# Status of the Red Knot
*(Calidris canutus rufa)*
# in the Western Hemisphere

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Pleasantville, New Jersey 08232

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**DISCLAIMER**

In August 2006, the red knot (*Calidris canutus rufa*) was designated a candidate species for possible addition to the Federal list of endangered and threatened wildlife (refer to: http://endangered.fws.gov/wildlife.html). A candidate species is one for which the U.S. Fish and Wildlife Service (USFWS) has on file sufficient information on biological vulnerability and threats to support a proposal to list as endangered or threatened, but for which preparation and publication of a proposal is precluded by higher priority listing actions. Copies of this document and additional information regarding the red knot are available on the USFWS's Region 5 web site (refer to: http://www.fws.gov/northeast/redknot/).

**USE OF DATA IN THIS PUBLICATION**

The data used in this review comes from published and unpublished sources from the authors and by permission of other researchers. It is requested that no data, figures, tables or images be reproduced without permission of the authors.

## EXECUTIVE SUMMARY

The population of the *rufa* subspecies of the red knot *Calidris canutus*, which breeds in the central Canadian arctic and mainly winters in Tierra del Fuego, has declined dramatically over the past twenty years. Previously estimated at 100,000-150,000, the population now numbers 18,000-33,000 (18,000 if just the Tierra del Fuego birds are *rufa*, more if the knots of uncertain subspecific status that winter in northern Brazil (7,500) or Florida (7,000) are also *rufa*). Counts show that the main Tierra del Fuego wintering population dropped from 67,546 in 1985 to 51,255 in 2000, 29,271 in 2002, 31,568 in 2004, but only 17,653 in 2005 and 17,211 in 2006.

Demographic studies covering 1994-2002, showed that the population decline over that period was related to a drop in annual adult survival from 85% during 1994-1998 to 56% during 1999-2001. Population models showed that if adult survival remained low, *rufa* would go extinct within about ten years. After 2002, the population held up in 2003-2004, but plunged again by nearly 50% in 2005 increasing the likelihood of extinction within the next decade.

Despite intensive studies, the reasons for the population decline and reduced adult survival are imperfectly known.

During northward migration, most *rufa* stopover in Delaware Bay where they feed mainly on the eggs of horseshoe crabs (*Limulus polyphemus*) and lay down fat and protein reserves both to fuel the 3,000 kilometer flight to the arctic breeding grounds and ensure their survival after they arrive at a time when food availability is often low.

The crucial importance of Delaware Bay is demonstrated by studies that show that lower weight knots in Delaware Bay have lower survival than heavier birds and that over 1998-2002 the proportion of birds there at the end of May that weighed more than the estimated departure mass of 180 grams declined by over 60%. This might be the result of the progressive failure of the food supply in Delaware Bay and/or a trend for birds to arrive there later and/or in poorer condition. In years when red knots experience both reduced food availability and there are late arrivals, the result may be an exacerbation of the effects of each of these deleterious factors.

The main identified threat to the *rufa* population is the reduced availability of horseshoe crabs eggs in Delaware Bay arising from elevated harvest of adult crabs for bait in the conch and eel fishing industries. Since 1990, there has been a substantial decline in the crab population. Although significant uncertainty regarding the extent of the decline of the horseshoe crab population remains, there is general agreement that horseshoe crab stocks have declined to a level where increased management of the fishery is necessary and appropriate. The decline in crabs has led to a decrease in the density of eggs available to shorebirds. Because of their delayed maturity, demographic models indicate that even if further exploitation of crabs ceases immediately, it will be some years before the horseshoe crab population recovers to its former level.

Although there is clear evidence, as in 2003 and 2005, that the reduced availability of eggs is already having an impact in some years on the knots ability to gain mass in Delaware Bay, it is likely that there are other threats to *rufa* and that these are the cause of some birds arriving in the Bay late and/or in poor condition. It is not known what these are, but they could be related to Bahia Lomas, the main wintering site in Tierra del Fuego (because the largest reduction in recent years has occurred there and

because northwards migration from Bahia Lomas along the Atlantic coast of Argentina has taken place 1-2 weeks later since year 2000).

If it is proved that there are factors that lead knots to arrive late in Delaware Bay and/or in poor condition, this does not diminish the importance of the Delaware Bay food resource. If anything, it is increased because it is of critical importance in enabling the birds to recover quickly and reach the breeding grounds on time and in good reproductive condition.

Actions already being taken to improve feeding conditions for red knots and other shorebirds in Delaware Bay include beach closures to prevent disturbance and exclosures to reduce competition from gulls. However, although these measures help, they are no substitute for a recovered horseshoe crab population. Actions to conserve horseshoe crabs have included reduced harvest quotas, more efficient use of crabs as bait, closure of the harvest in certain seasons and places and the designation of a sanctuary off the mouth of Delaware Bay. The latest information is that the crab population may have stabilized, but there is no evidence of recovery.

Another red knot subspecies, *roselaari*, breeds in Alaska and is presumed to include those knots that winter on the Pacific coast of the U.S. and Mexico. There are two other red knot wintering populations of uncertain subspecific status: one in the southeast of the United States (mainly Florida) of about 7,000 and one on the north coast of Brazil of about 7,500. These populations have not been the subject of regular systematic surveys, but it is not thought that either has suffered the same catastrophic decline as the *rufa* that winter in Tierra del Fuego. Substantial proportions of both pass through Delaware Bay during northward migration, but banding shows that these are distinct populations without interchange with the Tierra del Fuego birds. Moreover genetic studies show that there has been no exchange of genes between the SE United States and the Tierra del Fuego birds for at least 1,200 years.

Some progress has been made towards understanding why the Tierra del Fuego population has suffered a major decline, but the northern wintering birds have apparently remained more stable. It appears that physiological constraints mean that the southern birds, which mostly make a long, non-stop flight to Delaware Bay from at least Northern Brazil, are more reliant on soft, easily-digested horseshoe crab eggs in Delaware Bay than the northern winterers, many of which feed on blue mussel (*Mytilus edulis*) spat or surf clams (*Donax variablis*) on the Atlantic coast of New Jersey. There is also evidence from Patagonia that, for a reason that remains obscure, northward migration of Tierra del Fuego birds has become 1-2 weeks later since year 2000 and this has probably led to more red knots arriving late in Delaware Bay. Late arriving birds have been shown to have the ability to make up lost time by increasing their mass at a higher rate than usual provided there are sufficient food resources. However, late-arriving red knots failed to do this in 2003 and 2005 when egg availability was low.

Although *rufa* knots are spread thinly across a large area of the Canadian arctic during the breeding season, for the rest of the year they occur mainly in large flocks at a limited number of key coastal wintering and staging sites. This review describes each of these sites and the threats the birds face ranging from oil pollution to disturbance and reclamation for development.

Overall the goal of conservation activities throughout the flyway should be to increase the *rufa* population to at least the figure of 25 years ago of 100,000-150,000 by 2015. Given the uncertain genetic relationships between the three main wintering populations there should also be a target for each. The following are suggested:

1. Tierra del Fuego wintering population to 70,000-80,000 birds
2. Brazilian wintering population to 20,000-25,000
3. Florida wintering Population to 20,000-25,000
4. Other sites 15,000-20,000

The means whereby such population increases might be achieved include:

1) Recovery and maintenance of Delaware Bay horseshoe crab egg densities to levels sufficient to sustain stopover populations of all shorebirds including 100,000 red knots.
2) Control impact of disturbance at all stopovers and wintering areas, particularly in high-importance, high-disturbance areas like Delaware Bay and the west coast of Florida.
3) By 2008, develop a system for the yearly determination of population demographic status based on counts, capture data, and resightings of banded individuals.
4) By 2008, determine the genetic and breeding status of the three main wintering populations (Tierra del Fuego, Maranhão, and Florida).
5) By 2008, identify all important breeding locations in Canada and recommend protection needs and designations for the most important sites.
6) By 2009, complete site assessments and management plans for all important wintering areas and stopovers in the Flyway.
7) By 2009, delineate and propose protection measures for key habitats within the main wintering areas of Maranhão, Tierra del Fuego, and Florida, and develop management plans to guide protection.
8) By 2009, determine key southbound and northbound stopovers that account for at least 80% of stopover areas supporting at least 100 red knots, and develop coast-wide surveillance of birds as they migrate.
9) By 2011, create a hemisphere-wide system of protected areas for each significant wintering, stopover, and breeding area.

Also crucial to *rufa*'s recovery is adequate funding to support the conservation actions and research needed. Despite the fact that much of the research, survey, monitoring and conservation work has been carried out by volunteers and has been supported financially by state, federal government and non-government agencies, present funding levels are inadequate to sustain the work required.

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**APPENDIX**

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## I. INTRODUCTION

The red knot (*Calidris canutus*) is a worldwide species with a total population of approximately 1.05 million (Wetlands International 2006, Minton unpublished data, this review).

Breeding in the Arctic and wintering as far south as New Zealand, Australia, South Africa and Tierra del Fuego, the red knot is one of nature's most prodigious travelers exciting the interest of scientists and conservationists around the world. The red knot is also one of the most extensively studied of the world's 221 species of shorebird (Table 1). Central to this research effort is a team led by Professor Theunis Piersma on Texel in the Netherlands where the Royal Netherlands Institute for Sea Research has a purpose-built laboratory, the size of an aircraft hangar, for studying red knots under precisely controlled conditions.

Table 1. Number of citations of the most extensively studied shorebirds in the world (data extracted from the Web of Science for 1980-2003 and published in Thomas *et al.* 2003).

| Species | Number of citations in title only | Number of citations in text |
|---|---|---|
| Eurasian Oystercatcher *Haematopus ostralegus* | 112 | 292 |
| Dunlin *Calidris alpina* | 58 | 137 |
| Northern Lapwing *Vanellus vanellus* | 51 | 125 |
| Red Knot *Calidris canutus* | 36 | 132 |
| Redshank *Tringa totanus* | 29 | 88 |
| Ruff *Philomachus pugnax* | 22 | 57 |
| Eurasian Curlew *Numenius arquata* | 20 | 43 |
| Black-bellied Plover *Pluvialis squatarola* | 18 | 73 |

There are six subspecies of the red knot which together have a circumpolar arctic breeding distribution though each breeds in a distinct area and winter separately. Except as otherwise noted, this status assessment focuses on the New World red knot subspecies *Calidris canutus rufa*.

Building on earlier work led by the Manomet Center for Conservation Science, *rufa* has been the subject of intensive studies throughout the West Atlantic shorebird flyway since 1997. These studies were originally instigated and have since been sustained by concern that the Patagonian population has fallen from 100,000-150,000 in the early 1980s to around 17,200 in 2006. The work has involved a diverse selection of people and organizations, government and non-government from Argentina, Chile, Brazil, and Canada as well as all east coast states of the U.S. from Florida to Massachusetts and the U.S. Fish and Wildlife Service (USFWS). From the beginning, shorebird ecologists from

outside the Americas have also been involved, especially from the UK, The Netherlands and Australia, several of whom have contributed to this review.

Studies of *rufa* have focused on determining the cause of the population decline and whether anything can be done to reverse the situation. With limited resources, they have sought to cover the whole of *rufa*'s latitudinal range of over 120° from Tierra del Fuego (54°S) to King William Island (68°N) and the whole of its annual cycle from one arctic breeding season to the next. More specifically, a large proportion of the effort has been directed at measuring demographic rates and identifying where in the annual cycle the problems lie. All this has proved very challenging and we do not yet know all the answers. Nevertheless, considerable progress has been made, due in no small part to the use of modern and sometimes innovative techniques as well as much hard work and the support of many people and organizations.

Worldwide, the main organization concerned with research and conservation science in relation to the world's 221 species of shorebird is the International Wader Study Group[1], which organized a workshop attended by 132 specialists from 20 countries in 2003 to address the question "Are shorebird populations worldwide in decline?" The conclusions show that of those shorebirds whose population trend is known, 48 % are declining and only 16% increasing (International Wader Study Group 2003). Many of the declining populations were found to be those of long-distance migrants and *rufa* was cited as a prime example. Problems identified as common to several long-distance migrants were their high dependency on a very limited number of key stopover sites making them particularly vulnerable to habitat loss (as in the Yellow Sea where huge areas of intertidal habitat have been lost to reclamation) and declining food resources at stopover sites arising from the unsustainable exploitation of natural resources. In the latter case, the prime examples worldwide were considered to be unsustainable shell-fish harvesting in the Dutch Wadden Sea and the exploitation of horseshoe crabs (*Limulus polyphemus*) in Delaware Bay.

As a result of *rufa*'s decline, in November 2005 the parties to the Bonn Convention (which include Argentina and Chile, but not the U.S., Brazil, or Canada) determined that *rufa* was endangered and as such added it to Appendix 1 of the Convention which commits the parties to strive towards protection of the species and the conservation of its habitat. In April 2007, the Canadian government's Committee on the Status of Endangered Wildlife in Canada determined that *rufa* was endangered following completion of a status review. In Brazil the red knot is being proposed for listing as endangered.

A problem arising from the continuous nature of the *rufa* studies over the past nine years has been a lack of time and resources to write up and publish results. All too often, data have been analyzed and partly written up only to be overtaken by the accumulation of more data. We therefore greatly welcome the opportunity that this status review affords to take stock and set out a full account of our current knowledge. We will describe *rufa* in the context of worldwide red knot populations; we will assess its status, its general natural history, its habitat, its breeding system, its migrations and its feeding

[1] Outside North America, most English-speaking people call shorebirds "waders." Both terms refer to the world's 221 species of Charadrii. As some are never found on the shore and some never wade in water, neither term can be regarded as better than the other.

ecology. We will especially address the threats it faces and the conservation actions that may lead to its recovery.

## II. TAXONOMY

### A. Introduction

Red knots are currently classified into six subspecies, each with distinctive morphological traits, migration routes and annual cycles. Available evidence from long term ringing programs indicates that distinct flyways exist (Piersma and Davidson 1992) and six separate breeding areas are known to host different populations, all of which are now formally recognized as subspecies based on body size and plumage characteristics (Tomkovich 1992, Piersma and Baker 2000, Tomkovich 2001; Table 2, Fig. 1). *C. c. roselaari* is thought to breed in northwest Alaska and Wrangel Island. Its wintering areas are unknown, but museum skins studies by Tomkovich (1992) indicate that this subspecies may migrate down the Pacific coast of North America and winter in the Gulf of Mexico. Because knots wintering in Florida, Georgia and South Carolina have a different molt schedule, and they do not migrate to southern South America, they have been referred to *C. c. roselaari*. The breeding grounds of the southeast U.S. wintering knots have not been confirmed. *C. c. rufa* breeds in the central Canadian Arctic and winters in southern Patagonia and Tierra del Fuego. Another group wintering in northern Brazil and possibly Venezuela is presumed to belong to this subspecies. *C. c. rogersi* breeds on the Chukotski Peninsula in eastern Russia and winters in southeast Australia and New Zealand. *C. c. piersmai* breeds on the New Siberian Islands in north central Russia and winters in northwest Australia, and *C. c. islandica* breeds in northern Greenland and northeast Canada and winters in north west Europe. The nominate subspecies *C. c. canutus* breeds on the Taymyr Peninsula in western Siberia and winters in west and south west Africa. Earlier work failed to distinguish geographically isolated groups indicating apparent panmixia caused by a late Pleistocene bottleneck (Baker *et al.* 1994, Piersma 1994). This analysis, however, was limited by an extreme lack of genetic variability making it difficult to distinguish between genetic variation inherited from a common ancestral stock following a recent bottleneck and current gene flow between current populations.

Table 2. Population estimates of the six subspecies of the red knot *Calidris canutus*.

| Subspecies | Estimated population size | Source |
|---|---|---|
| *Canutus* | 400,000 | Wetlands International (2006) |
| *Islandica* | 450,000 | Wetlands International (2006) |
| *Rogersi* | 90,000 | Minton unpublished data |
| *Piersmai* | 50,000 | Minton unpublished data |
| *Roselaari* | 35,000-50,000* | Wetlands International (2006) |
| *Rufa* | 18,000-35,000 | This review |

* As discussed elsewhere in this review, *roselaari* almost certainly has a much smaller population than that suggested by Wetlands International (2006)

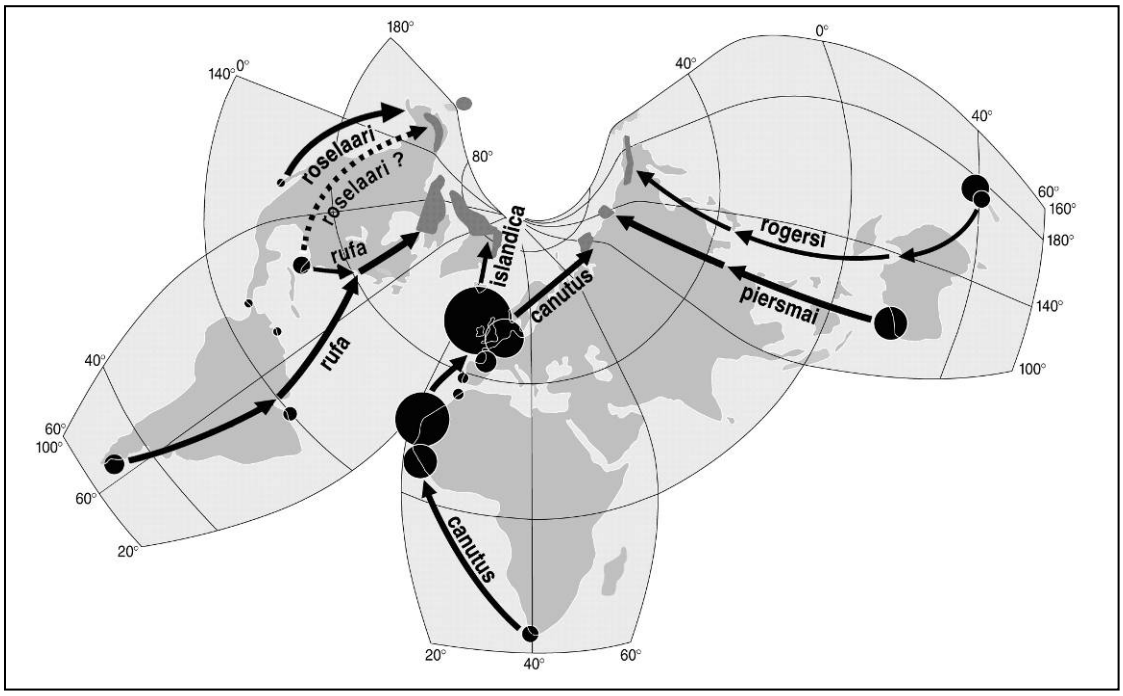



Figure 1. Worldwide distribution of the six recognized subspecies of the red knot. All breeding areas (dark gray shading) are on high-arctic tundra where the adults spend June-July. After their long-distance migrations (arrows) they spend the non-breeding season (August-May) mainly in intertidal soft-sediment habitats (dots, which are scaled according to population size). This map was prepared in 2003 and revised according to recent studies described in this review. Note that it is uncertain whether the knots that winter in Northern Brazil and/or Florida are *roselaari*, but some birds presumed to be *roselaari* winter on the coast of California and Baja California (map drawn by Dick Visser, provided by Jan van Gils, and reproduced with their permission).

**B. Genetic Evidence for Knot Subspecies**

To detect possible genetic differences among knot subspecies Buehler and Baker (2005) assayed genetic variation by sequencing 675 base pairs of the fast-evolving control region of the mtDNA molecule in 91 individuals sampled worldwide. Most haplotypes in the knot network differ by a single base change, producing a star-like pattern characteristic of a species that has undergone a recent bottleneck with subsequent expansion (Fig. 2). Despite the apparent lack of sorting of haplotypes into discrete genetic lineages in each subspecies, knots showed low but significant population differentiation using both conventional *F*-statistics and exact tests. Four genetically distinct groups were found corresponding to *C. c. canutus, C. c. piersmai, C. c. rogersi* and a North American group containing *C. c. roselaari, C. c. rufa* and *C. c. islandica* (see Table 3 for $F_{ST}$ summary; Pooled Exact test, $P < 0.001$).

Genetic differences between subspecies are also apparent in nuclear DNA. A genomic scan of 836 loci using amplified fragment length polymorphisms (AFLP) detected different frequencies of these dominant markers at 129 loci, and showed significant genetic differentiation among subspecies ($F_{st}$=0.089). The genetic distance

between *C. c. roselaari* and *C. c. rufa* is small (0.1) but similar to the genetic distance between *C. c. rogersi* (southeast Australia and New Zealand) and *C. c. canutus* (Eurasia).

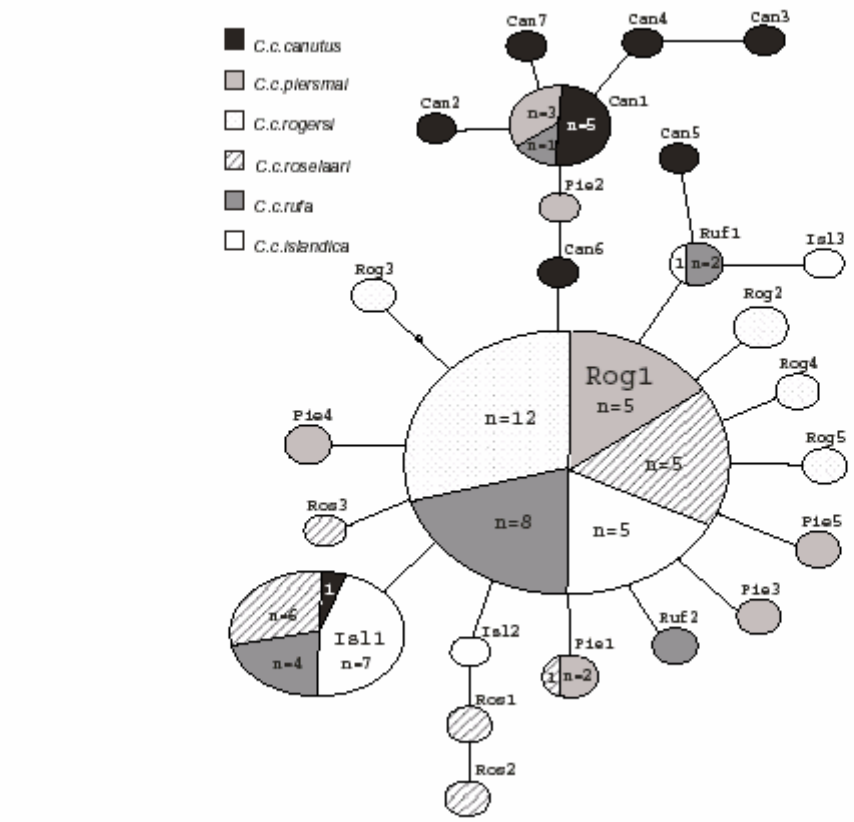



Figure 2. Minimum spanning network showing the relationships between haplotypes from the mitochondrial control region of knots. Ovals represent haplotypes and connecting lines represent a single base pair change between haplotypes. Small open circles on lines represent multiple base pair changes between haplotypes.

Table 3. Estimates of $F_{ST}$ for population differentiation in knots (below diagonal) calculated using mtDNA control region sequences. Above the diagonal "+" indicates significance at the 0.01 level, and – indicates not significant (P> 0.01).

| | *C.c. canutus* | *C.c. islandica* | *C.c. piersmai* | *C.c. rogersi* | *C.c. roselaari* | *C.c. rufa* |
|---|---|---|---|---|---|---|
| *C.c. canutus* | 0 | + | + | + | + | + |
| *C.c. islandica* | 0.19 | 0 | + | + | - | - |
| *C.c. piersmai* | 0.07 | 0.12 | 0 | + | - | - |
| *C.c. rogersi* | 0.27 | 0.20 | 0.07 | 0 | + | - |
| *C.c. roselaari* | 0.17 | -0.04 | 0.08 | 0.15 | 0 | - |
| *C.c. rufa* | 0.23 | 0.005 | 0.07 | 0.05 | 0.002 | 0 |

The demographic history of knot populations can be deduced from the genetic signature in the control region sequences, providing they are selectively neutral (which appears to be the case in knots) and can be done by computing the number of mutational differences between each pair of sequences in individual birds. These pair-wise differences in knot subspecies have a single peak pattern expected when a population expands after a recent bottleneck (i.e. most birds have haplotypes that differ by only 1-3 mutations) (Fig. 3).

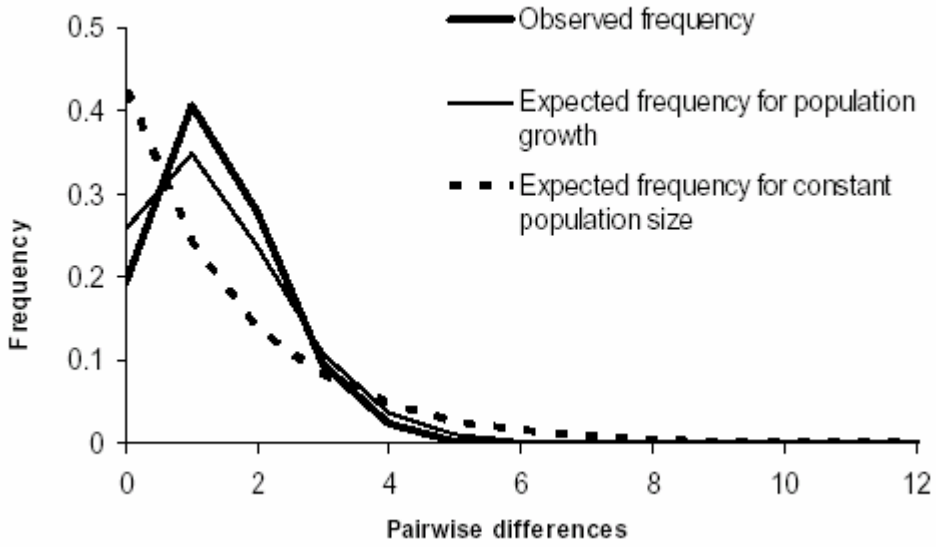



Figure 3. Observed and expected mismatch distributions of mitochondrial control region sequences in knots. Knots closely match the pattern expected under population growth in the recent past.

Coalescent modeling of the sequence variation using a rate of molecular evolution calibrated for shorebirds estimated that divergence times of populations representing all six subspecies of knots occurred within the last 20,000 years (95% CI: 5,600 – 58,000 years ago), thus corresponding to the Last Glacial Maximum 18,000-22,000 years ago. This basal split separated *C. c. canutus* in central Siberia that migrated to western Africa from a lineage that expanded into eastern Siberia and began to migrate to Australia (the ancestor of *C. c. rogersi* and *C. c. piersmai*).

As the ice retreated the latter lineage eventually expanded across Beringia into Alaska and established the North American lineage about 12,000 (95% CI: 3,300 – 40,000) years ago. At this time an ice-free corridor had opened between the ice sheets covering the Rockies to the west and the Great Plains to the east, which served as a dispersal route for an assortment of organisms including humans, other mammals and probably birds. This corridor was oriented NW-SE, and thus may have guided the evolution of a new migratory pathway between Alaska or the western Canadian arctic and the southeast U.S. As the ice sheets retreated further eastwards across the high arctic of Canada the ancestral population was fragmented sequentially within the last 5,500 years into three breeding populations, corresponding today to *C. c. roselaari, C. c. rufa* and *C. c. islandica*. If this is correct, then the present wintering flocks in the southeast U.S. are properly attributed to *C. c. roselaari* and we would predict that they return

annually to their ancestral breeding grounds in arctic northwest North America. Furthermore, the migration pathways of *C. c. rufa* and *C. c. islandica* are newly evolved responses to the eastward expansion of their breeding ranges. The divergence of *C. c. piersmai* and *C. c. rogersi* was estimated to have occurred about 6,500 (95% CI: 1,000 – 23,000) years ago, probably as a consequence of their isolated breeding ranges in the New Siberian Islands and the Chukotski Peninsula in Russia.

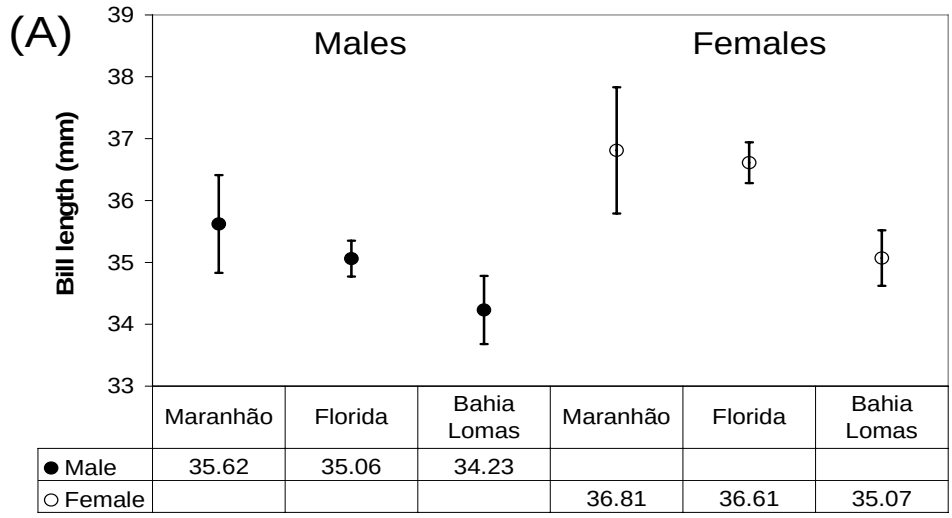
Given the recency of these divergence times, it is not surprising that the level of genetic differentiation in these neutral mtDNA sequences and nuclear AFLP is small. There simply has not been enough time for mutations to accumulate in these DNA regions to track evolutionary changes operating in the more immediate scale of ecological time. In such cases, conservation geneticists have cautioned that these apparent small genetic differences in neutral DNA sequences should not be misinterpreted in defining subspecies (Avise 1989). Instead, more emphasis should be placed on morphological and ecological differences because they likely track more immediate adaptive changes that are much more rapid responses to positive natural selection.

Despite the lack of fixed genetic differences among subspecies, the population divergence time of the knots that winter in the southeast of the United States (presumed to be *C. c. roselaari*) and those that winter in Tierra del Fuego (*C. c. rufa*) is estimated to be about 1,200 years ago (Buehler and Baker 2005). Therefore these populations have not been exchanging a significant number of individuals per generation for a long time, and clearly are independent units for conservation. This conclusion is supported by other biological information such as different primary molt schedules and, as described below, the lack of exchange of color-marked individuals.

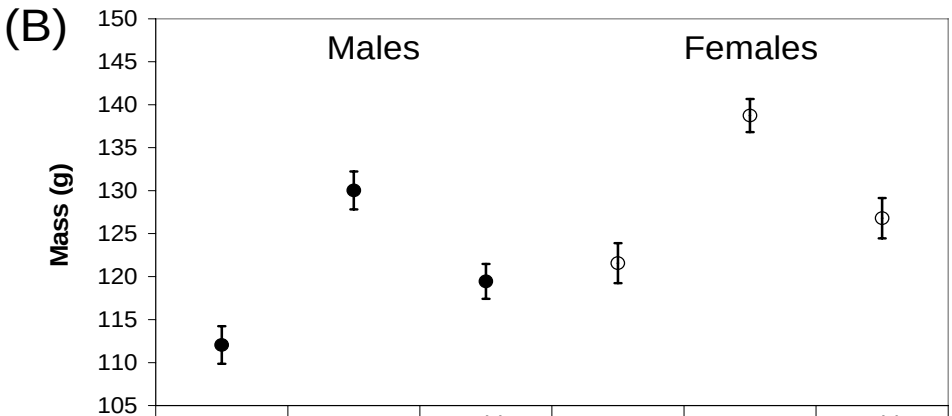
**C. Ecological and Morphological Evidence for Subspecies in North America**

Because *C. c. islandica* has a completely separate breeding range in northeastern Canada and Greenland, winters in western Europe and has brighter breeding plumage and considerably shorter average bill length than other Nearctic breeding knots, it clearly warrants subspecies status (Roselaar 1983). Knots attributed to *C. c. rufa* and *C. c. roselaari* are much paler by comparison and have much longer average bill length. To our knowledge no one has adequately compared morphological variation in *C. c. rufa* and *C. c. roselaari* populations. To address this inadequacy, bill length and body weight were measured in samples of knots from San Antonio Oeste in Argentina (the TDF -- Tierra del Fuego population), Maranhão in northern Brazil (MA population) and Florida (southeast U.S. population). The samples were selected because all specimens were sexed molecularly (Baker *et al.* 1999a.), and thus the sexes could be analyzed separately. Additionally, they were taken in January or February which reduces variation in body weight due to different periods of the annual cycle. Although the San Antonio Oeste (SAO) sample was taken in the early stage of the spring migration, there were no significant differences in body weight between birds caught there in early March or in Río Grande, Tierra del Fuego, in November for either sex (males, $F=0.603$, $p=0.442$; females, $F=1.809$, $p=0.183$). Thus the SAO sample was preferred because it probably contains knots from both primary wintering sites in TDF, Río Grande and Bahía Lomas. As in all knots, sexual dimorphism in both bill length and body weight is apparent, with females having longer bills and higher body weights on average than males in all three populations (Fig. 4). Comparisons among localities for each sex separately showed

highly significant geographic variation. Analysis of variance followed by HSD post hoc tests for unequal sample sizes revealed that average bill length is significantly longer in knots from Maranhão in northern Brazil than from San Antonio Oeste in Patagonia (females, p=0.027; males, p=0.016) indicating that these populations are discrete. Conversely, average body weight is significantly lower in females in Maranhão than in San Antonio Oeste (p=0.026), and in males is significantly lower in Maranhão than in Florida or San Antonio Oeste (p=0.0005 and 0.002, respectively). However, lower body weight in more tropical wintering populations of knots is also demonstrated in Australia (Minton unpublished data).




| | Maranhão | Florida | Bahia Lomas | Maranhão | Florida | Bahia Lomas |
|---|---|---|---|---|---|---|
| ● Male | 35.62 | 35.06 | 34.23 | | | |
| ○ Female | | | | 36.81 | 36.61 | 35.07 |




| | Maranhão | Florida | Bahia Lomas | Maranhão | Florida | Bahia Lomas |
|---|---|---|---|---|---|---|
| ● Male | 112.04 | 130.03 | 119.45 | | | |
| ○ Female | | | | 121.57 | 138.75 | 126.8 |

Figure 4. Biometrical variation of male and female red knots in the wintering populations of Maranhão (Brazil), Florida and Bahia Lomas (Tierra del Fuego) indicated by (A) bill length and (B) body mass (mean ± 95% confidence intervals (data are from Baker *et al.* 2005a and Niles *et al.* 2006).

In addition to the significant differences in these ecologically important biometrical variables, there is a small but apparently diagnostic difference in winter plumage in Florida knots. All 26 collected specimens from west Florida have more heavily marked flanks and throats, and have more pronounced brown flecks and vermiculations extending further distally on the background white plumage of the breast and belly (Fig. 5). Knots from Maranhão closely resemble the ventral plumage of the Tierra del Fuego population.

Figure 5. Ventral views of females collected in January in Florida (left three skins) and in February in Río Grande, Tierra del Fuego (right three skins) (A). Similar differences are apparent in males. Breeding plumage differences between *C. c. roselaari* (believed to be subspecies on the left) and *C. c. rufa* (right) (B). Birds were captured on the Delaware Bay and sexes are unknown.

**D. Evidence for Discrete Wintering Populations**

In addition to these morphological and ecological differences, discrete wintering populations are evident. Color-banding studies have been conducted where individuals are banded with color-marked flags based on the wintering grounds where they were captured. Based on re-capture and resighting data, individuals from the two northernmost populations in Florida and Maranhão have not been recaptured or re-sighted in Tierra del Fuego, and vice versa. Moreover, extensive searches of the Maranhão flocks in the austral summers of 2004 and 2005 failed to find any knots marked from Tierra del Fuego, or any birds with southeast U.S. color combinations, indicating that they are a completely separate population (Baker *et al.* 2005a). However, 15 of the 46 knots marked in Maranhão with individually inscribed blue flags were resighted in Delaware Bay in May-June 2005, showing that at least some of these birds pass through the Bay each spring.

One possibility is that both the Maranhão and southeast U.S. knots are *C. c. roselaari,* in which case the risk of extinction of this subspecies and *C. c. rufa* will be significant, as both have winter range census populations of only 15,000-20,000 (Baker *et al.* 2005a, Harrington unpublished data, Winn pers. comm. 2005) (see Section VII Population Size and Trends). Based on genetic data, the effective population size of either subspecies is probably in the order of 1,000-2,000 adult breeders, as the effective number of breeders can be as low as about 10% of the adult population (Whitlock 2000). At this threshold of effective population size, both theoretical modeling and empirical estimates of population genetic parameters predict a much greater risk of extinction both

from mutation accumulation in the long term and from the immediate ecological threats to small populations (Whitlock 2000).

Alternatively, the Maranhão population could be an easternmost part of the *C. c. roselaari* population which is also speculated to winter in Mexico. In this case, the southeast U.S. population would have a census population size of about 7,500 birds, based on counts in winter in west Florida and Georgia/South Carolina in 2005 implying that the effective size of the southeast U.S. population is approaching the critical population size for persistence in the longer term and is in danger of extinction from the perspective of stochastic ecological risk factors in the near future. These ecological risk factors caused the severe decline in the Tierra del Fuego population (Baker *et al.* 2004).

The third possibility is that all three red knot populations (Tierra del Fuego, Maranhão and southeast U.S.) really belong to one subspecies (*C. c. rufa*). This seems implausible biologically, as the aggregate evidence from genetic, ecological, morphological and banding data clearly document differences among these populations. Furthermore, these differences equate with those used to recognize the other four subspecies of knots worldwide (Tomkovich 1992, 2001). Risk-averse management should take as the absolutely minimum position that each of these three populations are distinctive population fragments of *Calidris canutus,* and that two subspecies are probably represented.

In summary, clarification of the taxonomic status of these populations will require further genetic research using a larger battery of high-resolution microsatellites and AFLPs. Additionally, we need to better understand their migration pathways, breeding ranges, and population vital rates. The status of the knots seen staging in South Carolina and Georgia and wintering in Florida and the Caribbean cannot be assumed to be *roselaari* until their breeding range is discovered and further genetic studies are completed. Of the six currently recognized subspecies of knots in the world, three nest in the U.S. / Canadian arctic (*rufa, roselaari* and *islandica*) and only the first two will be discussed throughout this document except where studies of other subspecies apply to knots worldwide. Within the Americas there is also taxonomic uncertainty about small population segments in Maranhão in northern Brazil and on the Pacific coast of Mexico. These segments along with the southeastern U.S. wintering population are each less than 10,000 birds and are apparently in decline, but by far the most alarming decline is in the long-distance migrant population in Tierra del Fuego which has fallen from 67,000 in the 1980s to about 17,200 in 2006.

## III. PHYSICAL DESCRIPTION

Essentially, the plumage of all red knots is mainly chestnut-red or salmon-colored during the breeding season and white and gray for the remainder of the year. The differences between the subspecies are largely confined to breeding plumage and size. In the detailed account of the subspecies set out below, we concentrate on male plumages because they show the most pronounced differences. We also focus on *rufa* and the critical difference (for some of the issues discussed in this review) between *rufa* and *roselaari*. In addition, we outline the plumages of the other subspecies to give an idea of the general nature of subspecific variation in the species. We also present biometric data from Harrington (2001) covering wing-chord and culmen length (Table 4) and mass

(Table 5), although differences noted by these data may possibly be attributed to phenotypic plasticity rather than inter-subspecific ones.

Table 4. Mean wing-chord and culmen measurements (mm; BAH) from museum specimens of adult red knots taken from Western Hemisphere locations between Apr and Jun and of juvenile knots taken during fall migration. Data given as mean ± SD (n). Taken From: Harrington 2001.

| Sex | Wing-chord length | Culmen length |
|---|---|---|
| Adults | | |
| Females | 164 (a) ± 22 (78) | 36.3 (b) ± 3.1 (78) |
| West (c) | 167 (e) ± 21 (11) | 37.0 (f) ± 6.0 (11) |
| Northeast (d) | 161 (e) ± 23 (29) | 35.9 (f) ± 2.8 (29) |
| Males | 161 (a) ± 17 (97) | 34.9 (b) ± 2.2 (97) |
| West (c) | 162 (g) ± 23 (18) | 35.8 (h) ± 1.8 (18) |
| Northeast (d) | 160 (g) ± 19 (35) | 34.9 (h) ± 2.6 (35) |
| Juveniles | | |
| Females | 160 (a) ± 16 (35) | 34.4 (b) ± 4.9 (35) |
| West (c) | 161 (e) ± 15 (13) | 36.0 (f) ± 4.7 (13) |
| Northeast (d) | 159 (e) ± 15 (13) | 33.4 (f) ± 2.6 (22) |
| Males | 154 (a) ± 27 (37) | 32.6 (b) ± 5.6 (37) |
| West (c) | 158 (g) ± 13 (9) | 33.7 ± 6.8 (9) |
| Northeast (d) | 159 (g) ± 15 (22) | 32.2 ± 4.9 (28) |

(a) Not significantly different between sexes; adults $F = 1.32$, $p = 0.10$, for juveniles $F = 1.65$, $p > 0.05$). (b) Significantly different between sexes in adults ($F = 1.45$, $p < 0.05$) but not in juveniles ($F = 1.15$, $p > 0.05$). (c) West includes Alaska, Alberta, British Columbia, and California. (d) Northeast coast includes N. Carolina and coastal points north and east. (e) West and northeast wing lengths are significantly different (for adults $t = 3.52$, $p < 0.001$, for juveniles $t = 2.06$, $p < 0.05$). (f) West and northeast bill lengths are significantly different (for adults $t = 1.67$, $p < 0.05$, for juveniles $t = 4.01$, $p < 0.001$). (g) West and northeast wing lengths are not significantly different among adults ($t = 1.27$, $p > 0.05$), but are significantly different in juveniles ($t = 1.96$, $p < 0.05$). (h) West and northeast are not significantly different ($t = 1.57$, $p > 0.05$) among adults but are significantly different among juveniles ($t = 1.96$, $p < 0.05$).

Table 5. Body mass (g) of Western Hemisphere red knots at different stages of north and south migration. From Manomet Center for Conservation Sciences unpublished data given as mean ± SD (range, n). Taken From: Harrington 2001.

| Location | Date (a) | Body mass | Significance (b) |
|---|---|---|---|
| Winter | | | |
| Sarasota, FL | 283 | 124.9 ± 7.1 (103–140, 101) | G |
| | 6 | 136.5 ± 8.9 (112–158, 120) | F |
| | 10 | 139.7 ± 9.1 (123–160, 25) | F |
| North migration | | | |
| Punta Rasa, Argentina (c) | 98 | 138.9 ± 16.6 (105–167, 30) | F |
| Península Valdés, Argentina (c) | 101 | 151.3 ± 13.1 (114–182, 102) | E |
| | 110 | 148.2 ± 17.0 (104–185, 162) | E |
| Lagoa do Peixe, Brazil (c) | 119 | 199.9 ± 17.6 (135–246, 139) | A |
| | 123 | 204.4 ± 21.6 (150–289, 141) | A |
| Delaware Bay, NJ | 133 | 159.2 ± 12.7 (129–198, 221) | CD |
| | 138 | 153.6 ± 16.8 (91–205, 385) | DE |
| | 143 | 175.4 ± 18.1 (107–210, 278) | B |
| | 148 | 162.4 ± 24.1 (105–198, 24) | C |
| South migration | | | |
| Scituate, MA | 209 | 148.4 ± 19.2 (101–206, 608) | E |
| | 215 | 169.3 ± 18.7 (135–205, 23) | B |
| | 220 | 172.4 ± 20.2 (103–225, 659) | B |
| | 232 | 168.9 ± 20.2 (128–207, 32) | B |
| Plymouth, MA | 235 | 124.2 ± 16.1 (90–149, 18) | G |
| (a) Dates are Julian dates, starting with 1 for 1 Jan and ending with 365 for 31 Dec. (b) Means sharing the same letter are not statistically different ($p > 0.05$) according to a General Linear Means Model (PROC GLM) and a Duncan's Multiple Range Test (SAS Institute, 1985). (c) Samples do not include birds recorded as in Basic plumage. | | | |

**A. Definitive Basic (non-breeding, or "winter") Plumage** (Fig. 6)

The upperparts (crown, mantle, tail and scapulars) are plain ash gray, with light fringes (when newly molted) on the scapulars and median wing coverts. The underparts are dull white. The under wing, rump and lower back and axillary feathers are light gray to dirty white with dark subterminal chevrons. The upper breast is dirty white, with faint, suffused, dark or gray to brown, fine vertical streaking, which may extend laterally to the flanks. The head has dull patterning: the crown, chin, throat, hindneck and neck sides are plain to light gray, with an indistinct whitish supercillium. The greater upper wing-coverts and inner primary-coverts have white tips, which appear as a white wing-line when in flight. The primaries are dark brown to black on the outer webs, more pale on the inner webs, and white at the base. The proximal primaries have light borders on the outer webs. The distal primary-coverts and alula are dark brown-black. The secondaries and tertials and remaining greater and lesser wing-coverts are ash gray, broadly tipped with

white. The rectrices are gray with narrow white fringes; the outer rectrices often have a dark subterminal band. The feather rachises are dark (Hayman *et al.* 1986, Harrington 2001).

Figure 6. Basic, or non-breeding, plumage (Arthur Morris).

**B. First Basic Plumage**

This is similar to the definitive basic plumage, except for retained back to upper tail-coverts, some rectrices and a few tertials or median upper wing-coverts, all of which may occasionally be replaced. Birds wintering in South America may also replace primaries (Harrington 2001).

**C. Definitive Alternate Plumage**

In definitive alternate plumage the face and underparts are variable chestnut-red, with variable amounts of white and brown on the rear belly and white flecks on the front belly. The lower rump and uppertail are whitish gray. The mantle, scapulars and tertials have blackish centers, and are edged with rufous and tipped with pale gray. The wing coverts are grayish with white (Hayman *et al.* 1986).

**D. Alternate Plumage** (Fig. 7)

Alternate, or breeding, plumages vary by subspecies and by sex (Harrington 2001). In alternate plumage, *C. c. rufa* is distinguished by its characteristic pale rufous color on the breast, neck and head (Sibley 2000). Back-feathers and scapulars have dark brown-black centers, edged with faded rufous. Scapulars and tertials are unevenly colored, with broad, dark, irregular-shaped centers, widely edged in notched patterns to variable degrees, some with faded rufous and others with bright salmon-red color. Post-breeding adults have a worn mantle and scapulars, which become extensively blackish, rendering the different subspecies indistinguishable (Hayman *et al.* 1986).

Figure 7. Alternate, or breeding, plumage (Arthur Morris).

**E. Females**

Females are similar to males, though rufous colors are typically less intense, with more buff or light gray coloration in the dorsal parts. Females of all subspecies have less evenly and less brightly colored underparts than males and may have scattered white feathers. Females also have more extensive white on the lower belly and may have scattered breast- and/or flank-feathers with wavy, dark marks at the tips. The supercillium is less pronounced than in males, and may be indistinct from the crown and eyeline. The hindneck is more buff than cinnamon.

**F. Male subspecies *C. c. rufa***

Of all races, *rufa* males have the palest chestnut underparts with more extensive white on the rear belly and a duller underwing area (Hayman *et al.* 1986). They have a nearly white vent, lower flanks, and under tail-coverts (Harrington 2001). Crown and nape are streaked with black and gray and/or salmon. Other features include: prominent superciliary stripe brick red or salmon red, auricular region and lores colored as in crown but with finer streaks; chin, throat, breast, flanks, and belly brick red or salmon red, sometimes with a few scattered light feathers mixed in; undertail white, often including scattered brick-red or salmon-red feathers, marked with dark, terminal chevrons laterally. Back-feathers and scapulars have dark brown-black centers, edged with faded salmon. Scapulars and tertials are unevenly colored, with broad, dark, irregular-shaped centers, widely edged in notched patterns to variable degrees, some with faded salmon and others with bright salmon-red color. Lower back and upper tail-coverts are barred black and white, with scattered rufous (Paulson 1993). Remiges, rectrices, and about half of wing-coverts are retained from Basic plumage. Primaries are dark brown to black, secondaries and remiges gray, and there is a narrow wingbar. Putative younger males tend to be less brightly colored dorsally (Harrington 2001) and have greater numbers of light feathers scattered among ventral feathering (Hobson 1972). Adults passing through James Bay during southward migration show molt of body feathers as well as scapulars (Hope and Shortt 1944). Southward-migrating individuals in Massachusetts during July and early August (mostly *C. c. rufa* bound for Austral wintering grounds) show molt of ventral and dorsal body-feathers, but do not show any flight-feather molt. Body-feather molt appears to become arrested before departure in mid-August (Harrington 2001). In contrast, data

from adults captured later than August in New England and many caught in southeastern states show advanced prebasic molt of primaries, secondaries, and rectrices, suggesting that these individuals may, in fact, be *C. c. roselaari*. This flight-feather molt appears to be virtually completed before *C. c. roselaari* move to Florida winter locations during October and November (Harrington 2001).

**G. Male subspecies *C. c. canutus***

This subspecies has deep chestnut underparts and dark chestnut fringes on the upper body (Hayman *et al.* 1986). The vent and under tail-coverts are deep rufous (Harrington 2001). The black marks on the upperparts are heavy, with rufous marks small and deeply colored, rounded on tips of scapulars (Harrington 2001).

**H. Male subspecies *C. c. rogersi***

*Rogersi* appears paler in color than the nominate subspecies (*C. c. canutus*), and the lower belly typically has more white (Hayman *et al.* 1986). This subspecies also has more coloration on lower belly and under tail-covert region and appears less grayish and slightly more rufous above than *C. c. rufa* (Harrington 2001). The vent and lower belly, however, are similarly light-colored as on *C. c. rufa*, but may be marked with black (Harrington 2001).

**I. Male subspecies *C. c. islandica***

*Islandica* is similar in appearance to *rogersi*, but with yellowish fringes on the mantle and has medium-chestnut underparts (Hayman *et al.* 1986). Coloration of this subspecies is also similar to that of *canutus*, but with less intense rufous on the underparts, more yellow on the hindneck with more narrow black marks and paired squarish dots of rufous on the tips of the scapulars (Harrington 2001). This subspecies also appears more richly colored than *C. c. rufa* (Harrington 2001).

**J. Male subspecies *C. c. roselaari***

The coloration of the dorsal plumage of *roselaari* is similar to that of *canutus*, but darker and with more variegated pattern. Ventral coloration is similar to *C. c. rufa* particularly with respect to the amount of white plumage on the lower belly and vent. There is also some evidence that this subspecies, in the south-east Atlantic states, show prebasic molt of ventral and dorsal body-feathers, as well as actively molting primaries and rectrices during August and September in contrast to other subspecies in the north-eastern states. Based on analysis of museum specimens, this subspecies is also longer-winged that other subspecies (Harrington 2001).

**K. First Alternate Plumage**

This is extremely variable among both individuals and subspecies. Individuals that molt few feathers may appear as basic-plumaged birds, but with worn and frayed primaries. Individuals that undergo a more extensive molt may appear as intermediates between definitive basic and definitive alternate plumages.

**L. Juvenile Plumage** (Fig. 8)

This is similar to definitive basic plumage, and there is no difference between the sexes (Harrington 2001). The mantle, scapular and covert feathers have "boldly-pencilled submarginal lines and white fringes which give a characteristic scaly appearance" (Hayman *et al.* 1986). The upper breast is suffused in buff with fine brown streaks and dots (Harrington 2001). The underparts appear suffused in olive to gray ash, slightly darker than in definitive basic plumage (Harrington 2001).

Figure 8. Juvenile plumage (Arthur Morris).

**M. Hatchlings** (Fig. 9)

Chicks have downy plumage with dull, blackish brown underparts speckled with rows of white or cinnamon hourglass-shaped dots. The plumage lightens on the sides and underparts with a buffy-grayish wash on the breast. The crown is dark with some stripes below the eye, the supercillium, cheek and auriculars are mottled and the chin is white. The bill is blue-gray with a dusky tip; the legs are grayish yellow with dusky spots. (Harrington 2001)

Figure 9. Hatchling on Southampton Island, Nunavut, Canada (Bruno Kern).

## IV. DISTRIBUTION IN TIME AND SPACE

### A. The Annual Cycle

The diagrammatic representation of the annual cycle of a typical Tierra del Fuego wintering red knot (Fig. 10) is based on the approximate dates that knots occur at different sites as more fully set out elsewhere in this review and is merely intended to assist the reader. It is not suggested that any individual knots make exactly the movements shown.

Soon after the chicks hatch in mid-July, the females leave the breeding grounds and start moving south. Thereafter, parental care is provided solely by the males, but about 25 days later (around August 10) they also abandon the newly fledged juveniles and move south. Not long after, they are followed by the juveniles, which start to appear along the northeast coast of the U.S. in the second half of August. Throughout the flyway, the adults generally precede the juveniles as they move south from stopover to stopover. At each, the adults gradually replace their red breeding plumage with white and gray, but do not molt their flight or tail feathers until they reach their winter quarters.

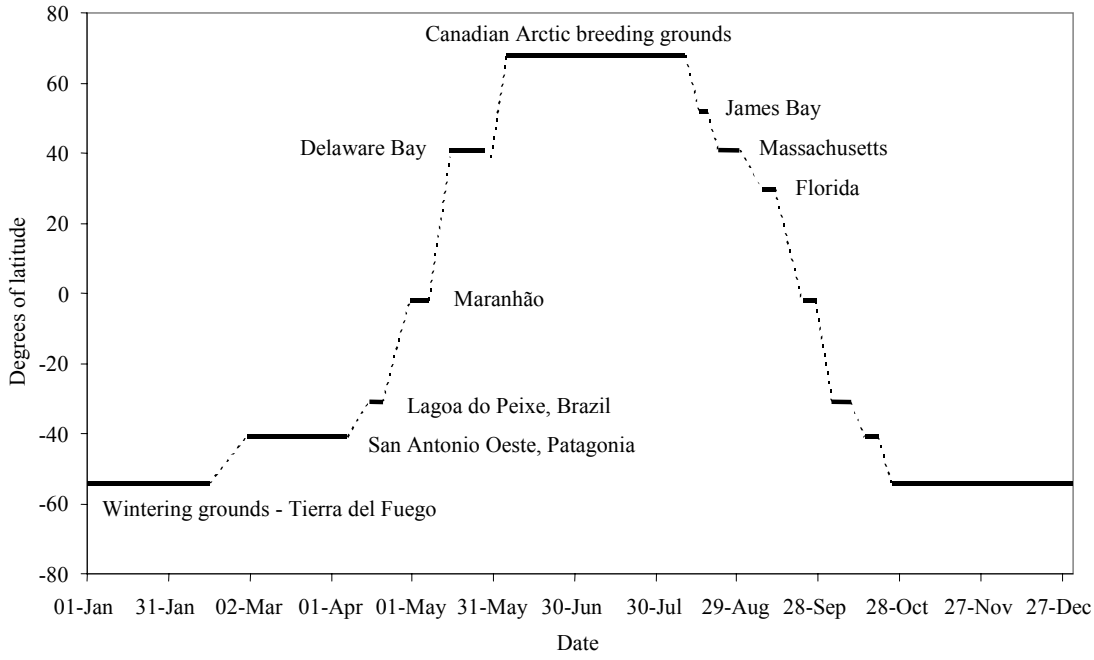



Figure 10. Diagrammatic representation of the annual cycle of a typical Tierra del Fuego wintering red knot (*Calidris canutus rufa*) in terms of latitudinal location and date. Horizontal lines represent periods when birds stay on the breeding or wintering grounds or stopover while on migration; dotted lines represent largely non-stop migratory flights.

During southward migration and in some parts of the winter quarters, the number of juveniles gives a good indication of breeding success which tends to show some correlation with predator/prey cycles and weather conditions on the arctic breeding grounds. In some years, when there are many arctic predators and few prey (mainly lemmings *Lemmus* and *Dicrostonyx*), and/or when there is unseasonably cold weather, breeding success may be extremely low and many adults may abandon their breeding territories and move south earlier than usual (van de Kam *et al.* 2004). In other years,

good breeding conditions may mean that substantial proportions of all knots in the flyway are juveniles. However, it seems that although some juveniles of the Tierra del Fuego wintering population migrate all the way to Tierra del Fuego, others winter farther north in South America (Gonzalez unpublished data).

Arrival in Tierra del Fuego is from late September through October. As soon as they arrive, the adults start their annual molt of flight and tail feathers, which they finish in January. Although a few may depart before the end of January, the main movement north is not until February. At each stopover as they move north along the coast of South America they molt into breeding plumage with most of the change from white/gray to red taking place during March and early April. From Maranhão in northern Brazil, most probably fly direct to Delaware Bay or to the southeast of the U.S. In Delaware Bay, they refuel on horseshoe crabs' eggs, and in an average of 10-14 days (Gillings *et al.* in prep.) almost double their weight and depart at the end of May on the 3,000 kilometer (km) flight to their arctic breeding grounds. This stopover duration is much shorter than final stopovers by other populations of red knots (21-28 days) and reflects the rapid mass gains possible when feeding on *Limulus* eggs (4.9 grams[g] $day^{-1}$) compared with other prey (2.7-3.0 g $day^{-1}$) (Gillings *et al.* in prep; Piersma *et al.* 2005).

It is thought that most or all of the juveniles of the Tierra del Fuego population remain in South America during their first northern breeding season. Those that have spent the austral summer in Tierra del Fuego move farther north, while others that have wintered in the mid- or northern latitudes of the continent may move relatively little. Eventually, in about September, these birds move to Tierra del Fuego in advance of most of the returning adults and commence their first molt of flight and tail feathers. After spending the austral summer in Tierra del Fuego, these immatures migrate with the rest of the adults to the Arctic where they breed for the first time, aged two.

**B. Breeding Range**

Morrison and Harrington (1992) considered that the breeding range of *rufa* extended across the central Canadian Arctic from Southampton Island to Victoria Island, but pointed out that uncertainty existed as to whether it occurred in all parts of this range owing to lack of coverage. In May 1999, biologists from the New Jersey Division of Fish and Wildlife (NJDFW) and the Royal Ontario Museum (ROM) attached radio transmitters to 65 red knots passing through Delaware Bay on their way to the breeding grounds. In July 1999, aerial radio-tracking was carried out on Southampton Island where eight birds were relocated. Six were found in the barren tundra uplands characteristic of most of the island, but two were found in the coastal wetlands. In a subsequent ground search, the nest of one radio-tagged *C. c. rufa* was located.

Using land cover characteristics at the sites where the eight knots were relocated in 1999, biologists with the NJDFW, ROM and Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) developed a simple model based on three main characteristics: elevation, amount of vegetation cover, and distance to ocean coast. Using land cover images of the entire eastern Arctic the team created a map predicting the location of red knot habitat (Fig. 11). Additional refinements to the habitat predictive model were added based on results from the radio tracking work.

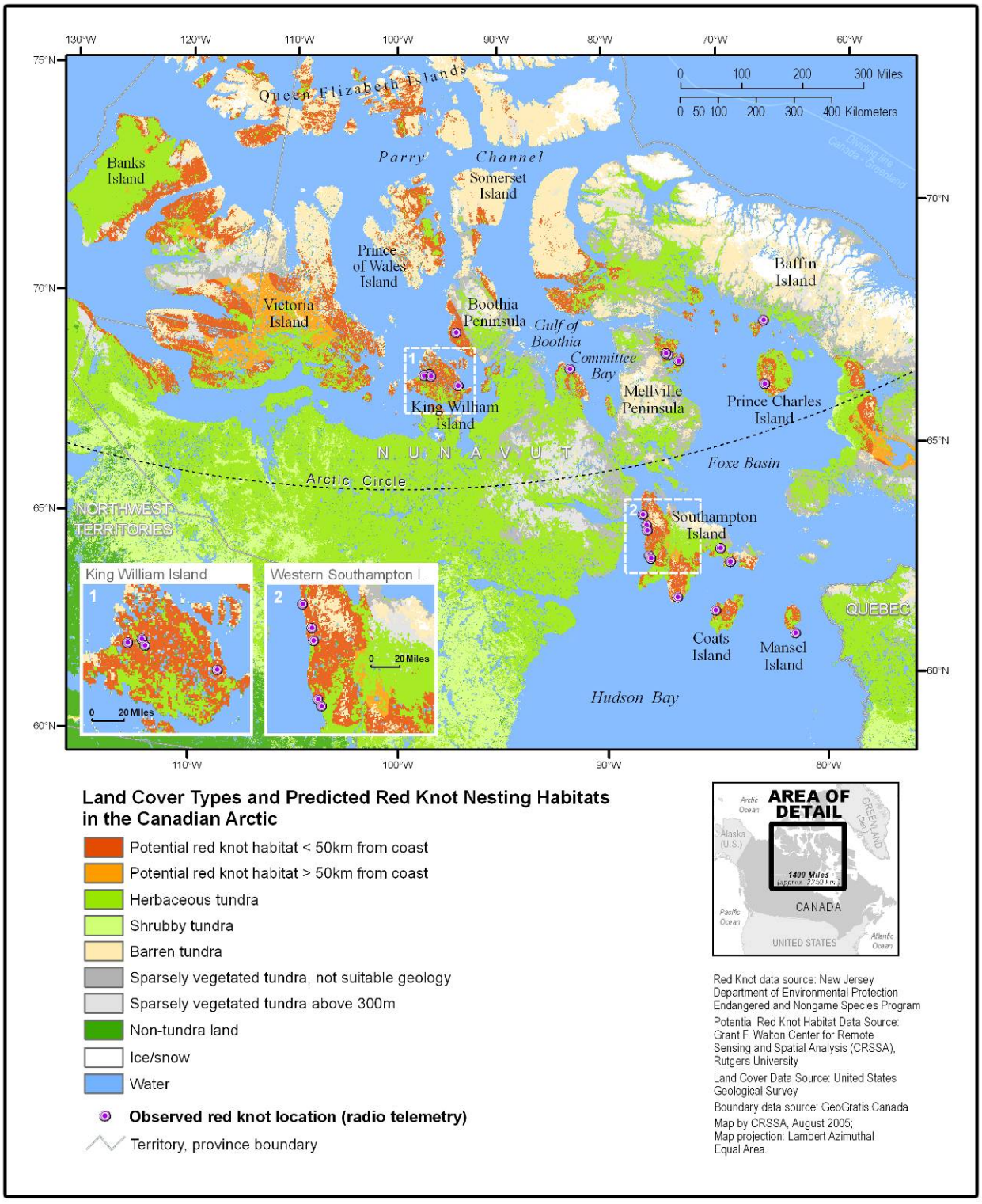



Figure 11. Predicted red knot nesting habitats based on land cover types in the Canadian Arctic and point locations of red knots obtained by radio telemetry.

Over the next three years, 200 more transmitters were attached to birds which were tracked throughout the Canadian Arctic as far west as Victoria Island, east to Baffin Island, north to Prince of Wales Island and south to Coats and Mansel Islands. In all, 20 birds were relocated, all within areas predicted to be red knot habitat. Additional refinements to the habitat predictive model were added based on the new relocated birds.

To summarize: our knowledge of the breeding range of *rufa* is sparse and we can only be sure that it extends to those places where birds have been found as shown in Fig. 11. There are no data to indicate whether the range or distribution has changed over time.

**C. Winter (Non-breeding) Range**

After breeding, all red knot populations migrate south to spend the northern winter in large flocks at a relatively small number of key intertidal wetlands. These invariably provide hard-shelled bivalves as the knots' main food resource. These are swallowed whole, the shells being crushed in the gut and excreted by defecation.

Red knots that are or might be *rufa* winter in four distinct coastal areas of the Western Hemisphere (Fig. 12): 1) the southeastern United States (mainly Florida and Georgia, with smaller numbers in South Carolina), 2) Texas, 3) Maranhão in northern Brazil, and 4) Tierra del Fuego (mainly Bahía Lomas in Chile and Bahía San Sebastián and Río Grande in Argentina with smaller numbers northwards along the coast of Patagonia). Other red knots, presumed to be *roselaari* winter on the Pacific coast of California and Baja California, parts of the Pacific Northwest coast of Mexico in the Gulf of California, and probably also farther south (Morrison and Ross 1989, Morrison *et al.*1992, 2004, Baker *et al.* 2005a, Baker *et al.* 2005b, Page *et al.* 1997, Page *et al.* 1999).

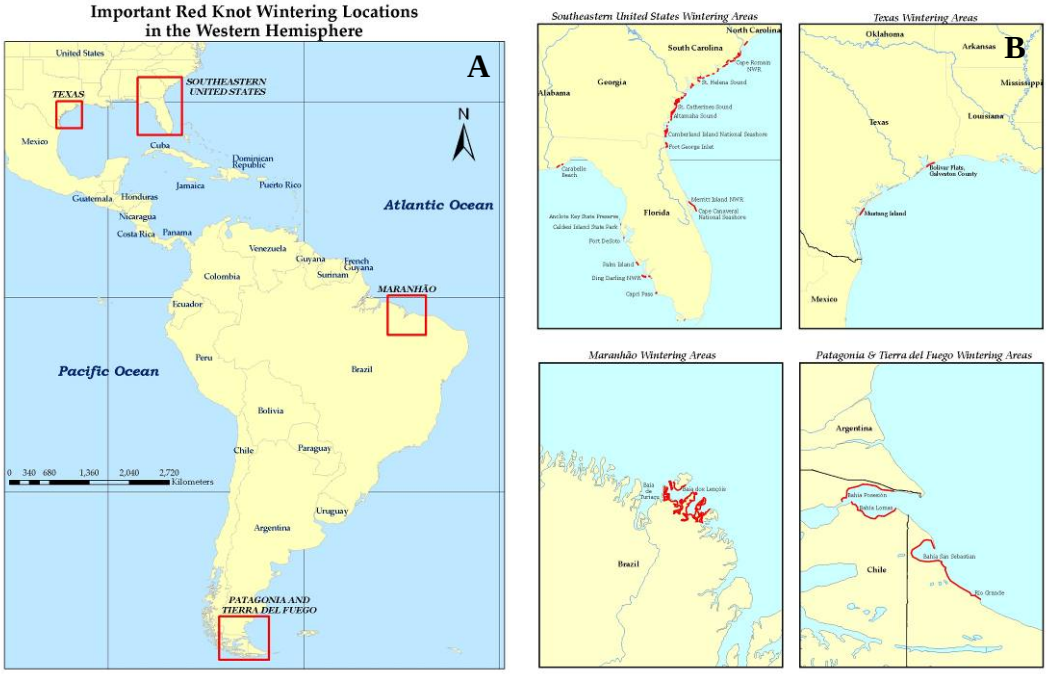



Figure 12. Red knot wintering areas in the Western Hemisphere (A). Each area outlined in red (A) are shown in greater detail and delineated in red (B).

In the 1982-1985 survey of South America (Morrison and Ross 1989), red knots were found wintering along the coast of Patagonia from Tierra del Fuego north to Buenos Aires Province in Argentina. However, as the southern wintering population has declined, only extremely low numbers of red knots have been observed in Patagonia north of Tierra del Fuego, with no birds found in some years (See Geographic Area Summary - Argentina, Morrison *et al.* 2004).

In the southern U.S., the wintering red knot population is believed to be distributed variably from year-to-year between Florida, Georgia and South Carolina (Fig. 13), depending on invertebrate prey abundance (Harrington and Winn unpublished data).

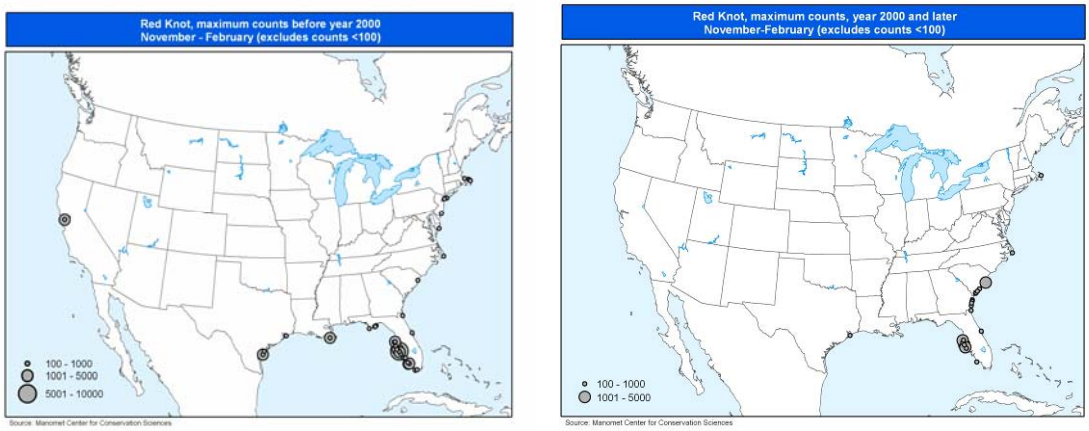



Figure 13. International Shorebird Survey Data (ISS) showing distribution of red knots in winter in the U.S. before year 2000 (left) and during 2000–2004 (right). Note: the level of ISS survey effort declined after 2000; therefore the differences in numbers before and since 2000 may partly represent reduced survey effort. Source: Brian Harrington, Manomet Center for the Conservation Sciences.

The number of wintering knots in Georgia varies between and within years. Results of an annual winter ground survey of the entire Georgia coast since 1996 during the last two weeks of January into early February show the minimum number of knots to be in the hundreds and the highest to be nearly 5,000. The distribution of wintering knots is generally unpredictable and dispersed over much of the barrier coast and appears to be linked closely with the abundance and availability of dwarf surf clams (*Mulinia lateralis*). The knots feed primarily on dwarf surf clams and secondarily on coquina clams (*Donax variablis*) (See Geographic Area Summary – Georgia, this volume).

In Florida, frequent beach replenishment in areas such as Fort Myers and Estero Island (Douglass pers. comm. 2005) may cause the loss of invertebrate prey populations and displace wintering red knots to more productive foraging areas elsewhere in Florida and Georgia.

In Texas, the wintering population was of the order of 3,000 during 1985-1996 with the largest numbers occurring on the Bolivar flats (Skagen *et al.* 1999). However, this population seems to have declined. The only recent count of any size is of 300 in January 2003 (Harrington unpublished data).

**D. Migratory Range/Major Stopover Areas**

While migrating, all knot populations are dependent on a limited number of stopover sites that provide adequate food resources. These act like stepping-stones in that if one is lost because the food supply fails, a whole population of knots may be jeopardized. For the subspecies *C. c. rufa*, Delaware Bay is a particularly vital link in its migration between Tierra del Fuego and the Canadian Arctic, since it is at this final stopover that the birds need to be able to accumulate both fuel for the journey and additional body stores to enable them to survive and attain good breeding condition after arrival in the Arctic.

The southbound 15,000 km migratory journey of *rufa* begins in August and takes it from its breeding grounds in the central Canadian Arctic through Hudson Bay and James Bay, through some parts of eastern Canada, such as the Mingan Islands in the Gulf of St Lawrence, and through most of the east coast states of the U.S. (Fig. 14). At this time, they tend to use northern sites in Massachusetts, Connecticut, and Rhode Island more than they do in spring. After a final U.S. stopover, they fly to northern Brazil and then on through Argentina to Tierra del Fuego. The majority of the population winters on the main island of Tierra del Fuego, where in one bay in the Chilean sector, Bahía Lomas, most of the population can be found from November to February (Morrison and Ross 1989, Morrison *et al.* 2004). Other red knot populations begin their migration from the arctic about the same time as the Tierra del Fuego birds, but stop to over-winter in the southeast of the U.S. (mainly Florida) and Maranhão, Brazil (Morrison and Ross 1989, Baker *et al.* 2005b). As discussed in the Taxonomy section of this volume, the subspecific status of these populations is uncertain.

In comparison with the southward migration, the northbound flight to the arctic is more time-constrained and demanding, especially in the northern parts of the route, because it is important for successful breeding and survival that the adults arrive on their arctic breeding grounds at the right time and in good condition for breeding, and with sufficient resources to sustain themselves while arctic food is in short supply.

After departing Tierra del Fuego, major stopover sites are found at Río Gallegos, Península Valdés, San Antonio Oeste and Punta Rasa in Argentina and Lagoa do Peixe in southern Brazil. From there, the birds fly across Amazonia to a possible last refueling stop in South America in the Maranhão region of northern Brazil (Fig. 15). From Maranhão, the majority fly direct to Delaware Bay, with a lesser proportion making landfall farther south along the U.S. east coast, anywhere from Florida to Virginia (Fig. 16). The knots that have wintered in Maranhão are also thought to fly direct to the U.S. east coast, but it is not known whether they migrate with or at the same time as the birds from Tierra del Fuego. The evidence is sparse, but there is the possibility that at least some Tierra del Fuego birds migrate direct from Lagoa do Peixe to Delaware Bay, a distance of 8,000 km, which is around the limit of a knot's potential flight range (Harrington and Flowers 1996)

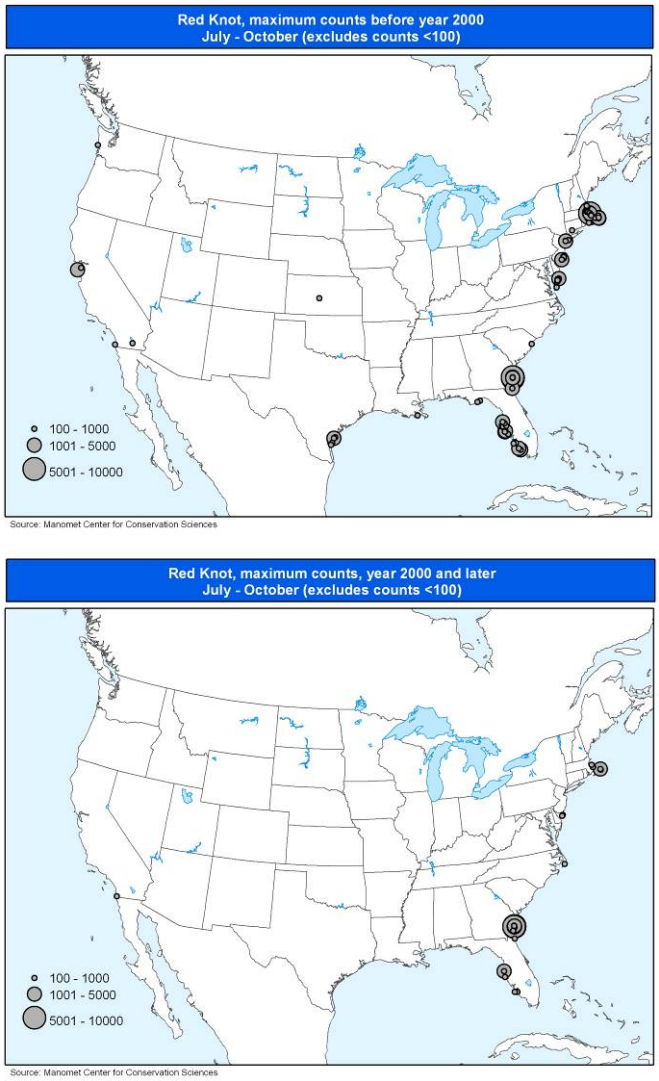
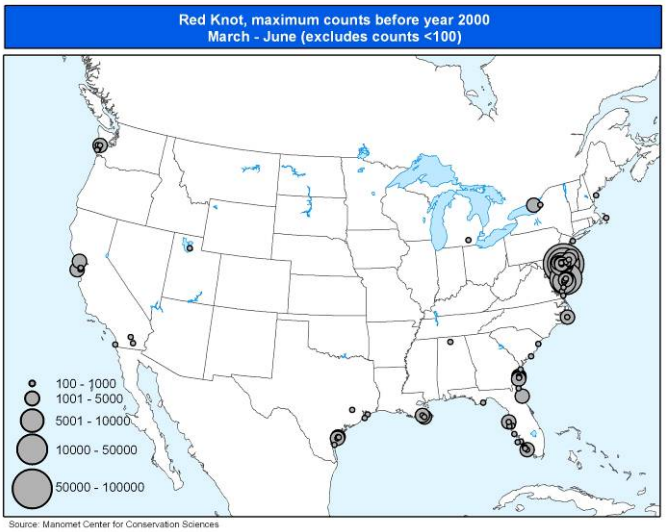



Figure 14. International Shorebird Survey (ISS) Data showing distribution of red knots during fall migration in the U.S. before year 2000 (above) and during 2000–2004 (below). Note: the level of ISS survey effort declined after 2000; therefore the differences in numbers before and since 2000 may partly represent reduced survey effort. Source: Brian Harrington, Manomet Center for the Conservation Sciences.

Figure 15. Critical stopover sites used by red knots during northward and southward migration in South America.



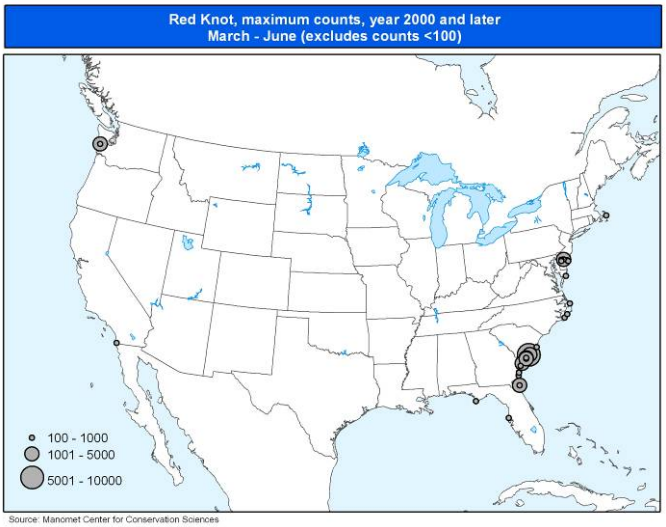




Figure 16. International Shorebird Survey (ISS) Data showing distribution of red knots during spring migration in the U.S. before 2000 (above) and during 2000–2004 (below). Note: the level of ISS survey effort declined after 2000; therefore the differences in numbers before and since 2000 may partly represent reduced survey effort. Source: Brian Harrington, Manomet Center for the Conservation Sciences.

Some birds arrive in Delaware Bay in a greatly depleted condition, weighing as much as 30% below their normal fat-free weight. There they spend about two weeks feeding on horseshoe crab eggs and virtually double their mass. Some of the birds that have spent the winter in Florida pass through Delaware Bay, but it seems that many migrate northwards along the Atlantic coast of the U.S. feeding on bivalves (mainly *Donax*. and blue mussel *Mytilus edulis* spat) and bypass Delaware Bay altogether (Atkinson *et al.* 2006a, Karpanty pers. comm. 2006). At the end of May, *rufa* depart on the last leg of their flight to the Arctic. In the final days before departure, the birds almost

cease feeding and undergo physiological changes to prepare for migration including reducing their digestive organs and increasing flight muscle size (Piersma and Gill 1998, Piersma *et al.* 1999). They leave Delaware Bay heading inland north-northwest toward their breeding grounds. This route takes them across the vast boreal forest and low tundra of Canada, which in late May to early June can be a hostile environment to shorebirds. Many pass through and along the coasts of James Bay and Hudson Bay, although they are not believed to stop in these areas for any significant period (Morrison unpublished data, Peck unpublished data).

Once they arrive on their breeding grounds, their digestive systems are restored, but often there is very little food available. Therefore their survival and their ability to attain good breeding condition may depend on surplus fat resources brought to the breeding grounds (Morrison *et al.* 2005) from Delaware Bay. This in turn may be affected by weather and feeding conditions further south because if knots arrive in Delaware Bay late and/or in poor condition they may have insufficient time to lay down the resources they require. In this way any problems further south may result in a cascade effect that jeopardizes their ability to survive and reproduce.

Of all the sites visited by the *C. c. rufa*, Delaware Bay is one of the most critical (Myers 1986, Harrington 2001, Flowers 1996). Without the ability to obtain sufficient resources in Delaware Bay, both the survival of the adult birds and their productivity may decline (Baker *et al.* 2004). As early as 1986, the importance of Delaware Bay to knots and at least five other shorebird species was recognized when it became the first Western Hemisphere Shorebird Reserve. This recognition was also part of the impetus for the development of shorebird reserves throughout the western hemisphere (Myers 1986).

The number of shorebirds stopping over in Delaware Bay has declined dramatically in the last ten years. In the 1980s and early 1990s, horseshoe crabs "cobbled" the beaches and, along much of the bayshore, the eggs within reach of a knot's bill in the top 5 centimeters (cm) of sand exceeded 50,000 $m^{-2}$ at a number of sites around Delaware Bay (see the Habitats section of this review for additional discussion on egg availability / density). In the 1980s, the combined peak counts of the three shorebird species that feed almost entirely on horseshoe crabs' eggs (red knot, sanderling (*C. alba*) and ruddy turnstone (*Arenaria interpres*)) averaged 163,000. Now egg densities at many sites are less than 4,000 eggs $m^{-2}$ and peak shorebird aerial census numbers for 2003-2005 were down to 66,500 with red knots showing the greatest drop from 1980s maxima of 95,000 to 15,000 in 2005 (Clark *et al.* 1993, K. Clark unpublished data). Although the knots from northern wintering populations exploit other food resources in the vicinity of Delaware Bay (such as blue mussels and surf clams on the Atlantic coast of New Jersey), horseshoe crab eggs are crucially important for the long-distance migrants from Tierra del Fuego. As explained in the Habitats section of this review, a combination of physiological and time constraints means that they cannot utilize the alternative foods and rely on the more easily digested eggs.

The harvest of horseshoe crabs along the northeast U.S. coast, and the associated reduced availability of their eggs as a food resource for migrating shorebirds, was first identified as a serious threat in the mid-1990s. Until 1993, the crab harvest, mainly for eel and minnow bait, was minimal and accounted for no more than about 400,000 per year, which were mostly taken by hand or as by-catch. However, in 1993, collapsing fisheries in New England and elsewhere led commercial fishermen to the profitable conch fishery,

for which horseshoe crabs are the preferred bait. This brought commercial fishermen to Delaware Bay, where the harvest increased dramatically as the conch fishery expanded in the mid-Atlantic coast. By 1996, the annual harvest from Virginia to New York, both mechanical and manual, exceeded 5 million crabs (Fig. 38). According to a Delaware Division of Fish and Wildlife survey, the population of crabs fell by about 85% between 1990 and 1998 (S. Michels 2005, pers. comm.). While minor restrictions were imposed, the intensive harvest of horseshoe crabs continued (Fig. 38). By 2000, egg densities had fallen from an average of well over 10,000 to fewer than 4,000 eggs $m^{-2}$ (see Threats section of this review). Only a few places favored by crabs, such as Mispillion Harbor, held significantly greater densities.

