Update to the Status of the Red Knot *Calidris canutus* in the Western Hemisphere, April 2010

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The purpose of this report is to provide a second update of *Status of the Red Knot,* Calidris canutus rufa*, in the Western Hemisphere* (Niles *et al.* 2007; "the Status Review") for the benefit of those organizations and individuals concerned with the conservation of Red Knots in the United States. We provided a first update in February 2008, which together with the Status Review itself has since been published in Niles *et al.* (2008). Further updates will be produced as new information becomes available. This update reflects the state of knowledge as of 1 April 2010. It is assumed that readers of this report are familiar with the contents of the Status Review and the first update. This material has not been peer-reviewed. We offer it in the interest of timely information exchange among researchers, managers and others interested in Red Knot conservation.

A complementary source of new information on American Red Knot populations is the report of a symposium held during the Third Western Hemisphere Shorebird Meeting at Mazatlan, Mexico, in March 2009 which has been published in the August 2009 issue of the *Wader Study Group Bulletin*. Moreover, eleven relevant papers, one report and two dissertations have been published during 2008-2009, details of which are presented in the appendix.

STATUS OF *RUFA*

Winter counts

Counts show that the Tierra del Fuego wintering population was stable at just over 17,000 during the three northern winters 2004/5, 2005/6 and 2006/7, but dropped to 14,800 in 2007/8. The 2008/9 count showed a return to the previous level (Table 1). At least part of the reason for the rebound must be the presence of larger-than-usual numbers of juveniles following a successful 2008 breeding season. Juveniles were particularly evident among knots stopping over at Orense, Buenos Aires province, Argentina, in October 2008 (Ricardo E. Doumecq Milieu) and occurred in greater numbers than usual in catches at Rio Grande and Bahia Lomas in December 2008. Moreover, a flock of 500 knots, assumed to be juveniles, were seen at Bahia Lomas in May 2009 (C. Espoz, R. Matus). However, it is not clear whether good productivity in 2008 is the sole reason for the increased wintering population in Tierra del Fuego in 2009/9. If there was high productivity in 2008, it should have led to an even higher count in Tierra del Fuego in 2009/10 because of evidence that many juveniles do not go there until their second northern winter (e.g. Baker *et al.* 2005). Therefore, unless there was low survival of adults or immatures between the northern winters of 2008/9 and 2009/10, there should have been an increase in numbers in Tierra del Fuego. However, there was a decline from 17,800 to 16,260, suggesting that one or both age-classes had suffered higher mortality than usual.

Table 1. Counts of Red Knots during the northern winters of 2004/5 to 2007/8 in Tierra del Fuego (Argentina and Chile) by R.I.G. Morrison & R.K. Ross, and on the west coast of Florida by L. Niles, A.D. Dey & R.I.G. Morrison (NC = no count).

	2004/5	2005/6	2006/7	2007/8	2008/9	2009/10
Tierra del Fuego	17,653	17,211	17,316	14,800	17,800	16,260
Florida west coast	NC	2,500	1,200	550	1,532	1,378

Winter counts along a 300-km stretch of the west coast of Florida showed a decline from 2005/6 to 2007/8 but then apparently some recovery in 2008/9 and 2009/10 (Table 1). The difficulties of counting birds on this coast, and the possibility that some birds may move to the north or south of the survey area, means that there is some uncertainty as to the trend of this population. Nevertheless, it is clear that it is much less than the 10,000 estimated in the 1980s (Morrison & Harrington 1992).

There has been no count of the population that winters in Maranhão, Brazil, since 2006/7, when it was estimated at about 3,000. However, Carmem Fedrizzi and Caio Carlos in a poster at the Western Hemisphere Shorebird Meeting in Mexico in March 2009 reported 513 on the coast of Ceara (the Brazilian state to the east of Maranhão) in December 2008. This remains the least-known wintering population (apart from those that are not known at all).

Delaware Bay counts

In 2009, the peak spring migration count of Red Knots in Delaware Bay showed a significant recovery after six years of low numbers during 2003-2008 (Fig. 1). However, there is some debate and doubt as to the precise figure that should be reported for 2009.

From 1986 to 2008, shorebirds in Delaware Bay in May and early June were monitored by a weekly aerial count organized by K.E. Clark who retired from this onerous task in 2008. This afforded an appropriate opportunity to reconsider the methodology. Previously, the aerial survey had covered the shoreline of Delaware Bay (following the route shown in Fig. 33 of Niles *et al.* (2008)), but because the aircraft had flown out and back along the length of the Mispillion Harbor entrance channel, the inner harbor, a high-use area for knots and other shorebirds, was poorly covered. Also, it has recently been realized that in some years varying numbers of knots (from very few up to about 4,000) habitually feed on mussel spat in the Atlantic marshes near Stone Harbor, an area that was not covered by the aerial survey, but these birds may also feed in Delaware Bay. The new survey methods devised for 2009 ensured better coverage of both areas (i.e. by including a ground count of Mispillion Harbor and by the flight including the Atlantic marshes at Stone Harbor), but there was a possibility that a perceived increase would merely reflect more complete survey coverage. It should be noted that small numbers of knots, usually tens to a few hundred, have sometimes been recorded in May further north along the New Jersey coast (e.g. at Brigantine). These have never been monitored by regular surveys and there are no current plans to include them in future.

The new survey methods got off to a good start in 2009, but unfortunately the weather complicated matters. Conditions were too poor for an aerial survey between 21 May, when the Red Knot count was 16,229, and 29 May when it was only 3,380. Ground counts show that peak numbers occurred between these dates. The highest count of 27,187 was made on 26 May; of these by far the majority was in Mispillion Harbor, Delaware, with only a few hundred elsewhere in Delaware and 900 in New Jersey. However, there are two problems in making comparisons between this figure and peak counts in previous years. First, previous peak counts did not adequately cover Mispillion Harbor, but in 2009 nearly all the knots were there. Therefore, an aerial count conducted under the old methodology may have missed many of the birds at this site in 2009. Second, in view of the high numbers, there is almost certainly an element of counting error because birds cannot be counted individually. No effort has been made to calibrate the accuracy of ground counts by the personnel involved, but we consider that at least ±10% would be accepted as the likely error by most experienced shorebird counters (i.e. the ground count might have been anywhere in the range 24,000-30,000). Taking these factors into consideration, it is our judgment that the right figure for 2009 to put alongside the pervious aerial survey peak counts is about 24,000. Therefore, it would seem that there was an increase in the peak number of Red Knots stopping in Delaware Bay in 2009. Hopefully, better conditions for counting in 2010 will show how accurate our estimate is likely to have been.

The fact that the peak count increased in 2009 should not by itself be regarded as evidence of an increase in the stopover population. Counts invariably underestimate total throughput because of turnover (Gillings *et al.* 2009). Moreover, the relation between the peak count and the total throughput is likely to vary from year to year: in some years the peak count might be made at a time when almost all have arrived and few have departed, while in other years many may have departed before latecomers arrive. Therefore, although the aerial counts have been invaluable in showing the long term trend, a single year’s count should be treated with caution. However, as highlighted by Gillings *et al.* (2009), their estimate of a total throughput stopover population of 18,000 in 2004 compares with a peak count of 50,360 in 1998; thus confirming the magnitude of the population decline.

