BTO Research Report No. 274

A Preliminary Analysis of the Survival Rates of Red Knots *Calidris canutus rufa* Passing Through the State of Delaware 1997-2001

Authors

Philip W. Atkinson, Ian G. Henderson & Nigel A. Clark

A report by the British Trust for Ornithology under contract to
Delaware Coastal Programs
Division of Soil and Water Conservation
Delaware Department of Natural Resources and Environmental Control

December 2001

British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, UK
Registered Charity No. 216652

This report was funded by the Delaware Coastal Programs pursuant to United States National Oceanic and Atmospheric Adiministration Award No. NA070Z0111.

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1. INTRODUCTION

1.1 Background and Context

Essential to the management of any wild bird population is an understanding of the relationship of the organism with its environment and particularly the processes that affect the demographics of the species. For the Nearctic population of Red Knot *Calidris canutus rufa*, understanding the factors that impact the fitness of the population are extremely difficult to measure due to their reliance on remote breeding, stop-over and wintering areas and the number of sites they rely on during migration.

Delaware Bay is a particularly important stopping-off site and the majority of the Nearctic population of Red Knots stop there in spring up before migrating to their Arctic breeding grounds. Although Red Knot only spend three to four weeks in Delaware Bay in spring, this time may be crucial in determining whether a bird successfully makes it to the breeding grounds to breed. Of particular concern in Delaware Bay is the Red Knot's reliance on one main food source, namely Horseshoe Crab *Limulus polyphemus* eggs. Reductions in the amount and availability of eggs may impact the Red Knots ability to reach their target weight which may (a) delay or reduce the probability of reaching the breeding areas, (b) reduce the ability to maintain sufficient body reserves within the first few days of arrival in the breeding areas in cases of bad weather or a late thaw and (c) reduce survival rates.

Survival analyses are a useful way of monitoring the health of and effects of habitat change on bird populations. These types of models do, however, require long data series as survival estimate confidence intervals tend to be larger at either end of the series and the power of small sample sizes to find an effect of any particular environmental variable is low. The large-scale banding that has taken place in Delaware Bay between 1997 and 2001 has provided an opportunity to estimate survival rates of this population, defined here as the proportion of the population that passes through the State of Delaware that survives over a 12 month period.

The main aims of this preliminary analysis are to investigate the current data (a) determine whether past metal banding data can be used to estimate survival, (b) assess whether survival can be accurately estimated from sightings of color-banded birds and (c) make recommendations for future metal- and color-banding studies.

1.2 Data Availability

Red Knot have been trapped on both sides of Delaware Bay since 1997. This provides five years of data and, thus, four annual periods from which survival can be estimated. For this exploratory analysis we have only used data collected in the State of Delaware as this was the only data available to BTO for analysis. All birds were caught using cannon nets during spring passage in May and early June. Birds were fitted with an individually-numbered metal band and also a number of plastic color bands which allowed birds to be identified either as individuals as a bird banded in a particular area in a certain year (referred to as 'cohorts' in this report). We have used two different approaches to estimate survival: (a) by using retraps of metal-banded birds in catches and (b) observations of color-banded birds made in the field.

2. SURVIVAL ESTIMATES FROM METAL BAND RECOVERY MODELS

Survival models for Red Knot over five years (1997 to 2001) were fitted using the Cormack-Jolly-Seber (CJS) method in the computer package MARK (White & Burnham 1999). There are two elements that need to be evaluated when performing survival analysis. The probability of retrapping or resighting an individual bird depends on its probability of surviving in the intervening period (survival rate) and also the likelihood of it being caught or resighted again (recapture/reporting rate). In many cases recapture rates may well vary between time periods and so it is essential to estimate both parameters.

The numbers banded and retrapped in the State of Delaware each year are detailed in the recovery matrix in Table 2.1.

		Number retrapped			
Year	**Number banded**	**1998**	**1999**	**2000**	**2001**
1997	889	14	8	8	8
1998	1133		15	8	5
1999	1226			7	12
2000	884				17
2001	1362				

Table 2.1 Recovery matrix for Red Knot banded in the State of Delaware from 1997-2001.