The greatest risk of the declining availability of horseshoe crab eggs in Delaware Bay to red knots is that it jeopardizes their ability to achieve the mass required to reach the Arctic and attain good breeding condition. Between 1998 and 2002, the proportion of knots that had attained an estimated threshold departure mass of 180g around the normal departure date (May 28) declined by over 60% (Baker *et al.* 2004). This decline may be the result of arriving late in Delaware Bay and/or in poor condition as well as an inadequate supply of crabs' eggs (Robinson *et al.* 2003, Clark *et al.* 2004). Moreover these factors could interact and exacerbate the birds' predicament. Birds might arrive late or in poor condition and find an inadequate supply of eggs. Bala *et al.* (2005, pers. comm. 2005) and Hernandez (unpublished data) report that northward passage of knots through Peninsula Valdés, Patagonia, Argentina has become 1-2 weeks later since year 2000. There is some evidence that this has been reflected by later arrival into Delaware Bay, in 2000, 2001 and especially in 2003 (Baker *et al.* 2004, K. Clark unpublished data).

Baker *et al.* (2004) found that there was a decline in the knot's annual survival rate from an average of 85% during 1994-1998 to 56% during 1998-2001. They further showed that over 1997-2002 birds caught in Delaware Bay at a lower weight were less likely to survive than heavier birds and that there had been a significant increase in the proportion of poorly-conditioned, low-weight birds at the end of May. This was postulated to be the result of a trend for birds to arrive later and/or in poor condition and/or an inadequate food supply. This change in survival coupled with almost zero recruitment of juveniles to the adult population (Atkinson unpublished data) lies behind the decrease in the Tierra del Fuego wintering population from over 50,000 in 2000 to 30,000 in 2002-2004. Baker *et al.* (2004) predicted that if annual survival of the Tierra del Fuego population remained stable at 56%, the population could approach extinction by 2010. It is not possible to predict future survival, but the most recent count of 17,221 in January 2006 shows that the trend is following this 'worst-case scenario' trajectory and the risk of extinction is high.

## V. BIOLOGY AND NATURAL HISTORY

Except as otherwise indicated, this account of the biology and natural history of *C. c. rufa* and the following account of its habitat is based on the red knot species text in the *Birds of North America* (Harrington 2001). This source is founded on an extensive review of the literature and the works cited in it are not repeated here. Some of the information from Harrington is quoted verbatim.

## A. Reproduction

Red knots are thought to have a monogamous mating system in which single pairs mate and nest in territories. Pair bonds form soon after arrival on breeding grounds and remain intact until shortly after the eggs hatch (Niles *et al*. unpublished data) when the females leave their broods. Thereafter the males look after the chicks until they fledge at about 25 days when they too abandon them. Little information is available for *rufa* on mate fidelity, though many knots return to the same area to breed from year to year (Morrison *et al*. 2005, Morrison unpublished data).

The breeding chronology of *rufa* is poorly known. Other races may be paired or unpaired on arrival in breeding areas in late May/early June; start of breeding varies with snowmelt conditions. Simultaneous arrival of male and female *C. c. islandica* has been noted in late May/early June, though males tend to predominate amongst early arrivals (Morrison *et al.* 2005), followed by movement into inland nesting habitats within a few days.

No published information is available for *rufa* on mate fidelity between years or duration of courtship between reunited mates versus new mates. On a 9.15 sq. km study site on Southampton Island, Nunavut, Canada, we observed only limited evidence of site fidelity despite the fact that studies of other subspecies suggest that breeding site fidelity is high, especially in males. In five years of monitoring breeding densities, we observed one male return to his territory of the previous year and only one female return to the study site but to a different territory (Niles *et al.* unpublished data). In some instances, knots have been thought to arrive on breeding grounds in pairs. Flocks sometimes arrive at breeding latitudes before snow-free ground is available in breeding habitats. Upon arrival, or as soon as favorable conditions exist, males and females occupy breeding habitat and territorial displays begin.

Age of first breeding is uncertain but for most birds is probably two years (Harrington 2001). All juveniles of the Tierra del Fuego wintering population are thought to remain in the Southern Hemisphere during their first northern summer though their distribution is largely unknown (Gonzalez unpublished data). Some basic-plumaged knots arrive in Delaware Bay in May and can constitute a considerable proportion of the individuals remaining at the end of the stopover. It would seem likely that these are one year old birds from northern wintering populations that will remain in the vicinity of Delaware Bay throughout the breeding season, but this has yet to be proved.

## B. Breeding Behavior

### *1. Mating Displays*

During early breeding stages, knots show a variety of behaviors associated with area defense and advertisement which may begin on the day of arrival. Most agonistic behaviors involve territorial males. Fighting, though uncommon, is mostly seen between males.

Song flights, performed only by males, occur as soon as males return to breeding grounds and evidently continue into the incubation period. Song flights usually begin and end in the territory, though they may extend well beyond its boundaries. Other aerial displays include the V-wing flight, which resembles a simple, low song flight originating

and ending in territories, and aerial chases which are initiated by territorial males and are the most frequently seen agonistic behaviors.

Ground displays include the two-wing lift, ground singing and horizontal point. The two-wing lift involves a standing bird, usually a male, and is often given after a song flight or a V-wing flight, but often immediately before flying or when one member of a pair lands near its mate, or by males landing near its chicks. Another display, ground singing is most commonly performed by a standing male on territory when other males are singing overhead, performing V-wing flights, or singing from the ground nearby. Horizontal point displays are performed by males in response to another male singing, at territorial borders, at a neighbor ground-singing male and is also given as a precursor to attacking intruders, when it is typically accompanied by singing.

The tail-up display is a common behavior seen in varied contexts, typically presented by a male to the receiver laterally or posteriorly. This display is most often seen during courtship or as prelude to copulation. It is also occasionally observed in pairs reuniting after a separation, in activity after roosting, during a nest-scrape ceremony, or after fights with intruding females. This display is not seen after the egg clutch has been completed.

The tail-drop fan display is given by a male as a prelude to nest-scrape advertisement, by a stationary male when his mate comes close, during a fight with an intruding female when the male walks away from his mate, and by a male after copulation. Males in the nest give the nest-scrape advertisement display, after arrival of females. Once the female settles in the scrape, the male assumes a ground point display.

### *2. Sexual Behavior*

The behaviors leading up to copulation are variable, though more predictable prior to mounting. A male typically follows behind a female in a tail-up display. Meanwhile, he begins the rapid, high-pitched copulation call while pecking rapidly at the female's back. If the female is receptive, the male flies up on to her back to begin copulation while continuing to flutter his wings.

The rate of male calling increases prior to cloacal contact. Meanwhile, the female drops her wings slightly to expose the back and rump. The female's tail is then raised, the male bends his tail under it, and cloacal contact is made. Coition lasts roughly a minute. Following contact, the male falls off the female's back and holds her head, neck or nape feathers in his bill for 1-30 seconds.

Copulation attempts are evidently initiated by the male, and take place throughout the day. In one pair, copulation was seen within 1-2 hours after arrival of the female; in another pair it was not seen for the first 36 hours. In three pairs, copulation was first noted 3, 5, and 8 days before laying of the first egg.

No data are available on extra-pair copulations, however they appear unlikely given the apparent monogamous mating system and the vigorous territorial defense shown by males.

## C. Nest Sites

Nests are cup-shaped depressions, often with well-defined rims, lined with dried leaves, grasses and sometimes lichens, and averaging 11.9 cm across, 11.1 cm wide and 4.4 cm deep (Fig. 17). The lichens, which knots use for nest lining, are species that form

hollow tubes, thus providing an excellent insulating layer above the cold ground. On Southampton Island, nest cups were most often lined with the small leaves of mountain avens (*Dryas octopetala*) and rarely lined with lichen; nest cups averaged 11.1 cm wide and 5.7 cm deep (Niles *et al.* unpublished data).

Figure 17. Red knot nest with eggs on Southampton Island, Nunavut, Canada (New Jersey Division if Fish and Wildlife).

Males prepare 3-5 nest scrapes in their territory before females arrive. Vegetation is removed by pulling with the bill and by sitting in the nest depression and pivoting on the breast while kicking backwards with the feet. Once in the nest, the female removes vegetation from under her breast, placing it at her side or tossing over her back while kicking backwards with her feet.

Red knot nests may be scraped into the main body or edges of mountain avens patches or in low, spreading vegetation on hummocky ground containing lichens, leaves and moss. Selection of nest sites may vary with snow or other conditions when individuals arrive in breeding areas. Knots generally use nest sites on dry, slightly elevated tundra locations, often on wind-swept ridges or slopes with little vegetation. Isolated patches of stunted willow (*Salix* species) and/or mountain avens (Fig. 18) often dominate the vegetation in the area. The majority of nests found on Southampton Island were within 300 meters (m) of wetlands >2 hectares (ha) in area, which allows suitable foraging habitat for parents and young after the eggs hatch (Niles *et al.* unpublished data).

On Southampton Island, nests were most often found on small patches (~0.5 m diameter) of mountain avens. Nests were located in exposed areas of glacial/shattered rocks and mudboils. The amount of vegetative cover averaged 33% within 1 m of the nest and 25% within 10 m of the nest (Niles *et al.* unpublished data).

Figure 18. Nest (in foreground) on the tundra on Southampton Island, Nunavut, Canada (New Jersey Division of Fish and Wildlife).

Red knot nests are located principally at elevations <150 m, often in damp habitats, though they may nest in drier sites, but not far from damp areas. Nest sites are often on higher ground where little winter snow accumulates and/or where spring snowmelt is earliest. Twenty-one nests on Southampton Island were found on average to be within 360 m of a glacial ridge/esker and within 200 m of a wetland (Niles *et al.* unpublished data). Red knot nests also tend to be widely separated, located between 0.75 km and 1.5 – 15 km apart. Nests evidently are located within the display flight areas.

**Nest Site Characteristics**

- Sparsely vegetated
- Dry
- Sunny
- Elevated
- Wind swept ridge or slope
- Near wetlands

**D. Number of Broods**

Red knots lay only one clutch per season and so far as is known do not lay a replacement clutch if the first is lost.

**E. Clutch Size**

The usual clutch size is 4 eggs, though 3-egg clutches have been recorded. It is estimated that the clutch of 4 eggs is laid over 4-6 days. The average egg size measured on Southampton Island (n=90) had a length of 42 mm (37.8 – 44.5 mm) and a width of 29 mm (26.6 – 31.3) (Niles *et al.* unpublished data) and is similar to other knot studies

(Harrington 2001). Fresh egg mass is estimated to be 18–19 g on Southampton Island (Peck unpublished data).

**F. Incubation Period**

The incubation period lasts approximately 22 days from the last egg laid to the last egg hatched. Both sexes participate equally in egg incubation.

**G. Nestling Period**

Hatching occurs within the first half of July and is generally synchronized. Hatching within clutches is apparently quite synchronous, occurring within the same day. The fledgling period is estimated to be 18 days.

Young birds leave the nest within 24 hours of hatching. Broods have been observed to move 300 m within 24 hours of leaving the nest. There are no published measures of growth and development, in part because broods are extremely cryptic, recognize and respond to parental alarm calls by "freezing", and are difficult to follow.

After hatching, families quickly move away from high nesting terrain to lower, wetland habitats. Although there is conflicting information, typically only the male parent stays with the brood once the chicks leave the nest. Male parents brood and defend the young. There is no information on how long young require brooding. Young forage for themselves and are not fed by their parents.

**H. Nesting Success**

There is no information on annual variation of hatching success. It probably varies in parallel with snow cover conditions at nest sites in spring, particularly the timing of snowmelt.

**I. Mortality**

***1. Predation***

There is little information from the breeding grounds, but the long-tailed jaeger (*Stercorarius longicaudus*) is prominently mentioned as a predator of chicks in most accounts. Also mentioned are parasitic jaeger (*S. parasiticus*) and arctic fox (*Alopex lagopus*), and it is likely that other arctic predators, including pomarine jaegers (*S. pomarinus*) commonly take chicks and eggs. Herring Gulls (*Larus argentatus*) and glaucous gulls (*Larus hyperboreus*) may also be predators of chicks.

Away from the breeding grounds, the most common predators of knots are large falcons, such as peregrine falcons (*Falco peregrinus*), harriers, accipiters, smaller falcons such as merlin (*Falco columbarius*), short-eared owl (*Asio flammeus*) and great black-backed gulls (*Larus marinus*). Knots' selection of high tide resting areas on the coast appears to be strongly influenced by raptor predation, something well demonstrated in other shorebirds.

***2. Disease and Parasites***

A full account of diseases and parasitic infections recorded in *rufa* is set out in the Threats section of this review.

**J. Longevity**

To our knowledge, the oldest red knot ever recorded worldwide was one that was originally banded on The Wash, SE England, in August 1968 as an adult and recaptured there in September 1992 (Wash Wader Ringing Group 2004). Given that it could not have been hatched later than July 1967, it was at least 25 years old when it was recaptured. The oldest recorded *rufa* knot was originally banded as a juvenile at Punta Rasa, Argentina, in October 1987 and recaptured on the wintering grounds at Bahía Lomas, Tierra del Fuego, in February 2003, making it 16 years old (Niles *et al.* unpublished data). Although these records demonstrate that the potential lifespan of a red knot is considerable, most live much shorter lives. Annual adult survival in stable populations has been estimated at around 80% and the survival of juveniles is about half that (Boyd and Piersma 2001). Therefore very few knots live for more than about seven years.

**K. Site Fidelity**

Knots, especially males, appear to exhibit high breeding site fidelity. They are also very faithful to specific migration and wintering staging sites. Banding studies indicate that that there is no mixing between red knots wintering in Florida and those wintering in Argentina, suggesting that knots are also faithful to wintering sites.

**L. Migration**

Red knots are long-distance migrants and have one of the longest-distance migrations in the animal kingdom. Those that breed in the Western Hemisphere, migrate from breeding grounds in the middle- and high-arctic to wintering sites on the eastern and western Atlantic coasts, including southernmost South America. Knots are "jump" migrants, flying many thousands of kilometers without stopping. In between these jumps, high proportions of entire populations may use a single migration stopover site. In some knot populations, including *rufa*, a substantial number of birds remain south of the breeding grounds throughout the breeding season, many but not all of which are one-year-old birds.

Red knots tend to migrate in single-species flocks, largely because of species-specific migration habits. Departures tend to occur in the few hours before twilight on sunny days. Size of the departing flocks tends to be large (>50 birds). Configuration of departing flocks may vary from V-formations to echelons, clusters or bunches.

As red knots prepare to depart on long migratory flights, they usually have a mean body mass 50–55% greater than estimated fat-free mass. At stopover sites, mass varies greatly from very light birds that have just arrived to very heavy birds that are just about to depart. In Delaware Bay, for example, some arrive as light as 89 g (32% below fat free weight), whereas near departure a few exceed 240 g (85% above fat free weight) (Niles *et al.* unpublished data) (Fig. 19). In addition to acquiring fat, knots undergo physiological changes on arrival and shortly before departure including substantial changes in metabolic rates, organ size and muscle mass. Before departure, these changes include substantial decreases in mass and size of the gizzard, liver, kidneys and guts, and increases in flight muscle and fat mass (Piersma and Gill 1998).

Red Knots arriving from lengthy migrations are not able to feed maximally until their digestive systems regenerate, a process that may take several days (Piersma *et al.* 1999). This exacerbates the situation of time-constrained migrants and underscores the need for stopovers that are rich in easily digested food resources.

**Preparation for Long Migratory Flight**

- Increase in body mass (50 – 100%)
- Increase in flight muscle
- Decrease in digestive organ mass and size
- Decrease in leg muscle mass and size

Figure 19. Two adults red knots in Delaware Bay: emaciated new arrival (left) and fattened adult ready for departure (right) (New Jersey Division of Fish and Wildlife)

*C. c. rufa* undergoes a lengthy migration, with wintering grounds on the southern coasts of the Chilean and Argentinian sectors of Tierra del Fuego (Fig. 20). There are two other populations of uncertain subspecific status, but which might be *rufa* (see Taxonomy section of this review). One winters in the southeast of the U.S. (mainly the western and northeastern coasts of Florida, but also the coasts of Georgia and South Carolina), the other in the Maranhão region of northern Brazil. Generally, northward migration begins in February for birds wintering in Tierra del Fuego, though a few leave before the end of January. They reach Brazil in April and depart in early May. Relatively few individuals were thought to use the southeast U.S. Atlantic coasts during migration. However, recent spring surveys on the Atlantic coasts of northern Florida, Georgia, South Carolina, North Carolina and Virginia indicate that red knots stopover in these states in May and early June with numbers ranging from tens to over 9,000 (Leary pers. comm. 2005, Watts pers.

comm. 2005, Truitt pers. comm. 2005). The length of stopover at these locations is generally believed to be brief and reliant on ephemeral food resources such as mussel spat (Truitt pers. comm. 2005) and small clams (*Donax spp*.) (Winn pers. comm. 2005). *Rufa* becomes abundant in the northeastern U.S. in early May, especially on Delaware Bay where the highest numbers occur. Some red knots use the interior flyway from Texas/Louisiana via Saskatchewan to the Arctic during spring and to a lesser extent during autumn migration (Skagen *et al.* 1999). Although up to 2,500 red knots were recorded in both Texas and Saskatchewan in spring during 1980-1996, we do not know of any more recent record of substantial numbers using this flyway. Nevertheless recent observations of an Argentinian-flagged knot on the Texas coast in May 2004 and a Delaware Bay flagged knot there in August 2005 indicate that the flyway is still being used.

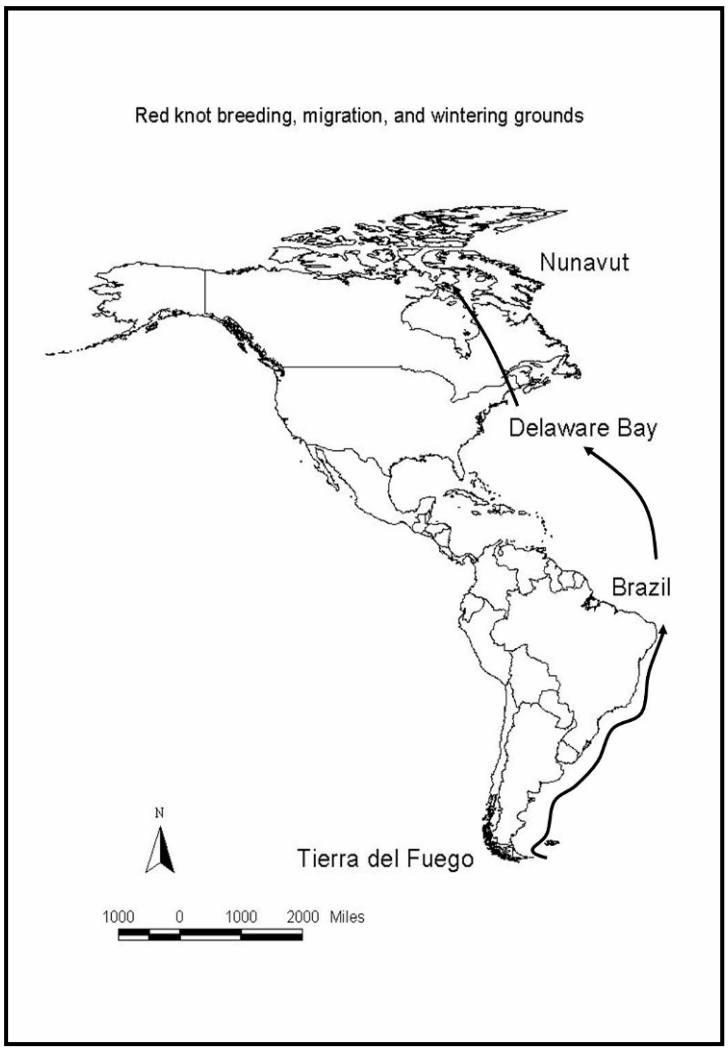



Figure 20. Migration route of *C. c. rufa* between its wintering grounds on Tierra del Fuego, South America, stopover areas along the Patagonian Coast of Argentina, and in the northeastern United States, and breeding grounds in the Canadian Arctic.

During southbound migration, *C. c. rufa* begin to stage in mid-July on Hudson and James Bays and on the Atlantic coast of the U.S., especially at sites in Massachusetts and New Jersey. Several studies suggest that adults fly directly to South America from the eastern seaboard of North America, departing U.S. staging areas and arriving in northern South America in August. Passage continues across Amazonia, towards wintering (non-breeding) areas in southern Argentina and Chile. Recent observations show that red knots banded in South America (mainly Argentina and Chile) start to move through Georgia in July and are gone by November (Harrington unpublished data, Winn pers. comm. 2005). This suggests that some portion of the red knot population migrates down the U.S. Atlantic coast and departs to South America from southern U.S. staging areas. Most adult knots pass through Suriname during the latter half of August and first half of September (Spaans 1978). Knots wintering in southern Argentina and Chile generally arrive by late September through October (Baker *et al.* 2005b; see the Population Trends and Estimates and the Threats sections of this review). *Rufa* knots are uncommon on the western coasts of the North and South American continents.

Another subspecies, *C. c. roselaari*, breeds in Alaska and Wrangel Island. At least some of these birds winter in California and Baja California, others probably winter farther south, but, as discussed in the Population Size and Trends section of this review, known winter numbers are far less than those thought to occur in Alaska in late spring.

**M. Feeding Habits**

On the breeding grounds, the diet of red knots consists mostly of terrestrial invertebrates, though they will also eat plant material especially early in the season. During the rest of the year, at stopover sites and on their wintering grounds in Tierra del Fuego, Chile, Maranhão, Brazil and the southeastern U.S., they feed almost exclusively in intertidal habitats, particularly on mudflats and beaches and, on the coast of Argentina, restingas (broad, wave-cut platforms extending across the intertidal zone) where they specialize on bivalves which are swallowed whole. Common bivalves consumed include *Mytilus sp*., *Mulinea*, *Donax*, *Macoma*, *Tellina*, *Myadora* and *Nucula*, and possibly *Gemma*. They will also take gastropods, such as *Hydrobia*, *Littorina* and *Heleobia*, amphipods and occasionally polychaetes.

When stopping over in Delaware Bay, they feed almost exclusively on the eggs of horseshoe crabs (Fig. 21). Feeding on horseshoe crab eggs on Delaware Bay, however, is a major departure from the prey usually taken.

Red knots drink water, including salt water of relatively high salinity, but may meet water intake requirements from diet alone.

Knots use three main foraging methods: pecking, plowing and probing (Fig 21). Pecking is generally used when foraging on epifauna, such as horseshoe crab eggs, small snails and mussels. Probing and plowing may be involved in detecting buried bivalve prey.

Figure 21. Red knots and ruddy turnstones feeding (left) on horseshoe crab eggs (right) on Delaware Bay (Kevin Karlson, New Jersey Division of Fish and Wildlife).

## VI. HABITAT

### A. General Description

Red knots use very different habitats for breeding and wintering/migration. Breeding habitats are located inland, but close to arctic coasts. Wintering and migration habitats are similar: generally coastal with large areas of intertidal sediments.

### B. Preferred Microhabitats

Selection of preferred microhabitats on breeding grounds may vary depending on the amount of snow cover individuals encounter when they arrive. Nests are usually located on sparsely vegetated, dry, sunny, elevated, windswept ridges or slopes. Nest locations are also usually located near wetlands and lake edges, which then become the preferred microhabitat after hatching.

Preferred wintering/migration microhabitats are muddy or sandy coastal areas, more specifically, the mouths of bays and estuaries, unimproved tidal inlets and tidal flats (Fig. 22; Table 6).

### C. Breeding Habitat

As described earlier under Nest Sites, red knot breeding habitat is principally at elevations of <150 m and includes small wetlands where the chicks can feed.

At the landscape scale, a model of potential breeding habitat was developed by New Jersey Endangered and Nongame Species Program (ENSP) and Rutgers University using remotely-sensed land-cover characteristics. The model showed that red knot breeding habitat is generally found at elevations <150 m above sea level, <50 km from the coast and where vegetation cover is <5% (See the Distribution - Breeding Range section of this review). Red knots and their chicks and fledglings forage in shallow sedge meadows and on sparsely-vegetated lake edges proximate to nest sites (Fig. 23).

Figure 22. Critical breeding, migration stopover, and wintering habitat for the red knot *C. c. rufa*. Numbers on the map correspond with the numbers on Table 6.

Table 6. Habitat types utilized by foraging red knots on breeding grounds (B), spring migration (S), fall migration (F), and wintering grounds (W). The numbers correspond to those on Fig. 22.

| # | Location | Sandy Beach | Tidal Mudflat | Peat Bank | Restinga/ Inter-tidal Rocky Flat | Salt Marsh | Mangrove | Brackish Lagoon/ Impoundment | Rocky Barrens | Source |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | King William Island, CAN | | | | | | | | B | Morrison unpublished data; Peck unpublished data; Ross pers. comm. 2005 |
| 2 | Southampton Island, CAN | | | | | | | | B | Morrison unpublished data; Peck unpublished data; Ross pers. comm. 2005 |
| 3 | James Bay, CAN | S,F | | | | | | | | Morrison unpublished data; Ross pers. comm. 2005 |
| 4 | Mingan Archipelago, CAN | | | | F | | | | | Aubry pers. comm. 2007 |
| 5 | Northern Bay of Fundy, CAN | | S,F | | | S,F | | | | Hicklin 1987; Morrison unpublished data.; Peck unpublished data |
| 6 | Massachusetts, USA | F | F | | | | | | | Harrington unpublished data |
| 7 | New York, USA | S,F | | | | | | S,F | | Harrington unpublished data; Tripp pers. comm. 2005 |
| 8 | Atlantic Coast New Jersey, USA | S,F | | | | | | | | K. Clark unpublished data; Hernandez unpublished data; Niles unpublished data; Sitters unpublished data |
| 9 | Delaware Bay, USA | S,F | | | | S | | | | Bennett unpublished data; K. Clark unpublished data; Kalasz unpublished data; Sitters unpublished data |
| 10 | Maryland, USA | S,F | S,F | | | | | | | Therres pers. comm. 2005 |
| 11 | Virginia, USA | S,F | | S,F | | | | | | Rice pers. comm. 2005; Truitt pers. comm. 2005; Watts pers. comm. 2005 |
| 12 | North Carolina, USA | S,F | S,F | | | | | | | Cameron pers. comm. 2005 |
| 13 | South Carolina, USA | S,F, W? | | | | | | | | Sanders pers. comm. 2005 |
| 14 | Georgia, USA | S,F, W? | | S,F, W? | | | | | | Winn pers. comm. 2005 |
| 15 | North Florida, USA | S,F, W | S,F, W | | | S,F ,W | | S,F,W | | Douglass pers. comm. 2005; Leary pers. comm. 2005; Sprandel *et al.* 1997 |

Table 6. Continued

| # | Location | Sandy Beach | Tidal Mudflat | Peat Bank | Restinga/ Inter-tidal Rocky Flat | Salt Marsh | Mangrove | Brackish Lagoon/ Impoundment | Rocky Barrens | Source |
|---|---|---|---|---|---|---|---|---|---|---|
| 16 | South Florida, USA | S,F, W | S,F, W | | | S,F ,W | S,F ,W | S,F,W | | Douglass pers. comm. 2005; Leary pers. comm. 2005; Sprandel *et al.* 1997 |
| 17 | Texas, USA | S,F, W | S,F, W | | | S,F ,W | | | | Arvin, pers. comm. 2005; Burkett, pers. comm. 2005; Ortego, pers. comm. 2005 |
| 18 | Panama Bay, PAN | S | S,W | | | | S | | | Buehler 2002 |
| 19 | Maranhão, BRA | S,F, W | S,F, W | | | | S,F ,W | | | Serrano unpublished data |
| 20 | Lagoa do Peixe, BRA | S,F, W | | | | | | S,F,W | | Serrano unpublished data |
| 21 | Punta Rasa, ARG | S,F | | | | | | | | González unpublished data |
| 22 | San Antonio Oeste, ARG | S,F | S,F | | S,F | | | | | González unpublished data |
| 23 | Chiloe Island, CHL | S | | | | | | | | Espinosa pers. comm. 2005 |
| 24 | Río Gallegos, ARG | S,F | S,F | | S,F | | | | | González unpublished data |
| 25 | Bahía Lomas, CHL | | W | | | | | | | Espoz pers. comm. 2005; Matus unpublished data |
| 26 | Bahía San Sebastián, ARG | | W | | | | | | | González unpublished data |
| 27 | Río Grande, ARG | W | W | | W | | | | | González unpublished data |

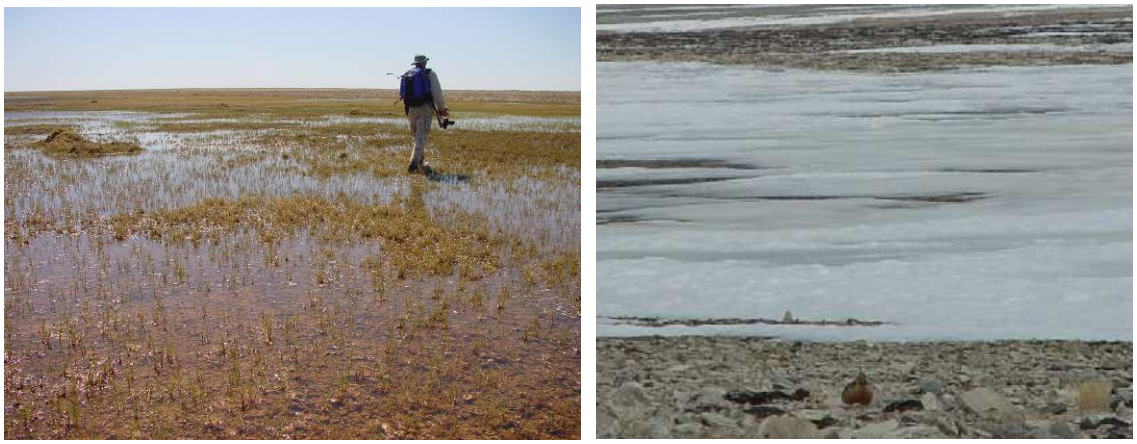


Figure 23. Typical Arctic foraging habitat of red knots in shallow sedge meadows (left) and sparsely vegetated lake edge; red knot in foreground (right) (New Jersey Division of Fish and Wildlife).

## D. Migration / Stopover Habitat

### *1. Canada*

The critical staging areas for red knots during spring and fall migration in Canada are along sandy beaches and tidal mudflats in James Bay and tidal mudflats and salt marshes in the northern Bay of Fundy (Morrison unpublished data, Peck unpublished data, Ross pers. comm. 2005). In the Bay of Fundy, red knot migrants are rare in spring, but relatively common in the fall (Hicklin 1987).

### *2. United States of America – Northeast*

It is not believed that Maine (Tudor pers. comm. 2005), New Hampshire (Raithel pers. comm. 2005), Connecticut, and Rhode Island (Dickson pers. comm. 2005, Varza pers. comm. 2005) have large numbers of red knots during migration. In the NE United States (New Jersey to Maine), the principal red knot staging areas are along the New Jersey, New York and Massachusetts coastlines. In Massachusetts, red knots use sandy beaches and tidal mudflats during fall migration near Scituate, Duxbury and Plymouth Beach, and along the shoreline in Cape Cod south to Monomoy (Harrington unpublished data). New York's Jamaica Bay Wildlife Refuge has a concentration of migratory red knots during spring and fall along sandy beaches and most commonly within the impoundment (Tripp pers. comm. 2006). Along the Atlantic Coast in New Jersey, red knots utilize sandy beaches during spring and fall migration for foraging (K. Clark unpublished data, Hernández unpublished data, Niles unpublished data, Sitters unpublished data).

### *3. United States of America – Delaware Bay*

Delaware Bay is the most important staging area during northbound migration and is normally used by the whole or a large proportion of the *rufa* population which spends 2-3 weeks staging there in the latter half of May. Beaches typical of the Delaware Bay shore are a mixture of sand and smooth gravel, and shorebirds are distributed on Delaware Bay relative to availability of horseshoe crab eggs (Fig. 24). One of the most critical issues for the conservation of the knot population is its dependence on huge quantities of eggs produced by the mass spawning of the largest known population of Atlantic horseshoe crabs (Shuster and Botton 1985) (Fig. 25). Crab eggs are especially important to red knots because of time constraints in completing their 15,000 km trans-hemispheric migration from Tierra del Fuego to the Canadian Arctic (Morrison and Harrington 1992, Harrington 2001). To stay on schedule and ensure breeding opportunities, knots must increase body mass in Delaware Bay by 50-100% in 2-3 weeks (Baker *et al.* 2004), one of the most rapid fattening events in birds. Some knots may arrive at or below normal lean body mass of 110 g and depart at 180-220 g. Food quality, quantity and availability as well as the time constraints associated with nutrient acquisition (foraging, food processing, and assimilation) are critically linked in achieving this unique anabolic event.

Figure 24. Typical sandy beach foraging habitat for red knots on Delaware Bay, New Jersey (New Jersey Division of Fish and Wildlife).

Figure 25. Horseshoe crabs spawning on Delaware Bay (New Jersey Division of Fish and Wildlife).

a. Habitats Important for Red Knots in Delaware Bay

Most horseshoe crabs spawn on sandy beaches around high tide, burying their eggs close to the high tide line. Spawning activity usually peaks during the latter half of May to early June, which coincides with the main red knot stopover (Botton *et al.* 1994). The most important habitats in Delaware Bay for spawning crabs are the sandy beaches along the New Jersey shore mainly from Town Bank to Gandys Beach and along the Delaware shore mainly from Slaughter Beach to Port Mahon (Fig. 26). In New Jersey, red knots also make extensive use of the Atlantic coast, particularly the sand-spits and sandbanks around Stone Harbor Point and Hereford Inlet for roosting and occasionally for foraging on surf clams. They also forage on spat of the blue mussel in the protected intertidal marshes behind the Atlantic coast. In Delaware, knots sometimes roost day and night in an area of relatively unvegetated marsh about 1.7 km inland from the bayshore and 500 m north of the Mispillion River. So far as we can determine, this is the only place in the world where red knots have been recorded roosting inland at night. In 2004 and 2005, this site became flooded and many knots regularly commuted from the Delaware shore, where they fed by day, to roost at Hereford Inlet on the Atlantic coast of New Jersey at night, a round trip of 94 km (Sitters 2004, 2005).

Figure 26. Map of the Delaware Bay (New Jersey and Delaware) showing some of the most important refueling sites for red knots.

Extensive coastal marshes and mudflats that are typically fronted by a sandy barrier beach fringe Delaware Bay. These sandy beaches mainly overlay marsh sediments (generally a fibrous peat formed by the root mat of the marsh plants) and vary in thickness from a thin veneer to about 2 m (Phillips 1986a). The back beaches, above normal high tide, form a low dune and are often colonized by common reed *Phragmites australis* (Phillips 1987). The intertidal portions of the sandy beaches are of special significance as these are the focus of horseshoe crab spawning activity and of red knots foraging. Horseshoe crabs prefer beaches dominated by coarse sandy sediments and avoid beaches that have a high amount of peaty sediments or are adjacent to exposed peat banks (Botton *et al.* 1988). These factors were used by Botton *et al.* (1988) to develop a classification scheme that ranked beaches as either preferred or avoided habitat for horseshoe crab spawning. Horseshoe crabs deposit most of their eggs 10-20 cm deep in sandy beach sediments (Botton *et al.* 1992) (Fig. 27); eggs are then redistributed to shallower depths or the surface and become available to foraging shorebirds by subsequent spawning and wave action. Although it is widely thought that the major process that brings eggs to the surface is the action of female crabs digging up earlier nests as they spawn, the way this works is poorly understood. Possibly there is some critical density of spawning crabs below which few eggs come to the surface and above which many do. If so, it would be valuable to determine what that density is as an aid to establishing the size of the crab population that is needed to support the shorebird stopover.

Figure 27. Horseshoe crab on beach in Delaware Bay depositing eggs in the sand (New Jersey Division of Fish and Wildlife).

Starting in 1999, systematic surveys were conducted to count intertidal (i.e. spawning) horseshoe crabs throughout Delaware Bay (Smith *et al.*, 2002a; 2002b). Various short-term studies of egg density preceded systematic surveys that were started on the New Jersey shore in 1996 and on the Delaware shore in 1997 (Botton pers. comm. 2005, Loveland pers. comm. 2005, NJDFW unpublished data, Weber 2003). These used different methods making it difficult to determine how egg densities varied between the two states and it was not until 2005 that the two projects were combined into a single bay-wide survey using the same methodology. All these surveys show that egg densities

vary by several orders of magnitude, sometimes exceeding $10^6$/m of shoreline (Smith *et al.*, 2002b). Smith *et al.* (2002b) found that beach morphology and wave energy interact with the density of spawning females to explain much of the variation in the density and distribution of eggs and larvae between the study beaches. Horseshoe crabs showed a preference for spawning on low-energy (i.e. wave-protected) sandy beaches. While the surveys only sampled bay-front beaches, beaches along tidal creeks were also noted as being potential hotspots for crab spawning and shorebird foraging. At a broader, bay-wide scale, the use of intertidal beaches as horseshoe crab spawning habitat is limited in the north by low salinity (i.e. at Sea Breeze in New Jersey and Woodland Beach in Delaware) and by ocean generated energy in the south (i.e. at North Cape May, New Jersey and Broadkill, Delaware).

**Preferred beach characteristics for horseshoe crab spawning**

- Narrow
- Low energy (wave-protected)
- Sandy
- Along sandy mouth of tidal creeks

Not surprisingly, migratory shorebird abundance is spatially variable within the Delaware Bay estuary as a consequence of these larger bay-wide patterns of horseshoe crab abundance and spawning activity. Migratory shorebirds in Delaware Bay showed a strong preference for beaches with higher numbers of crab eggs although shorebird abundance also depends on other factors such as competition, disturbance, and risk of predation (Botton *et al.* (1994). Shorebirds were recorded to aggregate near shoreline discontinuities, such as salt marsh creek deltas and jetties, which acted as concentration mechanisms for passively drifting eggs (Fig. 28). Human disturbance can greatly reduce the value of foraging habitat for knots, as discussed in the Threats section of this review. The various studies outlined above show that a complex array of factors determine the value of Delaware Bay beaches as horseshoe crab spawning and shorebird foraging habitat.

**Optimal Shorebird Foraging Habitat**

- High horseshoe crag egg density
- Lack of human disturbance
- Near shoreline discontinuities (i.e. salt marsh creek deltas and jetties)

Figure 28. Shorebirds and gulls foraging near a managed area (experimental gull exclosure center frame) on Delaware Bay, New Jersey (New Jersey Division of Fish and Wildlife).

A large portion of Delaware Bay shore has some form of conservation protection (Fig. 29). The New Jersey shore includes state-owned lands at Dennis Creek, Heislerville and Egg Island Wildlife Management Areas, USFWS-owned land (Cape May National Wildlife Refuge (NWR)), The Nature Conservancy (TNC) land, and the Public Service Electric and Gas Company land managed by TNC. The Delaware shore includes large areas in USFWS ownership at Bombay Hook and Prime Hook NWRs, state-owned land (Little Creek, Ted Harvey, and Milford Neck Wildlife Areas and Cape Henlopen State Park), and a significant amount of conservation land owned by TNC and Delaware Wildlands. However, in both states, there are large areas of shoreline in private ownership and subject to habitat disturbance and loss. In New Jersey, while the intertidal beach is considered publicly owned, there are key beaches immediately adjacent to residential development, including Villas, Reed's Beach, and Fortescue. In Delaware, private property ownership generally extends to mean low water. Similar to New Jersey, residential development in Delaware is adjacent to key beaches including Pickering, Kitts Hummock, Bowers and Slaughter beaches. Port Mahon and Mispillion Inlet are different in that commercial use and bulkheading threaten critical red knot habitat. Regardless of residential proximity where the bayfront is accessible by car, human disturbance is a threat that can reduce the value of habitat for red knots.

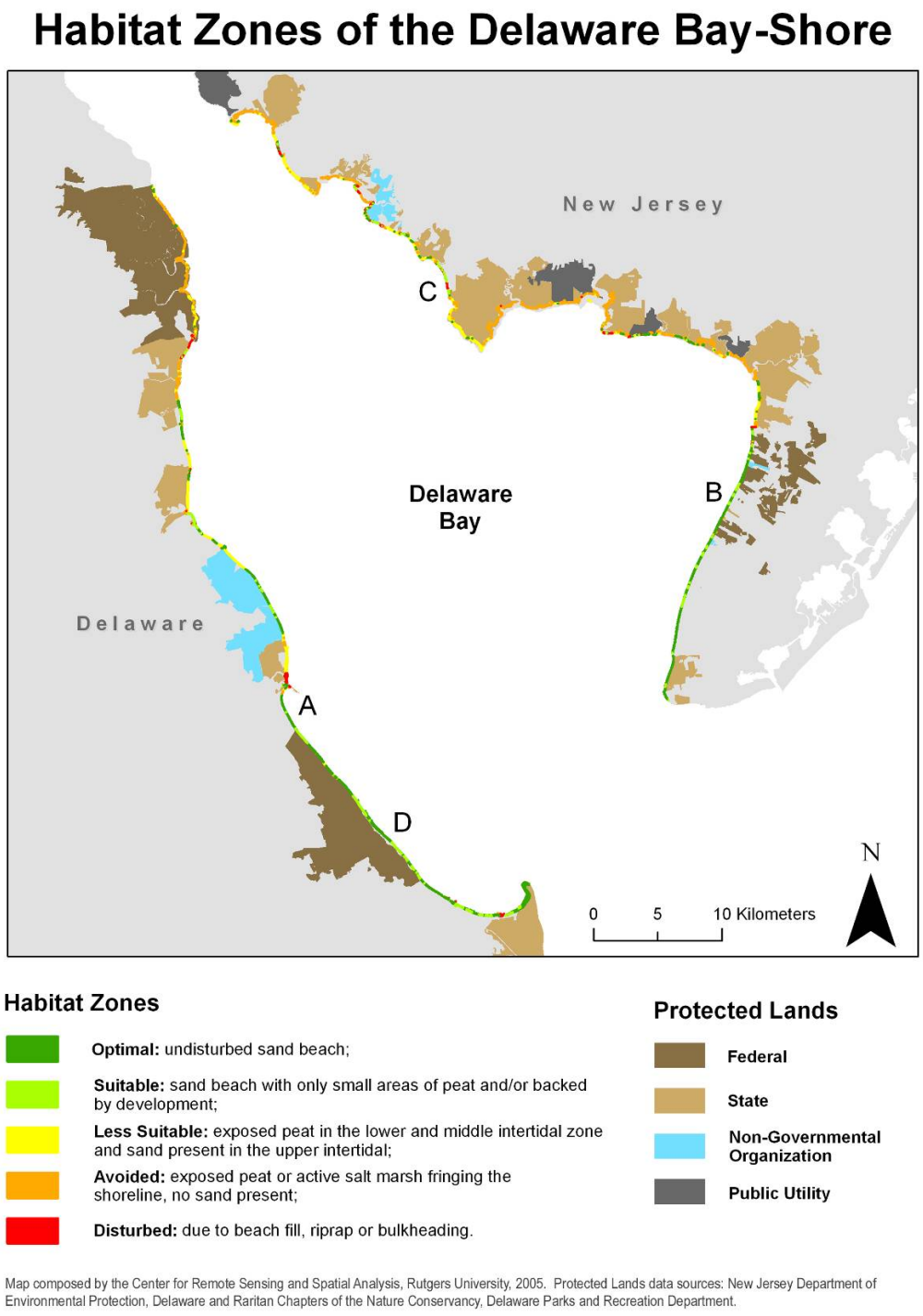



Figure 29. Map of horseshoe crab spawning habitat suitability with location of protected conservation lands. Several key locations have been annotated: A) Slaughter Beach; B) Cape May NWR; C) Fortescue; and, D) Broadkill Beach. Protected Lands GIS Data Sources: NJ DEP, NJ Green Acres, The Nature Conservancy-NJ Chapter, DE Parks and Recreation.

b. Red Knot Feeding Ecology in Delaware Bay

The strong reliance of red knots on horseshoe crab eggs has been confirmed by stomach content analyses (Tsipoura and Burger 1999) and stable isotope diet tracking studies, which show that horseshoe crab eggs are the main constituent of the red knots' diet during their stopover in Delaware Bay (Haramis *et al.* 2007). Other studies (e.g. Castro *et al.* 1989, Castro and Myers 1993) have estimated the daily requirement of shorebirds for horseshoe crab eggs based on the birds' energetic requirements. These show that sanderlings would need 8,300 and red knots 30,000 eggs per day (Castro *et al.* 1989, Castro and Myers 1993, Hernández 2005). A more recent study using pen trials estimated that red knots need 13,000 eggs per day to maintain body weight and 24,000 eggs per day when fattening optimally (Haramis *et al*. 2007).

A key question, however, is not just how many eggs are required or consumed, but how important are horseshoe crab eggs to migratory fattening and to what extent alternative foods in the Delaware Bay environment are utilized. Haramis *et al.* (2007) conducted research in Delaware Bay from 2000 to 2004 that considered the trophic link between red knots and crab eggs using stable isotope diet tracking and pen feeding trials. He measured Stable Isotopes (SI) (delta-15 nitrogen signal) in the plasma of captive red knots that were fed exclusively on horseshoe crab eggs and compared these signals to free-ranging red knots. The close consistency in SI pattern of response and convergence of diet asymptotes between free-ranging and captive birds confirm the importance of crab eggs in the diet of knots during stopover in Delaware Bay.

Throughout their worldwide range, red knots generally feed wholly or mainly on bivalves which are swallowed whole (Alerstam *et al.* 1992, Dekinga and Piersma 1993, Piersma *et al.* 1993, González *et al.* 1996). Therefore the most likely alternative prey in the Delaware Bay system would be blue mussels, coquina clams (*Donax variabili*s), or ribbed mussels (*Modiolus demissu*s). As filter feeders, bivalves are low in the food chain and have SI values that can be discriminated easily from crab eggs. This enabled Haramis *et al.* (2007) to show that while some knots may consume bivalves, they do not form a significant part of the diet of most birds in Delaware Bay in spring. However, in most years a significant minority of birds (<30%) has been observed foraging on these alternative food resources. These tend to occur on the Atlantic coast of New Jersey and the majority of these birds are short-distance migrants (possibly *C. c. roselaari*) from wintering areas in the south-eastern states of the U.S. (Atkinson *et al.* 2006a). It is hypothesized that these short-distance migrants are either able to arrive in Delaware Bay earlier than birds from South America and regrow their digestive apparatus to deal with the hard-shelled prey, or do not undergo the major physiological changes of gut size reduction that the long-distance migrants have to undertake to migrate in such long hops (Atkinson *et al.* 2006a). However, for long-distance migrants, particularly the birds from Tierra del Fuego, crab eggs are crucial to successful fattening and these birds are therefore likely to be more vulnerable to a decline in the availability of eggs than those that have not come so far.

Hernandez (2005) analyzed prey attack patterns (peck and probe rates), locomotion patterns (step rates) and the interactions between these patterns as a measure of foraging efficiency relative to egg density and patchiness. However, because he was not able to tell whether or not a peck or probe was successful, he could not determine the relationship between intake rate (eggs per second) and egg density, which is essential for

measuring the critical egg densities that affect overall foraging success. Atkinson *et al.* (2003) describe the use of feeding pans containing known numbers of eggs, either on the surface or buried in the top 5 cm of sand, and placed these in foraging flocks of red knots in the field and recorded feeding rates and depletion. Knowing the relationship between egg density and egg intake rate, and the daily egg requirements from the Haramis *et al.* (2007) study, it is possible to estimate the number of hours of feeding required for a given density of eggs.

From these experiments, Atkinson *et al.* (2003) determined that the number of eggs consumed per peck (i.e. success rate of pecks) increased asymptotically with egg density (see also Gillings *et al.* 2007). Whether present on the surface or buried in the sand, eggs consumed per second increase asymptotically with egg density (Fig. 30). Higher intake rates are achieved from pecking eggs off the sand surface and, even at very low surface egg densities, it is significantly more profitable to peck than probe (Fig. 31).

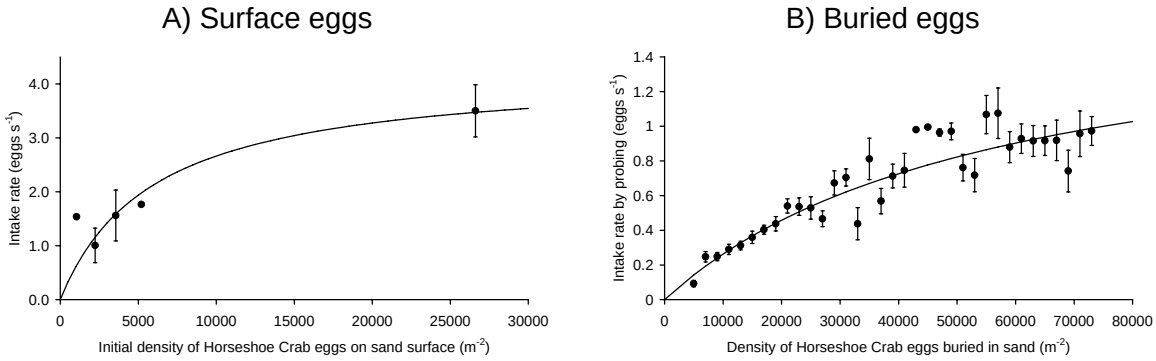



Figure 30. Functional responses relating the intake rate (eggs $s^{-1}$) achieved by red knots to the density of A) eggs present on sand surface and B) eggs buried and mixed in the top 5 cm of sand.

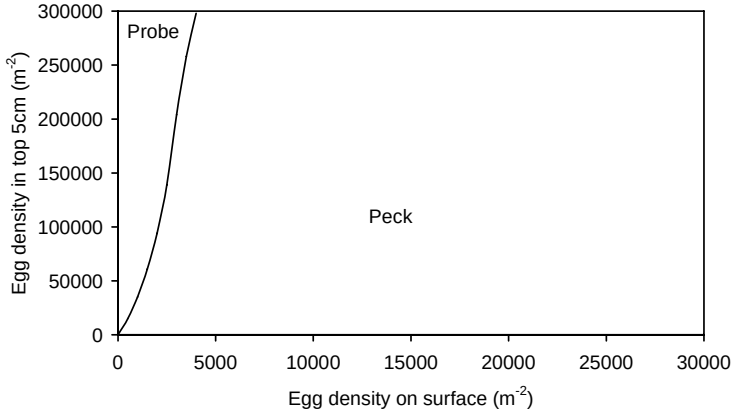



Figure 31. The density of eggs on the sand surface or buried and mixed in the sediment (down to 5 cm) will determine whether it is most profitable to peck or probe.

Daylight during staging is around 15 hours and crab eggs are laid near the high tide mark so birds could theoretically feed for most of daylight hours. Then, the required daily egg intake could be achieved by feeding on surface eggs at a density of only 360 eggs $m^{-2}$, or buried eggs at a density of 19,200 eggs $m^{-2}$ (Table 7). However, the availability of eggs on the sand surface, and buried in the top 5 cm of sand are likely to vary through the tidal cycle with density of spawning crabs, wave action and depletion by shorebirds and gulls. Furthermore, eggs remaining on the sand surface rapidly dry out (on hot windy days, within an hour of deposition) and become hardened. During 10 years of observations red knot have never been seen consuming these dessicated eggs and only semipalmated sandpipers (*Calidris pusilla*) have been seen consuming dessicated eggs on one day (Gillings pers. comm. 2006, N. Clark unpublished information). These processes mean that optimal feeding is constrained to bouts of consumption of eggs freshly deposited on the sand surface by the falling tide and/or consumption of buried eggs where they are present at sufficiently high density.

Table 7. The amount of time (hours) needed to achieve the daily egg consumption of 24,000 fresh eggs (Haramis *et al.* 2007) in relation to egg availability (eggs $m^{-2}$) dependent on whether eggs are a) freely available on the sand surface or b) buried within the top 5cm of sand. These calculations are based on intake rates from experimentally measured functional responses (Atkinson *et al*. 2003, Gillings *et al.* 2007). For reference, the density of eggs yielding a 15-hour foraging time (day length) is shown.

| a) | |
|---|---|
| surface egg density | required feeding time |
| 360 | 15.0 |
| 500 | 11.3 |
| 1000 | 6.7 |
| 2000 | 4.3 |
| 3000 | 3.6 |
| 4000 | 3.2 |
| 5000 | 2.9 |
| 10,000 | 2.5 |
| 20,000 | 2.2 |
| 30,000 | 2.2 |
| b) | |
| buried egg density | required feeding time |
| 19,200 | 15.0 |
| 50,000 | 8.1 |
| 100,000 | 6.0 |
| 200,000 | 4.9 |
| 300,000 | 4.5 |

Based on field studies in Delaware Bay between 2003 and 2004, Hernández (2005) predicted that a minimum density of at least 300,000 eggs $m^{-2}$ was needed for red knots to completely maximize foraging efficiency on buried eggs. This fits well with predictions in Table 7. So far as we know, knots do not feed on horseshoe crab eggs at night in Delaware Bay and cannot feed continuously throughout the day as they need to spend time on other behaviors such as vigilance and preening. Moreover feeding areas

are not available when the tide covers them, neither are surface eggs if they are subject to rapid desiccation at low tide on hot days. The foraging models also suggest that red knot foraging efficiency is adversely affected by decreased egg density and increased egg patchiness.

Studies by Haramis *et al.* (2007) and Hernández (2005) describe the importance of horseshoe crab eggs to red knots and the lack of alternative foods being used during stopover. Data from the New Jersey Division of Fish and Wildlife, Endangered and Nongame Species Program (NJDFW-ENSP) indicate average egg densities in New Jersey in 2004 of around 3,200 eggs $m^{-2}$ in the top 5 cm. If these were all on the surface they would theoretically be sufficient. However, in reality many of these will have been buried and those on the surface may have desiccated on hot days. Therefore knots may not be able to meet their energetic requirements during stopover due to insufficient numbers of eggs. In conclusion, low egg densities constitute a direct threat to migratory fattening in *C. c. rufa*. Moreover it has been demonstrated that low weight birds in Delaware Bay subsequently have a lower resighting rate in the flyway, implying lower adult survival (Baker *et al.* 2004).

Studies of knots trapped twice during a single spring stopover show that the mean rate of mass gain of birds that arrive in mid May is around 4g per day, but that late-arriving birds can achieve gains 2-3 times higher. This indicates that if there is sufficient food they have some flexibility and are able to make up for lost time (though it is likely that this comes at some physiological cost). This relationship broke down in 2003 and 2005 and late-arriving birds were apparently unable to achieve higher rates of mass gain because of inadequate food supplies (Atkinson *et al.* 2006b).

In summary, feeding studies in Delaware Bay appear to go some way towards explaining why Tierra del Fuego wintering knots have shown a sharp decline, but northern wintering populations have apparently been more stable (see section VII). The southern birds are more reliant on horseshoe crab eggs, the availability of which has declined. There has been a trend for their migration to become later in Patagonia and there is some evidence of later arrival into Delaware Bay (Bala *et al.* 2005, Baker *et al.* 2004, K. Clark, unpublished data). Late arrivals do not have the ability to recover lost time if there are insufficient eggs. In contrast, northern wintering birds have shown no change in migration phenology and are less reliant on crab eggs. Therefore if there are factors that lead knots to arrive late in Delaware Bay and/or in poor condition, this does not diminish the importance of the Delaware Bay food resource. If anything, it is increased because it is of critical importance in enabling the birds to recover quickly and reach the breeding grounds on time and in good reproductive condition.

c. Mapping Horseshoe Crab Spawning Habitat Suitability

Lathrop and Allen (2005) used visual interpretation of high spatial resolution color infrared digital orthophotography to provide the first "wall-to-wall" inventory and characterization of the Delaware Bay shoreline. Several categories of information were mapped that are relevant to the bayshore's value as horseshoe crab spawning habitat: 1) shoreline type and width; 2) presence of near-shore development; and 3) shoreline stabilization structures on both the fore-shore and back-beach. Sand beach dominates the foreshore of the Delaware side of the bay, while organic beach composed of either eroding peat banks or salt marsh dominates the New Jersey side (Table 8). Overall, about

54% of Delaware Bay's shoreline represents the horseshoe crab's preferred spawning habitat of sand beach (Fig. 29). These sand beaches are generally narrow in width, averaging only 10.9 m on the Delaware side and 5.9 m on the New Jersey side of the bay. Some of the widest beaches (some up to nearly 100 m in width) are found along the central and southern portions of Cape May in New Jersey and the central sections of the Delaware coast. Beach stabilization structures (e.g. armoring practices such as bulkheading or riprap) account for 4.0% of the Delaware shoreline and 5.6% of the New Jersey side (Table 8). An additional 2.9% and 3.4% of the Delaware and New Jersey shorelines, respectively, also had some form of armoring in the back-beach (Table 8), which may come into play as beaches erode and shorelines recede, exposing these structures in the future. About 8.0% of the Delaware Bayshore is subject to near-shore development. While some beaches in New Jersey and Delaware have had development removed (e.g. Thompson's Beach, New Jersey, and Big Stone Beach, Delaware), Lathrop and Allen's ground truthing surveys observed construction of new development and redevelopment on the Delaware side of the bay.

Table 8. Characterization and lengths of the Delaware Bay shoreline

| **Shoreline Type** | **Delaware** | | **New Jersey** | |
|---|---|---|---|---|
| | **km** | **(%)** | **km** | **(%)** |
| Sand | 67.50 | (74.3%) | 61.86 | (41.7%) |
| Armor (fore-shore) | 3.66 | (4.0%) | 8.35 | (5.6%) |
| Organic | 19.68 | (21.7%) | 78.10 | (52.7%) |
| Total Shoreline | 90.84 | (100%) | 148.30 | (100%) |
| | | | | |
| Armor (back)* | 2.67 | (2.9%) | 5.06 | (3.4%) |
| Development | 13.35 | (14.7%) | 5.72 | (3.8%) |

*Note: back-beach armor and developed area measurement are separate from the total shoreline measurement.

Using the mapped shoreline GIS data, Lathrop and Allen (2005) classified the Delaware Bay shoreline into 5 categories of horseshoe crab spawning suitability based on criteria proposed by Botton *et al.* (1988). These were:

1) Optimal: undisturbed sand beach;
2) Suitable: sand beach with only small areas of peat and/or backed by development
3) Less Suitable habitat with exposed peat in the lower and middle intertidal zone and sand present in the upper intertidal;
4) Avoided habitat with exposed peat or active salt marsh fringing the shoreline, no sand present; and
5) Disturbed due to beach fill, riprap or bulkheading.

Based on this more refined mapping assessment, less than a quarter (23.9%) of Delaware Bay's shoreline was classified as optimal spawning habitat (34.5% of Delaware and 17.4% of New Jersey bayshore) (Table 9). Only an additional 6.6% of shoreline came in the next, "suitable", category (11.6% Delaware, 3.4% New Jersey). Most of the optimal and suitable spawning habitat is located in the lower parts the Bay; it becomes more fragmented further up (Fig. 32). Lathrop and Allen's map should be regarded as

only a provisional assessment of spawning habitat suitability because it does not include site-specific consideration of beach morphology or wave energy characteristics that may also be important. Thus the map probably overestimates the amount of optimal habitat. For example, the lowest section of the Delaware shoreline (15 km south from Broadkill) and the southern third of the Cape May Peninsula (8.5 km) on the New Jersey side were mapped affording "optimal" or "suitable" habitat. However, Smith *et al.* (2002b) did not record high levels of horseshoe crab spawning on these beaches, presumably due to their greater exposure to the ocean leading to higher wave energies and less suitable beach morphology. It should be noted that in a few areas classified as "disturbed," groins have resulted in low energy sandy beaches which are ideal for spawning horseshoe crabs. An example of this is Mispillion Harbor, which has the highest reported density of crab eggs in the whole of Delaware Bay.

Table 9. Length of shoreline in Delaware and New Jersey according to suitability for horseshoe crab spawning. The 5 categories are adapted from Botton *et al.*, 1988. (Note: due to differences in GIS processing, the total shoreline lengths are slightly different compared with Table 8).

| **Habitat Suitability** | **Delaware** | | **New Jersey** | |
|---|---|---|---|---|
| | **km** | **(%)** | **km** | **(%)** |
| Optimal | 31.28 | (34.5%) | 25.69 | (17.4%) |
| Suitable | 10.56 | (11.6%) | 5.07 | (3.4%) |
| Less Suitable | 28.98 | (32.0%) | 48.88 | (33.1%) |
| Avoided | 16.78 | (18.5%) | 58.84 | (39.8%) |
| Disturbed | 3.08 | (3.4%) | 8.31 | (5.6%) |
| Total Shoreline* | 90.68 | | 147.79 | |

Of the "optimal" spawning habitat, 39.5% has some form of conservation protection (i.e. federal, state, public utility or non-governmental organization; 41% Delaware, 37% New Jersey) (Table 10). Therefore, while significant stretches of optimal habitat are protected, there are key sections that have no formal protection (Fig. 29), though that does not necessarily mean that they are threatened. On the Delaware side, Slaughter Beach is one of the longest stretches of optimal habitat that is largely unprotected. Similarly there are several pockets of optimal or suitable habitat along the northern New Jersey bayshore (e.g. Fortescue and Gandy's Beaches) that are largely unprotected. Although a long section of optimal or suitable habitat would appear to be protected by the Prime Hook National Wildlife Refuge (Fig. 29), this is only partially true as some stretches of the barrier beach are in private ownership and developed (e.g. Broadkill Beach) and only the back-bay marshes and adjacent uplands are in refuge protection.

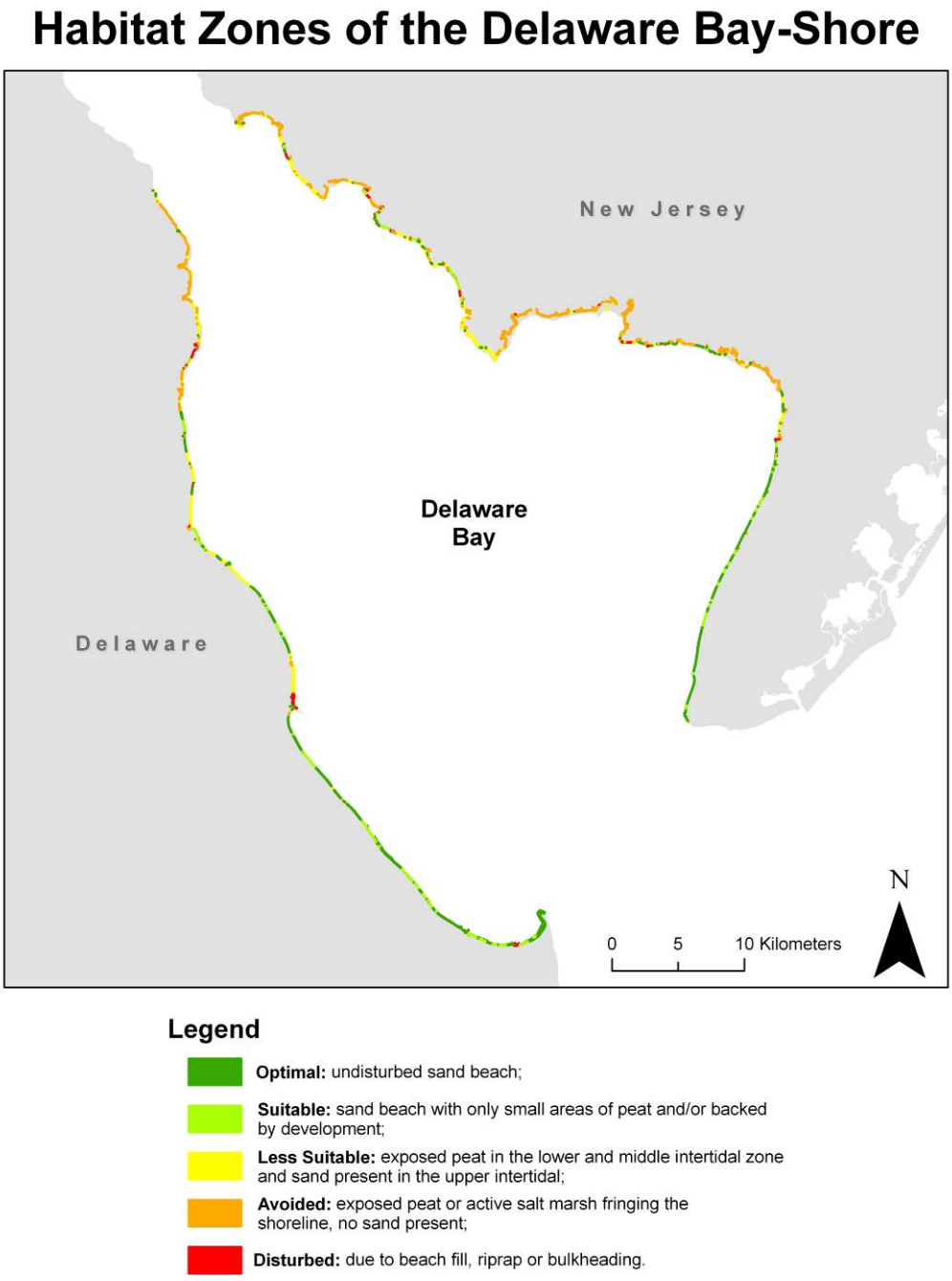



Figure 32. Map of horseshoe crab spawning habitat suitability based on beach sediment and development characteristics (from Lathrop and Allen 2005). Note that this mapping does not include consideration of beach morphology or wave energy characteristics that may be also be important in determining the suitability of the beach as horseshoe crab spawning habitat or other human disturbance or habitat factors that might influence bird usage.

Table 10. Length and percentage of each spawning habitat suitability category that is in some form of conservation ownership (i.e., federal, state, public utility or non-governmental organization land that is primarily held for the conservation of wildlife or other natural resources). (Note: the percentages are based on the shoreline lengths shown in Table 8).

| Habitat Suitability | In Conservation Ownership Delaware | | In Conservation Ownership New Jersey | |
|---|---|---|---|---|
| | km | (%) | km | (%) |
| Optimal | 12.87 | (41.1%) | 9.62 | (37.4%) |
| Suitable | 0.74 | (7.0%) | 0.13 | (2.6%) |
| Less Suitable | 18.57 | (64.1%) | 33.56 | (68.6%) |
| Avoided | 11.55 | (68.8%) | 48.87 | (83.0%) |
| Disturbed | 0.99 | (32.1%) | 0.53 | (6.4%) |

d. Mapping Critical Red Knot Habitat

During 1986-2005, weekly aerial shorebird surveys were carried out along the Delaware Bay shore over the 6-week period of the spring stopover from the beginning of May to early June (Clark *et al.* 1993, K. Clark unpublished data). These data have been examined to determine which Delaware Bay beaches are most important for red knots. For the survey, the bayshore was divided into 81 segments of about 3 km each (48 in New Jersey and 33 in Delaware), which were geo-referenced to permit mapping. The survey data have been summarized for 5-year periods. For each period, the aggregate number of red knots counted in each segment was expressed as a percentage of the total aggregate number summed (across the whole study area for the entire 5-year period). The survey data were analyzed as percentages to examine the spatial distribution of beach use on a relative, rather than absolute basis.

Comparison of the maps for the first and last 5-year periods suggests that the spatial distribution of red knot use has changed (Fig. 33, K. Clark unpublished data). During 1986-1990, the knots were relatively evenly distributed along the New Jersey shore from Reeds Beach to Ben Davis Point. However, during 2001-2005, there was a greater concentration from Norbury's Landing to Reed's Beach and from Egg Island Point to Gandy's Beach. During 1986-1990, the knots were relatively evenly distributed along Delaware shore from Bowers Beach through Bombay Hook National Wildlife Refuge with a major concentration in the Slaughter Beach-Mispillion Harbor area. During 2001-2005, however, there was a much greater concentration around Slaughter Beach-Mispillion Harbor and around Bowers Beach. Mispillion Harbor consistently supports high concentrations of red knots, sometimes more than 20% of the entire bay population.

Other areas of the Bayshore were little used by red knots; for example, in New Jersey the Cape May Peninsula south of Norbury's Landing, and in Delaware the central and lowest sections (Big Stone Beach and Broadkill Beach to Cape Henlopen). These low knot-use sections coincide with areas of low horseshoe crab spawning activity as recorded by Smith *et al.* (2002b). There are other parts of the bayshore that Lathrop and Allen (2005) classified as "less suitable" and even "avoided" as crab spawning habitat in 2002, that were recorded as having medium-high red knot use in 1986-1990. In many

cases, red knot use of these beaches had diminished by 2001-2005; for example the Bombay Hook NWR in Delaware and the Maurice River area in New Jersey (Fig. 33). Whether these changes are due to beach erosion and/or reduced numbers of horseshoe crabs or spawning activity is unknown.

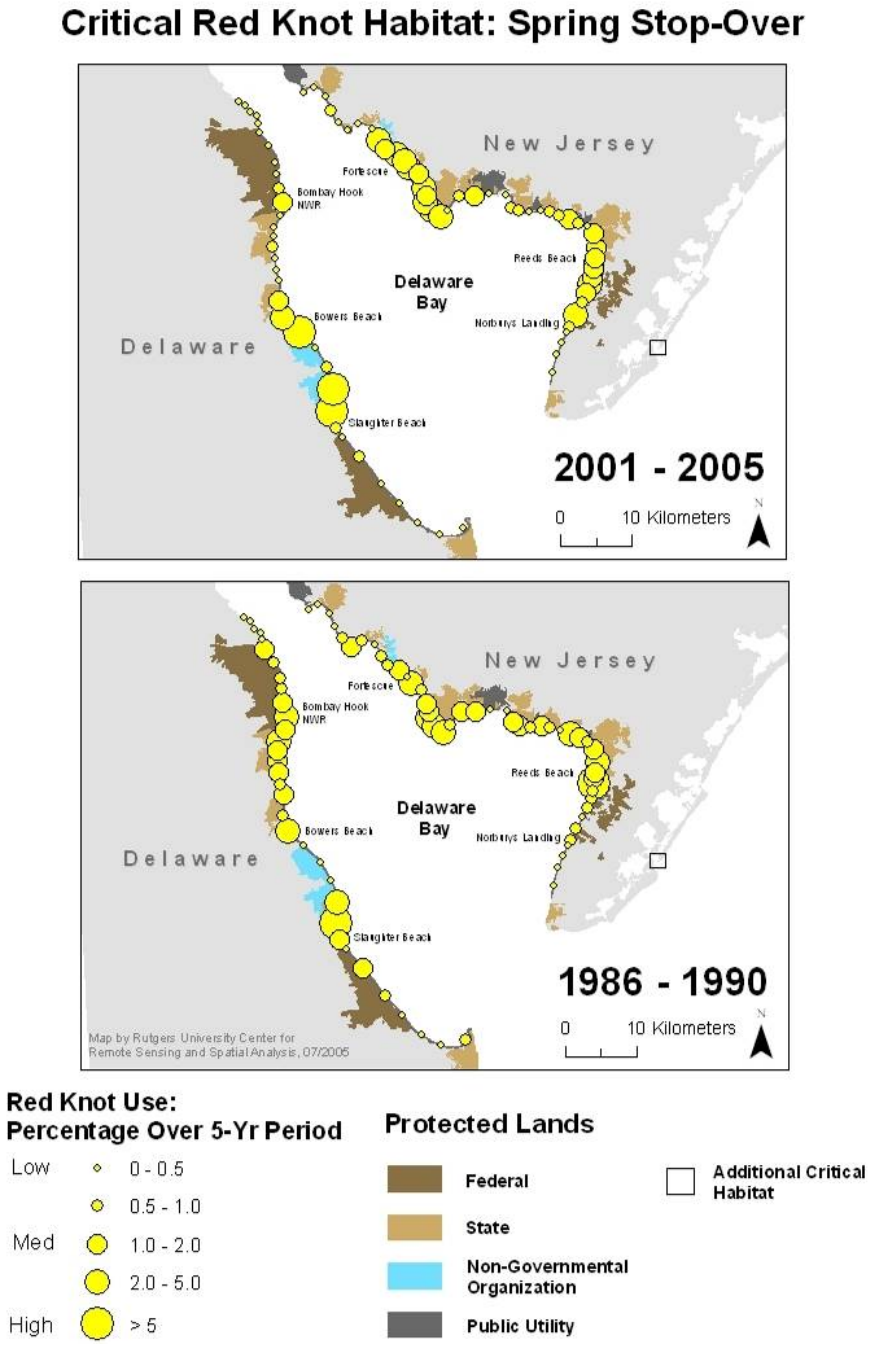



Figure 33. Map of percent red knot use between 1986-1990 and 2001-2005. Survey data summed across the 5-year period and percent of total calculated for each beach segment (K. Clark unpublished data).

In addition to the aerial surveys, ground surveys have been conducted by the New Jersey ENSP to identify other high use areas for red knots during both spring and autumn stopover. In particular, large numbers of red knots have been recorded using the Hereford Inlet area on the Atlantic coast of Cape May and the adjacent marshes in spring. Fall ground surveys have also recorded significant numbers of red knots in the Hereford Inlet area. Stone Harbor Point and the nearby Nummy, Champagne and Humphrey Islands include undeveloped sand beach, sandbar, mudflat, and salt marsh habitats which afford critically important roosting areas, especially on spring high tides and at night. This area is also important for supplementary foraging by red knots in spring and as a main foraging area in autumn when surf clams and mussel spat are available.

In addition to the Delaware beaches identified from aerial surveys, International Shorebird Surveys conducted in Delaware during the 1992-1997 spring migrations suggest that managed impoundments along Delaware Bay may also provide important habitat for red knots. Each year from 1993 through 1996, 1,200-5,300 red knots were recorded in an impoundment at the Ted Harvey Wildlife Area. Managed impoundments in Delaware may represent critical habitat for high-tide and nighttime roosts if conditions are suitable.

The maps showing the distribution of horseshoe crab spawning habitat and red knot use in Delaware Bay (Figs. 29, 32, and 33) together identify the main areas that should be considered as critical habitat to support the red knot's spring stopover. Knot use is probably the better criterion because it not only reflects areas of high egg density but also the birds' other requirements, such as safety from predators and suitable and safe high water and nighttime roost sites. For example, coastal areas of Egg Island modeled as "less suitable" or "avoided" by spawning crabs, are nevertheless valuable red knot habitat because they are used for roosting during day and night high tides. Their attraction is that they are protected by water channels from ground predators and are free from human disturbance.

On the basis of the most recent as well as the 1980s data, the Delaware Bay shore in New Jersey from Norbury's Landing to Dennis Creek should be considered critical red knot habitat. This portion of the Cape May Peninsula has been the focus of land conservation acquisition as part of the Cape May National Wildlife Refuge. However, there are still significant gaps in the existing refuge boundaries (Fig. 29) that should be a high priority for future acquisition or conservation management. Likewise there are important stretches of shoreline in the Fortescue and Gandys Beach areas that should be considered critical red knot habitat and prioritized for protection. The Hereford Inlet area, between Stone Harbor and Wildwood, and Stone Harbor Point should also be considered critical habitat due to its importance during both spring and fall migration.

The survey data suggest that some parts of the New Jersey shore between East Point and Moores Beach had higher relative use by knots during 1986-1990 than more recently. This area has experienced considerable beach erosion and some stretches have a history of development and beach armoring. Therefore it would seem possible that beach restoration might be feasible in this area (e.g. at Thompson's Beach). Probably the most southerly portion of the Cape May Peninsula (*i.e.* south of Villas), while mapped as optimal/suitable horseshoe crab spawning habitat (and appearing as major gaps in conservation protection in Fig. 29), need not be considered as important red knot habitat due to its lower usage by spawning crabs and foraging knots.

In Delaware, the shores in the vicinity of Bower's Beach and Slaughter Beach-Mispillion Harbor were recorded as critically important for red knots, but they are significantly lacking in protection due to private land ownership and density of residential development. These areas should be given priority for conservation acquisition or management in future. The area of Slaughter Beach-Mispillion Harbor should receive special consideration due to its outstanding concentrations of red knots (Fig. 33). The lowest section of the Delaware shore (i.e. south of Broadkill Beach), while mapped as optimal/suitable horseshoe crab spawning habitat (and appearing as major gaps in conservation protection, Fig. 29), should probably not be considered as critical red knot habitat due to its lower usage by spawning crabs and foraging shorebirds.

While it is the intertidal beaches that comprise the most important red knot habitat in Delaware Bay, Burger *et al.* (1997) have shown that migrant shorebirds, including knots, move actively between the Bay's habitats using them for foraging, resting and other behaviors according to the state of the tide, date and time of day. Though the beaches are of critical importance, during high tides (especially springs) the birds would be restricted to areas without sufficient food for profitable foraging and too close to vegetation and structures that could harbor predators. Therefore they often go elsewhere, including nearby salt marshes, sand spits and islands. On some occasions, red knots fly all the way across the Cape May Peninsula to use the extensive sandy beach, mud flats and salt marshes in the vicinity of Stone Harbor for both foraging and roosting.

e. Evidence of Decline in Both the Population of Horseshoe Crabs and the Availability of their Eggs for Red Knots

Currently several surveys monitor the horseshoe crab population, the total density of eggs in the beaches, and the proportion of eggs that are in the upper 5 cm of sand and therefore potentially available to the shorebirds. Only two surveys, however, have been running long enough (and using consistent methods) to show how crab and egg numbers have changed over the period of increased horseshoe crab harvest which started in 1996. These are the Delaware Division of Fish and Wildlife Trawl Survey of crabs in Delaware Bay, which has focused on the in-bay population of crabs, and egg density surveys on the New Jersey bay-shore since 1985. The egg density survey began in 1985-1986 by K. Williams, a contractor under New Jersey Division of Fish and Wildlife, and was continued by Rutgers University (Botton and Loveland) in 1990. Botton and Loveland analyzed the data collected by K. Williams in 1985-1986 in their subsequent study, using conversion factors derived from side-by-side sampling (Botton and Loveland 2000). The egg density survey has been carried out since 2000 by the NJDFW-ENSP. The Delaware Bay trawl survey shows that there has been a highly significant decline in the number of adult crabs in Delaware Bay (Fig. 34) and the latter shows that there has been a highly significant decline in the density of eggs in the upper 5 cm of sand in New Jersey (Fig. 35). In respect of both parameters, the main decline took place in the 1990s, before the Delaware Bay Horseshoe Crab Spawning Activity Survey began in 1999 (Michels and Smith 2006) and before the Horseshoe Crab Benthic Trawl Survey began in 2001 (Hata 2006). Both of these new and thorough surveys indicate that there has been no major change in the size of the horseshoe crab population since they were instigated. The Spawning Activity survey shows that in 2003 and 2005 spawning was later than usual, probably on account of cold weather, and was much reduced in May. This led to a

reduction in the availability of eggs during the peak red knot stopover and late-arriving birds in particular were unable to make the mass-gains they needed (Atkinson *et al.* 2006b). The confidence limits associated with the crab data preclude precise estimation of the scale of the decline, but it would seem to be of the order of 80% (based on geometric mean) (Fig. 34). Similarly there is uncertainty about the scale of the decline in available eggs, but the data suggest somewhere in the range 80-97% (Fig.35).

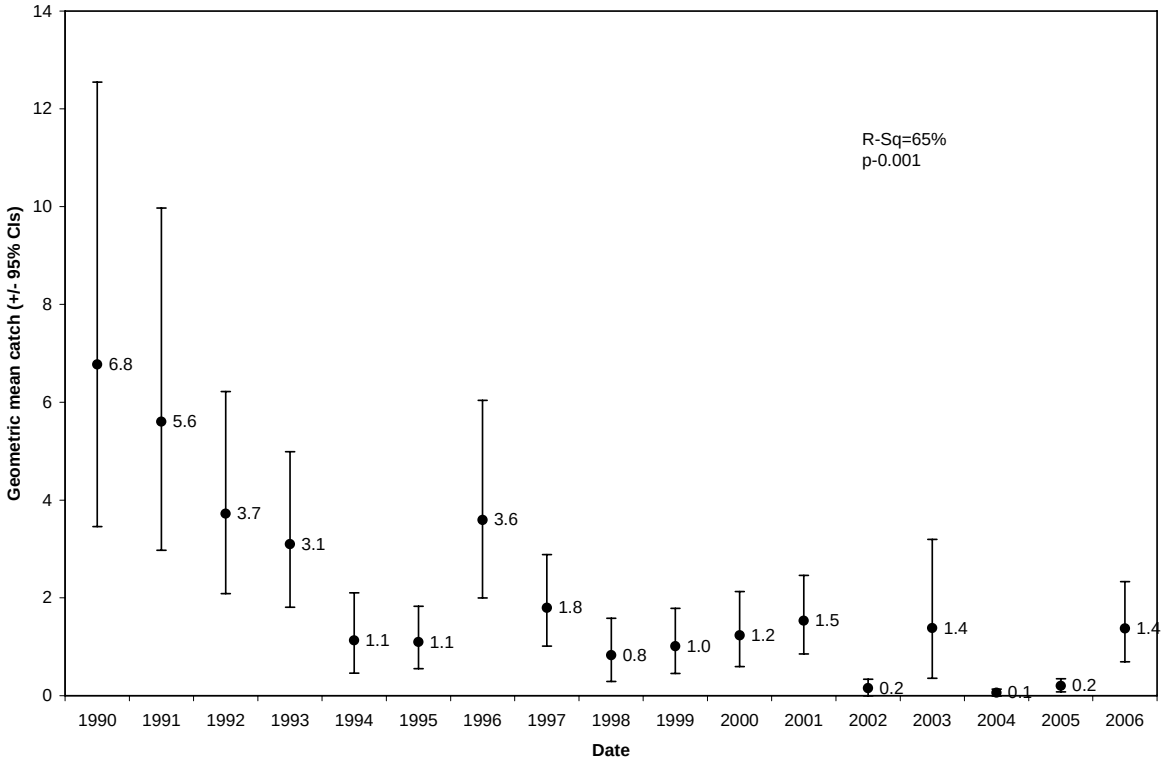



Figure 34. Number of horseshoe crabs in 30-foot trawls in Delaware Bay during May 1990-2006 (Michels pers. comm. 2006). The declining trend is highly significant (R-Sq = 65%, $p<0.001$).