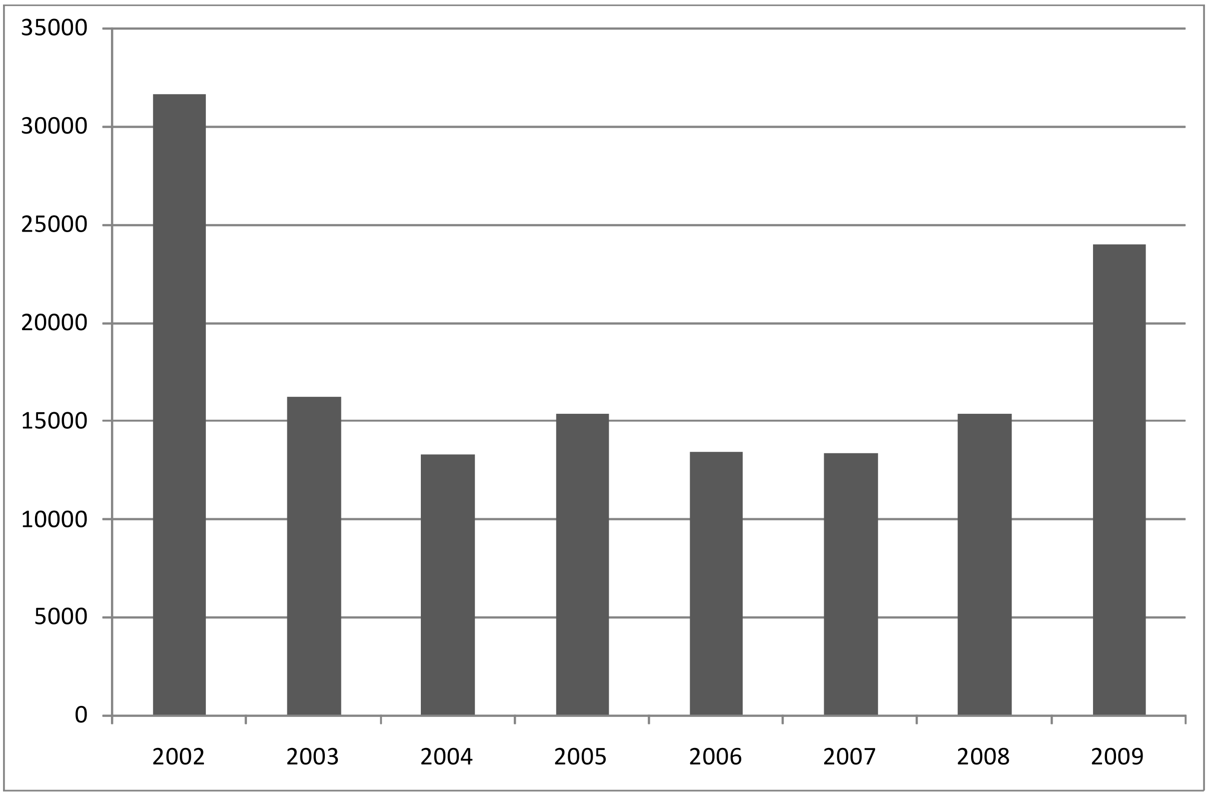

Fig. 1. Peak count of Red Knots in Delaware Bay during spring stopover 2002-2009.

Delaware Bay stopover 2008 and 2009

The 2008 and 2009 horseshoe crab spawning seasons could hardly have been more different. In 2008, a strong north-easterly storm on 12 May altered spawning habitat and led to lower water temperatures. Together these factors resulted in reduced spawning activity throughout May (Michels *et al.* 2009) and low egg densities (Table 2). As a consequence, the percentage of Red Knots achieving a mass of 180 g by 26-28 May, the assumed target mass and date of the stopover (Niles *et al.* 2009), was only 14% (Fig. 2).

In 2009, there was no severe weather event, the water was warm and, during the second half of May, it appeared from visual inspection that there had been a major increase in the density of both spawning crabs and surface eggs compared with the previous year. The proportion of Red Knots that achieved 180 g by 26-28 May increased to 34% (Fig. 2). However, this may underestimate the true proportion, as many knots – which had presumably already achieved departure mass – were seen to depart during this period. Nevertheless the year-on-year trend in the proportion of knots achieving 180g by 26-28 May is now quadratic, though much of the strength of this relationship can be attributed to the exceptionally low proportion of birds over 180g in 2003 (Fig. 2).

Although 2009 egg densities showed some recovery from the 2008 low (Table 2), there is no evidence of a significant increase in the mature horseshoe crab population either from the Delaware Trawl Survey (Table 2) or from the Virginia Tech Offshore Horseshore Crab Trawl

Survey (Fig. 3). Therefore it seems likely that the improved feeding conditions for Red Knots in 2009 arose largely because of a closer match between the timing of crab spawning and the birds' stopover.

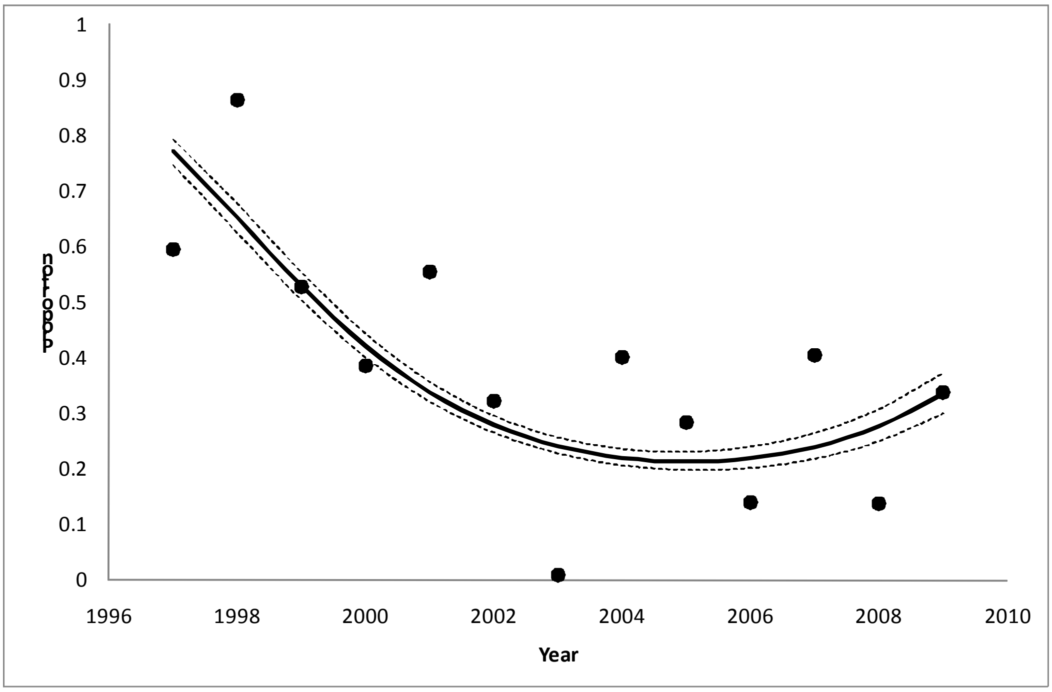

Fig. 2. Proportion of Red Knots in the >180 g body-mass category in Delaware Bay near the usual departure time each year (26-28 May) over 1997–2009. The line shows a significant quadratic trend over 1997-2009 (the trend line (±95% confidence intervals in respect of the line, not the variation in the data) was fitted using binary logistic regression of body mass >180g (1 = yes, 0 = no) on year (negative, $p<0.001$) and year^2 (positive, $p<0.001$)). The strength of the quadratic trend owes much to the very low proportion recorded in 2003, but it is still significant if the 2003 data are omitted.