Number	**Model**	**($\hat{c}$ = 2.286) QAICc**	**Delta QAICc**	**QAICc Weight**	**Number of Parameters**	**Qdeviance**
1	$\phi .\ p\ .$	501.716	0	0.34732	2	13.143
2	$\phi_{age}\ p\ .$	502.859	1.14	0.19612	3	12.283
3	$\phi .\ p_{age}$	503.693	1.98	0.12925	3	13.116
4	$\phi_t\ p\ .$	504.254	2.54	0.09764	5	9.668
5	$\phi_{age}\ p_{age}$	504.676	2.96	0.07906	4	12.096
6	$\phi .\ p_t$	505.624	3.91	0.04922	5	11.039
7	$\phi_t\ p_{age}$	505.941	4.22	0.042	6	9.35
8	$\phi_t\ p_{age}$	505.941	4.22	0.042	6	9.35
9	$\phi_t\ p_t$	507.705	5.99	0.01739	7	9.107

Table 2.2 Results of the survival analyses performed for Knot caught in the State of Delaware and banded between 1997 and 2001. Parameters: *f* = Survival; *p* = recapture rate. Subscripts: . = constant parameter, *age* = a two category parameter with separate recapture/survival rates for year after capture and constant thereafter; *t* = time-dependent (annual) parameter.

We built CJS models where both survival (ϕ) and recapture rates (p) were varied with time (annually, denoted by the subscript *t*) or kept constant between years. In survival models, model fit is usually assessed using the Akaike Information Criterion (AIC, the lowest value of which indicates the model which describes the data most parsimoniously). The difference between models can be assessed in two ways. For nested models a likelihood ratio test (LRT) can be used to confirm the results obtained using the AIC and the simpler model would be rejected if a significant result was obtained. Alternatively, model weights (normalised Akaike weights) can be compared. These relative measures indicate the degree of support for selecting one model over another. For example, if Model 1 has a weight of 0.62 and Model 2 has a weight of 0.13, then it can be said that Model 1 is over four times as well supported as Model 2 as (0.62/0.13) = 4.77.

As is common with such frequency data, a pooled chi-squared goodness of fit test indicated that the data were over-dispersed in respect of the recapture data. Hence, the model selection criteria were modified so that the corrected quasi-likelihood AIC ($QAIC_c$) was used to select the most parsimonious model. This adjustment incorporated a measure of the over-dispersion ($\hat{c}$) calculated from the goodness-of-fit test by dividing the observed model by the mean pooled deviance, calculated from 199 bootstraps of the recapture data. A value of $\hat{c}$ of 2.286 was calculated from the bootstrapping of the full ϕ_t p_t model.

Based around this value the model that most parsimoniously described the data was one where both survival and recapture rates were constant (Table 2.2). This gave a survival value of 0.805 with a recapture rate of 0.015 although confidence intervals were large. Breaking this down further, the model S_t p. indicated that the reason for the large confidence intervals is that the values for the survival from 1997-1998 and 2000-2001 were greater than one.

Parameter	**Mean**	**SE**	**Lower 95%CI**	**Upper 95% CI**
Survival	0.805	0.13	0.444	0.955
Recapture Rate	0.015	0	0.007	0.028

Table 2.3 Parameter estimates for the best fit model ϕ. p .

This suggests that recapture rate may vary between years. In this case, the recapture rate will be a combination of (a) the likelihood of a bird originally banded in Delaware returning to Delaware and (b) the probability of an individual bird in Delaware being caught. In fact, looking at the proportion of each cohort in the birds caught across years there is indeed an indication that recapture rates differ between years. Using the Delaware-only data there appear to be differences in the proportion of birds of each cohort caught each year which are not consistent with a constant survival and recapture rate (Figure 2.1). For example, the proportion of the 1997 cohort in catches during the 1999 field season was approximately 0.007 whereas in 2000 it was higher at 0.009. If recapture rates were constant between years then this would imply a survival rate of greater than one which is clearly erroneous. It would be expected that the proportion of birds in the flocks would reduce with time - the 1998 cohort shows a typical pattern whereas the other cohorts do not show this pattern.

It is possible that in the year following capture birds are either less likely to visit the bay or have a memory of being cannon netted. We tested this by allowing some models to have an 'age-dependent' recapture rate during the first year after capture and then a constant likelihood afterwards.

The results indicate that although Model 1 in Table 2.2 is a better fit, the difference between this and the age-dependent model (Model 2) is small and not significant (LRT: χ^2=0.860, df = 1, P = 0.35, NS). A difference of 1.14 QAIC indicates a high degree of similarity between the models. With the extremely large confidence intervals associated with the survival and recapture rate estimates, there can be little confidence in any of these models and the main conclusion is that we are trying to estimate survival with too few data.