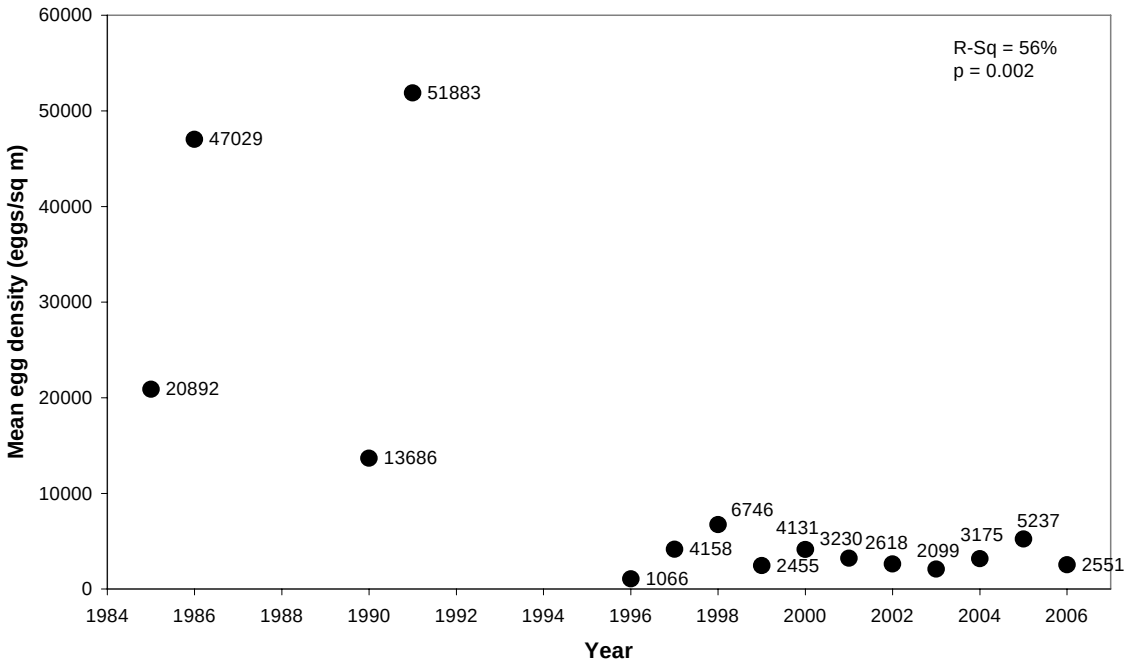



Figure 35. Density of horseshoe crabs' eggs in the upper 5 cm of sand in the Delaware Bay beaches of New Jersey during late May 1985-2006. The declining trend is highly significant (R-Sq = 56%, p = 0.002). Source: 1985-1999 – Botton (pers. comm. 2005), Loveland (pers. comm. 2005); 2000-2006 – New Jersey Endangered and Nongame Species Program (unpublished data). Confidence intervals are not plotted because the raw data are not available for the earlier period and for the later period they are very small in relation to the scale. All data points relate to 2-6 sampling dates spread over May and early June and to core samples taken along transects between the high and low tide lines at 3 m intervals.

Horseshoe crab spawning is greatly reduced by heavy on-shore wave action (Botton and Loveland pers. comm. 2005) and in some years, long periods of winds from a particular direction lead to more crab spawning on one side of the bay (the sheltered side, where the wind is offshore) than the other. For example, in 1997 persistent westerly winds led to far more spawning in Delaware than in New Jersey, but the reverse occurred in 2003 (Niles unpublished data). However, the fact that more red knots fed in New Jersey than Delaware every May from 2002 to 2005 (Fig. 36), including 2003 when winds were off-shore in New Jersey, indicates that on-shore winds alone are not responsible for the decreased densities of eggs on the New Jersey shore shown in Fig. 35.

Occasionally (as on the Delaware shore in May 2003 [N. Clark unpublished information]) a storm will deposit large quantities of new sand on exposed beaches so that eggs already laid become buried so deep that they are completely inaccessible to the shorebirds. Storms and wave action, as well as variation in the quality of different beaches as spawning habitat and depletion of eggs by foraging shorebirds and gulls mean that in any season there is considerable spatial and temporal variation in the availability of eggs to knots. The birds show a preference for foraging on beaches with high densities of available eggs; they also avoid concentrations of (and competition with) large numbers of gulls (Botton *et al.* 1994).

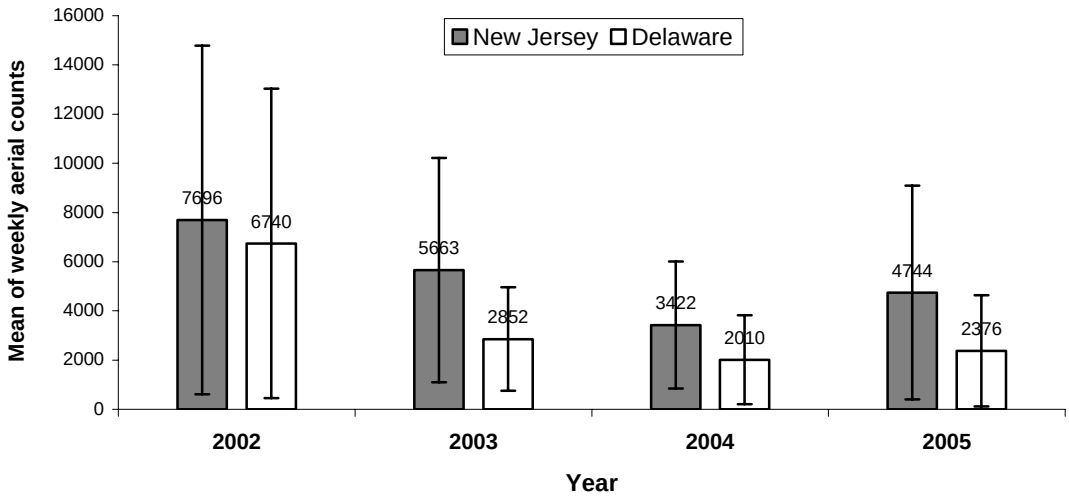
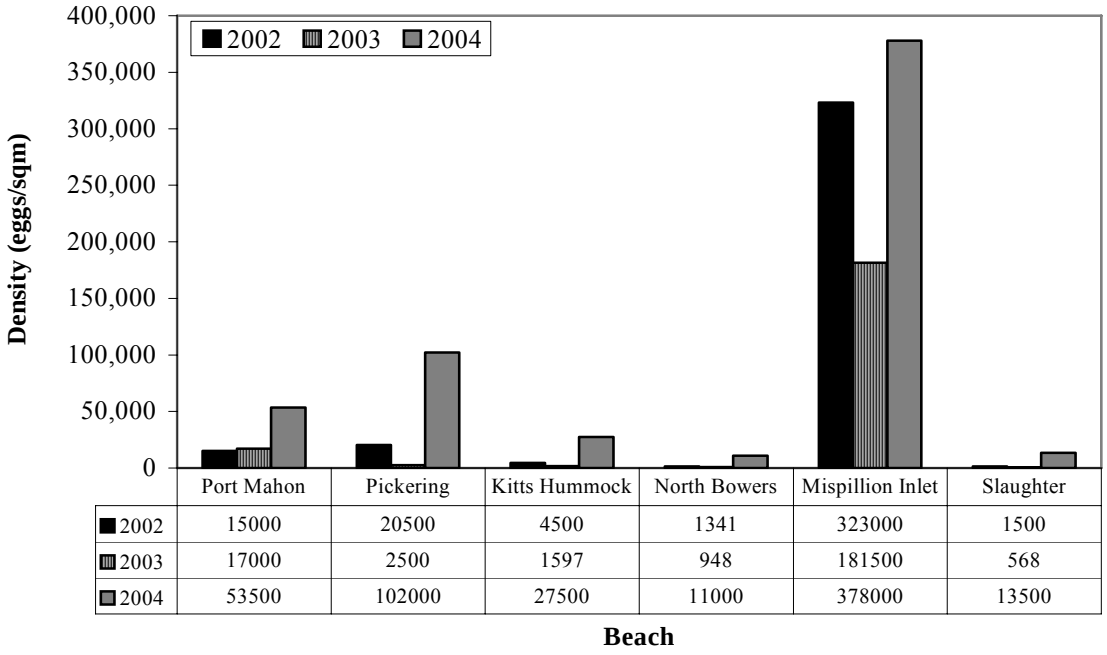



Figure 36. Mean of weekly aerial counts of red knots in New Jersey and Delaware in May 2002-2005.

Studies of horseshoe crab spawning phenology show variation associated with seawater temperature; for example spawning was delayed by about two weeks in 2003 when water temperatures averaged 2.8°C lower than the 1997-2002 mean (Weber 2003). This could have negative implications for the shorebird stopover if global warming results in a change in local seawater temperatures as a result of which the peak of spawning and the stopover do not coincide.

Egg-density sampling has not been carried out in Delaware for as long as in New Jersey and differences in methodology make comparison of trends between states virtually impossible. Therefore no such comparisons are presented here. However, sampling in Delaware has demonstrated that one site, Mispillion Harbor, which is very well sheltered by long groins, is by far the most important horseshoe crab spawning location in the entire bay and often has eggs densities that are an order of magnitude greater than any other site sampled (Fig. 37).

The peak in the harvest of horseshoe crabs took place during 1996-1999 since when harvest restrictions and management actions appear to have resulted in a more or less stable crab population, albeit at a relatively low level (Fig. 38, Table 11, Morrison *et al.* 2004, Fig. 35). Crabs do not breed until 9-11 years of age (Shuster *et al.* 2003), and thus measures already taken or even a complete cessation of all further harvest, may not be reflected by an increase in the breeding population of horseshoe crabs for several years.




| | Port Mahon | Pickering | Kitts Hummock | North Bowers | Mispillion Inlet | Slaughter |
|---|---|---|---|---|---|---|
| 2002 | 15000 | 20500 | 4500 | 1341 | 323000 | 1500 |
| 2003 | 17000 | 2500 | 1597 | 948 | 181500 | 568 |
| 2004 | 53500 | 102000 | 27500 | 11000 | 378000 | 13500 |

Figure 37. Mean densities of horseshoe crab eggs in the upper 5 cm of sand from beach transects sampled once in late May and once in early June at six sites on the Delaware shore of Delaware Bay during 2002-2004 ordered from north (Port Mahon) to south (Slaughter Beach) (Weber 2003, 2004). At each site on each sampling date, 20 core samples were taken along each of two transects covering 83% of the distance between the nocturnal high tide line and the tidal flat. Only the means for both transects are given by Weber so confidence intervals are not available.

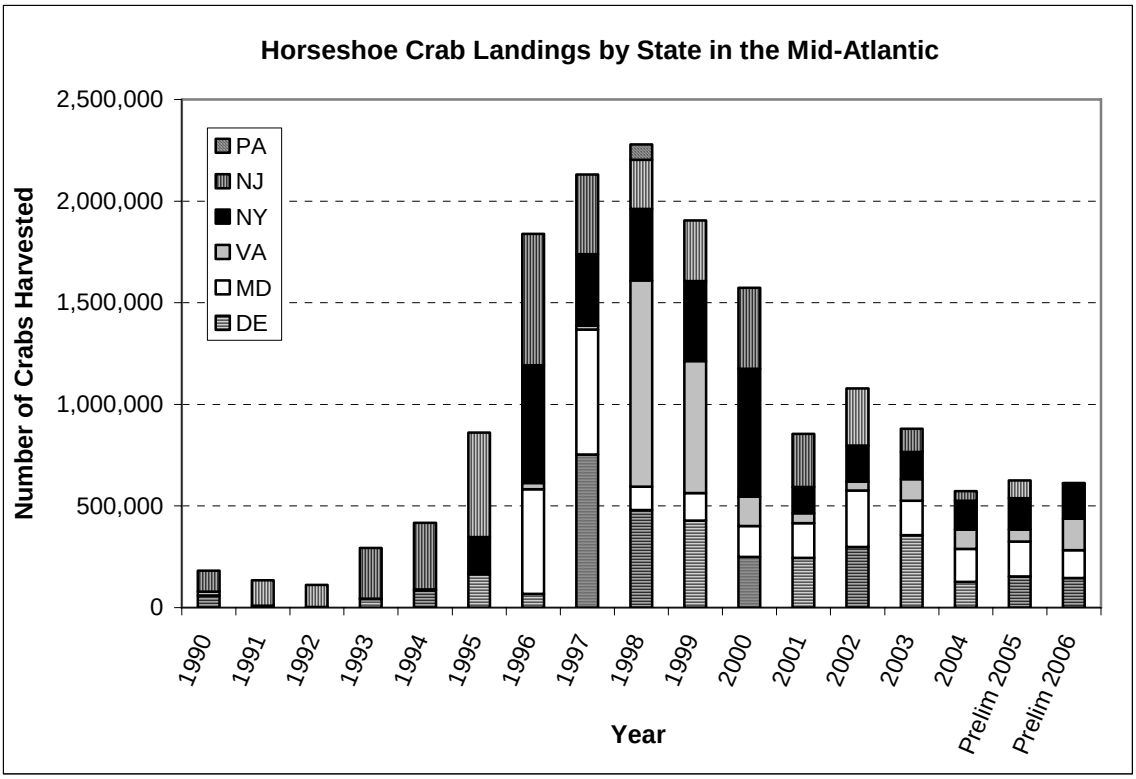



Figure 38. Annual landings of horseshoe crabs in Virginia, Maryland, Pennsylvania, Delaware, New Jersey and New York, 1990-2006 (see Morrison *et al.* 2004). Most states had mandatory reporting by 1996, all by 1998, so landings data prior to 1998 may be underrepresented.

Table 11. Annual landings of horseshoe crabs in Virginia, Maryland, Pennsylvania, Delaware, New Jersey and New York, 1990-2006.

| Year | NJ | DE | MD | VA | PA | NY |
|---|---|---|---|---|---|---|
| 1990 | 103,274 | 60,286 | 0 | 18,690 | 0 | 0 |
| 1991 | 125,305 | 0 | 0 | 8,989 | 0 | 0 |
| 1992 | 108,936 | 0 | 0 | 2,312 | 0 | 179 |
| 1993 | 249,562 | 42,250 | 0 | 1,476 | 0 | 0 |
| 1994 | 327,554 | 84,643 | 0 | 5,406 | 0 | 0 |
| 1995 | 514,810 | 165,464 | 0 | 7,354 | 0 | 173,280 |
| 1996 | 645,928 | 67,289 | 514,895 | 30,819 | 0 | 580,410 |
| 1997 | 393,213 | 753,204 | 615,211 | 19,063 | 0 | 350,968 |
| 1998 | 241,456 | 479,634 | 114,458 | 1,015,700 | 75,000 | 352,462 |
| 1999 | 297,680 | 428,980 | 134,068 | 650,640 | 0 | 394,026 |
| 2000 | 398,629 | 248,938 | 152,275 | 145,465 | 0 | 628,442 |
| 2001 | 261,239 | 244,813 | 170,653 | 48,880 | 0 | 129,074 |
| 2002 | 281,134 | 298,318 | 278,211 | 42,954 | 0 | 177,271 |
| 2003 | 113,940 | 356,380 | 168,865 | 106,577 | 0 | 134,264 |
| 2004 | 46,569 | 127,208 | 161,928 | 94,713 | 0 | 142,279 |
| 2005 | 87,250 | 154,269 | 169,821 | 59,865 | 0 | 155,108 |
| 2006 | 3,444 | 146,070 | 136,733 | 155,704 | 0 | 172,381 |

### *4. United States of America – Southeast*

In the southeastern United States, red knots forage along sandy beaches during spring and fall migration from Maryland through Florida and in Texas. During migration, red knots also use the tidal mudflats in Assateague Island National Seashore in Maryland and along the barrier islands in North Carolina (Cameron pers. comm. 2005, Therres pers. comm. 2005). In addition to the sandy beaches, red knots forage along peat banks for mussel spat in Virginia (Rice pers. comm. 2005, Truitt pers. comm. 2005, Watts pers. comm. 2005), and along small pockets of peat banks where the beach is eroding in Georgia (Winn pers. comm. 2005). Red knots in Florida also utilize salt marshes, brackish lagoons, and tidal mudflats, in addition to mangroves in southern Florida (Douglass pers. comm. 2005, Leary pers. comm. 2005, Sprandel *et al.* 1997). In Texas, migratory knots concentrate at the Bolivar Flats in Galveston County with smaller numbers on the outer beaches utilizing the tidal mudflats and salt marshes (Burkett pers. comm. 2005, Ortega pers. comm. 2005).

In Virginia, an invertebrate study was conducted in May 2000 (Truitt and Brown 2000). Nineteen days were spent in the field on Metompkin (12 days in peat bank habitat), Parramore (6 days in sandy beach habitat), and Fisherman Islands (1 day in sandy beach habitat); 105 core samples were collected for invertebrate analysis and counts were made of migratory red knots.

The peat banks of Metompkin Island had both the highest density and diversity of invertebrate species (Table 12). The blue mussel was by far the most abundant invertebrate with densities ranging from 33,000 to 181,000/$m^2$. Observations confirmed that the red knots were feeding on these mussels which covered the peat banks in dense mats. Other species noted in the core samples included six polychaetes, five amphipods, and one isopod.

Table 12. Total numbers of all benthic invertebrates collected during transect sampling on Metompkin, Parramore and Fisherman Islands, Virginia, in May 2000 (Truitt and Brown 2000).

| Transect | Substrate | Avg. # Inverts/Core Sample | Density/ $m^2$ | Dominant Sp. | Total # Species |
|---|---|---|---|---|---|
| MET1 | Peat | 1162 | 181,019 | *Mytilus edulis* | 12 |
| MET2 | Peat | 213 | 33,115 | *Mytilus edulis* | 7 |
| MET3 | Peat | 577 | 89,896 | *Mytilus edulis* | 10 |
| PARR1 | Sand | 60 | 9,285 | *Melitidae sp.* | 5 |
| PARR2 | Sand | 34 | 5,318 | *Melitidae sp.* | 5 |
| FISH1 | Sand | 16 | 2523 | *Parahaustorius* | 9 |
| FISH2 | Sand | 5 | 861 | *Parahaustorius* | 5 |

Of the three islands, Parramore had the least diversity, but the second highest density of invertebrates (Table 13). The Melitidae amphipods were by far the most abundant invertebrate species which suggests that they were the knots' main prey. However, observations could not confirm this as the birds held their heads underwater in the wash of the waves while probing.

Fisherman Island had the second highest diversity of invertebrates and the lowest density. The amphipod *Parahaustorius longimerus* was the most abundant, along with three other amphipods, two polychaetes, and two bivalves. Ash free dry weights were also the lowest among the three islands.

Metompkin Island offered the most food resources for knots in terms of ash free dry mass, while there was less at Parramore and least at Fisherman. This helps to explain the large numbers of knots observed at Metompkin during past aerial surveys. Without information on stopover times, it is impossible to estimate what proportion of the flyway knot population is supported by this island on migration, but it could be substantial. On 23 May 2005, a dusk count of the Hereford Inlet roost showed that there were 20,000 red knots in Delaware Bay. In the middle of the same day, an aerial count showed that there were 9,150 on the coastal islands of Virginia (Brian Watts pers.comm. 2006).

On Metompkin, the red knots roosted over high water on the beach adjacent to the peat banks. As soon as the banks became exposed, feeding activity began and continued for several hours. By half tide or just after, there was a marked decrease in feeding and most birds were observed preening, loafing, or sleeping. Usually, just before low water, many birds would fly off to the north at a time when the most peat and blue mussels were exposed. This suggests that feeding on blue mussels the birds are able to satisfy their food requirements remarkably quickly.

It is significant to note that none of the core samples from the three islands contained the Coquina clam *Donax sp.*, a common summer resident on many of the Virginia barrier islands. It is believed that in spring 2000, the red knot migration probably preceded this bivalve's seasonal migration from just offshore into the intertidal zone of the island beaches.

Table 13. Numbers of each invertebrate species counted during transect sampling on Metompkin, Parramore and Fisherman Islands, Virginia in May 2000 (Truitt and Brown 2000).

| Species List | Transect/ Number individuals | Transect/ Number individuals | Transect/ Number individuals |
|---|---|---|---|
| METOMPKIN: | 1M | 2M | 3M |
| Bivalves | | | |
| *Mytilus edulis (blue mussel)* | 16,047 | 3,224 | 7,410 |
| *Cyrtopleura costata (angel wing)* | 82 | 89 | 264 |
| Polychaete worms | | | |
| *Nereis succinea* | 43 | 85 | 191 |
| *Mediomastus ambiseta* | 26 | 0 | 3 |
| *Loimia medusa* | 0 | 1 | 1 |
| Chaetopteros piece | 0 | 0 | 1 |
| *Heteromastus filiformis* | 0 | 5 | 1 |
| *Capitellidae sp.* | | | |
| Amphipods | | | |
| *Jassa falcata* | 20 | 7 | 28 |
| *Caprela penantis* | 1 | 0 | 0 |
| *Eunice norvegica* | 1 | 0 | 0 |

Table 13. Continued

| Species List | Transect/ Number individuals | Transect/ Number individuals | Transect/ Number individuals |
|---|---|---|---|
| *Gammarus mucronatus* | 1 | 0 | 0 |
| *Erichthonius brasiliensis* | 13 | 0 | 0 |
| Isopods | | | |
| Cirolana sp. | 21 | 2 | 10 |
| Miscellaneous | | | |
| Fish larvae | 1 | 0 | 0 |
| Mollusk siphon | 1 | 0 | 0 |
| Gastropod sp. | 1 | 0 | 0 |
| Nemertean spp. | 3 | 0 | 4 |
| PARRAMORE: | 1P | 2P | |
| Bivalves | | | |
| *Cyrtopleura costata* | 57 | 27 | |
| Polychaete worms | | | |
| *Scolepsis squamata* | 32 | 21 | |
| Amphipods | | | |
| Melitidae sp. | 656 | 433 | |
| *Parahaustorius longimerus* | 7 | 1 | |
| Crustaceans | | | |
| *Emerita talpoida (mole crab)* | 2 | 4 | |
| FISHERMAN: | 1F | 2F | |
| Bivalves | | | |
| *Cyrtopleura costata* | 6 | 12 | |
| *Ensis directus (razor clam)* | 8 | 0 | |
| Polychaete worms | | | |
| *Scolepsis squamata* | 1 | 2 | |
| Lumbrinereis sp. | 1 | 0 | |
| Amphipods | | | |
| *Parahaustorius longimerus* | 222 | 63 | |
| *Trichophoxus epistomus* | 1 | 5 | |
| Haustorid sp. | 1 | 0 | |
| *Monoculoides edwarsi* | 1 | 0 | |
| Miscellaneous | | | |
| Nemertean spp | 1 | 0 | |

***5. Panama***

The Upper Panama Bay is a critical staging area for shorebirds during the spring. Red knots forage along the intertidal mudflats that extend several kilometers at low tide. They may also forage within mangroves and sandy beaches near Chitré (Buehler 2002).

***6. Brazil***

a. Maranhão

Maranhão is a migration stopover point during spring and fall for red knots. The knots forage on the sandy beaches and mudflats of Campechá Island in the Lençóis Bay and Coroa dos Ovos and Ingleses Island in the Turiaçú Bay. Knots also use extensive mangroves that permeate into the interior through the São Marcos Bay and the lower courses of several rivers. Among the important plant species are the red mangrove *Rizophora mangle, Avicenia germinans* and *Laguncularia racemosa*. The high primary productivity is important to migratory birds (Serrano unpublished information).

b. Lagoa do Peixe

Lagoa do Peixe National Park is one of the largest stopover grounds for North American migratory waterbirds in the South American continent. The lagoon naturally connects to the sea during winter through wind action, rain and accumulated water volume in the lagoon, and these processes are supplemented by pumping in summer. This maintains a constant influx of salt water which sustains a rich fauna of invertebrates all year round. During both northward migration in March-April and southward migration in September-October, red knots use the lagoon and the ocean beach for foraging. However, peak numbers have declined from around 10,000 in the mid-1990s to less than 1,000 in 2003 (see Population Size and Trends section of this review). In the lagoon, the knots' principal prey is the mud snail (*Littoridina australis*) (Serrano unpublished data).

***7. Argentina***

a. Pampas Region

In this region, available shorebird habitat is found along more than 1,200 km of shoreline from Buenos Aires, in the mouth of Río de la Plata estuary, to Punta Alta near Bahía Blanca.

Bahía de Samborombón and Bahía Blanca estuary contain extensive marshes and mudflats. Tide amplitude is low (2 m on average) and there are huge intertidal mudflats. South of Bahía de Samborombón (Punta Rasa), there are sandy beaches, and Laguna Mar Chiquita contains a shallow permanent brackish lagoon connected to the sea.

The highest numbers of red knots have been seen during spring migration on ocean sandy beaches backed by dunes southwards from Punta Rasa where the area has been heavily modified by urbanization to create appropriate conditions for tourism in summer (Ieno *et al.* 2004). Feeding studies showed that red knot's primary prey is the mud snail (Ieno *et al.* 2004).

b. Patagonian Shoreline

The Patagonian shoreline consists of the southern part of Buenos Aires Province coastline (south of Bahía Blanca) and includes Río Negro, Chubut, Santa Cruz and Tierra del Fuego Provinces. Critical feeding areas for red knots are associated with extensive sandy beaches and mudflats where the primary prey is clams (*Darina solenoides)* (Escudero *et al.* 2003, Hernández *et al.* 2003, Albrieu *et al.* 2004, González *et al* unpublished data), but also includes polychaetes (e.g. *Travisia olens*) (Hernández *et al.* 2003) and small crustacea (González *et al.* unpublished data). Other critical feeding habitats for red knots are the restingas (broad, wave-cut rocky platforms extending to the

lower intertidal zone) where they usually feed on blue mussels or *Brachidontes rodriguez*i (González *et al.* 1996, Escudero *et al.* 2003).

The entire Argentinian coast from Bahía Blanca to the Beagle Channel (Tierra del Fuego) contains sandy beaches and sandflats, mudflats, and restingas, which are often covered with a rich invertebrate fauna (Canevari *et al.* 1998). Gulfs and embayments are important coastal features, and the Patagonian (Tehuelche) gravels form beaches along the shoreline and occur in many places such as the area surrounding Península Valdés and in the southern part of the Golfo San Jorge. Restingas are found in many areas below cliff beaches near San Antonio Oeste.

During high tide, foraging areas are usually covered by water and knots roost along the upper shore of beaches, sandbars and shellbars, marshes, and other expansive coastal areas above high tide line.

***8. Uruguay***

The coastline of Uruguay was searched as part of the South American Atlas project in the mid 1980s; no red knots were found there (Morrison and Ross 1989). Recent enquiries indicate that knots are recorded in Uruguay very infrequently and in only low numbers (González unpublished information).

**E. Winter Habitat**

**1. *United States***

As explained in the Taxonomy section of this review, the subspecific status of the red knots that winter on the west and northeast coasts of Florida and on the coast of Georgia, South Carolina, and Texas is uncertain. Therefore, on the basis that this population might be *rufa* we present the following description of the habitats it occupies.

From South Carolina through Florida, red knots winter along sandy beaches. They may also utilize peat banks in Georgia and salt marshes, brackish lagoons, tidal mudflats, and mangroves in Florida. In Texas, wintering knots occur along sandy beaches on Mustang Island and other outer beaches and tidal mudflats and salt marshes on Bolivar Flats.

**2. *Chile***

Bahía Lomas is the main wintering area of *C. c. rufa* in South America (Morrison and Ross 1989, Morrison *et al.* 2004). It is located near the east entrance of the Straits of Magellan on the northern coast of the main island of Tierra del Fuego (52°28’08’’S; 69°22’54’’W) (Fig. 39) and mainly dominated by intertidal mudflats, which tend to be smooth and sandy towards the edges and highly channelled towards the middle (Fig. 40). The flats extend for about 50 km and on spring tides the intertidal distance reaches 7 km in places. The substrate of the bay comprises a large area of mud slopes with channels that diminish towards low water (Fig. 41).

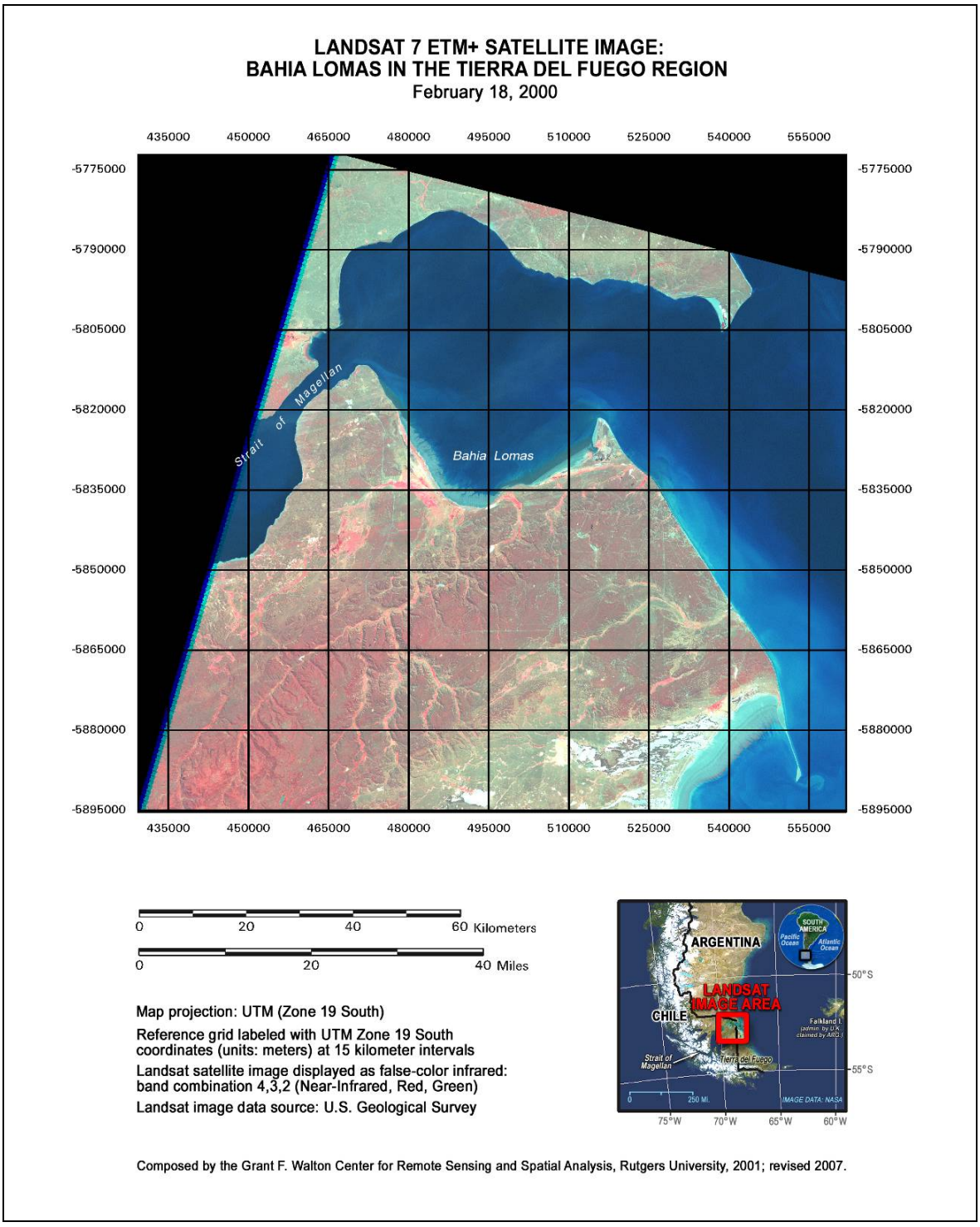



Figure 39. Location of Bahía Lomas in Tierra del Fuego, Chile.

Figure 40. Bahía Lomas tidal flat at low tide (Antonio Larrea).

Figure 41. Bahía Lomas tidal flat at high tide; the dark line at the water's edge is a large roosting flock of red knots and Hudsonian godwits (Antonio Larrea).

Since 2003, an on-going ecological study has been conducted on the tidal flats of Bahía Lomas. The main objective has been to determine the composition, distribution and abundance of the benthic community with special reference its trophic relationship with the red knot wintering population. The results indicate that the flats are dominated by three invertebrates: the mollusc *Darina solenoides*, an amphipod, and a polychaete (Table 14). Although each has its own characteristic distribution with respect to tide level, they all tend to increase in abundance towards low water. Of the three species, the bivalve *Darina solenoides* is the most abundant (Fig. 42) and stable isotope analysis shows that wintering red knots are mainly assimilating carbon and nitrogen present in that species (Fig. 43). Therefore *Darina* would appear to be the knots' main prey at Bahía Lomas, just as might be expected in view of the prey taken by knots worldwide (Piersma 1994).

Table 14. Invertebrates recorded in transect sampling at Bahía Lomas and the relative abundance of each.

| | N | % |
|---|---|---|
| **Mollusca Bivalvia** | | |
| *Darina solenoides* | 1815 | 51.3 |
| Bivalvia 1 | 3 | 0.1 |
| **Mollusca Gastropoda** | | |
| Gastropoda 1 | 4 | 0.1 |
| Gastropoda 2 | 3 | 0.1 |
| **Polychaeta** | | |
| **Paraonidae** | | |
| Paraonidae 1 | 875 | 24.8 |
| **Phyllocidae** | | |
| *Eteone* sp. | 331 | 9.4 |
| **Nephtyidae** | | |
| *Aglaophamus* sp. | 13 | 0.4 |
| **Opheliidae** | | |
| *Travisia* sp. | 13 | 0.4 |
| *Euzonus* sp. | 29 | 0.8 |
| **Spionidae** | | |
| *Scolelepis* sp. | 23 | 0.7 |
| *Scolecolepides* sp. | 165 | 4.7 |
| **Glyceridae** | | |
| *Glycera* sp. | 1 | 0.03 |
| Polychaeta 1 | 11 | 0.3 |
| **Crustacea** | | |
| Isopoda 1 | 13 | 0.4 |
| Amphipoda 1 | 178 | 5.0 |
| Amphipoda 2 | 1 | 0.03 |
| **Others** | | |
| Insecta | 3 | 0.1 |
| Insect larvae | 20 | 0.6 |
| Nematoda | 20 | 0.6 |
| Nemertea | 11 | 0.3 |
| Unidentified | 3 | 0.1 |

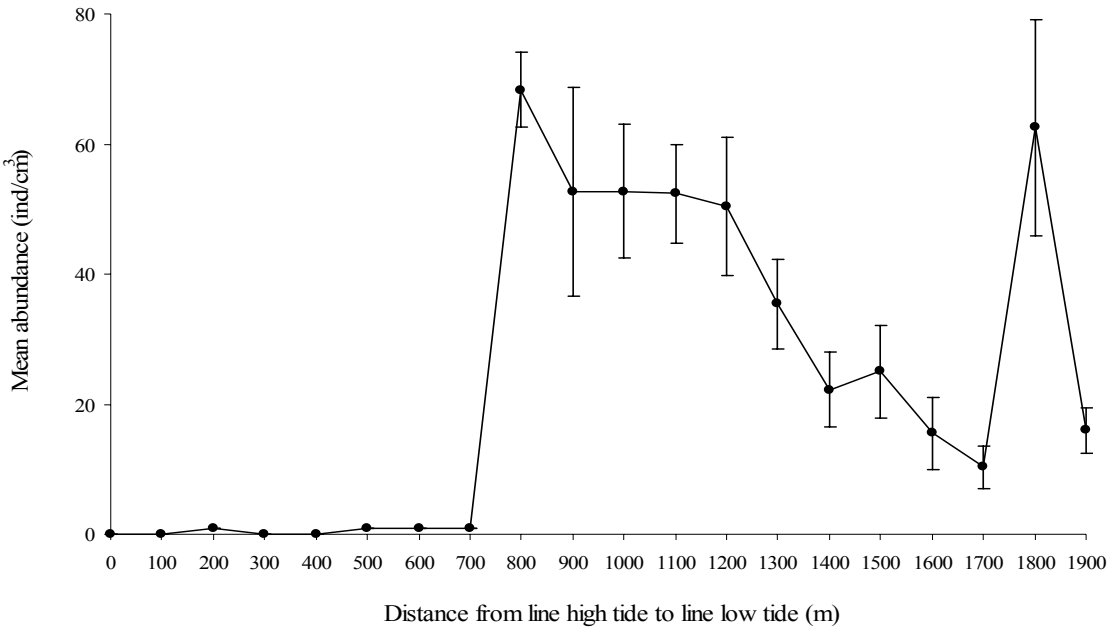



Figure 42. The distribution pattern for *Darina solenoides*

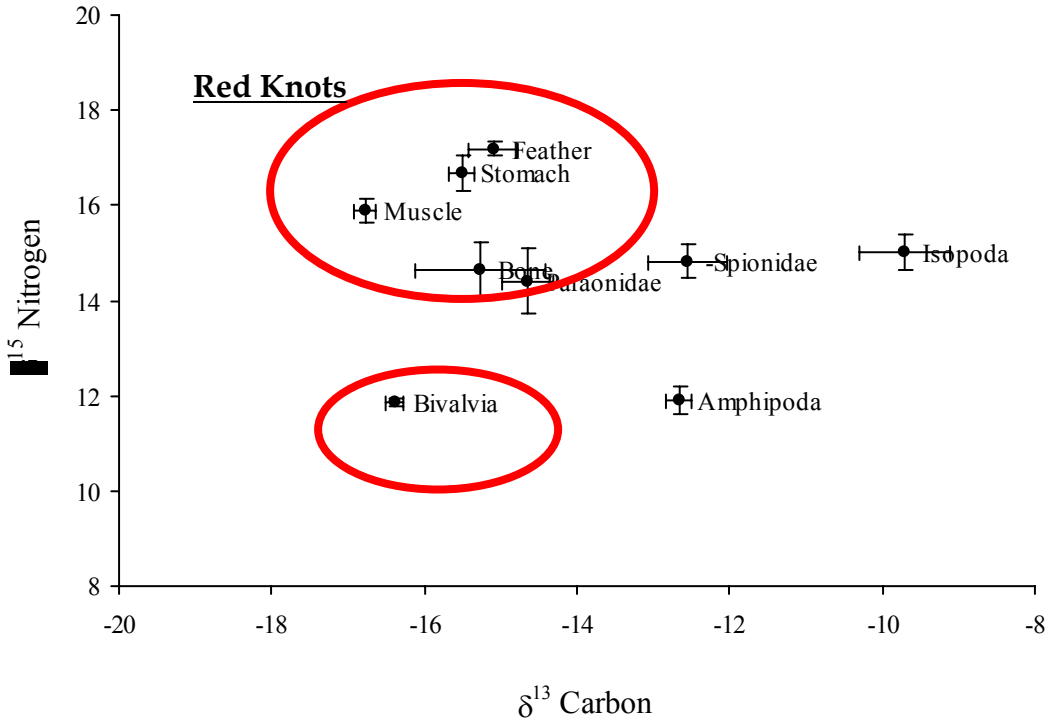



Figure 43. Nitrogen and carbon assimilated by red knots from ingested *Darina solenoides* (Espoz unpublished information)

### *3. Argentina*

Wintering red knots in Argentina are now largely confined to Bahía San Sebastián and Río Grande in the Province of Tierra del Fuego. Knots feed mainly within the mudflats of Bahía San Sebastián and along sandy beaches, mudflats, and restingas in Río Grande (González unpublished data).

### *4. Brazil*

The main wintering area of red knots winter in Brazil is in the coast of the state of Maranhão where they forage along sandy beaches, tidal mudflats, and mangroves (Serrano unpublished data).

### *5. Panama*

A small number of red knots winter in the Upper Panama Bay where they utilize the soft, silty mud in the tidal mudflats near Panama City (Buehler 2002).

## VII. POPULATION SIZE AND TRENDS

In breeding habitats, red knots are thinly distributed across a huge area of the Arctic, where we have no comprehensive understanding of breeding density or productivity. It is thus necessary instead to rely on surveys in primary wintering and stopover areas as the basis for monitoring population change. Fortunately the *C. c rufa* population of the red knot is one of the best studied long-distance migrant shorebird populations in the world, with surveys taking place in nearly all of the key sites used along its 15,000 km flyway. These give us a reasonably complete picture of its critical habitat throughout the flyway. The surveys have also identified a number of problems in population structure that need to be taken into account in the assessment of population change.

### A. Red Knot Populations of the Americas

The primary wintering area of the *rufa* subspecies of the red knot is now restricted to three sites on the main island of Tierra del Fuego (Morrison and Ross 1989, Morrison *et al.* 2004). In recent years, about 70% of the population has been found in just one bay, Bahía Lomas in Chilean part of the island, with most of the remainder at Río Grande in the Argentinian part with smaller numbers at Bahía San Sebastián (Fig. 44). In the mid 1980s, this population numbered 67,000 and the wintering area extended northwards along the Argentinian coast from Tierra del Fuego to Río Negro province. Now, the population is not only confined to Tierra del Fuego but has decreased to only 17,211 in 2006.

During migration to its Arctic breeding grounds, *rufa* stop over in Delaware Bay in late May and numbers counted there have fallen in broad correlation with those in Tierra del Fuego. However, recent studies have shown that knots from two other wintering areas also migrate through Delaware Bay. These are the populations that winter in the southeast of the United States (mainly Florida) and Maranhão, northern Brazil (Atkinson *et al.* 2005), the subspecific status of which is uncertain (see Taxonomy section).

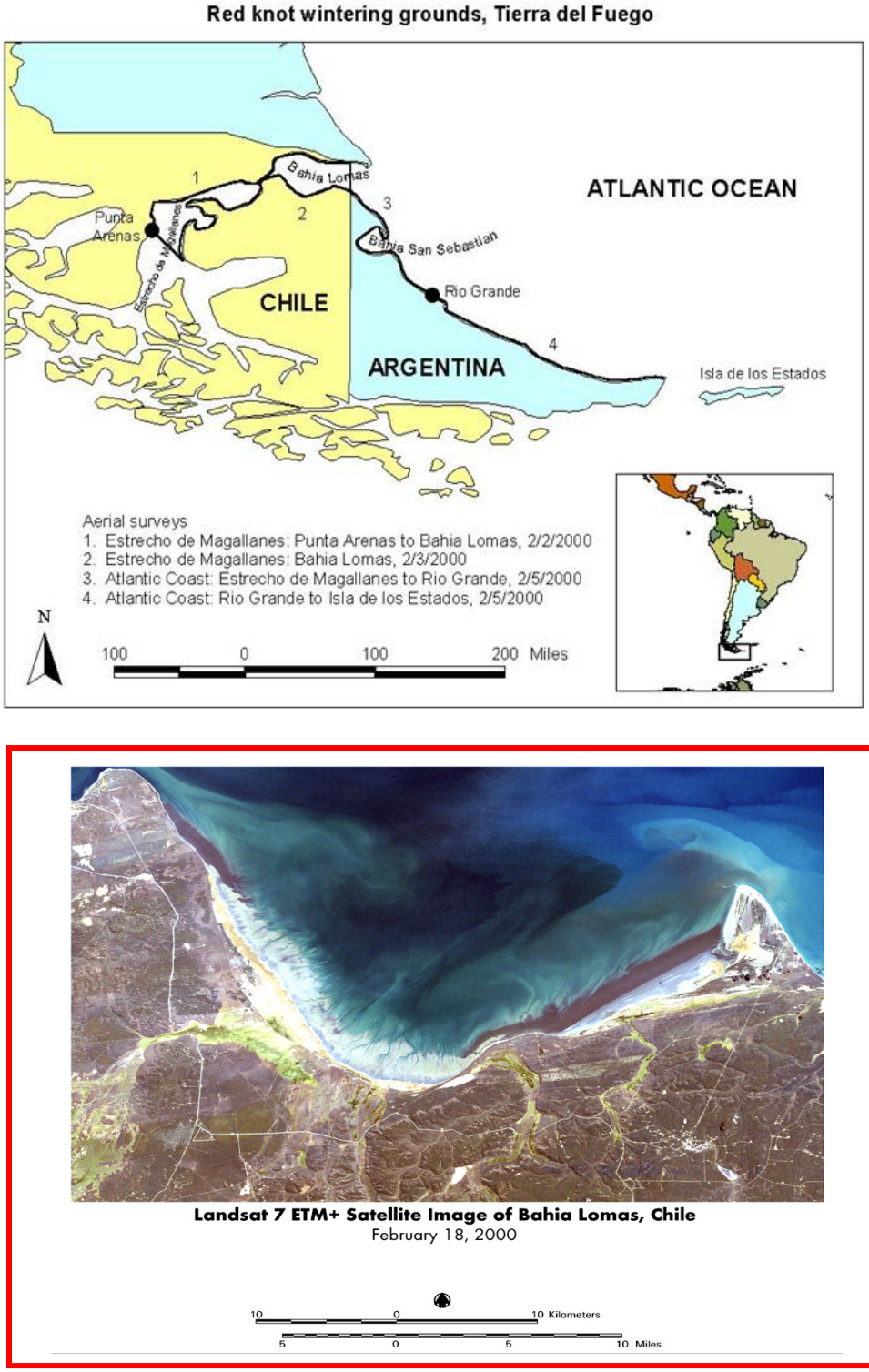



Figure 44. Tierra del Fuego (top), the primary wintering grounds of *C. c. rufa*, and Bahía Lomas, Chile where approximately 70% of the population is currently found.

The knot population that winters mainly on the west coast of Florida was counted by aerial surveys in the 1980s, and was variously estimated at between 6,500 and 10,000 (Morrison and Harrington 1992) and 4,500 (Sprandel *et al.* 1997). The most recent estimate is 7,500 birds based on a count of 7,000 knots in South Carolina (April 2003) and 4,000 to 5,000 in one area in western Florida (November 2004) (Harrington unpublished data). There is also recent evidence that this population may move with available resources as far north as the coast of Georgia and the winter population there can vary from hundreds in some years to a maximum of 5,000 in others (Winn pers. comm. 2005). There is no reliable evidence of trend for the Florida wintering population. The count data are very erratic from year to year, probably because of the difficulty of finding knots along Florida's greatly fragmented coastline. All that can be said is that there is no evidence of a major change in the size of the population and that it is probably still of the same order of magnitude as it was in the 1980s. Counts in Cape Romain National Wildlife Refuge, South Carolina, indicate declines in the number of knots on passage in both spring and late summer-fall (Fig. 45). It is not known to which wintering population or populations these birds belong. Possibly they are from the Tierra del Fuego population that has shown a clear decline, as described above.

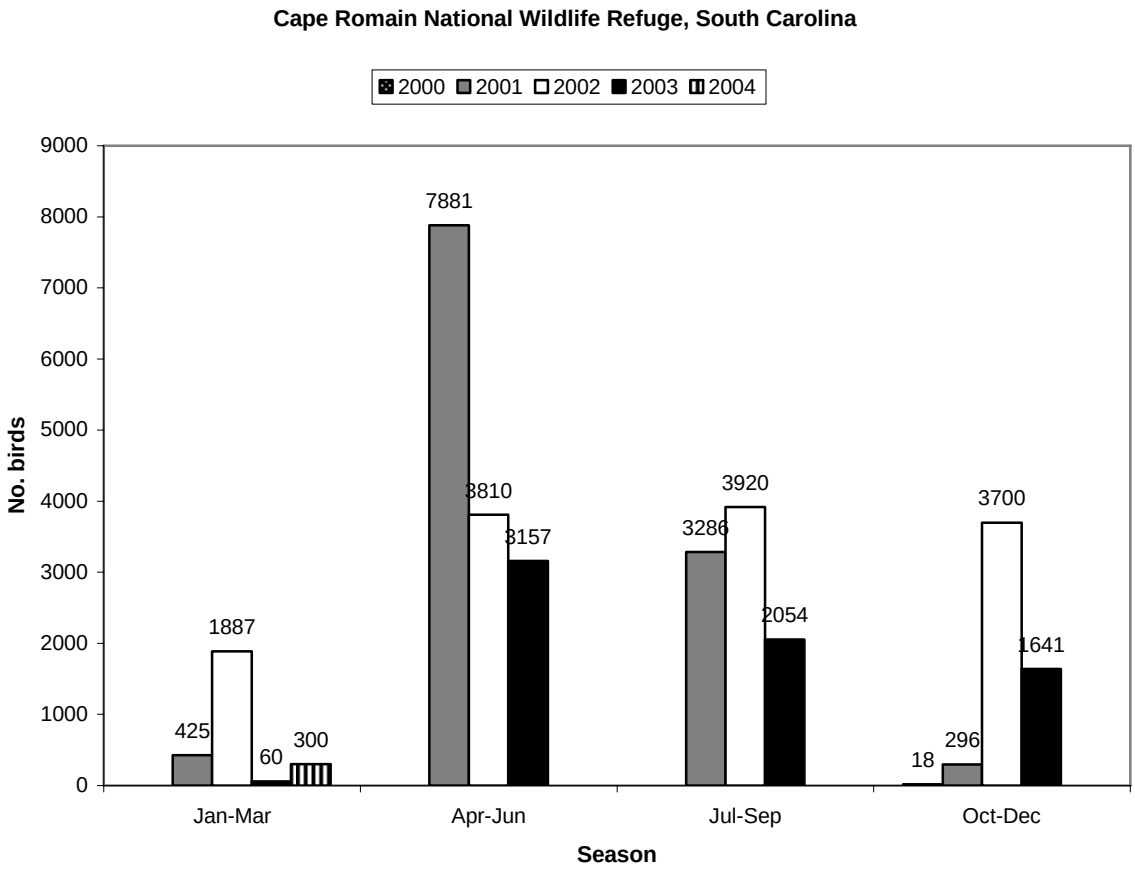



Figure 45. The number of red knots counted at Cape Romain National Wildlife Refuge, South Carolina, 2000-2004 (Source Cape Romain NWR; South Carolina DNR).

The population wintering in the Maranhão region of Brazil was surveyed in February 2005 with a count of 7,575 (Baker *et al.* 2005a), which is only slightly below the 8,150 recorded by Morrison and Ross (1989) in the mid 1980s. However, the 20-year gap between surveys means that there could have been trends that have not been detected.

In view of current uncertainties about the subspecific status of the northern wintering knots, they are here treated as distinct biogeographic populations and considered separately so far as is possible. *C. c. rufa* breeds in the central and eastern Canadian Arctic, and birds wintering in southern South America are referable to this race. However, it is unclear where the Florida and Maranhão birds breed or whether they are referable to *rufa* or *roselaari* or even a hitherto undescribed subspecies. Color banding and the isotope signature of flight feathers show that substantial numbers (though probably not all) of the birds that winter in both Maranhão and the southeast U.S. pass through Delaware Bay during spring migration along with the birds from Tierra del Fuego (Atkinson *et al.* 2005). Isotope signatures from Southampton Island (Atkinson, unpublished) suggest that some of the knots nesting there are from the northern-wintering roup, but birds with the orange flags of the Argentinian (Tierra del Fuego) population have also been seen on the same island at East Bay (P.A. Smith pers. comm. 2006).

If the southeast U.S. and Maranhão birds are *roselaari*, the implication is that at least some of them migrate from their wintering areas to Delaware Bay and then to Alaska. Isotope signatures of Alaskan birds (N. Clark unpublished data, Atkinson unpublished data) do not support this view. Furthermore, this would seem to be an unlikely scenario because the distance between Florida and Alaska is almost the same as the distance between Delaware Bay and Alaska (but both are well within the capability of red knots for a non-stop flight (Weber and Houston 1997) and Delaware Bay is on an approximate great circle route between Maranhão and Alaska). Therefore the flight from Florida to Delaware Bay would seem unnecessary. However, the possibility that Alaska-bound birds take such a circuitous migration route should not be discounted because it could have arisen in view of what is known about red knot evolution (see Taxonomy section). Another factor that might have led to or maintained such a migration route is the existence of an abundant food resource in Delaware Bay in the form of horseshoe crabs' eggs. Therefore the 5,000-6,000 km cross-continent flight might have been possible from Delaware Bay but not from Florida.

*C. c. roselaari* certainly use the Pacific coast flyway and at least some winter in California and Baja California (Tomkovich 1992, Page *et al.* 1997, Page *et al.* 1999, Paton *et al.* 2003). However, it has also been suggested that knots wintering in Florida conceivably may include *C. c. roselaari* and that they use a mid-continent route to reach breeding areas in Alaska (Harrington 2001). However, there is no good evidence to support or refute this idea.

Color-banding shows that there is little or no interchange between the knots that winter in Maranhão and Tierra del Fuego or between Florida and Tierra del Fuego. There is no evidence of interchange between Florida and Maranhão, but there have been insufficient observations (few knots marked in Maranhão) to accept this as verified.

Isotope analysis of primaries from 16 knots caught in Alaska in spring shows that almost certainly they did not molt in Florida (N. Clark unpublished data, Atkinson unpublished data). However, although this is inconsistent with *roselaari* molting and

wintering in Florida, it is not proof that they do not because at 35,000-50,000 (Wetlands International 2006) the Alaska population is much greater than the 7,500 wintering in Florida. Therefore, as most of the Alaskan birds must winter elsewhere, a much greater sample than 16 will be necessary before there can be any confidence that none go to Florida.

Isotope analysis of primary coverts taken from red knots nesting in the main *rufa* breeding area on Southampton Island, Hudson Bay, showed a southeast U.S. (or possibly northern Brazil) signature. This confirms that at least some birds wintering in that area are *rufa* (Atkinson unpublished data, Peck unpublished data).

Until the taxonomic uncertainties are resolved, the possibility remains that the Maranhão and Florida wintering populations include unknown numbers of *roselaari* as well as an unknown proportion of *rufa*. This complicates the assessment because the trend and population size of *roselaari* are uncertain. The estimate for *roselaari* in the U.S. Shorebird Conservation Plan (Brown *et al.* 2001) of 150,000 is based on counts in the 1970s and 1980s is probably a gross overestimate of the population at the time it was published. Current estimates at 35,000-50,000 are much lower (Wetlands International 2006). However, without systematic surveys it is uncertain whether there has been a decline in the *roselaari* population. It is likely that all knots using the Pacific flyway are *C. c. roselaari*. However, counts on the U.S. Pacific coast from California to Washington reported by Page *et al.* (1999) of 9,035 in spring, 7,981 in fall and 4,813 in winter during 1988-1995 suggest that that flyway comprises no more than about 10,000 birds. It is therefore very difficult to account for even the current *roselaari* estimate of 35,000-50,000 birds in winter, if it is true that they all winter in the Americas. This is especially so if it were shown that the Florida and Maranhão wintering populations are all *rufa* as some of the evidence would seem to suggest.

In summary, there are five known major wintering sites used by >1,000 red knots in the New World. These support a combined total of about 45,000 individuals (Table 15). To this figure a few small populations elsewhere can be added (e.g. 100 in the Upper Bay of Panama in Feb 2002 (Buehler 2002)) and possibly some in western Venezuela where there were 520 in the mid-1980s (Morrison and Ross 1989). Allowing for some error in counts and estimates, and the fact that some counts are not recent, it would seem unlikely that the total is less than 40,000 or more than 50,000.

Assuming that the figures in Table 15 are accurate and discounting small numbers elsewhere, then, depending on whether the populations of uncertain subspecies are all *rufa* or all *roselaari*, the population of these two subspecies can range from a *rufa* population of 17,653 to 35,728 birds and a *roselaari* population of 9,035 to 27,110 birds. This does not take account of the fact that the Alaskan population, assumed to be *roselaari*, has been estimated at 35,000-50,000 (Wetlands International 2006). However, as discussed below, there is the possibility that many of the Alaskan birds are not *roselaari* but *rogersi*.

Table 15. Recent population estimates of red knots wintering in the New World

| Location | Population | Recent trend | Date | Subspecies | Data source |
|---|---|---|---|---|---|
| Tierra del Fuego | 17,653 | Major decline | Jan 2005 | *rufa* | Morrison unpublished data, Ross pers. comm. 2005 |
| Maranhão, northern Brazil | 7,575 | Slight decline | Feb 2005 | uncertain | Baker *et al.* (2005a) |
| Florida | 7,500 | Not known | 2004/05 winter | uncertain | Harrington unpublished data |
| California, Mexico and possibly farther south | 9,035[1] | Not known | spring 1988-95[1] | *roselaari* | Page *at al.* 1999 |
| Texas coast | 3,000 (300)[2] | Probable decline | 1985-1996 (Jan 2003)[2] | uncertain | Skagen *et al.* 1999 |
| **Total** | 44,763 | | | | |

[1] The figure of 9,035 represents the maximum spring count along the main U.S. Pacific coast during 1988-1995 and probably includes both migrants and wintering birds. Winter counts alone produced 4,813 in the United States 1988-95 (Page *et al.* 1999) and 1,082 in Baja California (Page *et al.* 1997). Presumably the remaining 3,000 winter elsewhere in Mexico or further south.

[2] Inquiries suggest that the Texas coast wintering population may now be as little as 300, but there has been no recent census.

## B. Population Size and Trends in *C. c. rufa*

### *1. Wintering Population Trends*

The uncertainty about the numbers of *roselaari* and the areas in which it winters is in strong contrast to what is known about the *rufa* population of Tierra del Fuego. That population has been counted there several times since the mid 1980s and (mixed with birds from Florida and Maranhão) every year from 1986 to 2005 as it passes through Delaware Bay as well as at several sites in between. It is the decline in this distinct biogeographic population that is of primary concern.

Aerial counts during December to early February within the main *rufa* wintering area in southern South America have shown catastrophic decline over the 20 years, 1985-2005. The birds are thought to be relatively sedentary at this time of the year so there should be little possibility of double counting or missing those that have not yet arrived or have already departed. Moreover the same observers and survey techniques were used for all the aerial counts in South America. Surveys in the main non-breeding areas are the main method of population estimation for red knots recommended by the *U.S. Shorebird Conservation Plan* (Brown *et al*. 2001).

In the mid 1980s, the southern wintering *rufa* population numbered 67,546 and was found along 1,600 km of the Atlantic coast from Tierra del Fuego to Río Colorado in northern Patagonia (Morrison and Ross 1989). By 2006, numbers had fallen to 17,211

and almost the entire population was confined to Tierra del Fuego (Fig. 46). Within Tierra del Fuego, the largest numbers (at least 70% of the population) have always occurred at Bahía Lomas. There the count fell by about 50% (from over 45,000 to just over 20,000) between 2000 and 2002, remained stable in 2003 and 2004, but then fell again by a further 50% to less than 10,000 in 2005 (Fig. 47). In Tierra del Fuego as a whole, numbers fell from over 51,000 in 2000 (compared with 53,000 in the 1980s) to the 27,000-31,000 range between 2002 and 2004, and only 17,211 in 2006 (Fig. 46). By 2003, Bahía Lomas held 84% and the combined core areas 98% of all knots counted over the entire wintering range in southern South America. The most recent decreases have occurred mainly in the numbers at Bahía Lomas. At Río Grande in the Argentinian part of Tierra del Fuego, aerial counts show that the population has remained relatively stable at 3,500-5,000 (Fig. 46) though ground counts in November have shown a drop from 6,000 in 2000 to 4,000 in 2004 (Baker *et al.* 2005a). Knots have almost disappeared from wintering sites outside of Tierra del Fuego on the Patagonian coast of Argentina, falling from over 14,300 in the 1980s to 790 in 2004 (Morrison *et al.* 2004, Morrison unpublished data) (Fig. 46). This is reflected in surveys at all other sites in Patagonia where knots have occurred during the past 20 years, with 14 out of the 18 sites occupied in 1985 having none in 2004-2005. In the same period, the population of Hudsonian godwits (*Limosa haemastica*) which also spends the northern winter in Tierra del Fuego but takes the mid-continent flyway to breeding sites in Arctic Canada, remained stable (Morrison unpublished data, Ross pers. comm. 2005).

Banding studies in Tierra del Fuego invariably show a low proportion of juveniles and it is thought that most winter further north (Baker *et al.* 2005b). Therefore the aerial counts of the Tierra del Fuego wintering population will underestimate its true size to the (probably marginal) extent that not all of the juveniles are included.

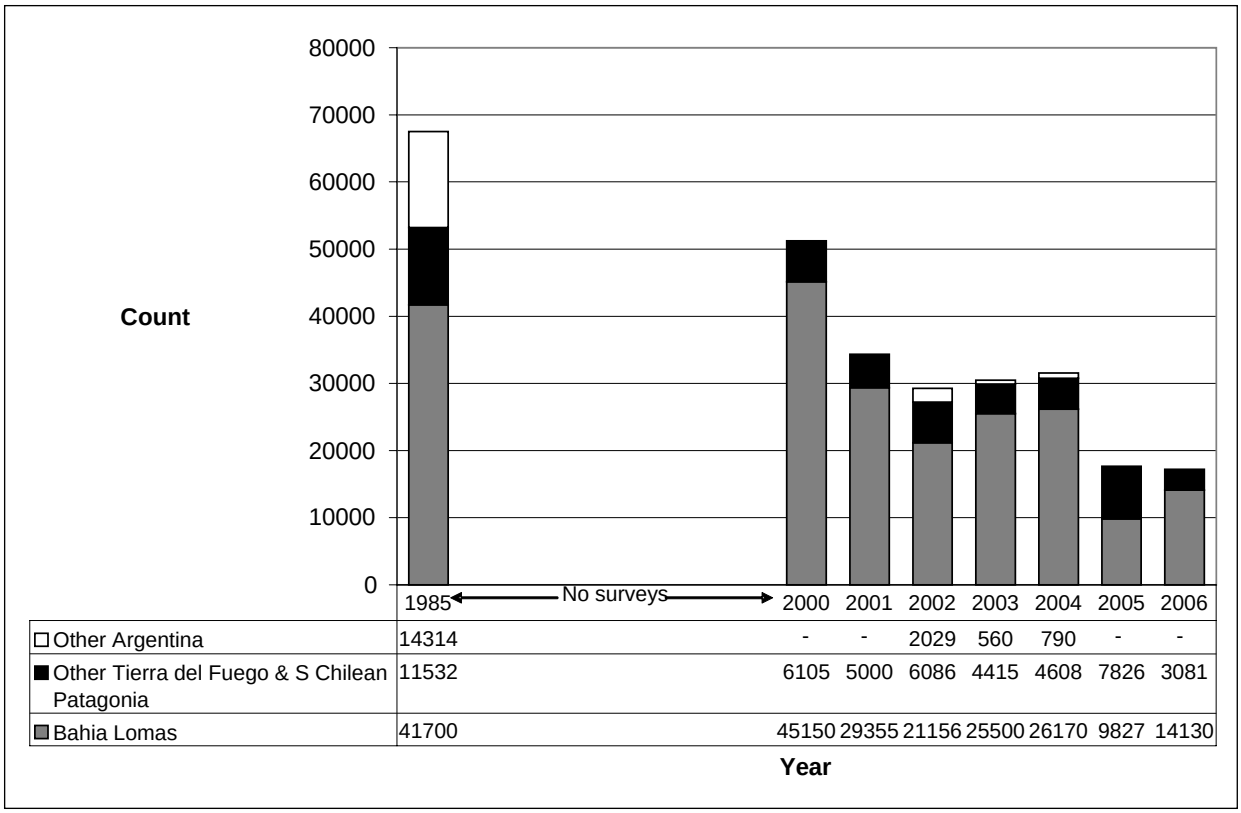



Figure 46. The number of red knots spending the austral summer in southern South America according to aerial counts made during the *Atlas of Shorebirds* project in 1985 (Morrison and Ross 1989) and during 2000-2006. Grey sections are numbers at Bahía Lomas, black other sites in Tierra del Fuego (mainly Río Grande) and Southern Chilean Patagonia and white other sites further north along the coast of Argentina. No counts were made north of Tierra del Fuego in 2000, 2001 or 2005 because reports by ground observers (e.g. Ferrari *et al.* (2002), Escudero *et al.* (2003)) showed that very few knots wintered at any of the sites at which they had previously been reported.

### *2. Passage Population Trends*

The decline observed in wintering populations is also reflected in surveys of knots at all major stopover sites along the coast of South America. At Bahía San Antonio, where surveys of passage birds are made during March and April, numbers have fallen from 15,000-20,000 in 1990-1997, to 7,000-12,000 in 1998-2002, to 5,000-6,500 in 2003-2005 (Fig. 47). Similar declines have been recorded at Península Valdés (Bala *et al.* 2001, Bala *et al.* 2002, Hernández *et al.* 2004). In Brazil, yearly counts at Lagoa do Peixe fell from a high of 10,000 in 1996 to 5,500-7,000 in 1996-1999, and 900-1,500 in 2001-2003 (Fig. 47). Taken together, these results support the conclusion that the Tierra del Fuego wintering population has declined significantly.

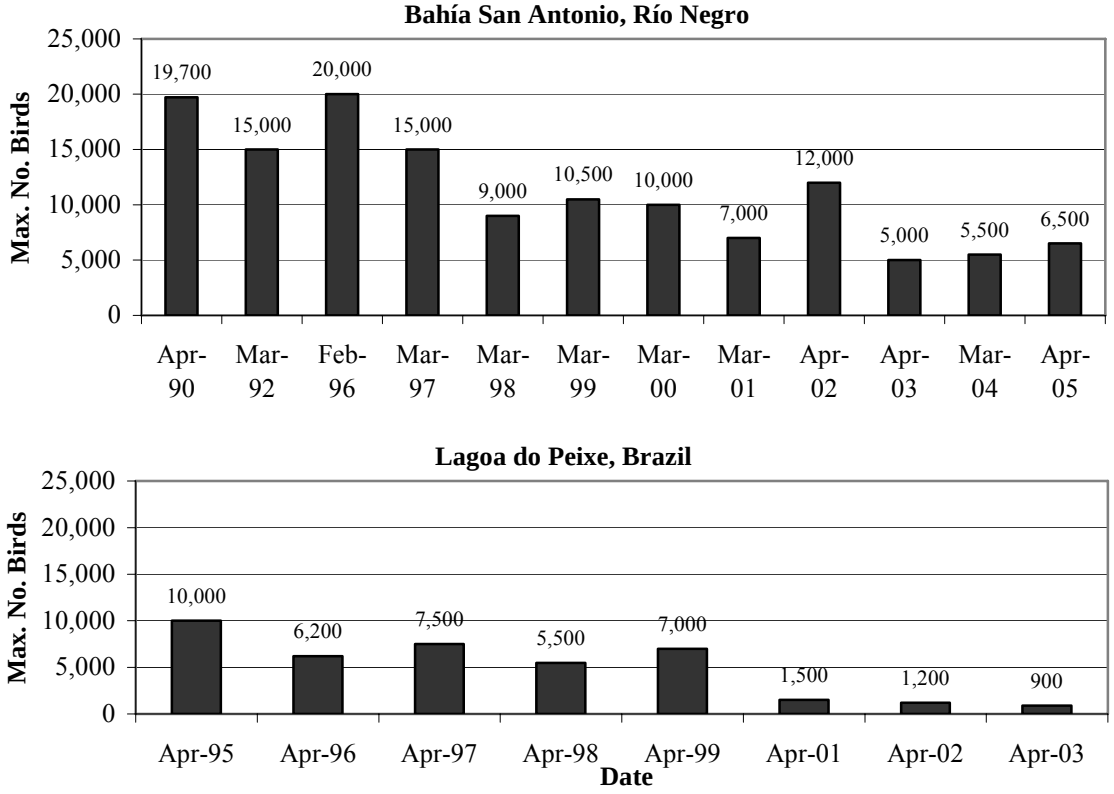



Figure 47. Peak numbers of red knots during northward passage at Bahía San Antonio, Argentina 1990-2005 (González unpublished data) and Lagoa do Peixe, Brazil 1995-2003 (Serrano unpublished data). Counts at Bahía San Antonio were mostly carried out on a weekly basis throughout February to April. Counts at Lagoa do Peixe were obtained during expeditions that covered the peak spring passage in April.

There have been no regular systematic surveys of knots at any site further north in South America, either on passage or during the northern winter. Baker *et al.* (2005a) found no evidence of decline in knots wintering in Maranhão, though this was based on just two counts 20 years apart (in 1985 and 2005). In South Carolina, the USFWS carried out annual surveys in Cape Romain National Wildlife Refuge during 2000-2004 (Sanders pers. comm. 2005) (Fig. 45). These show a decline in passage birds similar to that seen in South America with numbers dropping from a March-April high of over 7,000 in 2000 to a low of 3,157 in 2004. Southbound knots also declined from over 3,000 in 2001 and 2002 to 1,641 in 2003.

The longest running survey is the Delaware Bay Aerial Shorebird Survey that was started in 1982-1983 by the New Jersey Audubon Society and has been carried out from 1986 to the present by the NJDFW-ENSP (Fig. 48, Clark *et al.* 1993, K. Clark unpublished data). The survey covers both shores of the bay and takes place under similar tidal conditions each week for the six weeks of the stopover period. Every effort has been made to ensure even and consistent coverage. This has been achieved partly by keeping to the same methodology and partly by minimizing turnover of personnel. In fact the key role of counter has been fulfilled by the same person (K. Clark, NJDFW-ENSP) since 1986.

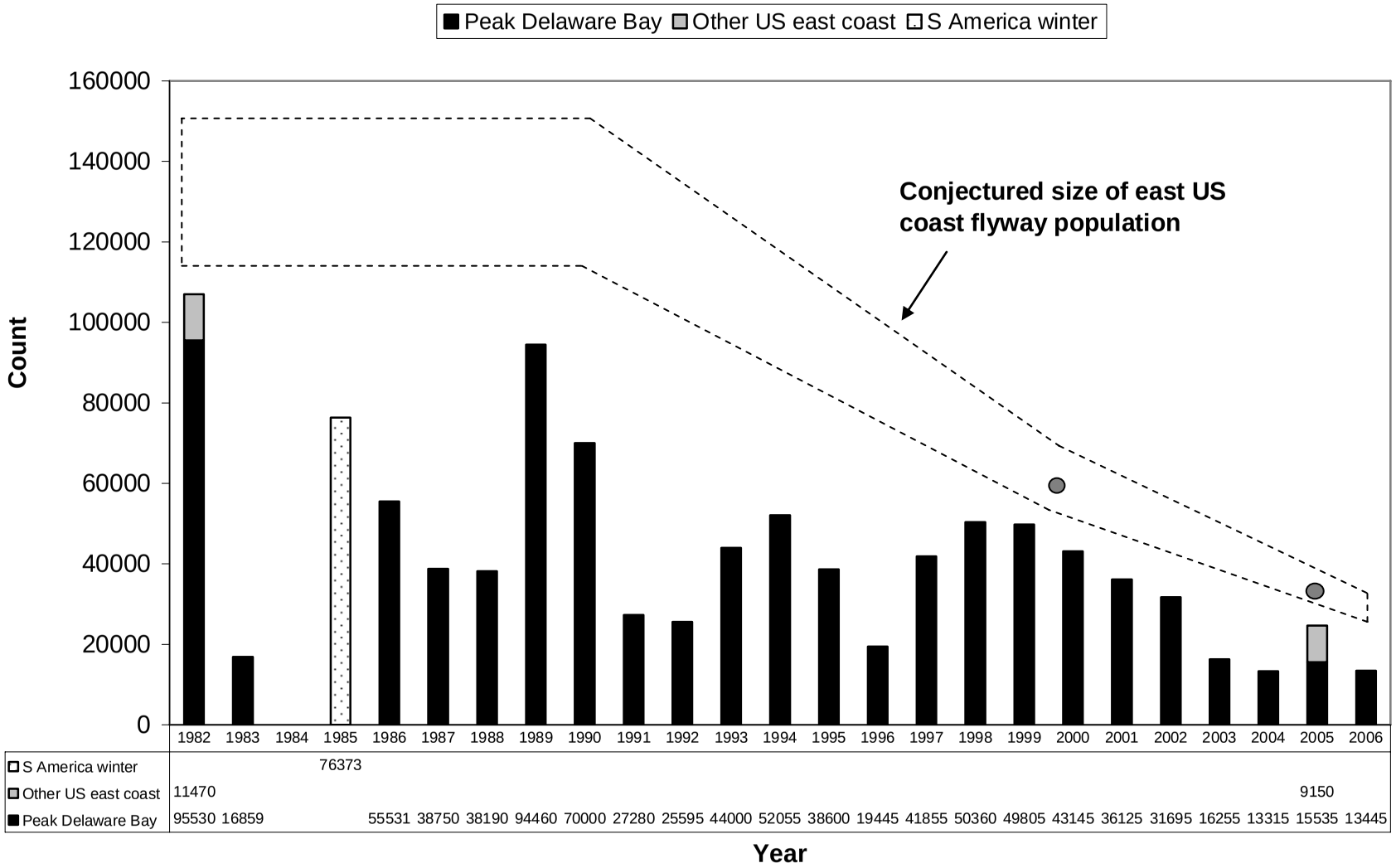



Figure 48. Peak counts of red knots in Delaware Bay May 1982-2006 as shown by weekly aerial counts. Source: New Jersey Audubon Society (1982-1983), NJDFW-ENSP (1986-2005). Also shown are simultaneous counts from other U.S. East Coast sites (mainly Virginia), the 1985 S. America winter count (Morrison and Ross 1989), our conjectured estimate of the size of the total U.S. east coast flyway population (range enclosed by dashed lines) and the estimates of the flyway population in 1999 of 60,000 (Baker *et al*. 1999a) and in 2005 of 32,728 (Table 15) shown by gray dots (also see text).

The Delaware Bay Aerial Shorebird Survey is not a total census, as it does not cover the adjacent Atlantic Coast of New Jersey or the intertidal marshes of Delaware Bay (Fig. 49). Moreover the peak count does not represent the total flyway population because of turnover (some birds may not have arrived, others may have departed). In 2004, for example, Gillings *et al.* (in prep.) estimated that, due to turnover, approximately 24,000 red knots passed through the Delaware Bay, despite the peak count being only 13,315 (Fig. 48). It is also likely that turnover rates have varied as the birds have responded to changes in the quantity of food. Overall, turnover rates were probably higher during 1986-1996 when horseshoe crab eggs were abundant than subsequently because of decreased egg availability. Higher turnover in the early years may be the reason for the greater volatility in peak numbers when compared with more recent years (Fig. 48).

Figure 49. Flight path of aerial surveys along the Delaware Bay conducted by the New Jersey Division of Fish and Wildlife.

In 1982 and 1989, the number of knots in Delaware Bay reached peaks of 95,530 and 94,460 respectively. Although peak counts in the intervening years were lower and in some years surprisingly few, there is no reason to suppose that the population declined. In

1985 when there was no aerial survey in Delaware Bay, for example, the South America count (mainly the far south and Maranhão) was 76,373 to which can be added whatever population was then wintering in Florida. Since the early 1990s, however, the aerial survey has documented a steady decline with only 13,445 in 2006 (Fig. 48).

Included in Fig. 48 are counts made simultaneously with the Delaware Bay peak elsewhere on the east coast of the U.S. (mainly in Virginia). The dashed lines represent our conjectured estimate of the flyway population and indicates the range over which we considered the population fluctuated as well as the broad trend. Included is the estimate of 60,000 for 1999 by Baker *et al.* (1999a) and the aggregate counts for the three main wintering populations (Tierra del Fuego, Maranhão and Florida) of 32,728 set out in Table 15.

Until the late 1990s, the peak aerial counts in Delaware Bay were quite erratic from year to year (Fig. 48). Many of these changes are so big that they cannot have reflected changes in the total population because they are demographically impossible. Moreover they are also far too large to be due to counting error. At this stage we can only speculate about the reasons. Possibly high availability of horseshoe crab eggs led to rapid turnover, leading to a reduction in the count; conversely bad weather may have prevented birds from departing leading to a build-up. It is also possible that in some years many birds exploited food resources, such as *Donax* or mussel spat, elsewhere along the Atlantic coast and did not visit Delaware Bay.

Our conjectured estimate of the east U.S. coast flyway population is based on the peak aerial counts in Delaware Bay, counts elsewhere along the U.S. east coast, the 1985 and 2000-2005 aerial counts in Tierra del Fuego, and the counts in Florida and Maranhão referred to above. It also takes into account the fact that peak counts will almost invariably underestimate total stopover population because of turnover (Gillings *et al.* in prep.).

In the past, it has been assumed that all the knots stopping over in Delaware Bay in May are *rufa*. This is no longer certain, but the fact that a large proportion of the birds that pass through Delaware Bay are *rufa* from southern South America is suggested by the fact that the stopover population and the southern South America wintering populations have shown similar declines (Fig. 48). However, recent studies using carbon and nitrogen isotope ratios of feathers (Atkinson *et al.* 2005), and resightings of birds marked from other wintering areas, have shown that approximately half the birds caught in Delaware Bay in 2004 and 2005 were from the Tierra del Fuego wintering population (Fig. 50). The remainder were from the more northerly wintering areas in Florida and Maranhão, Brazil.

The literature includes various estimates for the *rufa* population in the 1980s and early 1990s in the range 100,000-150,000 (Harrington *et al.* 1988, Morrison and Harrington 1992). These estimates were all made on the assumption that *rufa* includes all birds passing through Delaware Bay, i.e. those wintering in Maranhão and Florida as well as Tierra del Fuego which are consistent with the information presented in Fig. 49. Later, however, Morrison *et al.* (2001) suggested that *rufa* numbered as many as 170,000 around the turn of the century by including 18,700 using the Interior Flyway. This is presumably why the same figure is mentioned in the *U.S. Shorebird Conservation Plan 2001* (Brown *et al.* 2001). However, this figure appears to have been an over-estimation by a factor of almost three. There are two reasons: (1) Baker *et al.* (1999a) had already

published a much reduced estimate of only 60,000, and (2) the figure of 18,700 is the sum of maximum counts for all sites along the Interior Flyway for January to June (Skagen *et al.* 1999), which might involve duplication.

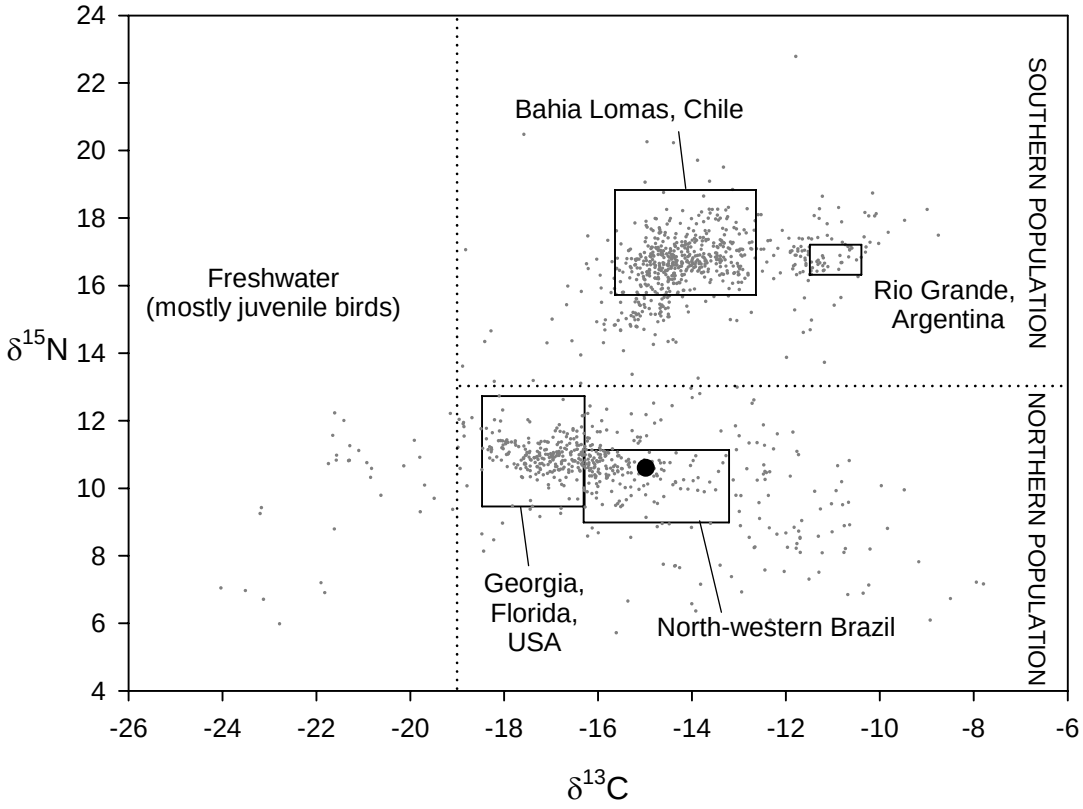



Figure 50. Stable isotope signatures of primary coverts taken from 1,150 red knot on spring migration through Delaware Bay in May and June 2004 (Atkinson unpublished data). Boxes mark the 90% confidence intervals of birds of known wintering origin. The large dot represents the signature of a tertial taken from a bird nesting on Southampton Island, Nunavut, Canada. Dotted lines show the approximate separation between juvenile birds (with a freshwater Arctic signature) and the northern and southern wintering populations.

Baker *et al.* (2004) showed that the reason the Tierra del Fuego population fell by almost 50% between 2000 and 2002 (Morrison *et al.* 2004) (Fig. 46) was because adult survival declined from an average of 85% in 1994-1998 to only 56% during 1999-2001. They also calculated trends in the population that could be expected if survival either recovered to 85% (Fig. 51a, the "best case scenario") or remained at 56% (Fig. 51b, the "worst case scenario"). Subsequent counts during 2003-2005 (added to Fig. 51b) show that although the population held up in 2003-2004, the sudden drop to only 17,653 in 2005 brought it right back towards the track of the worst case scenario, indicating an increased risk of extinction within the next decade.

