



BTO Research Report No. 308

**Red Knots *Calidris canutus* in
Delaware Bay 2002.
Survival, foraging and marking strategy**

With contributions from:

**Philip W. Atkinson, Graham F. Appleton, Jacquie A. Clark, Nigel A. Clark, Simon
Gillings, Ian G. Henderson, Robert A. Robinson, Richard A. Stillman.**

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EXECUTIVE SUMMARY

1. This report provides an analysis of work carried out by shorebird monitoring teams in Delaware Bay in spring 2002.
2. Data from six years of ringing studies of Red Knot were analysed to investigate the relationship between departure weights and survival. Departure weights were estimated for each bird and the hypothesis tested that Red Knot with lower departure weights had lower subsequent survival. The models supported this hypothesis and that there had been an increase in the proportion of Knot reaching the departure weight in more recent years.
3. In 1997 and 1998 most birds reached target weight but in later years an increasing proportion failed to reach target weight and so towards the end of the season a higher proportion of birds had lower predicted survival. This is likely to lead to a decline in the population if it is not countered by an increase in recruitment of young birds into the population.
4. Pilot work was carried out to assess the functional response (*i.e.* change in intake rate vs prey density) of three species of shorebird; Semipalmated Sandpiper *Calidris pusilla*, Dunlin *Calidris alpina* and Red Knot *Calidris canutus*. These studies were carried out by placing known densities of eggs on shallow trays of sand and videoing the birds that came to feed on them. The overall density of birds using the trays was related to the initial density of eggs on the trays. During the course of the five minute experiments about 80% of the eggs were taken.
5. Pecking rates were similar in all species even though there was a five-fold difference in the fat free weight between the species. There was no difference between the species in the number of eggs taken per peck, although this was related to initial egg density. The pilot work was considered to be a success and it was felt that a full project carried out on both sides of the Bay should be undertaken in 2003.
6. 11,527 Red Knot were checked for cohort-based colour ring combinations during the course of the 2001 season. Unlike the previous year there was not an expected relationship between the year that each cohort was marked and the probability of resighting. This was thought to be due to problems associated with staining or ring loss.
7. 100 Ruddy Turnstone were marked with individual combinations of colour rings and 31 of them seen again during the course of the season. The number of individuals needed to be marked in order to monitor survival will be assessed after the 2003 season.

Chapter 1. Survival rates and body condition of Red Knots in Delaware Bay – influence of body condition at departure on survival.

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1.1 Survival, recruitment, immigration and emigration..... How does the Nearctic Red Knot population add up?

One of the keys to understanding how a changing environment impacts on a population is to understand how these factors influence the demography of the population. There is strong evidence that the Nearctic *rufa* population of Red Knot has undergone a large decline over the past decade (Dr Larry Niles pers. comm.). Discounting emigration and immigration as being negligible, the ways this decline could have occurred could be through recruitment or survival. Recruitment is extremely difficult to measure as productivity in the Arctic will be difficult to estimate without some larger scale surveys than currently take place. In the fall (all seasons mentioned here relate to the northern hemisphere), juvenile Red Knot migrate to the southern wintering grounds (South America or Florida) and the majority remain there during the following summer. An unknown (but small) proportion of birds may attempt a migration back to the breeding grounds in the spring following birth. Some juveniles reach Delaware Bay at this time but generally are characterised by low weights and it is unlikely that many of these will make it back to the Arctic breeding areas that year. It is not known whether these come from the southern hemispheric wintering population or from the population of birds that winter in Florida.

An estimate of productivity (*i.e.* numbers of chicks produced per pair) could be made in the Arctic but would require a very large effort and is likely to be unsuccessful due to logistical reasons. Another alternative which has been successful is scanning wintering birds in South American wintering grounds for juveniles. It is thought that the majority of juveniles winter there and so annual scans of the number of juveniles per adult could give an estimate of productivity plus mortality following the migration down to South America. However there is evidence that juvenile birds may not make it down to the southern Argentinian and Chilean wintering areas during their first year and a higher proportion may winter further north in Brazil and so estimation of breeding success using this method may be flawed also.

In terms of the population passing through Delaware Bay the following year, these juveniles are effectively excluded from the population as most stay in South America for the summer following hatching or at least only very small numbers make it as far north as Delaware Bay. A third and potentially more useful way of estimating recruitment is to use the Delaware Bay banding data to estimate recruitment and rate of change using models developed by Pradel (1996). At this point recruitment would be juveniles hatched approximately 22-23 months previously and thus would incorporate first and second year survival. This figure is analogous to the actual number of birds recruited into the breeding population, assuming that all birds first breed at two years old. These models would be worth exploring in conjunction with the South American banding data.