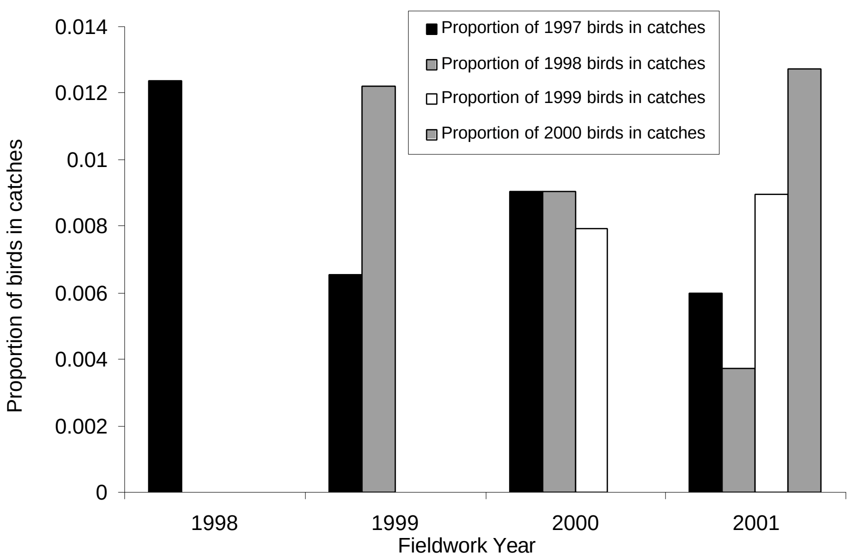


Figure 2.1 Proportion of metal-banded Knot from each cohort present in the cannon-net samples 1998-2001

3. ESTIMATING SURVIVAL FROM COLOR-BANDED BIRDS

3.1 Introduction

In this section we analyse the color band sightings made by the Delaware team during the 2001 spring field season. During this period over 26,000 birds were scanned, primarily at Mispillion Harbour but also at other sites including Slaughter Beach, Kitts Hummock and Port Mahon. The major aims of this piece of work were to (a) determine whether the mixing of birds banded in New Jersey and Delaware was at random or whether birds banded in Delaware were more likely to be seen in Delaware and (b) use sightings of cohort-marked birds (i.e marked by state and year) to determine annual survival rates and (c) examine the banding protocol and make recommendations for future work in Delaware.

3.2 General Methodological Considerations

Using sightings of cohort-marked birds (i.e. color-banded to year and site only) to estimate survival opens up new challenges compared with using individually-numbered metal bands which provide a more powerful method of estimating survival. Plastic bands have a number of disadvantages in that they have an increased tendency to (a) fall off, (b) discolor and (c) be misread as lighting conditions and distance to the bird may influence the reliability of the observer to correctly read the combination. However they do have the advantage over cannon-netting that a small number of people can collect a relatively large amount of data in a small space of time.

Methodologically, it also opens up new challenges although both require a number of concurrent years data to be able to obtain realistic estimates of survival. As this was the first year of scanning carried out by BTO we were able to estimate a snapshot survival for Delaware-banded birds since 1997 when the first mass banding expedition took place. The methods to estimate survival from the proportions of each cohort in the flocks are described in Box 3.1. This is a very crude way to estimate survival and is not recommended in future years when a different method can be used.

Estimating the proportions of color-banded birds in flocks is not an easy task. One problem with scanning birds and estimating the proportion of each cohort simply by dividing the number of each cohort observed by the total is that any mis-reads or incomplete combinations will deflate the estimate of each cohort in the flocks. In this first year of observation, we scanned approximately 26,000 birds and have estimated the proportions of each cohort using the concept of inter-cohort bird distances (IBDs), i.e. the number of birds scanned until another of the same cohort is observed. An alternative method is to count the number of each cohort in blocks of say 100 birds scanned and discarding those blocks that contain mis-reads. However, this will discard data that could be used under the IBD method and thus the IBD method makes the most efficient use of the scan data. Experience in Delaware in 2001 showed that staining of white and yellow bands caused much confusion (at least initially until the staining wore off) between several cohorts of birds marked in Delaware whereas New Jersey-banded birds were generally easier to identify due to the colors of the bands used in past years.