Table 2. Population parameters of horseshoe crabs in Delaware Bay for 2004-2009.

	2004	2005	2006	2007	2008	2009[4]	Trend	Source
Spawning females (index)	0.77	0.82	0.99	0.89	0.68		None [3]	Michels *et al.* 2009
Spawning males (index)	2.93	3.23	3.99	4.22	2.30		None [3]	Michels *et al.* 2009
Egg density New Jersey (index) [1]	61	100	50	27	23	96	None	NJDFW per D. Hernandez
Egg density Delaware (index) [1]	No survey	100	73	123	52	85	None	DEDFW per K. Kalasz
Egg density Delaware exc Mispillion (index) [1]	No survey	100	49	62	35	30	Decline	DEDFW per K. Kalasz
Delaware Trawl Survey (geo-mean) [2]	0.06	0.20	1.37	1.72	0.77	1.06	None [3]	S.F. Michels pers. comm.

[1] In top 5 cm of sand, 2005 = 100
[2] Data relate to trawls during April-July
[3] Trend relates to 1999-2009
[4] No data from the horseshoe crab spawning survey or the Delaware Trawl Survey were available when this version of the report was prepared in March 2010; such data will be added later.

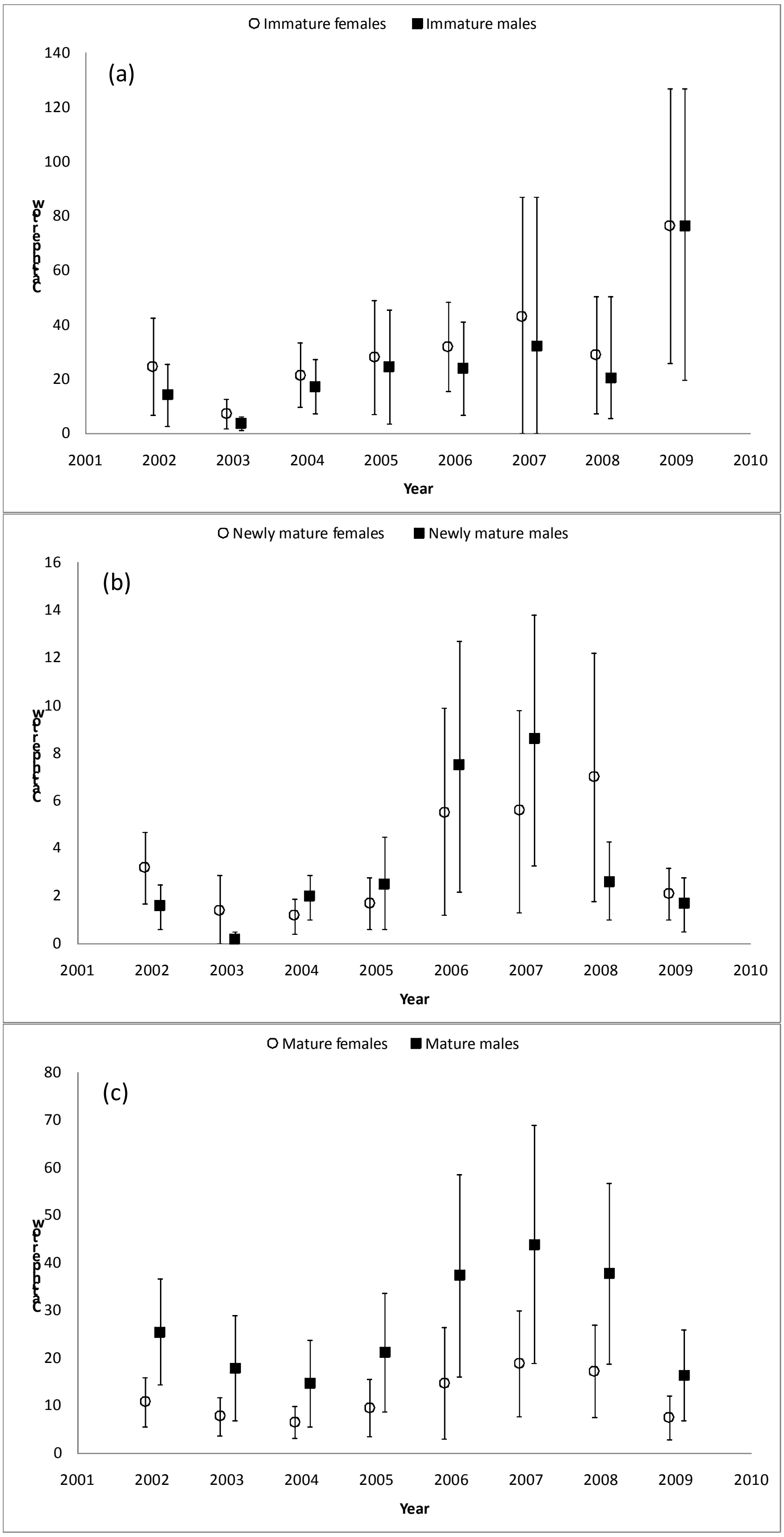

Fig. 3. Plots of stratified (delta distribution) mean catches per tow of horseshoe crabs in the Virginia Tech Delaware Bay Offshore Trawl Survey (Hata & Hallerman 2010) by sex and demographic group: (a) immatures, (b) newly mature adults and (c) mature adults by demographic group (± 95% confidence limits). The survey area is within 12 nautical miles of the coast and from 37°40’N to 39°20’N, but excludes Delaware Bay itself. Note different y-axis scales.

The egg density index shows a significant recovery in 2009 after the all-time low figures of 2008, although in neither New Jersey or Delaware did it exceed that of 2005 (Table 2). It is evident that the Delaware index is heavily influenced by the high densities recorded in Mispillion Harbor. If that key site is excluded, the Delaware index shows a significant year-on-year decline over 2005-2009 ($p<0.05$, $r = -0.90$, Table 2).

After reaching a peak in 1998, management actions by the Atlantic States Marine Fisheries Commission and various states have led to a reduction in the annual harvest of horseshoe crabs to a mean of 634 metric tons over 2004-2008 (Fig. 4). However, although a 15-year harvest low of 442 metric tons occurred in 2004, it has since been higher. Moreover, this harvest has happened despite the fact that a full moratorium has been in force in New Jersey since 2007.