It is also necessary to have a good understanding of the survival if we are to unravel the recruitment/survival complex and the relative impact on the observed population changes. Several sets of data are available. Probably the best set is the information collected from Delaware Bay from 1997 to the current day. There is also catch data from Argentina, Chile and Brazil, which will also be useful. Due to the mixing of the various populations from the different S American and south-eastern North American wintering populations in Delaware Bay, it would be unwise to combine the datasets without first thoroughly investigating whether this would be a valid approach.

With a migratory species such as the Red Knot, there are likely to be various 'bottle necks' through which the birds pass through. It follows that there could be several places within the annual life cycle which could have a large impact on survival. At present we do not know just know where these constraints lie but they could be many and various. On the annual migration, a bird must make the

decision as to when to move from the wintering areas, how long to stay in a particular staging site, at what weight to leave *etc.* Each of these decisions may be critically time-based, *e.g.* concurrent timing with a particular food resource (*e.g.* it might pay to arrive at peak spawning time of HSCs in DB) or by getting to the breeding areas by a certain time. Each of these stages can be influenced by stochastic events *e.g.* bad weather preventing migration or by other factors that affect the resources that occur in the staging areas (*e.g.* a decline in food resources).

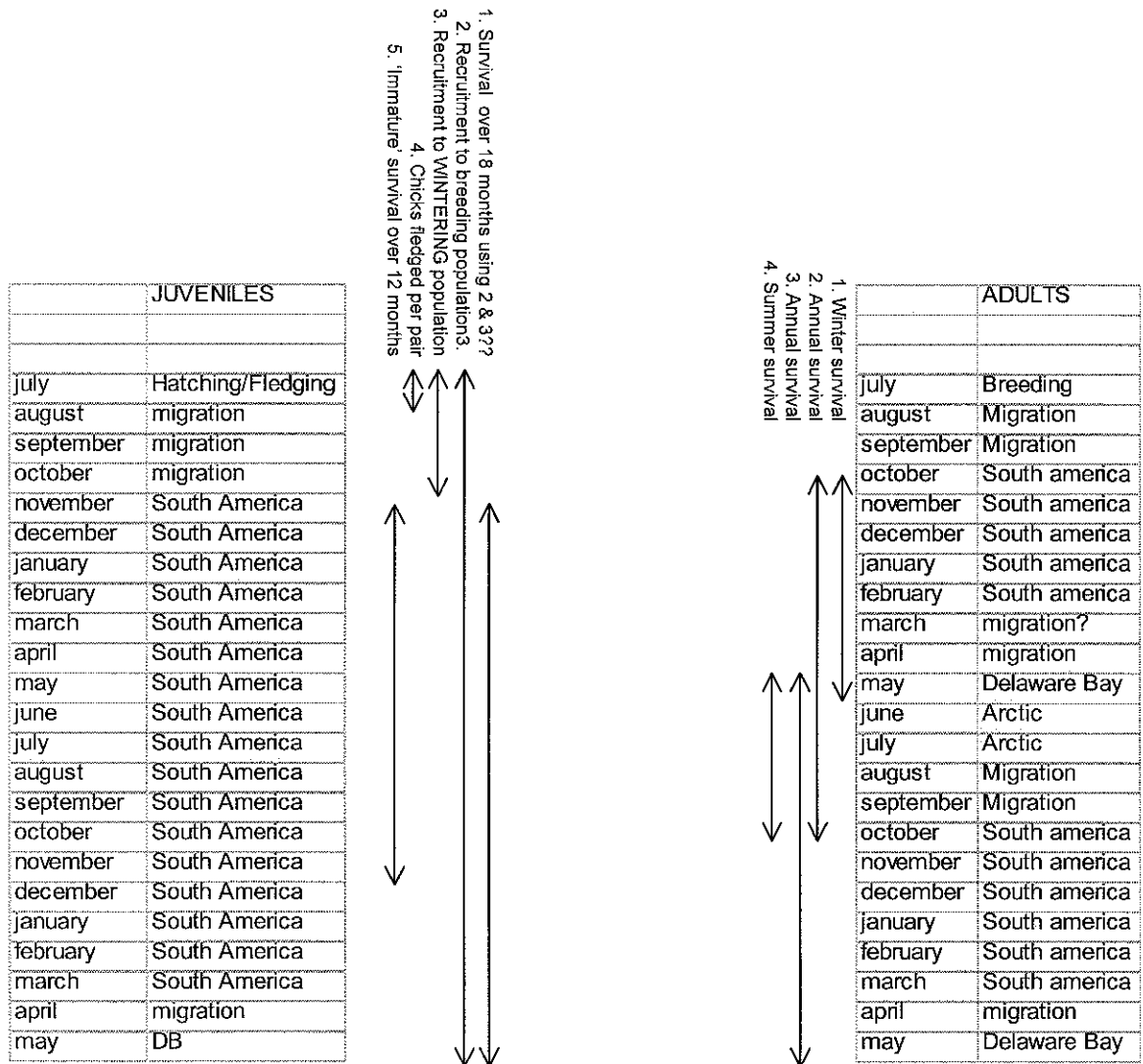
Making the best decision as to when to migrate when reacting to essentially stochastic factors such as weather requires complex decision making. It requires the bird to have knowledge of how weather conditions vary – for example if it is bad migration conditions one day is it likely to be bad the next or what is the likelihood of it being good in a two, three or four *etc.* days time. Each decision must be made in light of the bird's condition. For example, if there is the likelihood of bad weather for the next week and the bird is slightly underweight then the best decision may be to leave now rather than wait for a week when it will be at or above target weight but it will arrive at the next staging stop or the breeding areas too late.

