range and at a lower latitude, the environment at North Carolina seashores is likely to have different conditions for survival and reproduction. Storms in the early part of the breeding season cause breeding losses and delays, and high temperatures, especially late in the breeding season, impose heat stress that may indirectly cause chick mortality. For these reasons, productivity goals set in the recovery plan (1.5 fledged chicks/pair/year), established from studies of more northern populations, are probably unrealistic for North Carolina. Still, productivity can be improved over current levels, especially through use of predator exclosures. The little information that exists suggests that more realistic productivity levels may be sufficient to increase the population.

We make the following recommendations to help enhance the populations of CAHA and CALOI: (1) Continue to use predator exclosures on all piping plover nests. (2) Monitor exclosures to record any instances of predation or accumulation of sand over the nest. If raccoons learn to dig under the fencing, the fencing should be buried deeper (eight inches instead of four). If raccoons climb the fencing, the netting should be attached more securely to the fencing (as was done in 1995 on CALO). Exclosures should be monitored at least every other day according to USFWS guidelines. If sand builds up over the nest due to the exclosure (as happened at mile 3 on CALO), the exclosure should be removed. (3) If "smart" predators (raccoons, crows, gulls) continue to cue to exclosures and consume eggs/chicks or cause nest abandonment, predator removal should be conducted where feasible. (4) Monitor mink predation on Ocracoke. Predator removal may have to be initiated to prevent the spread of the mink population. (5) Continue vegetation removal at Cape Point along the south shore of the brackish pond. To delay the regrowth of vegetation in these treated areas, it may be beneficial to use raking machinery after disking to prevent vegetative growth from cuttings. Growth of vegetation in other piping plover foraging and nesting areas of CAHA should be monitored; additional areas may need to be maintained. Preservation of interior wet and mud flats on CAHA is critical; otherwise piping plovers may only find suitable foraging habitat along the ocean intertidal zone where human disturbance is a problem. (6) At present, beach closures are unnecessary and are not likely to favorably impact breeding piping plovers on the islands. (7) Piping plover population numbers and reproductive success must be consistently monitored so that reliable population trends can be tracked as a means to determine how the NC population is maintained.

General Introduction

and

Project Objectives

The North Carolina estuaries and barrier islands extend for 500 km north (Virginia) to south (South Carolina) (Parnell and Soots 1979). The Cape Hatteras (CAHA) and Cape Lookout (CALO) National Seashores are located along the barrier islands and encompass 161 km of the islands system. These islands provide habitat for nesting, migratory and wintering waterbirds. Available information suggested that at least 20,000 shorebirds used the barrier islands as stopover areas during fall and spring each year (Senner and Howe 1984). The Outer Banks is used as wintering habitat by about 47 shorebird, seabird and wading bird species (Root 1975). Of these species, the Piping Plover (Charadrius melodus) is federally and State listed, and Sanderlings (Calidris alba), Short-billed Dowitchers (Limnodromus griseus) and Whimbrels (Numenius paeopus) have undergone significant population declines (Howe et al. 1989). The barrier islands also serve as nesting grounds for shorebirds, wading and sea birds (Coutu et al. 1990, Parnell and Soots 1979, Parnell and Shields 1990). Parnell and Shields (1990) identified 125 nesting sites for 25 species of colonial waterbirds in coastal North Carolina. Of these, 16 were located within the two National Seashores Parks (CAHA & CALO). Species nesting in the Seashores included various herons, Least Terns (Sterna albifrons), Common Terns (Sterna hirundo), Gull-billed Terns (Gelochelidon nilotica) and Black Skimmers (Rynchops nigra). Unfortunately, complementary information on migratory and wintering shorebirds for the National Seashores is not available or is fragmentary at best. Descriptive information on shorebird migrations is available for Cape Hatteras (Buckley and Buckley 1973, Boone 1988), but estimates on numbers using the National Seashores is not, especially for Cape Lookout.

Colonial nesting as well as migratory and wintering waterbirds are particularly vulnerable to habitat alterations and degradation, and human disturbance (Myers 1983, Senner and Howe 1984, Myers et al. 1987, Parnell and Shields 1990, Pfister et al. in press). Parnell and Shields (1990) documented the use of a wide array of habitats by nesting waterbirds in the barrier islands and underscored the need for habitat management and protection. Parnell et al. (1989) noted that significant habitat changes occurred in the Cape Hatteras National Seashore during the past 25 years. In particular, the abundance of grassland and sparsely vegetated upper beach has decreased, and large sections of high beach have become vegetated. Some of these changes occurred on sites that at one time had significant numbers of ground-nesting terns and shorebirds. Migratory shorebirds concentrate and depend on stopover areas to complete their annual migratory cycle. Demographic parameters such as overwintering survival rates and subsequent reproductive output can be significantly affected by the quality of these areas and their continued availability (Myers et al. 1985). These habitats are equally important to wintering waterbirds, particularly those undergoing population declines (Howe et al. 1989). Information on abundance and distribution, and nesting locations of waterbirds throughout the year is necessary to design appropriate management strategies ensure the availability of suitable habitat for this avian assemblage.

The response of waterbirds to human disturbance is complex: responses are species-specific and often seasonally dependent. Human activities may affect a species either directly by disturbing individual birds repeatedly while feeding or nesting (Pomerantz et al. 1988, Erwin 1989, Belanger and Bedard 1989 & 1990, Parnell and Shields 1990); or it may affect a species indirectly by altering the structure of its habitat (Buckley and Buckley 1973, Parnell et al. 1989), introducing new predators or competitors to the system (Kress 1983, McKitrick 1975), altering the abundance of important food sources, or contaminating critical feeding areas (Ohlendorf et al. 1979).

Human activity on Atlantic coast beaches has apparently contributed to declines of species, such as the piping plover, that use these areas for nesting (Parnell and Soots 1979, Erwin 1979, Flemming et al. 1988). This species nests and winters at Cape Hatteras and Cape Lookout National Seashores in areas that experience moderate to high levels of human disturbance (Gifford 1974 & 1977; Golder 1985 & 1986; Nicholls and Baldassare 1990a & 1990b, Coutu et al. 1990). Beaches in several areas (e.g., Parker Island NWR and Monomy NWR, Mass) have been closed during the summer months to try to remove this source of disturbance to enhance the reproductive performance of the threatened piping plover (Christopher Marsh, Coastal Carolina College, S.C., personal communication). Feral cat populations are often associated with areas of increased human activity, and therefore, in addition to restricting public access, predator exclusions have been employed to protect nests (Rimmer and Deblinger 1990).

Human activity also can disturb birds during the non-breeding seasons and may reduce their ability to obtain sufficient caloric intake, which in turn, may reduce their survivorship or reproductive output. Although most research has focused on waterfowl concentrations (Bélanger and Bédard 1990, Derksen et al. 1990), a few recent studies indicate that non-breeding shorebirds also can be adversely affected by high levels of human disturbance (Howe 1989, Pfister et al. in press). At present, species specific responses to human disturbance and the levels of human disturbance that cause significant reductions in feeding time of shorebirds are poorly understood.

The extensive and aesthetic barrier islands, of which the National Seashores are part, attract millions of tourists every year. This creates a potential conflict in some areas between human recreational use and avian species sensitive to anthropogenic activities, and the need to provide essential habitat to meet life history requirements of resident and migratory waterbirds. Thus, to manage the North Carolina National

Seashores properly, information must be available on the extent and nature of use of available habitats by resident, migratory and wintering waterbirds, on how these bird populations and human recreational use interact, and on how adverse anthropogenic impacts on bird populations can be minimized. To address these needs a 3 year project was implemented to develop baseline data to promote the conservation of essential habitat and populations of listed waterbirds and the community as a whole, while still providing the public recreational access to the two National Seashores.

Specifically, we report on the abundance, distribution and species composition of aquatic birds along the entire beach front habitats of the two Seashore Parks. Emphasis was placed on understanding the population dynamics of migrant Sanderlings and regional importance of the Seashores to this species because it represented one of the most abundant migrant species on the Seashores and because the eastern population of this species had exhibited significant population declines (Howe et al. 1989). Research efforts also focused on finding and characterizing locations of breeding aquatic species (e.g., terns, gulls) throughout the Seashores. Two major components of our research efforts were to evaluate the effects of human disturbance on shorebird habitat use and distribution, and to describe and quantify the breeding biology and factors affecting the reproductive success and viability of Piping Plovers. Finally, ancillary data were collected to fill some obvious voids in our knowledge of the avifauna of the Seashores. For instance, a complementary bird checklist was prepared for Cape Lookout Seashores to match that already available for Cape Hatteras. Also, data on abundance and species composition were collected along the sound-side of Cape Lookout (e.g., Core Sound) and at Portsmouth Flats. These data were also summarized and included in this report.

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Seasonal numbers, distribution and population dynamics of shorebirds on the Outer Banks of North Carolina.

Chapters I and II

by

Stephen J. Dinsmore

and

Jaime A. Collazo

North Carolina State University
Department of Zoology
Raleigh, NC 27695

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INTRODUCTION

Recently, attention has been focused on the conservation of many migratory bird species, including shorebirds (Myers et al. 1987). However, our lack of understanding about the factors regulating shorebird populations and our inability to estimate population sizes accurately have hampered these efforts. Without such vital baseline information, effective conservation plans cannot be formulated.

Many shorebirds are long-distance migrants, making annual migrations in excess of 25,000 km (Myers et al. 1987). These species tend to concentrate at a few stopover sites on these migrations, often in large numbers (Myers 1983, Senner and Howe 1984). Many shorebirds have evolved this migration pattern to take advantage of the short-term abundance of food resources at these sites (see Myers 1983). As the food supply is depleted or reduced at more northerly sites, birds must weigh the risks of remaining at that site versus the risks of migrating south to a site with more abundant food. Food availability is thought to be the ultimate factor responsible for causing birds to migrate (Gauthreaux 1982). Many shorebirds therefore rely on a series of stopover sites between their breeding and wintering areas, without which they could not accumulate the necessary energy reserves to complete migration (Myers et al. 1987). The critical nature of these sites to many species cannot be overemphasized. The loss of even a single site could result in significant declines in those species (Myers et al. 1987). The sensitivity of shorebird populations to the continued availability of key stopover sites is illustrated by looking at p_i^N. This simple equation states that the extinction probability of a population (p_i) is a function of its size (N), assuming that individuals die independently. In shorebirds, concentrations at key areas remove that independence and lowers the effective population size towards the number of sites (Myers et al. 1987).

Little work has focused on the dynamics of stopover sites. Several studies have ascertained patterns of food availability (e.g. Myers et al. 1980), but few have documented turnover rates and length of stay (Butler et al. 1987, Dunn et al. 1988, Holmgren et al. 1993) or annual survivorship (Boyd 1962). How these components fit with or mold migration strategies of shorebirds has not been thoroughly addressed. Alerstam and Lindstrom (1990) formulated two hypotheses (time- and energy-selected) to explain migratory patterns in shorebirds. The time-selected hypothesis proports that shorebirds may try to minimize the time spent on migration by visiting only those sites with the highest energetic returns. The energy-minimization hypothesis proposes that shorebirds will try to minimize energy expenditure during migration by departing for subsequent stopover sites as soon as they have the necessary energy reserves to complete the flight. These hypotheses highlight the importance of shorebird body condition (energy reserves) and quality of stopover sites (food availability), which in turn influence site dynamics (e.g., turnover rates). Tying together information about seasonal changes in numbers, food availability, and migratory strategies is a necessary step to fully understand the role (or importance) of stopover sites to migratory shorebirds.