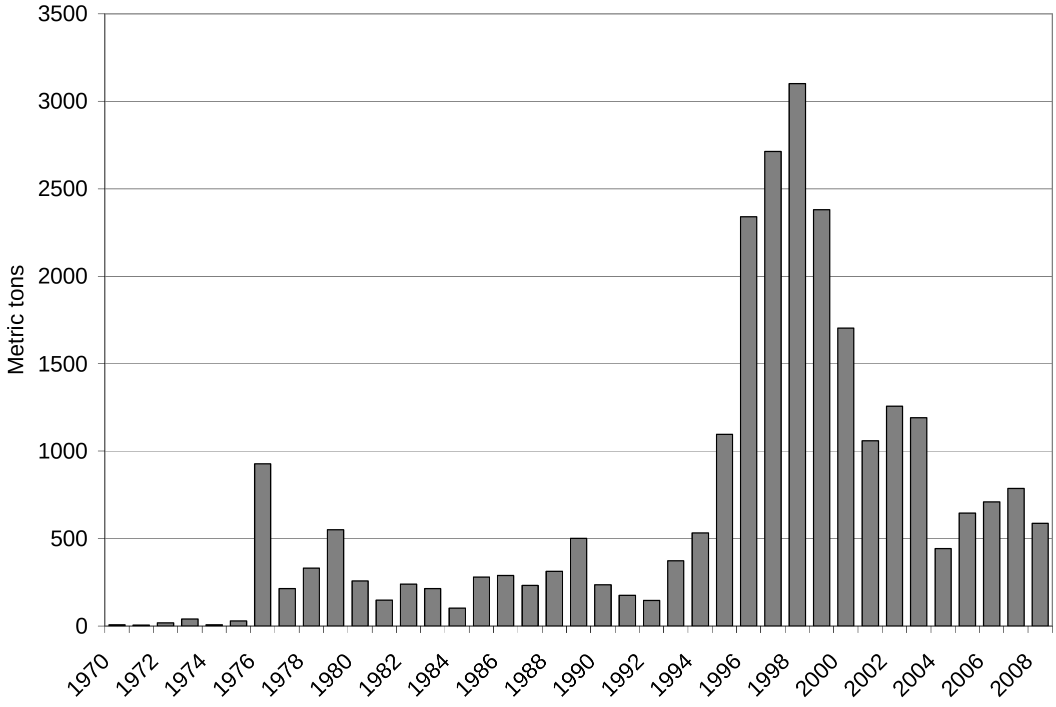

Fig. 4. Reported Atlantic coast horseshoe crab landings 1970-2008; note that reporting was not compulsory until 1998 so earlier figures may underestimate the true harvest (NMFS Commercial Fishery Landings Database 2009).

Despite management to reduce the horseshoe crab harvest, there is still no clear evidence that this has led to a recovery of the population. The Delaware Trawl Survey shows no significant trend over 2004-2009 (Table 2). Moreover, the Virginia Tech Offshore Trawl Survey shows no significant trend in any demographic group over 2002-2009 (Fig. 3; Hata & Hallerman 2010). The latter survey shows some patterns that are consistent between the sexes (Fig. 3), though these should be treated with caution because the confidence limits are large. Mature and newly mature crabs, especially females, are the most important demographic groups in terms of producing eggs for the birds; the relative abundance of both seems to have peaked during 2006-2008 but shown a decline in 2009 (Fig. 3). However, immatures showed a three-fold increase is the mean catch per tow in 2009 (Fig. 3). This might be the first evidence of recovery resulting from the major decrease in the harvest in 2004 (Fig. 4). However the change between 2008 and 2009 is not statistically significant. Moreover, it is not a change that is reflected in the whole of the area surveyed (there was about a 4-fold increase in the peripheral part of the survey area, but little change in the core part).

US east coast count of Red Knots in May

Since 2006, A.D. Dey has coordinated a count of Red Knots along the whole US east coast from Florida to Delaware Bay during two days in the period 20-24 May when it is thought that peak numbers normally occur along the coast as a whole (though not necessarily in any one locality). Coverage has been patchy, but was fairly comprehensive in 2008 apart from incomplete counts along the Delaware shore of Delaware Bay and Florida. In 2009 there was no coverage of Georgia because of logistic difficulties and weather (Table 3).

Table 3. Counts of Red Knots along the US east coast from Florida to Delaware Bay carried out over two consecutive days during 20-24 May in each year from 2006 to 2009.

<table>
<tr><th></th><th>2006</th><th>2007</th><th>2008</th><th>2009</th></tr>
<tr><td>New Jersey</td><td>7,860</td><td>4,445</td><td>10,045</td><td rowspan="2">16,229</td></tr>
<tr><td>Delaware</td><td>820</td><td>2,950</td><td>5,350</td></tr>
<tr><td>Maryland</td><td></td><td></td><td>663</td><td>78</td></tr>
<tr><td>Virginia</td><td>5,783</td><td>5,939</td><td>7,802</td><td>3,261</td></tr>
<tr><td>North Carolina</td><td>235</td><td>304</td><td>1,137</td><td>1,466</td></tr>
<tr><td>South Carolina</td><td></td><td>125</td><td>180</td><td>10</td></tr>
<tr><td>Georgia</td><td>796</td><td>2,155</td><td>1,487</td><td>?</td></tr>
<tr><td>Florida</td><td></td><td></td><td>868</td><td>800</td></tr>
<tr><td>TOTAL</td><td>15,494</td><td>15,918</td><td>27,532</td><td>21,844</td></tr>
</table>

Making allowance for those parts of the coast that were not covered and the likelihood that most or all juveniles of the South American wintering populations do not migrate northwards, the 2008 count suggests a flyway population of approximately 30,000. This is at least 8,000 more than the sum of known wintering populations and indicates that there may be significant undiscovered wintering sites. Although the 2009 count was about 5,700 lower than that of 2008, in view of the subsequent higher counts in Delaware Bay and a count of 6,079 in Virginia on 25 May, there is no reason to suppose that the size of the flyway population had declined.

Survival analyses

P.W. Atkinson *et al.* made a presentation to the Third Western Hemisphere Shorebird Meeting at Mazatlan, Mexico, in March 2009 of a survival analysis of knots captured in Delaware Bay during 2004-2008. Stable isotope signatures allowed the knots to be separated between southern winterers (Tierra del Fuego) and northern winterers (SE United States, N Brazil and probably other locations around the Caribbean and along the northern coast of South America). This analysis showed that during that period there was no significant difference between the annual survival rates of birds from the two wintering areas. The average survival rates measured seem high for knots at 93-94%; the reason is currently under investigation.

POPULATION STATUS OF *ROSELAARI*

Winter and passage counts

Counts at the only known significant wintering site, Guerrero Negro, Baja California, show a peak population of 6,458 in 2006-2007 (Carmona *et al.* 2008), 5,536 in 2007-2008 and 6,561 in 2008-2009 (R. Carmona, N. Arce, V Ayala-Pérez). Previously it was unclear whether Guerrero Negro is both a passage and wintering site or just a wintering site with little or no throughput to other wintering sites further south (Carmona *et al.* 2008). Observations in 2007-2008 and 2008-2009 show that numbers are fairly constant throughout the non-breeding season. Moreover there appears to be little or no turnover in the presence of knots marked with individually-inscribed color-flags. Therefore it seems likely that Guerrero Negro is the terminus of the *roselaari* migration flyway on the Baja California peninsula.