Given that the factors impacting on survival and recruitment can act at various different times, to try and understand where the constraints lie it is necessary to deconstruct the life history and using available data as far as possible (Figure 1.1) Given the life history and catching effort it may be possible to estimate recruitment based around (a) number of fledged birds per pair in the Arctic (unlikely to be of much use), (b) estimates of recruitment to the wintering population by estimating the number of juveniles per adult and (c) number of two year old birds entering the 'breeding population', *i.e.* those passing through Delaware Bay. Through the use of (b) & (c) it may be possible to obtain an estimate of juvenile/first-year mortality while the birds are in South America and migrating up to Delaware Bay although the caveats of juveniles wintering in different places to adults must be considered. The metal band data from S America should also be used to construct survival models to determine survival of juvenile birds from retraps in South America if sufficient data are available.

The decline in birds seen wintering in South America extremely worrying and there has been an apparent concurrent decline in the numbers of birds passing through Delaware Bay as well and we need to understand the relative contribution of recruitment and survival to the observed population change and understand the mechanisms and locations of where the major bottlenecks are.

In this report we solely look at survival in relation to the condition birds leave Delaware Bay. In particular we investigate whether birds with lower weights on departure have a different survival rate to those which are heavier.

Figure 1.1. Demographic parameters which could be collected from the Nearctic Red Knot population, given current fieldwork activity.



1.2 Red Knot and Horseshoe Crabs in Delaware Bay

One of the major bottlenecks that takes place in a Red Knot life history is to pass through Delaware Bay in spring, fatten up and reach the Arctic breeding areas by a certain time. Timing is likely to be critical for these high Arctic breeders – arrive too early and you run the risk of poor weather conditions, (as in Greenland in 1972 and 1974, Boyd 1992) and arrive too late and territories may be taken or there may not be enough time left to raise a brood.

One of the key questions in terms of Delaware Bay is whether changes in food supply have impacted on the bird's survival (and subsequent breeding success). There are several different approaches that can be taken to answer this question which are complementary. To look at the impact of changing egg densities on rates of weight gain the individuals-based modelling approach developed in the UK by John Goss-Custard, Bill Sutherland and Richard Stillman is most appropriate approach. In 2002 the use of feeding pans to calculate functional responses was trialled (see Chapter 2 in this report). This was extremely successful and further experiments are planned for 2003. This will give good estimates of how long it will take for birds to reach a specific target weight at varying densities of eggs.