Box 3.1 Calculating suvival from a snapshot series of scan data of cohort-marked birds

There are simple mathmatical relationships between the proportion of each cohort in the flocks in 2001 and survival rates. The proportion of each cohort of color marked birds in the flocks in 2001 can be estimated from the following equations

$p_{97} = [N_{97} * \phi_{97} * \phi_{98} * \phi_{99} * \phi_{00}] / Pop_{01}$
$p_{98} = [N_{98} * \phi_{98} * \phi_{99} * \phi_{00}] / Pop_{01}$
$p_{99} = [N_{99} * \phi_{99} * \phi_{00}] / Pop_{01}$
$p_{00} = [N_{00} * \phi_{00}] / Pop_{01}$

where p_t = the proportion of the birds in the flocks scanned during 2000, which were marked at time t; N_t = the number of birds color-banded at time t, ϕ_t = annual survival in year t, measured from May to May the following year; Pop_{01} = Population size in 2001.

By dividing p_{99} by p_{00} and rearranging the equation for ϕ_{99} survival for the 1999/2000 period can be calculated as follows:

$\phi_{99} = [p_{99}/p_{00}] / [N_{99}/N_{00}]$

Survivals for other periods can be calculated in a similar manner.

As an illustration, a typical sequence might read, DE98, 12 unbanded, NJ2000, 34 unbanded, DE98/99/00… indicating a bird banded in Delaware in 1998, then 12 unbanded birds, then a bird banded in New Jersey in 2000, 34 unbanded and then a bird that could have been banded in Delaware in 1998, 1999 or 2000. The inter-bird distances for each cohort are then calculated for the entire run of sighting data. If a bird, which could belong to more then one cohort, is encountered then the sequence is broken and the IBD is not started until that cohort is encountered again in the sequence.

At the end of the process there will be a series of IBDs for each cohort. These can be turned into proportions by taking the reciprocal of the average of the IBDs for each cohort and survival rates calculated according to the method described in Box 3.1. Confidence intervals can be estimated by bootstrapping the entire run of data and calculating a new average IBD for each cohort. For this study 499 bootstraps were performed and the mean and 95% CIs calculated.

3.3 Results

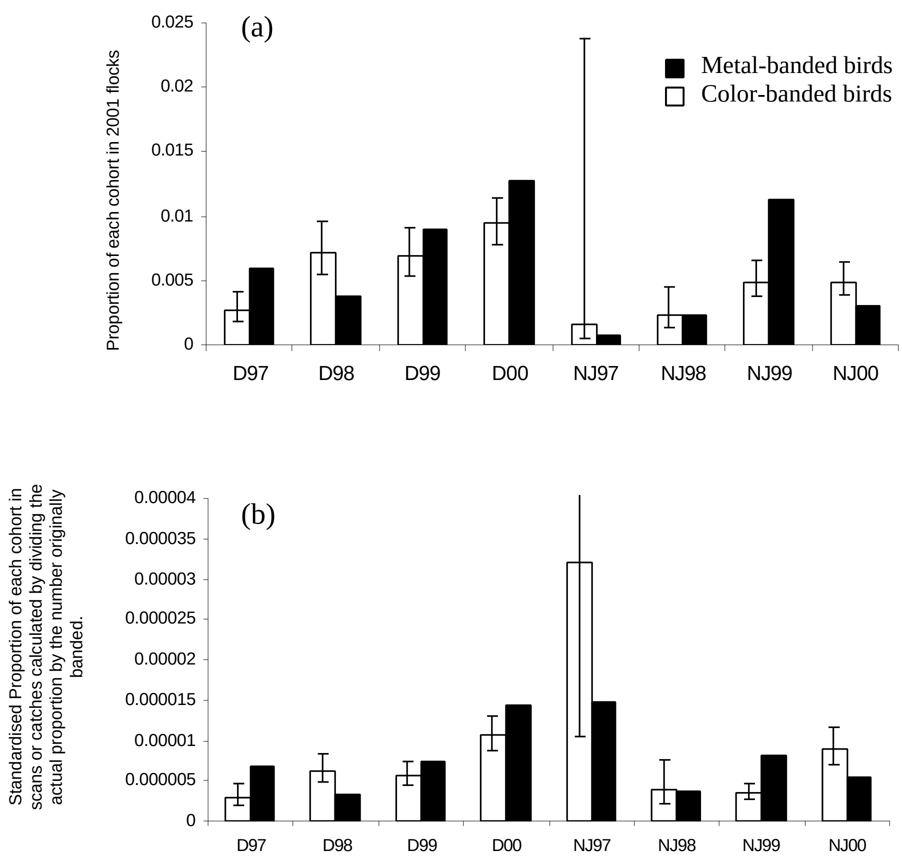
3.3.1 Proportions of each cohort in flocks scanned and caught in the State of Delaware in 2001