This study was implemented to assess the seasonal distribution and abundance of shorebirds on the Outer Banks of North Carolina, with emphasis on the population dynamics of Sanderlings. The general objective was to evaluate the Outer Banks as a migratory stopover and wintering area for shorebirds. The study focused on four specific objectives:

1) To describe the distribution and seasonal abundance of shorebirds on the Outer Banks.

2) To estimate the turnover rates of Sanderlings during spring and fall migration on the Outer Banks, and to see if these rates are affected by body condition.

3) To provide monthly estimates (± confidence intervals) of the size of the Sanderling population on the Outer Banks and compare these with population counts obtained from beach censuses.

4) To describe the distribution and movement of Sanderlings within the National Seashores.

These objectives were met during the 1992 and 1993 field seasons. Results of the study are described in the chapters that follow. Data on the seasonal numbers of shorebirds using the Outer Banks (Chapter 1) may be used to minimize human activities on areas used by large numbers of birds. Information on the site fidelity of Sanderlings (Chapter 1) hints at the dependence on Outer Banks by this species to complete their annual migratory cycle. Information about the turnover rates and population size of Sanderlings (Chapter 2) can be used to assess (evaluate) the effectiveness of shorebird censusing techniques and the relative importance of the Outer Banks when compared to other sites. As a whole, the study adds to our knowledge about the role of the Outer Banks to migrant shorebirds and will hopefully assist the National Park Service in developing plans for their conservation.

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CHAPTER 1

SEASONAL DISTRIBUTION AND NUMBERS OF SHOREBIRDS ON

As a group, shorebirds are very diverse with at least 49 species known to breed in North America (Morrison 1984). Many of these species make annual migrations in excess of 25,000 km between their Arctic breeding grounds and wintering areas in the tropics (Myers et al. 1987). Howe et al. (1989) noted that 36 of these species spend most of the year on wintering areas. Shorebirds have low reproductive potential (Winkler and Walters 1983) but high adult annual survivorship, often 75-80% or higher (Evans and Pienkowski 1984), to offset the investment in migration.

During their annual migratory cycle, many shorebirds concentrate at a few stopover sites (Myers 1983, Senner and Howe 1984, Myers et al. 1987). These sites often provide a unique combination of food resources and habitat requirements necessary to support a large number of birds (Myers 1986, Myers et al. 1987). The fact that a large proportion of a given species' population may be concentrated at one or a few sites during migration makes them particularly vulnerable to habitat loss and degradation, and thus, to population decline (see Gill and Handel 1990). Coastal areas, where the vast majority of these sites occur, are seriously threatened by habitat alteration and destruction from human development (Senner and Howe 1984, Davidson and Pienkowski 1987). Examples of important sites in North America are Delaware Bay (Clark et al. 1993), the Bay of Fundy (Hicklin 1987), the Copper River Delta of Alaska (Isleib 1979, Senner

1979), and Grays Harbor in Oregon (Senner and Howe 1989). Unfortunately, information for other potentially critical sites is lacking, mostly because resources to implement adequate survey programs have not been available.

The Outer Banks of North Carolina constitute a prime example of an area with limited information on migratory shorebirds (Buckley and Buckley 1973, Boone 1988). An estimated 20,000 shorebirds use the Outer Banks annually during migration (Senner and Howe 1984). The most abundant species include Black-bellied Plover (Pluvialis squatarola), Willet (Catoptrophorus semipalmatus), Red Knot (Calidris canutus), Sanderling (Calidris alba), Dunlin (Calidris alpina), and Short-billed Dowitcher (Limnodromus griseus). The area serves as a wintering ground for at least fifteen species of shorebirds (Root 1975). Only four species of shorebirds are known to breed on the Outer Banks [Wilson's Plover (Charadrius wilsonia), Piping Plover (Charadrius melodus), American Oystercatcher (Haematopus palliatus), Willet].

The Outer Banks attract millions of tourists every year and are subject to ever increasing development pressures. These factors may lead to conflicts between human uses and the conservation needs of resident and migratory shorebirds. To aid in the development of conservation measures for the Outer Banks, baseline data on the seasonal abundance and distribution of shorebirds using outer beach habitats were collected during 1992 and 1993. Outer beach habitat was the most abundant shorebird habitat on the Outer Banks, with relatively few birds using other habitats such as tidal flats and freshwater impoundments. Therefore, this study focused on species that were highly dependant on outer beach habitat. Information on the shorebird community as a whole, and the eight most abundant species, is presented here. Special attention was given to four species of concern (Piping Plovers, Whimbrels, Red Knots, and Sanderlings). Conservation needs of these species are heightened because of their endangered status (Piping Plover), recent population declines [Whimbrel (Numenius phaeopus) and Sanderling] (Howe et al. 1989), and their localized distribution along the Atlantic Flyway (Red Knot) (Morrison and Harrington 1992). In this study, the population size and turnover rates of Sanderlings were estimated using mark-resight techniques (Chapter 2). Using color-marked individuals, detailed information on the distribution and site fidelity of Sanderlings was gathered and is presented here. To assess the relative regional importance of the Outer Banks to the four species of special interest, peak counts from this study were compared to those obtained through the International Shorebird Survey (ISS, Manomet Observatory for Conservation Science) at seven selected sites along the Atlantic Flyway.

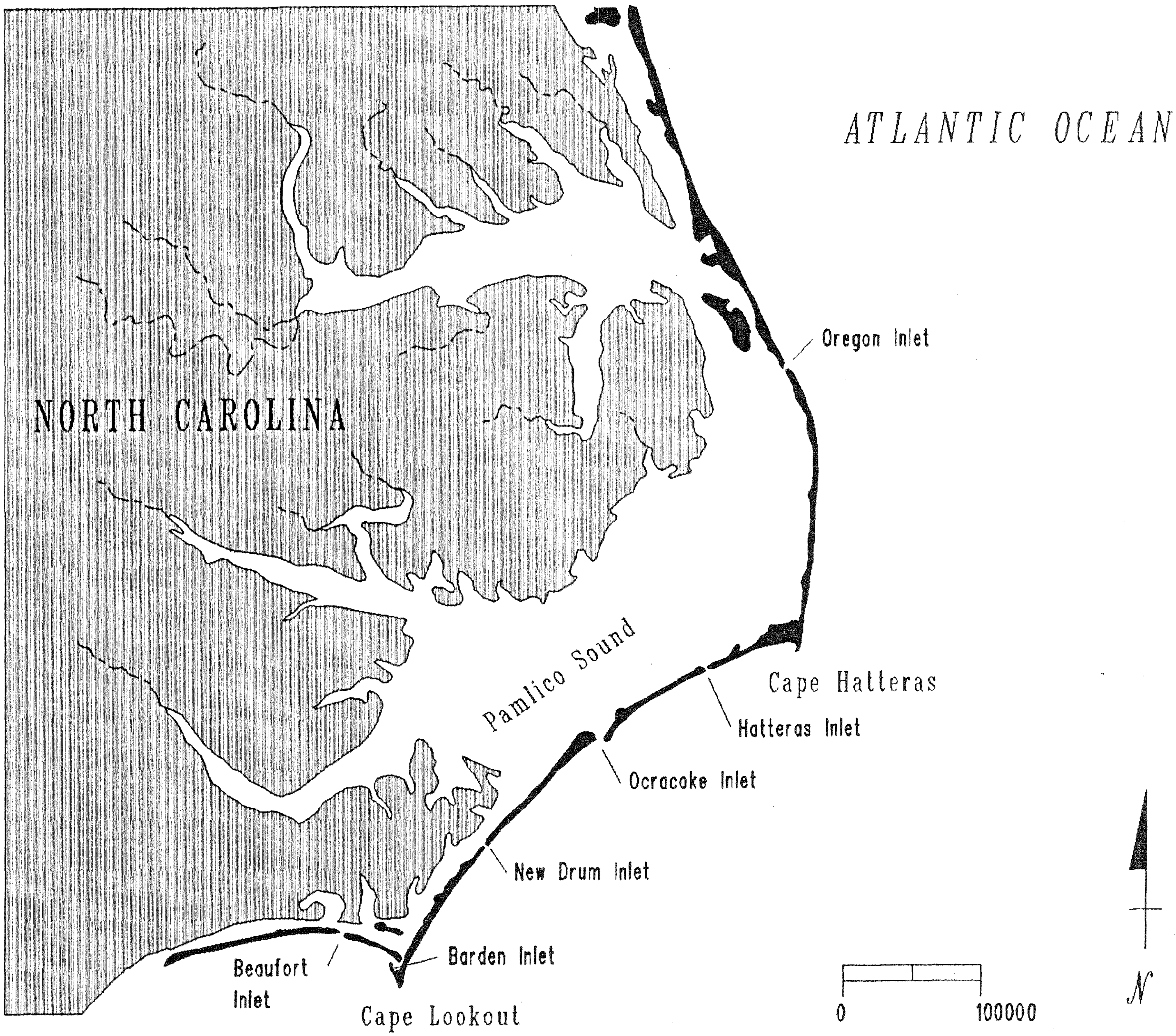
METHODS

Study Area

The Outer Banks are located along the east-central coast of North Carolina (34°34'-35°50' N lat., 75°27'-76°39' W long., Figure 1). The area consists of a series of narrow barrier islands of approximately 228 km in length, stretching from just north of Oregon Inlet in Dare County to Beaufort Inlet in Carteret County. Much of the area is included in Cape Hatteras and Cape Lookout National Seashores. Because of accessibility, this study was restricted to the northern portions of the Outer Banks north of New Drum Inlet. The topography is typical of barrier islands, with a low elevation and flat relief. Outer beach occupied by shorebirds is defined as the area from the base of the dune line to the ocean edge, including that portion of the intertidal zone exposed at low tide. Soundside tidal flats at inlets or other mudflat habitats were not surveyed since small numbers of shorebirds used those habitats. Mean tidal amplitude is approximately 1 m.

Censuses

From March 1992 to December 1993, five outer beach sites ranging from 9-34 km in length were surveyed. Bodie Island (9 km) extended from the south edge of Nags Head south to Oregon Inlet. North Beach (28 km) extended from the Rodanthe pier south to a point 1 km north of the Buxton town limit. South Beach


ATLANTIC OCEAN
NORTH CAROLINA
Oregon Inlet
Pamlico Sound
Cape Hatteras
Hatteras Inlet
Ocracoke Inlet
New Drum Inlet
Barden Inlet
Beaufort Inlet
Cape Lookout
0
100000
N

(24 km) extended from just south of the Cape Hatteras lighthouse south to Cape Hatteras point, then west to Hatteras Inlet. Ocracoke Island (28 km) included the entire island from Hatteras Inlet south to Ocracoke Inlet. North Core Banks (34 km) included the entire island from Ocracoke Inlet south to New Drum Inlet. The total amount of outer beach surveyed monthly for shorebirds was 123 km. Additionally, a stretch of Pea Island National Wildlife Refuge (19 km) extending from the Oregon Inlet jetty south to Rodanthe was censused during the fall 1993 season.