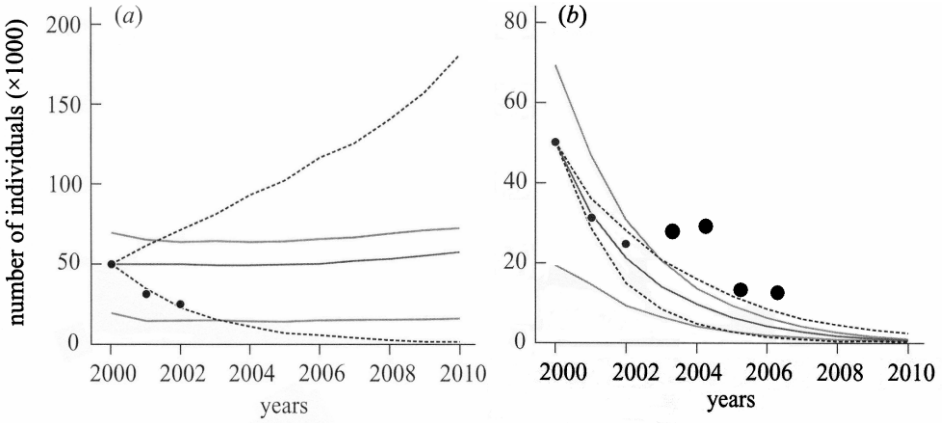



Figure 51. Predicted population trends and associated 95% confidence limits of adults (dashed lines), juveniles (lower gray line) and both combined (top gray line) for 10 years from 2000, with (a) constant adult survival of 85% and juvenile survival being half that of adults ($\lambda = 1$) and (b) constant adult survival of 56% and juvenile survival being half that of adults ($\lambda = 0.66$). The small dots represent the aerial censuses of the over-wintering flock of adults in Tierra del Fuego during 2000-2002, and the large dots are the counts during 2003-2006. The 95% upper and lower confidence limits are based on 1,000 bootstrap iterations. Modified from Baker *et al.* (2004) and published in this form in Baker *et al.* (2005a).

Since Fig. 51(b) was first published, it has been the subject of some misinterpretation. Therefore, it is emphasized that its purpose was to demonstrate the consequences of adult survival remaining as low as 56% and not recovering. It assumes constant adult survival, but all studies show that in the real world adult survival varies from year to year. Thus there is no expectation that it will remain fixed at any particular value. The fact that the 2003 and 2004 counts were above the 95% confidence limits means that survival was more than 56%; the sudden drop in 2005 suggests that survival was much less than 56%. Therefore although Fig. 51(b) predicts possible extinction as early as 2010, the year of extinction is unknowable, neither is extinction certain. The relevance and value of the model is that, combined with the recent counts, it shows that the current population trend is one that carries a considerably increased risk of extinction unless there is effective short term conservation action.

### *3. Breeding Area Population Trends*

Although knots can occur in huge flocks, during the breeding season they are spread out thinly across a vast area of the arctic tundra. From 2000 to 2004, the NJDFW-ENSP conducted regular annual surveys of the density of knot nests in a 9.2 $km^2$ study area on Southampton Island, Hudson Bay (Fig. 52 and 53). This showed a decline from 1.16 nests per $km^2$ in 2000 to 0.33 in 2003 followed by a slight increase to 0.55 in 2004 (Fig. 54). American golden plovers (*Pluvialis dominica*) nest commonly in the same study area but their numbers remained stable (Fig. 54). Golden plovers take the mid-continent flyway to South American wintering areas and do not migrate through Delaware Bay.

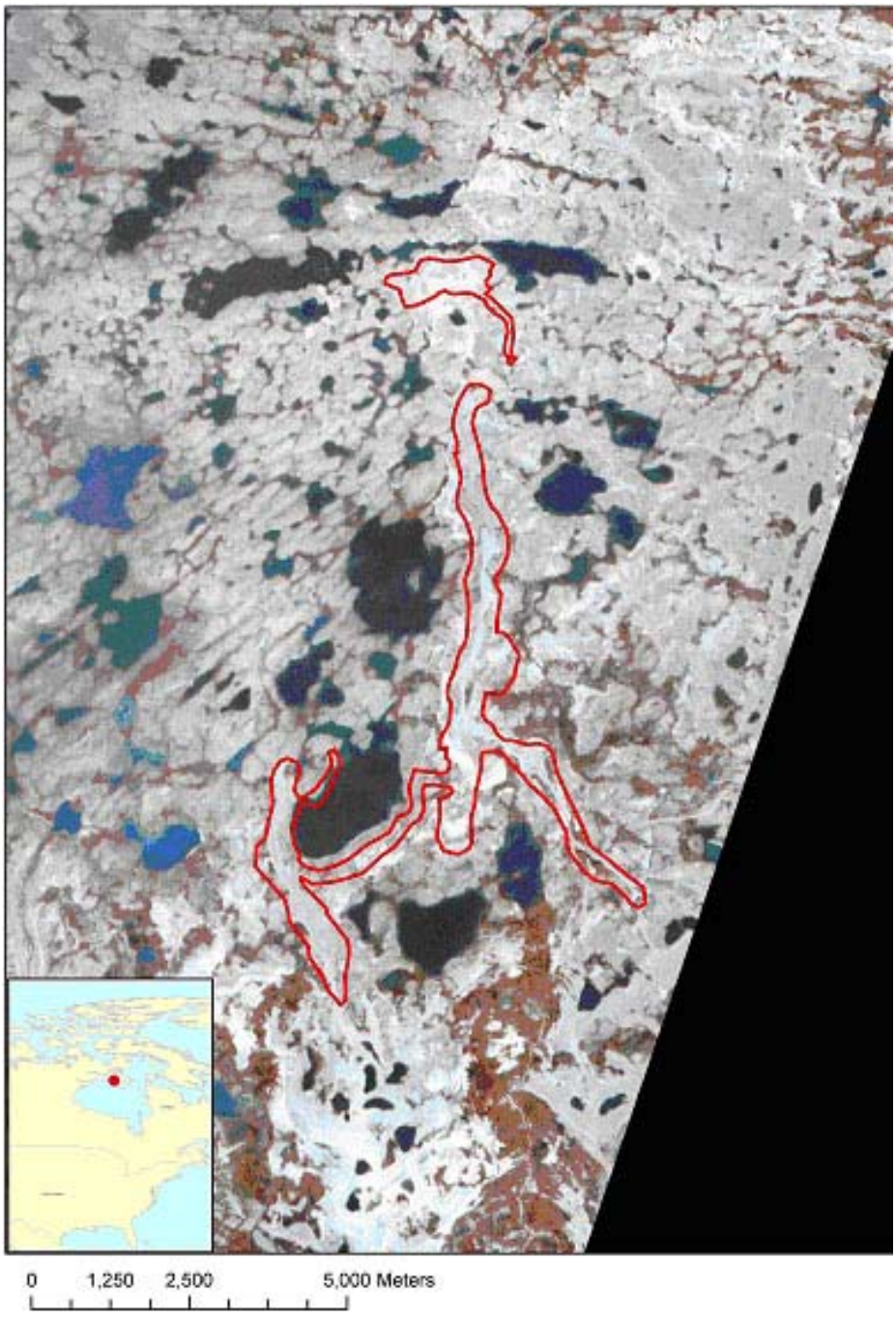



Figure 52. Study site on Southampton Island, Nunavut, Canada.

Figure 53. Scientists performing "sweeps" surveys for red knot nests in the Canadian Arctic (New Jersey Division of Fish and Wildlife).

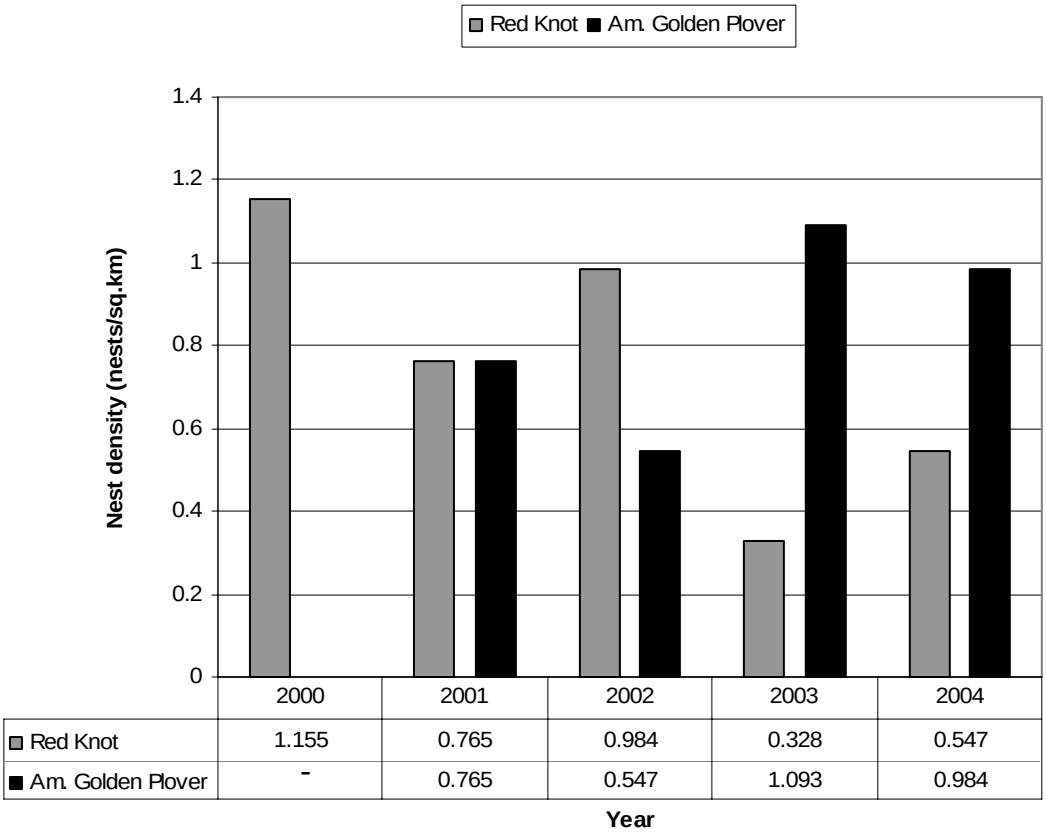



Figure 54. Density of the nests of red knots and American golden plovers in a 9.2 $km^2$ study site on Southampton Island, Nunavut, Hudson Bay, Canada during 2000-2004. American golden plovers were not included in the survey until 2001.

**C. Summary of Population Trends**

Shorebird life-history traits comprise low fecundity (clutch size ≤4 eggs, high nest failure, only one brood per year), delayed maturity and high annual survival (70-90%) (Sandercock 2003). In these respects, the red knot is an exemplar of a shorebird. As with most Arctic-breeding species, productivity is generally low and in some years can be virtually zero. Productivity depends on the weather, especially its effect on the chicks' thermoregulation requirements and the availability of their invertebrate food, and predator abundance. The latter tends to be cyclic with a 3-4 year period that is closely tied to the abundance of lemmings (Underhill *et al.* 1993). Years when there are few lemmings and many predators can be extremely unproductive for knots. However, predator cycles are usually not uniform across all breeding areas so most years there is generally some production of young.

To some extent, periodic changes in the numbers of knots may be related to arctic breeding conditions. However, other shorebird populations that breed in the same areas of the Arctic as knots have experienced these conditions, but, at least during 2000-2004 in a small study area on Southampton Island, have not shown the same recent, sharp decline (Fig. 54) as knots. Therefore, although some changes in knot populations can be ascribed to arctic breeding conditions, they are unlikely to be the primary cause of the recent declines.

Climate change is predicted to have adverse consequences for many arctic-breeding shorebirds (Rehfisch and Crick 2003). However, no study has yet shown an impact of climate change on red knot populations worldwide.

Intensive studies of *C. c. rufa* throughout the West Atlantic Flyway only began in 1997 by which time the population had already dropped from the 100,000-150,000 reported in the 1970s and 1980s to close to the 60,000 estimated in 1999 (Baker *et al.* 1999a). Therefore we have little information as to what caused this initial decline. Studies since 1997 have shown:

- the majority of the populations that winter in Tierra del Fuego, Maranhão and Florida pass through Delaware Bay during northward migration.
- the Tierra del Fuego population has suffered major decline, but there has been no discernible trend of decline in the birds from Florida or Maranhão.
- a major reduction in the survival of the Tierra del Fuego population from an average of 85% during 1994-1998 to 56% during 1998-2001 coupled with lower rates of recruitment (Baker *et al.* 2004) was responsible for the decrease in the Tierra del Fuego population from over 50,000 in 2000 to 30,000 in 2002-2004.
- continued low survival exacerbated by poor arctic productivity was likely responsible for the further fall in the Tierra del Fuego population from 30,778 in January 2004 to 17,653 in January 2005 (Atkinson unpublished data).
- birds caught in Delaware Bay in May at a low weight during 1998-2002 had significantly lower survival than birds caught at a higher weight (after controlling for the general increase in weights that takes place during the stopover) (Baker *et al.* 2004).
- between 1997 and 2003, the proportion of well-conditioned knots in Delaware Bay around the normal departure date at the end of May declined by 70% (Baker *et al.* 2004)

- in recent years, especially in 2003 and 2005, substantial numbers of Tierra del Fuego birds have arrived in Delaware Bay later than usual.
- since about 1996 there has been an order of magnitude decline in the availability of horseshoe crab eggs in Delaware Bay (as detailed elsewhere in this review).

Worldwide, studies of arctic-breeding shorebirds show that declining populations are often associated with food supply problems at the final spring stopover (International Wader Study Group 2003). Although the precise reason or reasons for the decline in the Tierra del Fuego *C. c. rufa* population are not entirely clear, there has been a major reduction in the availability of horseshoe crab eggs in Delaware Bay, a critical migration staging site used for refueling prior to the knots' last leg of migration to the Arctic.

**D. Population Size and Trends of *C. c. roselaari***

*C. c. roselaari* is thought to breed in Alaska and on Wrangel Island and winter in the Americas, whereas *C. c. rogersi* breeds in northeast Siberia, mainly the Chukotski Peninsula and winters in Australasia (Tomkovich 1992). *C. c. roselaari* are slightly larger than *C. c. rogersi* and more intensely colored in breeding plumage on the belly and under-tail coverts.

In the 1980s, the number of red knots seen on spring migration in Alaska was reported to be of the order of 150,000 birds (Morrison *et al.* 2001). Analysis of the carbon and nitrogen isotope signatures of flight feathers from 16 adult specimens taken during this time indicated that birds molted in two very different regions and, compared to known wintering areas on the eastern seaboard of the Americas, were most similar to habitats found in Tierra del Fuego and northwestern Brazil, i.e. a temperate region and a tropical/subtropical region. However, without further data it is not possible to determine the location of those regions; e.g. the temperate region could be in Australasia (Atkinson unpublished data). More recently, numbers appeared to have dropped to 20,000 (Morrison *et al.* 2006a). The *U.S. Shorebird Conservation Plan 2001* (Brown *et al.* 2001) states that *roselaari* numbers 150,000. As with *rufa*, this appears to be a major over-estimate of numbers at the time it was published in 2001.

If all knots seen in Alaska are *C. c. roselaari* and if all *roselaari* winter in the Americas, then it is very difficult to account for them in winter – either in the 1980s, when there were 150,000, or today. In the mid-1980s, Morrison and Ross (1989) carried out an aerial count of shorebirds along the entire coast of South America. The only significant numbers of knots recorded were the 67,500 *C. c. rufa* between Tierra del Fuego and Río Negro province, Argentina, and the 8,100 of uncertain status in Maranhão, Brazil. Farther north, there is no evidence that numbers wintering along the Pacific coast of the U.S. and Mexico ever exceeded more than about 10,000, with another 10,000 in Florida and perhaps 5,000 in Texas. These figures total approximately 100,000. Subtract the definite *rufa* population and only about 33,000 knots are left that could contribute to the 150,000 *roselaari* once thought to occur in Alaska. Similarly, if the present *roselaari* breeding population is 35,000-50,000, it is only possible to account for 9,000-27,000 in the Americas in winter (Table 15). It seems that any of the following hypotheses could explain this situation:

H1: Many of the birds seen in Alaska in spring are not *C. c. roselaari* but *C. c. rogersi* (which migrate to Australasia). If so, the current *C. c. roselaari*

population may be only the 9,000-27,000 suggested by winter counts. If the *C. c. roselaari* population numbers only 9,000, that subspecies may be even more threatened by the risks associated with small populations (such as extinction through stochastic events and the accumulation of harmful genetic mutation (International Wader Study Group 2003)) than *C. c. rufa*.

H2: Part of the *C. c. roselaari* population winters outside the Americas; if so, no one knows where.

H3: Major *C. c. roselaari* wintering grounds in the Americas remain to be discovered.

The resolution of which wintering populations are *C. c. roselaari* and which are *C. c. rufa* is important for the effective conservation of both subspecies, especially if one or the other turns out to far less numerous than has previously been supposed. Stable isotope analyses of feathers from Australasian wintering areas are a priority to determine whether staging Alaskan birds are likely to be *C. c. roselaari*, *C. c. rogersi* or a mix of both.

**E. Geographic Area Summaries**

The Geographic Area Summaries in this section discuss location of, and factors affecting, important red knot non-breeding (wintering) and migratory stopover areas in South America, United States and Canada. These accounts include detailed maps of critical and suitable habitats for red knots (see Appendix).

Identifying critical stopover/wintering sites for red knots is an important part of this status assessment. These maps represent current knowledge of areas known to be important migratory stopover and/or wintering habitats and will serve as a starting point for conservation action.

These important habitats are classified as "Critical" or "Suitable" according to the following criteria:

"Critical" habitats (red) are:

1) sites of known importance for red knots and are documented by survey
2) sites of known importance by expert opinion, and may or may not have survey data available
3) sites of known importance that are occupied intermittently (because of naturally fluctuating food resources, human disturbance, beach replenishment, etc.), and may or may not have survey data.

"Suitable" habitats (green) are:

1) sites of known importance that are occupied intermittently, may or may not have survey data, and are deemed by expert opinion as secondary sites not critical to the persistence of the red knot population at its current population level -- these sites may become critical if the red knot population increases
2) sites that were historically used by red knot but are now unused although the habitat has not been altered -- these sites may become critical if the red knot population increases.

### *1. South and Central America*

a. Chile

Red knots visit the coast in the Southern Hemisphere from October to March and are often observed in flocks of over 2,000 birds (Morrison and Ross 1989, Harrington and Flowers 1996) (Fig. 55). However, since the main flyway is along the Atlantic coast, red knots are a rare visitor in most parts of Chile with just a few sightings at Arica (18ºS), Río Huasco river mouth (29ºS), Valparaiso (33ºS), Río Maipo river mouth (33ºS), Yali wetland (33ºS) and Chiloe Island (42ºS) (Araya and Millie 1996, Couve and Vidal 2003). Although the flyway follows the Atlantic, the final destination for the majority of knots is in Chile; specifically Bahía Lomas on the north coast of the main island of Tierra del Fuego (56ºS) where 41,700 were recorded in 1985 (62% of the whole population of southern South American at the time) (Morrison and Ross 1989). Since then, the total population and the numbers at Bahía Lomas have declined. By 2005, the site held only 9,827 or 56% of the southern population (Morrison unpublished data, Ross pers. comm. 2005) (Fig. 56).

Figure 55. Flock of red knots in Bahía Lomas, Tierra del Fuego, Chile (Antonio Larrea)

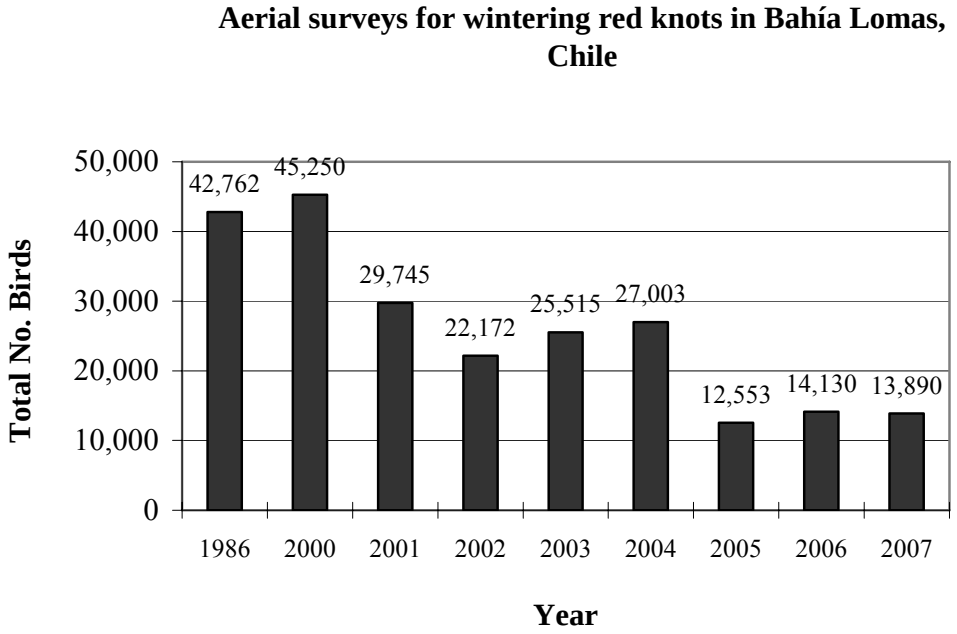



Figure 56. Total counts from aerial surveys of red knots done in Bahía Lomas, Tierra del Fuego, Chile.

b. Argentina

In Argentina, *C. c. rufa* occur during migration and the austral summer in tidal wetlands distributed along the Atlantic shore. They spend more than seven months of the year (September through April) in Argentina, but some individuals (mainly juveniles) can also remain during May and the austral winter. Counts at these sites mirror the severe decline of the population in recent years, and indicate that the birds have contracted into the main sites in Tierra del Fuego.

i. Wintering Area Numbers – 1980s

Aerial censuses conducted by the Canadian Wildlife Service along the Patagonian coasts (January 1982) and in Tierra del Fuego (Chile: 29 January 1985; Argentina: 1 February 1985) reported a total of 67,496 red knots of which 24,734 were in Argentina: 10,470 in the Argentinian coast of Tierra del Fuego and 14,264 in the continental Patagonian coast (Morrison and Ross 1989). Small numbers (tens to one hundred) were reported to spend the austral summer in Bahía Samborombón, at Punta Rasa and along the shores of Buenos Aires Province (Myers and Myers 1979, Blanco *et al.* 1992, Morrison and Ross 1989).

ii. Wintering Area Numbers – 1990s

No aerial censuses were carried out in the 1990s, but in the 1994-95 season a capture-recapture survey was conducted which estimated the total population that winters south of San Antonio Oeste at 74,193 knots with a 95% confidence range of 51,398-111,573 (González *et al.* 2004). At least 5,000 of these birds were recorded by ground counts in Argentinian Tierra del Fuego (Minton *et al.* 1996). Although all sites included in 1980s aerial censuses were not visited, small numbers were reported along the shores

of Buenos Aires Province (Vila *et al.* 1994) and at San Antonio Oeste (González unpublished data).

iii. Wintering Area Numbers – 2000-2005

From 2000, aerial censuses showed a dramatic 40% reduction in the core areas of Tierra del Fuego (Morrison *et al.* 2004). Although not all Argentinian sites were covered by aerial censuses in 2000 and 2001, capture-recapture estimates for the total winter population south of San Antonio Oeste showed the same declining trend (González *et al.* 2004) (Fig. 57).

Morrison and Ross (1989) reported important flocks of wintering red knots on the Patagonian coast at Península Valdés and Bahía Bustamante in the 1980s, but more recent studies have found none in these areas (Bala pers. comm. 2006, Escudero *et al.* 2003, Morrison *et al.* 2004) (Table 16, Fig. 58, see also Appendix, Maps 4, 5, and 6). Therefore, there has not only been a drastic decline in total numbers, but also a contraction in the range of the southern wintering population to core areas in Tierra del Fuego. That this change is not simply a redistribution of the birds but a true population decline is also supported by the following:

a) Survival estimates and lower recruitment of immatures in this population (Baker *et al.* 2004).

b) *rufa* red knots wintering in northern Brazil are a different population from Tierra del Fuego; no Argentinian or Chilean flagged knots were found wintering there (Baker *et al.* 2005a). Moreover, a subsequent decline in Tierra del Fuego numbers to 17,653 was reported in the 2005 season of which 5,000 were seen at Río Grande, Argentina in February (Morrison unpublished data).

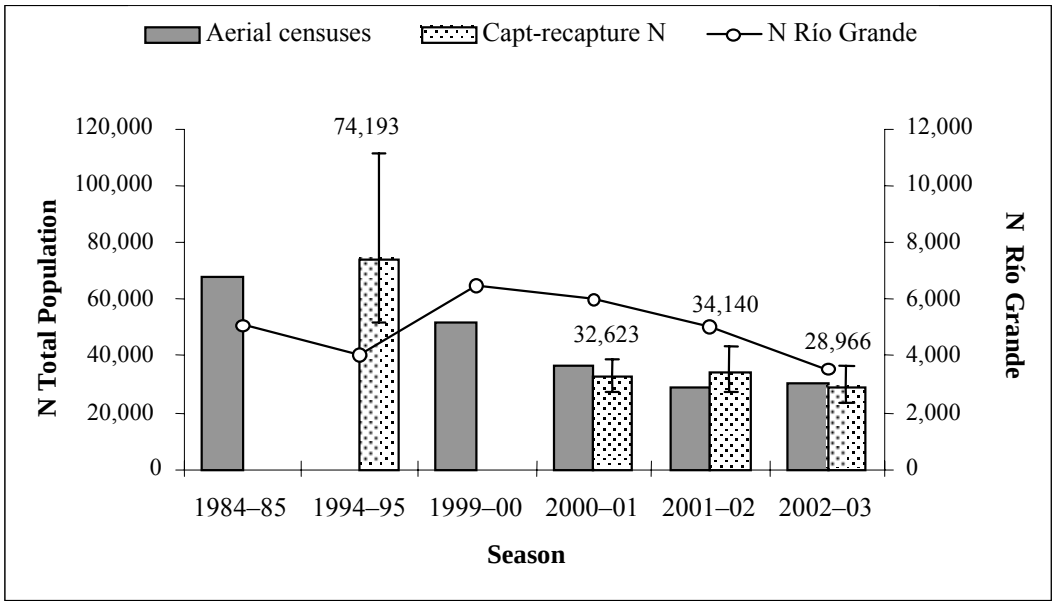


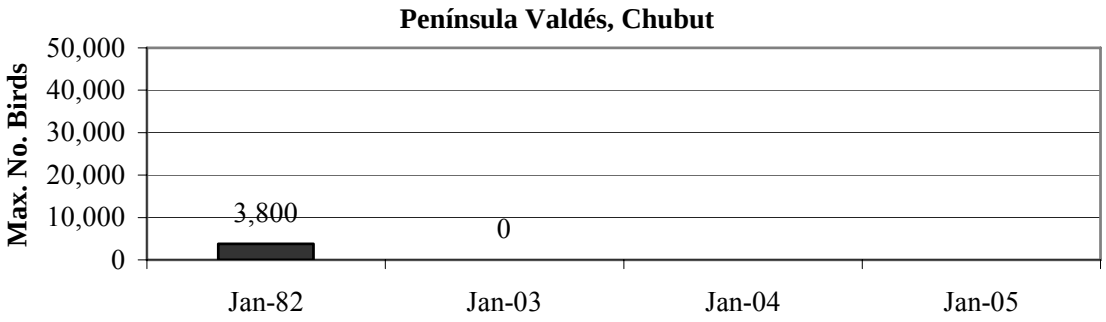

Figure 57. Total population estimates (± 95% confidence interval) of red knots spending the austral summer south of San Antonio Oeste, Río Negro, Argentina, from capture-recapture methods, compared with aerial census numbers (Morrison and Ross 1989, Morrison *et al.* 2004,) and number of red knots at Río Grande, Tierra del Fuego (González *et al.* 2004)

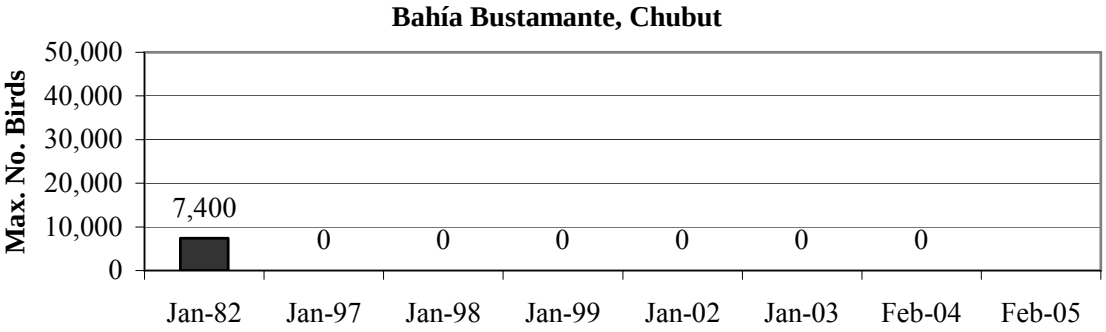
Table 16. Wintering sites of red knots in Argentina.

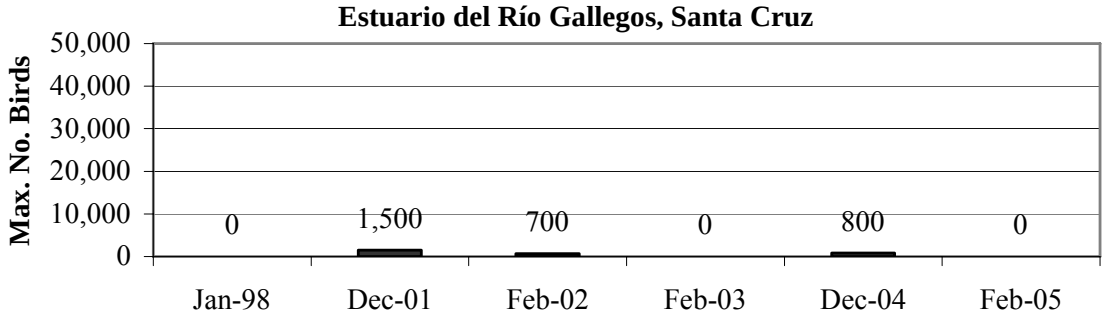
| Location | Month | Year | Max Count | Lat. | Long. | Source |
|---|---|---|---|---|---|---|
| *Río Grande* | Jan | 1976 | 3000 to 5000 | S53°45' | W67°44,3' | Devillers and Terschuren 1976 |
| *(Tierra del Fuego)* | Nov-Dec | 1979 | 5000 | | | Harrington and Flowers 1996 |
| | Feb | 1985 | 5100 | | | Morrison and Ross 1989 |
| | Feb | 1995 | 4000 | | | Minton *et al.* 1996 |
| | Jan | 2000 | 6500 | | | Escudero pers. comm. 2005 |
| | Nov | 2000 | 6000 | | | Baker *et al.*2005b |
| | Nov | 2001 | 5000 | | | Baker *et al.*2005b |
| | Nov | 2002 | 3500 | | | Baker *et al.*2005b |
| | Nov | 2003 | 3500 | | | Baker *et al.*2005b |
| | Feb | 2004 | 3520 | | | Morrison and Ross 2004 unpublished data |
| | Feb | 2005 | 5000 | | | Morrison unpublished data |
| *Bahía San Sebastián* | Feb | 1985 | 4440 | S53°02, 9' | W68°22' | Morrison and Ross 1989 |
| *(Tierra del Fuego)* | Feb | 2000 | 2250 | | | Morrison *et al.* 2004 |
| | Feb | 2002 | 50 | | | Morrison *et al.* 2004 |
| | Feb | 2003 | 900 | | | Morrison *et al.* 2004 |
| | Feb | 2004 | 230 | | | Morrison unpublished data |
| | Feb | 2005 | 100 | | | Morrison unpublished data |
| *Estuario del Río Gallegos* | Jan | 1998 | 0 | S51°30' | W69°00' | Ferrari *et al.* 2002 |
| *(Santa Cruz)* | Dec | 2001 | 1500 | | | Ferrari pers. comm. 2005 |
| | Feb | 2002 | 700 | | | Morrison *et al.* 2004 |
| | Feb | 2003 | 0 | | | Morrison *et al.* 2004 |
| | Dec | 2004 | 800 | | | Ferrari pers. comm. 2005 |
| | Feb | 2005 | 0 | | | Ferrari pers. comm. 2005 |
| *Bahía Bustamante* | Jan | 1982 | 7400 | S45°06' | W66°31' | Morrison and Ross 1989 |
| *(Chubut)* | Jan | 1997 | 0 | | | Escudero *et al.* 2003 |
| | Jan | 1998 | 0 | | | Escudero *et al.* 2003 |
| | Jan | 1999 | 0 | | | Escudero *et al.* 2003 |
| | Jan | 2002 | 0 | | | Morrison *et al.* 2004 |
| | Jan | 2003 | 0 | | | Morrison *et al.* 2004 |
| | Feb | 2004 | 0 | | | Morrison unpublished data |
| | Feb | 2005 | Not surveyed | | | |
| *Península Valdés* | Jan | 1982 | 3800 | S42°30' | W64°00' | Morrison and Ross 1989 |
| *(Chubut)* | Jan | 2003 | 0 | | | Morrison *et al.* 2004 |
| | Jan | 2004 | Not surveyed | | | Flight restriction |
| | Jan. | 2005 | Not surveyed | | | Morrison unpublished data |
| *Península Valdés, Fracasso* | Jan | 1994 | 0 | S42º25' | W64º04' | Bala *et al.* pers. comm. 2005 |
| *(Chubut)* | Jan | 1995 | 0 | | | Bala *et al.* pers. comm. 2005 |

Table 16. Continued

| Location | Month | Year | Max Count | Lat. | Long. | Source |
|---|---|---|---|---|---|---|
| *(Chubut)* | Jan | 1996 | 0 | | | Bala *et al.* pers. comm. 2005 |
| | Jan | 1997 | 0 | | | Bala *et al.* pers. comm. 2005 |
| | Jan | 1999 | 0 | | | Bala *et al.* pers. comm. 2005 |
| | Jan | 2000 | 0 | | | Bala *et al.* pers. comm. 2005 |
| | Jan | 2002 | 0 | | | Bala *et al.* pers. comm. 2005 |
| | Jan | 2003 | 0 | | | Bala *et al.* pers. comm. 2005 |
| | Jan | 2004 | 0 | | | Bala *et al.* pers. comm. 2005 |
| | Jan | 2005 | 0 | | | Bala *et al.* pers. comm. 2005 |



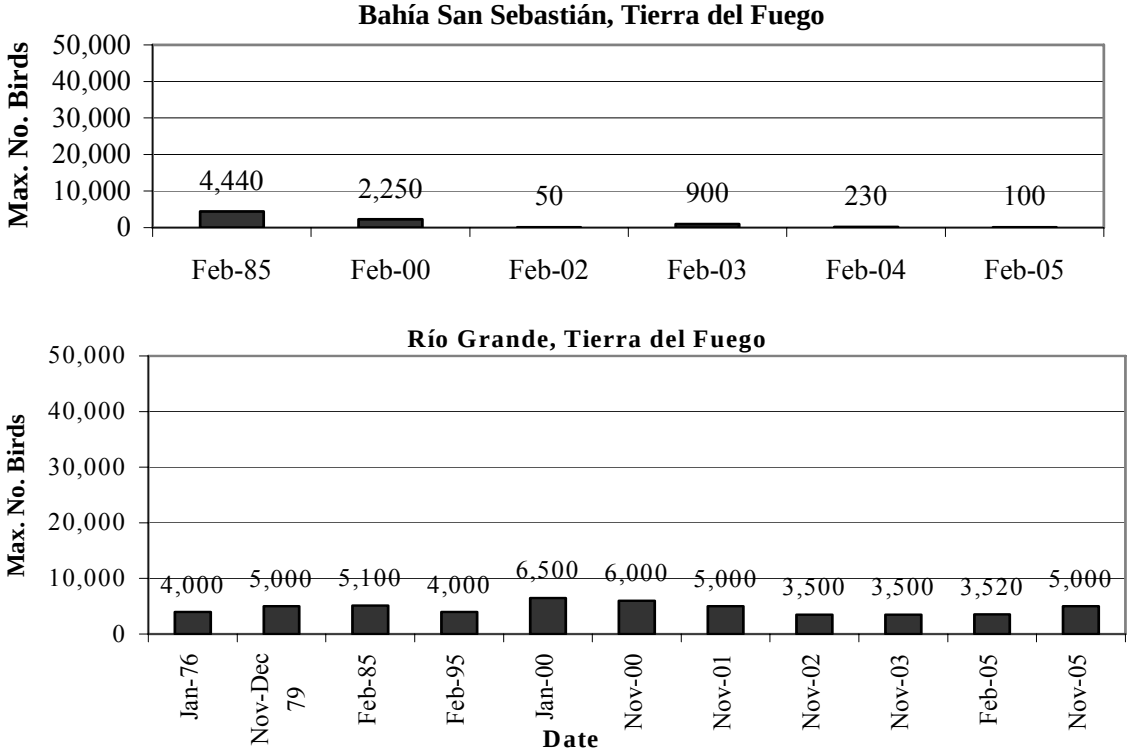



Figure 58. Results of red knot counts in critical wintering areas in Argentina (References in Table 16).

iv. Stopover Area Numbers - Northward Migration

Based on records from Río Grande (Minton *et al.* 1996, González *et al.* 2003), Río Gallegos Estuary (Ferrari *et al.* 2002) and San Antonio Oeste (González *et al.* 2004), northward migration begins at the end of January or early February. By the end of April, most red knots have already left Argentina although a small number of birds may stay longer, even remaining through the austral winter (usually juveniles) (e.g. González *et al.* 2004, Blanco *et al.* 1992, Blanco and Carbonell 2001).

In the 1980s, important known stopover places for knots were Península Valdés, Chubut Province, where up to 20,000 knots were estimated on passage (Morrison and Harrington 1992), and Bahía Samborombón with Punta Rasa, in Buenos Aires Province where up to 3,000 knots were seen in a single flock (Blanco *et al.* 1992) (Table 17, Fig. 58). In the 1990s, San Antonio Oeste in San Matías Gulf was one of most important stopover sites during northward migration, hosting 25-50% of the wintering population from southern Patagonia where up to 20,000 red knots were seen at one time (González *et al.* 2003) (Table 17). Despite being so close to the main wintering areas in Tierra del Fuego (300 km away), Río Gallegos Estuary was identified as an important stopover site during migration (Ferrari *et al.* 2002) with a high count of 2,500 knots. Although Morrison *et al.* 2004 recorded 700 wintering knots in this area in 2002, Ferrari *et al.* (2002) found no records in December or January from 1997 to 1999. Bahía Bustamante was another area censused regularly in the late 1990s with a highest count of 490 (Escudero *et al.* 2003) (Table 17).

Table 17. Stopover sites used by red knots in Argentina during northward migration (FSVA = Fundacion Vida Silvestre Argentina).

| Location | Month | Year | Max. Count | Lat. | Long. | Source |
|---|---|---|---|---|---|---|
| *Estuario del Río Gallegos* | Feb | 1998 | 2,500 | S51°30’ | W69°00’ | Ferrari *et al.* 2002 |
| *(Santa Cruz)* | Mar | 1999 | 1,800 | | | Ferrari *et al.* 2002 |
| | Mar | 2005 | 1,000 | | | Ferrari pers. comm. 2005 |
| *Bahía Bustamante* | Apr | 1997 | 26 | S45°06’ | W66°31’ | Escudero *et al.* 2003 |
| *(Chubut)* | Apr | 1998 | 23 | | | Escudero *et al.* 2003 |
| | Mar | 1999 | 490 | | | Escudero *et al.* 2003 |
| *Península Valdés (Chubut)* | Apr | 1981 | 20,000 | S42°30’ | W64°00’ | Morrison and Harrington 1992 |
| *Península Valdés, Fracasso* | Apr | 1994 | 8,000 | S42º25’ | W64º04' | Bala *et al.* pers. comm. 2005 |
| *(Chubut)* | Mar | 1995 | 2,625 | | | Bala *et al.* pers. comm. 2005 |
| | Apr | 1996 | 3,200 | | | Bala *et al.* pers. comm. 2005 |
| | Mar | 1999 | 3,020 | | | Bala *et al.* 2001 |
| | Apr | 2000 | 3,000 | | | Bala *et al.* 2002 |
| | Mar | 2002 | 80 | | | Hernández *et al.* 2004 |
| | Apr | 2003 | 1,000 | | | Bala *et al.* pers. comm. 2005 |
| | Apr | 2004 | 2,000 | | | Bala *et al.* pers. comm. 2005 |
| | Apr | 2005 | 500 | | | Bala *et al.* pers. comm. 2005 |
| *Península Valdés, Colombo* | Apr | 2002 | 1,500 | S42°38,8’ | W64°15’ | Hernández *et al.* 2004 |
| *(Chubut)* | Apr | 2003 | 250 | | | Musmeci 2005 |
| | Apr | 2005 | 700 | | | Bala *et al.* pers. comm. 2005 |
| *San Antonio Oeste* | Apr | 1990 | 19,700 | S40° 45' | W64° 55' | González 1991 |
| *(Río Negro)* | Mar | 1992 | 15,000 | | | González *et al.* 1996 |
| | Feb | 1996 | 20,000 | | | González *et al.* unpublished |
| | Mar | 1997 | 15,000 | | | Baker *et al.* 1999b |
| | Mar | 1998 | 9,000 | | | González and Piersma unpublished data. |
| | Mar | 1999 | 10,500 | | | González *et al.* unpublished |
| | Mar | 2000 | 10,000 | | | González *et al.* 2003 |
| | Mar | 2001 | 7,000 | | | González *et al.* 2003 |
| | Apr | 2002 | 12,000 | | | González *et al.* 2003 |
| | Apr | 2003 | 5,000 | | | González *et al.* 2003 |
| | Mar | 2004 | 5,500 | | | González *et al.* unpublished |
| | Apr | 2005 | 6,500 | | | González *et al.* unpublished |
| *Punta Rasa* | Apr | 1988 | 1,000 | S36° 22' | W56° 45' | Blanco *et al.* 1992 |
| *(Buenos Aires)* | Apr | 1989 | 3,000 | | | FVSA Banding Workshop |
| | Mar | 1997 | 200 | | | Baker *et al.* 1999b |

Long term datasets of regular ground counts (>10 years) only exist for San Antonio Oeste in San Matías Gulf (Jan to April biweekly until 1999, daily to every ten days from 2000 to 2005) and for Playa Fracasso (weekly from Feb to April), in the San José Gulf side of Península Valdés (Fig. 59). Although the highest counts (Table 17) are not necessarily correlated with either the actual number of red knots using stopover sites (because of turnover), or with wintering population size (e.g. because birds may bypass San Antonio Oeste after good wintering seasons (González *et al.* 2003)) or use other beaches at Península Valdés due to changes in sediments at Fracasso beach (D'Amico *et al.* 2003), it is evident that counts in the 1990s were at least 60% higher than during 2000-2005 (Fig. 60).

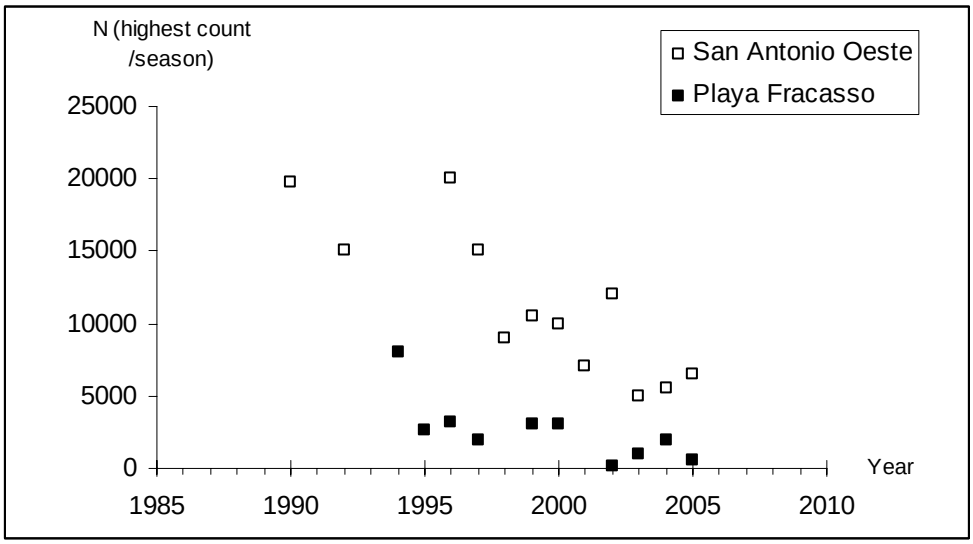
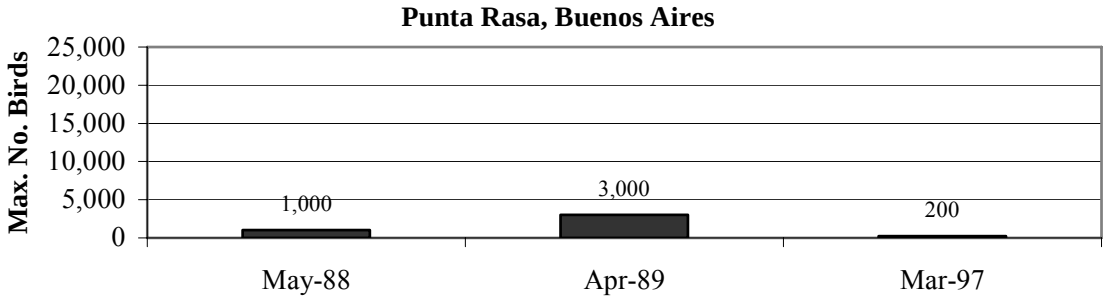



Figure 59. Maximum counts of red knots during northward migration at two stopover sites in Argentina: San Antonio Oeste and Playa Fracasso in Península Valdés (References in Table 17).



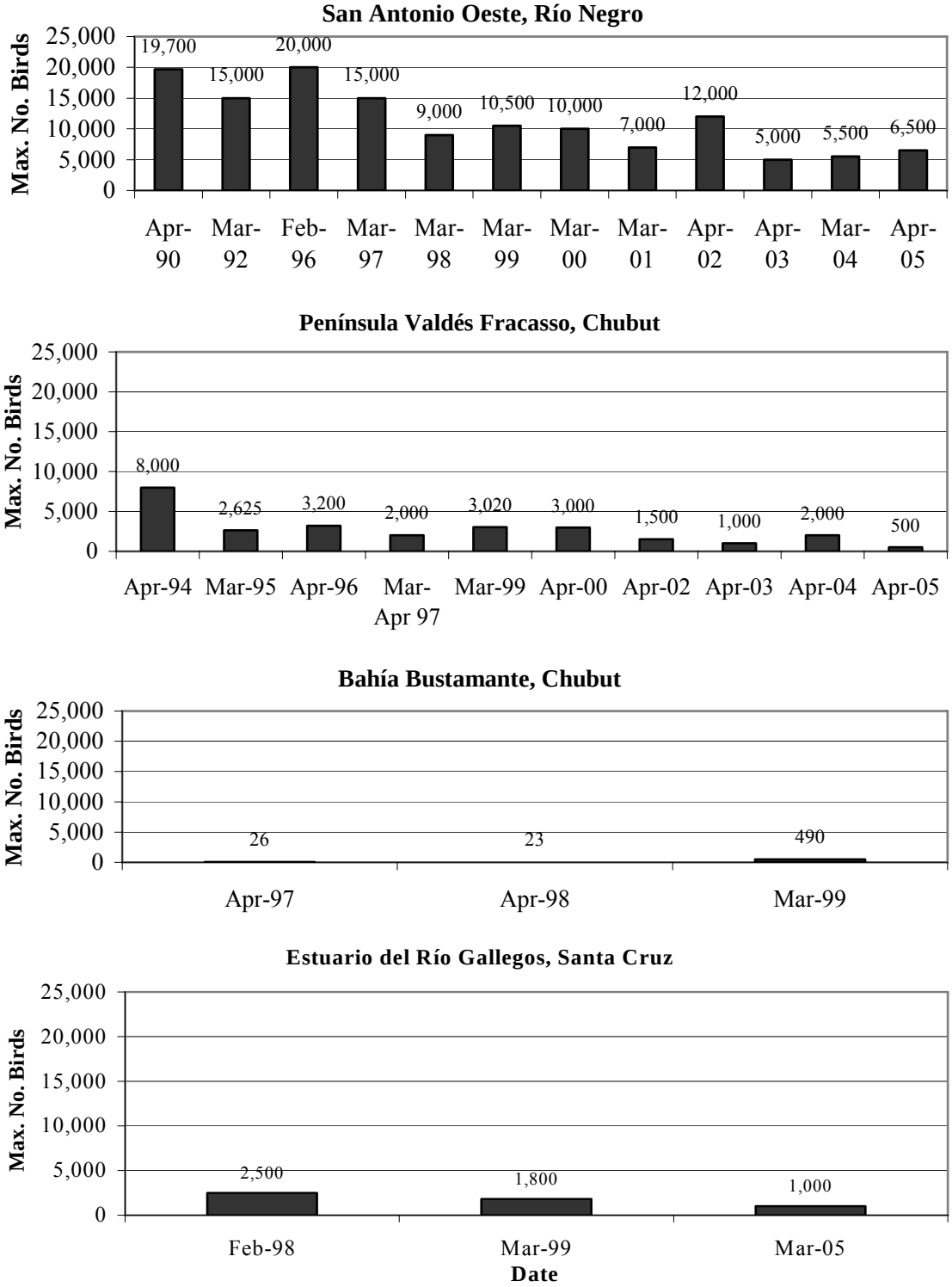



Figure 60. Results of red knot counts at critical stopover sites in Argentina during northward migration (References in Table 17).

In the 1981 season, Morrison and Harrington 1992 estimated that about 20,000 red knots occurred on passage in the entire Península Valdés area. However in 2005, thorough weekly ground, boat and aerial counts from March to May revealed only 700 knots at Colombo beach in the 5th week and 500 at Fracasso beach in the 7th week. Several individually marked birds were resighted more than once during the season, suggesting that the turnover rate was not very high (D'Amico pers. comm 2005). Thus, counts at stopover sites are consistent with a declining trend in the wintering population.

v. Stopover Area Numbers – Southward Migration

Very few sites are known to host knots during their southward migration. For example, at Península Valdés up to 3,800 birds were seen in early October 1980 (Harrington and Leddy 1982), but none have been recorded there during monthly surveys since 1994. At Bahía de San Antonio, there were records of 3,500 knots in October 1992 and 2,500 in October 1997, but only 1,000 in October 2001 (González *et al.* 2003). At the Río Gallegos Estuary, red knots have been seen from October to November (Albrieu *et al.* 2004) with a record of 900 knots in November 1997 (Ferrari *et al.* 2002). Small numbers have also been recorded in October at La Laguna in Puerto Madryn by Raúl Leon, and at Punta Rasa (Blanco *et al.* 1992) and Bahía Samborombón (Vila *et al.* 1994).

vi. Austral Wintering Records of Red Knots

Austral winter counts of red knots in Argentine (i.e. June-August) are scarce since it is mainly only juveniles that occur. However, there is a record of 600 during the austral winter of 1987 at Punta Rasa (Blanco *et al.* 1992) where it seems to have been common to see austral wintering knots in the 1980s (Blanco *et al.* 1992). Small numbers have been at San Antonio Oeste (González unpublished data) as well as 179 at Claromecó (Blanco and Carbonell 2001).

vii. Other Records

Occasional records of red knots have been reported from other sites in Argentina (Table 18). However, as these have not been the subject of systematic surveys, their importance cannot be determined.

c. Brazil

With an Atlantic coastline of 7,347 km and vast inland wetlands, such as the Pantanal, Brazil has a huge amount of shorebird habitat and supporting no less than 25 Nearctic shorebird migrants including red knots.

Although red knots can occur almost anywhere along the Brazilian shoreline, surveys show that two areas stand out as being of prime importance: the coast of the state of Maranhão in the north and the Lagoa do Peixe National Park in the state of Río Grande do Sul in the south (31º 10'S 51º 00'S) (Morrison and Ross 1989; Morrison *et al.* 1987, Morrison and Harrington 1992; Belton 1994; Nascimento 1995). Passage migrants especially use these areas during northward migration in April/May and during southward migration in Sept/Oct. Two factors suggest that passage knots make a direct overland flight between the two: (1) the general lack of records from the rest of the Brazilian coast, and (2) an observation of ten adults in September 1989 in the southern Pantanal in the state of Mato Grosso do Sul (19º 30'S 56º 10'W) (unpublished data from Centro Nacional de Pesquisa para Conservação das Aves Silvestres (CEMAVE)).

Table 18. Other areas in which red knots have been observed in Argentina.

| Place | Records | Date | Lat. | Long. | Source |
|---|---|---|---|---|---|
| Laguna Mar Chiquita, Buenos Aires | tens to hundreds | Unknown | S37º 45' | W57º 25' | Savigny pers. comm. 2005, and Olveira pers. comm. 2005 |
| Mar de Cobo, Buenos Aires | tens - few hundreds | Unknown | S37º 46' | W57º 26' | Isacch pers. comm. 2005, Blanco *et al.* 2001 |
| Claromecó, Buenos Aires | tens - hundreds | Unknown | S38º 51' | W60º 05' | Francia pers. comm. 2005 |
| Punta Alta, Buenos Aires | hundreds | Unknown | S38º 54' | W62º 03' | Delhey and Petracci 2004 |
| Bahía Anegada, Buenos Aires | tens - hundreds | Unknown | S40º 15' | W62º 16' | Isacch pers. comm. 2005 |
| Caleta de Los Loros, Río Negro | presence | Unknown | S41º 00' | W64º 01' | Canevari *et al.* 1998 |
| Complejo Islote Lobos, Río Negro | 800; 3,000; hundreds | Unknown | S41º 26' | W65º 01' | González pers. comm. 2005, Chillón pers. comm. 2005, Morrison *et al.* 2004 |
| South Golfo San Matías | 1,200; hundreds | Unknown | S42º 00' | W65º 06' | Morrison and Ross 1989, Morrison *et al.* 2004 |
| Laguna Puerto Madryn, Chubut | tens | Unknown | S42º 46' | W65º 03' | León pers. comm. 2005 |
| Punta Tombo, Chubut | presence | Unknown | S44º 02' | W65º 11' | Canevari *et al.* 1998 |
| South Golfo San Jorge to Cabo Blanco, Santa Cruz | hundreds - 1,300 | Unknown | S47º 12' | W65º 45' | Pérez *et al.* 1995, Canevari *et al.* 1998, Morrison and Ross 1989, Morrison *et al.* 2004 |
| Ría Deseado (Pta.Foca), Santa Cruz | 1,000 | Unknown | S47º 44' | W65º 50' | Pérez *et al.* 1995 |
| Punta Medanosa, Santa Cruz | 3,000 | Unknown | S48º 06' | W65º 55' | Pérez *et al.* 1995, Morrison and Ross 1989 |
| Cabo Dañoso, Santa Cruz | 150 | Unknown | S48º 50' | W67º 13'. | Morrison and Ross 1989 |
| Bahía San Julián, Santa Cruz | tens, 350 | Unknown | S49º 21' | W67º 42'. | Hernández 2004, Albrieu pers. comm. 2005 |
| Puerto Santa Cruz, Santa Cruz | 400-500 | Unknown | S50º 08' | W68º 20' | Imberti pers. comm. 2005 |

Although it is not known whether knots regularly stop over in the Pantanal or whether the ten birds had been forced to land there as a result of weather conditions, it does indicate that they take the overland route.

The north coast of Maranhão also supports the largest wintering population in South America outside Tierra del Fuego (Nascimento 2001; Baker *et al.* 2004; Baker *et al.* 2005a; Morrison and Ross 1989). During the breeding season small numbers of non-breeding birds (mainly juveniles) remain on the coast of Maranhão and Río Grande do Sul (Belton 1994), and in the Lagoa do Peixe National Park (Nascimento 1995). Other records of knots along the Brazilian coast are insignificant.

i. Brazilian North Coast – Maranhão

It became clear during censuses carried out on the South American coast in 1982 and 1986 (Morrison and Ross 1989) that the regions of Salgado Paraense (State of Pará) and Reentrâncias Maranhenses (State of Maranhão) on the north coast are amongst the most important shorebird sites in Brazil. A total of 398,000 shorebirds were counted including 8,324 red knots.

Ground surveys were conducted by CEMAVE/IBAMA in 1990 and 1994 in October and November and from April to the second week of May along the coasts of the state of Amapá (Nascimento 1998) and in 1991 and 1995 on the coast of Maranhão (Serrano *et al.* unpublished data). Activities included capture of migratory Nearctic shorebirds with mist-nets, banding (metal bands and color bands) and gathering of biometric data (molting, sex, age, weight, etc.).

In November 1992, 760 red knots were counted in Baía dos Lençóis near Campechá Island and in November 1993 there were 1,398 at the same site.

Between April 12 and May 5, 1995, a ground survey was carried out along the north/northeast coast of the states of Ceará and Maranhão, including the mouth of the Gurupi River on the border between the states of Pará and Maranhão. Over 450 km were surveyed and several areas east of the Cabelo da Velha, including Lençóis Bay (Campechá Island) and Turiaçú Bay were found to hold large numbers of red knots (Table 19): particularly Coroa dos Ovos Island and Ingleses Island (Serrano *et al.* unpublished data). In view of the dates of these observations, it is likely that the birds counted included both passage migrants that had over-wintered in Argentina or Chile as well as birds that had wintered locally.

Table 19. Number of red knots counted on the north coast of Maranhão in April and May 1995 (Serrano *et al.* unpublished data).

| Locality/Bays | LAT/LONG | Estimated number |
|---|---|---|
| São Marcos | 02º 20'S 44º 20'W | 50 |
| Cumã | 02º 17'S 44º 23'W | 0 |
| Capim | 01'S 29'S 44º 49'W | 4 |
| Cabelo da Velha | 01º 40'S 44º 40'W | 90 |
| Lençóis | 01º 22'S 44º 56'W | 600 |
| Turiaçú | 01º 25'S 45º 06'W | 11,198 |
| Total | | 11,942 |

In February 2005, an aerial census of the key coastal wetlands of Maranhão revealed a total of 7,575 red knots, the majority (5,000) in Turiaçú Bay and on Coroa dos Ovos Island (Baker *et al.* 2005a). Therefore there had only been a slight (7%) decline in the population since the previous winter count in the mid 1980s, well within the likely counting error (Table 20)

Table 20. Number of red knots recorded on the coast of Maranhão, Brazil.

| Source | Season | Count |
|---|---|---|
| Morrison and Ross (1989) | Winter | 8,150 |
| Serrano *et al.* (1995 unpublished data) | Spring (Apr/May) | 11,942 |
| Baker *et al.* (2005a) | Winter (Feb) | 7,575 |

Although the 1995 and 2005 surveys were made using different methods and took place at different seasons, they both indicate that the Turiaçú Bay is the most important area for red knots.

CEMAVE records show that four knots captured in Maranhão had been banded in Delaware Bay, U.S.: two in the Coroa dos Ovos Islands in November 1993 and two in Campechá Islanda in December 2003. Banding also shows that during northward migration birds marked in Lagoa do Peixe may stop over on the Maranhão coast. One color banded individual was seen at Lagoa do Peixe on northward passage in 1987 and again in Maranhão in May the same year. The same bird was observed in Delaware Bay in May 1988 and 1990 (Antas and Nascimento 1996). Another knot was banded by CEMAVE (H47610) on May 10, 2001 at Campechá weighing 165g and recaptured only 11 days later at Slaughter Beach, Delaware. This is the shortest migration time recorded for an individual knot between Maranhão and Delaware Bay. Based on theoretical estimates of flight capability, knots weighing more than 160g can reach 5,000 km, the distance involved. Scans for color-banded knots in the Coroa dos Ovos and Campechá Islands in February 2005 (Baker *et al.* 2005a) showed that 12 out of 663 red knots had been marked in Delaware Bay.

Recent resightings of color-banded knots in Maranhão and isotopic analysis of feathers shows that the Maranhão wintering population is distinct from that of Tierra del Fuego (Baker *et al.* 2005a). In May 2005 scans performed in Delaware Bay (NJDFW-ENSP unpublished data) revealed at least three birds that had been banded in Maranhão (one in October 2004 and two in February 2005). Despite the low number of birds captured in the October 2004 and February 2005 expeditions (10 and 38 respectively), this is a strong indication of the importance of the Maranhão coast both for wintering and as a stopover location during northward migration of birds from Tierra del Fuego.

ii. Lagoa do Peixe National Park (Río Grande do Sul)

Lagoa do Peixe National Park is located in the southernmost region of Brazil, between the Atlantic Ocean and Lagoa dos Patos (Appendix - Map 9). The Park is one of the most important wintering grounds and stopover sites for North American migratory shorebirds.

The 35-km lagoon naturally connects to the sea especially during winter during high wind, and when rain accumulates water in the lagoon. In summer, pumping sustains a constant influx of salt water. In this way, the lagoon has developed a rich invertebrate fauna all year round, making it an important source of food for migratory birds due to its high primary productivity. The major food resource for red knots at Lagoa do Peixe appears to be the mud snail *Littoridina australis*.

Ground counts of red knots carried out in the Lagoa do Peixe National Park by CEMAVE (unpublished) during the month of April 1995 to 2003 show a decrease of numbers of red knots especially since 2001 of over 90% (Fig. 61).

Other published counts of red knots at Lagoa do Peixe include 7,000 in April 1984 (Harrington *et al.* 1986), 11,000 birds (Lara-Resende and Leuwemberg 1987) and 8,900 birds (Vooren and Chiaradia 1990). According to Belton (1994) 1,000 individuals were seen at the end of May.

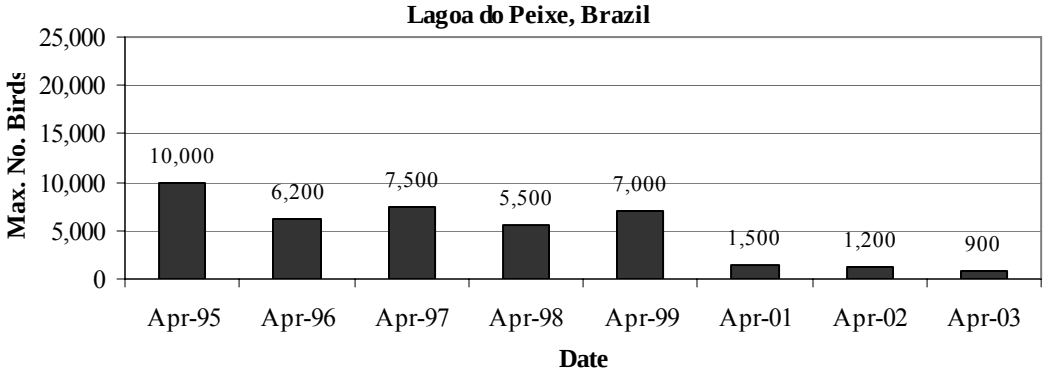



Figure 61. Peak numbers of red knots recorded in Lagoa do Peixe National Park, Brazil, 1995-2003 (CEMAVE/IBAMA).

During the breeding season, a small number of non-breeding birds (probably one-year-olds) remain at Lagoa do Peixe (Belton 1994).

Two birds color-banded at Lagoa do Peixe were later seen during southward migration on the coast of South Carolina, U.S., on July 28, 1986.

During northward migration, most birds arrive at Lagoa do Peixe in March and the last birds are seen at the end of April, when birds occur on the northernmost beaches in the state of Río Grande do Sul. The last migrants are seen at Santa Catarina in mid-May (Antas and Nascimento 1996). After Lagoa do Peixe, the next stop is in Maranhão and then Delaware Bay, U.S. There is a record of one color-banded bird from Lagoa do Peixe in the Presquile Provincial Park, Lake Ontario, Canada. Others have been seen in Florida in the second week of May (CEMAVE unpublished data).

About 8,900 migratory shorebirds have been banded by CEMAVE/IBAMA between 1984 and 2004 at the Lagoa do Peixe National Park, including 2,698 red knots, 1,871 white-rumped sandpipers (*Calidris fuscicollis*), 745 ruddy turnstones, and 658 sanderlings. Red knots have provided the most recaptures, especially in the United States (Delaware Bay) and Argentina (San Antonio Oeste and Río Grande) (CEMAVE).

d. Panama

Ten shorebird counts were made by Buehler (2002) between 5 January and 15 April 2002 in the Upper Panama Bay: five close to Panama City, two at Río Pacora and one at Chitré. These show that up to 200 occurred during winter (January) and 300 during northward passage (March) (Table 21).

Table 21. Counts of red knots at three sites in Panama between 5 Jan and 15 Apr 2002 (Buehler 2002).

| Date | 5 Jan | 19 Jan | 2 Feb | 21 Feb | 24 Feb | 28 Feb | 15 Mar | 28 Mar | 7 Apr | 15 Apr |
|---|---|---|---|---|---|---|---|---|---|---|
| Panama City | 200 | 200 | | | | 100 | 250 | 300 | 250 | 10 |
| Río Pacora | | | 20 | | 5 | | | | | |
| Chitré | | | | 100 | | | | | | |

In the Costa del Este area of Panama City, where prime roosting sites were recently lost to housing development, flocks of up to 80,000 shorebirds were observed flying continuously for the duration of the high tide.

Two red knots were seen with orange flags on the tibia, indicating that they had been banded in Argentina. One, with the flag on the left tibia and no color bands, was seen on 20 February and had probably been banded at Río Grande, Tierra del Fuego, in February 1995. The other, with the flag on the right tibia and a red band on the left tarsus, was seen on 15 and 28 March and had been banded at San Antonio Oeste, Patagonia, in March 1998. Many of the red knots seen in January and February were identified as juveniles because they had yellowish legs.

The first knots showing breeding plumage were observed on 15 March 2002 when the proportion was 20%. By 28 March, the proportion had increased to 70% with a similar figure on 7 April. By 15 April 2002, the majority of red knots had left the area and of the ten birds that remained, only one was in breeding plumage.

***2. United States Fish and Wildlife Service Region 2***

a. Texas

During 1980-1996, flocks of red knots in excess of 1,000 were recorded from several sites on the Texas coast especially during winter (Jan) and spring passage (April/May), with over 2,800 on one occasion at Mustang Island Beach (Skagen *et al.* 1999, Table 22). Since that period, however, numbers have been much lower with the largest number recorded only 300, at Bolivar Flats, Galveston County, on 30-31 January 2003 (Harrington unpublished data). Bolivar Flats, which are managed by the Houston Audubon Society, is now the only site where small numbers of knots (5-10) are seen regularly in winter with smaller numbers on the outer Gulf beaches. Slightly greater numbers occur during migration (around 20). Christmas bird count (CBC) data from 1997-98 (the only year for which data were available) shows a total of 36 red knots in the state.

The Gulf Coast Bird Observatory confirms that former estimates of 4,000 knots on passage through Texas may now be high by as much as an order of magnitude.

An important caveat to these figures is that there have been no systematic surveys for knots in Texas and there is nearly 1,000 km of outer coastline in the state from Port Arthur to Brownsville and 3,700 km of shoreline. Therefore it is quite possible that substantial numbers of knots occur in Texas and are undetected.

Three observations suggest that the knots that occur in Texas belong to the *rufa* subspecies. First, Oberholser (1974) identified a winter specimen from Cameron County as *rufa*. Second, an orange-flagged bird from Argentina was seen on the Texas coast in May 2004. Third, an individually flagged bird that had been banded in Delaware Bay in May 2003 was seen on the Texas coast in August/September 2005 (Ortego pers. comm. 2005; Burkett pers. comm. 2005; Arvin pers. comm. 2005).

Table 22. Records of red knots on the Texas coast during 1980-1996 (Skagen *et al.*1999).

| **January through June** | | | |
|---|---|---|---|
| Maximum Count | Latitude (°N) | Longitude (°W) | Location |
| 2,838 | 27.70 | 97.20 | Mustang Island Beach, Texas |
| 2,460 | 27.80 | 97.10 | Airport, Port Aransas, Texas |
| 900 | 26.00 | 97.10 | Boca Chica Beach, Cameron County, Texas |
| 800 | 28.20 | 96.60 | Matagorda National Wildlife Refuge, Texas |
| 750 | 29.50 | 94.60 | Bolivar Flats, Texas |
| 575 | 26.30 | 97.40 | Laguna Atascosa National Wildlife Refuge, Texas |
| 184 | 27.40 | 97.40 | Padre Island National Seashore, Texas |
| 81 | 26.20 | 97.20 | South Padre Island, Texas |
| 55 | 28.50 | 96.60 | Magnolia Beach, Indianola Island, Calhoun County, Texas |
| 48 | 27.60 | 97.30 | Laguna Madre, Corpus Christi, Texas |
| 48 | 28.90 | 95.10 | San Luis Pass, Galveston Island, Texas |
| 40 | 29.20 | 95.80 | Big Reef, Galveston Island, Texas |
| 40 | 29.40 | 94.60 | Shore east of Bolivar Flats, Galveston Island, Texas |
| **July through December** | | | |
| Maximum Count | Latitude (°N) | Longitude (°W) | Location |
| 1,443 | 27.70 | 97.20 | Mustang Island Beach, Texas |
| 1,439 | 27.40 | 97.40 | Padre Island National Seashore, Texas |
| 280 | 26.30 | 97.40 | Laguna Atascosa National Wildlife Refuge, Texas |
| 250 | 28.20 | 96.60 | Matagorda National Wildlife Refuge, Texas |
| 111 | 27.60 | 97.80 | Beach on border of Nueces County and Kleberg County, Texas |
| 88 | 27.80 | 97.10 | Airport, Port Aransas, Texas |
| 45 | 29.50 | 94.60 | Bolivar Flats, Texas |
| 30 | 26.10 | 97.20 | South Padre Island, Texas |
| 29 | 28.30 | 96.80 | Burgentine Lake, Aransas National Wildlife Refuge, Texas |
| 28 | 26.00 | 97.10 | Boca Chica Beach, Cameron County, Texas |
| 27 | 27.60 | 97.30 | Laguna Madre, Corpus Christi, Texas |
| 12 | 27.70 | 97.60 | Nueces County, Texas |
| 10 | 29.20 | 95.80 | Big Reef, Galveston Island, Texas |

### *3. United States Fish and Wildlife Service Region 4*

a. Florida

Red knots have been documented in Florida in all months of the year (Tables 23 and 24, Fig. 62) but are seen most frequently from November through May. During November to February, they are most commonly observed on the west coast where the highest number of 6,500 was recorded at Casey Key Beach on 23 January 1979. However, the second highest count of 5,000 was on the east coast on 23 March 1978 at Anastasia Island, St. Johns County.

There is considerable uncertainty about the number of red knots that currently winter in Florida and there has been no recent count as high as the 6,500 recorded in 1979. On the basis of International Shorebird Survey counts during 1993-1994, Sprandel *et al*. (1997) estimated the wintering population to be as low as 1,452. These were recorded at 27 of the 60 most important shorebird sites in Florida between 16 December 1993 and 1 March 1994 (Table 25; See also Appendix - Maps 11, 12 and 13). Evidence from Florida Christmas Bird Counts obtained by averaging data for each circle during 1980-1989 suggests a minimum state population of 2,928. More recently, 4,000-5,000 were recorded at a single site in western Florida in November 2004 (Harrington unpublished data). Although the data are sparse, we conjecture that the state population may currently be in the region of 7,500. Our reasons are:

1. The 2004 observation was at just one site whereas in 1993-1994 knots were found at 27 sites so it is likely that at least some sites would still support the species.
2. Knots are regularly recorded on the coast of South Carolina in early April. These include a flock of 7,000 in early April 2003 (Harrington unpublished data). It is thought that it would be too early for these birds to have come from South America and that they had probably wintered in Florida. (Extensive searches for color bands were made (163 sightings of marked individuals), but no knots marked in South America were found).
3. Calculations based on resightings of color-banded knots wintering in Florida made between 1981 and 2004 consistently suggest that the population could be even larger than 7,500 (10,000 or more). The error associated with these calculations and the lack of reports of large numbers suggests that the estimates from band resightings may be too high (Harrington unpublished data), but they do suggest relatively consistent numbers through the years.

The evidence of the size of the population of red knots wintering in Florida is therefore far from satisfactory and although the figure of 7,500 is used throughout this review, it should be regarded with considerable caution. Systematic surveys to determine the exact size of this important population should be treated as a high priority.