Both color-band scanning and cannon-netting estimates of the proportion of each cohort in the 2001 flocks yielded encouragingly similar results (Figure 3.1a) and the values were not orders of magnitude different. Excluding the NJ97 cohort, when only 57 birds were banded, the proportion of birds in catches compared with the IBDs was higher in four cases and lower in three. The proportion of each cohort depends on the numbers initially banded and their subsequent survival. Figure 3.1b shows standardised proportions (i.e. observed proportions divided through by the number banded). It would be expected that the value for each year class should follow a pattern of low values for 1997 cohorts, increasing through to 2000 cohorts. If birds from the two States are mixing randomly then values for a particular year class should be similar across States.

As so few data are available, no formal analysis can be undertaken. The D98/NJ98 and D99/NJ99 proportions are very similar for birds in catches and suggest that mixing of these two cohorts was at random. However, the NJ00 cohort occurred far less often than the D00 cohort in the Delaware cannon-net catches (compare D00 and NJ00 black bars in Fig 3.1b). The reasons for this are unknown and may be down to sampling error as is suggested by the IBDs (the D00 and NJ00 white bars in Fig 3.1b are similar). The D97 cohort is also much higher than expected, as it should be less than the D98 and D99 proportions. Again, error associated with sampling is likely to be an issue.

These results are intriguing in that if the observed anomalies are not all down to sampling error then there may be an issue with the banded cohorts having different reporting rates. This may be due to the timing of catches in different years and the timing of arrival of different groups of birds. Over the five years the temporal pattern of catches has not been constant in the State of

Figure 3.1 (a) The proportion of metal (black bars) and color-banded birds (white bars) observed in scans of Red Knot flocks in the State of Delaware in 2001. Means ± 95% CI obtained from bootstrapped inter-bird distances (IBDs) are presented; (b) Standardised proportions of each of the metal and color-banded cohorts in 2001 State of Delaware catches and scans.



Delaware. The rate of catching has been approximately constant between 16 and 25 May (data not presented) and in 1997, 2000 and 2001 more than 85% of the total birds caught were during this period. However in 1998 significant proportions of birds were caught both before (28%) and after (16%) this set of dates. In 1999, over 60% of the birds were caught after 25 May. If birds which winter or stage in different areas tend to pass through Delaware Bay at different times then this may alter reporting rates between years. Again, scans and catches in future years will confirm whether this is an issue.

3.3.2 Survival rates from proportions of metal and color-banded birds using simple proportions.

Given only one year of scan data, it is only possible to calculate snapshot figures for survival (Table 3.1). Further years data will allow a more sophisticated survival analysis method to be used.

The estimates of survival are way off what would be expected and clearly show that a one-off series of scanning data is not worthwhile if survival rates are to be estimated. Even excluding the 1997 New Jersey data due to a tiny sample size, two out of the remaining 5 survival rates are greater than one. Data from metal bands treated in the same manner also indicate that estimating survival from one year of data is extremely prone to error.

Table 3.1 Calculation of survival estimates of scans of Red Knot flocks in the State of Delaware in May and June 2001 based around the (a) proportion of each cohort in the flocks as measured by (a) color bands and (b) metal bands.