Surveys were conducted twice per month by vehicle. All surveys were begun 1.5 h before low tide, except for two counts on North Core Banks in July and August 1992 that were begun 1.5 h before high tide. Numbers of all shorebirds present on the outer beach were recorded. Flying birds were not recorded, unless they were clearly disturbed by the person(s) conducting the census. Since large shorebird concentrations (>500 birds) were rare, data here represent actual counts and not estimates.

Abundance was expressed as the mean of the two monthly censuses. This minimized variance problems associated with repeated measures within month. For a few sites, there was only one count in a given month and this was treated as the estimate for that month. Annual and seasonal numbers were obtained by summing monthly counts. Abundance data were expressed in two ways. First, annual patterns of abundance are described for each of the eight shorebird species. Second, a model was developed to test for seasonal patterns in abundance. In this model, seasons were defined as spring (April-June) and fall (July-November). These seasons span the major migration periods for the species examined. The effects of site and year on the variability of monthly counts were tested. Month, a repeated measure within season, was nested under the appropriate factor in the nested factorial ANOVA model. To reduce count variance, data were log or square root transformed. The most appropriate transformation was determined by examining plots of residuals. The relative abundance of the eight shorebird species (birds/km) was also calculated for each site.

Peak fall counts of Piping Plovers, Whimbrels, Red Knots, and Sanderlings obtained during this study were compared to similar counts obtained at seven other sites, except Delaware Bay, along the Atlantic Coast and the Gulf Coast of Florida. Counts were obtained from International Shorebird Survey (ISS) data for the fall migration period (July to November) in 1972-92. Delaware Bay was excluded because counts at this site were not represented in the ISS data set. Only marine sites surveyed over at least nine years were used for these comparisons. Censuses at ISS sites were generally conducted at 10-day intervals. Since sampling effort was variable, the peak count of each species was treated as the estimate for the site (see Colwell and Cooper 1993). Counts obtained during this study were ranked with counts for the other seven sites to assess the importance of the Outer Banks to each of these species.

Distribution and site fidelity of Sanderlings

To examine the seasonal distribution and site fidelity of Sanderlings, birds were color-marked during 1992-93. Sanderlings were caught primarily with a rocket net, though some were initially caught in mist nets. Most birds were caught at roost sites where they were herded in front of the rocket net for capture. A few were caught as they concentrated at foraging areas along the outer beach. Birds were removed from the net immediately after capture and transferred to cardboard holding boxes. All birds were fitted with an aluminum U.S. Fish and Wildlife Service leg band and a series of either four (1992) or three (1993) color bands arranged in a unique combination. The color bands were U.V. stable PVC bands (A.C. Hughes, London, England). Combinations were derived from six and ten possible colors during 1992 and 1993, respectively. Color band seams were melted together to reduce the possibility of band loss. Birds were released at the capture site within three hours of capture.

Because of seasonal changes in distribution, Sanderlings were trapped at North Core Banks in spring and at four sites on Cape Hatteras National Seashore during fall. Trapping efforts were from 28 April-27 May and 29 July-16 October in 1992 and from 22 April-23 May and 27 July-4 November in 1993.

Surveys for marked birds were done by four-wheel drive vehicle. During surveys, complete and partial color band combinations were recorded, as well as the number of unmarked birds examined for color bands. Very large (>500 birds) concentrations of Sanderlings were rare, which increased the ease of examining birds for color bands. The within-season site fidelity of Sanderlings was examined during fall 1993. During that season, birds were marked at Bodie Island, Pea Island, North Beach, and South Beach. Resighting efforts were conducted on all sites except North Core Banks. Only birds resighted at least once in each of two different capture periods were used in this analysis. A bird was site-faithful if at least two thirds of the resightings were from the banding site. The percentages of birds that were faithful to their banding site are reported by banding location.

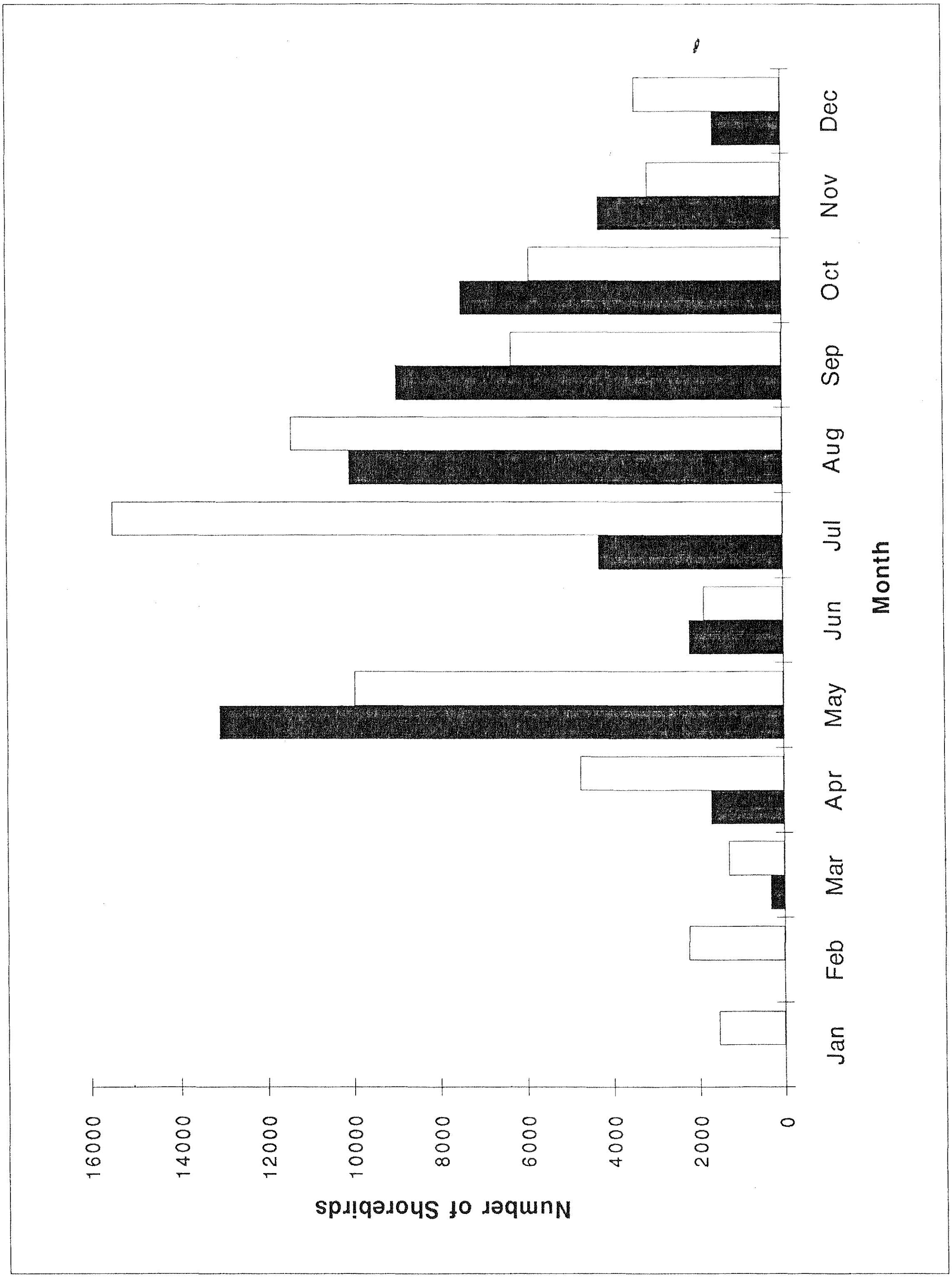
The inter-annual site fidelity of Sanderlings was examined by looking at 1993 resightings of birds banded in 1992 at North Core Banks, Bodie Island, and North Beach. Only birds resighted after April 1, 1993 were used since most overwinter mortality should have occurred by then. Resighting probabilities were assumed to be equal between sites. Birds resighted at >1 location in 1993 were excluded from this analysis. This resulted in the loss of 117 birds, or 31% of those resighted in 1993. A chi-square test for homogeneity of resightings by location was computed for each of the three locations. Given three sites (A,B,C), the observed values for each site were calculated by determining the number of birds marked at a given site (e.g., site A) and resighted at sites A, B, and C. The same calculations were made for birds marked at sites B and C. The expected value for each test was then the sum of the marked birds seen at each site divided by the number of sites. In each case, the denominator was three, and each test had 2 degrees of freedom.

RESULTS

Shorebird Assemblage

A total of 21 species was recorded on surveys (see Appendix 1). Species richness was slightly greater in fall (n=21) than in spring (n=18). A total of 52,651 shorebirds was recorded on censuses during 1992 and an additional 58,935 shorebirds during 1993. Surveys revealed that Sanderling, Red Knot, and Willet were the most abundant shorebird species in Outer Beach habitat and accounted for 89% of the total numbers counted. Sanderlings were the most abundant species and accounted for 68% of the total.

Shorebirds were present on the Outer Banks throughout the study, though numbers peaked during May in spring and from July to September in fall. Seasonally, shorebirds were most abundant in May and August with the fewest recorded during June ($F_{12,46}=4.93$, $P<0.0001$) (Figure 2). Shorebird numbers varied