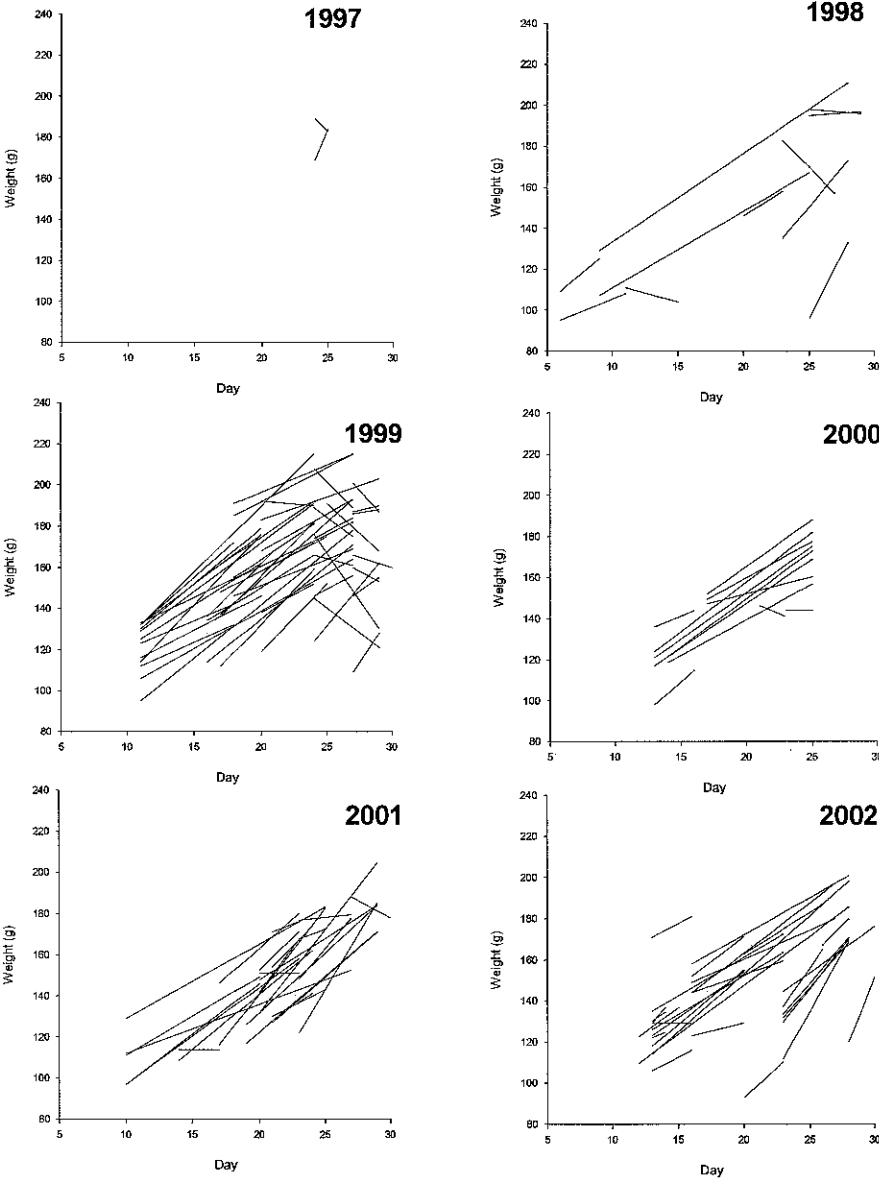
1.3 How do birds acquire weight and how do we model this?

To look at the impact of rates (or total) weight gain on survival requires an understanding of how birds acquire weight as in some years late-arriving birds have been able to put on weight at extremely fast rates in short periods of time whereas in some years where they have arrived earlier weight gains per day have been less dramatic. It is clear that, in some (most?) years birds arrive in the bay at different times. Weight gain for an individual bird is also likely to be non-linear (individuals brought into captivity by Mike Haramis for stable isotope sampling showed an exponential rate of increase).

Work by Theunis Piersma and colleagues indicate that in some ('good') years birds undergo hypertrophy, *i.e.* they elongate their gut and change the size of other organs, feed voraciously to gain sufficient weight and then sit around and shorten their guts (as well as changing other body parts). With birds arriving at different times and with this non-linear weight gain pattern, it is clearly inappropriate to use mean weights per catch to estimate the population weight progression and translate that back into a 'mean' weight gain for that particular year.

In this report we have used GLMs to estimate weight progressions from individuals retrapped in the same year (Fig 1.2) to look at how individuals gain weight with the rationale that the rate at which birds gain weight is likely to be determined by (a) the time interval in days between recapture, (b) its weight at capture (*i.e.* heavy birds may put on more/less weight than light birds at a specific date) and (c) the time (day in May) of its capture. Option (c) is included as late-arriving birds may need to put on weight faster than early arriving birds if there is an 'optimum' date at which birds should leave the bay. Putting on weight faster or being heavier at an early date may be a disadvantage.

Figure 1.2. Weight changes in individual birds caught twice in a season. Each line represents one bird and connects the weight at first and second captures.



Weight gains were modelled using a generalised linear model in SAS GENMOD procedure as an exponential function of the terms above and their interactions. As the log link function does not allow for negative weight gains, which do appear in the data, 50g was added to all weight gain values to make them positive. Once the model was run 50g was removed from all predicted values. Additional work (Robinson et al. draft ms) has shown that a linear model is very comparable and both approaches explain *c.* 70-80% of the variation recorded in the same-year retrap weight gain data. In the survival analysis we used the exponential model although the linear model gave similar results.