A previously unknown and potentially important *roselaari* site in the north of the Gulf of California has been reported by Soto-Montoya *et al.* (2009). There, during 2006-2008, up to 1,600 Red Knots have occurred on passage, up to 500 in winter and over 1,900 in summer (late June, so they are assumed to have been non-breeders, probably one-year-olds). The study area was a 4 km mudflat in a much larger area of intertidal habitat. It is not currently known whether knots use other intertidal areas in the northern Gulf of California, and if so, the number of additional birds that might use those areas. Counts during spring migration at the Salton Sea, California, an inland site a short distance north of the Gulf of California, indicate the presence of hundreds of Red Knots (Patten *et al*. 2003), and those birds may either have overwintered there or in the Gulf of California. Red Knots are virtually unreported during migration in non-coastal areas north of the Salton Sea (in California: Manolis & Tangren 1975, Shuford *et al.* 1998, Strauss *et al.* 2002; in Oregon: McGie 2003; and in Washington: Chappell 2005).

Studies at Grays Harbor and Willapa Bay, Washington, during May 2006-2009 coordinated by J.B. Buchanan have confirmed the continued importance of certain sites in these estuaries for Red Knots stopping over during spring migration (Buchanan 2006, 2007, 2008, 2010). Several sites within these estuaries were documented to support hundreds or thousands of Red Knots during spring migration in the early 1980s (Herman & Bulger 1981, Chappell 2005). Red Knots were regularly seen at Ocosta in 2006-2008, but less so at Bowerman Basin. However, counts of knots in 2007-2008 at Bowerman Basin and Ocosta, the two sites in Grays Harbor where knots were most abundant between 25 April and 14 May in 1981 (Herman & Bulger 1981), indicate that their mean abundance at those sites has declined by an order of magnitude (mean at Bowerman Basin in 1981: 829 [N=13 dates between 25 April and 14 May], 2007: 9.2 [N=9], 2008:16.1 [N=10]; mean at Ocosta in 1981: 1677 [N=13], 2007: 73.4 [N=8], 2008: 9.4 [N=7]). The relative dearth of knot observations from other years and areas in Grays Harbor strongly suggest that knots have not shifted their use to other parts of the harbor.

The 2008 effort in coastal Washington involved site visits to two key areas not included in 2006 or 2007 (the Grass Creek mouth and vicinity in Grays Harbor [referred to as Ned's Rock by Herman & Bulger 1981] and areas west and northwest of the Willapa River mouth in Willapa Bay). It is likely that few, if any, visits to count knots have been made at these sites since the early 1980s (e.g. Herman & Bulger 1981, Chappell 2005). Focus on these two sites, which supported more knots than any sites visited in 2006 and 2007, is probably the main reason why the peak single site count increased from 446 in 2006 and 750 in 2007 to

3,175 in 2008. In addition, the 2008 effort produced substantially more observations of knots previously marked at Guerrero Negro, Mexico, as well as single observations of knots marked at Wrangel Island, Russia, and the Yukon-Kuskokwim River delta, Alaska.

The investigation of Red Knot passage during spring migration in Washington continued in 2009 and focused on counts and scans for banded knots using two airboats as observation platforms (Buchanan *et al*. 2010). Simultaneous visits to the two primary sites identified in 2008 (Grass Creek and North Bay) were conducted on 20 days between 20 April and 26 May. Eight single-day counts exceeded 1,500 knots and 4,000 were observed at Grass Creek on 4 May. Marked knots were observed on 146 occasions, including 91 knots with individually identifiable flags. Given that many knots from Guerrero Negro (e.g. 15-20% of the marked population) have been seen at these two study sites in Washington, the 2009 results suggest that the majority of the Guerrero Negro wintering population stops over there. An analysis is underway to estimate the size of the stopover population using the study area in 2009.

To date, no significant knot spring stopover has been identified between Baja California and Alaska apart from the coast of Washington. However, comparatively much smaller flocks have been recorded along the coast of California (e.g. Storer 1951, Colwell 1994, Stenzel *et al.* 2002), and one of two knots at Bodega Bay on 26 April 2009 had been individually marked at Guerrero Negro. Possibly most of the Guerrero Negro population reaches Alaska in two flights with just one stop in Washington, but that remains to be confirmed.

What is the size of the *roselaari* population?

The largest single count of Red Knots in the East Pacific Flyway was of 110,000 on the Yukon-Kuskokwim Delta in May 1980; it was well documented and made by reliable observers. There was a previous count of 40,000 in the Copper River Delta in 1975 (Morrison *et al.* 2006). However, as shown by B.J. McCaffery *et al.* in a presentation to the Third Western Hemisphere Shorebird Meeting at Mazatlan, Mexico, in March 2009, all peak daily counts in Alaska since 1980 have not exceeded 6,000. Moreover there have never been counts of >6,500 in what appears to be the main *roselaari* wintering area on the Pacific coast of Mexico and California or anywhere else in the flyway. With hindsight, it can be seen that all recent estimates of the size of the *roselaari* population have been strongly influenced by the high numbers recorded in 1975-80. According to the *US Shorebird Conservation Plan* published in 2001 (Brown *et al.* 2001) *roselaari* numbered about 150,000 and even as recently as 2006 Wetlands International considered there were 35,000-50,000. Nevertheless for the last three decades there has been no evidence that the *roselaari* population has exceeded 10,000.

In their 2009 review, B.J. McCaffery *et al* concluded that, if the 1975-1980 counts are discounted, there is no compelling evidence for a long-term decline in the number of knots using the Yukon-Kuskokwim Delta during spring migration. However, there is some evidence that the density of *roselaari* knots breeding on Wrangel Island declined between the 1990s and 2007 (Tomkovich & Dondua 2008) and, as mentioned above, numbers stopping over at two sites in Washington declined between 1981 and 2007-8.

The high 1975-1980 counts of 40,000-110,000 knots in Alaska remain a mystery: possibly they represent influxes of the *rogersi* subspecies from E Siberia as suggested by Morrison *et al.* (2006). However, now that 30 years have passed without them being repeated, there seems no reason to suppose that *roselaari* numbers more than the 6,500 wintering at Guerrero

Negro plus a few more in the Gulf of California and elsewhere; perhaps around 10,000 in all. Therefore, in the light of the data summarized above we consider that all statements, past and recent, that *roselaari* exceeds about 10,000 individuals are likely to have been erroneous.

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Appendix

Papers, reports and dissertations about Red Knots in the Americas published during 2008-2009

Buchanan, J.B. 2008. The spring 2008 survey of Red Knots *Calidris canutus* at Grays Harbor and Willapa Bay, Washington. *Wader Study Group Bull.* 115(3): 177-181.

Two bays in coastal Washington serve as important spring staging areas for Red Knots *Calidris canutus*, likely of the *roselaari* subspecies, that migrate along the Pacific coast of North America. Counts conducted in 2006 and 2007 at Grays Harbor and Willapa Bay indicated the presence of several hundred birds, primarily at Ocosta, in Grays Harbor. Three key sites were not visited, however, due to access concerns (Grays Harbor) and uncertainty about the condition of tide flats (in Willapa Bay) that had been invaded by exotic smooth cordgrass. The 2008 effort included these three sites (Grass Creek in Grays Harbor, and North River and Willapa River bays in Willapa Bay). The mean of six counts at (or near) Grass Creek between 4 and 15 May was 2,298 (SD = 769) and of five counts at North River between 1 and 13 May was 1,144 (SD = 866). The highest count was 3,175 at a roost site near Grass Creek on 12 May. Ground access remains an issue at the Willapa River mouth. Thirty-three observations of colour-flagged knots were recorded; nearly all had been banded at Guerrero Negro saltworks in Baja California, Mexico.