Number of Shorebirds
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

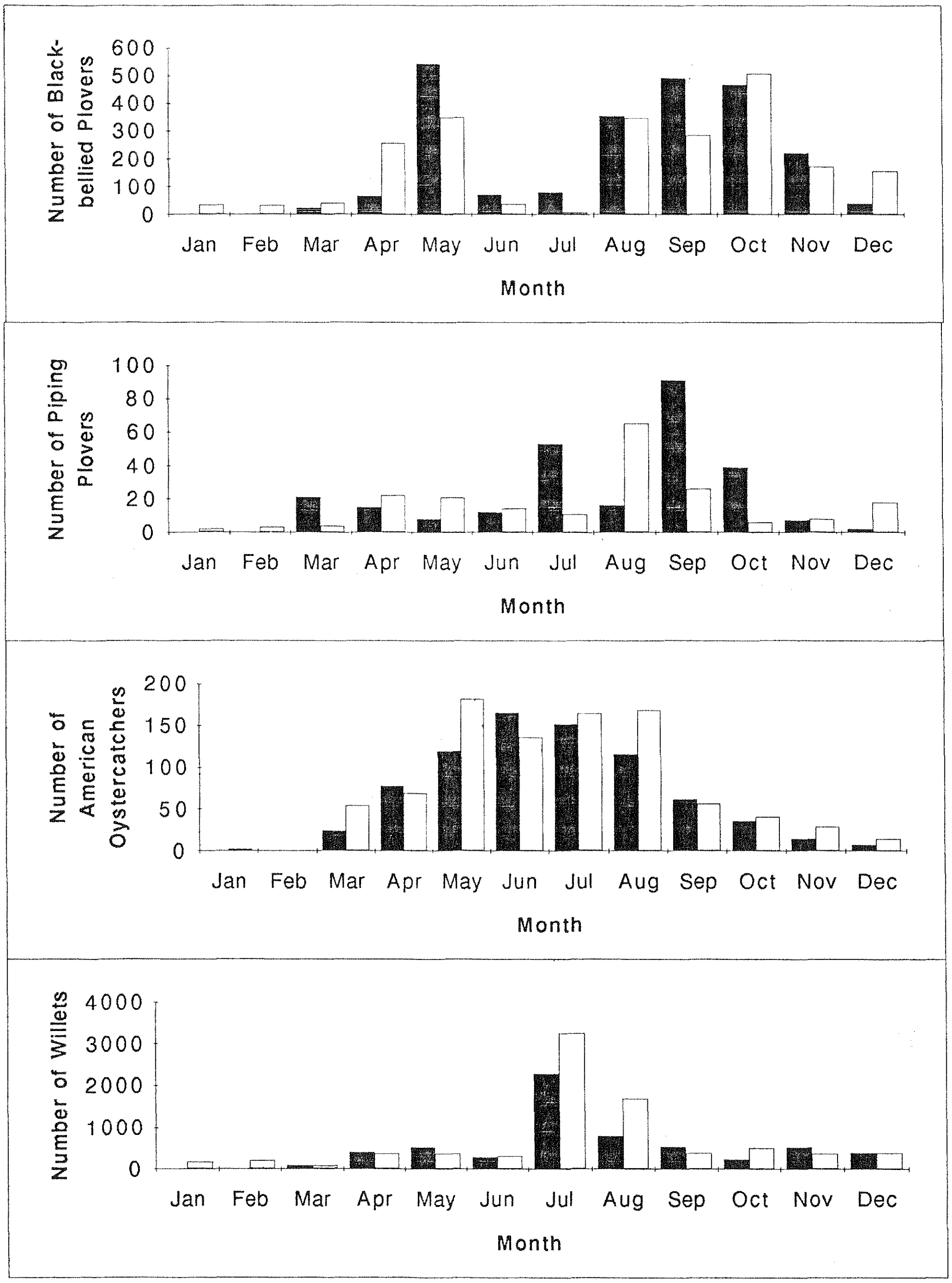
between sites and seasons ($F_{4,46}$=2.84, P=0.0348). Shorebirds were most abundant on North Beach during both years, and least abundant on South Beach during 1992 and on Bodie Island during 1993. On all sites except Ocracoke Island and North Core Banks, shorebird numbers were highest during the fall season. Relative abundance of shorebirds was slightly greater in fall (68 birds/km) than in spring (50 birds/km), with a peak at North Beach during fall (117 birds/km) (Table 1).

Species Accounts

The following accounts detail the annual and seasonal abundance of eight selected species of shorebirds. Peak numbers are listed for each season, and indicate the month when the mean of the 1992 and 1993 counts was greatest. Comparative information assessing the regional significance of the Outer Banks to four of these species is also presented.

Black-bellied Plover

Black-bellied Plovers were present every month of the year, though the greatest numbers were recorded in May and from August to October. The lowest numbers were recorded from January to March. Seasonally, spring migrants arrived in April, peaked in May, and were gone by early June. Fall migrants began arriving in August, peaked in October, and most departed by November ($F_{12,46}$=5.74, P<0.01) (Figure 3). Very small numbers overwintered. Numbers did not vary by site. Black-bellied Plovers were most abundant on North Core Banks (27% of total) and North


Number of Black-bellied Plovers
600
500
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Number of Piping Plovers
100
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Number of American Oystercatchers
200
150
100
50
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Number of Willets
4000
3000
2000
1000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

Beach (32% of total). Numbers did not vary by season. Relative abundance was quite low at all sites, being greatest at North Beach during fall (4 birds/km) (Table 1).

Piping Plover

Piping Plovers were recorded every month of the year, with the greatest numbers recorded in July to October. Numbers from April to June were stable. Very few were recorded during January and February. Seasonally, spring migrants arrived in March with a slight peak in April. Small numbers remained to breed during the summer. Fall migrants began arriving in July, peaked in August and September, and most birds departed by November. Small numbers overwintered. There were no significant differences between months within season and year ($F_{12,46}$=1.00, $\underline{P}$=0.47) (Figure 3). Numbers varied significantly between sites ($F_{4,46}$=3.01, $\underline{P}$=0.03). Most (69%) Piping Plovers were on North Core Banks. Numbers did not vary between seasons. Compared to other ISS sites, the Outer Banks ranked second in regional importance to this species (Table 2). Only Monomoy National Wildlife Refuge in Massachusetts had a higher peak count than the Outer Banks. Relative abundance was very low (<1 bird/km) at all sites (Table 1).

American Oystercatcher

American Oystercatchers were recorded mostly from March to December, with almost none present in January and February. Numbers peaked from May to August. Seasonally, spring birds

Table 2. Peak numbers of four shorebird species at eight sites along the Atlantic Coast and Gulf Coast of Florida from International Shorebird Survey data and this study.

Site	Piping Plover	Whimbrel	Red Knot	Sanderling
Plymouth Beach, MA	57	19	950	2,500
Monomoy NWR, MA	100	585	3,000	5,000
Jamaica Bay NWR, NY	0	10	1,685	350
Great Egg Harbor, NJ	23	33	2,294	1,400
Chincoteague NWR, VA	50	355	2,175	11,130
Outer Banks, NC	91	453	600	11,257
Cape Romano, FL	25	7	8,115	809
Marco River, FL	24	3	1,211	457

arrived in March, with stable counts from May to August indicating breeding birds. Most birds departed in September, with a few remaining in November ($F_{12,46}$=3.36, P<0.01) (Figure 3). Numbers varied significantly by site and season ($F_{4,46}$=3.36, P=0.02). American Oystercatchers were most abundant on North Core Banks (31% of total) and South Beach (33% of total). At North Core Banks and Ocracoke Island, numbers were greatest during spring. Numbers at the other three sites were higher during fall. Relative abundance was low at all sites, being greatest at South Beach during spring (2 birds/km) (Table 1).

Willet

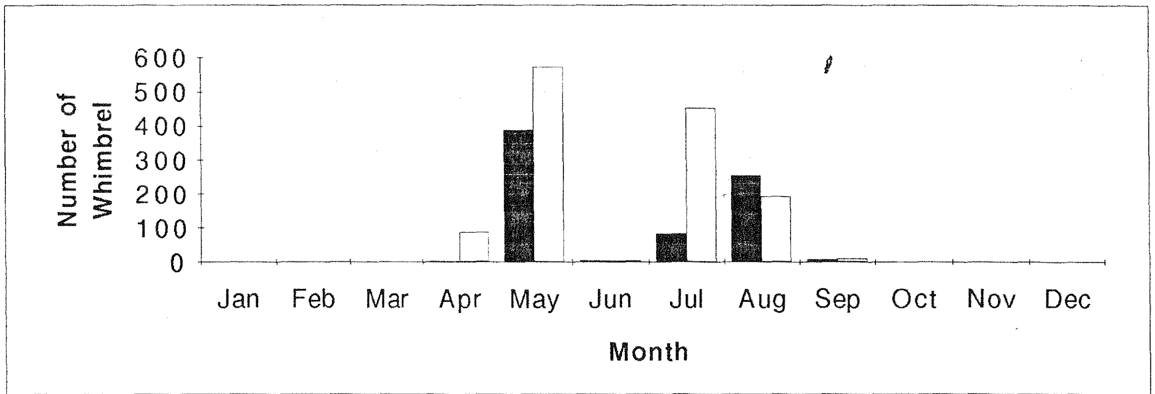
Willets were recorded every month of the year, though the greatest numbers were recorded in July and August. Otherwise, numbers were quite stable from April to December, with slightly fewer birds present from January to March. Seasonally, spring birds arrived in April, peaked in May, with some remaining into June to breed. During fall, the peak was in July, with smaller numbers remaining through November ($F_{12,46}$=7.43, P<0.01) (Figure 3). Numbers varied significantly by site and season ($F_{4,46}$=2.70, P=0.04). Willets were most abundant on North Core Banks (26% of total) and North Beach (29% of total). At all sites, numbers were higher during fall. They were three times more abundant in fall than spring at North Beach and Bodie Island. Relative abundance was much greater in fall (8 birds/km) than spring (3 birds/km) with the greatest relative abundance recorded at North Beach during fall (12 birds/km) (Table 1).

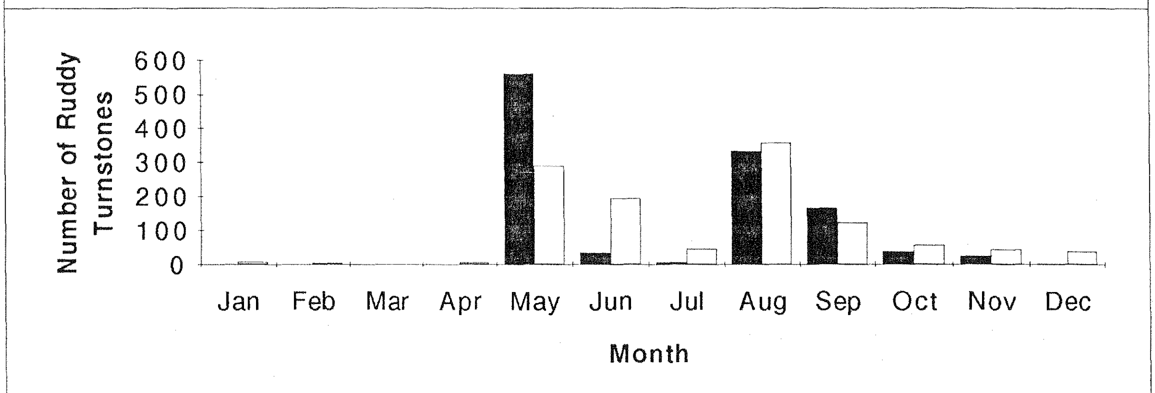
Whimbrel

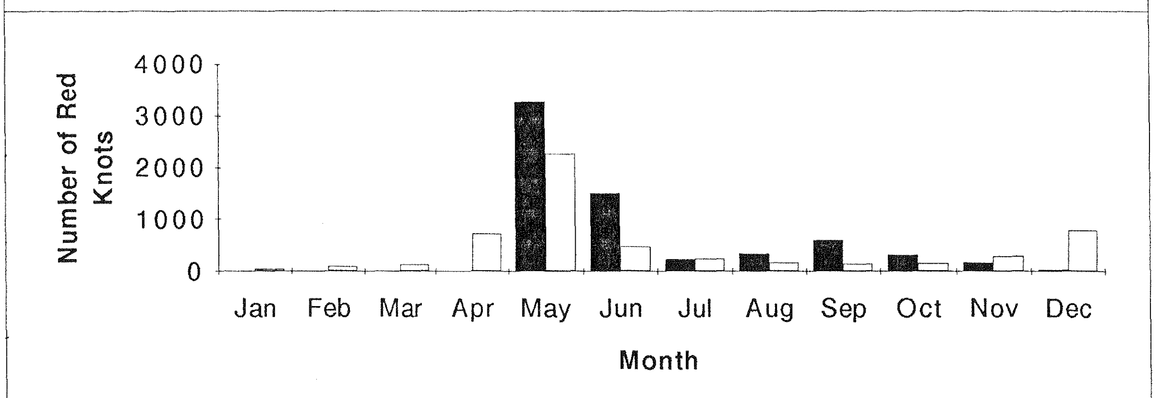
Whimbrel were recorded mostly from April to September, with distinct peaks in May and in July and August. None were recorded from December to March. Seasonally, spring birds arrived in April, there was a strong peak in May, and very few remained in June. Fall migrants arrived in July, peaked in July and August, and nearly all had departed by September with a few lingering to November ($F_{12,46}$=15.63, $\underline{P}$<0.01) (Figure 4). Whimbrel were most abundant on North Beach (42% of total) and Bodie Island (24% of total). Numbers increased significantly in 1993 ($F_{1,46}$=5.50, $\underline{P}$=0.02) for all sites except North Core Banks. There was also significant variation between seasons ($F_{1,46}$=7.10, $\underline{P}$=0.01). Whimbrels were slightly more abundant in spring. Almost no Whimbrel were seen between September and March. Compared to other ISS sites, the Outer Banks ranked second in regional importance to this species (Table 2). Monomoy National Wildlife Refuge in Massachusetts was the only site to have a higher peak count for this species. Relative abundance was low at all sites except Bodie Island where the peak was recorded during fall (7 birds/km) (Table 1).