Table 23. Peak counts of red knots during spring and fall migration at various sites in Florida. Interstitial periods not included. ISS = International Shorebird Survey (Harrington unpublished data).

| Fall Migration (Jul 1-Oct 31) | | | | Spring Migration (Apr 1-Jun 10) | | | |
|---|---|---|---|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** | **Location** | **Peak Count** | **Year** | **Source** |
| 5 Phosphate Mines | 1 | 1992 | ISS | 5 Phosphate Mines | - | - | - |
| Alligator Point | 132 | 1988 | ISS | Alligator Point | - | - | - |
| Anclote Key | - | - | - | Anclote Key | - | - | - |
| Bald Point | 10 | 1975 | ISS | Bald Point | 1 | 1981 | ISS |
| | 1 | 1977 | ISS | | 4 | 1982 | ISS |
| | 6 | 1979 | ISS | | 15 | 1983 | ISS |
| | 2 | 1981 | ISS | | 11 | 1993 | ISS |
| | 5 | 1993 | ISS | | 49 | 1993 | ISS |
| | 1 | 1994 | ISS | | 87 | 1994 | ISS |
| | | | | | 15 | 1995 | ISS |
| Bayway and Ft Desoto | 2 | 1975 | ISS | Bayway and Ft Desoto | - | - | - |
| | 9 | 1976 | ISS | | | | |
| Bell Glade Farm | 1 | 1977 | ISS | Bell Glade Farm | - | - | - |
| | 2 | 1980 | ISS | | | | |
| Caladesi Island | - | - | - | Caladesi Island | - | - | - |
| Cape Romano | 15 | 1980 | ISS | Cape Romano | 25 | 1981 | ISS |
| | 95 | 1981 | ISS | | 55 | 1982 | ISS |
| | 1,375 | 1982 | ISS | | 1,050 | 1983 | ISS |
| | 1,300 | 1983 | ISS | | 414 | 1984 | ISS |
| | 1,530 | 1984 | ISS | | 300 | 1985 | ISS |
| | 1,250 | 1985 | ISS | | 690 | 1986 | ISS |
| | 1,250 | 1986 | ISS | | 1,205 | 1987 | ISS |
| | 915 | 1987 | ISS | | 420 | 1988 | ISS |
| | 1,348 | 1988 | ISS | | 1,000 | 1989 | ISS |
| Cape San Blas | 6 | 1981 | ISS | Cape San Blas | 16 | 1999 | ISS |
| | 8 | 1988 | ISS | | | | |
| Capri Pass | - | - | - | Capri Pass | - | - | - |
| Carl Ross Key | - | - | - | Carl Ross Key | - | - | - |
| Carrabelle Beach | 160 | 1988 | ISS | Carrabelle Beach | 109 | 1993 | ISS |
| | 98 | 1992 | ISS | | 6 | 1994 | ISS |
| | 102 | 1993 | ISS | | 90 | 1995 | ISS |
| | 6 | 1994 | ISS | | | | |

Table 23. Continued

| Fall Migration (Jul 1-Oct 31) | | | | Spring Migration (Apr 1-Jun 10) | | | |
|---|---|---|---|---|---|---|---|
| Location | Peak Count | Year | Source | Location | Peak Count | Year | Source |
| Carrabelle Beach | 50 | 1995 | ISS | | | | |
| (Lighthouse) | 64 | 1995 | ISS | | | | |
| (W picnic) | 45 | 1993 | ISS | | | | |
| Casey Key Beach | 72 | 1977 | ISS | Casey Key Beach | 5 | 1978 | ISS |
| | 41 | 1978 | ISS | | 21 | 1980 | ISS |
| | 460 | 1979 | ISS | | 168 | 1981 | ISS |
| | 31 | 1981 | ISS | | 7 | 1982 | ISS |
| | 13 | 1983 | ISS | | 34 | 1983 | ISS |
| CC Causeway | 7 | 1977 | ISS | CC Causeway | - | - | - |
| Clear Springs | - | - | - | Clear Springs | 1 | 1981 | ISS |
| Crooked Island | - | - | - | Crooked Island | - | - | - |
| Ding Darling NWR | 28 | 1999 | ISS | Ding Darling NWR | 14 | 2003 | ISS |
| Dunedin | - | - | - | Dunedin | - | - | - |
| East of Bay North | - | - | - | East of Bay North | - | - | - |
| Englewood | - | - | - | Englewood | - | - | - |
| FSU Marine Lab | - | - | - | FSU Marine Lab | 27 | 1993 | ISS |
| | | | | | 4 | 1994 | ISS |
| Ft Desoto | 800 | 1999 | Harrington unpublished data | Ft Desoto | - | - | - |
| | 330 | 2004 | Harrington unpublished data | | | | |
| Ft George Inlet | 500 | 2003 | Harrington unpublished data | Ft George Inlet | 1,500 | 2004 | Harrington unpublished data |
| Ft Myers Beach | 351 | 1999 | Harrington unpublished data | Ft Myers Beach | - | - | - |
| | 400 | 2003 | Harrington unpublished data | | | | |
| (North) | 800 | 1999 | Harrington unpublished data | | | | |
| Ft Pierce Inlet | 2 | 1978 | ISS | Ft Pierce Inlet | - | - | - |
| | 2 | 1979 | ISS | | | | |
| | 5 | 1982 | ISS | | | | |
| Georgestone State Park | 20 | 1979 | ISS | Georgestone State Park | - | - | - |
| Hickory Mound Impound. | - | - | - | Hickory Mound Impound. | - | - | - |
| Honeymoon Island | 4 | 1986 | ISS | Honeymoon Island | 200 | 1987 | ISS |

Table 23. continued

| Fall Migration (Jul 1-Oct 31) | | | | Spring Migration (Apr 1-Jun 10) | | | |
|---|---|---|---|---|---|---|---|
| Location | Peak Count | Year | Source | Location | Peak Count | Year | Source |
| | 8 | 1987 | ISS | | 500 | 1988 | ISS |
| | 500 | 1989 | ISS | | 250 | 1990 | ISS |
| | 40 | 1990 | ISS | | 450 | 1993 | ISS |
| | 800 | 1992 | ISS | | 500 | 1994 | ISS |
| | 500 | 1993 | ISS | | 450 | 1995 | ISS |
| | 1,500 | 1994 | ISS | | 20 | 1996 | ISS |
| | 700 | 1995 | ISS | | 200 | 1997 | ISS |
| | 400 | 1996 | ISS | | 350 | 1998 | ISS |
| | 400 | 1997 | ISS | | 10 | 1999 | ISS |
| | 550 | 1998 | ISS | | 180 | 2000 | ISS |
| | 1,100 | 1999 | ISS | | 240 | 2001 | ISS |
| | 1,750 | 2000 | ISS | | 146 | 2002 | ISS |
| | 360 | 2001 | ISS | | 250 | 2003 | ISS |
| | 162 | 2002 | ISS | | | | |
| | 1,140 | 2003 | ISS | | | | |
| (South Beach) | 12 | 1992 | ISS | | | | |
| Hooker's Point | 200 | 1979 | ISS | Hooker's Point | 300 | 1980 | ISS |
| | 10 | 1980 | ISS | | | | |
| Hugenot State Park, Ward's Bank | 2 | 1977 | ISS | Hugenot State Park, Ward's Bank | 35 | 1980 | ISS |
| | 5 | 1978 | ISS | | | | |
| | 400 | 1979 | ISS | | | | |
| | 2,069 | 1980 | ISS | | | | |
| Island N Bunces Pass | - | - | - | Island N Bunces Pass | - | - | - |
| Kennedy Space Center | - | - | - | Kennedy Space Center | - | - | - |
| Lake Ingraham | - | - | - | Lake Ingraham | - | - | - |
| Lake Woodruff NWR | - | - | - | Lake Woodruff NWR | 1 | 2003 | ISS |
| Lanark Reef | - | - | - | Lanark Reef | - | - | - |
| Lido Beach | - | - | - | Lido Beach | - | - | - |
| Little Estero | - | - | - | Little Estero | - | - | - |
| Longboat Key | 1,700 | 1977 | ISS | Longboat Key | 39 | 1981 | ISS |
| | 700 | 1979 | ISS | | 2 | 1982 | ISS |
| | 1,300 | 1981 | ISS | | 60 | 1983 | ISS |
| | 750 | 1982 | ISS | | | | |
| | 250 | 1983 | ISS | | | | |

Table 23. Continued

| Fall Migration (Jul 1-Oct 31) | | | | Spring Migration (Apr 1-Jun 10) | | | |
|---|---|---|---|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** | **Location** | **Peak Count** | **Year** | **Source** |
| | 400 | 1999 | Harrington unpublished data | | | | |
| Marco Island, Tigertail Beach | - | - | - | Marco Island, Tigertail Beach | - | - | - |
| Marco River | 300 | 1974 | ISS | Marco River | 258 | 1981 | ISS |
| | 80 | 1975 | ISS | | 138 | 1982 | ISS |
| | 70 | 1976 | ISS | | 500 | 1983 | ISS |
| | 120 | 1977 | ISS | | 600 | 1984 | ISS |
| | 410 | 1978 | ISS | | 474 | 1985 | ISS |
| | 300 | 1979 | ISS | | 450 | 1986 | ISS |
| | 216 | 1980 | ISS | | 360 | 1987 | ISS |
| | 298 | 1981 | ISS | | 353 | 1988 | ISS |
| | 279 | 1982 | ISS | | 172 | 1989 | ISS |
| | 247 | 1983 | ISS | | | | |
| | 291 | 1984 | ISS | | | | |
| | 1,211 | 1985 | ISS | | | | |
| | 598 | 1986 | ISS | | | | |
| | 301 | 1987 | ISS | | | | |
| | 282 | 1988 | ISS | | | | |
| Mayport Naval Stn., Jetties Beach | 1 | 2003 | ISS | Mayport Naval Stn., Jetties Beach | - | - | - |
| Mckay Bay, Tampa | - | - | - | Mckay Bay, Tampa | 80 | 1993 | ISS |
| Merritt Island NWR (10D) | - | - | - | Merritt Island NWR (10D) | - | - | - |
| N. Sarasota Bay | 1 | 1978 | ISS | N. Sarasota Bay | - | - | - |
| Naples | 10 | 1981 | ISS | Naples | 33 | 1981 | ISS |
| | | | | | 1 | 1982 | ISS |
| Nassau Sound | 15 | 2004 | Harrington unpublished data | Nassau Sound | - | - | - |
| Nevarre Beach, Pensacola | 7 | 1977 | ISS | Nevarre Beach, Pensacola | - | - | - |
| New Smyrna Beach | 6 | 1975 | ISS | New Smyrna Beach | - | - | - |
| Palm Island Resort | - | - | - | Palm Island Resort | - | - | - |
| Palm Key | - | - | - | Palm Key | - | - | - |
| Passage Key | - | - | - | Passage Key | - | - | - |
| Phipps Preserve | - | - | - | Phipps Preserve | - | - | - |
| Port Orange Spoil Islands | - | - | - | Port Orange Spoil Islands | - | - | - |

Table 23. Continued

| Fall Migration (Jul 1-Oct 31) | | | | Spring Migration (Apr 1-Jun 10) | | | |
|---|---|---|---|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** | **Location** | **Peak Count** | **Year** | **Source** |
| Sanibel Island (A) | 292 | 1975 | ISS | Sanibel Island (Ramada to Lighthouse) | 41 | 1986 | ISS |
| | 198 | 1979 | ISS | | 10 | 1988 | ISS |
| | 150 | 2001 | Harrington unpublished data | | 200 | 1989 | ISS |
| | | | | | 109 | 1990 | ISS |
| | | | | | 200 | 1992 | ISS |
| Sarasota | 550 | 1981 | Harrington and Leddy 1982 | Sarasota | - | - | - |
| Shell Island Inlet, W | - | - | - | Shell Island Inlet, W | 3 | 1993 | ISS |
| Snake Bight | - | - | - | Snake Bight | - | - | - |
| St Marks NWR | 2 | 1988 | ISS | St Marks NWR | - | - | - |
| (Mounds Pool 3) | 4 | 1993 | ISS | | | | |
| St. Petersburg | 800 | 1981 | Harrington and Leddy 1982 | St. Petersburg | - | - | - |
| | 450 | 1999 | Harrington unpublished data | | | | |
| St. Vincent NWR | 75 | 1988 | ISS | St Vincent NWR | 22 | 1988 | ISS |
| | | | | | 7 | 2000 | ISS |
| | | | | | 120 | 2001 | ISS |
| St. George Island | 25 | 1978 | ISS | St George Island | 7 | 1981 | ISS |
| | 11 | 1979 | ISS | | 4 | 1983 | ISS |
| | 3 | 1982 | ISS | | | | |
| Three Rooker Bar | | | | Three Rooker Bar | | | |
| Turkey Point | - | - | - | Turkey Point | 1 | 1993 | ISS |
| Venice | 6 | 1977 | ISS | Venice | - | - | - |
| | 9 | 1978 | ISS | | | | |
| West Lake | | | | West Lake | | | |
| Virginia Key Mudflats | 26 | 1984 | ISS | Virginia Key Mudflats | 10 | 1985 | ISS |
| | 8 | 1985 | ISS | | | | |
| | 17 | 1986 | ISS | | | | |
| (Sewage) | 12 | 1984 | ISS | | | | |
| (Sewage) | 5 | 1985 | ISS | | | | |
| (Sewage) | 6 | 1986 | ISS | | | | |
| Yent Bayou | 2 | 1994 | Sprandel *et al.* 1997 | Yent Bayou | 22 | 1994 | Sprandel *et al.* 1997 |

Table 24. Peak counts of red knots during winter at various sites in Florida. Interstitial periods not included. ISS = International Shorebird Survey (Harrington unpublished data).

| Winter (Nov 1-Feb 28) | | | |
|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** |
| 5 Phosphate Mines | 1 | 1990 | ISS |
| Alligator Pt | 62 | 1988 | ISS |
| | 42 | 1989 | ISS |
| Anclote Key (North) | 1 | 1993 | Sprandel *et al.* 1997 |
| | 12 | 1994 | Sprandel *et al.* 1997 |
| (South) | 53 | 1994 | Sprandel *et al.* 1997 |
| Bald Point | 20 | 1977 | ISS |
| | 16 | 1994 | ISS |
| Bayway and Ft Desoto | - | - | - |
| Bell Glade Farm | - | - | - |
| Caladesi Island (North) | 300 | 1994 | Sprandel *et al.* 1997 |
| (Dunedin Pass) | 165 | 1994 | Sprandel *et al.* 1997 |
| Cape Romano | 600 | 1980 | ISS |
| | 902 | 1981 | ISS |
| | 1,025 | 1982 | ISS |
| | 1,625 | 1983 | ISS |
| | 1,800 | 1984 | ISS |
| | 2,000 | 1985 | ISS |
| | 1,410 | 1987 | ISS |
| | 1,170 | 1988 | ISS |
| | 650 | 1989 | ISS |
| | 200 | 2003 | Harrington unpublished data |
| (Morgan Beach) | 1,550 | 1993 | ISS |
| Cape San Blas | 37 | 1988 | ISS |
| | 120 | 1993 | ISS |
| Capri Pass | 30 | 1993 | ISS |
| | 286 | 1994 | Sprandel *et al.* 1997 |
| Carl Ross Key | 4 | 1993 | ISS |
| Carrabelle Beach | 203 | 1992 | ISS |
| | 114 | 1993 | ISS |
| | 69 | 1994 | Sprandel *et al.* 1997 |
| | 105 | 1995 | ISS |
| | 24 | 1996 | ISS |
| Casey Key Beach | 300 | 1977 | ISS |
| | 195 | 1978 | ISS |
| | 6,500 | 1979 | ISS |
| | 402 | 1980 | ISS |
| | 365 | 1981 | ISS |
| | 200 | 1983 | ISS |
| | 844 | 1984 | ISS |
| CC Causeway | 20 | 1977 | ISS |
| (A) | 36 | 1994 | Sprandel *et al.* 1997 |
| (B) | 3 | 1994 | Sprandel *et al.* 1997 |

Table 24. Continued

| Winter (Nov 1-Feb 28) | | | |
|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** |
| CC Causeway (East) | 15 | 1994 | ISS |
| (southwest) | 4 | 1994 | ISS |
| Clear Springs Phosphate Mine | - | - | - |
| Crooked Island | 3 | 1993 | ISS |
| (Walk) | 1 | 1993 | ISS |
| Ding Darling NWR | 1,000 | 1990 | ISS |
| | 30 | 1994 | Sprandel *et al.* 1997 |
| | 35 | 2000 | ISS |
| | 31 | 2003 | ISS |
| Dunedin | 3,000 | 2001 | Harrington unpublished data |
| East of Bay North | 1 | 1993 | ISS |
| | 5 | 1995 | ISS |
| Englewood | 1,125 | 1982 | Harrington and Leddy 1982 |
| FSU Marine Lab | 1 | 1978 | ISS |
| Ft Desoto | 400 | 2003 | Harrington unpublished data |
| | 125 | 2004 | Harrington unpublished data |
| (East) | 2 | 1994 | Sprandel *et al.* 1997 |
| (North) | 6 | 1993 | ISS |
| (North) | 7 | 1994 | Sprandel *et al.* 1997 |
| Ft George Inlet | - | - | - |
| Ft Myers Lagoon | 30 | 1993 | ISS |
| Ft Pierce Inlet | 1 | 1979 | ISS |
| Georgestone State Park | 16 | 1979 | ISS |
| Hickory Mound Impoundment | 15 | 1995 | ISS |
| Honeymoon Island | 10 | 1986 | ISS |
| | 30 | 1988 | ISS |
| | 200 | 1989 | ISS |
| | 100 | 1990 | ISS |
| | 1,000 | 1992 | ISS |
| | 1,520 | 1993 | ISS |
| | 1,500 | 1994 | ISS |
| | 2,300 | 1995 | ISS |
| | 1,000 | 1996 | ISS |
| | 300 | 1997 | ISS |
| | 400 | 1998 | ISS |
| | 700 | 1999 | ISS |
| | 550 | 2000 | ISS |
| | 300 | 2001 | ISS |
| | 140 | 2002 | ISS |
| | 191 | 2003 | ISS |
| | 4 | 2004 | ISS |
| (N of toll booth) | 1 | 1993 | ISS |
| Hooker's Point, Tampa | - | - | - |
| Hugenot State Park, Ward's Bank | 402 | 1977 | ISS |

Table 24. Continued

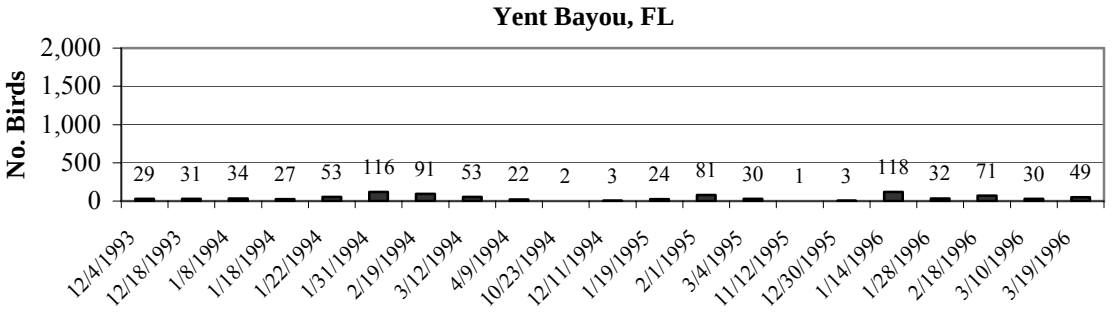
| Winter (Nov 1-Feb 28) | | | |
|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** |
| | 603 | 1978 | ISS |
| Hugenot State Park, Ward's Bank | 156 | 1979 | ISS |
| | 500 | 1980 | ISS |
| | 4 | 1980 | ISS |
| | 2 | 1981 | ISS |
| Island N Bunces Pass | 280 | 1994 | Sprandel *et al.* 1997 |
| Kennedy Space Center | 2 | 1994 | Sprandel *et al.* 1997 |
| Lake Ingraham | 10 | 1993 | Sprandel *et al.* 1997 |
| | 122 | 1994 | Sprandel *et al.* 1997 |
| Lake Woodruff NWR | - | - | - |
| Lanark Reef | 212 | 1993 | ISS |
| | 147 | 1994 | Sprandel *et al.* 1997 |
| Lido Beach | 7 | 1994 | Sprandel *et al.* 1997 |
| Little Estero | 241 | 1993 | Sprandel *et al.* 1997 |
| | 164 | 1994 | Sprandel *et al.* 1997 |
| Longboat Key | 1,400 | 1982 | Harrington and Leddy 1982 |
| | 3,000 | 2000 | Harrington unpublished data |
| | 2,300 | 2004 | Harrington unpublished data |
| (North) | 100 | 1977 | ISS |
| (North) | 2,000 | 1978 | ISS |
| (North) | 1,000 | 1979 | ISS |
| (North) | 700 | 1980 | ISS |
| (North) | 550 | 1981 | ISS |
| (South) | 140 | 1993 | ISS |
| (Beer Can Island) | 100 | 1977 | ISS |
| (Beer Can Island) | 100 | 1978 | ISS |
| Marco Island, Tigertail Beach | 25 | 1993 | ISS |
| Marco River | 150 | 1974 | ISS |
| | 20 | 1975 | ISS |
| | 5 | 1976 | ISS |
| | 1 | 1977 | ISS |
| | 100 | 1978 | ISS |
| | 35 | 1979 | ISS |
| | 60 | 1980 | ISS |
| | 130 | 1981 | ISS |
| | 89 | 1982 | ISS |
| | 70 | 1983 | ISS |
| | 25 | 1984 | ISS |
| | 487 | 1985 | ISS |
| | 490 | 1986 | ISS |
| | 2 | 1986 | ISS |
| | 800 | 1987 | ISS |
| | 275 | 1988 | ISS |
| | 200 | 1989 | ISS |

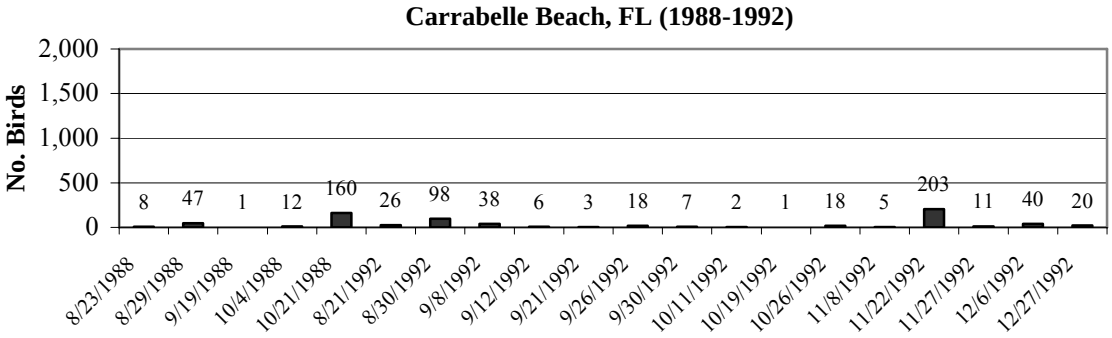
Table 24. Continued

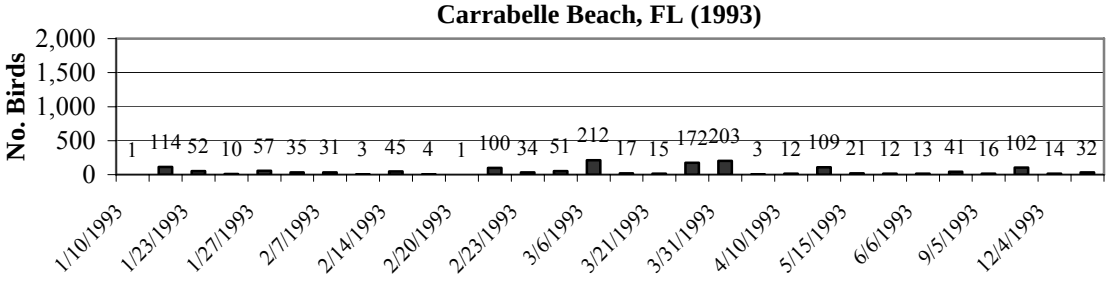
| Winter (Nov 1-Feb 28) | | | |
|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** |
| Mayport Naval Station, Jetties Beach | - | - | - |
| Mckay Bay, Tampa | - | - | - |
| Merritt Island NWR (10D) | 9 | 1999 | ISS |
| (10D) | 140 | 2002 | ISS |
| (Black Point Dr) | 31 | 1993 | ISS |
| (Black Point Dr) | 164 | 1994 | Sprandel *et al.* 1997 |
| (T10B) | 53 | 1999 | ISS |
| (T10B) | 3 | 2000 | ISS |
| (T10B) | 7 | 2002 | ISS |
| (T10C) | 47 | 1999 | ISS |
| N. Sarasota Bay | - | - | - |
| Naples | 19 | 1981 | ISS |
| | 12 | 1982 | ISS |
| Nassau Sound | - | - | - |
| Nevarre Beach, Pensacola | - | - | - |
| New Smyrna Beach | - | - | - |
| Palm Island Resort | 1 | 1993 | Sprandel *et al.* 1997 |
| | 223 | 1994 | Sprandel *et al.* 1997 |
| Palm Key | 22 | 1993 | ISS |
| | 65 | 1994 | Sprandel *et al.* 1997 |
| Passage Key | 300 | 1994 | Sprandel *et al.* 1997 |
| Phipps Preserve | 42 | 1993 | ISS |
| Port Orange Spoil Islands | 6 | 1993 | ISS |
| Sanibel Island A | 50 | 1980 | ISS |
| | 75 | 2004 | Harrington unpublished data |
| Sarasota | 900 | 1981 | Harrington and Leddy 1982 |
| | 4,200 | 1981 | Harrington and Leddy 1982 |
| | 200 | 2004 | Harrington unpublished data |
| Shell Key | 775 | 1994 | Sprandel *et al.* 1997 |
| | 3,000 | 2000 | Harrington unpublished data |
| | 3,000 | 2001 | Harrington unpublished data |
| Snake Bight | 120 | 1993 | ISS |
| | 60 | 1994 | Sprandel *et al.* 1997 |
| St Marks NWR | 10 | 1989 | ISS |
| (Lighthouse) | 10 | 1988 | ISS |
| (Lighthouse) | 3 | 1993 | ISS |
| St. Petersburg | 325 | 2004 | Harrington unpublished data |
| | | | |
| St. Vincent Island - Indian Pass | 15 | 1994 | ISS |
| St.George Island | 80 | 1978 | ISS |
| | 1 | 1982 | ISS |
| | 3 | 1983 | ISS |
| Three Rooker Bar (North) | 59 | 1994 | Sprandel *et al.* 1997 |
| (Southeast) | 20 | 1994 | Sprandel *et al.* 1997 |
| Turkey Point | - | - | - |

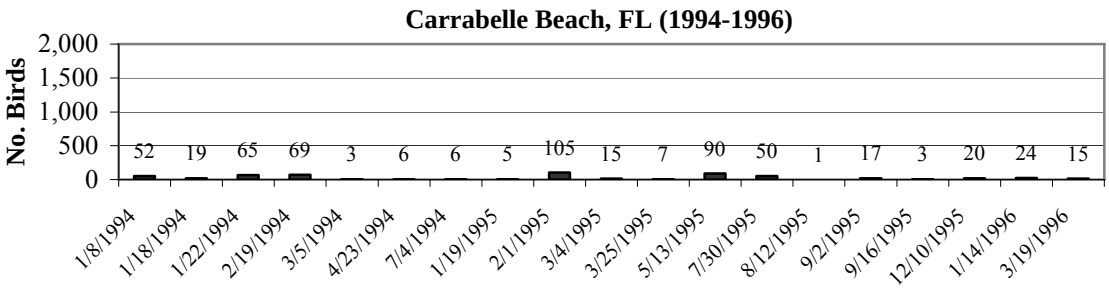
Table 24. Continued

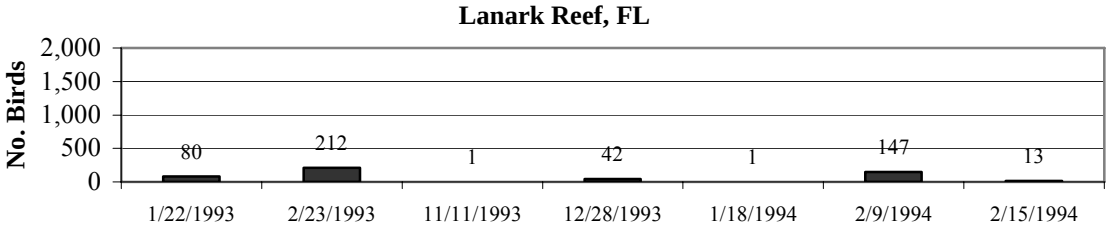
| Winter (Nov 1-Feb 28) | | | |
|---|---|---|---|
| **Location** | **Peak Count** | **Year** | **Source** |
| Venice | 125 | 1977 | ISS |
| Venice | 11 | 1978 | ISS |
| | 56 | 1979 | ISS |
| West Lake | 1 | 1994 | ISS |
| Virginia Key Mudflats | - | - | - |
| Yent Bayou | 31 | 1993 | ISS |
| | 116 | 1994 | Sprandel *et al.* 1997 |
| | 81 | 1995 | ISS |
| | 118 | 1996 | ISS |

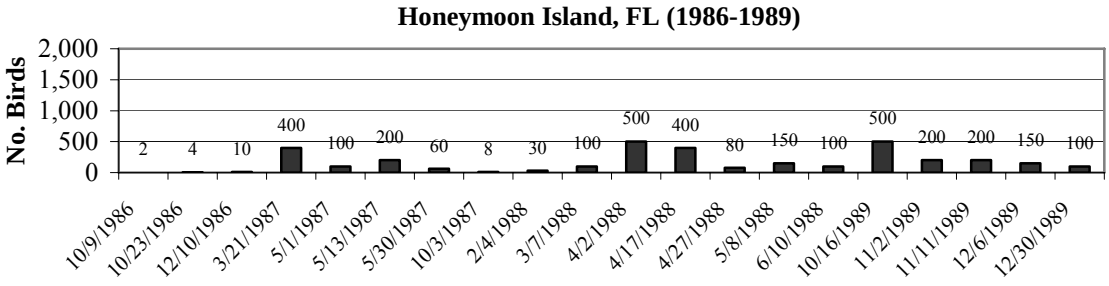


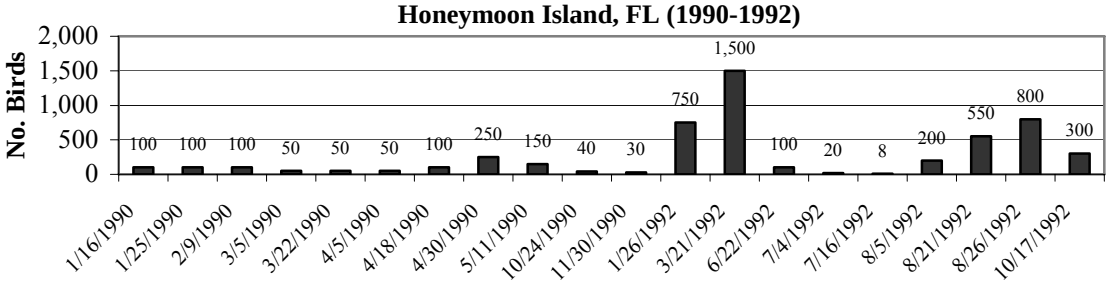



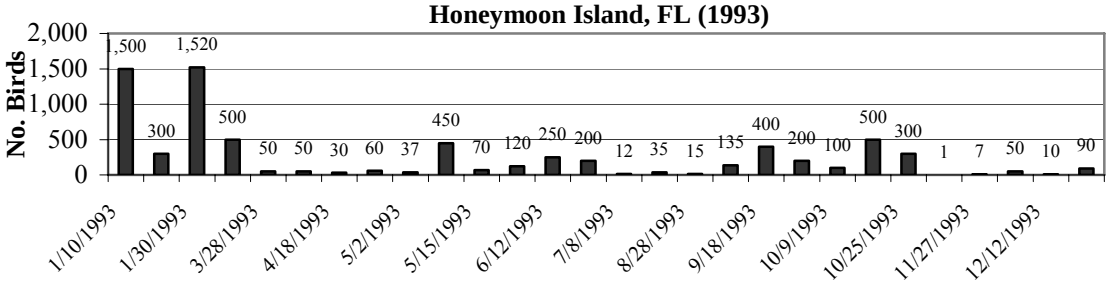



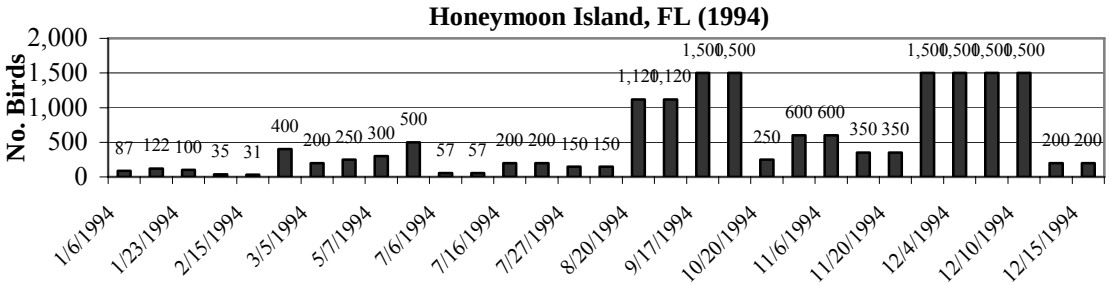

Carrabelle Beach, FL (1994-1996)
No. Birds
2,000
1,500
1,000
500
0
52 19 65 69 3 6 6 5 105 15 7 90 50 1 17 3 20 24 15
1/8/1994 1/18/1994 1/22/1994 2/19/1994 3/5/1994 4/23/1994 7/4/1994 1/19/1995 2/1/1995 3/4/1995 3/25/1995 5/13/1995 7/30/1995 8/12/1995 9/2/1995 9/16/1995 12/10/1995 1/14/1996 3/19/1996

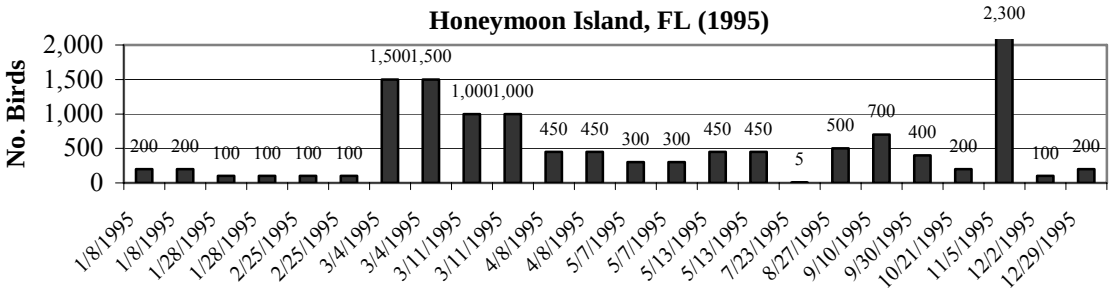

Lanark Reef, FL
No. Birds
2,000
1,500
1,000
500
0
80 212 1 42 1 147 13
1/22/1993 2/23/1993 11/11/1993 12/28/1993 1/18/1994 2/9/1994 2/15/1994

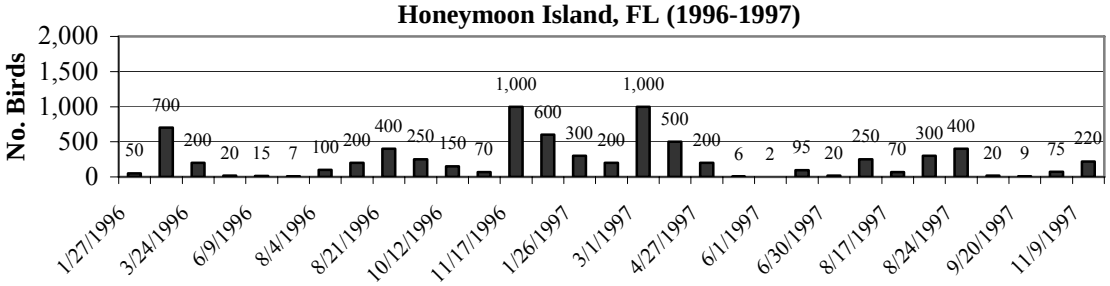

Honeymoon Island, FL (1986-1989)
No. Birds
2,000
1,500
1,000
500
0
2 4 10 400 100 200 60 8 30 100 500 400 80 150 100 500 200 200 150 100
10/9/1986 10/23/1986 12/10/1986 3/21/1987 5/1/1987 5/13/1987 5/30/1987 10/3/1987 2/4/1988 3/7/1988 4/2/1988 4/17/1988 4/27/1988 5/8/1988 6/10/1988 10/16/1989 11/2/1989 11/11/1989 12/6/1989 12/30/1989

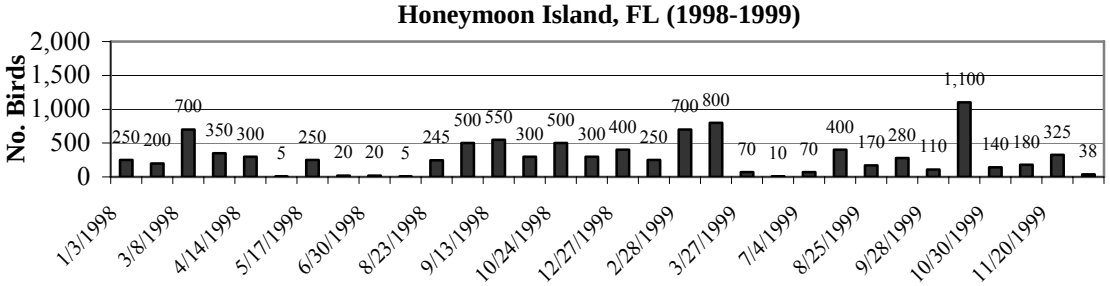

Honeymoon Island, FL (1990-1992)
No. Birds
2,000
1,500
1,000
500
0
100 100 100 50 50 50 100 250 150 40 30 750 1,500 100 20 8 200 550 800 300
1/16/1990 1/25/1990 2/9/1990 3/5/1990 3/22/1990 4/5/1990 4/18/1990 4/30/1990 5/11/1990 10/24/1990 11/30/1990 1/26/1992 3/21/1992 6/22/1992 7/4/1992 7/16/1992 8/5/1992 8/21/1992 8/26/1992 10/17/1992

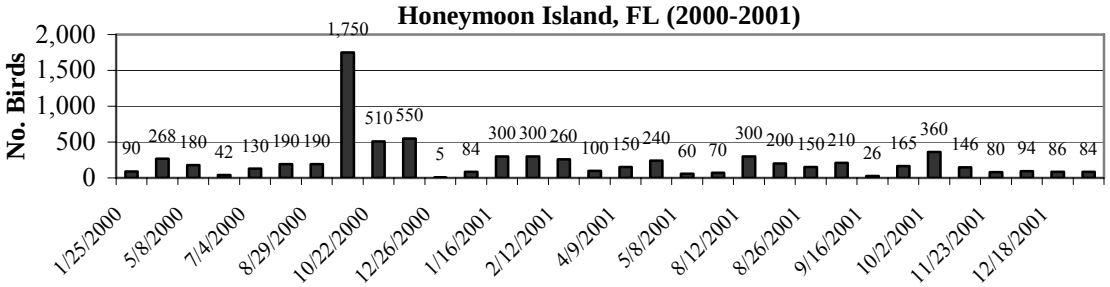

Honeymoon Island, FL (1993)
No. Birds
2,000
1,500
1,000
500
0
1,500 300 1,520 500 50 50 30 60 37 450 70 120 250 200 12 35 15 135 400 200 100 500 300 1 7 50 10 90
1/10/1993 1/30/1993 3/28/1993 4/18/1993 5/2/1993 5/15/1993 6/12/1993 7/8/1993 8/28/1993 9/18/1993 10/9/1993 10/25/1993 11/27/1993 12/12/1993

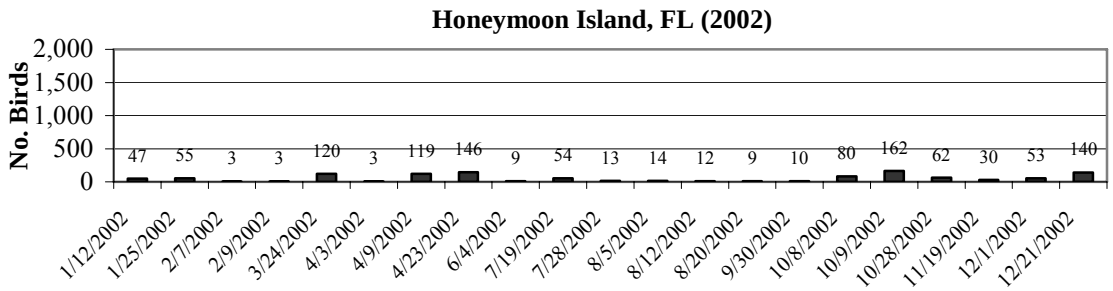

Honeymoon Island, FL (1994)
No. Birds
2,000
1,500
1,000
500
0
87 122 100 35 31 400 200 250 300 500 57 57 200 200 150 150 1,120 1,120 1,500 1,500 250 600 600 350 350 1,500 1,500 1,500 1,500 200 200
1/6/1994 1/23/1994 2/15/1994 3/5/1994 5/7/1994 7/6/1994 7/16/1994 7/27/1994 8/20/1994 9/17/1994 10/20/1994 11/6/1994 11/20/1994 12/4/1994 12/10/1994 12/15/1994

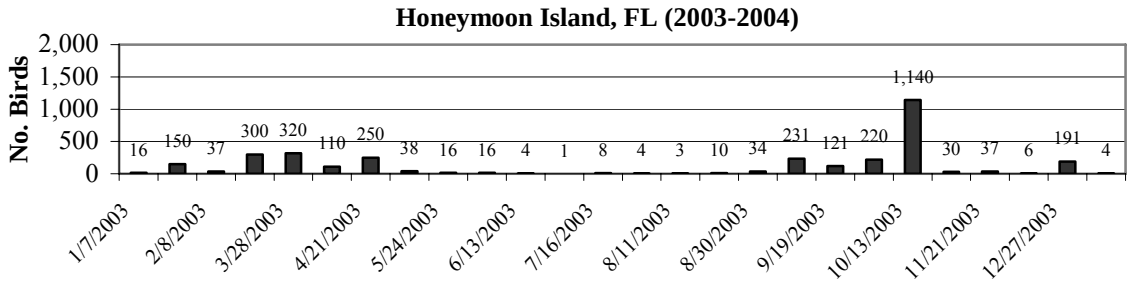

Honeymoon Island, FL (1995)
No. Birds
2,000
1,500
1,000
500
0
200 200 100 100 100 100 1,500 1,500 1,000 1,000 450 450 300 300 450 450 5 500 700 400 200 2,300 100 200
1/8/1995 1/8/1995 1/28/1995 1/28/1995 2/25/1995 2/25/1995 3/4/1995 3/4/1995 3/11/1995 3/11/1995 4/8/1995 4/8/1995 5/7/1995 5/7/1995 5/13/1995 5/13/1995 7/23/1995 8/27/1995 9/10/1995 9/30/1995 10/21/1995 11/5/1995 12/2/1995 12/29/1995

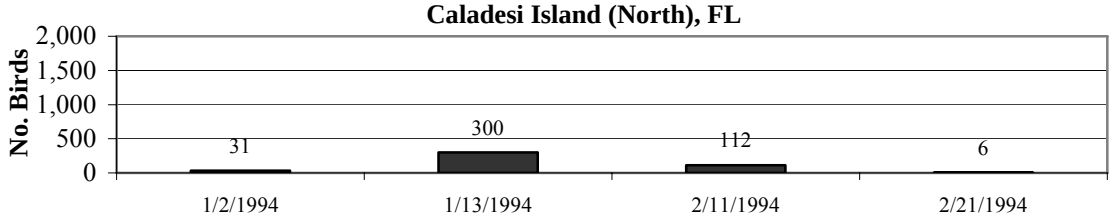

Honeymoon Island, FL (1996-1997)
No. Birds
2,000
1,500
1,000
500
0
50 700 200 20 15 7 100 200 400 250 150 70 1,000 600 300 200 1,000 500 200 6 2 95 20 250 70 300 400 20 9 75 220
1/27/1996 3/24/1996 6/9/1996 8/4/1996 8/21/1996 10/12/1996 11/17/1996 1/26/1997 3/1/1997 4/27/1997 6/1/1997 6/30/1997 8/17/1997 8/24/1997 9/20/1997 11/9/1997

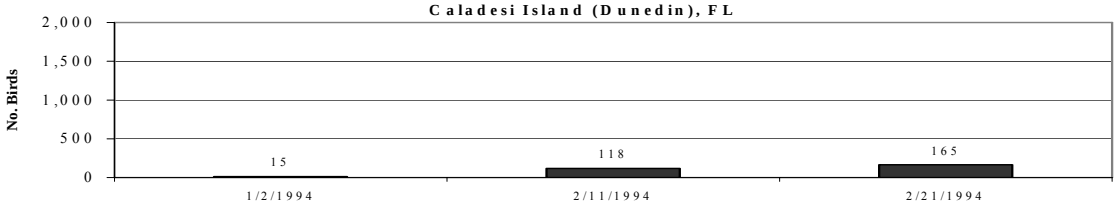

Honeymoon Island, FL (1998-1999)
No. Birds
2,000
1,500
1,000
500
0
250 200 700 350 300 5 250 20 20 5 245 500 550 300 500 300 400 250 700 800 70 10 70 400 170 280 110 1,100 140 180 325 38
1/3/1998 3/8/1998 4/14/1998 5/17/1998 6/30/1998 8/23/1998 9/13/1998 10/24/1998 12/27/1998 2/28/1999 3/27/1999 7/4/1999 8/25/1999 9/28/1999 10/30/1999 11/20/1999

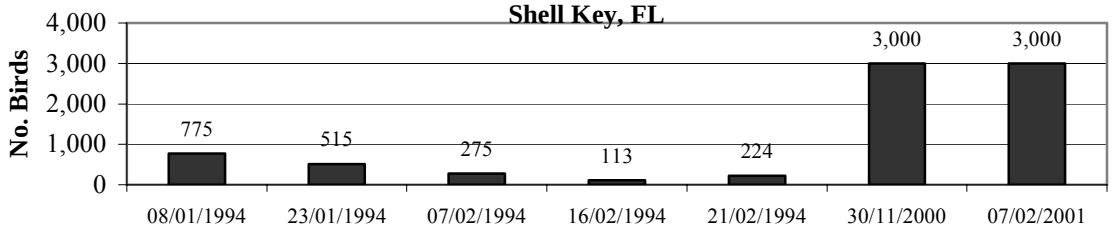

Honeymoon Island, FL (2000-2001)
No. Birds
2,000
1,500
1,000
500
0
90 268 180 42 130 190 190 1,750 510 550 5 84 300 300 260 100 150 240 60 70 300 200 150 210 26 165 360 146 80 94 86 84
1/25/2000 5/8/2000 7/4/2000 8/29/2000 10/22/2000 12/26/2000 1/16/2001 2/12/2001 4/9/2001 5/8/2001 8/12/2001 8/26/2001 9/16/2001 10/2/2001 11/23/2001 12/18/2001

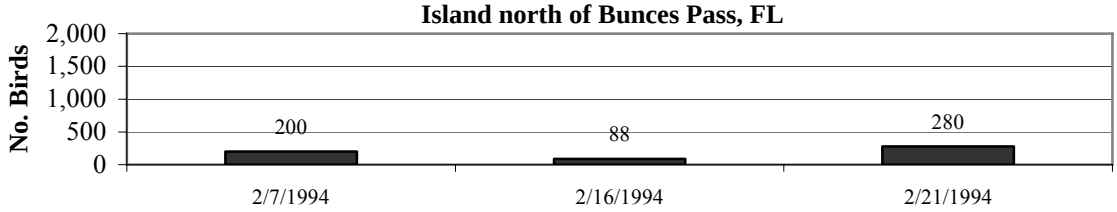

Honeymoon Island, FL (2002)
No. Birds
2,000
1,500
1,000
500
0
47 55 3 3 120 3 119 146 9 54 13 14 12 9 10 80 162 62 30 53 140
1/12/2002
1/25/2002
2/7/2002
2/9/2002
3/24/2002
4/3/2002
4/9/2002
4/23/2002
6/4/2002
7/19/2002
7/28/2002
8/5/2002
8/12/2002
8/20/2002
9/30/2002
10/8/2002
10/9/2002
10/28/2002
11/19/2002
12/1/2002
12/21/2002


Honeymoon Island, FL (2003-2004)
No. Birds
2,000
1,500
1,000
500
0
16 150 37 300 320 110 250 38 16 16 4 1 8 4 3 10 34 231 121 220 1,140 30 37 6 191 4
1/7/2003
2/8/2003
3/28/2003
4/21/2003
5/24/2003
6/13/2003
7/16/2003
8/11/2003
8/30/2003
9/19/2003
10/13/2003
11/21/2003
12/27/2003


Caladesi Island (North), FL
No. Birds
2,000
1,500
1,000
500
0
31 300 112 6
1/2/1994
1/13/1994
2/11/1994
2/21/1994


Caladesi Island (Dunedin), FL
No. Birds
2,000
1,500
1,000
500
0
15 118 165
1/2/1994
2/11/1994
2/21/1994


Shell Key, FL
No. Birds
4,000
3,000
2,000
1,000
0
775 515 275 113 224 3,000 3,000
08/01/1994
23/01/1994
07/02/1994
16/02/1994
21/02/1994
30/11/2000
07/02/2001


Island north of Bunces Pass, FL
No. Birds
2,000
1,500
1,000
500
0
200 88 280
2/7/1994
2/16/1994
2/21/1994

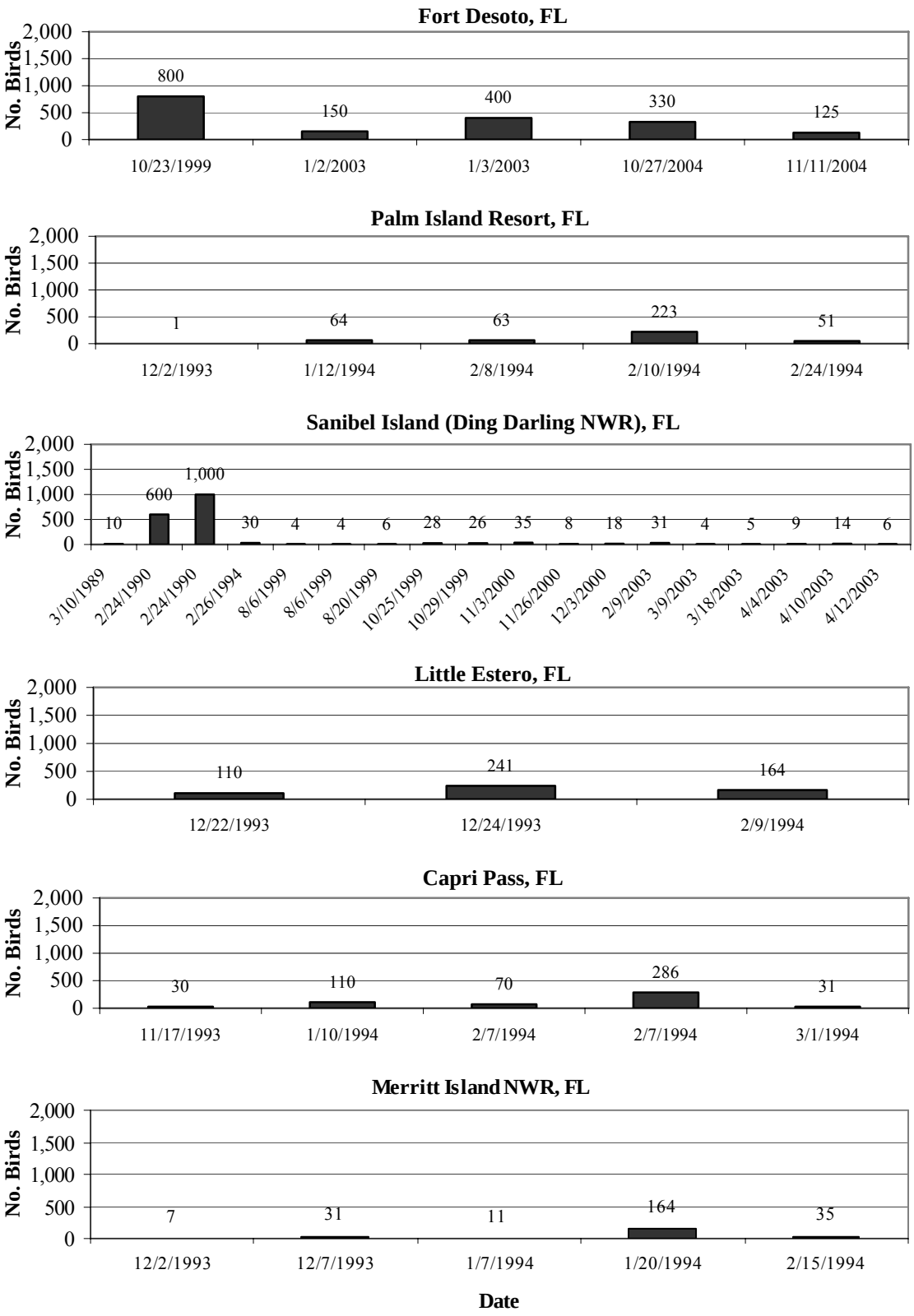



Figure 62. The number of red knots counted in Florida (Harrington, unpublished data).

Table 25. Red knot sites in Florida ordered according to the maximum number of knots recorded.

| Site Name | Importance (# knots recorded) | Location Lat. / Long. |
|---|---|---|
| Shell Key | 113-775 | 27 40.5 / 82 44.0 |
| Caladesi Island, Hurricane Pass | 6-300 | 28 03.0 / 82 49.3 |
| Passage Key | 0-300 | 27 33.5 / 82 44.5 |
| Capri Pass (a.k.a. Key Island) | 31-286 | 25 58.45 / 81 44.82 |
| Is. N. of Bunces Pass (now contiguous with Shell Key) | 0-280 | 27 40.0 / 82 44.0 |
| Little Estero Island | 0-241 | 26 25.0 / 81 54.0 |
| Palm Island Resort | 51-223 | 26 53.5 / 82 20.5 |
| Caladesi Island, Dunedin Pass | 0-165 | 28 01.0 /8 2 49.45 |
| Merritt Island NWR, Black Point Drive | 0-164 | 28 40.2 / 80 46.37 |
| Lanark Reef | 1-147 | 29 52.4 / 84 35.3 |
| Honeymoon Island | 31-122 | 28 04.0 / 82 49.5 |
| Lake Ingraham, SE End | 0-122 | 25 08.67 / 81 05.2 |
| Yent Bayou | 0-116 | 29 47.4 / 84 45.5 |
| Three Rooker Bar (N and S Ends) | 0-59 | 28 07.0 / 82 50.5 |
| Carrabelle Beach | 0-69 | 29 50.0 / 84 40.5 |
| NW of Palm Key | 0-65 | 25 07.38 / 80 53.73 |
| Snake Bite Channel | 0-60 | 25 08.13 / 80 53.79 |
| Anclote Key (N and S ends) | 0-53 | 28 12.5 / 82 51.0 |
| Courtney Campbell Causeway SE, (2 sites) | 0-36 | 27 58.0 / 82 33.0 |
| Ding Darling NWR, tower stop | 0-30 | 26 75.5 / 82 08.0 |
| Ft. DeSoto NW End | 0-7 | 27 37.5 / 82 42.0 |
| Lido Beach | 0-7 | 27 19.5 / 82 35.0 |
| Ft. DeSoto East End | 0-2 | 27 38.0 / 82 44.5 |
| Kennedy Space Ctr., Pad 39B | 0-2 | 28 37.48 / 80 36.7 |

b. Georgia

The barrier coast of Georgia, approximately 160 km long, supports measurable numbers of red knots from about mid-July through May. There is a six-week period in June and early July, when only a few birds might be found in some remote locations. Clearly, the most significant documented event involving red knots in Georgia is the annual fall staging event that can include as many as 10,000 birds at one time. Less well-understood is the biology of the knots that winter in Georgia, and those that migrate through Georgia in the spring (Table 26).

The fall staging phenomenon with large numbers of knots was first discovered in September 1996. This area is remote, and it is very likely red knots have been staging in this area prior to 1996. Knots in large but variable numbers have been recorded every September since 1996. The staging event appears to have a focal area at the mouth of the Altamaha River, where extensive river-generated shoals become exposed at lower tides creating vast areas of feeding habitat for the knots (Figs. 63 and 64). The use area includes the southern beaches of Sapelo Island (National Estuarine Research Reserve), Wolf Island and its bar (National Wildlife Refuge), Little Egg Island Bar (State Natural Area), and Little St. Simons Island (privately owned, undeveloped) (Appendix - Map 14).

.

Table 26. Important red knot stopover/winter locations in Georgia

| Site Name | Importance Fall Staging (scale 1-20) # of birds | Importance Winter (scale 1-20) # of birds | Importance Spring Migration (1-20) # of birds |
|---|---|---|---|
| Little Tybee Island | None (1) | Medium (10) 10-1000 | Low (5) 10-100 |
| Ogeechee River Bar | None (1) | Low (5) 10's | High (15) 100s |
| Wassaw Island | None (1) | Medium (10) 100-1000 | High (15) 100-1000 |
| Ossabaw Island | None (1) | High (15) 10-1000 | High (15) 10-1000 |
| St. Catherines Island | None (1) | High (15) 10-1000 | Medium (15) 100 |
| St. Catherines Bar | None (1) | Medium (8) 10-100 | Medium (12) 10-100 |
| Grass Island | None (1) | Low (5) 10 | High (18) 100-1000 |
| Blackbeard Island | None (1) | Medium (10) 10-100 | Medium (10) 10-100 |
| Sapelo Island | Very High (15) 1000 | Medium (10) 10-100 | Medium (10) 10-100 |
| Wolf Island | Very High/Critical (20) 1000-10,000 | Medium (8) 10-100 | High (17) 100-1000 |
| Little Egg Island Bar | Very High/Critical (20) 1000-10,000 | Medium (8) 10-100 | Medium (15) 10-100 |
| Little St. Simons Island | Very High/Critical (20) 1000-10,000 | Medium (10) 10-100 | High (15) 100 |
| Sea Island | None (1) | Medium (10) 10-100 | Low (5) 10-100 |
| Gould's Inlet, St. Simons Island | None (1) | Medium (12) 10-100 | Medium (10) 10-100 |
| Jekyll Island | None (1) | Low (5) 10-100 | Medium (8) 10-100 |
| Little Cumberland Island | None (1) | Low (3) 10 | Low (5) 10 |
| Cumberland Island | None (1) | High (15) 100-1000 | Medium (12) 100 |

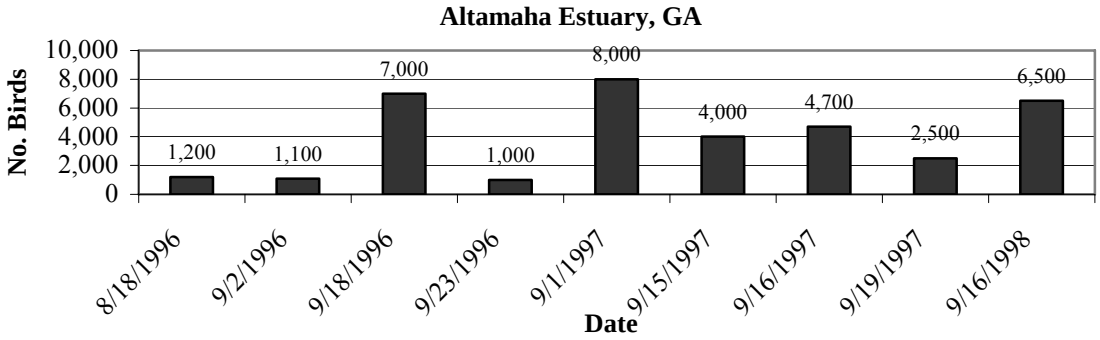



Figure 63. The number of red knots counted at Altamaha Estuary, Georgia, 1996-1998 (Winn unpublished data).

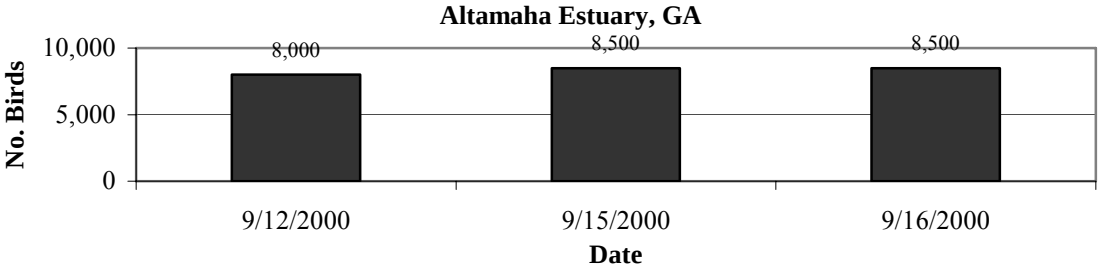



Figure 64. The number of red knots counted at Altamaha Estuary, Georgia, 2000 (Harrington unpublished data).

Temporally, knots begin to arrive in late July and early August, build in number into mid September, and disperse by mid-October. The length of stay for individual birds is not yet known. Birds banded in Delaware Bay, South Carolina, and Georgia make up nearly 100 percent of the color-marked and individually marked red knots seen in the fall staging event, and throughout the winter in Georgia.

The number of wintering knots in Georgia varies between and within years. Results of an annual winter survey for the entire Georgia coast show the minimum number of knots to be in the hundreds of birds, and the highest to be nearly 5,000. The distribution of wintering knots is generally unpredictable and dispersed over much of the barrier coast. The distribution appears to be linked closely with the abundance and availability of *Mulinia* clams.

Spring migrant use of the Georgia coast has not been studied well. Knots appear to increase in number during late April and May. Knots banded in Georgia and South Carolina can be seen with knots banded in Delaware Bay, Argentina, and Chile. Red knot use of horseshoe crab eggs appears to increase during the last two weeks of May in specific locations. By early June, knots have moved out of Georgia

c. South Carolina

Four surveys were conducted in the Cape Romain area and one in St. Helena Sound during the period 2001 to 2004. The Cape Romain surveys suggest red knot numbers peak in April and May during spring passage and then again in late August, September and October during fall passage (See Appendix - Map 15).

The graph of combined Bulls Island and Cape Romain NWR data indicate red knot numbers declined between 2001 and 2004. Bulls Island beach surveys suggest a 75 percent decline in red knots moving through in the spring from 2002 to 2004. The Cape Romain NWR surveys often did not include Bulls Island, which is part of Cape Romain NWR. Therefore, numbers can be added for a more accurate total of red knots in the Refuge.

Few surveys have occurred in the area north of Cape Romain to Pawley's Island. Most of this coastline is undeveloped and remote. The habitat appears optimal for red knot and they are often observed there. Deveaux bank and Bird Key, south of Charleston, are South Carolina Department of Natural Resources preserves for seabird nesting. These areas are visited in April to post the nesting area. Flocks of 200-400 red knots have been observed on these islands during April although formal surveys have not been conducted. Systematic surveys are required to document abundance, distribution and habitat use by red knots in coastal South Carolina. Surveys for shorebirds were conducted between 1997 and 2004 in the Cape Romain region north of Charleston, South Carolina (Fig. 65, Table 27). The amount of coastal habitat surveyed differed between years, so it is difficult to determine trend for entire period. Surveys of the same area during the period 2001 to 2004 show a decline in red knots peak numbers in April and May and then in late August, September and October (Figs. 66-68). The Cape Romain region was surveyed in 1988-1989. High counts for surveyed sites were also recorded in May and August through September suggesting these months are peak migration months in South Carolina.

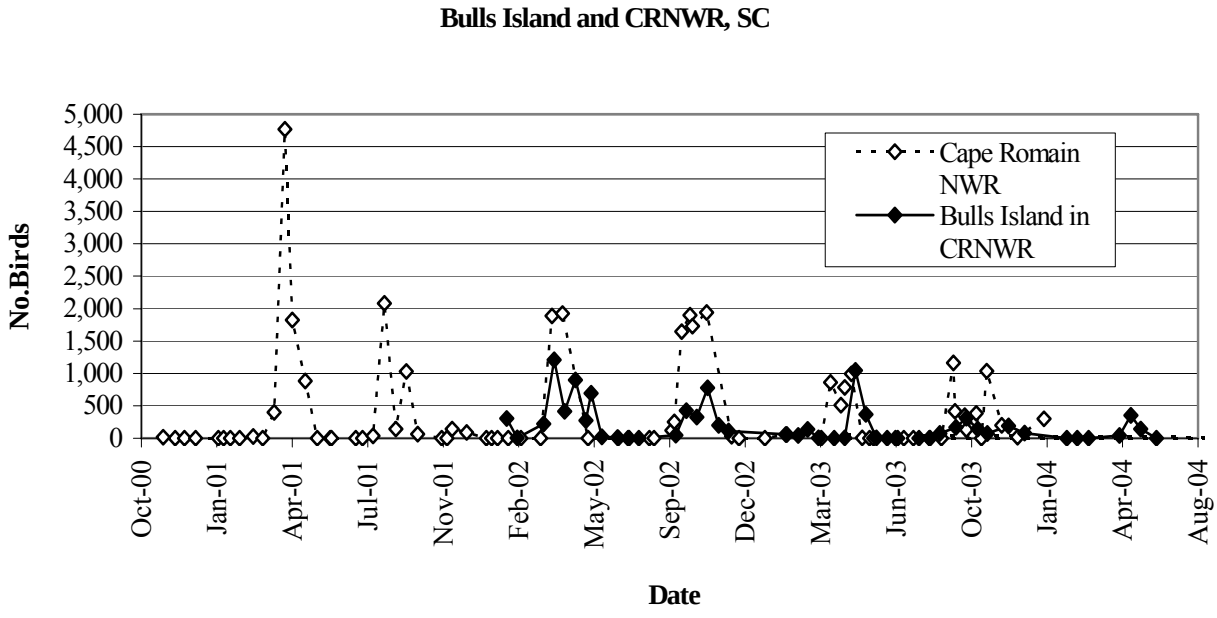



Figure 65. Red knot surveys conducted between 2000 and 2004 in the Cape Romain region of Charleston, SC (Sources provided in Table 27).

Table 27. Red knot surveys conducted between 2000 and 2004 in the Cape Romain region of Charleston, South Carolina.

| Cape Romain National Wildlife Refuge (Dawsey pers. comm. 2005) | | Bull's Island, Cape Romain National Wildlife Refuge (Cubie pers. comm. 2005, Nugent pers. comm. 2005) | |
|---|---|---|---|
| **Date Surveyed** | **# Birds** | **Date Surveyed** | **# Birds** |
| 30-Oct-00 | 18 | 28-Jan-02 | 303 |
| 15-Nov-00 | 0 | 11-Feb-02 | 5 |
| 27-Nov-00 | 0 | 18-Mar-02 | 219 |
| 12-Dec-00 | 0 | 1-Apr-02 | 1,210 |
| 11-Jan-01 | 0 | 15-Apr-02 | 417 |
| 18-Jan-01 | 0 | 29-Apr-02 | 900 |
| 27-Jan-01 | 0 | 13-May-02 | 274 |
| 8-Feb-01 | 0 | 20-May-02 | 694 |
| 26-Feb-01 | 25 | 3-Jun-02 | 20 |
| 11-Mar-01 | 0 | 24-Jun-02 | 9 |
| 26-Mar-01 | 400 | 8-Jul-02 | 0 |
| 9-Apr-01 | 4,771 | 22-Jul-02 | 0 |
| 19-Apr-01 | 1,825 | 9-Sep-02 | 49 |
| 6-May-01 | 885 | 23-Sep-02 | 426 |
| 22-May-01 | 0 | 7-Oct-02 | 327 |
| 8-Jun-01 | 0 | 21-Oct-02 | 778 |
| 10-Jun-01 | 0 | 5-Nov-02 | 201 |
| 12-Jul-01 | 0 | 18-Nov-02 | 110 |
| 21-Jul-01 | 0 | 3-Feb-03 | 58 |
| 4-Aug-01 | 36 | 18-Feb-03 | 44 |
| 19-Aug-01 | 2,080 | 3-Mar-03 | 135 |
| 3-Sep-01 | 140 | 17-Mar-03 | 4 |
| 17-Sep-01 | 1,030 | 7-Apr-03 | 0 |
| 2-Oct-01 | 65 | 21-Apr-03 | 4 |
| 3-Nov-01 | 0 | 5-May-03 | 1,047 |
| 10-Nov-01 | 0 | 19-May-03 | 368 |
| 17-Nov-01 | 140 | 2-Jun-03 | 6 |
| 6-Dec-01 | 91 | 16-Jun-03 | 0 |
| 1-Jan-02 | 0 | 30-Jun-03 | 0 |
| 8-Jan-02 | 0 | 28-Jul-03 | 0 |
| 16-Jan-02 | 0 | 11-Aug-03 | 0 |
| 30-Jan-02 | 0 | 25-Aug-03 | 72 |
| 16-Feb-02 | 0 | 15-Sep-03 | 167 |
| 14-Mar-02 | 0 | 29-Sep-03 | 310 |
| 29-Mar-02 | 1,887 | 14-Oct-03 | 142 |
| 12-Apr-02 | 1,923 | 27-Oct-03 | 74 |
| 16-May-02 | 0 | 24-Nov-03 | 191 |
| 25-Jun-02 | 0 | 15-Dec-03 | 81 |
| 9-Jul-02 | 0 | 9-Feb-04 | 0 |
| 5-Aug-02 | 0 | 23-Feb-04 | 0 |
| 11-Aug-02 | 0 | 9-Mar-04 | 0 |

Table 27. Continued

| Cape Romain National Wildlife Refuge | | Bull's Island, Cape Romain National Wildlife Refuge | |
|---|---|---|---|
| 4-Sep-02 | 121 | 19-Apr-04 | 41 |
| 7-Sep-02 | 253 | 4-May-04 | 350 |
| 17-Sep-02 | 1,646 | 17-May-04 | 140 |
| 28-Sep-02 | 1,900 | 7-Jun-04 | 0 |
| 1-Oct-02 | 1,730 | | |
| 20-Oct-02 | 1,940 | | |
| 22-Nov-02 | 30 | | |
| 2-Dec-02 | 0 | | |
| 5-Jan-03 | 0 | | |
| 2-Feb-03 | 60 | | |
| 3-Mar-05 | 0 | | |
| 21-Mar-03 | 0 | | |
| 2-Apr-03 | 864 | | |
| 16-Apr-03 | 510 | | |
| 21-Apr-03 | 782 | | |
| 30-Apr-03 | 996 | | |
| 14-May-03 | 5 | | |
| 24-May-03 | 0 | | |
| 29-May-03 | 0 | | |
| 27-Jun-03 | 0 | | |
| 8-Jul-03 | 0 | | |
| 21-Jul-03 | 0 | | |
| 12-Aug-03 | 0 | | |
| 27-Aug-03 | 0 | | |
| 12-Sep-03 | 1,164 | | |
| 14-Sep-03 | 415 | | |
| 27-Sep-03 | 345 | | |
| 29-Sep-03 | 130 | | |
| 12-Oct-03 | 386 | | |
| 19-Oct-03 | 0 | | |
| 26-Oct-03 | 1,035 | | |
| 15-Nov-03 | 202 | | |
| 6-Dec-03 | 18 | | |
| 10-Jan-04 | 300 | | |

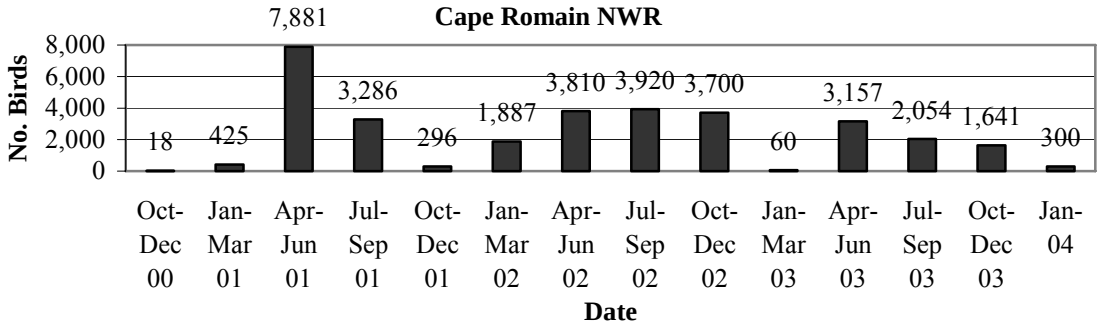



Figure 66. The number of red knots counted at Cape Romain National Wildlife Refuge, South Carolina, 2000-2004 (Dawsey pers. comm. 2005).

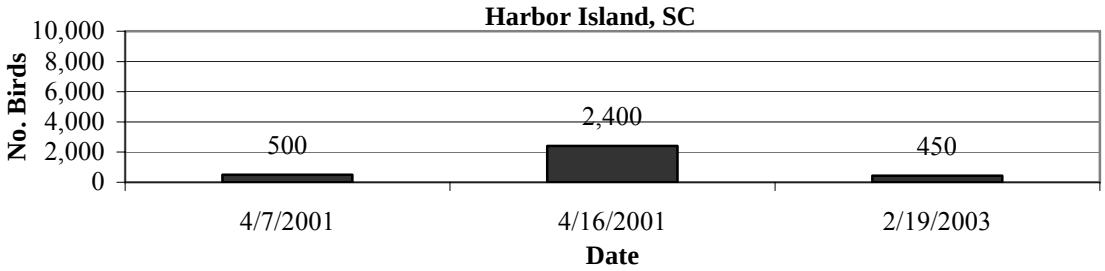



Figure 67. The number of red knots counted at Harbor Island, South Carolina, 2001-2003 (Harrington unpublished data).

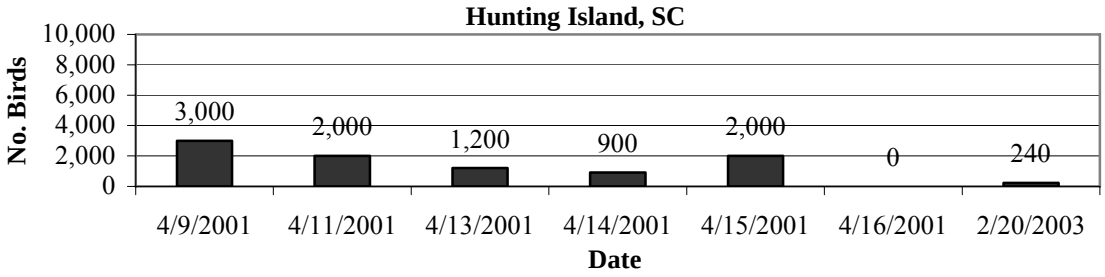



Figure 68. The number of red knots counted at Hunting Island, South Carolina, 2001-2003 (Harrington unpublished data).

d. North Carolina

Based on the limited survey information and anecdotal observations by wildlife professionals and local ornithologists, the following sites, presented from south to north, are believed to be important stopover and wintering areas for red knots (Table 28), (Appendix - Map16). Available information suggests red knots are consistently using coastal areas of North Carolina during spring and fall migration. Knots are wintering in North Carolina in limited numbers. Systematic surveys during migration and wintering seasons are necessary to determine distribution, abundance and habitat use of coastal areas by red knots.

Table 28. Stopover and potential wintering areas for red knots in North Carolina.

| Location | Spring | Count | Fall | Count | Winter | Count |
|---|---|---|---|---|---|---|
| Tubbs Inlet | 4-28-04<br>4-05-05 | 500<br>90 | --<br>-- | --<br>-- | --<br>-- | --<br>-- |
| Ocean Isl. Beach | 4-25-86 | 200 | -- | -- | -- | -- |
| Fort Fisher | --<br><br><br><br><br>-- | -- | -- | -- | Consistent winter use; CBC also records knots at this location (Fussell pers. comm. 2005) | ~30<br><br>-- |
| Bear Is./Bogue Inlet | 5-18-85<br>5-19-89<br>May (late 1990's) (Fussell pers. comm. 2005) | 200<br>1250<br>max. 100 | --<br>--<br>-- | --<br>--<br>-- | February (year unknown)<br>-- | 2<br>--<br>-- |
| Bird Shoals | --<br><br><br><br>-- | -- | -- | -- | Winter (Fussell pers. comm. 2005)<br>CBC | Max. 100<br><br>~4 |
| Cape Lookout Nat. Seashore North Core Banks | Early May, 2005 | 1,000* | -- | -- | -- | -- |
| Cape Hatteras Nat. Seashore Ocracoke | Early May, 2005 | 1,000* | -- | -- | -- | -- |
| Pea Island NWR | -- | -- | -- | -- | November (year unknown) | 100 |
| Rachel Carson Reserve | -- | -- | -- | -- | Winter consistent use (Fussell pers. comm. 2005) | 100 |
| Cedar Island NWR | May consistent use (Fussell pers. comm. 2005) | 50 - 200 individuals | -- | -- | -- | -- |

* These counts may represent the same birds

On Tubbs Inlet, 90 red knots were observed foraging on the ocean side of the island in early April 2005 (4/5/05) and 500 red knots were observed roosting on the bay side of the island in late April 2004 (4/28/04). There is little or no information concerning use of red knots during fall or winter months.

Fort Fisher State Historic Site hosts a natural rock outcrop that appears to be an important feeding area for small numbers of birds each winter and almost certainly in migration. Approximately 30 red knots are recorded there each winter by Fussell (pers. comm. 2005) and the Christmas Bird Count (CBC).

Bear Island and Bogue Inlet regularly host small numbers of red knots. The maximum number recorded in spring was 60 individuals and two birds were observed in winter (February). Historically, good numbers of red knots occurred at the outer beaches of Bear Island. This area has not been systematically surveyed.

Bird Shoals is potentially an important wintering site for red knots. A few red knots have been recorded at this site during the CBC in December. Fussell (pers. comm. 2005) has documented up to 100 birds here in the winter. No systematic surveys have been conducted during spring or fall migration to determine shorebird abundance.

Surveys conducted in 1992-93 revealed moderate numbers of red knots using the Outer Banks of Cape Lookout National Seashore during migration and in winter (Dinsmore *et al.* 1998). Most observations during this study were on North Core Banks. Recent observations suggest that South Core Banks and North Core Banks have significant numbers of red knots. About 1,000 birds were observed on the north end of North Core Banks in early May, 2005. Good numbers were observed foraging on outer beach of South Core Banks this spring. North Carolina Nongame and Endangered Wildlife Program started an International Shorebird Survey (ISS) survey at New Drum Inlet on the north end of South Core Banks (see ISS Results below). This survey will continue in the fall. Portions of Cape Lookout are important stopover sites. The east end of Shackleford Banks has extensive intertidal flats bordering Bardens Inlet and Back Sound and is considered a suitable migratory stopover for red knots in spring

Approximately 1,000 red knots were observed on south end of Ocracoke on Cape Hatteras National Seashore in early May 2005. These may be the same birds observed on North Core Banks. Red knots numbering from 10 to 200 (maximum 400) are observed on Ocracoke (Maddock pers. comm. 2005)

Results of the ISS on Clam Shoal (Table 29) indicate this site is an important wintering area and is used during spring and fall migration.

Table 29. Number of red knots observed during the 2001-2002 International Shorebird Survey on Clam Shoal, North Carolina.

| Species | Date | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 14 Feb 2001 | 26 Jul 2001 | 16 Aug 2001 | 10 Oct 2001 | 31 Oct 2001 | 9 Jan 2002 | 21 Feb 2002 | 18 Apr 2002 | 15 May 2002 |
| **Red Knot** | 80 | | | 218 | 398 | 305 | | 31 | 25 |

Refuge staff at Pea Island NWR conduct shorebird surveys and record small numbers of red knots. Staff recorded a peak of 100 birds in November. This site is likely serving as a stopover and wintering location for red knots.

A consistent number of about 100 red knots are observed in winter at the Rachel Carson Reserve (Fussell pers. comm. 2005).

Small numbers of Red knots (50 to 200 individuals) are regularly seen in the spring along a 6-mile stretch of beach on the Pamlico Sound Shoreline of Cedar Island, part of which is within Cedar Island NWR (the northwest end).

### *4. U. S. Fish and Wildlife Service Region 5*

a. Virginia

On 23 May, 2005 at the request of the New Jersey Division of Fish and Wildlife, Bryan Watts of the Center for Conservation Biology and Barry Truitt of The Nature Conservancy's Virginia Coast Reserve conducted an aerial survey of Virginia barrier islands for red knots. The survey resulted in a total estimate of 9,150 knots along the island chain. Significant concentrations were observed on Wreck Island, Paramore Island, Hog Island, and Myrtle Island.

i. Barrier Island and Lagoon System

Aerial surveys conducted throughout the springs of 1994-1996 by the same observers and using the same techniques showed that red knot migration on the Virginia Barrier islands peaks during the third week of May. The peak estimate during these 3 years was 8,955 birds documented on 21 May, 1996. The estimate for 2005 is within 200 individuals of the peak estimate from 10 years earlier. It should be noted that the Chimney Pole Marsh/Sandy Island complex inside Quinby Inlet was surveyed in 2005 (710 knots detected) but not in the mid 1990s. Although there is overwhelming evidence that the red knot population within the western hemisphere has experienced dramatic declines, current use of the Virginia Barrier Islands by migrating knots appears to be similar to the mid-1990s (Tables 30-32, Fig. 69). Volunteers have conducted weekly shorebird surveys along the outer beach surf zone of Chincoteague NWR since 1992 (Table 33). Extensive shorebird surveys conducted by the late Claudia P. Wilds at Chincoteague in the 1970s and 1980s indicated that most of the red knots documented in the area were found on Tom's Cove Beach.

Table 30. Results of aerial surveys conducted at low tide for red knots along outer beach surf zone of Virginia barrier islands from Virginia/Maryland border to mouth of Chesapeake Bay in 1995[1], 1996[2] and 2005 (Watts pers. comm. 2005, Truitt pers. comm. 2005).

| SITE | 1995 | 1996 | 2005 |
|---|---|---|---|
| Assateague Island | 57 | 174 | 60 |
| Wallops Island | 20 | 395 | 0 |
| Assawoman Island | 500 | 214 | 0 |
| Metompkin Island | 1,915 | 1,272 | 230 |
| Cedar Island | 486 | 1,622 | 200 |
| Dawson Shoals | | | |
| Parramore Island | 2,485 | 1,758 | 1,040 |
| Chimney Pole Marsh | n/a | n/a | 710 |
| Hog Island | 1,260 | 1,243 | 1,115 |
| Cobb Island | 675 | 1,030 | 780 |
| Little Cobb Island | 0 | 0 | 0 |
| Wreck Island | 5 | 31 | 4,250 |
| Ship Shoal Island | 42 | 150 | 75 |
| Myrtle Island | 90 | 150 | 500 |
| Smith Island | 423 | 883 | 100 |
| Fisherman Island | 0 | 0 | 90 |
| TOTAL | 7,958 | 8,922 | 9,150 |

[1] Results for the 1995 survey represent the high count of five surveys conducted between 25 April and 30 May 1995. See Table 31 for results of all 1995 surveys.

[2] Results for the 1996 survey represent the high count of six surveys conducted between 27 April and 10 June 1996. See Table 32 for results of all 1996 surveys.

Table 31. Results of aerial surveys conducted at low tide for red knots along outer beach surf zone of Virginia barrier islands from Virginia/Maryland border to mouth of Chesapeake Bay in 1995 (Watts pers. comm. 2005, Truitt pers. comm. 2005).

| SITE | 4/25/1995 | 5/9/1995 | 5/16/1995 | 5/24/1995 | 5/30/1995 |
|---|---|---|---|---|---|
| Assateague Island | 0 | 0 | 0 | 57 | 418 |
| Wallops Island | 0 | 0 | 190 | 20 | 5 |
| Assawoman Island | 0 | 0 | 0 | 500 | 5 |
| Metompkin Island | 0 | 20 | 1,000 | 1,915 | 34 |
| Cedar Island | 0 | 0 | 10 | 486 | 80 |
| Dawson Shoals | | | | | |
| Parramore Island | 0 | 20 | 505 | 2,485 | 1,095 |
| Hog Island | 0 | 0 | 155 | 1,260 | 655 |
| Cobb Island | 0 | 0 | 940 | 675 | 700 |
| Little Cobb Island | 0 | 0 | 0 | 0 | 0 |
| Wreck Island | 0 | 0 | 0 | 5 | 5 |
| Ship Shoal Island | 0 | 0 | 95 | 42 | 30 |
| Myrtle Island | 0 | 0 | 175 | 90 | 120 |
| Smith Island | 0 | 0 | 305 | 423 | 140 |
| Fisherman Island | 0 | 0 | 0 | 0 | 8 |
| TOTAL | 0 | 40 | 3,375 | 7,958 | 3,295 |

Table 32. Results of aerial surveys conducted at low tide for red knots along outer beach surf zone of Virginia barrier islands from Virginia/Maryland border to mouth of Chesapeake Bay in 1996 (Watts pers. comm. 2005, Truitt pers. comm. 2005).

| SITE | 4/27/1996 | 5/5/1996 | 5/13/1996 | 5/21/1996 | 6/1/1996 | 6/10/1996 |
|---|---|---|---|---|---|---|
| Assateague Island | 0 | 0 | 0 | 235 | 174 | 0 |
| Wallops Island | 0 | 0 | 0 | 0 | 395 | 0 |
| Assawoman Island | 0 | 0 | 0 | 0 | 214 | 0 |
| Metompkin Island | 0 | 0 | 0 | 2,150 | 1,272 | 0 |
| Cedar Island | 0 | 0 | 400 | 1,940 | 1,622 | 0 |
| Parramore Island | 0 | 0 | 1,035 | 1,459 | 1,758 | 0 |
| Hog Island | 0 | 0 | 60 | 947 | 1,243 | 200 |
| Cobb Island | 0 | 0 | 0 | 30 | 1,030 | 0 |
| Little Cobb Island | 0 | 0 | 0 | 0 | 0 | 0 |
| Wreck Island | 0 | 0 | 85 | 25 | 31 | 0 |
| Ship Shoal Island | 0 | 0 | 80 | 30 | 150 | 0 |
| Myrtle Island | 0 | 0 | 0 | 55 | 150 | 0 |
| Smith Island | 0 | 0 | 20 | 1,713 | 883 | 0 |
| Fisherman Island | 0 | 0 | 0 | 0 | 0 | 3 |
| TOTAL | 0 | 0 | 1,680 | 8,584 | 8,922 | 203 |

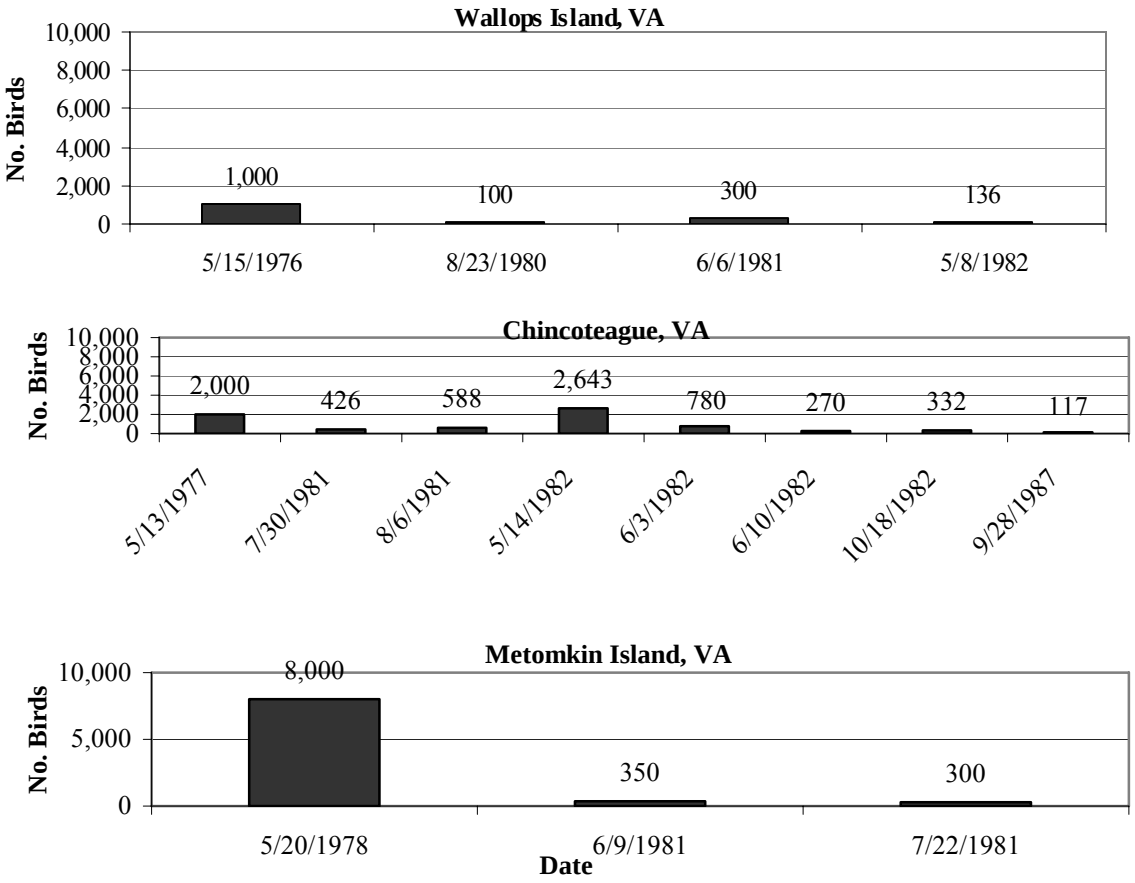



Figure 69. The number of red knots counted at Wallops Island, Chincoteague, and Metompkin Island, Virginia, 1976-1982 (Harrington unpublished data).

Table 33. Results of ground surveys conducted for red knots along outer beach surf zone of Chincoteague NWR between 1992 and 2003. Area surveyed does not include lagoon shores of Tom's Cove. Numbers indicate peak count of one to five counts conducted monthly at varying tidal stages.

| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 |
| February | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 |
| May | 15 | 36 | 47 | 144 | 133 | 73 | 54 | 90 | 5 | 0 | 543 | 4 |
| June | 28 | 9 | 124 | 98 | 5 | 11 | 42 | 48 | 13 | 66 | 282 | 0 |
| July | 105 | 27 | 58 | 143 | 3 | 62 | 25 | 1 | 0 | 2 | 8 | 0 |
| August | 209 | 106 | 306 | 20 | 5 | 13 | 0 | 0 | 3 | 4 | 88 | 24 |
| September | 23 | 19 | 65 | 99 | 10 | 5 | 1 | 0 | 0 | 1 | 35 | 0 |
| October | 37 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 1 | 55 |
| November | 26 | 2 | 0 | 12 | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 1 | 11 | 25 | 52 | 8 | 0 | 0 | 0 | 1 | 64 | 0 |

[1] Data collected and provided to Chincoteague National Wildlife Refuge by volunteers

Surveys of the outer beach surf zone of Fisherman Island NWR at the southern tip of the Delmarva Peninsula indicate very little use of the island by the red knots during spring migration (Tables 30-32). It should be noted that over 200 knots were documented on the island in May of 2005 (Denmon pers. comm. 2005). In 2004, refuge personnel initiated systematic fall shorebird surveys following International Shorebird Survey protocol (Table 34). One year of results indicate very little use of the island by red knots between August and October.