Buehler, D.M. 2008. *Bottlenecks, budgets and immunity: the costs and benefits of immune function over the annual cycle of Red Knots* (Calidris canutus). Ph.D. dissertation, University of Groningen, Groningen, Netherlands.

The immune system is important for survival, but maintaining and using that system carries energetic and immunopathological costs. Because of this combination of importance and cost, trade-offs between immune function and other costly activities (i.e. thermoregulation, migration, reproduction) have been predicted over the annual cycle and during times of resource limitation. However, empirical data on variation in immune function under controlled conditions is lacking, as is information on when most wild species might be immunocompromised. My PhD research bridges these gaps and addresses how animals allocate resources between competing physiological systems to maximize fitness. I had three goals: (1) Determining when in the annual cycle migrants face bottlenecks or “tough times”. (2) Determining annual variation in immune function under controlled conditions. (3) Experimentally testing the effects of various environmental factors on immune function.

To determine when in the annual cycle migrants face bottlenecks, I synthesized knowledge on Red Knot ecology and found that both resource and disease risk bottlenecks are most severe during spring migration. This highlights the complex nature of the optimization of immune function since both decreased immune function due to energetic trade-offs and increased immune function due to increased disease risk can be predicted from this result. To determine annual variation in immune function under controlled conditions I employed new techniques for measuring different aspects of immune function from blood samples (microbial killing ability, cellular immune potential, and complement, natural antibody and haptoglobin levels). I also used multivariate statistical techniques to examine how different aspects of immune function group together into strategies and how these strategies change over the year. I took monthly measurements of baseline immune function and found that it varied significantly over the annual cycle, even in captive birds, and that higher cost immune strategies were important during migration, but were down regulated during peak feather moult. I also found that immune index scores were repeatable over the annual cycle and that covariation among indices suggests that birds use different “immune strategies” during different annual cycle stages. Finally, I experimentally manipulated various environmental factors and found that increased energy expenditure, decreased temperature and decreased energy availability did not affect baseline immune function, although aspects of induced immune function were affected by decreased food availability. Furthermore, variation in baseline immune function over the annual cycle did not correlate with fluctuations in photoperiod or melatonin exposure. Concurrently, I examined the effect of investigation artefacts (handling stress) on immune function, contrasted immune function in captive and free-living knots and examined immune function in free-living knots in terms of age and habitat quality.

Taken together my results establish that baseline immune function varies over the annual cycle, but that this variation is not driven by any of the factors I measured in captive birds. What then is driving this variation in immune function? An obvious answer is disease risk, and I hope to test this idea in the future.

Carmona, R., N. Arce, V. Ayala-Pérez & G. Danemann. 2008. Abundance and phenology of Red Knots in the Guerrero Negro–Ojo de Liebre coastal lagoon complex, Baja California Sur, Mexico. *Wader Study Group Bull.* 115(1): 10–15.

To determine the spatial and temporal distribution of Red Knots *Calidris canutus roselaari* in the Guerrero Negro-Ojo de Liebre coastal lagoon complex, including the Guerrero Negro Saltworks, we carried out a monthly census from July 2006 to June 2007. The aggregate total of the twelve monthly counts was 32,059, and the maximum count of 6,458 was made in September 2006. The Red Knots arrived in July and August and their numbers were high until October, decreased in November and increased again in December (to 4,595), but then declined constantly until March; in April there was a notable increase to 4,647. We suggest two hypotheses to explain the fluctuations in numbers: (1) that there is onward migration with birds departing in late autumn and more birds arriving for the winter or (2) that Guerrero Negro is the terminus of the migration and numbers vary because of local movements to and fro other sites within a 200 km radius.

77% of all knots counted occurred in 11 of the 45 zones into which we divided the study area. We classified the 11 zones into four sections according to their seasonal use by the knots: Los Medanitos was important in autumn; Estero Norte in spring; Guerrero Negro was consistent and with regular abundance throughout the year; and Salitrales showed large fluctuations. We conclude that the abundance of knots in these four sections can be used to estimate the total number in the entire lagoon/saltworks complex (r^2=0.94).

Cohen J.B., Karpanty S.M., Fraser J.D. & Truitt B.R. Red knot foraging ecology in coastal Virginia. (in press, *J. Ornithol.*).

A population decline of the western Atlantic red knot (*Calidris canutus rufa*) has been linked to food limitation during spring migratory stopover in the Delaware Bay, USA. Stopover ecology at potential alternative sites has received little attention. We studied factors affecting red knot habitat selection and flock size at a coastal stopover site in Virginia in 2006-2007. The most common potential prey items were coquina clams (*Donax variabilis*) and crustaceans. Red knot foraging sites had more clams and crustaceans than unused sites in 2006. Prey abundance increased during the 2007 stopover period and remained high after the red knot peak. Red knot flock size in 2007 increased with mean clam shell length, and probability of flock presence decreased with increasing distance from night use locations. Our results suggest that red knots preferred coquina clams and that these clams were not depleted during the stopover period in 2007. Thus prey abundance did not appear to be a population limiting factor at this coastal stopover site in Virginia in that year. Protection of coastal sites outside of the Delaware Bay, many of which have been altered by human development, would likely benefit red knot population recovery, as they can apparently provide abundant food resources in at least some years.

Cohen J.B., Karpanty S.M., Fraser J.D., Watts B.D. & Truitt B.R. 2009. Residence probability and population size of red knots during spring stopover in the mid-Atlantic region of the United States. *J. Wildlife Management* 73:939-945.

Weekly counts of western Atlantic red knots (*Calidris canutus rufa*) at their Delaware Bay migration stopover site have suggested a major decline since the 1980s. We estimated red knot spring passage population size in the New Jersey Coast–Delaware Bay region (DENJ; 2004 and 2006) and Virginia (VA; 2006 and 2007), USA, by correcting weekly aerial counts for mean daily residence probability between counts in a Monte-Carlo simulation. We used daily telemetry relocations in mark–resight models to estimate mean daily residence probability. Average daily residence probability was approximately 1.0 in mid-May, 0.96–0.97 in the week of 22 May, and 0.64–0.77 after May 28 in DENJ in 2004 and 2006 and in VA in 2006. Average daily residency was approximately 0.88 in VA in 2007 from 22 May to 5 June. No birds moved from VA to DENJ in 2006 and only 2 birds (5.5%) moved in 2007. Stopover population sizes (±SE) in DENJ were 17,108 ±1,322 in 2004 and 19,555 ±831 in 2006, and in VA were 7,224 ±389 in 2006 and 8,332 ±718 in 2007, significantly greater than peak aerial counts. Years with similar peak counts had different residence probabilities; hence, adjustments for turnover should be used in the future to assess annual population changes. Our results suggest that VA can support a significant portion of this red knot subspecies during migration in at least some years. Managing red knots for recovery should entail improving our understanding of the use of other Atlantic Coast sites and protecting key coastal habitat from disturbance and development.