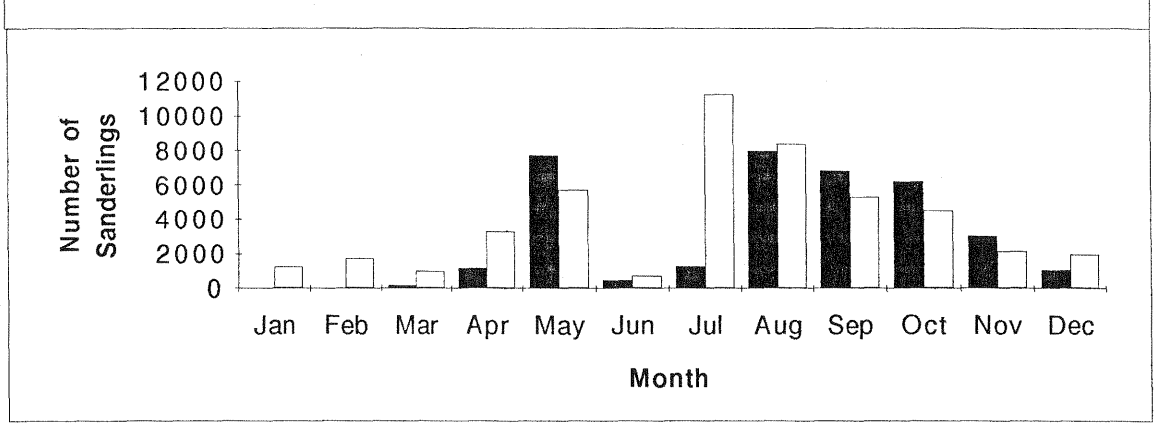
Ruddy Turnstone

Ruddy Turnstones were present every month of the year, though the majority were present from May to June and from


600
500
400
300
200
100
0
Number of Whimbrel
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


600
500
400
300
200
100
0
Number of Ruddy Turnstones
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


4000
3000
2000
1000
0
Number of Red Knots
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


12000
10000
8000
6000
4000
2000
0
Number of Sanderlings
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month

August to September. Numbers were lowest from January to April. Seasonally, spring birds arrived in April, showed a strong peak in May, and most departed by June. Fall migrants arrived in July, peaked in August, and most were gone by October ($F_{12,46}$=11.49, $\underline{P}$<0.01) (Figure 4). Ruddy Turnstones were most abundant on South Beach (33% of total) and North Beach (30% of total), though site differences were not significant. Relative abundance was low at all sites with the peak recorded at South Beach during spring (3 birds/km) (Table 1).

Red Knot

Red Knots were present every month of the year, though the greatest numbers were recorded in May and June. Numbers from July to December were fairly stable, with the lowest numbers recorded from January to March. Seasonally, spring migrants arrived in April, peaked in May, and most were gone by June. During fall, birds arrived in July, showed a small peak in September, and moderate numbers were still present in November ($F_{12,46}$=2.87, $\underline{P}$<0.01) (Figure 4). Numbers varied significantly between sites ($F_{4,46}$=5.62, $\underline{P}$<0.01). Most Red Knots were seen at North Core Banks (65% of total) and Ocracoke Island (28% of total). Compared to other ISS sites, the Outer Banks ranked last in regional importance to this species (Table 2). Relative abundance was much higher in spring (11 birds/km) than in fall (2 birds/km), with most birds recorded at North Core Banks (34 birds/km in spring) and Ocracoke (16 birds/km in spring) (Table 1).

Sanderling

Sanderlings were present every month of the year, though the greatest numbers were present in May and from July to October. The lowest numbers were recorded in March and June. Seasonally, spring migrants arrived in April, peaked in May, and most were gone by June. Fall migrants arrived in July, peaked in August and September, followed by a steady drop in numbers through November ($F_{12,46}$=4.19, $\underline{P}$<0.01) (Figure 4). Sanderlings were most abundant on North Beach (41% of total) and North Core Banks (20% of total), though site differences were not significant. Compared to other ISS sites, the Outer Banks ranked first in regional importance to this species (Table 2).

Sanderling relative abundance was much higher in fall (51 birds/km) than in spring (30 birds/km) (Table 1). Spring birds peaked on Bodie Island (44 birds/km) while fall birds peaked on North Beach (97 birds/km). The Outer Banks are most important to Sanderlings during fall migration, though substantial numbers use the area during spring.

Sanderlings exhibited moderate within-season site fidelity (Table 3). Most (69%) Sanderlings remained near where they were banded during the fall 1993 migration period. However, some birds (31% of total) moved, usually to an adjacent site. Movement was a short distance (<20 km) in most cases.

Table 3. Percentage of resightings of Sanderlings on the Outer Banks of North Carolina by banding location, fall 1993.

	Resighting locations						
Banding site	Bodie I.	Pea I.	North Beach	South Beach	Ocracoke I.	2 sites	>2 sites
Bodie I.	62.6	8.0	1.1	0	0	26.2	2.1
Pea I.	7.5	52.5	7.5	2.5	0	25.0	5.0
North Beach	2.9	2.6	52.2	11.9	1.1	27.0	2.3
South Beach	0	0	6.3	50.0	0	12.5	31.2

Sanderlings showed high inter-annual site fidelity. Fifty-eight percent (380/655) of the birds marked during 1992 were resighted in 1993. A significant proportion of the birds returned to their banding site. The proportions returning were 0.89 for North Core Banks (χ^2=102.9, $\underline{P}$<0.01, 2 d.f.), 0.82 for Bodie Island (χ^2=174.7, $\underline{P}$<0.01, 2 d.f.), and 0.69 for North Beach (χ^2=74.2, $\underline{P}$<0.01, 2 d.f.).

DISCUSSION

The 21 species detected in this study were representative of shorebirds commonly found on barrier island beaches along the Atlantic Coast. Sanderlings were the most abundant species, followed by Red Knot and Willet. Because sampling was done only in outer beach habitat, it is possible that some shorebirds were not counted because they used other habitats, namely tidal flats and mudflats at freshwater impoundments. However, these habitats were very localized on the Outer Banks, and only small numbers of species using outer beach habitat were missed as a result of the habitat surveyed. The patterns of abundance contrast markedly with those at Delaware Bay, one of the most important stopovers for shorebirds along the Atlantic Coast (Myers 1983). At Delaware Bay, Semipalmated Sandpipers were the most abundant species, followed by Ruddy Turnstones, Red Knots, and Sanderlings (Clark et al. 1993). Differences in abundance between these sites are likely due to the differences in habitats surveyed. This study focused on outer beach habitat, while the Delaware Bay study sampled other habitats including beaches adjacent to tidal flats and salt marshes (Clark et al. 1993).

Two species of shorebirds examined in this study (American Oystercatcher and Willet) are common breeders on the Outer Banks, which explains their abundance in the study area. Two other species (Black-bellied Plover and Ruddy Turnstone) are common migrants on the Outer Banks, with the greatest numbers recorded at North Beach, South Beach, and North Core Banks. All four of these species winter on the Outer Banks in smaller numbers.

By examining patterns of distribution for species of local and regional significance, the importance of the Outer Banks to the conservation of shorebirds is better understood. The abundance of Piping Plovers using the Outer Banks highlights the importance of the area to this endangered species. In addition to a breeding population of around 40 pairs, the area is an important staging site, especially in fall. Censuses recorded a peak of 89 during September 1992, most on North Core Banks. However, single-day counts of 128 on 29 August 1992, 110 on 25 September 1992, and 136 on 20 August 1993 on North Core Banks were made independently of censuses. These counts included large numbers of plovers using tidal flats at Ocracoke and New Drum inlets. North Core Banks is probably one of the most important staging areas for the Atlantic Coast population of Piping Plovers (see Haig and Plissner 1993). The 1991 International Piping Plover Census recorded 1,975 adult plovers along the Atlantic Coast of Canada and the United States (Haig and Plissner 1993). Based on these numbers and assuming no turnover, a minimum of 7% of the Atlantic Coast population of Piping Plovers uses North Core Banks during migration.

The Outer Banks may also be important as a stopover for migrant Whimbrel. Howe et al. (1989) reported a significant decline in Whimbrel numbers during 1972-1983 using International Shorebird Survey data, though their conclusions were based on a small sample size. Peak numbers on the Outer Banks were found during May and July-August. Large numbers use the Cape Romain-Santee Delta region of South Carolina (Marsh and Wilkinson 1991), including single-day counts of >400 in April and >200 in August. Comparisons to other ISS sites revealed that substantial numbers of Whimbrel used the Outer Banks. Information about critical staging areas for this species is scant, and the numbers found on the Outer Banks are probably indicative of the importance of this area to Whimbrel.

This study documents that moderate numbers of Red Knot use the Outer Banks during migration and in winter. Morrison and Harrington (1992) estimated the North American population of Red Knots at 180,000. The vast majority of these birds stage in Delaware Bay during spring (Clark et al. 1993), with small concentrations noted at other sites along the Atlantic Coast (Hicklin 1987, Marsh and Wilkinson 1991). On the Outer Banks, over 4,700 knots were counted in May and June 1992, with 73% on North Core Banks. Not accounting for turnover, the Outer Banks host 2-3% of the estimated North American Red Knot population during spring. The importance of the Outer Banks as a wintering area is less understood. Censuses indicated that >500 knots wintered each year, the northernmost sizeable wintering aggregation on the Atlantic Coast. The largest known wintering group in North America is on the Gulf Coast of Florida, where a mean of 6300 ± 3400 were detected in 1980-82 (Harrington et al. 1988). In South Carolina, no sizeable winter concentrations of knots were noted in the Cape Romain-Santee Delta region (Marsh and Wilkinson 1991).