Table 34. Results of shorebird surveys conducted on Fisherman Island NWR following International Shorebird Survey protocol in 2004[1].

| Date | No. Red Knots |
|---|---|
| 11 Aug 2004 | 0 |
| 24 Aug 2004 | 0 |
| 7 Sept 2004 | 0 |
| 13 Sept 2004 | 2 |
| 23 Sept 2004 | 0 |
| 7 Oct 2004 | 1 |
| 14 Oct 2004 | 0 |

[1] Data collected and provided to Fisherman Island National Wildlife Refuge by volunteer

ii. Back Bay National Wildlife Refuge and False Cape State Park

Ten years of shorebird survey data along the ocean facing beaches of Back Bay NWR and False Cape State Park suggest that the number of red knots using those beaches during spring migration is insignificant relative to the amount of use received by the barrier islands bordering the Delmarva Peninsula (Schwab pers. comm. 2005).

iii. Metompkin and Parramore Islands

Shorebird surveys conducted during a May 2000 invertebrate study, showed that red knot numbers peaked on Metompkin Island on May 19 with approximately 3000 birds present and on Parramore Island on May 21 with approximately 3000 present. A total of 68 banded and flagged birds were noted, with 37 from Argentina, 27 from Delaware Bay, and four from Brazil.

iv. Summary of Various Studies and Surveys Documenting Red Knot Use of Different Habitats in Virginia

1. Chesapeake Bay – Western shore, various years: No systematic survey data exists for the isolated beaches that occur along the western shore of the Chesapeake Bay. These areas are almost certainly used by red knots during migration, but in unknown numbers. Over 200 individuals have been observed at Plumtree Island, National Wildlife Refuge in mid-May. Fewer numbers have been observed at Goodwin Island (property of The College of William and Mary). Other areas that may be used by knots include the beaches at Newpoint Comfort, Melford Haven and Grandview Beach (Watts pers. comm. 2005).
2. Chesapeake Bay – Western shore (Craney Island), 1975: Shorebird surveys conducted on Craney Island 2-3 days per week from 18 February through 17 July

1975 recorded large numbers of shorebirds of various species but only a single red knot near the end of May (Shopland 1975).

3. Lower western shore salt marshes, 1992: Surveys conducted for birds using 30 salt marshes along the lower western shore of the Chesapeake Bay between 6 May and 10 July, 1992. More than 1,800 shorebirds were recorded including 3 red knots (Watts 1992).
4. Lower western shore salt marshes, 1993: Tidepool surveys within salt marshes of the lower western shore of the Chesapeake Bay were conducted from 25 April through 23 October of 1993. Several hundred shorebirds were recorded using tidepools but no red knots were observed (Allen 1995).
5. Chesapeake Bay – Eastern Shore, various years: No systematic survey data exists for the Eastern Shore of the Chesapeake Bay. Flocks of more than 500 red knots have been observed during aerial surveys over Plantation Creek, Northampton County, Virginia (Watts pers. comm. 2005).
6. Lower Delmarva mainland, 1991 - 1992: Shorebird surveys within 400 agricultural fields in Northampton County, Virginia from March 1991 to February 1992 recorded more than 20,000 observations of 21 species. Only 1 observation of a red knot was made during the study. This individual was observed in May (Rottenborn 1992).
7. Beaches of Norfolk and Virginia Beach, 1992: Shorebird surveys were conducted along six beach segments within Norfolk and Virginia Beach from 8 February to 11 June, 1992. More than 3,000 observations including less than 50 red knots (McLean 1993).

v. Resighting Data

To date, no formal resighting surveys have been conducted in Virginia. In 2005, casual scans of red knot flocks on Virginia's barrier islands during spring migration revealed a number of observations of birds that were banded throughout their range (See Appendix - Map 17). This suggests that the development of a formal and systematic spring migration resighting survey effort on the barrier islands would be worthwhile expenditure of time and resources.

b. Maryland

The state of Maryland does not conduct or sponsor any organized surveys that include red knots. There are also no research, monitoring or management efforts regarding red knots in the state (Therres pers. comm. 2005). Suitable habitats do exist within the state including: Hart Miller Island, Assateague Island and Poplar Island. Poplar Island is located off the Chesapeake Bay coastline, about 34 miles south of Baltimore in Talbot County. At the time of this writing there were no accessible records of sightings of red knots within the state.

c. New Jersey and Delaware

The Delaware Bay is a migratory stopover of hemispheric importance for red knots and at least five other species of shorebird including ruddy turnstone, sanderling, dunlin, short-billed dowitcher (*Limnodromos griseus*) and semipalmated sandpiper. This section presents information specific to New Jersey and Delaware habitats and shorebird populations. Historic and current research has been conducted from the perspective of the

Delaware Bay ecosystem as migratory shorebirds use the entire bay to meet their energetic needs. This report present results of work that has been conducted collaboratively by the States of New Jersey and Delaware.

Delaware Bay, a major estuary of the United States Middle Atlantic coastal region, is located at the mouth of the Delaware River in the states of Delaware and New Jersey. Delaware Bay serves as critical stopover habitat for migrating shorebirds, especially during the spring migration when it supports some of the highest numbers recorded in the lower 48 states (Clark *et al.* 1993). Many of these migrants rely heavily on the eggs of horseshoe crabs, which come to spawn in Delaware Bay in high numbers (Myers 1986; Tsipoura and Burger 1999). Because a significant proportion of the red knot population moves through Delaware Bay during the spring migration, this area is of critical concern.

Delaware Bay is fringed by extensive coastal marshes and mudflats that are typically fronted by a sandy barrier beach. The sandy barrier beaches overlay marsh sediments (generally a fibrous peat formed by the root mat of the marsh plants) and vary in thickness from a thin veneer to about 2 m thick (Phillips 1986a). The back beaches, above normal high tide, form a low dune and are often colonized by common reed, (Phillips 1987). The intertidal portions of these sandy barrier beaches are of special significance as these are the locus of horseshoe crab spawning activity and the red knots' foraging activities. Horseshoe crabs appear to prefer beaches dominated by coarse sandy sediments and avoid beaches that have a high amount of peat sediments or are adjacent to exposed peat banks (Botton *et al.* 1988). Horseshoe crabs deposit most of their eggs 10-20 cm deep in the sandy beach sediments (Botton *et al.* 1992); eggs are then redistributed to shallower depths by subsequent spawning and wave action where they are then available for shorebird foraging. At a bay-wide scale, the use of intertidal beaches as horseshoe crab spawning habitat is limited in the north (i.e., Sea Breeze in New Jersey and Woodland Beach in Delaware) by low salinity and by ocean generated energy in the south (*i.e.*, North Cape May, New Jersey and Broadkill, Delaware).

Not surprisingly, migratory shorebird abundance is spatially variable within the Delaware Bay estuary as a consequence of these larger bay-wide patterns of horseshoe crab abundance and spawning activity. In their study of site selection of migratory shorebirds in Delaware Bay, Botton *et al.* (1994) found that migrant shorebirds, including red knots, showed a strong preference for beaches with higher numbers of crab eggs. Shorebirds were recorded to aggregate near shoreline discontinuities, such as salt marsh creek deltas and jetties that acted as concentration mechanisms for passively drifting eggs. Foraging and roosting shorebirds also react to human disturbance and are often displaced from prime foraging areas (Burger 1986, Erwin 1996). Thus near-shore development or high human use may lower a beach's value as optimal shorebird foraging habitat. During the spring 2005 migratory period, the NJDFW took aggressive measures to limit access of people and pets to key stretches of beach habitat as a means of minimizing disturbance to foraging and resting shorebirds. These various studies suggest that a complex array of factors determines the optimality of particular Delaware Bay beaches as horseshoe crab spawning and shorebird foraging habitat.

i. Red Knot Abundance and Distribution in the Delaware Bay

Aerial surveys of migrating shorebirds have been conducted along Delaware Bayshore since 1982 (Dunne *et al.* 1982, Kochenberger 1983, Clark *et al.* 1993). In 1982 and 1983 surveys were done by New Jersey Audubon Society up to three times in the stopover period; since 1986 surveys have followed a standardized method (Clark *et al.* 1993). All bayshore surveys were conducted from Cape May Canal to Cohansey River in New Jersey, and Cape Henlopen to Woodland Beach in Delaware (See Appendix - Maps 19 and 20). Surveys were conducted once per week for the six-week period of early May to mid-June each year. Aerial survey data are summarized as a single-day peak count of red knots each year (Table 35). These survey data are analyzed in conjunction with other data sources within this document. A simple correlation analysis shows that red knot counts have declined by 52 percent; however, birds' length of stay is a strong influence when calculating the population trend in the bay. As the horseshoe crab egg food source declines, birds must spend more time in the bay, and the likelihood of counting the same birds in multiple weekly surveys increases. Such a scenario would mean the actual decline is greater than 52 percent.

Aerial survey data were mapped to illustrate the distribution of red knots in two time periods: 1986 to 1990 and 2001 to 2005 representing pre- and post-horseshoe crab decline, respectively. The survey data were summarized into the five-year periods, the total number of red knots summed (across the entire study area) and the percentage of the total five-year sum calculated for each beach segment. The survey data were analyzed as percentages to examine the spatial distribution of beach use on a relative, rather than an absolute basis.

Comparison of the maps for these two time periods suggests that the spatial distribution of red knot use has changed (See Fig. 33 in Habitat Section). During the 1986-1990 time period, the red knots were relatively evenly distributed along the New Jersey shoreline from Reeds Beach to Ben Davis Point. However, during the 2001 to 2005 time period there appears to be a greater concentration in the Norbury's Landing to Reed's Beach area and the Egg Island Point to Gandy's Beach area. During 1986-1990, red knots were relatively evenly distributed along Delaware shoreline from Bowers Beach through Bombay Hook National Wildlife Refuge, with a major concentration in the Slaughter Beach-Mispillion Harbor area. During 2001-2005, there was a much greater concentration in the Slaughter Beach-Mispillion Harbor and Bowers Beach areas. Mispillion Harbor should be noted as the site of incredibly high concentrations consistently containing upwards of 15 to 20 percent of all the red knots recorded on the Bay.

Other areas of the Bayshore were recorded as receiving comparatively minimal use by red knots; for example, the Cape May Peninsula south of Norbury's Landing, the central (Big Stone Beach) and eastern most (Prime Hook-Broadkill Beach to Cape Henlopen) sections of the Delaware shoreline. It is interesting to note that these low bird use areas coincide with areas of low horseshoe crab spawning activity as recorded by Smith *et al.* (2002a).

Table 35. Peak counts of red knots observed in aerial surveys of Delaware Bay shoreline.

| Year | Red Knot |
|---|---|
| 1982[a] | 95,530 |
| 1983[b] | 16,859 |
| 1984 | No survey |
| 1985 | No survey |
| 1986[c] | 55,531 |
| 1987 | 38,750 |
| 1988 | 38,190 |
| 1989 | 94,460 |
| 1990 | 45,785 |
| 1991 | 27,280 |
| 1992 | 25,595 |
| 1993 | 44,000 |
| 1994 | 52,055 |
| 1995 | 38,600 |
| 1996 | 19,445 |
| 1997 | 41,855 |
| 1998 | 50,360 |
| 1999 | 49,805 |
| 2000 | 43,145 |
| 2001 | 36,125 |
| 2002 | 31,695 |
| 2003 | 16,255 |
| 2004 | 13,315 |
| 2005 | 15,345 |
| 2006 | 13,445 |
| Geometric mean | 34,279 |
| Correlation with year | -0.52 (p = 0.009) |

[a] 1982 by Dunne *et al.* 1982
[b] 1983 by Kochenberger 1983
[c] 1986-2005 by Clark *et al.* 1993

In addition to the aerial surveys, ground based surveys have been conducted by NJDFW-ENSP to identify other high use areas for red knots during the spring stopover. In particular, large numbers of red knots have been recorded using the Stone Harbor Point area on the Atlantic coast of Cape May County, New Jersey (Sitters 2001, 2005). Stone Harbor Point and adjacent islands contain undeveloped sand beach/bar, mudflat, and salt marsh and serve as both foraging and resting habitat for red knots. In 2001, red knots were surveyed roosting (Table 36) and feeding (Table 37) in the Stone Harbor Point area, reaching a maximum count of 18,000 on 28 May 2001. In 2005, Sitters (2005) recorded both nighttime counts in the area and the presence of telemetered red knots (Table 38). These data suggest possibly all red knots in Delaware Bay were using the Stone Harbor Point area for nighttime roosting in late May 2005, and underscore the importance of this area for the population.

Table 36. Numbers of red knots roosting at high water by day and at dusk at Stone Harbor Point, New Jersey during May 2001 (Sitters 2001).

| Date | Time of high tide | Knots roosting | Day or dusk |
|---|---|---|---|
| 9 May | 1032 | 152 | day |
| 10 May | 1120 | 100 | day |
| 21 May | 2011 | 11,000 | dusk |
| 22 May | 2050 | 14,000 | dusk |
| 23 May | 0922 | 700 | day |
| 23 May | 2130 | 15,000 | dusk |
| 24 May | 1008 | 1,200 | day |
| 27 May | 1253 | 12,000 | day |
| 28 May | 1353 | 18,000 | day |
| 29 May | 1451 | 15,000 | day |
| 30 May | 1550 | 3,200 | day |
| 1 June | 1747 | 3,000 | day |
| 2 June | 1841 | 1,500 | dusk |
| 3 June | 1931 | 2,000 | dusk |

Table 37. Observations of red knots feeding in the Stone Harbor area wetlands during May 2001 (Sitters 2001).

| Date in May | Time of low water | Knots counted | Time observed | Location | Total daily count of knots |
|---|---|---|---|---|---|
| 4 | 1258 | 2 | 1400-1445 | Grassy Sound | 2 |
| 5 | 1346 | 250 | 1120-1530 | Great Sound | 250 |
| 7 | 1519 | 500 | 1415-1630 | Great Sound | 500 |
| 8 | 1602 | 700 | 1420-1740 | Great Sound | 700 |
| 9 | 1644 | 700 | 1500-1815 | Great Sound | 700 |
| 10 | 1724 | 1,400 | 1630-1830 | Great Sound | 1,400 |
| 17 | 1100 | 43 | 0930-1230 | Great and Jenkins Sound | 43 |
| 19 | 1239 | 300 | 1015-1450 | Jenkins Sound | 300 |
| 21 | 1404 | 700 | 1445-1500 | Stone Harbor | 700 |
| 22 | 1448 | 800 | 1440-1510 | Back-bay Stone Harbor | |
| | | 200 | 1530-1555 | Grassy Sound | |
| | | 3,500 | 1600-1625 | Stone Harbor | 3,500 |
| 23 | 1533 | 130 | 1330 | Stone Harbor | |
| | | 156 | 1340 | Back-bay Stone Harbor | |
| | | 350 | 1400-1500 | Back-bay Stone Harbor | |
| | | 200 | 1520-1550 | Grassy Sound | |
| | | 150 | 1615 and 1637 | Back-bay Stone Harbor | |
| | | 700 | 1630 | Stone Harbor | 850 |
| 24 | 1618 | 600 | 1445-1700 | Back-bay Stone Harbor | |
| | | 500 | 1445-1700 | Back-bay Stone Harbor | |
| | | 37 | 1740 | Stone Harbor | 1,200 |
| 27 | 0647 | 6,500 | 0930-1000 | Stone Harbor | |
| | 1847 | 3,000 | 1745-1845 | Stone Harbor | |
| | | 5,000 | 1745-1845 | Back-bay Stone Harbor | 8,000 |
| 28 | 0743 | 250 | 0800-0900 | Stone Harbor | |
| | | 950 | 0800-0900 | Back-bay Stone Harbor | |
| | 1950 | 3,000 | 1800-1900 | Stone Harbor | |
| | | 2,200 | 1800-1900 | Back-bay Stone Harbor | 5,500 |
| 29 | 0845 | 3,000 | 0945 | Stone Harbor | |
| | | 7,000 | 0955-1040 | Jenkins Sound | 7,000 |
| | | 5,000 | 2000-2015 | Back-bay Stone Harbor | 5,000 |
| 30 | 0949 | 400 | 1100 | Stone Harbor | |
| | | 2,000 | 1130 | Jenkins Sound | 2,400 |
| 31 | 1048 | 700 | 1100 | Stone Harbor | |
| | | 1,800 | 1100 | Back-bay Stone Harbor | |
| | | 3,000 | 1130 | Jenkins Sound | 5,500 |

Table 38. Summary of red knot evening/night counts and location of radio-tagged knots at Hereford Inlet, Stone Harbor, New Jersey, during 19-31 May 2005 (Sitters 2005).

| Date | Time of high tide | Time of observations | Red Knots counted | Radio-tagged knots recorded |
|---|---|---|---|---|
| 19 May | 1735 | 1800-1900 | 3,500 | |
| 20 May | 1821 | 1800-1900 | 4,500 | |
| 21 May | 1904 | 1900 | 4,500 | |
| 22 May | 1946 | 1900-2000 | 13,000 | |
| 23 May | 2029 | 1900-2000 | 20,000 | |
| 24 May | 2114 | 1900-2030 | 16,000 | |
| 25 May | 2204 | 2030 | 14,000 | 21 |
| | | 2100 | | 28 |
| 26 May | 2259 | 2030 | 14,000 | 16 |
| | | 2315 | | 33 |
| 27 May | 2359 | 2350 | | 30 |
| 29 May | 0059 | 0040 | | 26 |
| 30 May | 0159 | 0215 | | 25 |
| 31 May | 0257 | 0305 | | 20 |

Thus while the Delaware Bay intertidal beaches are essential for horseshoe crab spawning and are therefore the egg resource for red knots, migrating shorebirds including the red knot move actively between Delaware Bay habitats with changes in the tidal cycle (Burger *et al.* 1997, Sitters unpublished data). Shorebirds use all these habitats for foraging and resting depending on location, seasonal date, time of day, tide and species. Though the beaches are of critical importance; during high tide, they are often too narrow for foraging, and the birds go elsewhere, including nearby salt marshes, tidal mudflats and creeks. Telemetry has documented flights by red knots across Delaware Bay from Mispillion Harbor, and across Cape May Peninsula, to use the sand beach and salt marshes near Stone Harbor Point for foraging, resting and roosting (Sitters 2004, 2005). Burger *et al.* (1997) suggested that in addition to the massive food resource provided by spawning horseshoe crabs, Delaware Bay's complex mosaic of coastal habitat types of mudflats, beaches, tidal creeks and salt marshes is essential to maintain the large migrant shorebird population. Sitters (2004) suggests that red knots move to Atlantic coast habitats in the Stone Harbor area when horseshoe crab eggs are limited on the bayshore; they will forage on mussel spat when that is available. In recent years knots made daily flights to roost at Stone Harbor even though they foraged at Mispillion in Delaware and Fortescue in New Jersey (Sitters 2004). This suggests that safe, predator-free roost sites are also of critical importance.

d. New York

The red knot does not occur in high numbers in the Jamaica Bay area. The East Pond, an impoundment that is part of the Jamaica Bay Wildlife Refuge, is the most common location where red knots occur (Appendix - Map 21).

Plumb Beach is also a site where red knots feed on horseshoe crab eggs. Plumb Beach is the prime location for horseshoe crab spawning in the Jamaica Bay area. There are several other secondary sites that serve as suitable habitat for red knots. Gerritsen Inlet (Saltmarsh Nature Center, City Parks) has an extensive shoreline that is used by red knots and other shorebirds. Red knots are also consistently seen in the area of Far Rockaway, Long Beach, and Jones Beach.

Although most of the Long Island shorebird experts queried do not believe these secondary areas host large numbers of red knots, these sites are used consistently by small numbers of red knots during spring and fall migration and should be considered suitable.

e. Connecticut

The state of Connecticut does not have habitat deemed critical to red knots, though there is some consistent use in the state by a small number of birds (Dickson pers. comm. 2005). Records indicate however, that red knot populations within the state have declined. Christmas Bird Count data from 1972-2001 indicate that the highest numbers of knots in the state occurred in 1986 (20 knots recorded) and in 1992 (27 knots recorded). Based on surveys by the Connecticut Department of Environmental Protection, the maximum number of red knots found in the state during migration surveys was 90, during August 1984. The maximum observance rate of knots in surveys was less than 22 percent, typically between May and October (Varza 2004).

Important habitats in Connecticut may include the Housantonic River mouth (4 knots observed in 2001), which is a key migratory corridor. Specifically, the outer bars, Short Beach on the south side of Milford Point in the Housantonic River mouth was the site of all the recorded red knots activity. Other areas that may be important to red knots in Connecticut are Milford Point (Milford), Long Beach (Stratford) and Sandy Point (West Haven) where small numbers of birds (< 9 knots recorded in these location in 2001) have been recorded (Appendix - Map 22) Varza (2004). The sand bars on Cockenoe Island (Westport) are regularly used by 3-6 red knots during spring and fall migration according to data from Connecticut Audubon and the Connecticut Ornithological Association.

f. Rhode Island

There are no historic records of large numbers of red knots using coastal areas of Rhode Island during spring or fall migration. Red knots occur consistently, but intermittently and in low numbers, at three of five important shorebird migratory stopovers in Rhode Island: Napatree Point-Sandy Point Island, Westerly; Ninigret Pond, Charlestown; and Quicksand Pond, Little Compton (Appendix - Map 22). In R. L. Ferren's (unpublished) historical compilation of Rhode Island birds, he cites only a single count of more than 100 birds. Maximum counts on any given site rarely exceed 50 individuals. There are no stopover sites in Rhode Island considered to be critical for red knots; however, existing stopover sites for knots tend to be areas that host relatively large concentrations of other shorebirds as well.

The movement of knots through Rhode Island on northward migration in spring is decidedly uni-modal, peaking between the third week of May and the first week of June. Conversely, the number of knots on southward migration (July through October) is

generally greater than spring but much more sporadic, with a loose "peak" around 22 August. The intermittent nature of red knot use of Rhode Island stopovers (anecdotally) may be related to inclement weather; that is, storms or fog may force coastal or pelagic migrating knots to seek safe roosts or foraging areas along the Rhode Island shoreline. While most shorebird species moving through Rhode Island have regular and predictable migration patterns, the red knot stands out as a species with unpredictable migration patterns, particularly on southward migration. At Napatree Point, where shorebird surveys have been conducted regularly (Raithel pers. comm. 2005) since 1980, high (25+ birds) red knot counts have been recorded between 1982 and 2004 (Table 39).

Table 39. Summary of spring and fall migration surveys for red knots in Rhode Island between 1982 and 2004 (Raithel pers. comm. 2005).

| **Spring Migration** | | | **Fall Migration** | | |
|---|---|---|---|---|---|
| Year | Day | Number of red knots | Year | Day | Number of red knots |
| 1982 | 02-Jun | 60 | 1984 | 11-Aug | 43 |
| 1983 | 22-May | 26 | 1989 | 15-Aug | 33 |
| 2002 | 04-Jun | 28 | 1989 | 22-Aug | 67 |
| | | | 1989 | 05-Sep | 36 |
| | | | 1989 | 11-Sep | 32 |
| | | | 1989 | 21-Sep | 65 |
| | | | 1989 | 22-Sep | 72 |
| | | | 1989 | 25-Sep | 25 |
| | | | 1990 | 09-Aug | 32 |
| | | | 1990 | 13-Aug | 51 |
| | | | 1994 | 22-Aug | 51 |
| | | | 1996 | 21-Jul | 55 |
| | | | 2000 | 21-Aug | 33 |
| | | | 2000 | 05-Sep | 31 |
| | | | 2000 | 06-Sep | 47 |
| | | | 2004 | 22-Aug | 50 |

It is evident, in contrast to what Ferren (pers. comm. 2005) says in his species account, that large counts of knots are much more likely to occur in fall (3 of the 19 records above were in spring). The sporadic nature of knot migration is evident even in these cursory numbers. "High" counts (≤ 100 individuals) occurred in only 10 of 24 years of this survey. Some knot-years are apparently much "better" than other knot-years in Rhode Island. For example, 7 of the 19 high counts occurred in 1989. This phenomenon could simply be due to autocorrelation in the data – when large knots appear in Rhode Island, they tend to stay for a while and are therefore counted repeatedly. However, the spread of fall dates (between 21 July and 25 September) for high counts is similarly unusual for Rhode Island shorebirds – most species display a very predictable bi-modal or uni-modal fall pattern. These numbers suggest that the variance in survey counts for the red knot (at least in this area) is higher than that for other shorebirds.

It would be interesting if the sporadic nature of red knot migration in Rhode Island (relative to other shorebird species) is related to its demonstrably greater vulnerability, because there are examples with other species groups where high variation in breeding cycles and/or habitat use seems to be linked to vulnerability at landscape scales. Other researchers (this volume) have suggested that knots use highly ephemeral resources, such as mussel spat and small surf clams (*Donax variabalis*), and red knot distribution from year-to-year likely depends on the abundance of these food resources. It is unknown if this is a factor contributing to knot abundance and distribution on coastal Rhode Island.

However, the sporadic nature of red knot use of some coastal areas all along the eastern seaboard suggests knots may have a narrower foraging niche in time and space than other species. As long as a heterogeneous mixture of suitable habitats exist, and prey are available at least in some locations, knots can persist. However, as habitats become lost to disturbance, development, abundant predators, and subject to activities that reduce prey availability (e.g., beach replenishment), foraging and roosting options for knots become limited. Particularly on northbound migration where time is critical, these factors are likely to negatively impact the population.

g. Massachusetts

During southward migration, regions on Cape Cod and Massachusetts Bay are important migration staging sites (Appendix - Map 23). To identify major stopover locations, we searched historical records in publications such as Records of New England Birds (1939-1972), selected volumes (migration seasons) of Audubon Field Notes (and its successor American Birds) (1948-1999), Bird Observer of Eastern Massachusetts (1970's-2002), and The International Shorebird Surveys (ISS, 1974-2002). In general, these sources (except the ISS, which follows prescribed count routines) record early and late arrival dates, and often, maximum seasonal counts.

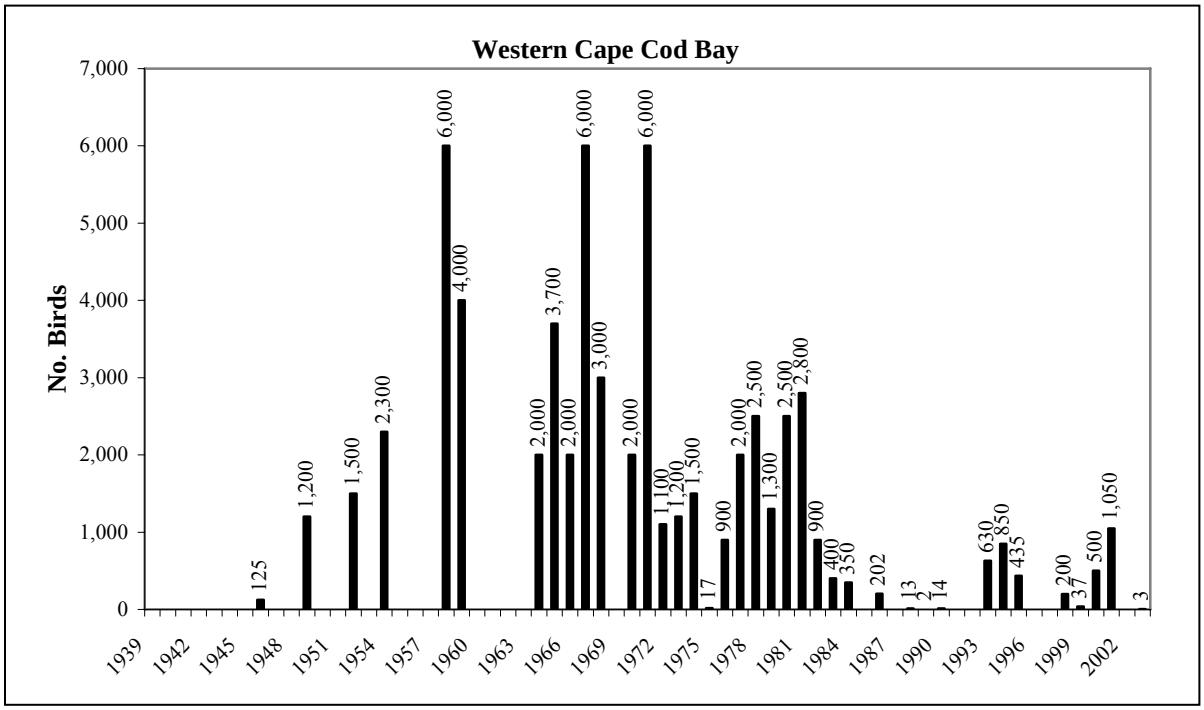
Where available, maximum counts during south migration were made during south migration in each of three regions of Massachusetts (the coast North of Boston, Western Cape Cod Bay, and Eastern Cape Cod) (Harrington unpublished data) (See Appendix - Map 23). Although maximum counts are difficult to statistically assess, there was a strong correlation ($R^2 = 0.90$, $P<0.001$) between maximum and mean ISS counts of red knots during south migration in Massachusetts (Harrington unpublished data), indicating that maximum counts are a reasonable metric for an historic review.

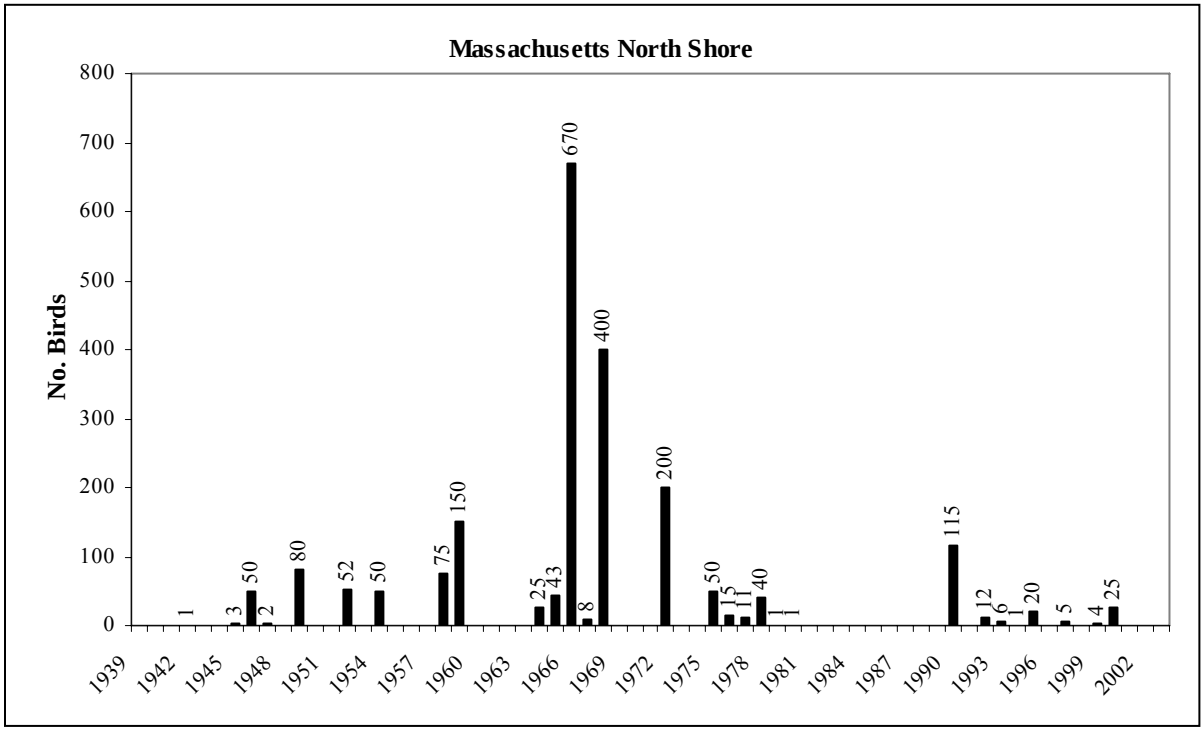
The historic count data, summarized in Figure. 70, indicate relatively consistent use of eastern Cape Cod locations by knots during the last 50 years, as well as less regular periods when high numbers used sites on Western Cape Cod Bay. In contrast, the North Shore of Massachusetts was relatively little used by knots throughout the 50 years.

It is appropriate to note that Massachusetts is clearly used by southbound knots with South American destinations during July and August. However, it also is clear that numbers of knots using the Massachusetts coast are substantially lower than the numbers that pass through Delaware Bay during the Northward migration (Morrison and Harrington 1992).

The banding locations were identified for 327 of the 334 color-banded knots found in Massachusetts during southward migration. Most (75%, n = 245) of the identified birds had been marked on Delaware Bay, 23 percent (n = 77) had been marked

in South America, and only 5 (2%) had been marked in South Carolina. None from Georgia were found. The frequencies of marked knots from different banding locations were not statistically significantly different from the frequencies found in Delaware Bay ( $\chi 2$ = 10.54, P > 0.05, 5 df).



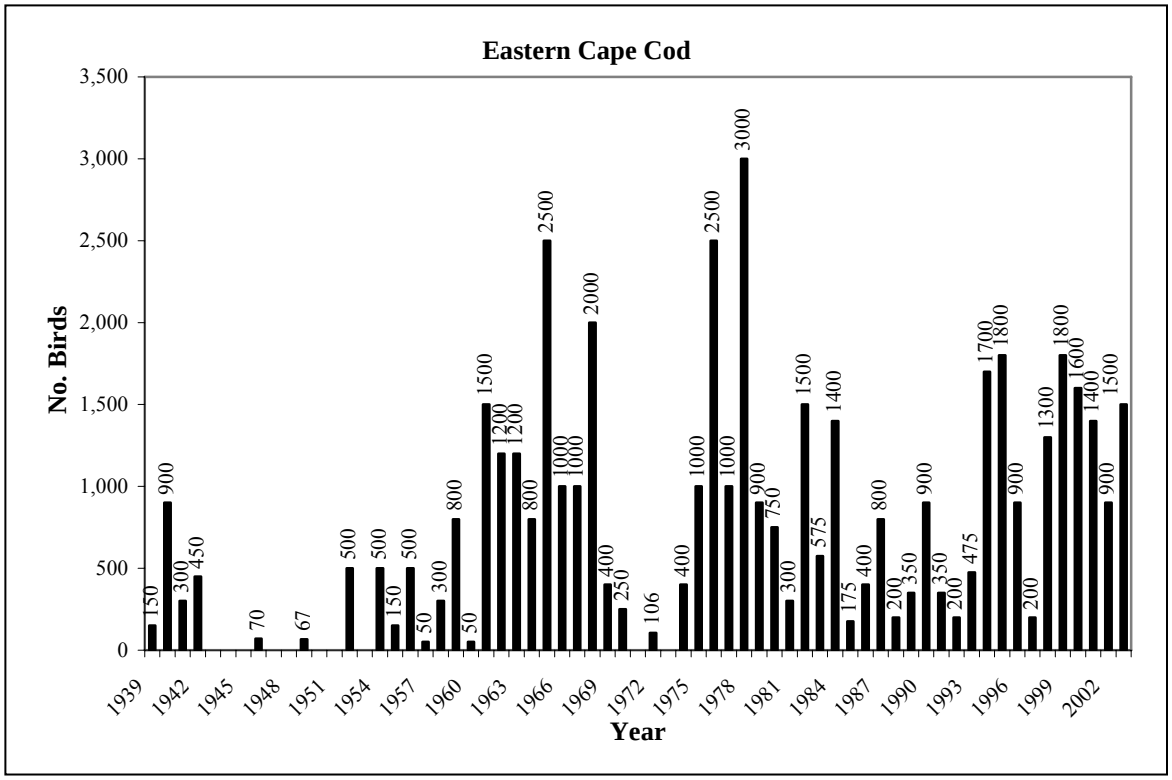



Figure 70. Maximum historic red knot counts from three regions of Massachusetts during southbound migration.

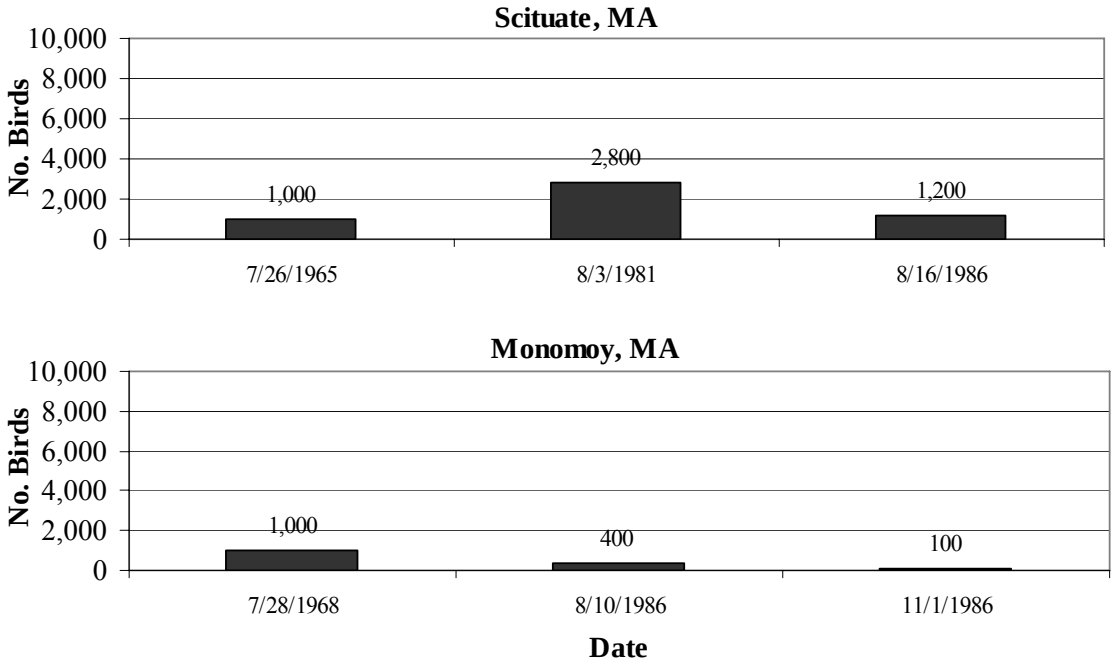



Figure 71. The number of red knots counted at Scituate and Monomoy, 1965-1986 (Harrington unpublished data).

h. New Hampshire

New Hampshire does not host large numbers of staging red knots. At the time of writing, the Nongame Program of the New Hampshire Department of Natural Resources does not conduct any surveys, monitor or have any available data on red knots within the state. All records for this state are from bird sightings submitted to New Hampshire Audubon. According to these reports, no more than 50 red knots were ever seen at any one place in New Hampshire from 1986 to 2004. Though not seen in large numbers, there seems to be consistently intermittent use of at least three locations: Hampton Harbor, Seabrook Harbor and White and Seavey Islands (Isle of Shoals) (See Appendix - Maps 24 and 26) (Audubon Society of New Hampshire, unpublished data).

i. Maine

The state of Maine conducts coast-wide counts between July and September of shorebirds to identify shorebird habitats (Table 40) (Tudor pers. comm. 2005). Currently it is not believed that Maine provides red knots with critical stopover habitats. Red knots are usually not seen on northward migration, always on southward migration. Habitats that may possibly be important for red knots include, Petite Manan Island and Bluff and Stratton Islands (Appendix - Maps 24, 25 and 26). The most productive staging area for shorebirds in Maine is Lubec and Sprague Neck (Appendix - Maps 24 and 25). In 1979 and 1980 these areas were surveyed intensively, only 11 red knots were recorded at Lubec and 64 red knots were recorded at Sprague Neck. In 1989, the state of Maine began intensive shorebird surveys to locate and designate critical staging areas. Surveys were concentrated on one section of coastline per year, with surveys completed in 1995. Areas were surveyed every two weeks at varying tides starting in mid-July through the end of September. Since 1995, the state has monitored key sites in Washington County and has started collecting data for the Program for Regional and International Shorebird Monitoring (PRISM). PRISM is being implemented by a Canada-U.S. Shorebird Monitoring and Assessment Committee formed in 2001 by the Canadian Shorebird Working Group and the U.S. Shorebird Council. PRISM is based on the shorebird conservation plans recently completed in Canada and the U.S. and provides a single blueprint for implementing both of these plans. For more information see http://www.fws.gov/shorebirdplan/USShorebird/downloads/PRISMOverview1_02.doc

These surveys start in mid-July and go through end of September, covering select areas every two to three weeks. The state also cooperates with non-government organizations working on nesting tern islands which recording shorebird numbers, this data is collected from June to end of July with scattered data collected in August.

Table 40. Red knot survey data for Maine (1980- 2004)

| Date | # Red Knots | Location |
|---|---|---|
| Aug-89 | 115 | Hog Bay, Franklin, Hancock County |
| Sep-89 | 27 | Hog Bay |
| Aug-85 | 10 | Spruce Island, Deer Isle, Hancock County |
| Jun-04 | 2 | Ship Island, Tremont, Hancock County |
| May-88 | 38 | Over Point, Milbridge, Washington County |
| May-89 | 15 | Over Point |
| Oct-88 | 12 | Over Point |
| Oct-89 | 9 | Over Point |
| Aug-04 | 1 | Over Point |
| Aug-89 | 14 | Petit Manan Island, Milbridge, Washington County |
| Aug-99 | 4 | Petit Manan Island |
| Jul-04 | 6 | Petit Manan Island |
| Sep-89 | 8 | Petit Manan Point, Steuben, Washington County |
| Sep-80 | 80 | Holmes Creek, Cutler, Washington County |
| 1980 | 87 | Sprague Neck, Cutler, Washington County |
| Sep-94 | 26 | Sprague Neck |
| Aug-94 | 10 | Mash harbor, Addison, Washington County |
| Aug-04 | 1 | Flat Bay, Addison, Washington County |
| Sep-91 | 10 | West River – Indian River, Addison-Jonesport, Washington |
| 1980 | 11 | Lubec Flats, Lubec, Washington County |
| Sep-80 | 25 | Lubec Flats |
| Sep-91 | 6 | Lubec Flats |
| Aug-94 | 25 | Lubec Flats |
| Sep-96 | 10 | Lubec Flats |
| Sep-96 | 18 | Lubec Flats |
| Sep-02 | 13 | Lubec Flats |
| Oct-02 | 4 | Lubec Flats |
| Aug-93 | 53 | Eastern Egg Rock, St George, Knox County |
| Jul-93 | 26 | Eastern Egg Rock |
| Jul-94 | 20 | Eastern Egg Rock |
| Aug-94 | 7 | Eastern Egg Rock |
| Sep-93 | 16 | Scarborough Marsh, Scarborough, Cumberland County |
| May-85 | 26 | Biddeford Pool, Biddeford, York County |
| Jul-93 | 14 | Bluff and Stratton Island, Old Orchard Beach, York Co. |
| Jul-93 | 6 | Bluff and Stratton Island |
| Aug-04 | 5 | Bluff and Stratton Island |
| Aug-04 | 3 | Bluff and Stratton Island |

***5. Canada***

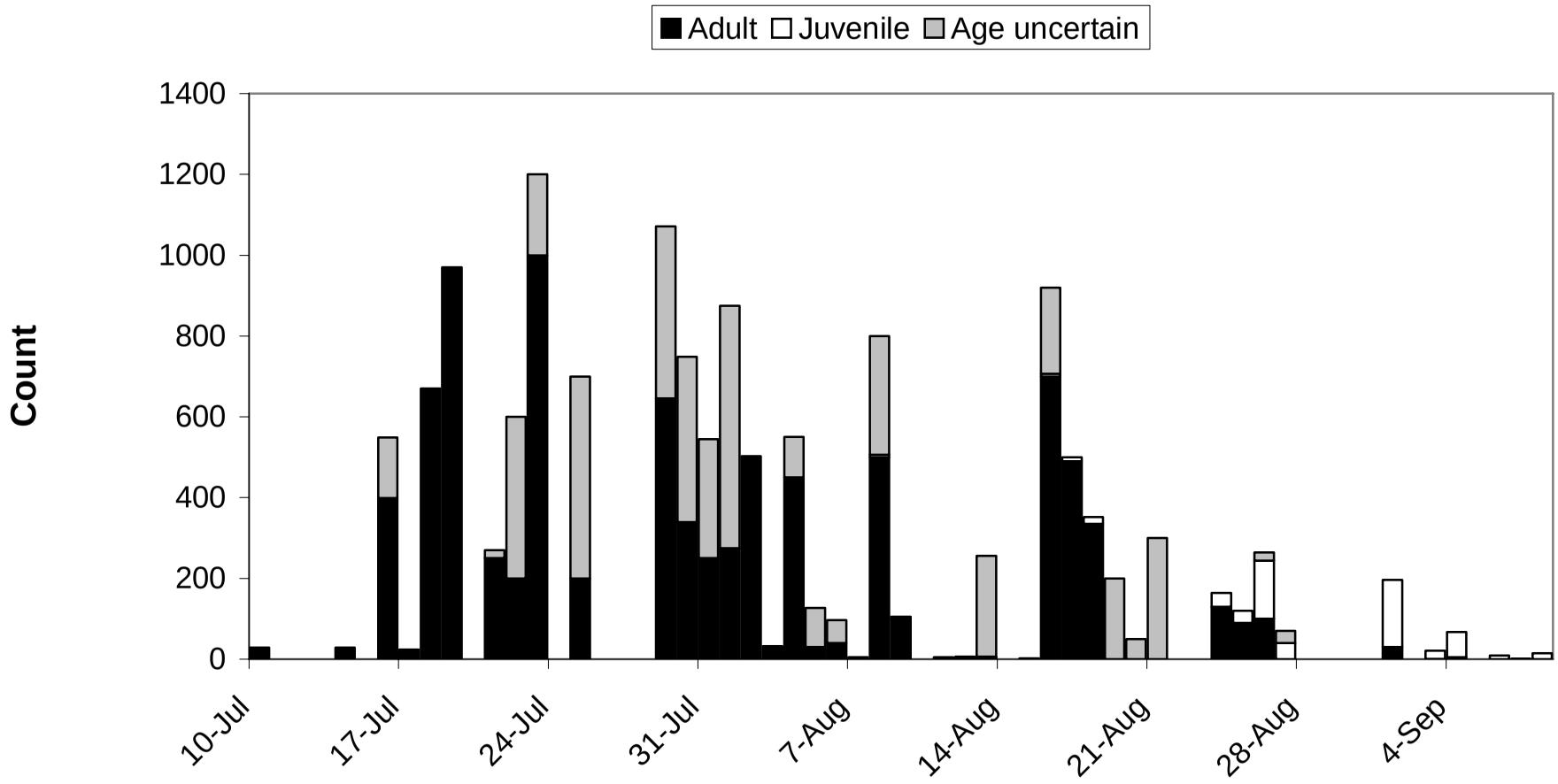
Although the entire adult population *of C. c. rufa* breeds in arctic Canada, estimating the population on its Arctic breeding grounds is problematical owing to very low breeding densities (e.g., Southampton Island, Fig. 53), lack of detailed habitat maps and information, and the need to extrapolate over very large areas. Trends may be derived from counts at migration areas, though in North America such counts may involve mixtures of populations from different wintering areas. For *C. c. rufa* wintering in southern South America, the most authoritative counts are those conducted at the main wintering sites in Tierra del Fuego.

During spring migration in North America, it appears that many *rufa* may fly direct to the breeding grounds from Delaware Bay. Large flights of knots have been observed passing northwards through southern James Bay at the end of May or start of June (Morrison unpublished data, Peck unpublished data), having probably flown directly from Delaware Bay (Morrison and Harrington 1992). Large concentrations are occasionally found around Lake Ontario (e.g. 400 at Presqu'ile Provincial Park on 18 May 1969; 1,500 at Prince Edward Point on 30 May 1979; 1,000 near Amherstview on 21 May 1985), though these probably represent weather related dropouts from the main migration (McRae 1982, Weir 1989, see Morrison and Harrington 1992). The sighting of a knot that had been color-banded at Lagoa do Peixe in southern Brasil at Presqu'ile Provincial Park indicates that these birds include migrants from the southern *C. c. rufa* population. Knots are rare in spring on the Atlantic coast of Canada, where food resources have not yet recovered from winter ice conditions. Farther west along the route of the Interior Flyway, there have been occasional observations of knots occurring briefly in atypical habitats during spring migration; these are likely to involve birds wintering in Florida (or Maranhão). For example, 2,500 were seen on a burned over stubble field near Last Mountain Lake, Saskatchewan, on 21 May 1972 (Skagen *et al.* 1999). Such records probably again relate to migrants bound for the western edge of *rufa's* breeding range being forced to land during poor weather. We know of no similar records in more recent years.

The number of knots occurring at autumn migration stopover sites in Canada, such as James Bay, the Bay of Fundy and on the Mingan Islands in the Gulf of St. Lawrence, is greater than in spring (Hicklin 1987, Morrison unpublished data, Peck unpublished data). Large numbers of knots pass southwards through the southwestern coast of Hudson Bay (Manitoba and Ontario) and the western and southern coasts of James Bay during July and August (Ontario) (Hope and Shortt 1944, Manning 1952, Ross *et al.* 2003). Mainland coastal surveys in late July 1990 and early August 1991 resulted in totals of 23,251 and 15,055, respectively (Morrison and Ross unpublished data). The southeast corner of Akimiski Island also appears to be important for knots, with 6,900 being observed on a survey in late August 1995 (Ross pers. comm. 2007). Counts of 100-350 knots have been recorded on the south coast of James Bay in Quebec (Aubry and Cotter 2001). Currently, the most important area for red knots on migration in eastern Canada is along the north shore of the St. Lawrence River in Quebec and the Mingan archipelago where counts of 1,000 or more have been made in late July or early August in several years (Étude des Populations d'Oiseaux du Québec data, Y. Aubry pers.

comm., Fig. 72). During July to September 2006, 842 different individually banded knot from elsewhere in the West Atlantic flyway were seen amongst those stopping over on the Mingan Islands. Most (585) had been banded during northward migration in Delaware Bay, but as many as 217 had been banded in Argentina and Chile confirming that the majority belonged to the *rufa* population that winters in southern South America (Fig. 72, Aubry pers. comm. 2007). In view of the likely proportion of banded birds in the *rufa* population (~ 10%) and the fact that some are likely to have been missed, it would seem likely that around a half of the flyway population stopped in the Mingan Islands in 2006. The islands are granitic and their shores are mostly rocky. However, on their southern sides there are small intertidal flats of gravel or sand that support an abundance of invertebrates (*Mytilus*, *Littorina* and *Gamarus* sp.) suitable for foraging knots. These invertebrates are mostly attached to the *Fucus* sp.and the other algae that cover the flats.

Up to the early 1980s, knots were moderately numerous during southward migration in the upper Bay of Fundy, but fell rapidly to low levels in the mid 1980s and have remained at low levels since then. This may represent a withdrawal from relatively peripheral areas as the population started decreasing. Trend analyses of data from both Quebec and the Atlantic Provinces of Canada have indicated significant declines (Morrison *et al.* 2006b).




| | 10-Jul-06 | 14-Jul-06 | 16-Jul-06 | 17-Jul-06 | 18-Jul-06 | 19-Jul-06 | 21-Jul-06 | 22-Jul-06 | 23-Jul-06 | 25-Jul-06 | 29-Jul-06 | 30-Jul-06 | 31-Jul-06 | 1-Aug-06 | 2-Aug-06 | 3-Aug-06 | 4-Aug-06 | 5-Aug-06 | 6-Aug-06 | 7-Aug-06 | 8-Aug-06 | 9-Aug-06 | 11-Aug-06 | 12-Aug-06 | 13-Aug-06 | 15-Aug-06 | 16-Aug-06 | 17-Aug-06 | 18-Aug-06 | 19-Aug-06 | 20-Aug-06 | 21-Aug-06 | 24-Aug-06 | 25-Aug-06 | 26-Aug-06 | 27-Aug-06 | 1-Sep-06 | 3-Sep-06 | 4-Sep-06 | 6-Sep-06 | 7-Sep-06 | 8-Sep-06 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age uncertain | | | 150 | | | | 20 | 400 | 200 | 500 | 425 | 410 | 295 | 600 | | | 100 | 97 | 57 | | 294 | | | | 250 | 2 | 213 | | | 200 | 50 | 300 | | | 20 | 30 | | | | | | |
| Juvenile | | | | | | | | | | | | | | | | | | | | | 6 | 5 | | | 2 | | 7 | 10 | 17 | | | | 34 | 30 | 144 | 40 | 166 | 20 | 62 | 9 | 1 | 15 |
| Adult | 29 | 29 | 399 | 24 | 670 | 970 | 250 | 200 | 1000 | 200 | 646 | 339 | 250 | 275 | 503 | 32 | 450 | 30 | 40 | 5 | 500 | 100 | 5 | 6 | 4 | | 700 | 490 | 335 | | | | 130 | 90 | 100 | | 30 | 1 | 5 | | | |

Figure 72. Counts of red knots on four islands (Nue, Grande, Quarry and Niapiskau) of the Mingan archipelago in the Gulf of St Lawrence, Quebec, Canada, during July-September 2006 (Aubry pers. comm. 2007).

## VIII. THREATS

Under section 4 of the Endangered Species Act 1973 (ESA), a species that is endangered or threatened may be listed as such if it is endangered or threatened because of:

A. The present or threatened destruction, modification, or curtailment of its habitat or range;
B. Overutilization for commercial, recreational, scientific, or educational purposes;
C. Disease or predation;
D. The inadequacy of existing regulatory mechanisms; or
E. Other natural or manmade factors affecting its continued existence.

Threats are therefore listed under these headings. In principle, a threat is only important if it has or may have an adverse impact on an animal's evolutionary fitness: its ability to survive and reproduce. In conservation science perceived threats are often assumed to have fitness implications, but except where actual mortality occurs this is seldom proved. Therefore a major focus of *rufa* studies has been to measure adult survival and attempt to identify those factors that lead to its reduction. This has met with some success, as described below. Nevertheless several threats are identified which in our opinion are likely to have fitness consequences, but we are unable to prove that this is the case.

### A. The Present or Threatened Destruction, Modification, or Curtailment of Red Knot Habitat or Range

#### *1. Threats to Habitats in Delaware Bay During Spring Migration*

a. Reduction in Foraging Resources at Habitats in Delaware Bay

The principal known threat to a substantial proportion of red knots in the Americas is the dwindling supply of their main food resource at their final spring stopover in Delaware Bay, the eggs of the horseshoe crab. As described in the Habitats section, this once abundant resource has declined through the exploitation of the adult crabs.

As discussed in the Population Size and Trends section, a greater or lesser proportion of three wintering populations of red knots pass through Delaware Bay during northward migration. However, as far as can be ascertained, only the Tierra del Fuego wintering population has undergone a major decline. Those wintering farther north, in the southeast U.S. and Maranhão, have shown no clear trend. The main difference between these populations is that the Tierra del Fuego birds have a much longer, time-constrained migration that carries a greater risk of arriving in Delaware Bay in poor condition and/or late, whereas the latter fly a relatively short distance and may arrive on time and in better condition. Either way, the Tierra del Fuego birds have a greater need for an abundant food supply in Delaware Bay than the others. Therefore, the decline in the availability of food resources, especially horseshoe crab eggs, may have the greatest impact on the long-distance migrants rather than those that have not traveled as far. Alternatively, the lack of food in Delaware Bay is not the immediate problem, but the birds are arriving there late and/or in poor condition because of difficulties farther south along their migration route

(see sections C and E below). Therefore they have lower survival because they have less time to obtain the resources they require.

Although the precise role of reduced food supplies in Delaware Bay has not always been clear, there have been some years when its impact has been patent. In 2003, for example, crab spawning was delayed probably as a result of low water temperatures (Weber 2003) and although the knot stopover was also later than usual, the birds failed to achieve their normal rate of mass gain (Atkinson *et al.* 2006b, Niles *et al.* unpublished data). In contrast, in 2004 the stopover and the availability of crabs' eggs was more closely synchronous and the birds achieved good weight gains despite the fact that that overall egg densities were little different to the previous year (Atkinson *et al.* 2006b, Niles *et al.* unpublished data).

When the knots leave for the Arctic, they not only need the resources for the 3,000-km non-stop flight across territory without food supplies, but they also need additional resources to ensure their survival during the first few weeks after arrival when little food is available. Therefore the food supply in Delaware Bay is crucial for their survival and ability to reproduce successfully. This is demonstrated by studies that show that birds caught at a lower weight in Delaware Bay (controlling for date) were less likely to be observed in future years than heavier birds and were therefore assumed to have lower survival (Baker *et al.* 2004).

Without doubt, the main reason for the reduced availability of horseshoe crab eggs (See Fig. 35) for shorebirds on the Delaware Bay beaches is the over-exploitation of the adult crabs (See Figs. 34 and 38; Table 11). However, three factors exacerbate the situation and have the effect of reducing the availability of eggs further: (a) beach erosion reducing the amount of optimal crab spawning habitat, (b) disturbance by people, dogs and potential predators and (c) competition from gulls, especially laughing gulls (*Larus atricilla*). These are considered below.

b. Decreased Habitat Availability From Beach Erosion and Shoreline Stabilization

Delaware Bay's sandy barrier beaches are dynamic features that respond in a generally predictable manner, migrating landward by storm overwash as the bayward shoreline is also retreating landward in the face of continued sea level rise (Phillips 1986a). While future rates are difficult to predict, the current level of sea level rise in Delaware Bay is generally thought to be about 3 mm/yr (Phillips 1986a). This has resulted in erosion of the Bay's shorelines and a landward extension of the inland edge of the marshes. During 1940-1978, Phillips (1986a) documented a mean erosion rate of 3.2 m/yr for a 52-km long section of New Jersey's Delaware Bay Cumberland County shoreline and indicated that this was a high rate of erosion compared to other estuaries. The spatial pattern of the erosion was complex with differential erosion resistance related to local differences in shoreline morphology (Phillips 1986b). Phillips' shoreline erosion studies (1986a, 1986b) suggest that bay-edge erosion is occurring more rapidly than the landward/upward extension of the coastal wetlands and that this pattern is likely to persist.

Galbraith *et al.* (2002) examined several different scenarios of future sea level rise as a consequence of global climate change and project major losses of intertidal habitat in Delaware Bay due to continued sea level rise. Under the 50% probability scenario, Delaware Bay is predicted to lose 60% or more of the shorebird intertidal feeding habitats

by 2100. Under more extreme sea level rise, Delaware Bay may actually have a net gain of intertidal flats as the coastline migrates further inland converting dry land to intertidal habitat. However, this prediction assumes that the coastal protection structure do not constrain the ability of shorelines to migrate landward. Within the Delaware Bay system, as elsewhere in the Mid-Atlantic region, coastal development and shoreline protection activities are expected to interfere with the longer-term landward migration of shorelines (Najjar *et al.* 2000). Though Delaware Bay is less developed than many similar stretches of Mid-Atlantic coastline, some optimal crab-spawning beach habitat is also the site of existing shoreline residential development. Significant sections of the Delaware Bay shoreline have already been impacted by shoreline stabilization projects. Coupled with continuing sea level rise and shoreline erosion, the demand for additional shoreline protection structures is expected to increase (Najjar *et al.* 2000). Shoreline stabilization or armoring projects employing bulkheading, riprap or other solid beach-fill can either completely eliminate intertidal sand beach habitat or sufficiently alter sediment quality and beach morphology to negatively affect the suitability of the remaining habitat for horseshoe crab spawning (Myers 1996; Botton *et al.* 1988). Beach replenishment through offshore pumping of sandy sediments (as carried out along several sections of the Delaware shore, but not New Jersey) provides an alternative means of beach stabilization as well as creating potential crab-spawning habitat. Smith *et al.* (2002c) evaluated the effects of beach nourishment on spawning activity, egg density, egg viability and sediment / beach characteristics on Delaware Bay beaches; however, all factors that affect the function of beach replenishment for crab-spawning and shorebird foraging habitat have not yet been fully evaluated. The fact that during 2002-2005 more knots on average fed on the New Jersey side of the bay (where no replenishment has taken place) than on the Delaware side (See Fig. 36) suggests that beach replenishment may not have a major impact on the value of beaches as crab-spawning habitat.

Besides affecting crab-spawning / knot-feeding habitat, erosion has also led to loss of sites used by knots for roosting, especially around Mispillion Harbor.

***2. Threats to Red Knot Habitat in Massachusetts***

Potential threats to red knot habitats in Massachusetts include human development and beach replenishment

***3. Threats to Red Knot Habitat in North Carolina***

Along the coast, threats to migrant and wintering red knot habitat include beach stabilization works (nourishment, channel relocation, bulkhead construction), and housing development. This particularly applies at Tubbs Inlet.

***4. Threats to Red Knot Habitat in South Carolina***

A large area of the South Carolina coast is protected due to public ownership and conservation easements. There are few opportunities to increase the amount of protected coastal land. Coastal counties are experiencing annual human population growth rates of 2-3%. Wetlands are being degraded by pollution, development, and oil spills; invertebrates are declining due to pollution; and horseshoe crabs are over-harvested.

### *5. Threats to Red Knot Habitat in Florida*

Shoreline hardening, dredging, and deposition, including beach nourishment activities, are significantly altering much of Florida's coastline. Similarly, beach-raking activities alter the natural characteristics of the beach zone. Despite the fact that all of these activities require permits, there is no centralized documentation of their location or extent. Furthermore, the impacts on knots and other shorebirds is not well known but is thought to be significant.

### *6. Threats to Red Knot Habitat in Brazil*

Very little is known about the red knots that winter on the coast of Maranhão. They occur along 150 km of highly fragmented shore which is difficult to survey, even from the air, and difficult to access (Baker *et al.* 2005a). Among the most important threats that can be identified is petroleum exploration in the sea on the continental shelf, as well as iron ore and gold mining, which leads to loss of coastal habitat through the dumping of soil, oil pollution, mercury contamination, and uncontrolled urban spread along the coast. Mangrove clearance has also had a negative impact on knot habitat by altering the deposition of sediments which leads to a reduction in benthic prey.

At the Lagoa do Peixe National Park, the main management activities relate to the controlling of water levels in the lagoon and ameliorating the effects of *Pinus* afforestation. Red knots feed on snails and other invertebrates around the edges of the lagoon and the abundance and availability of this food supply depends on water levels. Connection between the lagoon and sea occurs naturally mainly during winter and spring when a combination of southerly winds and rainfall opens the sandbar through water pressure. Closure occurs as a result of the deposition of sand in the lagoon mouth during northerly and northeasterly winds. Farmers use pumps to drain water from their lands and this can have a major effect on the level of the lagoon. During drought years, like 1997, the sandbar cannot be closed due to strong continental drainage that limits deposition at the mouth of the lagoon. It is the periodic exchange of water with the sea that allows invertebrates to colonize the lagoon and provide a food resource for migratory shorebirds. Although water levels are controlled to some extent by pumping, any factor that interferes with this, such as nearby farmers draining their land, is a threat to the value of this important site for knots.

Another threat to Lagoa do Peixe is the uncontrolled *Pinus*-afforestation of land in the vicinity, which probably has the effect of lowering the water table (IBAMA, unpublished data). In some areas, the plantations appear to help siltation of the lagoon by altering the movement of sand dunes. *Pinus* harvesting leads to the appearance of gullies, which contribute to higher erosion. According to the management plan (IBAMA 1999), studies were to be conducted on the impact of *Pinus* forests, but no results have been published to date.

### *7. Threats to Red Knot Habitat at Migration Stopover Sites along the Atlantic coast of Patagonia, Argentina*

Oil pollution is a threat in Reserva Provincial de Río Chico para Aves Playeras Migratorias and Reserva Urbana Costera del Río Chico, at Bahía Bustamante (where 15% of knots were polluted with oil in a study in 1979 (Harrington and Morrison 1980))

and at Península Valdés. However, oil pollution has recently decreased significantly along the Patagonian coast (Estévez pers. comm. 2005).

Development and associated pollution are threatening the Reserva Provincial de Río Chico para Aves Playeras Migratorias (created in 2001) and Reserva Urbana Costera del Río Chico (created in 2004). This comprises filling-in of the tidal flat and marshes for urban use, location of a rubbish dump near shorebird feeding and roosting sites as well as pollution from urban waste.

At the Bahía San Antonio Natural Protected Area (created in 1993) there is major potential for pollution from a soda ash factory which began to operate in 2005 and from port activities which are likely to expand as the factory increases production.

In the Bahía Samborombón reserve (created in 1979) there are threats from urban and agrosystem expansion and development.

### *8. Threat of Oil Pollution and Possibility of Other Unidentified Factors Affecting the Principal* **Rufa** *Non-breeding Site at Bahía Lomas, Chile*

The region of Magellan, Chile, has traditionally been an important producer of oil and natural gas ever since the first oil discovery was made in 1945 within 10 km from the bayshore in Manantiales. Even though local oil activity has diminished over the last 20 years and only covers a small percentage of national demand, it is a resource that is still exploited. Oil is extracted by drilling on land and offshore, the latter with no new drillings in the last eight years. Bahía Lomas, located at the eastern end of the Magellan Strait on the northern coast of Tierra del Fuego has several oil platforms. Most are static, while several have been closed within the last year as the oil resource has been depleted. Apparently, there is no incentive to continue drilling in the Straits of Magellan. However, on the nearby Atlantic Ocean coast of Argentina, oil drilling has been increasing in the last 10 years. The boat traffic from oil production in the Straits of Magellan is another potential risk as significant oil spills may occur with detrimental consequences similar to two recorded incidents in the vicinities of the bay (53,500 tons from the *Metula* in 1974 and 100 tons from the *Berge Nice* in 2004).

Although the potential threat to the red knot population would appear to be significant, there have been no reported incidents of knots being affected by oil either directly by major contamination of the plumage or indirectly through their food supplies (though small amounts of oil have been noted on some birds caught (Dey unpublished information, Niles unpublished information). However, major declines at Bahía Lomas have not been mirrored at nearby Río Grande (Fig. 73). This suggests that there could be a problem at Bahía Lomas. If there is, it is more likely to be connected with the oil industry than anything else because that is virtually the only significant human activity in the area.

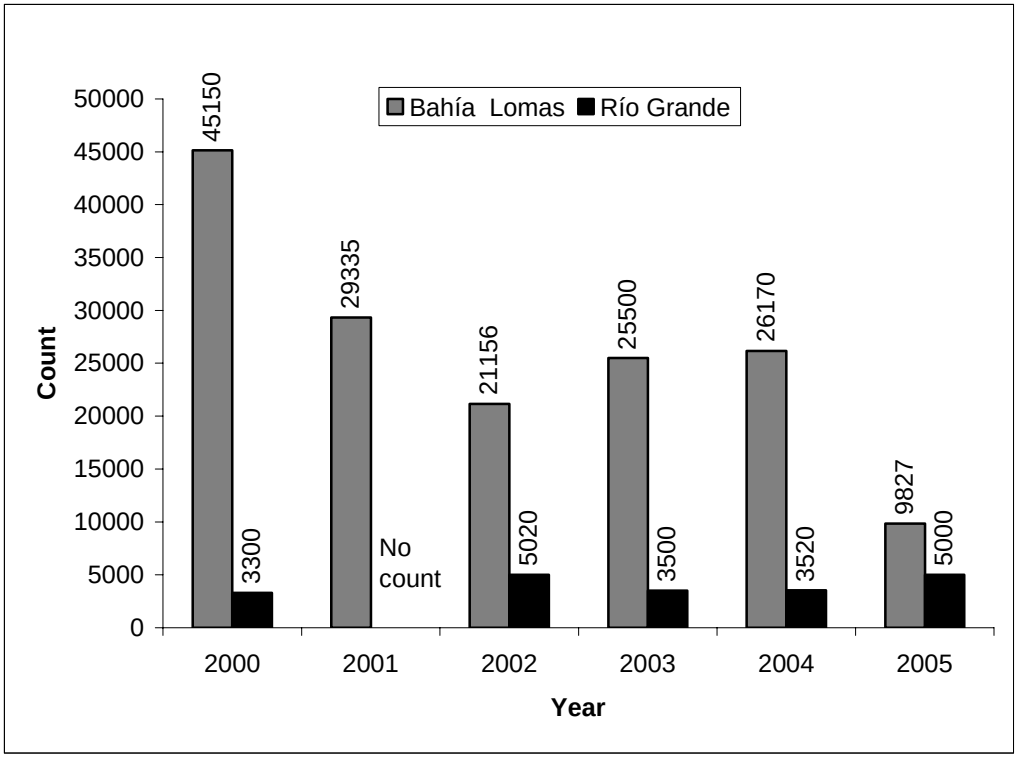



Figure 73. Aerial counts of red knots (*Calidris canutus rufa*) on major wintering areas in southern South America, January-February 2000-2005: Bahía Lomas, Río Grande, All = all sites in main wintering area (Morrison *et al.* 2004).

The possibility that problems at Bahía Lomas are entirely responsible for the *rufa* population crash would seem unlikely in view of the observation that it is birds at a lower weight in Delaware Bay that have lower survival (Baker *et al.* 2004). Nevertheless there could be a connection between birds leaving Bahía Lomas in poor condition and arriving in Delaware Bay in poor condition. Another scenario is that, though much smaller than Bahía Lomas, Río Grande is a preferred site. Therefore, just as knots have deserted sites further north along the Patagonian coast since 1985 becoming more and more concentrated in what is presumably the better non-breeding area of Tierra del Fuego, they may now be doing the same within Tierra del Fuego, deserting Bahía Lomas for Río Grande.

These are matters that deserve further investigation.

### *9. Oil Pollution Threat and Human Disturbance at the Only Other Major Non-breeding Site at Río Grande, Argentina*

Most of the sites used by red knots at Río Grande on the Atlantic coast of the Argentinian part of Tierra del Fuego are within the Reserva Costa Atlántica de Tierra del Fuego created in 1992. However, as at Bahía Lomas, the area is important for on- and off-shore oil production with the potential for oil pollution, especially from oil tankers loading around Río Grande City. Again, there is no direct evidence of knots having being affected by oil pollution but it remains a threat.

The knots frequently suffer human disturbance while feeding and roosting around Río Grande city, especially by people using all terrain vehicles and motor cycles, as well as from walkers, runners, fishermen and dogs.

#### *10. Threats to Red Knot Habitat in Canada*

The shorebird habitats of the Mingan Islands in the Gulf of St Lawrence, Quebec, are at risk because of the proximity of ships carrying oil, titanium and iron through the archipelago to the Havre-St-Pierre Harbour. In March 1999, one ship spilled 49 tons of crude oil that came ashore in the Mingan area. A similar accident occurring during the July to October stopover could have a serious impact on red knot feeding areas.

### B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

In the United States, no overutilization of the red knot for commercial, recreational, or educational purposes has been identified. However, hunting migratory shorebirds for food used to be common among local communities in Maranhão, Northern Brazil. They provided an alternative source of protein and birds with high subcutaneous fat content for long migratory flights were particularly valued (Serrano unpublished information). According to locals, the most consumed species were red knot, black-bellied plover (*Pluvialis squatarola*) and whimbrel (*Numenius phaeopus*), though no data are available as to the number of birds taken. Local people say that although some shorebirds are still hunted, this has greatly decreased over the past decade and hunting is not thought to amount to a serious cause of mortality.

Commercial overutilization of the red knot food resource in Delaware Bay (horseshoe crabs) is discussed in subsection A above.

It is sometimes claimed that the more intrusive forms of avian research, such as catching birds for banding and examination, has a detrimental effect. Therefore we address the question: Has the red knot population been overutilized for scientific purposes?

#### *1. Have Scientific Studies Contributed to the Red Knots Decline?*

The most serious form that overutilization for scientific purposes might take would be if it affected the birds' ability to survive and reproduce and so contributed to the population decline.

Bird banding has been carried out across the world, especially in Europe and North America, for over a century. Virtually all taxa have been banded at one time or another and the practice has come under considerable scrutiny. In most countries, bird banding is highly regulated and limited to trained personnel only. As such, it is considered a valuable and safe research tool. If it led to significant mortality or atypical behavior, it would not be permitted. Moreover there would be no purpose in doing it because the whole point is to study what birds do naturally. Some bird populations that have been the subject of intensive banding studies have increased while others have decreased. In Europe, for example, the Icelandic race of the black-tailed godwit (*Limosa limosa*) has increased, but the westerrn European race has declined, yet both have been banded extensively (Wetlands International 2006).

As to *rufa*, the banding effort has been fairly constant since intensive studies began in 1997, yet the population has remained stable between some years but declined dramatically between others (See Figs. 46 and 48). Moreover the number of birds caught annually (about 1,000 in Delaware Bay plus 300 in South America) is relatively small compared with some of the year-to-year population declines (14,000 from 2004 to 2005), so most of the birds that disappeared, presumed dead, had never been caught. Therefore it can be concluded that scientific studies have not been responsible for the major decline of *rufa*.

Each year, about 50 of the birds caught in Delaware Bay have been the subject of radio-telemetry studies in which a 2 g radio-tag has been glued to their backs. The tags are expected to drop off after 1-2 months through the natural replacement of skin. These birds, like the remainder of knots caught, are also fitted with individually numbered color-flags. Resighting studies in subsequent years show that the annual survival of birds that had been radio-tagged was no different to that of birds there had merely been banded (Atkinson unpublished information).

***2. Do scientific Studies Cause Significant Disturbance to Red Knots?***

Harrington (2005) evaluated the response of red knots to disturbance associated with research activities, including cannon-net catches. Observers recorded the frequency of disturbance events and time spent in flight during attempts to catch shorebirds with cannon-nets and at the same sites when catch attempts were not conducted. Disturbance events recorded when there was no catching were attributed to sources unrelated to research activities. Results indicate that the mean hourly disturbance rate during catch attempts was 13.0 versus 11.7 when catch attempts were not being conducted; this is not a statistically significant difference (t-test, $P>0.05$). Harrington also compared the duration of flights by knots that were disturbed by research-related activities (N=145) with that of knots that were disturbed by natural causes, (N=179). About 20% of the knots that were timed flew out of sight, so their flight duration could not be determined. The proportion of knots that flew out of sight during natural disturbance events (21%) was similar to the proportion that flew out of sight during research activities (21%). Of the remaining sample, flights of knots from natural causes tended to be shorter than for knots disturbed by researchers. Harrington also found no statistically significant difference in the mean number of calories used by knots reacting to natural disturbances and knots reacting to the activities of researchers. Analysis of research-related disturbance data for ruddy turnstones produced results similar to those for red knot (i.e. tests did not detect statistically significant differences between natural and research-related disturbances).

***3. Steps to Minimize Disturbance by Research Activities***

In recent years, especially since 2003, considerable care has been taken to minimize disturbance caused to shorebirds in Delaware Bay by researchers. Catching in particular has been limited in terms of total numbers caught, frequency and catch size consistent with the twin aims of monitoring annual survival and weight gain. Moreover most close observation, e.g. to read inscribed color flags, has where possible been carried out from well-concealed sites including blinds.

**C. Disease or Predation**

In Europe and North America, the study of shorebirds over most of the past thirty years has been conducted in what Butler *et al.* (2003) called a "predator vacuum" arising from greatly depleted raptor populations caused by persecution and pesticide poisoning. Only in the past decade have these shown recovery to pre-WWII levels in temperate North America. Butler *et al.* have demonstrated how recovering raptor populations appear to have led to changes in the migratory strategies of some shorebirds. These include lower numbers of shorebirds, reduced stopover length and lower mass in the more dangerous sites. However, increased raptor numbers have not yet been shown to affect the size of shorebird populations. Given that red knots spend most of the year in regions where raptor populations were never greatly affected by persecution and poisoning (arctic Canada and South America), it would seem unlikely that increased raptor predation has been responsible for the population decline.

In the Arctic, 3-4 year lemming cycles give rise to similar cycles in the predation of shorebird nests. Therefore, when lemmings are abundant, arctic foxes and jaegers concentrate on them and shorebirds breed successfully, but when lemmings are in short supply few shorebird eggs or chicks survive (Summers and Underhill 1987). It is evident that these cycles have always affected the productivity of arctic-breeding shorebirds and lead to fairly minor year-to-year changes in otherwise stable populations. We have no reason to suppose that increased arctic nest predation has been responsible for the long term decline in the *rufa* population. However, unsuccessful breeding seasons have contributed to at least some recent reductions in the population.

Potential predators of shorebirds, especially peregrines, red foxes (*Vulpes vulpes*) and feral cats (*Felis catus*), are possibly more of a threat to knots in Delaware Bay as sources of disturbance than as agents of mortality. Over the past decade, peregrines in North America have largely recovered from reduced numbers in the mid 20$^{th}$ century caused by persecution and pesticide poisoning. Now several pairs nest close to both shores of Delaware Bay. However, they are almost all using artificial nest sites and it is likely that without these, peregrines would be largely absent, as they probably were before their numbers crashed. The disturbance they cause to knots in Delaware Bay has not been properly evaluated. This should be done and, if it is found to be significant, steps taken to reduce its impact by removal or relocation of the nesting towers.

An epizootic disease resulting in large-scale mortality of knots reported from the west coast of Florida in December 1973 and November 1974 was caused by a protozoan parasite, most likely an undescribed sporozoan species (Harrington 2001). Further reports on knot mortality in Florida in 1981 were due to *Plasmodium hermani* (Harrington 2001).

In 1981 there was a report of an adventitious molt in knots caused by a mallophagan parasite (Mallophaga: Menoponidae) in feather shafts (Harrington 2001).

On 7 April 1997, 26 red knots, ten white-rumped sandpipers and three sanderlings were found dead or dying along 10 km of beach at Lagoa do Peixe, southern Brazil. The following day, another 13 dead or sick knots were found along 35 km of beach nearby (Baker *et al.* 1999b). Some, but not all of these birds, were infected with hookworms *Acanthocephala.* Although hookworms can cause death, it would seem more likely that the mortality had another cause. Smaller mortalities of spring migrants with similar symptoms of malaise have also been reported from Uruguay in recent years.

Since 2002, migratory birds in Brazil have been tested for viruses including West Nile, Newcastle and avian influenza, by the National Health Foundation in collaboration with Instituto Brasileiro do Meio Ambiente dos Recursos Naturais Renováveis and Centro Nacional de Pesquisa para Conservação das Aves Silvestres. To date, avian influenza type H2 has been found in one red knot, Mayaro virus in seven knots, and Equine Encephalite virus in another (Araújo *et al.* 2003).

Since December 2003, blood and feather samples have been collected in Brazil not only from red knots but also from several other shorebird species for genetic variability studies and stable isotope analysis. In the course of these studies in February 2005, all of a sample of 38 knots caught in Maranhão was found to be heavily infected with ectoparasites. The birds were also extremely light, less than the usual fat-free mass of knots (Baker *et al.* 2005a). Recent studies have shown that tropical wintering shorebirds have a higher incidence of parasites and pathogens than those wintering at higher latitudes (Mendes *et al.* 2005). However, without further studies there is no means of knowing whether this observation is typical of knots wintering in that area or peculiar to one winter, or whether such infestation leads to significant mortality, or whether it can be passed on to other populations, such as when Tierra del Fuego birds stopover in Maranhão during northward or southward migration. Nevertheless the potential importance of this observation is considerable if it is shown that ectoparasite infection leads to a loss of fitness. No systematic effort has yet been made to assess the parasite load of birds passing through Delaware Bay, but fieldworkers have noticed ectoparasites on a substantial number of knots caught there (Minton and Niles unpublished information). This is a factor worthy of further investigation.

**D. The Inadequacy of Existing Regulatory Mechanisms**

There are a number of regulatory issues that have negatively influenced the protection of red knots. Most have arisen because they range over such a large area that coordinating conservation regulations is not just an interstate issue in the U.S. but also the subject of international diplomacy.

*C. c. rufa* breeds in one country (Canada), uses stopovers in at least four countries (U.S., Brazil, Argentina and Chile) and winters in mostly different locations in the same four countries (See Fig. 72). The birds also use spring stopovers in all Atlantic coast states from Florida to New Jersey, wintering sites in at least three states, and autumn stopover sites in all eastern states from New England to Florida (Figs. 74 and 75).

In the U.S., the red knot is protected from hunting but has special status in only two states: New Jersey where it is has “threatened” status and Georgia where it is a “species of special concern.”

In April 2007, the Committee on the Status of Endangered Wildlife in Canada determined that *rufa* was endangered. In Brazil it is being proposed for listing as endangered.

In Chile, both the red knot and its habitat are protected. The federal law that regulates hunting (LEY No. 19.473) includes the red knot in the list of protected species. All coastal habitats (extending to 300 m inland from the high tide line) are managed by the Chilean Navy and are the property of the national government.

Figure 74. Important *C. c. rufa* breeding, stopover, and wintering areas in the Western Hemisphere

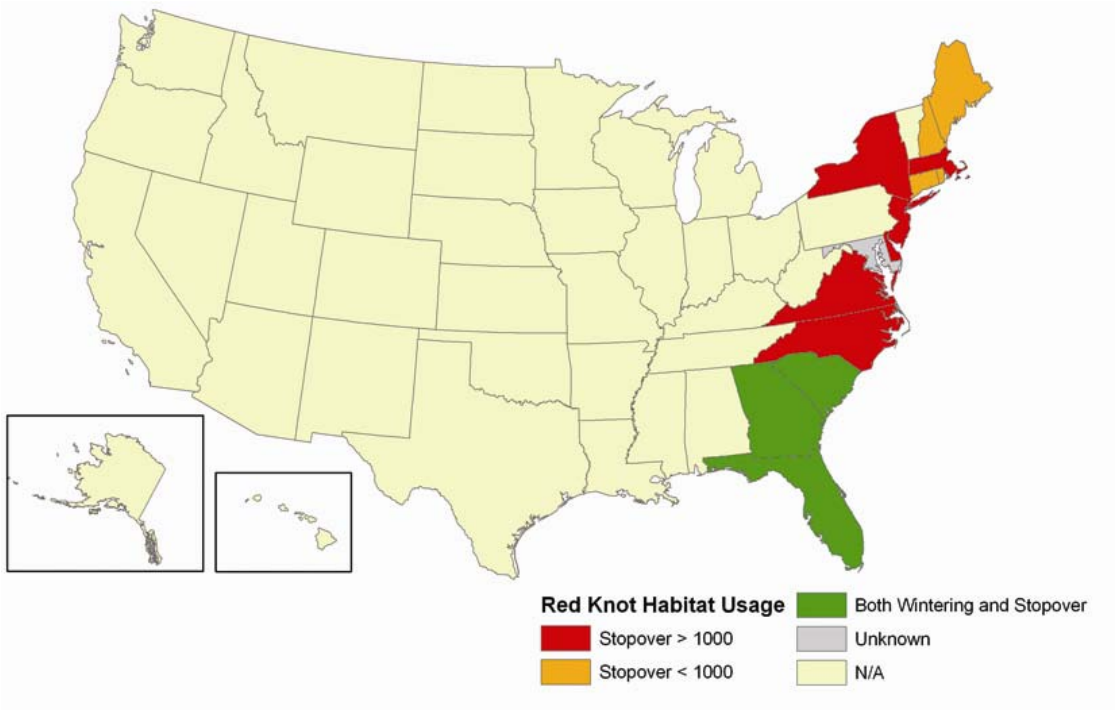



Figure 75. Important *C. c. rufa* stopover and wintering areas in the United States.