(a) From Scans of Flocks

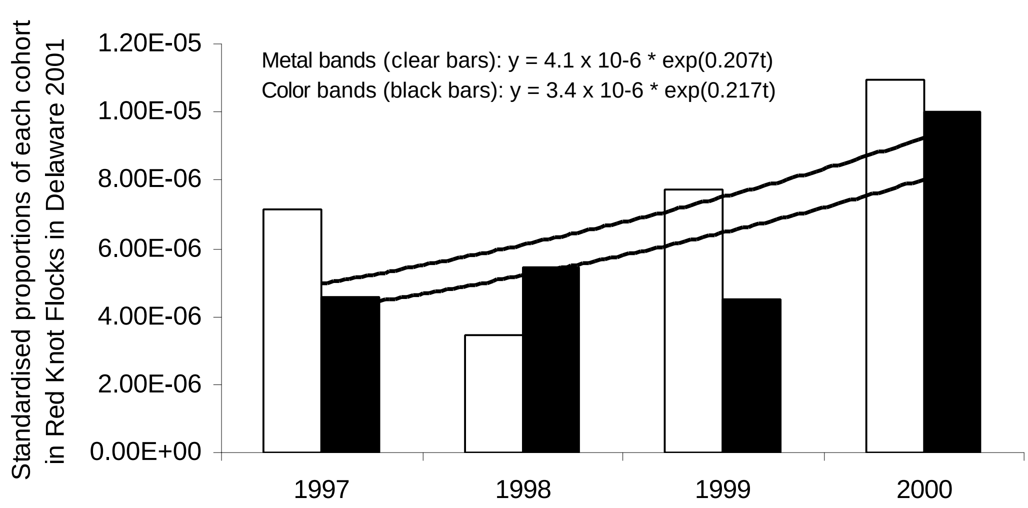
Cohort	**D97**	**D98**	**D99**	**D00**	**NJ97**	**NJ98**	**NJ99**	**NJ00**
Proportion of cohort in 2001 DE flocks (P_t)	0.00265	0.00711	0.00694	0.00947	0.00164	0.002328	0.0049	0.0049
Number originally banded (N_t)	893	638	1247	831	54	598	1402	583
P_{t-1}/P_t		0.37	1.02	0.73		0.70	0.48	0.99
N_{t-1}/N_t		1.40	0.51	1.50		0.09	0.43	2.40
Apparent Survival		0.27	2.00	0.49		7.78	1.11	0.42

(b) From Cannon-Net Catches

Cohort	D97	D98	D99	D00	NJ97	NJ98	NJ99	NJ00
Proportion of cohort in 2001 DE flocks (P_t)	0.00599	0.00374	0.00898	0.01272	0.00075	0.002246	0.01123	0.00299
Number originally banded (N_t)	893	638	1247	831	54	598	1402	583
P_{t-1}/P_t		1.6	0.42	0.71		0.33	0.2	3.75
N_{t-1}/N_t		1.40	0.51	1.50		0.09	0.43	2.40
Apparent Survival		1.14	0.81	0.47		3.69	0.47	1.56

Alternatively, if it is assumed that survival rates are constant, then a constant loss curve can be fitted through the standardised proportions data for both the color and metal band data. Figure 3.2 amalgamates the New Jersey & Delaware birds caught/scanned in the State of Delaware using a mean proportion for each year weighted by the number originally banded in each state. The constant loss curves fitted (of the form $y = a * e^{bt}$, where *a* and *b* are constants and *t* is time) show a remarkable similarity; the line for metal bands indicates an annual survival of 81.3% and for color bands at 80.5%. This assumes of course that recapture/resighting rates are constant between cohorts/years, something which, as discussed above, needs to be investigated in further detail.

Figure 3.2 Mean proportions of each year cohort in the State of Delaware weighted by the number originally banded.



4. ESTIMATING POPULATION SIZE OF THE POPULATION OF RED KNOT *CALIDRIS CANUTUS RUFA* PASSING THROUGH DELAWARE

The metal band recovery matrix used to calculate survival was entered into the Jolly Program (available at http://detritus.inhs.uiuc.edu/wes/jolly_info.html) and population size estimated using the Jolly-Seber approach (Figure 4.1).Given the result of the metal band survival analysis, constant survival and recapture rates were assumed. A mean figure of 77,000 birds were estimated for the four years with 95% CI of 28,000-126,000. The mean lies well within the range estimated by previous biologists. As stressed above, this estimate relies on survival estimates which have large 95% CI. It is not until more data are available that more precise estimates can be calculated. It should also be noted that if there is not complete random mixing between Delaware and New Jersey-caught Red Knot and birds are, on average, more likely to return to the side of the bay where they were originally caught, then this will be an underestimate of the total population size.