Sanderlings were the most abundant species detected during censuses. They were present every month of the year, though peak numbers were detected in May and from July to October. The relative abundances of Sanderlings reported here are similar to those reported by Walters (1984) for fall (50 birds/km) on the Outer Banks. Comparative data for the Atlantic Coast are limited to Delaware Bay in New Jersey, a site of hemispheric importance to this species (>200,000 during migration) (Myers et al. 1990). Concentrations of up to 30,000 birds/km have been reported at this site. Other comparative data come from the Pacific Coast. From California to Washington, concentrations of 40 birds/km were reported in winter (Myers et al. 1984). Concentrations of

185 birds/km were reported in coastal Oregon and Washington during spring, with a peak of 472 birds/km at Clatsop Beach, Oregon in early May (Myers et al. 1984). Myers et al. (1988) reported abundances of 46, 41, and 22 birds/km in California during fall, winter, and spring, respectively. Differences in abundance between the Outer Banks and western sites might be attributed to differential habitat quality, though some might be related to the availability of beach habitat. The relative abundances in North Carolina might be lower because outer beach is not as limited as in coastal California (see Connors et al. 1981, Myers et al. 1984).

Sanderlings were most abundant on North Beach and North Core Banks, which collectively hosted more than 60% of all Sanderlings counted during this study. Sanderlings tended to be sedentary during migration periods. Most birds (69%) remained at their banding site during a given season. This total might have been much higher, but since sites were not isolated, many birds moved to adjacent sections of a nearby site. For example, North Beach and South Beach were adjacent to each other, and small numbers of Sanderlings fed on North Beach but roosted on the nearest portion of South Beach. These distributional patterns may result from differential food availability between sites. Observations of food items captured by Sanderlings ($\underline{n}>1000$) and limited work on food availability (see Appendix 2) suggest that Sanderlings prey almost exclusively on mole crabs (*Emerita* *talpoida*) along the beaches of the Outer Banks. This is consistent with other sites where Sanderlings and mole crabs co-occur (Myers et al. 1980, Connors et al. 1981, Maron and Myers 1985). Comparisons between North Beach (high Sanderling abundance) and Ocracoke Island (low Sanderling abundance) indicate that the abundance of mole crabs was significantly higher ($F_{1,56}$=4.52, P=0.0380) on North Beach (see Appendix 2). Variations in food supply are thought to influence seasonal variation in Sanderling numbers in North Carolina (Walters 1984). At Pea Island National Wildlife Refuge, Dolan et al. (1993) found considerable seasonal variation in mole crab numbers. Mole crab numbers there peaked in May to July and in October. Few were detected from December to March.

This pattern of mole crab abundance matches very closely the seasonal trends in the numbers of Sanderlings on the Outer Banks. The late fall exodus of Sanderlings is a pattern not found in California, where the Sanderling population remains fairly stable after early October until it begins to decline in February (Myers 1980). On the Outer Banks, the Sanderling population quickly increased in late July and early August and remained somewhat stable through October. There was some turnover during this period, with late-arriving juveniles replacing adult birds that departed. It is likely that Sanderlings remain on the Outer Banks as long as possible, departing only when the food supply crashes.

The drastic reduction in mole crab numbers after October may explain the drop in Sanderling numbers in November.

The Outer Banks appear to be an important staging area for Sanderlings. It ranked as the site with the highest peak count during fall migration when compared to seven other sites along the Atlantic Coast. Delaware Bay in New Jersey is the only site to record higher peak counts than those on the Outer Banks. The importance of the Outer Banks to migrant Sanderlings becomes clearer when turnover is considered. Information on the turnover of Sanderlings indicates that the number using this area is much greater than indicated by peak counts (Chapter 2). An estimated 35-40,000 Sanderlings use the Outer Banks annually, most during fall migration. These data suggest that the Outer Banks are an area of regional importance to Sanderlings under the guidelines of the Western Hemisphere Shorebird Reserve Network, supporting 20-40,000 birds annually during migration (Myers et al. 1987). The dependency of many migrant Sanderlings on the Outer Banks is confirmed by the strong inter-annual site fidelity reported in this study. The 1993 return rate of Sanderlings banded on the Outer Banks in 1992 was 58%. Philopatry of Sanderlings during winter has been demonstrated in California (Myers et al. 1988, Myers 1988) and in southern Africa (Summers et al. 1987). Other studies have made similar findings during migration and in winter (Evans et al. 1980, Myers 1980, Myers et al. 1988, Myers et al. 1990). At Bodega Bay, California, the annual return rate of

Sanderlings was 72% for adults and 50% for first-winter birds (Myers 1980). In Norway, the adult and first-winter annual return rate was estimated as 56% and 38%, respectively (Boyd 1962). Return rates provide a conservative estimate of annual survival since they do not account for birds which may have survived but did not return to the site they were banded.

The demographic implications of these results are clear. The Outer Banks of North Carolina provide a critical link in the migratory path of several shorebird species. Significant portions of the Atlantic Coast populations of some species may depend on the Outer Banks to complete their annual migrations. Several species such as the endangered Piping Plover depend on the Outer Banks for breeding habitat. This detailed study of Sanderlings hints at the implications of habitat loss or alteration on the Outer Banks. If such losses were to occur, a significant portion of the Atlantic Flyway population of Sanderlings would be negatively impacted, causing possible population declines. Other shorebird species could be similarly affected. Given the regional significance of this area, further protection for shorebirds under the guidelines of the Western Hemisphere Shorebird Reserve Network is necessary.

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CHAPTER 2

TURNOVER RATES AND POPULATION ESTIMATES OF MIGRANT SANDERLINGS ON NORTH CAROLINA'S OUTER BANKS.

Many shorebirds undergo lengthy annual migrations from their Arctic breeding grounds to wintering areas in the tropics (Myers et al. 1987). The distance each species migrates is dependant upon trade-offs between overwinter survival and the costs of migration (Greenberg 1980, Gauthreaux 1982, Alerstam and Lindstrom 1990). How shorebirds invest time and energy during migration is of critical importance to their fitness (Gudmundsson et al. 1991). Regardless of the distance traveled, south and northbound migrants are under different time constraints. Southbound migrants are pressured to reach a migratory terminus that maximizes overwinter survival. Time constraints during this part of the annual cycle are not as tight (Gudmundsson et al. 1991). Generally, sites furthest from the breeding grounds have better resources and can be exploited for longer time periods. Northbound migrants are under different constraints. Individuals must meet nutritional requirements for migration and reproduction under the constraints of reaching the breeding grounds on time to compete successfully for territories and mates (Morrison 1984, Gudmundsson et al. 1991).

Alerstam and Lindstrom (1990) and Gudmundsson et al. (1991) proposed two hypotheses to account for the selection of and time spent on stopover sites. The time-selected hypothesis states that shorebirds seek to minimize the time spent on migration, by-passing lower quality sites in favor of sites where potential energy gains are greater. The energy-selected hypothesis states that shorebirds migrate to the next stopover site as soon as their fat reserves allow them to cover the distance safely, regardless of the quality of the next site. In both cases, departure from an area (i.e. turnover rates) is a function of body mass. Thus, regardless of the strategy followed by shorebirds, birds with greater body mass should depart from stopover sites at a faster rate than birds of lower body mass.

Knowledge of turnover rates is of practical importance. Identification of important stopover areas relies heavily on population estimates (Myers et al. 1987). Counts of shorebirds at stopover areas, collected as part of the International Shorebird Survey (ISS) program, are the basis of population trend analyses (Howe et al. 1989). Analysis of data from the period 1972-83 revealed significant ($\underline{P}<0.05$) declines for Whimbrels, Sanderlings, and Short-billed Dowitchers. While such data are sensitive to general population trends, their accuracy depends on untested assumptions about turnover rates. A better understanding of the factors affecting population estimates of many shorebirds is necessary (Howe et al. 1989). Factors such as age, sex, body condition, and food availability may differentially affect timing of migration and the rates with which shorebirds depart an area. Knowledge of how these factors influence the dynamics of migrant shorebirds at a staging area can be used to improve population monitoring efforts, and thus, improve the sensitivity of trend analyses to gauge the status of shorebird populations.

Despite their intimate relationship to the ecology and population dynamics of stopover areas, turnover rates have been documented for few shorebird species. Turnover of wintering Sanderlings in California was investigated by Myers (1984). Baseline information is available on the length of stay of Western Sandpipers in British Columbia (Butler et al. 1987) and Semipalmated Sandpipers in Maine (Dunn et al. 1988). The relationship between body mass and length of stay has been reported for few species of shorebirds (Page and Middleton 1972, Post and Browne 1976, Butler et al. 1987, Dunn et al. 1988). In western Europe, departure rates as a function of body mass have been studied for Ruddy Turnstones, Red Knots, and Sanderlings (Gudmundsson et al. 1991) and for Dunlin (Holmgren et al. 1993). In most cases, departure rates have been estimated for small segments of the migratory period and with limited sample sizes.

An essential requirement to test either the time- or energy-selected hypothesis is that body condition be a factor influencing turnover rates. In this study, explicit tests were made to determine if residence probabilities differed between migratory Sanderlings of different body condition classes (heavy and light). It was assumed that every bird was capable of gaining weight to a threshold or minimum level permitting departure to the next destination regardless of the weight at capture. Residence probabilities were estimated using mark-resight techniques. Unlike other studies where this parameter has been reported

(Myers 1984, Butler et al. 1987, Dunn et al. 1988, Holmgren et al. 1993), the underlying theoretical basis, assumptions, and robustness of the analytical approach are well-developed and tested (see Pollock et al. 1990).

In this study, mark-resight techniques (Pollock et al. 1990) were used to estimate the turnover rates of migratory Sanderlings (Calidris alba) in spring and fall 1993. Mark-resight data were also used to estimate the population size and mean length of stay of Sanderlings. Population estimates (±SE) were used to evaluate biases and limitations of beach censuses conducted during this study (Chapter 1). It is hoped that information presented here will aid in the understanding of the dynamics of migrant shorebirds on the Outer banks, provide a basis to assess the importance of the Outer Banks as a staging area for the Atlantic Flyway Sanderling population, and help improve sampling designs to monitor migratory shorebirds.

METHODS

Study Area

The Outer Banks are located along the east-central coast of North Carolina (see Chapter 1, Figure 1). The area consists of a series of narrow barrier islands of approximately 228 km in length, stretching from just south of Nags Head in Dare County to Beaufort Inlet in Carteret County. Much of the area is included in

Cape Hatteras and Cape Lookout National Seashores. Because of accessibility, this study was restricted to the northern portions of the Outer Banks north of New Drum Inlet. The topography is typical of barrier islands, with a low elevation and flat relief. Outer beach habitat occupied by shorebirds was devoid of vegetation. Mean tidal amplitude is approximately 1 m.

Beach censuses

From March 1992 to December 1993, five outer beach sites ranging from 9-34 km in length were surveyed. These were Bodie Island, North Beach, South Beach, Ocracoke Island, and North Core Banks. Additionally, a stretch of Pea Island National Wildlife Refuge (19 km), extending from the Oregon Inlet jetty south to Rodanthe, was surveyed for color-marked Sanderlings during the 1993 fall season. A total of 142 km of beach were surveyed during this study.