Argentina does not allow the red knot to be hunted and specifically protects it from subsistence hunting. Both Chile and Argentina are among the 101 parties to The Convention on the Conservation of Migratory Species of Wild Animals which, at its meeting in November 2005, determined that the *rufa* subspecies of the red knot was endangered and as such added it to Appendix 1 of the Convention. Under the terms of the Convention the Parties agree "to strive towards strictly protecting animals listed in Appendix 1, conserving or restoring the places where they live, mitigating obstacles to migration and controlling other factors that might endanger them" (http://www.cms.int). The U.S., Canada and Brazil are among the minority of countries that are not yet parties to the Convention.

***1. Inadequacies of the Federal and Regional Regulatory System***

The existing regulatory system creates a number of problems for the conservation of red knots stopping over in Delaware Bay in that different agencies have jurisdiction over the protection of horseshoe crabs (and their eggs) on the one hand and red knots on the other. The birds are under the legal jurisdiction of the USFWS, and the horseshoe crabs are under the legal jurisdiction of the Atlantic States Marine Fisheries Commission (ASMFC) which has the authority to set quotas for adoption by the states. The ASMFC is overseen by the National Marine Fisheries Service (NMFS) which has ultimate responsibility for the management and conservation of living marine resources. Presently NMFS has limited it involvement to participating in the ASMFC subcommittees and has not taken any regulatory action to protect crabs or birds. Individual states have authority

to implement more restrictive harvest regulations than those set by the ASMFC and have done so on numerous occasions.

The ASMFC has promulgated a horseshoe crab management plan to conserve the horseshoe crab resource based on the current commercial uses of the crab for bait and for the biomedical industry, and the competing needs of migratory shorebirds and the federally-listed, (threatened) loggerhead turtle. The protection of the adult horseshoe crab population as food source for the loggerhead turtle is specifically identified in the plan with the recognition that the plan should be coordinated with the federal agencies having jurisdiction over the turtle population. Migratory shorebirds, and specifically the red knot, and their reliance on horseshoe crab eggs are also identified and discussed in the management plan. The plan specifically protects the food resource of the loggerhead turtle pursuant to Section 7(a)(2) of the ESA; the food resource of the red knot is not similarly protected. Although the ASMFC does not have direct legal jurisdiction to protect the food resource for the red knot, it has taken steps to improve horseshoe crab egg availability including decreasing harvest quotas, more efficient use of crabs as bait and facilitating a horseshoe crab sanctuary at the mouth of Delaware Bay.

In contrast the USFWS does have authority to protect the birds under the Migratory Bird Treaty Act (40 Stat. 755; 16 U.S.C. 703-712) (MBTA) which provides that no migratory bird can be taken, killed or possessed unless in accordance with the provisions of the Treaty. The MBTA is the only current federal protection provided for the red knot. The MBTA prohibits "take" of any migratory bird, which is defined as: "to pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to pursue, hunt, shoot, wound, kill, trap, capture, or collect." However, other than for nesting sites, which are not located in the United States, the MBTA provides no authority for protection of habitat or food resources. Human disturbance is cited as one of the major threats to red knots throughout it migratory range within the United States. Therefore, the MBTA provides inadequate protection to the red knot in that it does not afford red knots protection from human disturbance on migratory and wintering areas or ensure protection of food resources.

Under the Endangered Species Act 1973, a species may be designated as threatened or endangered. However, this may be precluded through lack of resources if there are species of higher conservation priority. Therefore species whose listing is warranted may receive none of the benefits of listing including those involving little or no cost. This is a shortcoming that needs to be addressed.

### *2. Inadequacies of Regulatory Systems in Individual States*

Without adequate federal coordination, the attempts of individual states to conserve red knots have lacked consistency. This has led to substantial gaps in protection, especially when horseshoe crab fishermen have exploited differences in regulations among states.

In 1996, New Jersey restricted the harvest of horseshoe crabs when it was confronted with mounting evidence of the decline of crabs, eggs and shorebirds, particularly red knots. In response, the horseshoe crab fishermen took crabs but landed them in Delaware and Maryland. The following year, Delaware and Maryland followed New Jersey's lead and instituted increased restrictions on the horseshoe crab harvest. That year the fishermen harvested crabs but landed them in Virginia. Subsequently, the

ASMFC imposed modest restrictions to the harvest and fishermen attempted to land crabs in Pennsylvania while Virginia disregarded the ASMFC restrictions. After the development and implementation of the Horseshoe Crab Management Plan, which regulated landings coast-wide, the problem was solved, but this experience makes it clear that individual states alone without federal or regional coordination cannot adequately protect wide-ranging inter-jurisdictional species such horseshoe crabs or shorebirds.

Another inadequacy of regulatory mechanisms relates to the protection of red knots from disturbance. New Jersey Division of Fish and Wildlife has been protecting beaches used by shorebirds from disturbance since 1985. In 2003, the Division closed seven beaches to all human use during the peak of the shorebird stopover. The reason for the closure was to increase the availability of eggs for shorebirds by preventing repeated disturbances, which have been demonstrated to be significantly detrimental to the birds' ability to feed (Burger *et al.* 2005). Moreover, disturbance by humans and dogs often increases the competitive advantages of gulls because gulls adapt more easily than shorebirds to repeated disturbance (Burger *et al.* 2005) (Fig. 76). Only in the state of New Jersey is the red knot listed as a threatened species and as such provided with legal protection. In all other states, there is no legal basis for preventing disturbance (Fig. 77). The need to protect red knots from repeated disturbance on beaches also applies during southward migration in autumn as shown by recent studies (Mizrahi pers. comm. 2005).

Figure 76. Unrestrained dog and parked cars on the beach at Fort George Inlet, Duval County, Florida (Patrick Leary).

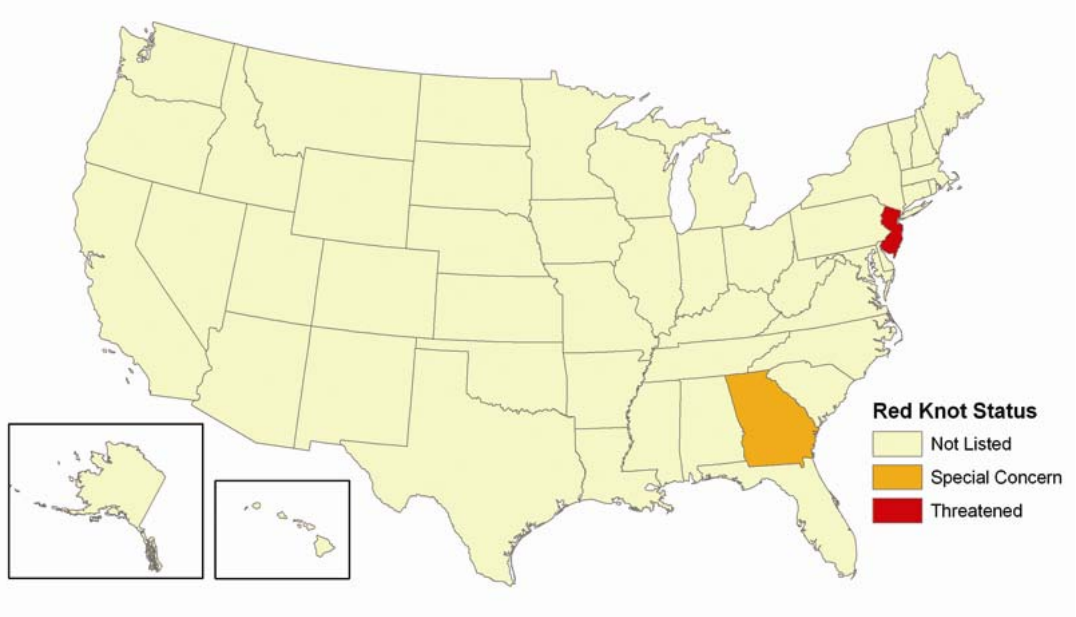



Figure 77. Red knot state legal status in each state in the United States.

In Delaware, even if the red knot was listed as a State Endangered Species, the listing would only pertain to collection, possession, transportation, and sale. There are no regulatory mechanisms to protect the habitat of Delaware state-listed species or to regulate "take" due to activities such as chronic disturbance, destruction of habitat, or removal or depletion of food resources.

Regulation of human use of the inter-tidal zone is greatly complicated by variation between states in ownership and jurisdiction of the foreshore. In New Jersey, for example, most inter-tidal areas are owned by the state and managed by the state's Tideland Council, whereas in Delaware lands can be privately owned to the mean low tide line. Thus, in New Jersey restrictions on activities that may interfere with shorebird foraging or roosting apply statewide. In eight sections of beach, use can be eliminated entirely. However, in Delaware, restrictions can only be applied to state-owned lands and lands designated as Delaware River and Bay Shoreline Refuge (Smyrna River to St. Jones River). At present Delaware does not have legal authority to restrict or eliminate activities that would disturb shorebirds on all privately owned beaches including the harvest of horseshoe crabs unless the beach is voluntarily registered as a Horseshoe Crab Sanctuary. Similar legal barriers to restrict disturbance of wintering shorebirds exist in nearly all Atlantic coast states. These state-by-state variations in jurisdiction create significant impediments to region-wide or nationwide restrictions to protect shorebirds and horseshoe crabs.

## E. Other Natural Or Man-made Factors Affecting Red Knot Continued Existence.

### *1. Curtailment of Habitat Use from Disturbance by People and Dogs*

Human disturbance can have an adverse effect on shorebird foraging and this depends on the degree of disturbance and the availability of other suitable feeding areas. Disturbance compels birds to pay the energetic cost of flying to a new area; it may reduce the amount of time that the birds are able to feed, and can prevent them from feeding in the

most preferred sites. Any overall reduction in energy intake as a result of these responses is the net impact of disturbance on energy budgets (Davidson and Rothwell 1993). Disturbance, however, may have little impact on birds if there are suitable foraging areas nearby in which they can feed.

a. Delaware Bay and New Jersey Coast

The spectacle of shorebirds and spawning horseshoe crabs draws hundreds of bird watchers to Delaware Bay beaches during the spring migratory stopover (Burger *et al.* 1995). The beaches are also vulnerable to the usual beach activities, such as walking, jogging, fishing and dog walking. Disturbance along the New Jersey shore of Delaware Bay was first investigated in 1982, with further studies in the 1980s, 1990 and 2002 (Burger *et al.* 2004). The results show that the average period that that a beach was disturbed during any hour of the day dropped from 32.9 minutes in 1982 to 3.2 minutes in 2002. This was the direct result of increased management efforts by the New Jersey Division of Fish and Wildlife. Though the period of disturbances decreased during this period, it appears that the birds' sensitivity to disturbance increased. In 1982, 30% of shorebirds disturbed at Reeds Beach South and 98% at Reeds Beach North flew away when disrupted by people and did not return within ten minutes. In 2002, 98% and 93% respectively did not return, with an increasing proportion of disturbance coming from dogs.

When shorebirds are disturbed by people and dogs on their foraging beaches, they usually respond by flying away (Fig. 76). When there were no restrictions on disturbance in the 1980s, shorebirds were disturbed for over half of the time by day and when all beaches were disturbed the shorebirds often returned to the same beaches (Burger *et al.* 2004). When most beaches were protected from disturbance in 2002, the shorebirds were able to move to nearby beaches that were undisturbed. Therefore management that restricts human activities on Delaware Bay beaches is shown to be effective in creating disturbance-free beaches necessary for feeding and resting shorebirds.

Starting in 2003, major sections of the New Jersey shore have been closed to human use during the peak of the stopover at the initiative of the NJDFW in order to reduce disturbance to shorebirds by people and dogs. Before this, disturbance of the beaches was a particular problem, especially during Memorial Day weekend. In 2001, for example, all 18,000 red knots that had previously been feeding on the bayshore spent Memorial weekend on the Atlantic coast in the vicinity of Stone Harbor (Sitters 2001).

An additional source of disturbance is that caused by off road vehicle (ORV) use. Although not quantified, areas along the Delaware shore are occasionally used by ORVs. The frequency and duration of this type of disturbance varies but can have a major impact if ORVs remain at a specific location for an extended period of time. An ORV driving along a beach without stopping may have a relatively insignificant effect. However, when they are used with great frequency or for long periods (such as when they are used for recreation as opposed to transportation), ORVs probably cause shorebirds to leave and not return.

Disturbance by people is not limited to direct use of Delaware Bay beaches. Low energy beaches, particularly those along the mouths of tidal creeks and rivers have been identified as optimum horseshoe crab spawning habitat. Where these have high levels of boat traffic, such as at Mispillion Harbor, disturbance due to the presence, noise, speed, or wake of boats is likely to be considerable (Harrington 2005). Preliminary results indicate

that boat traffic in Mispillion Harbor represents a significant source of disturbance to feeding shorebirds, particularly when boats travel at high speed (Harrington 2005).

b. Massachusetts

Disturbance by humans and domestic dogs has been identified as a threat.

c. Virginia

Some of the potential threats red knots currently face on the barrier islands include frequent interruptions in foraging and roosting bouts caused by humans and an introduced breeding population of peregrines

d. North Carolina

Along the coast, threats to migrant and wintering red knots include human disturbance, especially at the following key sites:

- Tubbs Inlet – human disturbance
- Bear Island/Bogue Inlet – some human disturbance at inlet and nearby bath house during the spring and summer months but very limited at present
- Bird Shoals – human disturbance primarily during the spring and summer months
- Cape Lookout National Seashore – human disturbance including beach driving during spring/summer months
- Cape Hatteras National Seashore – human disturbance including beach driving during spring/summer months
- Pea Island – human disturbance during the spring and summer months
- Clam Shoal – this site is fairly inaccessible, but more people have visited it in recent years so possibly human disturbance during the spring and summer months is increasing.

e. South Carolina

A large area of the South Carolina coast is protected due to public ownership and conservation easements. There are few opportunities to increase the amount of protected coastal land. The biggest threat to red knots is disturbance by boats, humans and dogs, even in Cape Romain NWR. Presently in South Carolina, there are only two islands (in Cape Romain NWR) closed to boat landings that are known to be important red knot loafing and foraging areas. Coastal counties are experiencing annual human population growth rates of 2-3%.

f. Georgia

Human disturbance (pedestrians, dogs, boats, bicyclists) is the most significant threat to important winter and stopover habitats for red knots.

g. Florida

Although the implications are poorly understood, it appears that the most immediate and tangible threat to red knots wintering in and migrating through Florida is chronic disturbance (Niles *et al.* 2006). With the exception of a few federally owned sites, most beaches experience very high human disturbance rates, which are increasing. While almost all foraging habitat and most roosting sites are in public ownership, very few locations are managed in any way for winter or passage shorebirds. Seasonal posting in Florida is done primarily for beach-nesting birds during the spring and summer months. Publicly owned lands, if managed at all, are generally under tremendous recreational pressure from a rapidly growing human population. Some sites receive incidental protection under restrictions designed to protect other resources (combustible motor

exclusion zones to protect sea grass beds or homeland security restrictions at ports, military installations, space center, etc.).

h. Argentina

Human disturbance is a threat on the beaches at Reserva Provincial de Río Chico para Aves Playeras Migratorias and Reserva Urbana Costera del Río Chico (tourism), on Península Valdés (tourism, with dogs a particular problem, and fishermen with cats [Bala pers. comm. 2005]), in the Bahía San Antonio Natural Protected Area (beach tourism) and in Bahía Samborombón (tourism).

Knots frequently suffer human disturbance while feeding and roosting around Río Grande city, especially by people using all-terrain vehicles and motor cycles, as well as from walkers, runners, fishermen and dogs.

***2. Competition from Gulls***

Gulls are both competitors for food and potential predators of shorebirds. They take advantage of abundant horseshoe crab eggs, particularly on that part of the New Jersey bayshore that lies close to their Atlantic coast breeding colonies. During 1979-2004, numbers of two common species, laughing gull and herring gull (*Larus argentatus*), fluctuated widely, but with no statistically significant long-term trend. However, greater black-backed gulls (*L. marinus*) increased significantly (Table 41). There has been no significant change in the number of gulls using the New Jersey bayshore for feeding (Sutton and Dowdell 2002). During 1992-2002, the number of gulls recorded in single-day counts on accessible New Jersey bayshore beaches ranged from 10,000 to 23,000.

Table 41. Aerial survey counts of gulls on the Atlantic Coast of New Jersey (Jenkins unpublished data).

| Year | Laughing Gull | Herring Gull | Great Black-backed Gull | All gulls |
|---|---|---|---|---|
| 1979 | 59,914 | 5,802 | 128 | 65,844 |
| 1983 | 58,267 | 5,237 | 260 | 63,764 |
| 1985 | 54,434 | 4,720 | 226 | 59,380 |
| 1989 | 58,797 | 7,097 | 293 | 66,187 |
| 1995 | 39,085 | 6,828 | 781 | 46,694 |
| 2001 | 80,253 | 9,814 | 1,036 | 91,103 |
| 2004 | 52,765 | 5,347 | 795 | 58,907 |
| Mean | 57,645 | 6,406 | 503 | 64,554 |
| Correlation with year ($R_s$) | -0.286 (ns) | 0.393 (ns) | 0.929 ($p = 0.003$) | -0.179 (ns) |

Gull breeding colonies in Delaware are not located as close to the bayshore beaches as in New Jersey. However, immature, non-breeding, large gulls (i.e. greater black-backed gull and herring gull) and some laughing gulls (most likely from New Jersey breeding colonies) do congregate on the Delaware shore during the spring, especially at Mispillion Harbor. Though gull numbers have been recorded along the Delaware bayshore in recent years, there are insufficient long-term data to show populations trends.

Although total gull numbers have shown no significant long-term trend (Table 41), the effect of their competition on the shorebirds may have increased as a result of the decline in the availability of horseshoe crab eggs. Burger *et al.* (2005) found that gulls are more tolerant of human disturbance than shorebirds. When disturbed by humans, gull numbers returned to pre-disturbance levels within 5 minutes. Even after 10 minutes shorebird numbers failed to reach pre-disturbance levels. Shorebirds showed a particularly strong reaction to dogs. When disturbed by a dog, shorebirds did not return to the same beach. Red knots are also more vigilant when feeding near gulls and must spend more time in aggression than if they are not near gulls (Burger in press).

Thus the size and aggression of gulls, coupled with their greater tolerance of human disturbance, give them the advantage over shorebirds in prime feeding areas. In the present scenario of limited availability of good feeding beaches, gulls appear to be an increasing threat to red knots in the Delaware Bay.

The influence of gulls on horseshoe crab egg densities has been shown to be significant through exclosure experiments conducted by Virginia Polytechnic Institute (Karpanty pers. comm. 2005). Burger *et al*. (2004) found that gulls outcompete all shorebird species including red knots for horseshoe crab eggs, and that the influence of gulls increases with repeated disturbance. People walking dogs caused shorebirds to leave beaches whiles gulls returned shortly after the disturbance ended.

Red knot foraging efficiency is also adversely affected by the mere presence of gulls. Hernandez (2005) found that the foraging efficiency of knots feeding on horseshoe crab eggs decreased by as much as 40% when feeding close to a gull.

***3. Risks Associated With Small Population Size***

The threat to *rufa* may become further increased if the population drops below about 10,000 because Baker *et al*. (2005a) has shown that, due to their low genetic variability, the effective size of shorebird populations is much smaller than numbers censused (i.e., not all individuals contribute to the gene pool). As a result, census populations of 5,000-10,000 are likely to be especially vulnerable to the accumulation of harmful genetic mutations. Small populations are also at greater risk from the effects of stochastic events. This applies especially those which, like the red knot, are highly dependent on a small number of sites.

***4. Weather-related Threats to Red Knots:***

Cold and/or wet weather during the brief arctic summer can have a severely adverse effect on the breeding success of shorebirds (van de Kam *et al.* 2004). Global climate warming may lead to alterations in arctic weather patterns. These may be beneficial to shorebirds if they lead to warmer, longer breeding seasons but this is by no means certain (Rehfisch and Crick 2003).

In the very long term global warming may lead to large-scale habitat changes which will greatly exacerbated by vegetation responses to increased atmospheric carbon dioxide (Rehfisch and Crick 2003). It has been predicted that this may lead to a 65% decrease in tundra habitat over a large area of the Arctic (Cramer 1997). If so, red knot breeding habitat would become so scarce that there is little doubt that this would restrict the size of its population.

## IX. SUMMARY OF LAND OWNERSHIP AND EXISTING HABITAT PROTECTION FOR POPULATIONS

Table 42 summarizes details of the ownership of all land considered to be important for red knots throughout the West Atlantic Flyway. This table also indicates the approximate percentage of land that is subject to some arrangement for habitat protection. However, it should be noted that the nature of such arrangements varies from place to place and in only a very few cases is the arrangement specifically for the benefit of red knots.

Table 42. Summary table of land ownership and existing habitat protection for populations of red knots in the Western Hemisphere.

| Country and Province/State | Area | Ownership | Approximate Percent of Habitat Under Protection |
|---|---|---|---|
| *Chile* | | | |
| Region XII- Magellanes y la Antártica Chilena | Bahía Lomas | **1.** Federal - Chilean Navy - Dirección del Territorio Marítimo y Marina Mercante<br>**2.** Private | 100% |
| *Argentina* | | | |
| Tierra del Fuego | Río Grande | **1.** Reserva Costa Atlántica de Tierra del Fuego<br>**2.** Private | 100% |
| | Bahía San Sebastián | **1.** Reserva Costa Atlántica de Tierra del Fuego<br>**2.** Private | 100% |
| Santa Cruz | Río Gallegos Estuary | **1.** Reserva Urbana Costera del Río Chico<br>**2.** Reserva Provincial de Río Chico para Aves Playeras Migratorias | 100% |
| Chubut | Bahía Bustamante | 1. Public<br>2. Private | 100% |
| | Península Valdés | 1. Public<br>2. Private | 100% |
| Río Negro | San Antonio Oeste | Bahía San Antonio Natural Protected Area | 100% |
| Buenos Aires | Bahía Samborombón | **1.** Provincial Integral Natural Reserve with Restricted Access<br>**2.** Provincial Integral Natural Reserve "Rincón de Ajó"<br>**3.** "Campos del Tuyú" Private Reserve- Fundación Vida Silvestre Argentina<br>**4.** "Punta Rasa" Biological Station- (Argentinean Navy) and the Fundación Vida Silvestre Argentina<br>**5.** Punta Rasa "Traveled Municipal Ecological Reserve" | 100% |

Table 42. Continued

| Country and Province/State | Area | Ownership | Approximate Percent of Habitat Under Protection |
|---|---|---|---|
| *Brazil* | | | |
| Maranhão | Baía de Turiaçu | Protected Environmental Area of Reentrâncias Maranhenses | ~50% |
| | Baía dos Lençóis | Protected Environmental Area of Reentrâncias Maranhenses | ~50% |
| Río Grande do Sul | Lagoa do Peixe National Park | **1.** Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis<br>**2.** Municipal- São José do Norte, Mostardas and Tavares | 2,971.44 ha, or 8.6% of total area |
| *United States* | | | |
| Franklin County Florida | Yent Bayou | Private land- Part of the Hidden Beaches and Victorian Village developments | 0% |
| | Carrabelle Beach | State and county land | |
| | Lanark Reef | State and private land | ~50% |
| Brevard County Florida | Merritt Island NWR- Black Point Drive | USFWS | 100% |
| | Kennedy Space Center | NASA | 100% |
| Pinellas County Florida | Anclote Key | Florida Park Service | 100% |
| | Three Rooker Bar | Florida Park Service | 100% |
| | Honeymoon Island | Florida Park Service | 100% |
| | Caladesi Island- Hurricane Pass | Florida Park Service | 100% |
| | Caladesi Island- Dunedin Pass | Florida Park Service | 100% |
| | Courtney Campbell Causeway SE | Department of Transportation | 0% |
| | Shell Key | Owned by the state of Florida but leased by Pinellas County | 100% |
| | Island north of Bunces Pass | Owned by the state of Florida but leased by Pinellas County | 100% |
| | Fort Desoto- NW end | Pinellas County | ~50% |
| | Fort Desoto- east end | Pinellas County | ~50% |
| | Passage Key | USFWS | 100% |
| Sarasota County Florida | Lido Beach | Sarasota County | 0% |
| | Palm Island | State and private resort | ~50% |
| Lee County Florida | Ding Darling NWR- Back bay of Sanibel Is. | USFWS | ~50% |
| | Little Estero Island | State | 100% |
| Collier County Florida | Capri Pass (Key Island) | State and Federal | ~50% |
| Monroe County Florida | Lake Ingraham- SE end | National Park Service | 100% |
| | Snake Bite Channel | National Park Service | 100% |
| | Area NW of Palm Key | National Park Service | 100% |

Table 42. Continued

| Country and Province/State | Area | Ownership | Approximate Percent of Habitat Under Protection |
|---|---|---|---|
| Chatham County Georgia | Little Tybee Island | State Government | ~50% |
| | Wassaw Island | Federal Government | 100% |
| | Ogeeche River Bar | State Government | 100% |
| Bryan County Georgia | Ossabaw Island | State Government | 100% |
| Liberty County Georgia | St. Catherines Island | Private- St. Catherines Island Foundation | 100% |
| | St. Catherines Bar | State | 100% |
| | Grass Island | State | 100% |
| McIntosh County Georgia | Blackbeard Island | Federal Government | 100% |
| | Sapelo Island | State Government | 100% |
| | Wolf Island | Federal Government | 100% |
| | Little Egg Island Bar | State Government | 100% |
| Glynn County Georgia | Little St. Simons Island | Private – resort | ~50% |
| | Sea Island | Private | 0% |
| | St. Simons Island-Gould's Inlet | Municipality | 0% |
| | Jekyll Island | State Park | ~50% |
| Camden County Georgia | Little Cumberland Island | Private | ~50% |
| | Cumberland Island | Federal Government | 100% |
| Horray County South Carolina | Waites Island | State- Coastal Carolina University segment | ~50% |
| | Myrtle Beach State Park | State | ~50% |
| Georgetown County South Carolina | Huntington Beach State Park | State | ~50% |
| | North Island | State - Tom Yawkey Wildlife Center South Carolina Department of Natural Resources (SCDNR) Heritage Preserve | 100% |
| | Sand/South Island | State- Tom Yawkey Wildlife Center SCDNR Heritage Preserve | 100% |
| | Cedar Island | State- SCDNR Santee Coastal Reserve | 100% |
| Charleston County South Carolina | Murphy Island | State- SCDNR Santee Coastal Reserve | 100% |
| | Cape/Lighthouse Islands | Federal – Cape Romain NWR | 100% |
| | Raccoon Key | Federal – Cape Romain NWR | 100% |
| | Bull Island | Federal – Cape Romain NWR | 100% |
| | Capers Island | State- SCDNR Heritage Preserve | 100% |
| | Isle of Palms County Park | County | ~50% |

Table 42. Continued

| Country and Province/State | Area | Ownership | Approximate Percent of Habitat Under Protection |
|---|---|---|---|
| | Folly Beach County Park north end | County | ~50% |
| | Folly Beach County Park south end | County | ~50% |
| | Beachwalker County Park at Kiawah Island | County | ~50% |
| | Botany Bay Island | Private- conservation easement held by SC Nature Conservancy | 100% |
| | Botany Bay Plantation (Edisto Island) | State | 100% |
| Colleton County South Carolina | Edisto Beach State Park | State | 100% |
| | Pine Island | State- SCDNR | 100% |
| | Otter Island | State- SCDNR Heritage Preserve | 100% |
| Beaufort County South Carolina | Hunting Island State Park | State | 100% |
| | Pritchards Island | State- University of South Carolina | 100% |
| | St. Phillips Island | Private – conservation easement held by SC Nature Conservancy | 100% |
| Jasper County South Carolina | Turtle Island | State- SCDNR Heritage Preserve | 100% |
| Dare County North Carolina | Pea Island | Federal- NWR | 100% |
| | Clam Shoal | Private - remote due to remote nature. | 100% |
| Hyde County North Carolina | Cape Hatteras National Seashore | Federal- NPS | 100% |
| Carteret County North Carolina | Bird Shoals | State- NC National Estuarine Research Reserve | 100% |
| | Rachel Carson | State- NC National Estuarine Research Reserve | 100% |
| | Cape Lookout National Seashore | Federal- NPS | 100% |
| Onslow County North Carolina | Bear Island/Bogue Inlet | State- NC State Parks | 100% |
| Brunswick County North Carolina | Tubbs Inlet | **1.** Private – not protected<br>**2.** State | ~50% |
| Accomack County Virginia | Assateague Island | Chincoteague National Wildlife Refuge (CNWR) | 100% |
| | Wallops Island | NASA | 100% |
| | Assawoman Island | CNWR | 100% |
| | Metompkin Island | **1.** Virginia Department of Conservation and Recreation (VDCR)<br>**2.** CNWR | 100% |
| | Cedar Island | **1.** VDCR<br>**2.** CNWR | 100% |
| | Parramore Island | VDCR | 100% |

Table 42. Continued

| Country and Province/State | Area | Ownership | Approximate Percent of Habitat Under Protection |
|---|---|---|---|
| Northampton CountyVirginia | Hog Island | VDCR | 100% |
| | Cobb Island | VDCR | 100% |
| | Little Cobb Island | VDCR | 100% |
| | Wreck Island | VDCR- Division of Natural Heritage | 100% |
| | Ship Shoal Island | VDCR | 100% |
| | Myrtle Island | VDCR | 100% |
| | Smith Island | VDCR | 100% |
| | Fisherman Island | Fisherman's Island NWR | 100% |
| Baltimore County Maryland | Hart-Miller Island | State- Maryland State Park | 100% |
| Talbot County Maryland | Poplar Island | **1.** U.S. Army Corps of Engineers<br>**2.** MD Port Administration | 100% |
| Worcester County Maryland | Assateague Island | **1.** Assateague Island National Seashore- National Park Service<br>**2.** Chincoteague National Wildlife Refuge- USFWS<br>**3.** Assateague State Park- Maryland Department of Natural Resources | 100% |
| Kent County Delaware | Bombay Hook | Federal- National Wildlife Refuge (NWR) | 100% |
| | Port Mahon | State | 0% |
| | Little Creek Wildlife Area | State | 100% |
| | Ted Harvey Wildlife Area | State | 100% |
| | Pickering beach | Private – not protected | 0% |
| | Kitts Hummock | Private – not protected | 0% |
| | North Bowers Beach | Private – not protected | 0% |
| | South Bowers Beach | Private – not protected | 0% |
| | Bennetts Pier | Delaware Wildlands | 100% |
| | Big Stone Beach / Conch Bar | **1.** The Nature Conservancy<br>**2.** State<br>**3.** Private – not protected | 75% |
| | Mispillion Inlet | State and Private- not protected | ~50% |
| Sussex County Delaware | Slaughter beach | Private- not protected | 0% |
| | Prime Hook | Federal- NWR | 100% |
| | Cape Henlopen | State Park | 100% |
| Cumberland and Cape May Counties New Jersey | Delaware Bay shoreline | **1.** Dennis Creek Wildlife Management Area (WMA)<br>**2.** Heislerville WMA<br>**3.** Egg Island WMA<br>**4.** USFWS- Cape May NWR | 30% |

Table 42. Continued

| Country and Province/State | Area | Ownership | Approximate Percent of Habitat Under Protection |
|---|---|---|---|
| Cape May County New Jersey | Hereford Inlet | Municipal | 0% |
| Atlantic County New Jersey | Brigantine | North Brigantine Natural Area | 50% |
| NewYork City-Jamaica County New York | Jamaica Bay Wildlife Refuge | **1.** Federal- Gateway National Recreation Area<br>**2.** Private | ~50% |
| Middlesex County Connecticut | Sandy Point | Private | 0% |
| New Haven County Connecticut | Milford Point | Stewart McKinney NWR | 100% |
| Fairfield County Connecticut | Long Beach | Private | 0% |
| | Cockenoe Island | Private | 0% |
| Newport County Rhode Island | Quicksand Pond | Goosewing Beach Preserve | 100% |
| Washington County Rhode Island | Ninigret Pond | Ninigret NWR | 100% |
| | Napatree Point | Napatree Point Conservation Area | 100% |
| Essex County Massachusetts | Plum Island | Federal- NWR | 75% |
| | Newbury Port | Private- Municipal (part of Plum Island) | 0% |
| Plymouth County Massachusetts | Scituate | **1.** Municipal<br>**2.** Private | 50% |
| | Duxbury Beach | **1.** Private- Duxbury Beach Reservation, Inc.<br>**2.** Municipal | ~50 % |
| | Plymouth Beach | **1.** Private– not protected<br>**2.** Municipal | 0% |
| Barnstable County Massachusetts | Nauset Coast Guard Beach | National Park Service- Cape Cod National Seashore | 100% |
| | Sandy Neck | **1.** Private- The Nature Conservancy<br>**2.** Municipal- Town of Barnstable | 100% |
| | South beach Island | **1.** Federal- Monomoy NWR (USFWS)<br>**2.** Municipal | 100% |
| | Monomoy NWR | Federal- USFWS | 100% |
| Rockingham County New Hampshire | Seabrook Harbor Flats and Beaches | **1.** County and Municipal<br>**2.** Private | 85% |
| Washington County Maine | Lubec Flats | Maine Department of Inland Fisheries and Wildlife. | 100% |
| | Sprague Neck and Holmes Bay | U.S. Navy Ecological Reserve-Cutler Naval Station | 100% |

Table 42. Continued

| Country and Province/State | Area | Ownership | Approximate Percent of Habitat Under Protection |
|---|---|---|---|
| | West River (Indian River) | **1.** Private<br>**2.** Maine Dept. of Inland Fisheries and Wildlife (MDIFW) | 25% |
| | Mash Harbor | Private- not protected | 0% |
| | Flat Bay | **1.** Private<br>**2.** MDIFW | 25% |
| | Petit Manan Island and Petit Manan Point | Federal- Petit Manan National Wildlife Refuge | 100% |
| | Over Point | Private- not protected | 0% |
| | Ship Island | Maine Coastal Island National Wildlife Refuge | 100% |
| Hancock County Maine | Hog Bay | Private- Farmland | 0% |
| Waldo County Maine | Spruce Island | Private- not protected | 0% |
| Lincoln County Maine | Eastern Egg Rock | MDIFW- managed by National Audubon Society. | 100% |
| Cumberland County Maine | Scarborough Marsh | MDIFW | 100% |
| York County Maine | Stratton Island | National Audubon Society | 100% |
| | Bluff Island | National Audubon Society | 100% |
| | Biddeford Pool | Private- not protected | 0% |
| *Canada* | | | |
| Nunavut | King William Island | Inuit-owned lands (Nunavut Land Claims Agreement)- Canadian Wildlife Service (CWS) management | 100% |
| | Southampton Island | 1. Inuit-owned lands (Nunavut Land Claims Agreement)<br>2. CWS- East Bay Bird Sanctuary and Harry Gibbons Bird Sanctuary | 100% |
| Ontario | Western James Bay | Unknown | ? % |
| New Brunswick | Northern Bay of Fundy- Chignecto Bay | Fundy National Park | ? % |
| Nova Scotia | Northern Bay of Fundy- Minas Basin | Boot Island National Wildlife Area | ? % |

## X. PAST AND CURRENT CONSERVATION AND HABITAT MANAGEMENT ACTIVITIES UNDERTAKEN TO BENEFIT THE SPECIES

As part of this assessment, biologists representing each state and country were contacted and were requested to outline management efforts for red knots. We found that there are no management efforts directed specifically at red knots along the entire length of the flyway except in the area of Delaware Bay. However, many global, national, regional, and State-specific management and conservation efforts have been implemented to benefit shorebirds in general, including the red knot.

### A. Global Level

#### *1. The Ramsar Convention on Wetlands*

The Convention on Wetlands, signed at Ramsar Iran in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. There are presently 146 Contracting Parties to the Convention, with 1463 wetland sites, totaling 125.4 million hectares, designated for inclusion in the Ramsar List of Wetlands of International Importance.

The Mission Statement of the Convention agreed at the eighth meeting of the Conference of the Contracting Parties in Valencia in 2002 is: "The Convention's mission is the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world"(www.ramsar.org).

#### *2. Western Hemisphere Shorebird Reserve Network (WHSRN)*

The Network is a voluntary, non-regulatory coalition of over 160 private and public organizations in seven countries working together to study and conserve shorebirds throughout their habitats. Membership in WHSRN provides the site with international recognition as a major host for shorebirds.

The Network now includes 46 officially designated sites that are responsible for managing over 20 million acres. Member sites are located in Argentina, Brazil, Peru, Suriname, Mexico, U.S., and Canada. Further, there are almost 150 more sites in Canada and the U.S. alone that are known to meet WHSRN site criteria but have not yet joined the Network.

Of the 47 species of migratory shorebirds in North America, five are predicted to decline by 25% or more over the next five years and 16 others have projected or actual population declines of 5-20%. Habitat degradation at critical staging, breeding and non-breeding sites may be a major factor along with many problems that a migratory species encounter.

#### *3. Important Bird Areas Program (IBA)*

Audubon, as the Partner for BirdLife International, is working to identify a network of sites that provide critical habitat for birds. This effort known as the Important Bird Areas Program (IBA) recognizes that habitat loss and fragmentation are the most serious threats facing populations of birds across America and around the world. By working through partnerships, principally the North American Bird Conservation Initiative, to identify those places that are critical to birds during some part of their life

cycle (breeding, wintering, feeding and migrating) it is hoped to minimize the effects that habitat loss, and degradation have on bird populations. Unless the rapid destruction and degradation of habitat can be slowed, populations of many birds may decline to dangerously low levels. The IBA program is a global effort to identify areas that are most important for maintaining bird populations, and focus conservation efforts at protecting these sites. In the U.S. the IBA program has become a key component of many bird conservation efforts, for example: Partners in Flight; North American Waterbird Conservation Plan; and the U.S. Shorebird Conservation Plan.

**4. *Convention on the Conservation of Migratory Species of Wild Animals 1979 (CMS or Bonn Convention)***

The Convention on the Conservation of Migratory Species of Wild Animals (also known as CMS or Bonn Convention) aims to conserve terrestrial, marine and avian migratory species throughout their range. It is an intergovernmental treaty, concluded under the aegis of the United Nations Environment Program, concerned with the conservation of wildlife and habitats on a global scale. Since the Convention came into force, its membership has grown steadily to include 101 Parties (as of 1 January 2007) from Africa, central and South America, Asia, Europe and Oceania (Fig. 77). At the instigation of Argentina, the Conference of the Parties to the Convention meeting in November 2005 determined that the *rufa* subspecies of the red knot was endangered and as such added it to Appendix 1 of the Convention. Under the terms of the Convention the Parties agree "to strive towards strictly protecting animals listed in Appendix 1, conserving or restoring the places where they live, mitigating obstacles to migration and controlling other factors that might endanger them" (http://www.cms.int).

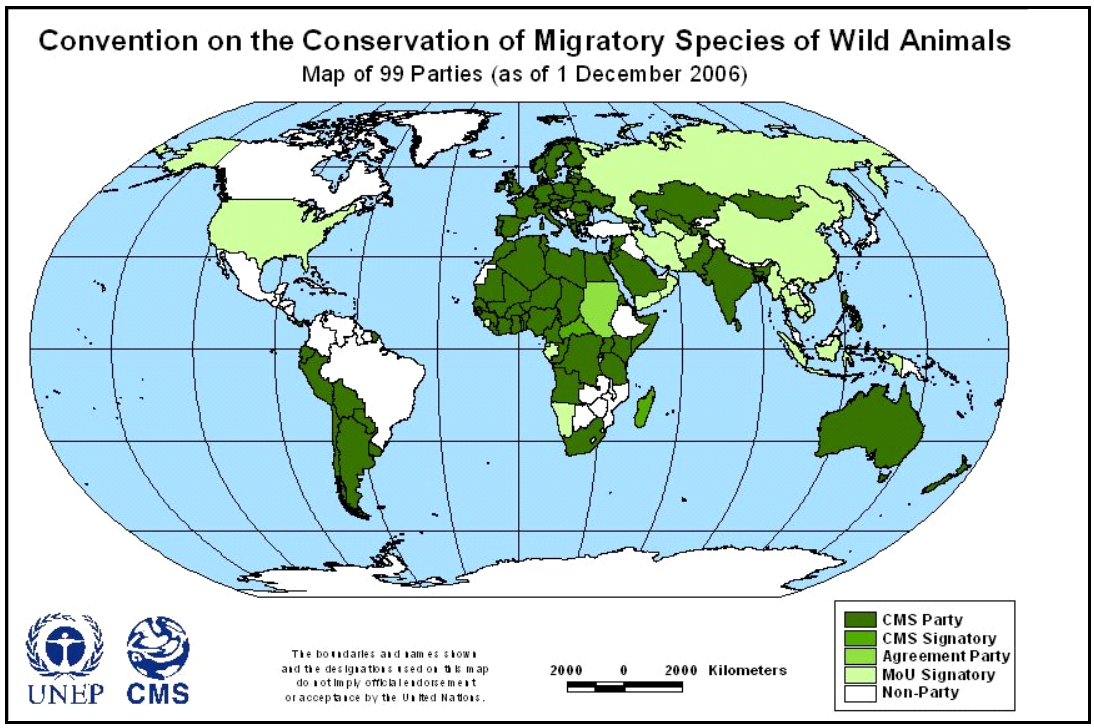



Figure 78. Participating countries of the Convention on the Conservation of Migratory Species of Wild Animals.

## B. National Level

### *1. National Wildlife Refuges*

Refuge Managers in Regions 2, 4 and 5 were solicited for information on management plans that might affect red knots.

Management efforts for shorebirds are taking place in many wildlife refuges in the flyway, but most focus on impoundment management that aim primarily at species likely to forage in moist soil, such as semi-palmated sandpiper, dunlin, short-billed dowitcher and greater yellowlegs. The red knot feeds primarily on small mussels and clams normally associated with tidal sands, and would only benefit indirectly from impoundment management for shorebirds. While not the focus of specific management efforts, red knots benefit from the creation of safe high tide or nighttime roosts on the small islands formed by the natural topography of shallow water impoundments.

### *2. The International Shorebird Survey (ISS) and Program for Regional and International Shorebird Monitoring (PRISM)*

In 1974 the Manomet Center for Conservation Sciences organized the International Shorebird Surveys (ISS) to gather information on shorebirds and the wetlands they use. Information gathered by ISS cooperators over the last 30 years show some disturbing trends. The data have long suggested that several shorebird species were declining rapidly, but until recently the design of the ISS did not allow for a sensitive statistical analysis. A new initiative called the *Program for Regional and International Shorebird Monitoring* (PRISM) is underway to coordinate and expand on existing shorebird survey efforts, including the ISS, the Western Shorebird Survey (WSS) and the Canadian Maritimes Shorebird Survey (MSS). The closer coordination and expanded survey effort will increase the power of statistical analyses and more clearly define shorebird conservation issues on a continental scale. (Source: www.manomet.org/programs/shorebirds/).

Volunteer participation in the ISS has declined since 2000 (Harrington unpublished data) and the level of effort from year-to-year and state-to-state is highly variable. Concerted effort should be made by state and federal agencies to reinvigorate survey efforts through PRISM.

## C. Regional Level

### *1. Delaware Bay and Its Environs*

a. Increase Availability of Horseshoe Crab Eggs by Protecting Crab Population

Management in the Delaware Bay aims primarily at the protection of horseshoe crabs and spawning beaches, which increases the availability of horseshoe crab eggs, the red knot's prime food resource. Central to the protection of horseshoe crabs is the ASMFC Management Plan for the Horseshoe Crab. The plan adopted in 1998, along with subsequent addenda in 2000, 2001, 2004, and 2006 has provided the coast-wide framework for the protection of horseshoe crabs. The protection of horseshoe crabs has been achieved through tighter restrictions on the harvest of crabs as bait. This is covered in the section on history of regulations. However, past restrictions on the harvest have not created a substantial increase in the spawning population or crab egg numbers to date, partially because it takes nine years for crabs to reach breeding age. Thus other options have been explored to improve egg availability in the short and mid-term periods.

b. Increase Availability of Horseshoe Crab Eggs and Duration of Undisturbed Foraging for Shorebirds by Reducing Human/dog Disturbance.

Management efforts to increase the availability of horseshoe crab eggs have taken several forms. The first is protecting beaches important for crabs and birds from repeated disturbances by people and dogs. The first part of the protection is the Shorebird Steward Program conducted by NJDFW, USFWS, New Jersey Audubon Society, the Nature Conservancy and other groups, and the former Shorebird Ambassador Program conducted by the Delaware Division of Fish and Wildlife, where volunteers (who were reimbursed for expenses incurred) form a corps of stewards, educating beach users about the effects of disturbance on shorebirds and warn them of regulations that protect shorebirds. This effort is supported by agency staff who provide logistical support in the form of outreach materials, signs and post-and-string symbolic fencing. The second part of protection is conservation law enforcement, which has become necessary to obtain full compliance at the protected beaches. In New Jersey the red knot is a state threatened species and conservation officers have authority to issue summonses for disturbance. In three spring seasons, only a small number of warnings and one summons have been issued. Conservation officers have become the backup for shorebird beach stewards who may encounter difficulties with the public. Finally, the ASMFC approved addendum III to the horseshoe crab management plan. In addition to reducing the Delaware Bay harvest to 300,000 crabs annually, it prohibits the collection of horseshoe crabs during the shorebird migratory period of 1 May through 7 June. By prohibiting the collection of crabs during the spawning period, females are free to spawn providing much needed eggs, and disturbance to foraging and roosting shorebirds due to beach harvesting is eliminated.

c. Increase Availability of Horseshoe Crab Eggs by Excluding Gulls from Prime Spawning Areas

The second effort to increase the availability of horseshoe crab eggs is to develop management solutions to the high gull numbers along the New Jersey and Delaware Bay shore.

The impact of gull numbers is greatest on bayshore beaches that are closest to gull colonies on the Atlantic Coast, namely those along the shore of the Cape May peninsula. These beaches, including Norbury's Landing, Kimbles Beach and Reed Beach were among those where shorebird numbers were the greatest (Harrington unpublished data, Clark *et al.* 1993, K. Clark unpublished data). In 2003-2004, shorebirds shifted to beaches most distant from gull colonies on the Atlantic Coast: Fortescue Beach and Gandy Beach. Birds returned to Reeds Beach in 2005 coinciding with the introduction of an experimental gull exclosure. Created by the NJDFW Shorebird Team, the exclosure consisted of metal conduit supporting strands of 200lb test monofilament approximately 1-3 meters high (Minton unpublished information). The team applied a number of variations that prevented gull predation on eggs but also restricted shorebird use. However, flocks of up to 3,000 knots roosted and foraged in areas adjacent to and within the exclosure for most of the latter half of the May. Further experimentation is planned for 2006.

The gull exclosure is considered to be only a short-term solution to the low density of horseshoe crab eggs in New Jersey. A longer-term solution is the control of gulls. Although the killing of gulls would provide an immediate solution, the control of gull productivity presents a more publicly acceptable management alternative.

d. Protection of Roosting Sites

The fourth management focus on Delaware Bay is to create secure day and nighttime high tide roosts. Shorebirds at stopover sites require not only an adequate food supply but also safe and disturbance-free sites that are close to their feeding grounds where they can roost when not feeding and be relatively free from ground predators (Rogers 2003, Sitters *et al.* 2001). As is typical worldwide the main roosting sites used in New Jersey have always been the sand-spits and sand islands in Hereford Inlet on the Atlantic coast between Stone Harbor and Wildwood. In contrast, the bay-shore of Delaware has no similar roosting site so birds tend to roost in areas of open marshland about 1.7 km inland near Mispillion River (Sitters *et al.* 2003 unpublished data). Presently, this is the only place in the world where red knots have been recorded as roosting inland at night.

In 2004, radio tracking showed birds commuting from diurnal feeding areas on the Delaware coast to roost at Hereford Inlet, New Jersey, at night, a 94-km round trip. In 2005, perhaps because of tidal flooding just before the main arrival of knots, most, if not all, knots that fed in Delaware commuted to Hereford Inlet every night. On some nights, when high water occurred in the evening, the whole of the Delaware Bay stopover population of up to 20,000 birds roosted at Hereford Inlet.

In response to the increasing numbers of shorebirds roosting on the Atlantic coast at Stone Harbor Point, in 2005 NJDFW created protection zones on two areas covering approximately 300 acres. By the end of May, over 20,000 red knots and thousands of dunlin and sanderlings were using the protected area as a night time roost, and as many as 2,000 red knots were roosting in the same area during daytime high tides. In 2006, NJDFW partnered with the municipality of Stone Harbor to create year-round protection of Stone Harbor Point with emphasis on spring, fall and winter populations of all shorebirds, and spring and fall populations of red knots. Protection efforts include physical barriers to disturbance, outreach materials, a full time naturalist on duty at critical periods, and the development of plans for long-term protection.

On the southbound journey the same consideration for safe and secure roosts and foraging areas also apply. In a study conducted on the Two Mile Beach Unit of the Cape May National Wildlife Refuge, which is closed to beachgoers during the period of the southbound migration, red knots and other shorebird species occurred ten times more often than on beaches open to the public (Mizrahi 2002).

e. Reduce Disturbance by Minimizing Research Activities

Research efforts on Delaware Bay, including trapping, banding and resighting efforts, have been minimized to reduce disturbance to foraging shorebirds. Trapping and banding effort was reduced to the minimum necessary to 1) monitor weight gains of red knots, ruddy turnstones and sanderlings during the migratory stopover period, and 2) individually mark enough birds to perform survival analyses via resightings of marked individuals. Catch effort is limited to six catches of 50–75 individuals of each species spread throughout the migratory stopover period (approximately May 10 to June 7), and

catches are spaced three to five days apart. On any one day, catching activities take place at no more than one site on each side of the bay and catching effort is spread out over various locations to avoid frequent disturbance to individual beaches. Where catching takes place, disturbance is mostly limited to around 100 m of shoreline and, except for around 20 minutes when a catch is made, is much less than that caused by typical recreation use. Optimally, all three species are caught in one attempt to reduce disturbance and catch frequency. The effects on migratory shorebirds of disturbance by researchers were quantified and no difference was found between either the frequency or flight duration of researcher-caused disturbance as compared to control periods (Harrington 2006). Most birds are weighed, measured and banded within two hours of capture, and banding activities take place away from foraging beaches to allow shorebirds to return to forage.

Researchers carrying out systematic resighting surveys for individually-marked shorebirds are restricted to hidden or distant viewing areas including viewing platforms constructed for shorebird viewing, roads, and occasionally from beachfront property with the permission of the landowner.

Shorebird banding teams are lead by biologists from New Jersey and Delaware Divisions of Fish and Wildlife and are comprised of professional local and foreign shorebird biologists as well as experienced local and foreign bird banders. The Delaware Bay Shorebird Project began in 1997 and employed a method of trapping (cannon netting) widely used in Europe and Australia. Because this method is not widely used in the U.S., biologists requested the aid of certified cannon netters from the United Kingdom and Australia, all with decades of experience, to train U.S. teams in this trapping technique. This dedicated corps of experienced cannon netters, many of whom are professional shorebird biologists (active or retired) in their respective countries, have returned each year since 1997 to help carry out this project.

All research activities are carried out with the utmost care, respect, and highest ethical conduct with regard to the shorebirds, landowners and visitors on the Delaware Bay.

f. Monitor numbers of Migratory Shorebirds on the Delaware Bay Stopover

In 1986, the NJDFW and Delaware Division of Fish and Wildlife (DEDFW) commenced weekly aerial surveys of the Delaware Bay coastline to document shorebird abundance during the migratory stopover (May through early June). This long-term survey has tracked the decline of the migratory stopover in terms of shorebird abundance has been used to track changes in shorebird distribution relative to horseshoe crab egg densities on bayshore beaches. This survey has been conducted by the same observers throughout its nearly 20-year duration and continues to be one of the most valuable long-term monitoring programs in place on the Delaware Bay stopover.

g. Past and Current Management Actions for Shorebird Populations

- 1986: Delaware Governor Michael Castle and New Jersey Governor Thomas Kean designated the bay-shore as a Sister Reserve, the first such commitment under WHSRN. The WHSRN ties together critical shorebird stopovers in North, Central and South America.

- 1987: NJDFW-ENSP with DEDFW conducted bay wide aerial surveys of shorebirds. This survey has been conducted every year since 1987.
- 1992: NJDFW contracted a study of shorebird/shorebird habitat vulnerability to oil spills in the bay. This study projected the likely impact areas of spills from different locations under different weather conditions to provide information necessary for response planning.
- 1993: In May 1993, the NJDFW-ENSP convened a two-day Delaware Bay Shorebird Workshop, which resulted in the "Comprehensive Management Plan for Shorebirds on Delaware Bay." The workshop included over 100 people representing 22 organizations, and aimed to improve communication and develop a framework for conservation actions across two states and multiple government and non-governmental organizations.
- 1994: In May 1994 the NJDFW-ENSP convened a single day Delaware Bay meeting to finalize the management plan drafted after the 1993 workshop. The final plan was printed and distributed to regulatory agencies and conservation groups in the region. NJDFW-ENSP completed mapping of shorebird distribution and suitable habitats, and made it available to emergency response and planning agencies.
- 1994: New Jersey convened a Shorebird Outreach Team as a result of the 1993 planning meeting, including representatives from NJDFW-ENSP, DEDFW Nongame and Endangered Spesies Program (NGES), New Jersey Audubon, Bay Shore landowners (The Nature Conservancy, New Jersey Natural Lands Trust, New Jersey Conservation Foundation, USFWS) and the Wetlands Institute. This team developed educational materials including fact sheets on shorebirds and safe viewing locations.
- 1995: New Jersey hosted a two-day Delaware River and Bay Oil Spill Emergency Workshop, assembling all agencies responsible for spill response on the bay. The results of this workshop were incorporated into the Area Contingency Plan, the chief reference document in the case of a spill.
- 1997: Delaware Coastal Management Program (DECMP) and WHSRN host a shorebird management workshop for Delaware Bay. The goal of the workshop was to provide information that can be used to integrate shorebird management into traditional environmental practices and programs in the Delaware Bay Region such as wetlands management, public access management, and the beneficial use of dredged material.
- 2003: NJDFW-ENSP and DEDFW-Natural Heritage and Endangered Species Program (NHESP) conducted bay-wide aerial shorebird surveys during the fall migratory period.
- 2005: NJDFW-ENSP, Richard Stockton University in New Jersey, and DEDFW-NHESP carried out the first year of bay wide horseshoe crab egg surveys using a standardized sampling protocol developed by the U.S. Geological Survey.
- 2004: ASMFC approves Addendum III of the horseshoe crab management plan. The addendum limits Delaware Bay harvest to 300,000 crabs annually and prohibits the harvest of crabs during the shorebird migratory period (1 May – 7 June). This closure decreases the number of gravid females collected and limits the disturbance to shorebirds caused by beach harvesting.
- 2006: ASMFC approves Addendum IV of the horseshoe crab management plan. In relation to New Jersey and Delaware for the two years from October 1, 2006, this

prohibits the directed harvest and landing of all horseshoe crabs between January 1 and June 7 and female horseshoe crabs between June 8 and December 31 and limits the harvest to 100,000 (male) crabs per state per year. In relation to Maryland and for the same two year period, it prohibits the directed harvest and landing of horseshoe crabs between January 1 and June 7. It also prohibits the landing of horseshoe crabs in Virginia from federal waters between January 1 and June 7.

h. Past and Current Management Actions for the Horseshoe Crab Populations

i. Regulation/Closure of the Fishery

- 1991: DEDFW was given authority to regulate horseshoe crabs. Collecting Permits were required and mandatory reporting regulations were established and horseshoe crab dredge licenses were capped at five.
- 1992: DEDFW prohibited horseshoe crab harvesting within 1,000 feet of all state and federal lands from May 1 – June 7 (except Port Mahon on Wednesday, Thursday, and Friday). A personal possession limit of 6 horseshoe crabs was established for non-permitees (i.e. people can have up to 6 to bait a minnow trap or eel pot to catch fish bait).
- 1993: New Jersey passed regulations that prohibited harvest of horseshoe crabs on New Jersey Delaware Bay beaches during daylight hours. Reporting of harvest was voluntary.
- 1994: New Jersey passed regulations that prohibited harvest of horseshoe crabs on New Jersey Delaware Bay beaches or within 1,000' of beaches. Reporting of harvest was mandatory.
- 1995: Regulations limited harvest of horseshoe crabs on New Jersey Delaware Bay beaches to nighttime hours on Mondays, Wednesdays and Fridays only during the period May 1-June 7.
- 1996: An amendment to NJAC 7:25-18.16 to provide added protection to spawning horseshoe crabs and reduce the disturbance to the migratory shorebirds feeding on the Delaware Bay waterfront beaches. Regulations prohibited harvest of horseshoe crabs on Delaware Bay waterfront at any time; hand harvest permitted only in back bays and tidal creeks of the state (minimum of 1,000 feet from bay front) on Tuesdays and Thursdays commenting one hour after sunset until one hour before sunrise. Harvest and landing of crabs was prohibited during May unless by hand.
- 1997: DEDFW instituted an emergency closure of the horseshoe crab fishery in May and closed the dredge fishery and hand harvest (state and federal lands) through June 30.
- 1998: The ASMFC approved the Interstate Fishery Management Plan for Horseshoe Crabs. DEDFW closed horseshoe crab fishery May 1 – June 30 except Tuesday and Thursday hand harvest at Port Mahon and Monday, Wednesday, and Friday hand harvest on private lands. A 300 cu ft containment limit on hand harvest fishery was established. The dredge fishery was closed from May 1 – June 30 and a 1500 horseshoe crab limit on dredge harvest was imposed. Hand harvest permit eligibility criteria were established (had to have secured 2 permits prior to July 1997). Requirements for timelier reporting were established. Landings from the Exclusive Economic Zone ("EEZ",- 2 - 300 miles) prohibited. Nighttime harvest prohibited.

- 2000: The ASMFC approved Addendum I to the Fishery Management Plan for Horseshoe Crab. The addendum caps bait landings to 25% below reference period landings and recommends a closure of horseshoe crab harvest in Federal waters within 30 nm of the mouth of the Delaware Bay.
- 2001: The NMFS established the Carl N. Shuster, Jr. Horseshoe Crab Reserve. The establishment of this reserve prohibits the harvest of horseshoe crabs in nearly 1,500 square miles of federal waters off the mouth of the Delaware Bay.
- 2004 (March): The ASMFC Horseshoe Crab Management Board agreed to adopt new conservation measures for the horseshoe crab. Specifically, the Addendum capped annual harvest in New Jersey and Delaware at 150,000 crabs per state and set Maryland's annual quota at its 2001 landings level (170,653 crabs). Further, it required the three states to prohibit the harvest and landings of horseshoe crab for bait from May 1 to June 7. Addendum III also encouraged states with both bait and biomedical fisheries to allow biomedical companies to bleed harvested crabs prior to their use as bait. This would eliminate mortality associated with the process of bleeding and returning crabs to the waters from which they were harvested.
- 2003 for 2004 season: New Jersey and Delaware quota reduced to 150,000 horseshoe crabs. Season established to be April 1 through April 30 and June 8 through August 15. No harvest allowed during the period May 1 through June 7. Permit holders must report their harvest each Friday by telephone. The dredge fishery was limited to 35% of total quota prior to May 1. The use of bait savings devices required. DEDFW bans the personal exemption of 6 horseshoe crabs.
- 2006: ASMFC approves addendum IV of the horseshoe crab management plan. In relation to New Jersey and Delaware for the two years from October 1, 2006, this prohibits the directed harvest and landing of all horseshoe crabs between January 1 and June 7 and female horseshoe crabs between June 8 and December 31 and limits the harvest to 100,000 (male) crabs per state per year. In relation to Maryland and for the same two year period, it prohibits the directed harvest and landing of horseshoe crabs between January 1 and June 7. It also prohibits the landing of horseshoe crabs in Virginia from federal waters between January 1 and June 7.

ii. Management Plans

- 1998 (Dec): The ASMFC Fisheries Management Plan for Horseshoe Crab was approved requiring a suite of monitoring requirements - Delaware, New Jersey, and Maryland required to keep current regulations in place.
- Late 1999: ASMFC Horseshoe Crab Management Board approved Addendum I to the Interstate Fishery Management Plan for Horseshoe Crab, which implemented harvest reduction measures along the Atlantic coast for the commercial horseshoe crab bait fishery. Specifically, the Addendum established a state-by-state cap at 25% below 1995-1997 levels of 2,999,491 horseshoe crabs for all states.
- 2000 (May): Addendum I of the Fishery Management Plan approved requiring a cap on the fishery at 361,801 horseshoe crabs.
- 2001: ASMFC (2001) approves Addendum II to the FMP for Horseshoe Crabs allowing or interstate transfer of harvest quotas.
- 2004: ASMFC approves Addendum III to the FMP for Horseshoe Crabs. Addendum III further limits harvest of Delaware Bay horseshoe crabs to 300,000. It also closes

harvest from 1 May through 7 June to limit harvesting of spawning crabs and to limit disturbance of shorebirds from harvesters.

- 2006: ASMFC approves Addendum IV of the horseshoe crab management plan. In relation to New Jersey and Delaware for the two years from October 1, 2006, this prohibits the directed harvest and landing of all horseshoe crabs between January 1 and June 7 and female horseshoe crabs between June 8 and December 31 and limits the harvest to 100,000 (male) crabs per state per year. In relation to Maryland and for the same two year period, it prohibits the directed harvest and landing of horseshoe crabs between January 1 and June 7. It also prohibits the landing of horseshoe crabs in Virginia from federal waters between January 1 and June 7.

iii. Habitat Protection

- 1999: The Ecological Research Development Group (ERDG) launches its community-based horseshoe crab sanctuary program. The program works with private landowners and communities to establish sanctuaries where crabs cannot be harvested.
- 2000: ERDG works with the community of Broadkill Beach, Delaware to become the first Horseshoe Crab Sanctuary restricting the harvest of horseshoe crabs along a 2.5 mile section of beach.
- 2005: Currently approximately 20 miles are registered as designated horseshoe crab sanctuaries with DEDFW.

iv. Bait Bags

- 1999: ERDG initiated phase I of its bait bag initiative dispersing 500 bait bags to Virginia conch fishermen. Bait bags were found to reduce the amount of horseshoe crab bait needed by 25-50%.
- 2000: ERDG completes phase II of its bait bag initiative by manufacturing and distributing 6000 bait bags to commercial fishermen in Maryland, Delaware, and New Jersey free of charge.

**D. Non-breeding (winter) and Stopover Area Management and Conservation**

***1. South America***

a. Chile

In Chile, there are no special protection measurements for Bahía Lomas. In 1996, the Corporación Nacional Forestal (CONAF) recommended Bahía Lomas as one of the 21 sites in the "urgent category" stated in the priority sites for the conservation of the biodiversity in Chile (CONAF 1996). No activities were associated with this conservation status. Due to its world importance, Bahía Lomas was recently (December 2004) declared a Ramsar site, the second southern most after the neighboring Atlantic coastal reserve of Tierra del Fuego in Argentina. Thus far, the Ramsar designation is the only unique conservation measurement that Bahía Lomas has received. The red knot is protected by the hunting law N° 19.473.

b. Argentina

Argentina is a signatory party of Convention on the Conservation of Migratory Species of Wild Animals (also known as CMS or Bonn Convention). Migratory species that need or would benefit significantly from international co-operation are listed in Appendix II of the Convention. The family Scolopacidae is listed in Appendix II. Migratory species threatened with extinction are listed on Appendix I of the Convention. CMS Parties strive towards strictly protecting these animals, conserving or restoring the places where they live, mitigating obstacles to migration and controlling other factors that might endanger them.

In the 12th Scientific Council (ScC) Meeting held in Glasgow, United Kingdom, 31 March - 3 April 2004, the ScC approved the inclusion of red knot *C. c. rufa* in Appendix I, by request of Argentina under a presentation of the author (PMG). The next step is that The Conference of the Parties, which is the CMS decision-making body, will consider the recommendation from ScC to amend Appendix I during their upcoming meeting in November 2005.

Besides the CMS national and inter-government agreement, different government levels provide legal protection status to key red knot critical areas as described below. International recognition from the WHSRN and IBA from Birdlife International are also included:

- Reserva Costa Atlántica de Tierra del Fuego (1992): Provincial Natural Area Protected
    - Ramsar Site (1995)
    - WHSRN Hemispheric Site
    - IBA area (Bahía San Sebastián is priority IBA area).
- Reserva Provincial de Río Chico para Aves Playeras Migratorias (2001) and Reserva Urbana Costera del Río Chico (2004): Provincial Natural Area Protected and Urban Natural Area Protected
    - Potential WHSRN Site
    - IBA area
- Bahía Bustamante: No conservation status
- Península Valdés: Reserva Natural Integral Provincial
    - Patrimony of the Humanity
    - Potential Ramsar and WHSRN Site
    - IBA area.
- Bahía Samborombón (1979): Integral Natural Reserve
    - Provincial Integral Natural Reserve with Restricted Access (9,311 ha)
    - Provincial Integral Natural Reserve "Rincón de Ajó" (2,311)
    - "Campos del Tuyú" Private Reserve, Fundación Vida Silvestre Argentina.
    - "Punta Rasa" Biological Station, Agreement between the Naval Hydrography Service (Argentinian Navy) and the Fundación Vida Silvestre Argentina
    - Punta Rasa "Traveled Municipal Ecological Reserve" (1991)
    - Ramsar Site (1997)
    - Priority IBA area.
    - Potential WHSRN Site
- Bahía San Antonio Natural Protected Area
    - Potential Ramsar Site
    - Priority IBA area
    - WHSRN Site

Management plans are being developed for Reserva Costa de Tierra del Fuego, Provincial de Río Chico para Aves Playeras Migratorias, Reserva Urbana Costera del Río Chico, in conjunction with ongoing shorebird research and public education. Shorebird research is also ongoing at Península Valdés, which has a current management plan and is used as a camp by artesanal fishermen, and Bahía Samborombón, where an Environmental Ordering Plan is implemented. No research or management is being done at Bahía Bustamante.

The Bahía San Antonio Natural Protected Area has an urban management plan which restricts land use near key shorebird areas and actively protects shorebird roosting sites. Besides the CMS national and inter-government agreement, this area has international recognition from the WHSRN, is designated as a priority IBA by Birdlife International, and is a potential Ramsar site.

c. Brazil

The Brazilian government through IBAMA (Brazilian Institute of the Environment and Renewable Natural Resources) by CEMAVE has been developing conservation projects on migratory Nearctic species since the beginning of the 1980s. Besides the Brazilian legislation to protect fauna, enhancement for the need for conservation projects increased with the adhesion to international agreements as the Washington Convention ratified by the country in 1948, and Ramsar Convention to which the country has taken part since 1993. Particularly in the coastal areas, projects developed have as their main objective the monitoring of Pan-American migratory birds in order to subsidize strategies of joint action aiming at its conservation.

Over the years, international technical cooperation has been established, the first of them established in 1981 with the American government, through the USFWS. This cooperation resulted in training in techniques of capture by the use of net-cannons in Salinas, in the state of Pará. In the same year, a project with CWS (Canadian Wildlife Service) resulted in aerial survey in the Brazilian coastline, to identify areas of occurrence of Nearctic migratory birds. This survey was carried out between 1982 and 1986 along the Brazilian coastline, and the results were published in 1989 in the chapter for Brazil, of the Atlas of Nearctic shorebirds on the coast of South America.

In 1984, a partnership with the Manomet Bird Observatory (MBO), financial support from the World Wildlife Fund, and participation of teachers and researchers of the UNISINOS (University of the Valley of the Sinos River) and FZBRS (Zoobotanical Foundation of Río Grande do Sul) a workshop was promoted in Porto Alegre about techniques and methodologies utilized for monitoring migratory birds. Field activities were developed in Lagoa do Peixe, including banding of captured birds. Since then, CEMAVE started an annual monitoring program of birds in Lagoa do Peixe, during the northward migration between April and May, in which activities include capture by mist-nets and net-cannon, banding, collecting biological data (molting, biometry, age estimation, sex), and terrestrial censuses in the region of the Park.

Since 1992 the center has surveyed, by land and by sea, several points of the coast for ecological characteristics of the areas preferentially utilized by the Nearctic migratory birds. Leaning on the support of the Executive Management of IBAMA in several Brazilian states, as well as on banding-trained people registered in the National Banding

System, the center has worked along several other points of the coasts of the states of Amapá, Pará, Maranhão, Ceará, Río Grande do Norte, Pernambuco, Alagoas and Bahía.

Between 1996 and 1998, CEMAVE in partnership with the Canadian Wildlife Service, with support from the Interamerican Development Bank, and World Wildlife Fund (Canada), developed the project "Surveys of the Nearctic and Neotropical avifauna in the Marshland of the state of Mato Grosso." These surveys were carried out in the states of Mato Grosso and Mato Grosso do Sul, seeking to identify the main points of occurrence and passage of migratory species, during their migrations after reproduction in the Arctic, between September and October. The results have not been published yet.

Since 1997, the Center has participated in an international cooperative project, "Migration of red knots in South America: ecological research to support the conservation of the longest bird flights on earth**"**, with the goal to extend the knowledge of the strategies of migration of this species, integrating monitoring activities in the states of Maranhão and Río Grande do Sul, to those carried out in others countries that share these resources such as Argentina and United States.

With the creation of the Executive Committee implemented and coordinated by the System of Vigilance for the West Nile Virus, constituted by representatives of the Ministers of the Health, Agriculture and Environment, FUNASA (National Health Foundation), IBAMA, Office of the Secretary of Agricultural Defense of the Department of the Agriculture, Livestock Farming and Supplying, and Zoological Society of Brazil, the monitoring of the of transmissible diseases started in 2001. The monitoring goal is to early detect and prevent infection of migratory birds, including those on the routes of known migration in the country. Until now eight serological tests have been carried out including the coastline of the States of Amapá, Maranhão, Río Grande do Norte, Pernambuco and Río Grande do Sul, and at other points located in the Amazon, Mato Grosso do Sul and Paraná. The results so far can be accessed through the Epidemiology Bulletins produced by FUNASA.

Among the main results achieved, we highlight the creation of Conservation Units, as the Lagoa do Peixe National Park, in November of 1986, as well as of the Reentrâncias Maranhenses as significant international and regional reserves, respectively, to the Western Hemispheric Shorebirds Reserve Network, in 1991; these areas have been included in the Convention of Ramsar, on the occasion of the adhesion of Brazil; the presentation of results in international and national congresses, as well as the publication of articles in scientific journals; and participation in the elaboration of the Management Plan of the Lagoa do Park National Park between 1997 and 1999.

The Center has promoted the training and qualification of personnel in techniques of capture, marking, censuses, with participants from others countries, like Argentina, Uruguay, Paraguay, Peru, Chile, Colombia, Venezuela, and Panama. Already forty-five professionals and students of in the Biological Sciences were coached, in six courses of small and medium duration.

It is noteworthy that the activities describe above received 95% of financing from the Brazilian federal government, which has subsidized the monitoring of migratory birds over the years, despite of the economic instability of the country.

To determine if *Pinus* harvesting impacts shorebirds, field activities were developed in Lagoa do Peixe, including banding of birds captured. CEMAVE started an annual monitoring program of birds in Lagoa do Peixe, during the northward migration

between April and May, in which activities include capture by mist-nets and net-cannon, banding, collecting biological data (molting, biometry, age estimation, sex), and terrestrial censuses in the region of the Park. Thus far the results have not been published.

There are no current management activities in Maranhão. However, CEMAVE has promoted scientific expeditions for banding and collecting of biological data in May, during the migration of the birds to the North Hemisphere, and in November. With the goal to integrate the local communities in the conservation activities, as well as promote the objectives of banding and collecting of biological data, CEMAVE have sought to promote the work, by lectures in schools, associations of local fishermen, etc.

***2. United States***

The following is a list of key sites with current management for wintering shorebirds:

a. Florida

- Shell Key – Portions of the island closed to entry
- Caladesi Island, Hurricane Pass – Limited posting of signs on a roosting site
- Passage Key – Closed to entry but poorly enforced
- Merritt Island NWR, Black Point Drive – Restricted access
- Ding Darling NWR, tower stop – Restricted access
- Kennedy Space Center – Limited access

b. Georgia

- Little Tybee Island- Heritage Preserve/Natural Area.
- Ogeeche River Bar- Not managed.
- Wassaw Island- Wildlife Refuge.
- Ossabaw Island- Heritage Preserve/Wildlife Management Area.
- St. Catherines Island- Undeveloped, conservation intent.
- St. Catherines Bar- Closed Natural Area.
- Grass Island- Not Managed.
- Blackbeard Island- Wildlife Refuge.
- Sapelo Island- National Estuarine Research Reserve/Wildlife Management Area.
- Wolf Island- Wildlife Refuge/Wilderness.
- Little Egg Island Bar- Closed Natural Area.
- Little St. Simons Island- Undeveloped, conservation intent.
- Sea Island- Developed.
- St. Simons Island, Gould's Inlet- Developed.
- Jekyll Island- Developed.
- Little Cumberland Island- Partially developed.
- Cumberland Island- National Seashore, Some private residences

c. South Carolina

Presently there are no protection efforts specifically designed for red knots. Complete closures of important red knot roosting areas in Cape Romain NWR are planned for winter 2005/2006. Motions to completely close SCDNRs seabird nesting

islands, which are also red knot roosting areas, will begin winter 2005/2006. SCDNR has begun tagging horseshoe crabs, identifying their critical spawning and nursery habitat, and working with harvesters to estimate and minimize fishery mortality.

**E. Stopover Habitat Management**

***1. United States***

a. North Carolina

The following is a list of key sites with current management for wintering shorebirds:

- Cape Lookout National Seashore – posting to protect breeding birds (April – August) also benefits migrants.
- Cape Hatteras National Seashore – posting to protect breeding birds (April – August) also benefits migrants.
- Pea Island – posting to protect breeding birds (April – August) also benefits migrants.

b. Virginia

Previous red knot aerial surveys conducted in late May and/or early June indicate that the barrier islands located along the seaward margin of Virginia's Eastern Shore harbor the State's greatest densities and abundance of spring migrants and serve as important stopover locations. In addition, most of the islands are remote, free of development, and have for the most part been allowed to revert back to their natural state following periods of settlement by humans and livestock over the past several centuries.

Today, most management measures are directed towards minimizing human disturbance, reducing predator populations, and removal and/or control of invasive species. Organizations that own and manage the islands already have in place seasonal and year round public use policies designed to protect breeding waterbird populations. They include confining recreational activities to areas of the beach below the high tide line, prohibiting dogs and other pets on the islands, temporarily closing portions of the islands that are particularly vulnerable to disturbance, and for a few of the islands, seasonal and year round closures. It should be noted that there are a few private inholdings remaining on two of the barrier islands. Owners of these private land parcels work cooperatively with conservation organizations to ensure their activities do not impact the islands' natural resources. Many of the seasonal closures and public use policies cover the peak red knot spring migration period.

Other sites where red knots have been observed during spring migration in substantially fewer numbers include Plum Tree Island NWR and Goodwin Island; both are located on the western shore of the lower Chesapeake Bay. Very little is known about the extent of use of these sites by red knots. Moreover, they receive very little human disturbance because they are remote and difficult to access (Plum Tree Island NWR is largely off limits to the public because of unexploded ordinances), therefore will likely not require much in the form of management.

c. Maryland

The state of Maryland does not conduct or sponsor any organized surveys that include Red Knots. There are also no research, monitoring or management efforts

regarding Red Knots in the state. Suitable habitats do exist within the state, however, these include: Hart Miller Island, Assateague Island and Poplar Island. Hart Miller Island is owned and managed by the state of Maryland. Assateague Island is divided into three areas: Assateague Island National Seashore, managed by the National Park Service, Chincoteague NWR, managed by the USFWS and Assateague State Park, managed by Maryland Department of Natural Resources. Current management of Assateague Island consists of managed areas at the northern end of the island for piping plovers and tidal flats behind island managed as part of a coastal management program. Poplar Island is located off the Chesapeake Bay coastline, about 34 miles south of Baltimore in Talbot County. It is currently being managed by the U.S. Army Corps of Engineers, the Maryland Port Administration, and other Federal and State agencies as a site for habitat restoration and beneficial use of dredged materials.

d. New Jersey

The principle shorebird conservation issues in the Delaware Bay stopover are human disturbance to birds and their habitats and the availability of abundant food in the form of horseshoe crab eggs. While recognition of the shorebird migration was improved with the reporting of bay wide surveys beginning in 1981 (Wander and Dunne 1981), management began in 1989 with the first "shorebird wardens" on three New Jersey beaches.

i. Outreach and Protection

- 1989: NJDFW-ENSP contracted New Jersey Audubon Society to train and supervise shorebird wardens at three New Jersey beaches (Norbury's Landing, Reed's Beach and Fortescue) to reduce disturbance. Educational signs were created and placed at two of those beaches (Reed's and Fortescue), and a brochure was distributed by the wardens.
- 1990: The first year that NJ ENSP provided a viewing platform at Reed's Beach, to limit disturbance of that beach by encouraging use of a single viewing point. ENSP contracted New Jersey Audubon Society to train and supervise shorebird wardens at four New Jersey beaches (Sunray, Norbury's Landing, Reed's Beach and Fortescue) on weekends in May. Wardens distributed an informative brochure to 1,000 people.
- 1992: Viewing areas were put in place at Norbury's Landing, Reed's Beach (2), and Fortescue. A map was created that identified all designated viewing areas
- ENSP trained and supervised 12 shorebird wardens who monitored four beaches on May weekends
- 1994: Viewing areas were set up at Norbury's Landing, Reed's Beach and Fortescue, and other accessible beach access points were posted with information signs warning of the problems of disturbance to feeding and resting shorebirds. A new brochure that included a viewing area map was distributed at all viewing areas and through local nature centers and businesses. New Jersey fielded shorebird wardens at viewing areas on May weekends.
- 1995: The New Jersey Shorebird Outreach Team continued to work together on educational materials for the public. This team developed educational materials including a map of viewing areas with a local business listing on the back. Viewing areas were set up at Norbury's Landing, Reed's Beach and Fortescue, and other

accessible beach access points were posted with a new sign designed to clearly indicate the safe viewing point to prevent disturbance to feeding and resting shorebirds. New Jersey fielded shorebird wardens at viewing areas on May weekends. A new brochure that included a viewing area map was distributed at all viewing areas and through local nature centers and businesses.

ii. Human use/Disturbance:

- 1985: NJDFW-ENSP began research and survey actions initiating surveys of human use (Clark and Niles 1985).
- 1987: NJDFW conducted human use surveys on New Jersey bayshore beaches.
- 1988: NJDFW conducted human use surveys on New Jersey bayshore beaches.

iii. Habitat Restoration

- 1991: Fishing Creek marsh was managed to promote shorebird habitat by controlling *Phragmites* and restore tidal flow to its western section.
- 2006: NJDFW received funding to remove rubble from Moore's and Thompson's Beach to improve spawning conditions for horseshoe crabs

iv. Radio Telemetry of Shorebirds

- 1989: NJDFW-ENSP initiated a shorebird telemetry study to determine habitat use patterns.
- 1990: A limited telemetry study continued (7 red knots) to determine habitat use patterns.
- 2003 - 2005: NJDFW-ENSP, in cooperation with DEDFW and the USFWS, initiated a baywide red knot telemetry study using stationary receivers to monitor bay wide bird movements and identify critical foraging and roosting sites.

v. Aerial and Ground Surveys

- 1990: NJDFW-ENSP conducted aerial transect surveys across New Jersey Atlantic and Delaware Bay habitats three times per day, once a week for three weeks; continued in 1991.
- 1991: This year saw increased demand for (and harvest of) horseshoe crabs as bait.
- NJDFW-ENSP conducted aerial transect surveys across New Jersey Atlantic and Delaware Bay habitats three times per day, once a week for three weeks, similar to those done in 1990. Ground surveys of shorebirds in marsh and beach habitats were conducted in 1991 and 1992, resulting in the Burger *et al.* (1997) paper.
- 2004: NJDFW-ENSP and New Jersey Audubon Society began fall shorebird surveys using a modified ISS methodology. Trained volunteers count/estimate flock size of individual species, determine the ratio of juvenile:adult red knots in flocks, collect data on individually marked shorebirds, record sources of disturbance.
- 2005: NJDFW-ENSP and New Jersey Audubon Society conduct spring shorebird surveys using modified ISS methodology. Trained volunteers count/estimate flock size of individual species, collect data on individually marked shorebirds, record sources of disturbance.

vi. Monitor Horseshoe Crab Egg Densities

- 1985: NJDFW-ENSP began research and survey actions initiating surveys of horseshoe crab egg density (Clark and Niles 1985). In 1985 and 1986 egg density was measured at selected Bay Shore beaches (Botton *et al.* 1988).
- 2000 - 2005: NJDFW-ENSP took over horseshoe crab egg sampling following a protocol established by Drs. Robert Loveland, Rutgers University, and Mark Botton, Fordham University. This survey will be replaced in 2006 with a method developed by the U.S. Geological Survey to be implemented both in New Jersey and Delaware.

vii. Monitor Shorebird Mass Gains and Adult Survival

1997 - present: NJDFW-ENSP began an intensive shorebird trapping and banding program in New Jersey and Delaware to monitor weight gains of shorebirds stopping over on Delaware Bay and color-mark individuals for survival analyses and population estimation. In 1998, the DECMP took over the trapping effort on the Delaware side of the Bay. These studies are ongoing and continue to the present under the direction of DEDFW-NHESP.

viii. Monitor Winter Population of Red Knots in South America

- 2000 - 2005: NJDFW-ENSP and the Canadian Fish and Wildlife Service instituted a winter survey of red knots in South America following the protocol of Morrison and Ross (1989). Continuation of this survey is dependent on availability of funding.
- 2000 - 2005: NJDFW-ENSP and biologists from Chile and Argentina captured and individually marked red knots wintering on Bahía Lomas, Chile, to augment adult survival analyses and assess proportion of immature birds in the wintering population.

ix. Monitor Breeding Densities on Arctic Breeding Area

1999 - 2004: NJDFW-ENSP, the Royal Ontario Museum and Rutgers University instituted a study to relocate red knots (outfitted with radio transmitters on the Delaware Bay) on Arctic breeding grounds in 2000, 2001 and 2003, develop a model of potential breeding habitat, and monitor breeding densities on a 10-ha. study site in Nunavut, Canada. Breeding densities were monitored during June-July of 2000 to 2004; limited funding in 2005 was dedicated to aerial survey of winter red knot population in South America (see above).

e. Delaware

i. Outreach and Protection

- 1995: DEDFW-NGES established shorebird interpretive signs and viewing platforms at key shorebird viewing areas including Ted Harvey Wildlife Area and Little Creek Wildlife Area at Port Mahon Road.
- 1995 DEDFW-NGES launched the Shorebird Ambassador Program that placed volunteers at key shorebird stopover sites in Delaware during the weekends. The shorebird ambassadors were to provide outreach and education to Delaware Bayshore visitors.
- 1998: DEDFW-NGES developed a shorebird viewing guide to promote shorebird conservation and viewing opportunities in Delaware.