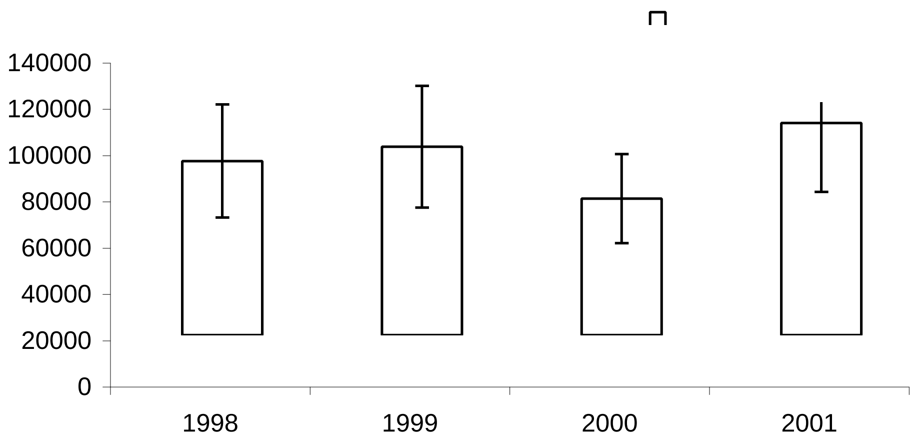


Figure 4.1 Estimated population size (mean ± 95% CI, based on mark-recapture data) of the population of Red Knot *Calidris canutus rufa* from birds passing through the State of Delaware.

5. DISCUSSION

5.1 Metal Band Survival Analysis

The overall result from this investigation is that we have been trying to calculate survival rates with too few years worth of data. As such, confidence estimates were large, survivals often out of range and speculation as to why a particular cohort was under or over represented in a particular year is unlikely to give rise to meaningful insights. Further years data or analyses using both Delaware and New Jersey data will be required.

One major problem associated with cannon-net derived retrap data is that the number of catches each field season has tended to be relatively small and, as such, have been prone to large sampling variances and possibly also sampling bias - birds which have been caught before may be less likely to be caught again for a period after capture. This may explain the anomalies observed in the data. If so, then several more years data will be needed to estimate an annual, rather than an average, survival with a reasonable degree of precision.

The survival analyses presented here are simple and development of a more sophisticated analysis may provide better estimates. The effect of trap dependence should be tested and also the use of multi-strata and possibly also Pollock's Robust Design. The former allows movement of birds between sites and, the latter, immigration and emigration to and from the population. Although these are complicated models, if the data support them, they will add more biological reality to the survival estimation.

5.2 Metal vs Color Band Survival Analyses

The comparison of the survivals calculated from the metal and the color band scan data was probably the most useful part of this study. The results were encouraging in that the estimates of the proportion of each cohort in the flocks were broadly similar between the two methods. There were however many problems associated with collecting these data, not least of which were the quality of the color bands and also the combinations used.

Despite this, the use of cohort-banded birds will become a useful technique to estimate survival. Large amounts of data can be collected relatively quickly by a small number of people. To some extent, it overcomes the problem of stochastic variation and possible bias associated with a small number of cannon-net catches. Once further years data are available then it will be possible to develop a modelling framework to determine survival and recapture rates with a greater degree of precision. Within this, an exploratory analysis will be required to determine whether the degree of precision associated with the survival rates derived from color band scans is adequate compared with metal band analysis.

The survival estimate calculated here of 80-81% is not dissimilar to other populations of Knot. Although this document is not the place to enter into a detailed discussion of Knot survival, Atkinson *et al*. (2000) found that adult Knot banded on the Wash, England, had survival rates varying between 70.2 to 97.3% per year with an average of 87.98 ± 1.18 SE. Boyd & Piersma

(2001) examined British Knot survival rates during three periods of differential population change and found that survival varied between 76.4 and 85.8%.

5.3 Band Quality and Colors Used

During the early part of the 2001 spring migration, many of the color bands were stained a ferric yellow/orange color, presumably from a stopping-off point further south. This caused problems with identifying white, yellow and orange color bands. This particularly affected Delaware-caught birds for the 1997, 1998 and 1999 cohorts which were extremely difficult to discriminate between in 2001 (Table 5.1) and further thought is necessary to avoid these problem in future. It is unfortunate that, by chance, during the first three years of this study Delaware-banded birds carried only yellow, orange and white color bands! Although it is impossible to know, the two main observers (PWA & IGH) are confident that some, possibly many, errors were made. As New Jersey birds have always had a green band the two States have been easy to separate. Also, during the earlier years, only 1997 (green & white) and 1999 (green and yellow) New Jersey cohorts are likely to be confused and, as very few Red Knot were banded in the state during 1997, this is unlikely to cause a large problem when estimating survival.