Surveys were conducted twice per month by vehicle. All surveys were begun 1.5 h before low tide, except for two counts on North Core Banks in July and August 1992 that were begun 1.5 h before high tide. Numbers of all shorebirds present on the outer beach were recorded. Outer beach is defined as the area from the base of the dune line to the ocean edge, including that portion of the intertidal zone exposed at low tide. Outer beach did not include soundside tidal flats at inlets or other tidal flat habitats. Flying birds were not recorded, unless they were clearly disturbed by the person(s) conducting the census. Since large shorebird concentrations (>500 birds) were rare, data here represent actual counts and not estimates. Abundance was expressed as the mean of two monthly censuses. For a few sites, there was only one count in a given month and this was treated as the value for that month. Monthly counts were summed across sites to obtain seasonal and annual counts.

Capture and marking of birds

The capture of Sanderlings was described in detail earlier (Chapter 1). All birds were fitted with an aluminum U.S. Fish and Wildlife Service leg band and a series of either four (1992) or three (1993) color bands arranged in a unique combination. The color bands were U.V. stable PVC bands (A.C. Hughes, London, England). Combinations were derived from six and ten possible colors during 1992 and 1993, respectively. Color band seams were melted together to reduce the possibility of band loss. Before release, each bird was weighed (to nearest 0.5g) and aged as juvenile or adult by plumage (Prater et al. 1977). Birds were released at the capture site within three hours.

Surveys for marked birds were done by four-wheel drive vehicle. Resighting efforts were restricted to North Core Banks in spring and to the five sites on Cape Hatteras National Seashore in fall. The study area was sampled every five days during spring (22 April-11 June) and during a two- to four-day period every seven days during fall (26 July-8 December), except that the first week of September was missed because of a hurricane. These periods are referred to as resighting periods. During surveys, complete and partial color band combinations were recorded, as well as the number of unmarked birds examined for color bands. Very large (>500 birds) concentrations of Sanderlings were rare, which increased the ease of examining birds for color bands.

Residence probability estimation

Residence probabilities (survival rates) were estimated using the Jolly-Seber models for open populations (Pollock et al. 1990). Program JOLLY was used to generate the parameter estimates. The assumptions and robustness of this approach were reviewed by Pollock et al. (1990). Careful consideration of several of the assumptions is relevant for this study. Residence probability is equal to 1-(mortality+emigration). Since this was estimated for periods of less than two weeks, mortality was assumed to be zero. The Jolly-Seber model assumes emigration is permanent. The extensive coverage of the study area and information about the site fidelity of Sanderlings suggest this assumption was met, though temporary emigration may have introduced a slight bias. Temporary emigration may have occurred when birds fed on tidal flats in nearby inlets, since these sites were not searched for marked birds. No band loss was detected among the 2,830 marked birds examined. Temporary trap response may bias the precision of the survival estimates. It is possible that the handling and stress associated with capture temporarily altered the resighting probabilities and survival of newly-marked birds, but it was assumed this response was negligible and was not permanent. Therefore, the survival estimates generated were assumed to be representative of the entire Sanderling population on the Outer Banks.

The data were tested under the general model for open populations (Model A; Jolly 1965, Seber 1965) and a model that allowed for a temporary marking effect (Model 2; Brownie and Robson 1983). Residence probability ($\hat{\phi}_i$) is defined as the probability a bird alive in sampling period i will remain to sampling period i+1. Turnover is defined as ($1-\hat{\phi}_i$) and is the estimated rate at which birds departed the area. Differences in residence probabilities due to age or sex were not tested because of limited sample sizes. Residence probabilities ($\hat{\phi}_i \pm$ SE) were estimated at nine five-day intervals from 22 April to 6 June, and at eighteen intervals of 1.5-14 days from 26 July to 30 November. Because marking was done between capture periods, the first resighting was treated as the initial capture (except for birds marked at the onset of each season). To correct for the unequal interval length between resighting periods, daily residence probabilities ($\hat{\phi}_d$) were calculated. The daily residence probability is the n^{th} root of the period residence probability ($\hat{\phi}_i$), where n is the number of days in the interval.

Residence probabilities were modeled as a function of body condition. To account for differences in body size, the ratio of body mass at capture to exposed culmen length (bill length) was calculated and used as an indicator of body condition. Wing chord was not used because birds were molting their primaries, making this measurement unreliable. All birds were assigned to a cohort for the spring ($\underline{n}$=4 cohorts) and fall ($\underline{n}$=8 cohorts) seasons. A cohort consisted of a group of birds banded during the same interval between two consecutive resighting periods. Each bird was then categorized as heavy (upper 40%) or light (lower 40%) based on within-cohort bill length to body mass ratios. Heavy birds were considered to be in good body condition, while light birds were in poor body condition. Birds with mean bill length to body mass ratios ± 10% were excluded in an effort to make body condition classes more distinct, while still retaining adequate sample sizes. Under these criteria, 42 birds were excluded from the spring data set and 128 birds were excluded from the fall data set. Small numbers of birds that were never resighted also were not included since the first resighting was treated as the initial capture. The number of individuals falling in each category may have been biased towards light birds since some birds were released almost 3 hours after capture. Those individuals may have lost up to 2.3 g during that time (Schick 1983). Such weight loss is uniform, regardless of the initial weight of the bird, and probably results from dehydration (Schick 1983). However, weight loss was small (<5% of the weight of the average bird) and was believed to have little effect on residence probabilities.

A series of goodness-of-fit tests were then performed to compare resightings of heavy and light birds in spring and fall. For each period, a 2x2 matrix was compiled which compared numbers of newly-released birds of both body condition classes that were resighted in some later period versus those never resighted.

Output from JOLLY also included resighting probabilities for each sampling period. A chi-square test comparing resighting probabilities of heavy and light birds was performed. For each period, a 2x2 matrix was compiled which compared numbers of newly-released birds of both body condition classes that were resighted in the next sampling period versus those not resighted in the next sampling period.

To obtain an estimate of the residency time of Sanderlings during the spring and fall seasons, a variation of the formula for mean life expectancy given by Brownie et al. (1985) was used. The mean length of stay (MLS, in days) was estimated as $MLS=\frac{1}{-\ln(\hat{\phi}_d)}$, where $\hat{\phi}_d$ is the mean daily survival rate from JOLLY.

Population estimation

Population size was estimated with a simple Lincoln-Peterson Index (see Pollock et al. 1990). The output from JOLLY provided estimates of the number of marked birds ($\hat{M}_i$) in the population during each resighting period. Using the output from JOLLY and counts of marked and unmarked birds from each resighting period, the total population ($\hat{N}_i$) for each resighting period was estimated as $\hat{N}_i = \hat{M}_i \times \frac{\text{Total number of birds}}{\text{Number of marked birds}}$. Population size was estimable for all but the first and last resighting periods in each season.

Population estimates ($\hat{N}_i \pm$ SE) were used to determine if actual monthly beach counts from spring (May and June) and fall (August to November) fell within the 95% confidence limits. Using census data, the number of Sanderlings in the study area each month was calculated as the sum of the monthly counts for each site. For mark-resight data, there were 2-6 population estimates ($\hat{N}_i$) within each month. These population estimates were log-transformed and a mean and standard error were calculated from the transformed estimates. The estimates were then back-transformed to provide comparable monthly estimates. The relationship between beach censuses and mark-resight population estimates was examined using linear regression through the origin.

By combining information from population estimates and estimates of turnover, the numbers of Sanderlings moving through the study area were estimated. The number of Sanderlings departing during period i is $(1-\hat{\phi}_i)(\hat{N}_i)$, where $\hat{\phi}_i$ is the turnover rate for the interval from period i to i+1 and $\hat{N}_i$ is the population estimate for that period. The sum of departing birds across all resighting periods estimates the number of Sanderlings moving through the area. This estimate is obtained for periods 2 through i-2 for each season.

RESULTS

A total of 964 Sanderlings was marked during the study. From these, 759 capture histories were generated to estimate residence probabilities. Weights varied seasonally, with the heaviest birds present during late spring and early fall (Table 1). During fall, mean weight for Sanderlings was 63.4g. Weights were high in July and August then decreased and stabilized somewhat after September. Heavy birds had a mean weight >80g in early fall (July-August), then dropped to 60-73g thereafter. During spring, mean weight was 55.4g, being highest during late May. Heavy birds were roughly 10g heavier than light birds.

Residence probability estimation

Data were insufficient to estimate residence probabilities under Model 2. The fit to Model A was significant (spring: $\chi^2=26.76$, $\underline{P}=0.005$, 11 d.f., fall: $\chi^2=96.66$, $\underline{P}<0.0001$, 42 d.f.). Despite the overall significance, Model A was selected for these data because the lack-of-fit was due to low numbers of resightings in a few periods. In spring, period 4 contributed 46% of the chi-square value. In fall, five periods (8,9,13,14,17) contributed 65%

Table 1. Weights (mean ± SE), overall and by body mass class, of Sanderlings captured during spring and fall on the Outer Banks of North Carolina, 1993.

Cohort	N	Weight	N	Light birds	N	Heavy birds
		Spring				
22-25 April	99	52.81 ± 0.35	45	49.81 ± 0.19	33	56.94 ± 0.40
30 April	55	56.69 ± 0.74	26	51.90 ± 0.53	23	62.04 ± 0.61
18-21 May	34	59.21 ± 1.39	18	52.89 ± 0.77	13	67.88 ± 1.37
23 May	16	59.19 ± 1.64	4	51.25 ± 2.85	4	66.88 ± 2.16
Spring Total	204	55.42 ± 0.42	93	51.05 ± 0.28	73	61.04 ± 0.62
		Fall				
26 July	53	70.63 ± 1.29	20	61.40 ± 1.19	21	79.76 ± 1.20
29 July-2 August	96	72.59 ± 1.30	38	62.37 ± 0.96	41	87.41 ± 1.01
6 August	97	78.92 ± 1.33	37	64.97 ± 1.31	44	90.59 ± 0.73
Early Fall Total	246	75.72 ± 0.80	95	63.18 ± 0.70	106	87.22 ± 0.67
9-10 September	116	57.24 ± 0.55	37	51.78 ± 0.39	47	61.64 ± 0.90
16 September	83	57.58 ± 0.43	29	53.33 ± 0.51	37	60.92 ± 0.31
29 September-1 October	211	55.38 ± 0.32	87	51.24 ± 0.24	85	59.71 ± 0.35
21 October	55	60.19 ± 0.70	24	55.83 ± 0.50	22	65.14 ± 0.82
4 November	49	64.30 ± 1.07	23	58.13 ± 0.85	16	73.03 ± 1.00
Late Fall Total	514	57.52 ± 0.26	200	52.99 ± 0.25	207	61.97 ± 0.37
Fall Total	760	63.41 ± 0.44	295	58.62 ± 0.31	313	70.52 ± 0.75

of the chi-square value, and were also due to low numbers of resightings.