- 1998: DEDFW closed horseshoe crab fishery May 1 – June 30 except for limited hand-harvest; landowners were allowed to have their beaches declared sanctuaries.

ii. Horseshoe Crab Radio Telemetry

- 2003-2005: DEDFW and DECMP, in partnership with the USGS have used an array of stationary telemetry receivers located throughout Delaware Bay to track horseshoe crab movement patterns and spawning frequency. In 2004 and 2005 shorebirds were added to the system to simultaneously track horseshoe crabs and shorebirds providing insight into the spatial and temporal overlap of beach use by these species.

iii. Aerial and Ground Surveys

- 1992: DEDFW coordinates ISS in Delaware during spring migrations. The ISS surveys were largely conducted by volunteers from the Delmarva Ornithological Society and continued through 1997.
- 2003: DEDFW-NHESP began coordinating fall shorebird surveys for the Program for Regional and International Shorebird Monitoring Program.

iv. Monitor Shorebird Mass Gains and Adult Survival

1998: DECMP initiated a shorebird-monitoring program that including intensive survey and banding operations that continues to this day.

v. Horseshoe Crab Egg Densities

- 1997-2005: DECMP began studying horseshoe crab egg densities for a variety of objectives related to coastal management activities and permitting issues.
- 2005: DEDFW initiated the Delaware portion of a Bay-wide horseshoe crab egg survey.

vi. Land acquisition

- Acquisition of former Lighthouse Restaurant facility in Mispillion Harbor to create the DuPont Nature Center, an interpretive and research center for horseshoe crab and shorebird outreach, education and viewing opportunities. Facility opened spring 2007.
- Acquisition of approximately 70 acres of marsh and dunes in Mispillion Harbor, purchased by DNREC from the Conservation Fund in July 2006 for the purpose of protecting prime horseshoe spawning and shorebird feeding areas. This acquisition, along with the DuPont Nature Center and additional surrounding state wildlife area lands, comprise the Mispillion Harbor Reserve.

f. New York

Jamaica Bay has been designated and mapped as an otherwise protected beach unit pursuant to the federal Coastal Barrier Resources Act, prohibiting incompatible federal financial assistance or flood insurance within the unit. The New York State Natural Heritage Program, in conjunction with The Nature Conservancy, recognizes two Priority Sites for Biodiversity within the Jamaica Bay and Breezy Point habitat complex: Breezy Point (B2 - very high biodiversity significance) and Fountain Avenue Landfill (B3 - high biodiversity significance). Jamaica Bay and Breezy Point have been designated as Significant Coastal Fish and Wildlife Habitats by the New York State

Department of State, and the bay up to the high tide line was designated as a Critical Environmental Area by the New York State Department of Environmental Conservation. Jamaica Bay was also designated as one of three special natural waterfront areas by New York City's Department of City Planning. A comprehensive watershed management plan for the bay was completed in 1993 by the New York City Department of Environmental Protection in order to better protect and restore habitats and improve water quality. Wetlands are regulated in New York under the state's Freshwater Wetlands Act of 1975 and Tidal Wetlands Act of 1977; these statutes are in addition to federal regulation under Section 10 of the Rivers and Harbors Act of 1899, Section 404 of the Clean Water Act of 1977, and various Executive Orders. (Source: USFWS, http://training.fws.gov/library/pubs5/web_link/text/jb_form.htm)

g. Connecticut

Connecticut-DEP Wildlife Division completed a Shorebird Use Assessment as part of the Wildlife Conservation and Restoration Program. This project helped in identifying priority sites for protection.

h. Rhode Island

Rhode Island has monitored spring and fall passage of shorebirds annually and all important shorebird stopovers are known.

i. Massachusetts

Currently there are management and protection plans in place for some of the important stopover areas in MA. Federally owned areas, Plum Island [southern ¾ only], Nasuset Coast Guard Beach, South Beach Island [portions] and Monomoy NWR, are currently managed by their respective agencies. Portions of Sandy Neck are managed by The Nature Conservancy. The remainder of the important areas is municipal / private land and may or may not be managed. Information on the management and protection status of private / municipal-owned important stopover areas was not available at the time of writing.

j. New Hampshire

No known management of shorebird stopover locations at the time of writing.

k. Maine

During the period 1989 to 1995, the state of Maine began intensive shorebird surveys to locate and designate critical staging areas. These locations have been designated as "Shorebird areas of Management Concern" and are candidate areas under Maine's Natural Resource Protection Act, which allows the Maine Division of Inland Fisheries and Wildlife to review permits relating to development and dock placement.

***2. Panama***

The total number of shorebirds using the Upper Panama Bay at some time during the year has been estimated at well over 500,000 qualifying it as a Hemispheric Reserve of the Western Hemisphere Shorebird Reserve Network (Morrison *et al.* 1998). Despite

this, the site remains unprotected and unmonitored, and only recently the westernmost part (the main study area of Watts (1998)) was lost to housing (Buehler 2002).

***3. Canada***

Migration staging areas are along coastal areas in Canada and are either federally or provincially owned. The federal government has many tools and programs for nature conservation. These range from outright ownership and management of various types of formal protected areas to the negotiation of voluntary agreements with private landowners. The federal approach to conservation and protection is to combine this range of approaches and partners, using each tool when and where appropriate.

Within the federal government, Environment Canada, the Parks Canada Agency, and Fisheries and Oceans Canada have the mandate to protect critical habitats by managing complementary protected area programs:

- Environment Canada, directly and/or through partnership arrangements, establishes and manages National Wildlife Areas, Migratory Bird Sanctuaries and Marine Wildlife Areas to protect wildlife habitat, and unique and productive ecosystems. The first two designations also allow Environment Canada to set up marine protected areas off Canada's shores and along the coasts of inland waters.
- Fisheries and Oceans Canada has the authority to establish Marine Protected Areas for a variety of purposes, including the conservation and protection of species at risk and their habitats, the conservation and protection of unique habitats, and the conservation and protection of marine areas of high biodiversity or high biological productivity.
- Parks Canada establishes and manages National Parks and National Marine Conservation Areas, which are intended to protect a representative sample of the features of the country's natural regions and marine natural heritage and to provide opportunities for public education and enjoyment.

Finally, the federal government plays a lead role in managing the implementation of international protected areas programs in Canada, including UNESCO Biosphere Reserves, UNESCO World Heritage sites.

**F. Breeding Habitat Management**

Nunavut Tunngavik Incorporated (NTI) was set up as a private corporation in 1993 to ensure that promises made in the Nunavut Land Claims Agreement are carried out. The operations of NTI are managed through offices in Iqaluit, Rankin Inlet, Cambridge Bay and Ottawa. Features of the Nunavut Land Claims Agreement include some to the more outstanding of its 41 articles include the title to approximately 350,000 square kilometers of land, of which about 35,000 square kilometers include mineral rights.

**G. Other Management Considerations and Opportunities**

***1. Create High Tide Roost Sites within Impoundments on State and Federal Wildlife Areas.***

Recent research conducted by NJDFW-ENSP has demonstrated the importance of roosts for migratory shorebirds on Delaware Bay. One series of high tides in late May

flooded all available roost on the bay and the entire population of shorebirds moved elsewhere to find safe roosts. NJDFW and DEDFW biologists plan to investigate the creation of new roosts sites in Delaware Bay marshes and state and USFWS impoundments.

***2. The Biomedical Industry***

The Biomedical Industry could play a major role in 1) supporting survey and monitoring of the horseshoe crab population and 2) identifying ways to reduce crab mortality through improved monitoring (pre- and post-bleeding) to identifying sources of mortality, subsidize improvements to transport and holding facilities, bleeding methods, and reduction of holding time to reduce mortality.

Long-term research to improve/lower cost of a synthetic test for contaminants in injectable drugs would eliminate the need for horseshoe crabs altogether.

## XI. MONITORING EFFECTS AND MANAGEMENT ACTIVITIES

There are several very robust methods of monitoring the efficacy of conservation action because of the significant amount of work that has already been accomplished by scientists throughout the West Atlantic flyway.

In Delaware Bay, the departure weight of red knots has been statistically linked to survival rates and would serve as a key indicator of the vitality of the stopover. Weight gain achieved is primarily influenced by the availability of food resources (horseshoe crab eggs) and weight on any particular date is a function of that as well as arrival date and arrival condition. Therefore these interrelated effects need to be monitored carefully.

A bay-wide survey of crab eggs was implemented in 2004 after five years of similar surveys conducted on the New Jersey side of the bay. Moreover a bay-wide survey of spawning crabs has also been conducted since 1999 and could serve as a useful counterpart to the egg survey. Finally, a count of shorebirds on the bay has been conducted by New Jersey Fish and Wildlife since 1986. The best monitoring tool for the long term is a model based on four main parameters: shorebird numbers, egg densities, crab numbers and departure-weight profiles.

Survival rate is a critical input into long term modeling of the population. Banding with individually identifiable flags allows for yearly assessment of the survival of birds coming through the Delaware Bay. Ultimately, banding in each of the three major wintering areas, Tierra del Fuego, Maranhão and the southeast U.S., coupled with stable isotope studies will help distinguish survival rates related to each. A continued focus on resighting flagged birds must be a key element of monitoring, at least until recovery is assured.

With populations of shorebirds and crabs in Delaware Bay at such low levels, departure weights may also be influenced by competition for eggs from other species, particular laughing gulls, as well as disturbance especially in areas of high egg-density. Therefore in the short term it will be necessary to monitor disturbance and gull populations as inputs into the model based primarily on the four parameters mentioned above.

Ultimately the model could help decide the size of the horseshoe crab harvest for bait or as a source for lystate that is consistent with maintaining the shorebird population.

The goals of management in Delaware Bay should be

1. for the majority of the knots (>80%) to reach a departure weight of at least 185g by the end of May, and
2. to increase the peak stopover population of knots to at least 100,000 as it was in the 1980s.

More comprehensive monitoring of the effect of management on the red knot population will come from the continuation of yearly counts in the primary wintering areas. The Patagonia counts have been carried out every year since 2000 allowing direct comparison with the population size at the time of the first comprehensive survey in the mid 1980s. A new count was carried out along the coast of Maranhão, northern Brazil, in February 2005 and if this can be repeated regularly, it too may serve as a useful measure of recovery. The wintering population in the southeast U.S. must also be monitored with the same intensity as in Patagonia. The Florida Division of Fish and Wildlife intends to restart a coast-wide survey of shorebirds, first conducted in 1996. This survey, or at least that part that relates directly to knots, should be conducted every year.

The population of red knots breeding in a study area of 9.2 $km^2$ on Southampton Island in arctic Canada was surveyed from 2000 to 2004. During this time it fell from about 1 to 0.3 nests/$km^2$. No survey was possible in 2005 due to lack of funds. These surveys are logistically challenging and costly and this means that it is difficult to expand them to an area of sufficient size to make year-to-year comparisons statistically robust. However they would be a useful means of measuring recovery. Therefore, if at all possible, they should be continued in order to monitor future change. The nest densities of knots can be compared with those of other species to determine whether population change is likely to be the effect of arctic breeding conditions or factors affecting them elsewhere.

## XII. CONSERVATION GOALS AND THE SURVEYS, MONITORING, RESEARCH, AND MANAGEMENT NEEDED TO SUPPORT THEM

### A. Conservation Goals

The *US Shorebird Conservation Plan* (Brown *et al.* 2001) proposes a tentative target for restoration of the *rufa* population to 240,000. Though we agree that this would be desirable and would ensure *rufa*'s future, it does not now seem to be realistic. Moreover there is no evidence that the population was ever that large. Overall the goal of conservation activities throughout the flyway should be to increase the *rufa* population to at least the figure of 25 years ago of 100,000-150,000 by 2015. Given the uncertain genetic relationships between the three main wintering populations there should also be a target for each. The following are suggested:

1. Tierra del Fuego wintering population to 70,000-80,000 birds
2. Brazilian wintering population to 20,000-25,000
3. Florida wintering Population to 20,000-25,000
4. Other sites 15,000-20,000

The means whereby such population increases might be achieved include:

1) Recovery and maintenance of Delaware Bay horseshoe crab egg densities at levels sufficient to sustain stopover populations of all shorebirds including 100,000 red knots. In part this will be supported by:
    a) Continuation of all current yearly studies of shorebird numbers, weight distribution and rate of mass gain, horseshoe crab numbers and egg densities, as continuing inputs for models
    b) Development and testing of a predictive model for use by managers to determine the egg densities appropriate to support the existing stopover population and the gradual increase necessary as shorebird numbers recover.
2) By 2008, development of a system for the yearly determination of population demographic status based on survey results, capture data and resightings of banded individuals. This will involve:
    a) Creation of a survival and population status model using existing data, and updated annually with new data.
    b) Development of annual estimates of productivity and juvenile survival as inputs for population models using the framework established for waterfowl population assessments
    c) Distinguishing the population parameters of each wintering population (Tierra del Fuego, Maranhao and Florida) based on site-specific banding, resightings of marked individuals and stable isotope analyses.
3) By 2008, determine the genetic and breeding status of the three main wintering populations (Tierra del Fuego, Maranhao and Florida). This will involve:
    a) Identifying the arctic breeding area associated with each wintering subpopulation
    b) Determine subspecific status of each wintering population
    c) Determine the migration routes used by each wintering population
4) By 2011, create a hemisphere-wide system of protected areas for each significant wintering, stopover and breeding area
5) By 2009, complete site assessment, using Western Hemisphere Shorebird Reserve Network (WHSRN) site assessment tools, for Bahia Lomas, Rio Grande, San Antonio Oeste, Lagoa do Piexe, Maranhao, the west coast of Florida, the Altamaha Region of Georgia, the Virginia Barrier Islands, Delaware Bay, Stone Harbor Point, James Bay, Southampton Island and King William Island. This will lead to:
    a) The development of management plans and their integration into local and national conservation systems.
    b) The identification of survey and research needs for each site
6) By 2008, identify all important breeding locations in Canada, and recommend protection needs for the top ten sites. This will require:
    a) Use of radio telemetry to determine the arctic breeding areas of each winter populations (Florida, northern Brazil and Tierra del Fuego).
    b) Use of GIS to determine suitable breeding habitat and extent of important breeding areas
    c) Formulation of recommendations to national governments on protection designations for most important breeding areas

7) By 2009, delineate and propose protection measures for key habitats within the main wintering areas of Maranhao, Tierra del Fuego and Florida, and develop management plans to guide protection. This will involve:
    a) Conducting intensive surveys and determining areas of greatest importance within each site
    b) Creating maps of each site and determine chief threats and management needs using WHSRN site assessment tools
    c) In conjunction with national and local government agencies, create management plans for each wintering area that identify actions necessary to improve conditions and protect sites.
    d) Conducting site-specific research necessary to determine important-use areas as well as existing and emerging threats
        (i) Carrying out studies of food resources
        (ii) Carrying out studies of habitat-use using radio telemetry
8) Determine key southbound and northbound stopovers that account for at least 80% of stopover areas supporting at least 100 red knots, and develop coastwide surveillance of birds as they migrate. This will require:
    a) Setting up survey, resighting, and banding programs to determine importance of individual stopovers relevant to associated wintering and breeding areas in places other than the Delaware Bay, including James Bay, the Mingan Islands in the Gulf of St Lawrence, at least two sites each in New Jersey, Virginia, South Carolina, Georgia, Maranhao (Brazil) and Patagonia (Argentina).
    b) Use WHSRN site-assessment tools to determine threats and management needs at each site and develop a plan to meet them.
9) Control impact of disturbance at all stopovers and wintering areas, particularly in high-importance, high-disturbance areas like Delaware Bay and the west coast of Florida
    a) Identify, through site-assessment tools, all sites where human use is impacting birds by preventing access to key resources and/or roost sites
    b) Restrict access to all beaches using methods developed in Delaware Bay as outlined in this report

**B. Survey Needs**

To effectively manage the red knot population, it is necessary to undertake regular assessment of numbers, demographic rates and conditions in wintering, staging and breeding areas. A comprehensive and integrated monitoring program is necessary, not only to monitor the status of the populations but also for the objective assessment of the results of any management actions undertaken as a result of this review and further research.

***1. South America***

Red Knots use South America both for locations to spend the northern winter and for stopover sites to and from the breeding areas. During northward migration, passage through Peninsula Valdés, Patagonia, Argentina, has become later since year 2000 (Bala *et al.* 2005). This may have led the number of Tierra del Fuego birds arriving late into Delaware Bay to have increased and there is some evidence of this for 2000, 2001 and

2003 (Baker *et al.* 2004, K. Clark unpublished data). Any such late arriving birds will be at a lower weight compared with those that arrived earlier and Baker *et al.* (2004) has shown that low weight birds in Delaware Bay subsequently have a lower resighting rate throughout the flyway, implying lower survival. Therefore further investigation is required to determine the reasons why northward passage has become later. This should focus particularly on the food resources used in South America, especially in Chile, Argentina and Brazil. More specific needs are detailed below.

Very little is known about the distribution of juvenile red knots during their first northern winter apart from the fact that most do not go as far south as the main wintering area of the adults in Tierra del Fuego. It should be a priority to determine their distribution and monitor their survival as well as year-to-year changes in their numbers as a measure of breeding productivity.

a. Argentina

Counts of, and resighting of individually marked knots at Rio Grande, Tierra del Fuego, to increase the precision of annual survival and recruitment estimates of specifically the *rufa* population, and to allow the estimation of specific locality-survival-resighting parameters with multi-state models is needed. Training of more local biologists and shorebird rangers at key sites is needed.

b. Chile

Aerial surveys of Bahia Lomas and surrounding areas have provided the best estimate of the change in the *rufa* population and these should continue. Studies on population dynamics of the wintering population (i.e. monitoring survival and recruitment through marking and subsequent resighting of individually marked birds) are needed as this area represents the largest known wintering concentration of *rufa*. Given the delayed northward migration through Patagonia and its implications, studies of any interactions of knots with other migrant and non-migrant species, and use of the Bahia Lomas by all these birds as a foraging ground will determine whether this is caused by lack of food supplies on the non-breeding grounds

c. Brazil

How red knots use Brazil as a wintering and staging area is one of the greatest unknowns in their life cycle. Basic count and distribution information is needed before more detailed studies can be designed.

- Aerial surveys on the Amazon Coast, especially in the coast of the state of Maranhão, during migration (boreal and austral), as well as during wintering seasons
- Ground surveys on the Río Grande do Sul coast, during the migrations
- Aerial survey on the Amapá and Pará Coast when knots are wintering in Maranhão
- Establish to what extent the Pantanal is used as a stopover site during northward and southward migration using aerial and/or ground surveys (April and end of September to first week of October)

d. Caribbean Countries, Northern South America

- As feather isotope studies suggest that a substantial number of birds winter in an unidentified area, clarification of the status and numbers wintering around the Caribbean and less known parts of northern South America is necessary. This unidentified area may be within Brazil (see above) but other likely areas include the Gulf of Maricaibo, where high hundreds were found during an early March survey in the early 1980s.

***2. Mexico***

- Confirm numbers and subspecific status of knots wintering and staging on both the east and west coasts. Birds wintering on the east coast may be *C. c. rufa,* those on the west coast, *C. c. roselaari*

***3. United States***

a. Delaware Bay

- Cross-bay commuting for the whole 12-14 day stopover is equivalent in distance to almost half of the flight to the arctic breeding grounds. This is an energetic cost the birds can ill afford at a time when they are under pressure to reach the breeding grounds. Continued surveys of the Hereford Inlet roosting site are warranted to help evaluate roost site management and improvement. Roost sites in Delaware should be identified and surveyed to monitor management actions.

b. Virginia

- Systematic resighting survey efforts should be conducted in conjunction with daily counts of red knots using the barrier islands during spring migration, April through early June.

c. North Carolina

- Additional surveys during migration are needed.

d. South Carolina, Georgia, Florida

- The survey of wintering knot numbers in southeastern U.S. needs to be expanded with an annual winter aerial survey of appropriate coasts including the west coast of Florida, and the Atlantic coasts of Georgia, South Carolina and Florida. Early January would be best because that is when annual ground-based counts are traditionally carried out in Georgia. Determining the size of the population wintering in the southeast of the U.S. is seen as a high priority. It is particularly important that surveys aimed at achieving this are coordinated, time-constricted and wide-ranging in view of the apparent mobility of this population. Ideally aerial counts should be combined with ground counts.
- Conduct statewide surveys of red knots to document important areas, habitats and timing of migration. Surveys would include color-band resightings. Participate in ISS surveys that have long-term data sets.

e. Alaska

- Spring aerial or ground surveys are needed in the major spring staging areas to compare with previous counts which may no longer reflect the current situation. Ground-based searching for color-marked birds to determine which wintering populations these birds come from is a major objective. This could be particularly productive in view of the large numbers of knots that are currently marked in the West Atlantic and East Asian – Australasian flyways.

f. California

- Statewide surveys need to be carried out to update counts of wintering and staging knots in California.

g. Washington State

- Regular monitoring of the red knot on spring passage through areas such as Westport and Gray's Harbor.

**C. Monitoring Needs**

- Monitoring is essential to objectively determine trends in numbers, survival and recruitment to the red knot population on an annual basis. As there are several separate, apparently isolated populations, it is important to focus attention on wintering areas (i.e. the discrete wintering populations) as well as staging sites such as Delaware Bay.
- It is important to continue to individually color-mark samples from all populations (Florida, Georgia, Carolinas, Northern Brazil and Tierra del Fuego). Comparison of the proportions of birds from each wintering and migration site will facilitate a clear understanding of the migration routes and breeding areas of each population. Without this information it will be impossible to monitor the success of conservation actions throughout the flyway.
- Considerable effort is needed in all major sites to locate individually-marked birds to determine which populations use which sites.
- Other wintering sites need to be investigated to locate the wintering location of the group identified by their isotope signatures as being from an unknown wintering area.
- To ensure that conservation action is focused on reversing the declines observed it is vital that we identify all migration stopover sites that are used by the species on a regular basis. Identification of individually marked birds will enable conservation effort to be focused on those sites that hold the highest proportion of birds from groups that are known to be in greatest decline. Catching samples at these sites and individually marking (and taking a feather for isotope analyses) may also help in identifying the location of the unknown group.
- Autumn monitoring of return rates and juvenile abundance should be developed further to increase our understanding of breeding success and how it feeds through into recruitment into the breeding population monitored in spring in Delaware Bay.

***1. South America***

a. Argentina

- Continue the long-term monitoring programs and management plan development already in place.
- Continue to catch and mark knots as individuals. Collect blood samples from a sample of birds to monitor parasite levels, collect a feather from a sample of birds to maintain a current up-to-date isotopic signature for wintering areas.
- Resight individually marked knots to increase the precision of annual survival and recruitment estimates, and to allow the estimation of specific locality-survival-resighting parameters.
- Monitor food sources at Argentinian wintering and staging areas to investigate the cause behind the delayed northward migration reported by Bala *et al.* (2005).

b. Chile

- Constant abundance monitoring, both aerial and terrestrial, during every season of the year is needed, especially during the key arrival and departure periods.
- Continue to catch and mark knots as individuals. Collect blood samples from a sample of birds to monitor parasite levels, collect a feather from a sample of birds to maintain a current up-to-date isotopic signature for wintering areas.
- Resight individually marked knots to increase the precision of annual survival and recruitment estimates, and to allow the estimation of specific locality-survival-resighting parameters.
- Continue with, and develop, the benthic invertebrate sampling program at Bahia Lomas to investigate the cause behind the delayed northward migration reported by Bala *et al.* (2005).

c. Brazil

- Monitor red knots on the coast of Maranhão during passage and winter stage (September to May), with development of the following activities:
    - Capture knots using cannon- and mist-nets and individually mark
    - Attach radio transmitters in May to determine date of arrival in Delaware Bay
    - Biometric data gathering (molt, age, sex, ectoparasites load, collection of feathers for stable isotope analysis, blood sampling for studies of genetic variability and disease transmission such as West Nile Virus, Avian Influenza, etc.)
    - Scans for individually-marked birds to increase the precision of annual survival and recruitment estimates, and to allow the estimation of specific locality-survival-resighting parameters.
    - Initiate a benthic invertebrate sampling program to determine whether the later northward passage is due to poor food supplies further south.
- Create a field station in the municipality of Cururupu for supporting field work in Maranhão

- Monitor red knots and their food supplies in Lagoa do Peixe National Park during September, October, April, and May using the same methods as described above.
- Publish literature and give talks about the conservation importance of the red knot and the activities mentioned above for local communities and the authorities responsible for land management (IBAMA, Government of the States of Maranhão and Río Grande do Sul).
- Monitor shorebird species in the Pantanal (Río Negro) during northward and southward migration

***2. United States***

a. Delaware Bay

- Monitor survival and recruitment of different sub-populations of red knots. In order to fill in the gaps in knowledge that have been identified in this status review, regular samples of knots need to be caught throughout the spring season at a range of locations. Each bird should be individually color-marked, a primary covert taken (for isotope analysis to identify wintering area) along with full biometrics including weight. The level of the catching should be minimized, consistent with keeping enough individually color-marked birds in the population to assess survival rates of the different populations coming through the bay and sufficient to allow Pradel modeling of recruitment rates.
- A program of daily counts and resightings should be undertaken each spring in Delaware Bay to estimate the total number of birds of each wintering population passing through the bay.
- Continuation of the aerial survey during May and early June using consistent methods to ensure the long-term data set is maintained.
- Continuation of the various Horseshoe Crab monitoring programs, specifically the Delaware Bay Spawner Survey and Delaware Bay Egg Abundance Survey, both of which need support and provide critical data.
- Continuation of fall ground-based shorebird counts, especially in the Atlantic coast of New Jersey.
- Site use should be monitored through aerial and ground surveys. Bay-wide radio-tracking should be further evaluated for its application to monitor and track changes in site use patterns. These data in combination with other site-specific data should be used to determine site-specific management actions.

b. Virginia

- Regular counts and band resighting to investigate arrival date, departure date and residence time of knots using the barrier islands during spring migration
- Assessment of the body condition of knots upon arrival and also at the time of departure in order to determine whether they are able to fly direct to the Arctic or may need to stop over further north, such as in Delaware Bay.
- Determine food supplies available at the main staging sites.

c. North and South Carolina

- Cannon net flocks and mark as individuals, during winter and passage periods, to determine how these birds use the Florida/Georgia wintering areas and Delaware Bay in spring.

d. Florida and Georgia

- Catch birds using cannon and/or mist-nets and mark as individuals using coded flags in winter.
- Collect biometric data and details of molt, age, sex and ectoparasites; collect feathers for stable isotopic analysis and blood samples for studies of genetic variability.
- Resight individually-marked knots to increase the precision of annual survival and recruitment estimates, and to allow the estimation of specific locality-survival-resighting parameters.

e. Other Sites on the U.S. East Coast

- Search for and monitor other potentially important stopover sites for red knots along the U.S. east coast, such as Jamaica Bay, New York.

***3. Canada and Alaska***

Marking knots in the Arctic will be incredibly valuable for understanding the migration routes. Feather samples need to be taken to obtain isotope signatures of their wintering areas. This is extremely difficult as the birds are highly dispersed but even small samples of individually marked birds can be extremely valuable as resighting rates are over 50%.

If sites are located where adults congregate even in small numbers on arrival in the Arctic or before departure, effort should be put into increasing the samples of birds from the Arctic. It would be of particular value to mark samples of birds in Alaska in order to identify their wintering areas, as resighting effort in some known wintering areas is quite high.

**D. Research Needs**

There are several key gaps in our knowledge of the red knot's life cycle in the Americas. Some relate to specific sites or countries while others can only be addressed by broad-scale coordinated research throughout one or more of the major flyways.

***1. Broad-scale Research Topics***

- How do birds from different wintering populations use Delaware Bay? There is good evidence from feather isotope studies that birds from different wintering areas use the foraging resources of Delaware Bay in different ways. New Jersey-banded knots (based on resightings and isotope signatures) are being found in the southeastern U.S. more frequently than Delaware-banded knots, particularly those feeding on mussel spat on the Atlantic coast of New Jersey adjacent to Delaware Bay. Collection of these data should be amplified by expansion of individual marking efforts in Tierra del Fuego and in the northern Brazil and southeastern U.S. migration and wintering

areas and intensified searches for them on Delaware Bay. In addition, a well designed radio-tracking (telemetry) program could be used to establish whether knots from the various wintering areas use Delaware Bay in the same way with respect to foraging activities. The focus for radio-tracking of knots from the U.S. wintering areas should be on migrants during April in South Carolina. In view of this apparent difference in usage, efforts should be made to improve conditions across the Delaware Bay, rather than just in a few 'hotspots.'

- Why has there been a trend for northward migration to become later? Bala *et al.* (2005) showed that the passage of knots through Peninsula Valdés, Patagonia, Argentina, has become significantly later since year 2000 and there is some evidence of late arrival of Tierra del Fuego birds into Delaware Bay in 2000, 2001 and 2003 (Baker *et al.* 2004, K. Clark unpublished data). This is of particular concern for the long distance migrants, as they will require high densities of crab eggs to be available when they do arrive to achieve their target mass in time to reach their Arctic breeding areas. This may be due to problems with the food supplies in the South American wintering or passage areas and research effort needs to address this.

- About 20% of the red knots passing through Delaware Bay have isotope signatures not compatible with known molting areas – where do these birds molt? Currently, the nonbreeding distribution (migration and wintering) of the northern wintering knots is not well known. The group of knots that winters in the northern hemisphere may now comprise as much as half of the knots passing through Delaware Bay during northward migration. This is a dramatically higher proportion than was estimated to have been the case in the middle 1980's. One possible cause of this change is that the Patagonian-wintering knots have shown a major decline since the 1980s, whereas the northern-wintering group has not declined. If so, the health of the knot population passing through Delaware Bay may substantially depend on the continued well-being of the northern wintering group.

  Although it is clear that some of this group winters in the southeastern U.S. (coasts of South Carolina, Georgia, and the Gulf coast of Florida), it is possible that substantial numbers also use other major wintering areas. The individual marking and scanning of knots from this group will be valuable at key migration staging sites during southward migration, especially at Cape Cod, Massachusetts and the Altamaha River Estuary, Georgia, as well as during winter and in March/April on the coasts of South Carolina, Georgia, and the Gulf coast of Florida. In combination with counts, such a banding/scanning effort should yield a much better idea of the size of the northern-wintering group, an improved understanding of its migration strategies as well as a clearer understanding of the relationships between the U.S.-wintering knots and those that spend winter on the coast of northern Brazil.

- Why have there been declines in some wintering areas in southern South America and not others? There is a need for a better understanding of Patagonian-wintering knots and their food supplies. Numbers at Bahía Lomas have declined dramatically since 2000, whereas those at Río Grande have not. This suggests that the cause of the recent decline may originate at Bahía Lomas. Birds from both wintering sites pass through Delaware Bay, so both populations should have decreased if the environment

of Delaware Bay is the root cause of the overall decline in the red knot population. There is also evidence that the northerly wintering populations (southeastern U.S. and northen Brazil), of which some pass through Delaware Bay, have not undergone the catastrophic decline observed in Tierra del Fuego. Individual color-marking and resighting can be used to determine whether there is any difference between the survival of birds from Bahía Lomas and Río Grande. Consistent monitoring of knots and their food resources at Bahía Lomas and other wintering areas is also required. This should include regular (e.g. monthly) counts to determine whether knot numbers change during the season, monitoring body condition (e.g. plumage-oiling, ectoparasites and general heath, molt and mass), and regular sampling of food resources. This work might be promoted through the formation and funding of a Chile/Argentina working group.

- Why have many southern South American wintering birds not passed through Delaware Bay in spring? Feather isotope studies indicated that in 2003-2005, a third to a half of the knots passing through Delaware Bay were from northerly wintering areas. As far as it is possible to ascertain, there has not been a dramatic decline amongst these birds since 2000. In spring 2004, turnover and isotope studies indicated that 24,000 birds passed through Delaware Bay, 12,000 from each population (Gillings *et al.* in prep.).

  Although 31,568 birds were counted in southern South America in January 2004 (See Fig. 47), it is apparent that many did not pass through Delaware Bay on northward migration that year. In January 2005, the southern wintering count dropped to 17,653, indicating a major decline. If this dramatic population change was due to mortality solely caused by changes in conditions in Delaware Bay then most if not all of the 12,000 southern South American knots passing through Delaware Bay in May 2004 must have died. Annual survival rates of the Tierra del Fuego population averaged only 56% during 1999-2001 (Baker *et al.* 2004), and little different at around 60% in 2004 and 2005. This indicates that there may be major problems for knots in the wintering or staging grounds – and this may be a reason for some of the later arriving birds into Delaware Bay. Studies aimed at understanding why numbers have dropped at Bahía Lomas and at other traditional wintering sites in southern South America are urgently needed. Although the decline in Bahía Lomas suggests problems in the wintering areas, an alternative explanation is that birds are facing problems at staging areas further north in South America. One possibility is that they are affected by ectoparasite infestation as found in the Maranhão, Brazil, wintering area in February 2005 (Baker *et al.* 2005a) and amongst birds from each of the three wintering areas passing through Delaware Bay in the springs of 2004 and 2005. As very little is known about conditions at several staging sites in South America, exploration of this part of the life cycle is a priority.

- What is the extent of the *roselaari* and *rufa* wintering areas, do they both pass through Delaware Bay and where do they breed? As discussed in the Taxonomy section of this review, there is a great deal of uncertainty about the subspecific status of knots wintering in southern South America, in comparison with those in Maranhão, in the southeastern U.S., on the northern hemisphere Pacific coast (San Francisco Bay, Mexico (Baja California and Sonora/Sinaloa), and on the Pacific coast of Chile.

Genetic and isotopic studies need to be continued and expanded. In view of numbers claimed for Alaska, it is possible that populations wintering in Mexico and on the west coast of South America are higher than currently thought. Surveys of Mexican knot populations should be expanded. This might be achieved as part of the annual January winter waterfowl surveys conducted jointly by the U.S. and Mexico.

- Breeding productivity is a major unknown – monitoring it might help with understanding the impact of depleted food resources in Delaware Bay as well as allowing full demographic modeling. It is argued that knots unable to secure adequate resources on Delaware Bay have lower survival. It should follow that they also have lower breeding productivity. Given the difficulty of measuring breeding success in sufficient representative areas of the nesting grounds, the most practical option would seem to be counting juveniles during southward migration and possibly also in the wintering areas. This might be achieved using volunteer surveys. Participation in the collection of juvenile/adult ratios during the ISS has been low, but appropriate training could change this and increase participation in age-monitoring.

***2. Country-specific research needs***

a. South America

i. Argentina

- Trophic ecology studies at San Antonio Oeste, the key site hosting highest numbers of red knots in Argentina to determine whether food supplies at this site limit the pace or timing of migration.
- Monitor food supplies at Río Grande and movements between nearby Bahía Lomas.
- Continuation of individually marking birds with coded flags and resighting of individually-marked birds to allow analyses of site and population specific survival and recruitment rates.
- Collection of a sample of primary covert feathers each year to maintain a current isotopic signature for each major wintering site.

ii. Chile

- Studies on geomorphology of the intertidal ecosystem, floristic analysis of the palustrine and steppe communities and ecosystem ecological risk are needed.
- Studies on population dynamics of the wintering red knot population and interaction with local species and other Nearctic visitors, and use of the bay by all these birds as a foraging ground including regular surveys of benthic invertebrates.
- Continuation of individually marking birds with coded flags and resighting of individually-marked birds to allow analyses of site and population specific survival and recruitment rates.
- Collection of a sample of primary covert feathers each year to maintain a current isotopic signature for each major wintering site.

iii. Brazil

- How birds use staging sites in Brazil constitutes one of the greatest unknowns in the life cycle of the Red Knot wintering in Chile and Argentina. Research into this aspect is urgently needed to determine whether problems affecting sites in Brazil are the cause of birds arriving late into Delaware Bay. This will require the development of studies on foraging ecology and food availability in Maranhão and Lagoa do Peixe National Park
- Studies on potential impact of disease (West Nile Virus, Avian Influenza, Newcastle Virus, etc.)
- Studies on ectoparasites infection during winter and also during different stages of migration, especially in Maranhão

b. Mexico

- Clarification of the status and number of knots wintering in Baja California, and Sonora/Sinaloa.
- Collection of a sample of primary covert feathers to obtain a current isotopic signature for comparison with passage birds in Delaware and also other wintering sites.
- Initiate marking programs, in conjunction with other knot biologists.
- Collection of genetic material to determine affinity of these populations with others.

c. United States

i. New Jersey and Delaware

- How many crab eggs are enough? To provide a scientific basis for management there is a need for integration of Horseshoe Crab egg data and shorebird behavior into a model that can predict the numbers of eggs needed by shorebirds. From this an estimate of the density of eggs required to support present and future numbers of shorebirds can be calculated. This can be used as one benchmark against which to determine whether Delaware Bay is in a satisfactory condition for shorebirds and provides an easily collected metric against which to assess the impacts of management actions.

  The changes in food supply are thought to be the main reason for the decline in birds in Delaware Bay, but it is also important to determine the importance of changes in gull numbers and human disturbance (including at roost sites) on the stopover birds. The behavior-based individuals models developed by Drs John Goss-Custard and Richard Stillman of the United Kingdom's Centre for Ecology and Hydrology (CEH) are suitable for this situation and steps need to be taken to integrate the existing egg density and bird-behavioral data into a comprehensive model. Much of the data required for the models exist, but they still need to be integrated.
- Modeling food availability to red knots in Delaware Bay will need bay-wide egg data and an understanding of the conditions under which the egg supply in the top 5 cm of sand (and therefore potentially available to knots) increases and decreases. These data can then be used for determining the minimum level of the crab population necessary to produce a sustainable food resource

for the birds. These data are also needed to fully parameterize the CEH individual based population model and use it to predict the quantity of eggs that need to be on the beaches for current shorebird populations and for future populations if they recover from the declines of the last two decades.

- Studies that determine the level of harvest that will ensure enough eggs for migratory shorebirds are essential. Horseshoe crabs do not breed until they are about eight years old and the demographic structure of the population, especially immature survival, is only partly understood.

ii. Virginia

- Investigation of which prey knots are targeting on the Virginia barrier islands, with specific attention paid to identifying the availability of prey on peat banks vs. on high energy beaches and the relative importance of each to migrating knots.

iii. North Carolina

- Research on impacts of beach stabilization and impacts of human disturbance

iv. South Carolina

- Develop a South Carolina Department of Natural Resources web site with information on the status, management, and natural history of red knots in South Carolina. Work with public and private land managers to protect areas identified as important red knot roost sites. Obtain travel money to participate in red knot working groups.

v. Massachusetts

- High priority needs for the state of Massachusetts include research and monitoring of human disturbance in shorebird habitats, particularly those disturbances associated with commercial and recreational fishing and public access to beaches.
- Monitoring of recruitment through observations of juveniles during fall migration.

**E. Management Needs**

The management needs presented in this section are preliminary and largely based work described in more detail in previous sections. As nearly all management work focused on red knot occurs in the area of the Delaware Bay, management needs in other locations will only be determined after preliminary survey and research is complete. However, the experiences of conserving the Delaware Bay stopover, as well as work in Patagonian wintering areas, provide general management needs.

1. On the Delaware Bay, recover and maintain horseshoe crab egg densities at levels sufficient to maintain a stopover population of red knots of over 100,000 birds.
2. Control impacts of disturbance at all stopovers and wintering areas where appropriate. This is especially important at key stopovers like Delaware Bay, but

applies to the many Atlantic Coast stopovers that occur in both spring and fall. This would include use restrictions and outreach programs.

3. Create an oil spill response plan for key stopovers and wintering areas.
4. Maintain precise GIS maps of important use areas in each stopover and on wintering areas.
5. Ensure that all major stopover and wintering areas are recognized in protection initiatives such WHSRN, International Association of Fish and Wildlife Agency's (IAFWA) expanded flyway system, and Ramsar.
6. Avoid impacts of beach replenishment through timing restrictions, and specifications on beach fill to ensure quick recovery of beach invertebrates and horseshoe crab spawning (in the Delaware Bay).
7. Clean up and restore all beaches on the Delaware Bay that include any structures impeding crab spawning such as bulkheads, homes or rip rap. Avoid the placement of any new structures.
8. The cross-bay commuting of knots from feeding sites in Delaware to roosting sites on the Atlantic coast of New Jersey for the whole 14-day stopover is equivalent in distance to almost half the flight to the arctic breeding grounds. In energetic terms, the daily flight involves expenditure of about 83 kilojoules, which would require the ingestion of about 6,000 horseshoe crab eggs (H Sitters, unpublished information). Conservation management prescriptions should therefore include ensuring the existence of suitable roosting sites for knots at various locations throughout the bay, especially in Delaware where steps should be taken to conserve the known inland roosting site near Mispillion. Coastal impoundments should be managed to maximize their potential use as red knot roosting sites, or sites created by building isolated sandbars or islands along the shore (such as beside the jetty protecting Mispillion Harbor where suitable high water roosting islands once existed but have since eroded away).

## XIII. REFERENCES

### A. Literature Cited


Albrieu, C., S. Imberti and S. Ferrari . 2004. *Las Aves de la Patagonia Sur, El Estuario del Río Gallegos y Zonas Aledañas.* Ed. Univ. Nac. de la Patagonia Austral, Río Gallegos. 204 pp.

Allen, A. S. 1995. Tidepool value as foraging patches for breeding and migrating birds in tidal salt marshes in the lower Chesapeake Bay. Unpublished M. A. Thesis. College of William and Mary, Williamsburg, VA. 72 pp.

Alerstam, T., G. A. Gudmundsson, and K. Johannesson. 1992. Resources for long distance migration: Intertidal exploitation of Littorina and Mytilus by knots *Calidris canutus* in Iceland. Oikos 65(2): 179-189.

Antas, P.T.Z. and I.L.S. Nascimento. 1996. *Tuiuiú: sob os céus do Pantanal*. CEMAVE e Monsanto. Brasília. 169p.

Araújo, F. A. A., Wada, M. Y., da Silva, E. V., e Cavalacante, G. C., Magalhaes, V. S., Filho, G. V., Rodrigues, S. G., Martins, L. C., Fedrizzi, C. E., Scherer, A., Morh, L. V., de Almeida, M. A. B., Buna, B. S., Csota, L. R. O., Scherer, S. B., Vianna, R. S. and Gatas, V. L.. 2003. Primeiro inquérito sorológico em aves migratórias no Parque Nacional da Lagoa do Peixe para detecção do vírus da febre do Nilo Ocidental. Secretaria de Vigilância em Saúde. Ministério da Saúde. http://portal.saude.gov.br/portal/arquivos/pdf/boletim_eletronico_01_ano03.pdf

Araya B. and G. Millie. 1996. *Guía de campo de las aves de Chile. Séptima edición.* Editorial Universitaria, Santiago.

ASMFC. 2001. Addendum II to the Interstate Fishery Management Plan for Horseshoe Crab. ASMFC, Washington D.C. 5 pp.

Atkinson, P.W., Appleton, G.F., Clark, J.A., Clark, N.A., Gillings, S., Henderson, I.G., Robinson, R.A. and Stillman, R.A. 2003. Red Knots *Calidris canutus* in Delaware Bay 2002. Survival, foraging and marking strategy. Thetford, UK: BTO Research Report 308.

Atkinson, P.W., A.J. Baker, K.A. Bennett, N.A. Clark, J.A. Clark, K.B. Cole, A. Dey, A.G. Duiven, S. Gillings, P.M. Gonzalez, B.A. Harrington, K. Kalasz, C.D.T. Minton, J. Newton, L.J. Niles, R.A. Robinson, I. de L. Serrano and H.P. Sitters. 2006a. Hard or soft-shelled prey? Migration strategy determines resource use by Red Knot *Calidris canutus* on their final stopover in Delaware Bay.

Atkinson, P.W., A.J. Baker, K.A. Bennett, N.A. Clark, J.A. Clark, K.B. Cole, A. Dey, S. Gillings, P.M. Gonzalez, K. Kalasz, C.D.T. Minton, L.J. Niles, R.A. Robinson and H.P. Sitters. 2006b. Mass gain in Red Knot on their final spring staging site is both time- and condition dependent. Submitted to J. App. Ecol.

Atkinson, P. W., A. J. Baker, R. M. Bevan, N. A. Clark, K. B. Cole, P. M. González, J. Newton, L. J. Niles, and R. A. Robinson. 2005. Unravelling the migratory strategies of a long-distance migrant using stable isotopes: Red knot *Calidris canutus* movements in the Americas. Ibis 147: 738-749.

Aubry, Y. and Cotter, R. 2001. Using trend information to develop the Quebec Shorebird Conservation Plan. Bird Trends 8: 21-24.

Avise, J. C. 1989. A role for molecular genetics in the recognition and conservation of endangered species. Trends in Ecology and Evolution 4: 279-281.

Baker, A.J., P. M. González, L. Benegas, S. Rice, V. L. D'Amico, M. Abril, A. Farmer, and M. Peck. 2005b. Annual international shorebird expeditions to Río Grande in Tierra del Fuego 2000-2004. Wader Study Group Bulletin 107: 19- 23.

Baker, A. J., P. M. González, C. D. T. Minton, D. B. Carter, L. Niles, I. L. S. do Nascimento, and T. Piersma. 1999c. Hemispheric problems in the conservation of red knots (*Calidris canutus rufa*). *In* Proceedings of the Neotropical Ornithological Congress International Shorebird Symposium, 9 October 1999, Monterrey, Mexico. pp. 21-28.

Baker, A. J., P. M. González, T. Piersma, C. D. T. Minton, J. R. Wilson, H. Sitters, D. Graham, R. Jessop, P. Collins, P. De Goeij, M. Peck, R. Lini, L. Bala, G. Pagnoni, A. Vila, E. Bremer, R. Bastida, E. Ieno, D. Blanco, Y de Lima S. do Nascimiento, S. S. Scherer, M. P. Schneider, A. Silva and A. A. F. Rodrigues. 1999b. Northbound migration of red knots *Calidris canutus rufa* in Argentina and Brazil: report on results obtained by an international expedition in March- April 1997. Wader Study Group Bulletin 88: 64-75.

Baker, A. J., P. M. González, T. Piersma, L. J. Niles, I. L. S. do Nascimento, P. W. Atkinson, N. A. Clark, C. D. T. Minton, M. K. Peck, and G. Aarts. 2004. Rapid population decline in red knot: fitness consequences of decreased refueling rates and late arrival in Delaware Bay. Proceedings of the Royal Society B 25:125-129.

Baker, A. J., P. M. González, I. L. Serrano, W. R. T. Júnior, M. Efe, S. Rice, V. L. D'Amico, M. Rocha, and M. A. Echave. 2005a. Assessment of the wintering area of red knots in Maranhão, northern Brazil, in February 2005. Wader Study Group Bulletin 107: 10-18.

Baker, A. J., T. Piersma, and L. Rosenmeier. 1994. Unraveling the intraspecific phylogeography of knots (*Calidris canutus*) - A progress report on the search for genetic markers. Journal fur Ornithologie 135**:** 599-608.

Baker, A. J., T. Piersma, and A. Greenslade. 1999a. Molecular versus phenotypic sexing in red knots. Condor 101:887-893.

Bala, L. O., V. L. D´Amico, and P. Stoyanoff. 2002. Migrating shorebirds at Península Valdés, Argentina: Report for the year 2000. Wader Study Group Bulletin 98: 6-9.

Bala, L. O., M. A. Hernández, and V. L. D´Amico. 2001. Shorebirds present on Fracasso Beach (San José Gulf, Península Valdés, Argentina): report of the 1999 migrating season. Wader Study Group Bulletin 94:27-30.

Bala, L.O., M.A. Hernández and L.R. Musmeci. 2005. Phenology of northward migration of Red Knots at Peninsula Valdés, Argentina, 1994-2005. Wader Study Group Bull. 108: 23.

Belton, W. 1994. *Aves do Río Grande do Sul: Distribuição e biologia.* Editora UNISINOS, São Leopoldo, 584p.

Blanco, D. E. and M. Carbonell (eds.). 2001. The Neotropical Waterbird Census. The first 10 years: 1990-1999. Wetlands International, Buenos Aires, Argentina and Ducks Unlimited, Inc. Memphis, USA.

Blanco, D. E., G. D. Pugnali, and H. Rodríguez Goñi. 1992. La importancia de Punta Rasa, Prov. de Buenos Aires, en la migración del Chorlo rojizo *Calidris canutus*. Hornero 13: 203–206.

Blanco, D. E., P. Yorio, G. Pugnali and P. Petracci. 2001. Distribution and abundance of migratory shorebirds along the coasts of the Buenos Aires Province, Argentina: towards a model of habitat use and conservation guidelines. *In abstract*. Extra Wader Study Group Conference Wallops Marine Consortium, Virginia, USA, 11-13 May 2001. Wader Study Group Bulletin 95: 21.

Botton, M.L. and R.E. Loveland. 2000. The diminishing abundance of horseshoe crabs in Delaware Bay: potential impacts on migrant shorebirds. *In abstract*. The Society for Integrative and Comparative Biology (Lecture).

Botton, M. L., R. E. Loveland and T. R. Jacobsen. 1988. Beach erosion and geochemical factors: influence on spawning success of horseshoe crabs (*Limulus polyphemus*) in Delaware Bay. Marine Biology 99:325-332.

Botton, M.L., R. E. Loveland, and T. R. Jacobsen. 1992. Overwintering trilobite larvae of the horseshoe crab, *Limulus polyphemus*, on a sandy beach of Delaware Bay (New Jersey, USA). Marine Ecology Progress Series 88:289-292.

Botton, M. L., R. E. Loveland, and T. R. Jacobsen. 1994. Site selection by migratory shorebirds in Delaware Bay, and its relationship to beach characteristics and abundance of horseshoe crab (*Limulus polyphemus*) eggs. The Auk 111(3): 605-616.

Boyd, H. and T. Piersma. 2001. Changing balance between survival and recruitment explains population trends in Red Knots Calidris canutus islandica wintering in Britain, 1969-1995. Ardea 89: 301-317.

Brown, S., C. Hickey, B. Harrington, and R. Gill (eds.). 2001. *The U.S. Shorebird Conservation Plan, 2nd ed.* Manomet Center for Conservation Sciences, Manomet, MA.

Buehler, D. M. 2002. Shorebird counts in Panama in 2002 emphasize the need to monitor and protect the Upper Panama Bay. Wader Study Group Bulletin 99: 41-44.

Buehler, D. M and A. J. Baker. 2005. Population divergence times and historical demography in red knots and dunlins. Condor 107: 497-513.

Burger, J. 1986. The effect of human activity on shorebirds in two coastal bays in Northeastern United States. Environmental Conservation 13:123-130.

Burger, J. 2005. Foraging and aggression in shorebirds as a function of species of nearest neighbor at a migratory stopover in Delaware Bay, New Jersey. Bird Behavior.

Burger, J., S. A. Carlucci, C. W. Jeitner and L. Niles. 2005. Habitat choice, disturbance, and management of foraging shorebirds and gulls at a migratory stopover.

Burger, J., M. Gochfeld, and L. Niles. 1995. Ecotourism and birds in coastal New Jersey: contrasting responses of birds, tourists, and managers. Environmental Conservation 22: 56-65.

Burger, J., C. Jeitner, K. Clark, and L. Niles. 2004. The Effect of Human Activities on Migrant Shorebirds: Successful Adaptive Management. Environmental Conservation 31(4): 283-288.

Burger, J., L. Niles and K.E. Clark. 1997. Importance of beach, mudflat and marsh habitats to migrant shorebirds on Delaware Bay. Biological Conservation 79: 283-292.

Butler, R.W., R.C. Ydenberg and D.B. Lank. 2003 Wader migration on the changing predator landscape. Wader Study Group Bulletin 100: 130-133.

Canevari P., D. E. Blanco, E. H. Bucher, G. Castro and I. Davidson (eds.) 1998. Los Humedales de la Argentina: Clasificación, Situación Actual, Conservación y Legislación. Wetlands International Publ. 46, Buenos Aires, Argentina. 208 pp.

Castro, G. and J.P. Myers. 1993. Shorebird Predation on Eggs of Horseshoe Crabs During Spring Stopover on Delaware Bay. Auk 110(4): 927- 930

Castro, G., J. P. Myers, and A. R. Place. 1989. Assimilation efficiency of sanderlings (*Calidris alba*) feeding on horseshoe crab (*Limulus polyphemus*) eggs. Physiological Zoology 62: 716–731.

Clark, K and L. Niles. 1985. Research and survey actions initiating surveys of human use and horseshoe crab egg density. Unpublished Report to the Endangered and Nongame Species Program, New Jersey Division of Fish and Wildlife, Trenton, NJ.

Clark, K., L. Niles and J. Burger. 1993. Abundance and distribution of shorebirds migrating on Delaware Bay, 1986-1992. Condor 95: 694-705.

Clark, N.A., Atkinson, P.W., Clark, J.A., Gillings, S. and Robinson, R. 2004. Report on the migration of Red Knots *Calidris canutus rufa* and Turnstone *Arenaria interpres* passing through Delaware Bay in 2003. Thetford, UK: BTO Research Report 351.

Cramer, W. 1997. Modeling the possible impact of climate change on broad-scale vegetation structure: examples from northern Europe. In: Oechel, W.C., T. Callaghan, T. Gilmanov, J.I. Holten, B. Maxwell, U. Molau and B. Sveinbjornsson (eds). *Global change and Arctic terrestrial ecosystems*. Springer-Verlag, New York, USA, pp. 312-329.

Couve E. and C. Vidal. 2003. *Birds of Patagonia, Tierra del Fuego and Antarctic Peninsula*. Fantastico Sur. Chile. 656 pp.

CONAF. 1996. *Libro rojo de los sitios príoritarios para la conservación de la diversidad biológica de Chile*. Eds. Muñoz, Nuñez and Yañez. 203 pp.

D'Amico, V. L., M. A. Hernández, and L. O. Bala. 2003. Changes in the use of Fracasso beach, Península Valdés, Patagonia, Argentina, as a stopover site by shorebirds. *In abstract*. Wader Study Group Annual Conference Cádiz, Spain. Wader Study Group Bull. 101/102: 32.

Davidson, N. and P. Rothwell. 1993. Disturbance to waterfowl on estuaries. Wader Study Group Bulletin, (Special Issue) 68. Royal Society for the Protection of Birds (RSPB): Bedfordshire, UK. 106 pp.

Delhey, K. V. and P. F. Petracci. 2004. Aves Marinas y Costeras en: El ecosistema del estuario de Bahía Blanca. Píccolo M. C y Hoffmeyer M. S (Eds.). Instituto Argentino de Oceanografía (CONICET-UNS), Bahía Blanca, Argentina.

Dekinga, A. and T. Piersma. 1993. Reconstructing diet composition on the basis of faeces in a mollusc-eating wader, the knot *Calidris canutus*. Bird Study. 40(2): 144-156.

Devillers, P. and J. A. Terschuren. 1976. Some distributional records of migrant North American Charradriiformes in coastal South America (Continental ARgentina, Falkland, Tierra del Fuego, Chile and Ecuador). Gerfaut 66: 107-125.

Dinsmore, S. J., J. A. Collazo and J. R Walters. 1998. Seasonal Numbers and Distribution of Shorebirds on North Carolina's Outer Banks. Wilson Bulletin 110(2): 171-181.

Dunne, P., D. Sibley, C. Sutton, and W. Wander. 1982. 1982 Aerial shorebird survey of Delaware Bay. Records of NJ Birds 8(4): 68-75.

Erwin, R.M. 1996. Dependence of waterbirds and shorebirds on shallow-water habitats in the Mid-Atlantic coastal region: An ecological profile and management recommendations. Estuaries 19(2A): 213-219.

Escudero, G., M. Abril, M. G. Murga and N. Hernández. 2003. Red knots wintering in Bahía Bustamante, Argentina: are they lost? Wader Study Group Bull. 101/102: 59-61.

Ferrari, S., C. Albrieu and P. Gandini. 2002. Importance of the Río Gallegos estuary, Santa Cruz, Argentina, for migratory shorebirds. Wader Study Group Bulletin 99: 35-40.

Ferren, R. L. The Birds of Rhode Island- their seasonal distribution and ecological history. Unpublished report to Rhode Island Division of Fish and Wildlife, Heritage Program, West Kingston, RI.

Galbraith, H., R. Jones, R. park, J. Clough, S. Herrod-Julius, B. Harrington and G. Page. 2002. Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. Waterbirds 25(2): 173-183.

Gillings, S., P. W. Atkinson, A. J. Baker, K. A. Bennett, N. A. Clark, K. B. Cole, P. M.González, K. S. Kalasz, C. D. T Minton, I. Serrano do Nascimento, L. J. Niles, and R. C. Porter. Arrival of red knot at a staging site is asynchronous: Implications for monitoring mass and turnover. ***In prep.***

Gillings, S., P.W. Atkinson, S.L. Bardsley, N.A. Clark, S.E. Love, R.A. Robinson, R.A. Stillman, and R.G. Weber. 2007. Shorebird predation of horseshoe crab eggs in Delaware Bay: species contrasts and availability constraints. Journal of Animal Ecology 76: 503-514.

González, P. 1991. Importancia de las Bahía de San Antonio y zona de influencia en el Golfo San Matías para la comunidades de aves costeras. Legislatura de la Provincia de Río Negro (Mayo 1991). 102 pp.

González, P. M. in press. Las Aves Migratorias. Chapter in "Las Mesetas Patagónicas que caen al Mar". Eds. Ricardo Freddy Masera *et al.* Secretaría de Estado de Acción Social, Gobierno de Río Negro.

González, P. M., M. Carbajal, A. J. Baker, M. E. Echave, R. Pissaco, and L. Benegas. 2003. Migración austral en relación al tiempo de llegada de Calidris canutus rufa al Hemisferio Norte. P. 98 in Programa y libro de resúmenes. VII Congreso de Ornitología Neotropical, Puyehue, Chile.

González, P. M., M. Carbajal, R. I. G. Morrison, and A. J. Baker. 2004. Tendencias Poblacionales Del Playero Rojizo (*Calidris canutus rufa*). En El Sur De Sudamérica. Ornithologia Neotropical (Suppl.) 15:357-365.

González, P. M., T. Piersma and Y. Verkuil. 1996. Food, feeding, and refueling of red knots during northward migration at San Antonio Oeste, Río Negro, Argentina. Journal of Field Ornithology 67: 575-591.

Haramis, G.M., W.A. Link, P.C. Osenton, D.B. Carter, R.G. Weber, N.A. Clark, M.A. Teece, and D.S. Mizrahi. 2007. Stable isotope and pen feeding trial studies confirm the value of horseshoe crab *Limulus polyphemus* eggs to spring migrant shorebirds in Delaware Bay. Journal of Avian Biology 38(3): 367-376.

Harrington, B. A. 2001. Red Knot (*Calidris canutus*). In The Birds of North America Online (A. Poole Ed.). Ithaca: Cornell Laboratory of Ornithology; Retrieved from The Birds of North American Online database: http://bna.birds.cornell.edu/BNA/account/Red_Knot/

Harrington, B. A. 2005. Studies of disturbance to migratory shorebirds with a focus on Delaware Bay during north migration. Unpublished report to The Delaware Coastal Management Program.

Harrington, B. A. 2006. Studies of disturbance to migratory shorebirds with a focus on Delaware Bay during north migration. Unpublished report to The Delaware Coastal Management Program.

Harrington, B. A., P. T. Z. Antas, and F. Silva. 1986. Northward Shorebird Migration on the Atlantic Coast of southern Brazil. Vida Silvestre Neotropical 1(1): 45-54.

Harrington, B. and C. Flowers. 1996. *The flight of the red knot.* W.W. Norton and Company. New York. 192pp.

Harrington, B. A., J. M. Hagan, and L. E. Leddy. 1988. Site fidelity and survival differences between two groups of New World red knots *Calidris canutus*. Auk 105: 439-445.

Harrington, B. A. and L. Leddy. 1982. Sightings of knots banded and color-marked in Massachusetts in August 1980. Journal of Field Ornithology 53(1): 55-57.

Harrington, B. A. and R. I. G. Morrison. 1980. An investigation of wintering areas of red knots (*Calidris canutus*) and Hudsonian Godwits (*Limosa haemastica*) in Argentina. Report to WWF, Washington D.C. and Toronto, Canada. 54 pp.

Hata, D. 2006. Preliminary analyses of the 2005 horseshoe crab benthic trawl survey. Horseshoe Crab Research Center, Virginia Polytechnic Institute and State University, Blacksburg, VA. Report to the ASMFC Horseshoe Crab Management Board.

Hayman, P, J. Marchant and T. Prater. 1986. *Shorebirds: An Identification Guide*. Houghton Mifflin Co., Boston, MA.

Hernández, D. 2005. Conservation and Foraging Dynamics of Migratory Shorebirds. Unpublished Ph.D Dissertation. Rutgers University, New Brunswick, New Jersey. 176 pp.

Hernández, M.A., V. D'Amico, L. Bala, J. Scolaro, and L. Musmesi. 2003. Ecología trófica del Playero Rojizo (*Calidris canutus rufa*) durante las temporadas 1999 y 2000 en Playa Fracasso (Península Valdés, Patagonia). *In abstract*. VII Congreso de Ornitología Neotropical, Parque Puyehue, Chile, 5 - 11 Octubre 2003.

Hernández, M.A., V. D'Amico and L. Bala. 2004. Presas consumidas por el playero rojizo *Calidris canutus* en Bahía San Julián, Santa Cruz, Argentina. Hornero 19(1): 7-11.

Hicklin, P. W. 1987. The migration of shorebirds in the Bay of Fundy. Wilson Bulletin 99(4): 540-570.

Hobson, W. 1972. The breeding biology of the Knot. Proceedings of the Western Foundation of Vertebrate Zoology 2:1-29.

Hope, C. E. and T. M. Shortt. 1944. Southward migration of adult shorebirds on the west coast of James Bay, Ontario. Auk 61: 572-576.

IBAMA. 1999. Plano de Manejo do Parque Nacional da Lagoa do Peixe. Ministério do Meio Ambiente, Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, Fase 2.

Ieno, E., D. Alemany, D.Blanco and R.Bastida. 2004. Prey Size Selection by Red Knot Feeding on Mud Snails at Punta Rasa (Argentina) during Migration. Waterbirds 27(4): 493-498.

International Wader Study Group. 2003. Waders are declining worldwide: conclusions from the 2003 International Wader Study Group Conference, Cadiz, Spain. Wader Study Group Bulletin 101/102: 8-12.

Kochenberger, R. 1983. Survey of shorebird concentrations along the Delaware Bayshore, spring 1983. Peregrine Observer (Fall): 3-4.

Lara-Resende, S. M. and F. Leuwemberg. 1987. Ecological studies of Lagoa do Peixe. Final Report to WWF-U.S., Washington.

Lathrop, R. G. and M. Allen. 2005. Mapping the Critical Horseshoe Crab Spawning Habitats of Delaware Bay. Rutgers University Center for Remote Sensing and Spatial Analysis unpublished report.
http://www.crssa.rutgers.edu/projects/delbay/hcrab/ALS_DelBay_hcrab_report_20060718.pdf

McLean, E. F. 1993. Human impacts on beach use by wintering and migrating birds in lower Chesapeake Bay. Unpublished M. A. Thesis. College of William and Mary, Williamsburg, VA. 48 pp.

Mendes, L., Piersma, T., Lecoq, M., Spaans, B. and R. E. Ricklefs. 2005. Disease-limited distributions? Contrasts in the prevalence of avian malaria in shorebird species using marine and freshwater habitats. Oikos 109: 396-404.

Michels, S. and Smith, D. 2006. Horseshoe Crab Spawning Activity in Delaware Bay: 1999-2005. Report to the Atlantic States Marine Fisheries Commission's Horseshoe Crab Technical Committee.

Minton, C. D. T., T. Piersma, D. Blanco, A. J. Baker, L. Benegas, P. de Goeij, R. E. Manriquez, M. Peck, and M. S. Ramírez. 1996. Wader numbers and the use of high tide roost at the Hemispheric Reserve "Costa Atlántica de Tierra del Fuego," Argentina, January and February 1995. Wader Study Group Bulletin 79: 109-114.

Mizrahi, D.S. 2002. Shorebird Distribution along New Jersey's Southern Atlantic Coast: Temporal Patterns and Effects of Human Disturbance. Final report, U.S. Fish and Wildlife Service.

Morrison, R.I.G., P.T.Z. Antas, and R.K. Ross, 1987. Migration Routes in the Amazon Basin. Anais do Seminario Conservaçao e Desenvolvimento, CVRO.

Morrison, R.I.G., A.J. Baker, P.M. Gonzalez, L.J. Niles, and R.K. Ross. 2006b. COSEWIC Status Report on Red Knot *Calidris canutus.* Revised draft, November 2006. 106 pp. Ottawa: Canadian Wildlife Service.

Morrison, R.I.G., R.W. Butler, F.S. Delgado, and R.K. Ross. 1998. *Atlas of Nearctic shorebirds and other waterbirds on the coast of Panama*. Canadian Wildlife Service Special Publication. Environment Canada. 112 pp.

Morrison, R. I. G., N. C. Davidson, and T. Piersma. 2005. Transformations at high latitudes: Why do red knots *Calidris Canutus* bring body stores to the breeding grounds? Condor 107: 449-457.

Morrison, R. I. G., R. Gill, B. Harrington, S. Skagen, G. W. Page, C. L. Gratto-Trevor and S. M. Haig. 2001. Estimates of Shorebird Populations in North America. Occasional paper No. 104, Canadian Wildlife Service, Ottawa, Ontario. 64 pp.

Morrison, R. I. G. and B. A. Harrington. 1992. The migration system of the red knot *Calidris canutus rufa* in the New World. Wader Study Group Bulletin 64(Supplement): 71-84.

Morrison, R.I.G, B.J. McCaffery, R.E. Gill, S.K. Skagen, S.L. Jones, G.W. Page, C.L. Gratto-Trevor, and B.A. Andres. 2006a. Population estimates of North American shorebirds. Wader Study Group Bull. 111: 67-85.

Morrison, R. I. G. and R. K. Ross. 1989. Atlas of Nearctic shorebirds on the coast of South America. 2 vols. Special Publication, Canadian Wildlife Service, Ottawa, Ontario. 325 pp.

Morrison, R. I. G., R. K. Ross, and L. J. Niles. 2004. Declines in wintering populations of red knots in southern South America. Condor 106: 60-70.

Morrison, R. I. G., R. K. Ross, and M. S. Torres. 1992. Aerial surveys of Nearctic shorebirds wintering in Mexico: Some preliminary results. Canadian Wildlife Service, Ottawa, Ontario. 11 pp.

Musmeci, L. R. 2005. Evaluación de Playa Colombo (Golfo Nuevo, Chubut) como sitio de parada utilizado por aves playeras. Tesis de Licenciatura. Facultad de Ciencias Naturales, Universidad Nacional de la Patagonia. 78 pp.

Myers, J. P. and L. P. Myers. 1979. Shorebirds of coastal Buenos Aires Province, Argentina. Ibis 121: 186-200.

Myers, J. P. 1986. Sex and gluttony on Delaware Bay. Natural History 95(5): 68-77.

Najjar, R. G., H. A. Walker, P. J. Anderson, E. J. Barro, R. J. Bord, J. R. Gibson, V. S. Kennedy, C. G. Knight, J. P. Megonigal, R. E. O'Connor, C. D. Polsky, N. P. Psuty, B. A. Richards, L. G. Sorenson, E. M. Steele, and R. S. Swanson. 2000. The potential impacts of climate change on the mid-Atlantic coastal region. Climate Research 14: 219-233.

Nascimento, I. L. S., 1995. As aves do Parque Nacional da Lagoa do Peixe. IBAMA, Brasília, 41p.

Nascimento, I. L. S. 2001. Migrations and other biological data of *Calidris canutus rufa* from Brazil. Wader Study Group Bulletin 95: 11 (Abstract).

Nascimento, J. L. X. 1998. Muda de Charadriidae e Scolopacidae (Charadriiformes) no norte do Brasil. Ararajuba 6(2): 141-144.

Niles, L.J., A.D. Dey, N.J. Douglass, J.A. Clark, N.A. Clark, A.S. Gates, B.A. Harrington, M.K. Peck, and H.P. Sitters. 2006. Red Knots wintering in Florida: 2005/6 Expedition. Wader Study Group Bull. 111: 86-99.

Oberholser, H.C. 1974. *Bird life of Texas*. 2 vols. Univ. Texas Press, Austin.

Page, G. W., E. Palacios, L. Alfaro, S. González, L. E. Stenzel, and M. Jungers. 1997. Numbers of wintering shorebirds in coastal wetlands of Baja California, Mexico. Journal of Field Ornithology 68: 572-574.

Page, G.W., L. E. Stenzel, and J. E. Kjelmyr. 1999. Overview of shorebird abundance and distribution in wetlands of the Pacific coast of the contiguous United States. Condor 101: 461-471.

Paulson, D. 1993. *Shorebirds of the Pacific Northwest*. University of Washington Press. Seattle, WA. 406 pp.

Pérez, F., P. Sutton and A. Vila. 1995. Aves y mamíferos marinos de Santa Cruz. Recopilación e integración de relevamientos realizados entre 1986 y 1992. Bol. Técnico No. 26. Fundación Vida Silvestre Argentina. Buenos Aires.

Phillips, J. D. 1986a. Coastal submergence and marsh fringe erosion. Journal of Coastal Research 2(4): 427-436.

Phillips, J. D. 1986b. Spatial analysis of shoreline erosion, Delaware Bay, New Jersey. Annals of the Association of American Geographers 76(1): 50-62.

Phillips, J. D. 1987. Shoreline processes and establishment of *Phragmites australis* in a coastal plain estuary. Vegetatio 71:139-144.

Philips, R. L. 1990. What's bugging your birds ? Avian parasitic arthropods. Wild Rehabilitation 8: 155-203.

Piersma, T. 1994. Close to the edge: Energetic bottlenecks and the evolution of migratory pathways in knots. Ph.D. Dissertation. University of Groningen. Groningen.

Piersma, T. and A. J. Baker. 2000. Life history characteristics and the conservation of migratory shorebirds. p. 105-124. *In* Gosling, L. M. and W. J. Sutherland [eds.], *Behaviour and Conservation*. Cambridge University Press. Cambridge.

Piersma, T. and N. C. Davidson. 1992. The migrations and annual cycles of five subspecies of knots in perspective. Wader Study Group Bulletin 64(Supplement): 187-197.

Piersma, T. and R. E. Gill Jr. 1998. Guts don't fly: Small digestive organs in obese bar-tailed godwits. Auk 115: 196-203.

Piersma, T., G. A. Gudmundsson, and K. Lilliendahl. 1999. Rapid changes in the size of different functional organ and muscle groups during refueling in a long-distance migrating shorebird. Physiological and Biochemical Zoology 72: 405-415.

Piersma, T., R. Hoekstra, A. Dekinga, A. Koolhaas, P. Wolf, P. Battley, P. Wiersma. 1993. Scale and intensity of intertidal habitat use by knots *Calidris canutus* in the western Wadden Sea in relation to food, friends and foes. Netherlands Journal of Sea Research 31(4): 331-357.

Piersma, T., D.I. Rogers, P.M. González, L. Zwarts, L.J. Niles, I. de Lima do Nascimento, C.D.T. Minton, and A.J. Baker. 2005. Fuel storage rates before northward flights in red knots worldwide: facing the severest constraint in tropical intertidal environments? In Greenberg, R. and Marra, P.P. (eds) *Birds of Two Worlds*: 262–273. Washington DC: Smithsonian Institution Press.

Rehfisch, M.M. and H.Q.P. Crick. 2003. Predicting the impact of climatic change on Artic-breeding waders. Wader Study Group Bulletin 100: 86-95.

Reise, K. 1985. *Tidal flats ecology*. Springer-Verlag, New York.

Robinson, R.A., P.W. Atkinson, and N.A. Clark. 2003. Arrival and weight gain of Red Knot *Calidris canutus*, Ruddy Turnstone *Arenaria interpres* and Sanderling *Calidris alba* staging in Delaware Bay in spring. Thetford, UK: BTO Research Report 307.

Rogers, D. I. 2003. High-tide roost choice by coastal waders. Wader Study Group Bulletin 100: 73–79.

Roselaar, C. S. 1983. Subspecies recognition in knot *Calidris canutus* and occurrence of races in Western Europe. Beaufortia 33: 97-109.

Rottenborn, S. C. 1992. Cover utilization and flocking behavior of shorebirds foraging in agricultural fields in Northampton County, Virginia. Undergraduate Honors Thesis. College of William and Mary, Williamsburg, VA. 94 pp

Sandercock, B.K. 2003. Estimation of survival rates for wader populations: a review of mark-recapture methods. Wader Study Group Bull. 100: 163-174.

Shopland, J. M. 1975. Foraging strategies of a shorebird community in a manmade habitat. Undergraduate Honors Thesis. College of William and Mary, Williamsburg, VA. 60 pp.

Shuster, C.N. Jr. and M.L. Botton. 1985. A contribution to the population biology of horseshoe crabs, *Limulus polyphemus* (L.), in Delaware Bay. Estuaries 8(4): 363-372**.**

Shuster, C.N. Jr, R.B Barlow and H. J. Brockmann. 2003. *The American Horseshoe Crab*. Harvard University Press, Cambridge, MA.

Sibley, D. A. 2000. *The Sibley Guide to Birds*. Alfred A Knopf, Inc., New York, NY.

Sitters, H. P. 2001. Notes on sites where red knots fed at low water and roosted at high water in the Atlantic coast wetlands, near Stone Harbor, New Jersey, during May. Unpublished Report to the Endangered and Nongame Species Program, New Jersey Division of Fish and Wildlife, Trenton, NJ.

Sitters, H. P. 2004. Time budgets in stopover red knots at Mispillion, Delaware, in May 2003. Unpublished Report to the Endangered and Nongame Species Program, New Jersey Division of Fish and Wildlife, Trenton, NJ.

Sitters, H. P. 2005. Preliminary report on observations during May 2005 of red knots in the Atlantic marshes near Stone Harbor New Jersey and radio-tracking red knots in Delaware Bay. Unpublished report to the Endangered and Nongame Species Program, New Jersey Division of Fish and Wildlife, Trenton, NJ.

Sitters, H.P., P. M. González, T. Piersma, A. J. Baker and D. J. Price. 2001. Day and night feeding habitat of red knot in Patagonia: profitability versus safety? Journal of Field Ornithology 72: 86-95.

Skagen, S. K., Sharpe, P. B., Waltermire, R. G. and Dillon, M. B. 1999. Biogeographical profiles of shorebird migration in mid-continental North America. Biological Science Report USGS/BRD/BSR-2000-0003. U.S. Government Printing Office, Denver, CO.

Smith, D. R., P. S. Pooler, B. J. Swan, S. F. Michels, W. R. Hall, P. J. Himchak, and M. J. Millard. 2002a. Spatial and temporal distribution of horseshoe crab spawning in Delaware Bay: Implications for monitoring. Estuaries 25(1): 115-125.

Smith, D. R., P. S. Pooler, R. E. Loveland, M. L. Botton, S. F. Michels, R. G. Weber, and D. B. Carter. 2002b. Horseshoe crab (*Limulus polyphemus*) reproductive activity on Delaware Bay beaches: implications for monitoring. Journal of Coastal Research 18(4): 730-750.

Smith, D., N. Jackson, S. Love, K. Nordstrom, R. Weber, and D. Carter. 2002c. Beach nourishment on Delaware Bay beaches to restore habitat for horseshoe crab spawning and shorebird foraging. Report to The Nature Conservancy – Delaware Bayshores Office. 51pp.

Spaans, A. L. 1978. Status and numerical fluctuations of some North American waders along the Surinam coast. Wilson Bulletin 90: 60-83.

Sprandel, G.L., J.A. Gore, and D.T. Cobb. 1997. Winter shorebird survey. Final performance report, Florida Game and Fresh Water Fish Commission. Tallahassee, FL.

Summers, R.W. and L.G. Underhill. 1987. Factors related to breeding production of Brent Geese *Branta b. bernicula* and waders (Charadrii) on the Taimyr Peninsula. Bird Study 34: 161-171.

Sutton C. and J. Dowdell. 2002. Survey of Gull Populations Along New Jersey's Delaware Bay Beaches Spring, 2002 With Comparisons to identical surveys conducted in Spring 1990-1992. Report to the Endangered and Nongame Species Program, New Jersey Division of Fish and Wildlife, Trenton, NJ.

Thomas, G. H., T. Székely and W. J. Sutherland. 2003. Publication bias in waders. Wader Study Group Bulletin 100: 216-223.

Tomkovich, P. S. 1992. An analysis of the geographic variability in knots *Calidris canutus* based on museum skins. Wader Study Group Bulletin 64(Supplement): 17-23.

Tomkovich, P. S. 2001. A new subspecies of red knot *Calidris canutus* from the New Siberian Islands. Bulletin of the British Ornithologists' Club 121: 257-263.

Truitt, B.R. and B. Brown. 2000. Stopover Biology of Red Knots - Virginia Barrier Islands. Report to the U.S. Fish and Wildlife Service, 5 Pp.

Tsipoura, N. and J. Burger. 1999. Shorebird diet during spring migration stopover on Delaware Bay. The Condor 101: 633-644.

Underhill, L.G., R.P. Prys-Jones, E.E. Jr. Syroechkovski, N.M. Groen, V. Karpov, H.G. Lappo, M.W.J. Van Roomen, A. Rybkin, H. Schekkerman. 1993. Breeding of waders (Charadrii) and brent geese *Branta bernicla bernicla* at Pronchishcheva Lake, northeastern Taimyr, Russia, in a peak and a decreasing lemming year. Ibis 135: 277-292.

van de Kam, J., B. Ens, T. Piersma and L. Zwarts. 2004. *Shorebirds: An illustrated behavioural ecology*. KNNV Publishers, Utrecht, The Netherlands.

Varza, D. 2004. Wildlife Conservation Restoration Program Shorebird Use Assessment, Unpublished Report. Connecticut Department of Environemntal Protection, Wildlife Division.

Vila, A. R., E. R. Bremer and M. S. Beade 1994. Censos de chorlos y playeros migratorios en la Bahía de Samborombón, Provincia de Buenos Aires, Argentina. Bol. Técnico No. 22. Fundación Vida Silvestre Argentina. Buenos Aires.

Vooren, C.M. and A, Chiaradia. 1990. Seasonal abundance and behaviour of coastal birds of Csasino Beach, Brazil. Ornithologia Neotropical 1:9-24.

Wander, W. and P. Dunne. 1981. Species and numbers of shorebirds on the Delaware Bayshore of New Jersey – Spring 1981. Occas. Paper No. 140. Records of NJ Birds 7(4): 59-64.

Wash Wader Ringing Group 2004. *Wash Wader Ringing Group 2002-2003 Report.* Wash Wader Ringing Group, Thetford, UK.

Watts, B. D. 1992. The influence of marsh size on marsh value for bird communities of the lower Chesapeake Bay. Center for Conservation Biology Technical Report series CCBTR- 92 01. Center for Conservation Biology, College of William and Mary. 115 pp.

Watts, B. 1998. An investigation of waterbirds within the Panama Canal Zone and the upper Bay of Panama. Center for conservation Biology, College of William and Mary. 68 pp.

Weber R. G. 2003. Horseshoe Crab Egg densities Observed on Six Delaware Beaches, Final Report. Unpublished report to Delaware Coastal Management Program,

Weber R. G. 2004. Horseshoe Crab Egg densities Observed on Six Delaware Beaches, Final Report. Unpublished report to Delaware Coastal Management Program,

Weber, T.P. and A. I. Houston. 1997. Flight costs, flight range and the stopover ecology of migrating birds. Journal of Animal Ecology 66: 297-306.

Wetlands International. 2006. *Waterbird Population Estimates – Fourth Edition.* Wetlands International Global Series, Wageningen, The Netherlands.

Whitlock, M. C. 2000. Fixation of new alleles and the extinction of small populations: drift load, beneficial alleles, and sexual selection. Evolution 54: 1855-1861.

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Albrieu, C. 2005. Universidad de la Patagonia Austral, Río Gallegos, Santa Cruz, Argentina.

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Burkett, W. 2005. Houston Audubon Society. Houston, TX.

Cameron, S. 2005. North Carolina Wildlife Resources Commission, Nongame and Endangered Wildlife Program. Stella, NC.

Chillón, J. P. 2005. Planetario de la Ciudad de Buenos Aires, Argentina.

Cubie, D. 2005, Cape Romain NWR, Awendaw, SC.

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Maddock, S. 2005. Audubon North Carolina. Chapel Hill, NC.

Michels. S. 2005. Delaware Division of Fish and Wildlife. Dover, DE.

Michels. S. 2006. Delaware Division of Fish and Wildlife. Dover, DE.

Mizrahi, D. 2005. New Jersey Audubon Society. Goshen, NJ.

Nugent, P. 2005. Cape Romain NWR, Awendaw, SC.

Olveira, L. 2005. Centro de Observación de la Naturaleza (CONAT). Buenos Aires, Argentina.

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Ross, R. K. 2007. Canadian Fish and Wildlife Service, National Wildlife Research Center.

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