D'Amico, V.L. 2009. Migration strategies of Red knots, *Calidris canutus rufa*: parasite effects on immune and energetic investments in non-breeding sites. Ph.D. dissertation, Universidad Nacional del Comahue and Centro Nacional Patagónico - Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina.

Parasitic infections and immune function investments in shorebirds are predicted to play an important role in patterns of habitat selection and spatial behaviour, including long-distance migration. Therefore, it has been proposed that evolution of migration in some shorebird species could be determined by a trade-off between energetic and immunologic investments, the impact of parasites and pathogens being the selective forces that shape migratory strategies. This hypothesis is based on the idea that in marathon migrants, demanding migrations and a history of genetic bottlenecking on an evolutionary time-scale may have led to poor immune resistance that further restricts them to low parasite habitats with less disease risk. Therefore, long-distance migrants might trade-off investment in immunocompetence against energetically costly and prolonged flights to marine-shore wintering sites.

Long-distance migrant Red Knots *Calidris canutus rufa* breed in the Arctic tundra and migrate to different wintering sites in northern and southern South America during the non-breeding season. The pronounced difference in migratory pathways, climates and habitats used by birds wintering in the tropics of Brazil (Maranhão) versus cold-temperate Tierra del Fuego (Río Grande) provide an excellent opportunity to test some of the basic assumptions of the parasite hypothesis at a latitudinal scale. Therefore, the main objective of my study was to evaluate the effects of ectoparasites and blood parasites on physiological processes related to immune and energetic investments at non breeding sites.

Red Knots carried a heavier burden of ectoparasites in tropical Maranhão than cold-temperate Río Grande. However, as both are marine sites, the degree of exposure to blood parasite vectors was very low; consequently no blood parasites were found in samples from either site. Although I expected a higher immune investment in birds from Maranhão; it was actually higher in Río Grande birds. Possibly this is a characteristic of long-distance migrants: long flights can cause muscle damage, recovery from which can lead to an immune response. Birds that spend the non-breeding season at Río Grande have to make a long flight northwards to Delaware Bay on the east coast of the United States, making one or more stopovers in the tropics. Therefore, these birds are equally exposed to parasites as those that spend the northern winter in Maranhão. In Delaware Bay, the abundance of ectoparasites was similar in birds that made the long migration from Tierra del Fuego and those that made the shorter migration from Maranhão. Immune investments were similar in birds with isotopic signatures from northern and southern wintering sites. This suggests on the one hand that short-distance migrants are not detrimentally affected by ectoparasite burdens. On the other hand, birds from Tierra de Fuego have to invest more resources in long-distance flights, so they might be immunodepressed and consequently more vulnerable to infestations during stopovers in the tropics (or they simply cannot avoid being infested by ectoparasites when they roost in mixed flocks with resident birds).

Long flights require more energetic resources, and at stopover sites birds generally carried higher quantities of proteins and lipids, which are essential to fuel such energetically demanding activity. However, glucose levels were higher during winter at Río Grande and decreased during northwards migration. This is to be expected since glucose is consumed very quickly, especially during the first phase of intensive exercise.

It seems puzzling that some knots make a long distance flight to spend the winter at Río Grande, flying about 6,000 km further than Maranhão, but are finally exposed to the same detrimental ecological factors found in the tropics. What is the advantage of make that long migration? Probably, Río Grande offers a good quality food supply and exposure to parasites is low. But, these birds have suffered a drastic population decline. It is equally surprising that some knots opt to winter in Maranhão despite the high exposure to parasites. Moreover, recently more knots have been discovered wintering in neotropical sites. Currently, other research groups are carrying out survival analyses of knots from the different wintering sites. These studies may help to elucidate this striking question.

Verónica L. D'Amico, Marcelo Bertellotti, Allan J. Baker & Patricia M. González. Hematological and plasma biochemistry values for endangered red knots (*Calidris canutus rufa*) at wintering and migratory sites in Argentina. (in press *J. Wildlife Diseases*)

We obtained hematological and plasma biochemistry values for adult long distance migrant red knots in their southernmost wintering site in Río Grande (Tierra del Fuego, Argentina) and at the first refueling site in San Antonio Oeste (Río Negro, Argentina). Lymphocytes (L) followed by heterophils (H) were the most abundant leukocytes. H/L ratio and glucose levels were significantly higher at Río Grande possibly due to stresses of migration and molting. Ranges of packed cell volume were wide probably as a response to a need for oxygen transportation necessary for the long migration. Protein profile and lipids were higher at the stopover site and attributable to birds storing reserves for subsequent flights. These can be considered as reference values for this endangered species.

Espoz, C., A. Ponce, R. Matus, O. Blank, N. Rozbaczylo, H.P. Sitters, S. Rodriguez, A.D. Dey & L.J. Niles. 2008. Trophic ecology of the Red Knot *Calidris canutus rufa* at Bahía Lomas, Tierra del Fuego, Chile. *Wader Study Group Bull.* 115(1): 69–76.

Using stable isotope analysis, we investigate the diet of Red Knots of the subspecies *rufa* at Bahía Lomas, Chile, their main over-wintering site in the West Atlantic Flyway. Benthic sampling showed that the most abundant and available potential prey for knots is the clam *Darina solenoides* and the isotope analysis confirmed that this is their main food resource. However, 91% of *Darina* were <6.0 mm in length, much smaller and therefore less profitable than size-classes chosen by knots at other sites. We speculate as to whether this apparently poor quality food supply could have contributed to the catastrophic decline in the *rufa* population recorded over the past decade.

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, L.J. Niles, R.C. Porter, I.L. Serrano, H.P. Sitters & J.L. Woods. 2009. Staging Behavior in Red Knot (*Calidris canutus*) in Delaware Bay: Implications for Monitoring Mass and Population Size. *The Auk* 126: 54-63.

Many migratory birds use staging sites to gain essential resources to fuel their ongoing migration. Understanding staging strategies reveals much about migration systems and is essential if one is concerned with monitoring population trends and mass gains, two of the principal methods for assessing the "health" of a migratory population. In spring 2004, we investigated the staging behavior in Delaware Bay of Red Knot (*Calidris canutus*) using mark-recapture techniques and resightings of birds marked in the preceding spring. Individuals staged for 11-12 days, which declined to 8-10 days late in the season. Arrivals were asynchronous, but departures tended to be synchronized. A simple sensitivity analysis showed that the mark-recapture analysis estimated length of stay to within ±10% and confirmed biases in monitoring trends and mass gains using peak counts and mass-on-date regressions. Alternative methods using staging duration to estimate passage population size and mass gains were shown to be unbiased. Using these methods, we estimated a passage population size in 2004 of 18,000 Red Knot that arrived at an average mass of 111 g and, on average, gained mass at 7.2 g day^{-1}. Thus, in 2004, the passage population was substantially smaller than the recent peak count of 50,360 in 1998, which confirms a significant decline in the number of Red Knot staging in Delaware Bay. Use of refined techniques such as these is essential if management decisions such as those in Delaware Bay are to be based on firm scientific advice.

McCaffery, B.J., van de Kam, J. & Woodley, K. 2008. Observations of Red Knots *Calidris canutus* at Old Chevak, Yukon-Kuskokwim Delta, Alaska, spring 2008. *Wader Study Group Bull.* 115(3): 167-170.