Mean period residence probability ($\hat{\phi}_i \pm$ SE) for spring was 0.79 ± 0.02, with a mean daily residence probability ($\hat{\phi}_{\bar{d}} \pm$ SE) of 0.94 ± 0.01 (Table 2). Mean resighting probability ($\hat{p}_i$) was 0.46 (SE not estimable). Daily residence probability was relatively high (>0.96) through 27 May, but declined sharply thereafter. Mean period residence probability ($\hat{\phi}_i \pm$ SE) for fall was 0.81 ± 0.01 with a mean daily residence probability ($\hat{\phi}_{\bar{d}} \pm$ SE) of 0.96 ± 0.01 (Table 3). Mean resighting probability ($\hat{p}_i$) was 0.41 ± 0.02. Daily residence probability was slightly lower (0.82-0.97) from late July to early September, but relatively constant (0.95-1.00) from mid-September through late November.

In spring, light and heavy birds had the same residence probabilities (Table 4) (χ^2=14.61, P>0.05, 9 d.f.). During fall, light and heavy Sanderlings had different residence probabilities (χ^2=43.20, P<0.01, 18 d.f.). Differences in fall were significant in periods 4,6,13, and 19, when light birds had higher residence probabilities than heavy birds (Table 5). The resighting probabilities of heavy and light birds did not differ in spring (χ^2=4.87, P>0.05, 8 d.f.) or fall (χ^2=18.21, P>0.05, 18 d.f.).

Mean length of stay (MLS) was estimated for the spring and fall seasons. During spring, Sanderlings remained an average of 15.5 days (95% C.I. 13.0-19.1), while in fall they stayed an average

Table 2. Residence probabilities ($\hat{\phi}_i$) of Sanderlings at North Core Banks on the Outer Banks of North Carolina, spring 1993. (interval length in days)

Resighting Period	Interval length	Interval $\hat{\phi}_i$ (±SE)	Daily $\hat{\phi}_i$ (±SE)
22-27 April	5	0.84 ± 0.05	0.97 ± 0.01
27 April-2 May	5	1.00 ± 0.08	1.00 ± 0.01
2-7 May	5	0.83 ± 0.07	0.96 ± 0.02
7-12 May	5	0.91 ± 0.08	0.98 ± 0.02
12-17 May	5	1.00 ± 0.13	1.00 ± 0.02
17-22 May	5	0.78 ± 0.11	0.95 ± 0.03
22-27 May	5	1.00 ± 0.25	1.00 ± 0.05
27 May-1 June	5	0.33 ± 0.15	0.80 ± 0.07
1-6 June	5	0.20 ± 0.09	0.72 ± 0.06
Mean	-	0.79 ± 0.02	0.94 ± 0.01

Table 3. Residence probabilities ($\hat{\phi}_i$) of Sanderlings at five sites[1] on the Outer Banks of North Carolina, fall 1993. (interval length in days)

Resighting Period	Interval length	Interval $\hat{\phi}_i$ (± SE)	Daily $\hat{\phi}_i$ (± SE)
26-28 July	1.5	0.74 ± 0.07	0.82 ± 0.05
28 July-3 August	7	0.85 ± 0.11	0.98 ± 0.02
4-10 August	7	0.81 ± 0.10	0.97 ± 0.02
11-17 August	7	0.86 ± 0.11	0.98 ± 0.02
18-25 August	7.5	0.56 ± 0.09	0.93 ± 0.02
25 August-8 September	14	0.62 ± 0.10	0.97 ± 0.01
8-14 September	6.5	0.97 ± 0.10	0.99 ± 0.02
15-21 September	7	1.00 ± 0.05	1.00 ± 0.01
22-28 September	6.5	0.90 ± 0.04	0.98 ± 0.01
28 September-5 October	7	0.96 ± 0.06	0.99 ± 0.01
5-12 October	7	0.83 ± 0.04	0.97 ± 0.01
12-19 October	7	0.94 ± 0.05	0.99 ± 0.01
19-27 October	8.5	0.89 ± 0.09	0.99 ± 0.01
28 October-2 November	6	0.81 ± 0.10	0.96 ± 0.02
3-9 November	7	0.81 ± 0.15	0.97 ± 0.02
10-16 November	6.5	0.70 ± 0.14	0.95 ± 0.03
16-23 November	7	0.89 ± 0.32	0.98 ± 0.05
23-29 November	6.5	0.39 ± 0.17	0.87 ± 0.06
Mean	-	0.81 ± 0.01	0.96 ± 0.01

[1] The five sites are Bodie Island, Pea Island, North Beach, South Beach, and Ocracoke Island.

Table 4. Daily residence probabilities of Sanderlings by body condition on North Core Banks on the Outer Banks of North Carolina, spring 1993. (NE=not estimable) (Residence probability is the probability a bird alive in resighting period i will survive to the next period).

	Body Condition	
REsighting Period	Poor	Good
22 April	0.96 ± 0.04	1.00 ± 0.01
27 April	1.00 ± 0.03	1.00 ± 0.02
2 May	0.96 ± 0.03	0.96 ± 0.03
7 May	1.00 ± 0.04	0.96 ± 0.03
12 May	1.00 ± 0.07	1.00 ± 0.03
17 May	0.86 ± 0.06	0.98 ± 0.03
22 May	1.00 ± 0.10	0.97 ± 0.05
27 May	0.71 ± 0.09	0.82 ± NE
1 June	0.76 ± NE	NE
Mean	0.93 ± NE	0.96 ± NE

Table 5. Daily residence probabilities of Sanderlings by body condition at five sites[1] on the Outer Banks of North Carolina, fall 1993. (NE=not estimable) (Residence probability is the probability a bird alive in resighting period i will survive to the next period).

	Body Condition	
Resighting Period	Poor	Good
26 July	0.77 ± 0.08	0.79 ± 0.11
27-28 July	0.99 ± 0.03	0.96 ± 0.04
3-4 August	0.95 ± 0.02	0.98 ± 0.04
10-11 August[2]	1.00 ± 0.01	0.93 ± 0.05
17-18 August	0.94 ± 0.02	0.98 ± 0.11
24-26 August[2]	0.98 ± 0.01	0.85 ± NE
7-9 September	0.99 ± 0.02	NE
14-15 September	1.00 ± 0.01	0.99 ± 0.01
2--23 September	1.00 ± 0.01	0.99 ± 0.01
27-29 September	0.98 ± 0.02	1.00 ± 0.01
4-6 October	0.97 ± 0.01	0.98 ± 0.01
11-13 October	0.99 ± 0.01	1.00 ± 0.02
18-20 October[2]	0.99 ± 0.02	0.98 ± 0.03
26-29 October	0.94 ± 0.03	0.95 ± 0.04
2-3 November	0.97 ± 0.03	0.96 ± 0.05
9-10 November	0.96 ± 0.04	0.95 ± 0.05
15-17 November	0.98 ± 0.07	0.92 ± 0.06
22-24 November	0.83 ± 0.07	1.00 ± NE
Mean	0.96 ± 0.01	0.95 ± NE

1 The five sites are Bodie Island, Pea Island, North Beach, South Beach, and Ocracoke Island.

2 Differences in survival of heavy and light birds were significant ($\underline{P}<0.05$) for these resighting periods.

of 24.5 days (95% C.I. 21.0-30.8). Mean length of stay was lower in early fall (mean=18.5 days) than in late fall (mean=31.9 days).

Population estimation

A total of 2,830 sightings of marked birds were made during spring (491) and fall (2,339). An additional 138,140 birds (12,495 in spring and 125,645 in fall) were examined and found to be unmarked. Population size was estimated for nine of eleven resighting periods during spring (Table 6). Peak numbers were present on 27 April and 12,17 May when >3000 Sanderlings were estimated to be on North Core Banks. There was high variability in the spring population estimates, though they generally declined through early June, when <500 birds were present. Population size was estimated for eighteen of twenty resighting periods during fall (Table 7). Peak numbers were present on 24-27 August and 7-9 September when an estimated 19,415-20,460 Sanderlings were at the five sites on Cape Hatteras National Seashore. Numbers dropped sharply in mid-September, then declined slowly through late November.

Using estimates of turnover and population size, the total number of Sanderlings migrating through selected portions of the Outer Banks was estimated. During spring, an estimated 3,566 Sanderlings used North Core Banks (Table 6). During fall, an estimated 28,744 Sanderlings used the five sites at Cape Hatteras National Seashore (Table 7). These estimates are conservative since they do not account for birds present in the first or last two

Table 6. Population estimates ($\hat{N}_i$) and the number of Sanderlings that departed $[(1-\hat{\phi}_i)(\hat{N}_i)]$ from mark-resight data for nine of eleven resighting periods at North Core Banks on the Outer Banks of North Carolina, spring 1993. (NE=not estimable; $\hat{\phi}_i$ is the residence probability rate from resighting period i to i+1)

Resighting Period	$\hat{N}_i$	Departures
27 April	4,003	0
2 May	1,528	260
7 May	2,353	220
12 May	3,179	0
17 May	3,214	699
22 May	1,924	0
27 May	2,399	1,607
1 June	975	780
6 June	499	NE
Total		3,566

Table 7. Population estimates ($\hat{N}_i$) and the number of Sanderlings that departed $[(1-\hat{\phi}_i)(\hat{N}_i)]$ from mark-resight data for eighteen of twenty resighting periods at five sites[1] on the Outer Banks of North Carolina, fall 1993. (NE=not estimable; $\hat{\phi}_i$ is the residence probability rate from resighting period i to i+1)

Resighting Period	$\hat{N}_i$	Departures
27-28 July	10,460	1,572
3-4 August	4,445	849
10-11 August	5,656	797
17-18 August	9,742	4,305
24-26 August	19,415	7,465
7-9 September	20,460	706
14-15 September	2,837	0
20-23 September	5,192	500
27-29 September	8,327	367
4-6 October	5,234	914
11-13 October	8,193	527
18-20 October	8,181	891
26-29 October	8,706	1,685
2-3 November	6,333	1,178
9-10 November	8,516	2,560
15-17 November	4,047	456
22-24 November	6,552	3,972
29-30 November	4,040	NE
Total		28,744

[1] The five sites are Bodie Island, Pea Island, North Beach, South Beach, and Ocracoke Island.

resighting periods, or those birds that may have migrated through prior to the first resighting period. Assuming 1,000 Sanderlings used each of these sites not surveyed in spring (Bodie Island, Pea Island, North Beach, South Beach, and Ocracoke Island) and the single site not surveyed in fall (North Core Banks), a conservative estimate of the annual number of Sanderlings using the Outer Banks is 35-40,000. The assumption of 1,000 birds using each site not included in population estimates is valid, given that beach censuses documented greater numbers at each of these sites.

Numbers of Sanderlings varied considerably between sites within months (Table 8). Some of the greatest variability was during the peak migration, when mean counts for the five sites were 1,140 ± 225 in May and 2,251 ± 1,841 in July. During spring, mean monthly population estimates from mark-resight data were 2,352 for May and 698 for June, compared to census counts of 1,407 in May and 213 in June (Table 9). During fall, mean monthly population estimates from mark-resight data were 8,304 for August, 7,078 for September, 7,435 for October, and 5,655 for November. Only in November did the census count fall outside the confidence limits for the mark-resight population estimate (Table 9). In both seasons, beach censuses provided consistently lower estimates of the Sanderling population. There was a significant relationship between beach censuses and the mark-resight population estimates ($F_{1,5}$=88.9, $P<0.01$). Estimates of