Color band quality was also an issue. The use of split bands and especially celluloid bands has led to major fading and discoloration. Some of the birds caught during 2001 also carried split rings which were in the process of opening. One bird even had a gap of 3-4 mm and the ring would have fallen off soon after capture. The solution to this is to use wrap-around Darvic bands which are then glued closed. To overcome the issue of confusion over discolored bands, it may be best to avoid the use of two of the yellow, orange or white bands or use them in unambiguous combinations with a stronger color such as blue, green or red. Table 5.2 shows the two-color combinations used in previous years in New Jersey and Delaware and we recommend that white and yellow be dropped from the list of colors used. Once the two-color band combinations have been used up then it will be necessary to use a series of three-color combinations, two on one leg and one on the other.

Year	STATE OF DELAWARE		STATE OF NEW JERSEY	
1997	Fg/W:M/W		Fg/Y:M/G	
1998	Fg/W:M/O		Fg/G:M/G	
1999	Fg/Y:M/O		Fg/R:M/G	
2000	Fg/G:M/O		Fg/W:M/G	
2001	Fg/O:M/O	North	Fg/B:M/GO	May week 1
	Fg/R:M/O	South	Fg/B:M/GR	May week 2
			Fg/B:M/GW	May week 3
			Fg/B:M/GY	May week 3

Table 5.1 Combinations of color bands used to mark cohorts of Red Knot in Delaware Bay since May 1997. A number of birds were also marked as individuals, details of which are not shown here. Fg = Green Flag, B = Blue band, G = Green band, M = Metal USFWS band, O = Orange band, R = Red band, W = White band, Y = Yellow band. / indicates the position of the knee joint and : indicates break between left and right leg combination. Thus Fg/W:M/W indicates Green flag upper left, White lower left, Metal upper right and W lower right.

		RIGHT LEG					
		B	G	O	R	W	Y
	B						
	G		NJ98	D00			
LEFT LEG	O			D01			
	R		NJ99	D01			
	W		NJ00	D98		D97	
	Y		NJ97	D99			

Table 5.2 Two color-band cohort combinations used in Delaware Bay. Avoiding white and yellow will avoid confusion in the recognition of cohorts due to band staining. The shaded in combinations are recommended for future use.

6. RECOMMENDATIONS

6.1 Future Survival Analyses

- The main problem with the current survival analyses is lack of data. Analyses using catch/scan data from both sides of the bay will improve precision.
- Once further years data are available, the use of multi-strata and robust design models should be investigated.
- Once issues over band color and quality have been resolved, scanning data has the potential to become a useful tool to estimate survival. However, this will take several years further fieldwork.

6.2 Bands and Future Cohort Combinations

- Wrap-around Darvic bands should be used in future.
- Yellow and white should be avoided in the 2-color band cohort combinations.
- Where possible, pale blue darvic should be avoided in Delaware Bay due to possibility of confusion with white.
- Where possible, bands should be glued to ensure they do not fall off.
- Cohort combinations should be kept simple to facilitate reading in the field and make recognition, and subsequent identification, of non-cohort marked birds (i.e. individuals) easier.

6.3 Catch Sizes

- Given the variation in the proportions associated with the metal band data, it is prudent to maintain current catching levels until there are sufficient birds marked to be able to monitor survival rates with a reasonable degree of precision. At present 750-1000 birds per year for each side of the bay would be sufficient.
- From observations in the field in 2001, there was a suggestion that birds were net-shy. To counter this catches should be made where there is minimal disturbance before the catch so that birds do not recognise catching operations are taking place. Records of visual evidence that banded birds are avoiding the net should be recorded in future.
- Samples should be mist-netted to determine any obvious bias in cannon-net catches.

6.4 Scanning

- Scanning may avoid some of the potential biases associated with cannon-netting given the caveats noted above. The scan totals for this study season gave a reasonable precision but 10,000-15,000 should be adequate. In future years, the optimum number will be explored statistically using power analysis or similar.
- Autumn scans would be particularly valuable to determine if similar proportions of color-marked birds are present compared with spring.

Acknowledgements

This work was funded by Division of Soil and Water, Delaware Department of Natural Resources and Environmental Control. A vehicle was kindly loaned to us by US Fish and Wildlife Service. Thanks to all the volunteers who have helped out on catches over the years. Without their increasing support, these catches would not have been possible. We would like to thank the following for their observations of color-banded birds: Dave Carter, Jacquie Clark, Graham Crouchman, Simon Gillings, Rob Robinson & Robin Ward. Allan Baker and Patricia Gonzalez very kindly provided details of previously-ringed birds. We would especially also like to thank Dave Carter and Jim Hewes for the enormous logistical support throughout the study and Mark DelVeccio for putting up with the shorebird researchers who descended on the St Jones Reserve during May 2001.

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