We report our observations of Red Knots during spring migration at Old Chevak, 20 km inland from the coast on the central Yukon-Kuskokwim Delta. Migrant Red Knots were detected over a three-week period in May, a period that coincided with both snow-melt and river ice break-up. Among our 1,178 observations were three knots color-marked in Mexico. Knots foraged primarily in three habitats: riparian sedge meadows, tidal marshes, and rotting river ice. Our observations indicated that hundreds, and perhaps thousands, of knots use areas inland from the immediate coast of the Yukon-Kuskokwim Delta during spring migration. Spatio-temporal variation in habitat availability during the migration period will make population assessments challenging.

Niles, L.J., H.P. Sitters, A.D. Dey, P.W. Atkinson, A.J. Baker, K.A. Bennett, R. Carmona, K.E. Clark, N.A. Clark, C. Espoz, P.M. González, B.A. Harrington, D.E. Hernández, K.S. Kalasz, R.G. Lathrop, R.N. Matus, C.D.T. Minton, R.I.G. Morrison, M.K. Peck, W. Pitts, R.A. Robinson & I.L. Serrano. 2008. Status of the Red Knot (*Calidris canutus rufa*) in the Western Hemisphere. *Stud. Avian Biol. 36*.

Niles LJ, J. Bart, H.P. Sitters, A.D. Dey, K.E. Clark, P.W. Atkinson, A.J. Baker, K.A. Bennett, K.S. Kalasz, N.A. Clark, J. Clark, S. Gillings, A.S. Gates, P.M. Gonzalez, D.E. Hernandez, C.D.T. Minton, R.I.G. Morrison, R.R. Porter, R.K. Ross & C.R. Veitch. 2009. Effects of horseshoe crab harvest in Delaware Bay on red knots: Are harvest restrictions working? *BioScience* 59: 153–164.

Each May, red knots (*Calidris canutus rufa*) congregate in Delaware Bay during their northward migration to feed on horseshoe crab eggs (*Limulus polyphemus*) and refuel for breeding in the Arctic. During the 1990s, the Delaware Bay harvest of horseshoe crabs for bait increased 10-fold, leading to a more than 90% decline in the availability of their eggs for knots. The proportion of knots achieving weights of more than 180 grams by 26–28 May, their main departure period, dropped from 0.6–0.8 to 0.14–0.4 over 1997–2007. During the same period, the red knot population stopping in Delaware Bay declined by more than 75%, in part because the annual survival rate of adult knots wintering in Tierra del Fuego declined. Despite restrictions, the 2007 horseshoe crab harvest was still greater than the 1990 harvest, and no recovery of knots was detectable. We propose an adaptive management strategy with recovery goals and annual monitoring that, if adopted, will both allow red knot and horseshoe crab populations to recover and permit a sustainable harvest of horseshoe crabs.

Smith, F.M., A. E. Duerr, B.J. Paxton & B.D. Watts. 2008. An Investigation of Stopover Ecology of the Red Knot on the Virginia Barrer Islands. Center for Conservation Biology Technical Report Series, CCBTR-07-14. College of William and Mary, Williamsburg, VA. 35pp.

The Virginia barrier island chain plays a significant role in the life cycle of many of the most vulnerable shorebird species in North America. The large areas of relatively undisturbed beach and marsh habitat available to shorebirds during the migratory period, along with the strategic geographic position of the region for migrants, combine to make this one of the most important stopover regions in eastern North America.

One of the shorebird species that utilizes the Virginia barrier island system is the Western Hemispheric subspecies of Red Knot (*Calidris canutus rufa*). The *rufa* subspecies migration is one of the longest in the world as they routinely fly over 30,000 km each year (Harrington *et al.*, 1988, Clark *et al*., 1993). Over the past 20 years, the *rufa* population of Red Knot within North America has declined by approximately 80-90% (Piersma and Davidson, 1992, Baker *et al*., 2000, Morrison *et al*., 2004, Niles *et al*., unpublished data). Concern for this species led to an application to the U.S. Fish and Wildlife Service for fast track consideration for federal listing under the Endangered Species Act and a large-scale investigation of conflicts between migrant shorebirds and the Horseshoe Crab (*Limulus polyphemus*) industry (Baker *et al*., 2004, Morrison *et al*., 2004). Most of the conservation efforts to date have focused on the Delaware Bay where the Red Knot is a horseshoe crab egg specialist (Harrington, 1996, Tsipoura and Berger, 1999, Karpanty *et al*., 2006). It is increasing evident that the specialized feeding adaptations of Red Knots using the Delaware Bay, coupled with the lack of adequate horseshoe crab egg density, increases their risk for adult mortality, which is the single most important factor influencing shorebird survival (Davidson and Piersma 1992, Hitchcock and Gratto-Trevor 1997, Baker and Piersma 2000).

In the mid-1990s 3 years of aerial surveys showed that numbers of knots moving through the barrier islands of Virginia between mid-May and the second week of June reach 8,000-10,000 individuals (Watts and Truitt 2000). A single survey on 25 May 2005 showed similar numbers (Watts and Truitt, unpublished data). This compares to approximately 13,000 birds using Delaware Bay in 2006 (Niles *et al*., unpublished data). These findings suggest that the Virginia barrier islands may have more significance to the species than previously believed. Knots using Virginia as a stopover site, unlike the birds staging in Delaware Bay, and similar to knots utilizing other stopover areas (Harrington, 1986, Gonzalez *et al*., 1996), do not depend on horseshoe crabs as a food source (Truitt *et al*., 2001). There are many questions yet to be addressed for knots staging in Virginia that may have broad implications for the future conservation of this species.

A total of 6 barrier islands were intensively surveyed during the 2007 migration season. A total of 60 line transect surveys were conducted between 28 April 2007 and 18 June 2007 on the barrier islands. Transects were positioned to cover the barrier islands with the most Red Knot use. A total of 18,770 Red Knots were detected on surveys, with 12,580 of those knots scanned and resighted, of which 642 were banded. A total of 277 individually marked Red Knots were detected at least once during the spring 2007 migration season.

Soto-Montoya, E., Carmona, R., Gómez, M., Ayala-Pérez, V., Arce, N. & Danemann, G.D. 2009. Over-summering and migrant Red Knots at Golfo de Santa Clara, Gulf of California, México. *Wader Study Group Bull.* 116(3): 191-194.

We report the occurrence of Red Knots *Calidris canutus* on the northeast coast of the Gulf of California, México. Monthly counts were conducted from Jan 2006 to Dec 2008 along a muddy beach at Golfo de Santa Clara, Sonora. An aggregate total of 10,565 Red Knots were recorded, with a maximum count of 1,928 on 25 June 2007. Substantial numbers of over-summering birds occurred consistently in Jun-Jul with varying numbers in Aug, but virtually none from Sep to Dec. Occasional flocks were recorded in Jan-Feb and there was evidence of a small passage in Mar-Apr, but virtually none in May. Thus it seems that the area is used as a stopover in early autumn and spring and that small numbers occur in winter, but its main importance is an over-summering site for immatures that do not go to the breeding grounds. To date no other site has been found to support significant numbers of over-summering Red Knots in the East Pacific flyway.