To identify and estimate the variables in the minimum adequate model to explain weight increase, the three variables and their interactions were entered into a model and a backwards selection procedure used to find the minimum adequate model (Table 1.1). As the data were over dispersed the PSCALE option was used. This fixes the scale parameter at the value 1 in the estimation procedure. After the parameter estimates were determined, the exponential family dispersion parameter is assumed to be given by Pearson's chi-square statistic divided by the degrees of freedom, and all statistics such as standard errors and likelihood ratio statistics were adjusted appropriately

Models were produced with various combinations of the different parameters and interactions. The interaction term W*D was found to be significant. The best fit model using data from all years was found to be:

$$\text{Weight gain (g)} = \exp[\alpha I + \beta D + \chi W + \delta DW]$$

Where *I* = recapture interval (day), *D* = day of first capture (days after 1 May) and *W* = weight at initial capture.

Table 1.1. Estimates of the parameters from the minimum adequate growth model resulting from the GLMs (log transformed).

Parameter	Estimate ± SE	$\chi^2_{1,122}$	<i>P</i>
Intercept	2.82 ± 0.354	63.57	<.0001
I	0.0525 ± 0.0045	140.39	<.0001
D*W	-0.00072 ± 0.00013	29.68	<.0001
D	0.105 ± 0.0175	37.19	<.0001
W	0.0079 ± 0.0028	8.05	<.001

The parameter associated with recapture interval was positive, *i.e.* birds put on more weight the longer the retrap interval. The day and weight terms are positive indicating birds caught later and heavier are putting on weight at a higher rate but these are modified by the significant day*weight interaction, which is negative. Birds which are light in late May put on weight at a greater rate than an equivalent bird in early May and vice versa. Again this shows that the rate of weight gain is flexible— if birds arrive early, they do not put on weight at such a fast rate as birds arriving later. In effect, rates of weight gain can vary between years but there are opportunities for later arriving birds to compensate and put on weight at a quicker rate and have some capacity to ‘catch up’ with birds arriving earlier.

For example Fig 1.3 (a-b) shows example predicted rates of weight gain per day over a two week period for a bird weighing 110g caught at different times during May. If it was caught on 10 May it is predicted that it would take 18 days to reach a target weight of 195g and be ready for departure by 28 May. However if a bird arrives on 25 May, it is predicted that it only need to spend 14 days feeding to reach target weight. These are average growth parameters. Year was entered into these models (in the form the parameters I and I*year thus allowing the slope, *i.e.* the rate of increase per day to vary between years) and not found to be a significant factor ($\chi^2_{4,118} = 0.94$, NS) but with 30 or less same-year retraps in each year the power to detect changes may well be small. Larger samples would be extremely useful. However a plot of the average growth function through the data for individual years shows that there was a good fit, explaining over 70% of the variation in weight gain in each case (Fig 1.4).

Figure 1.3. (a) Growth trajectories for a bird weighting 110 grams at different dates of initial capture in May (see inset box for dates of arrival) and (b) Days a bird was predicted to take to reach a target weight of 195g after weighing 110g at various dates in May.

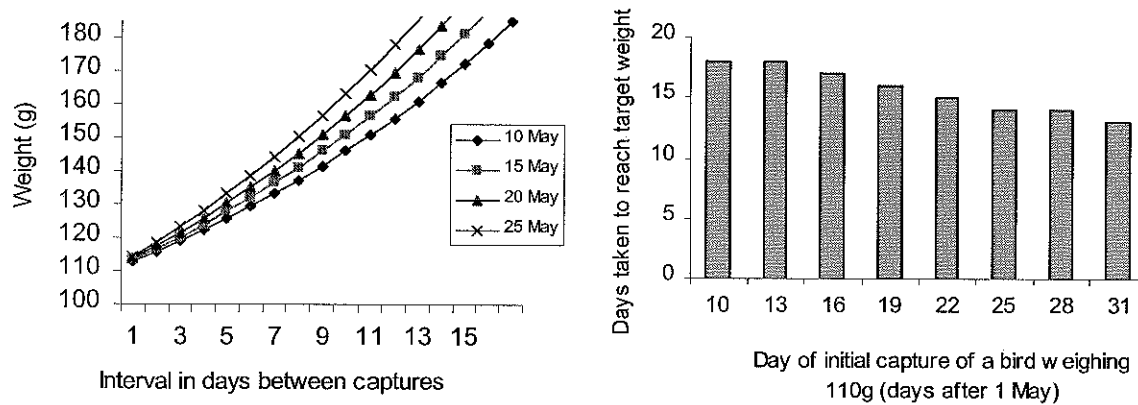
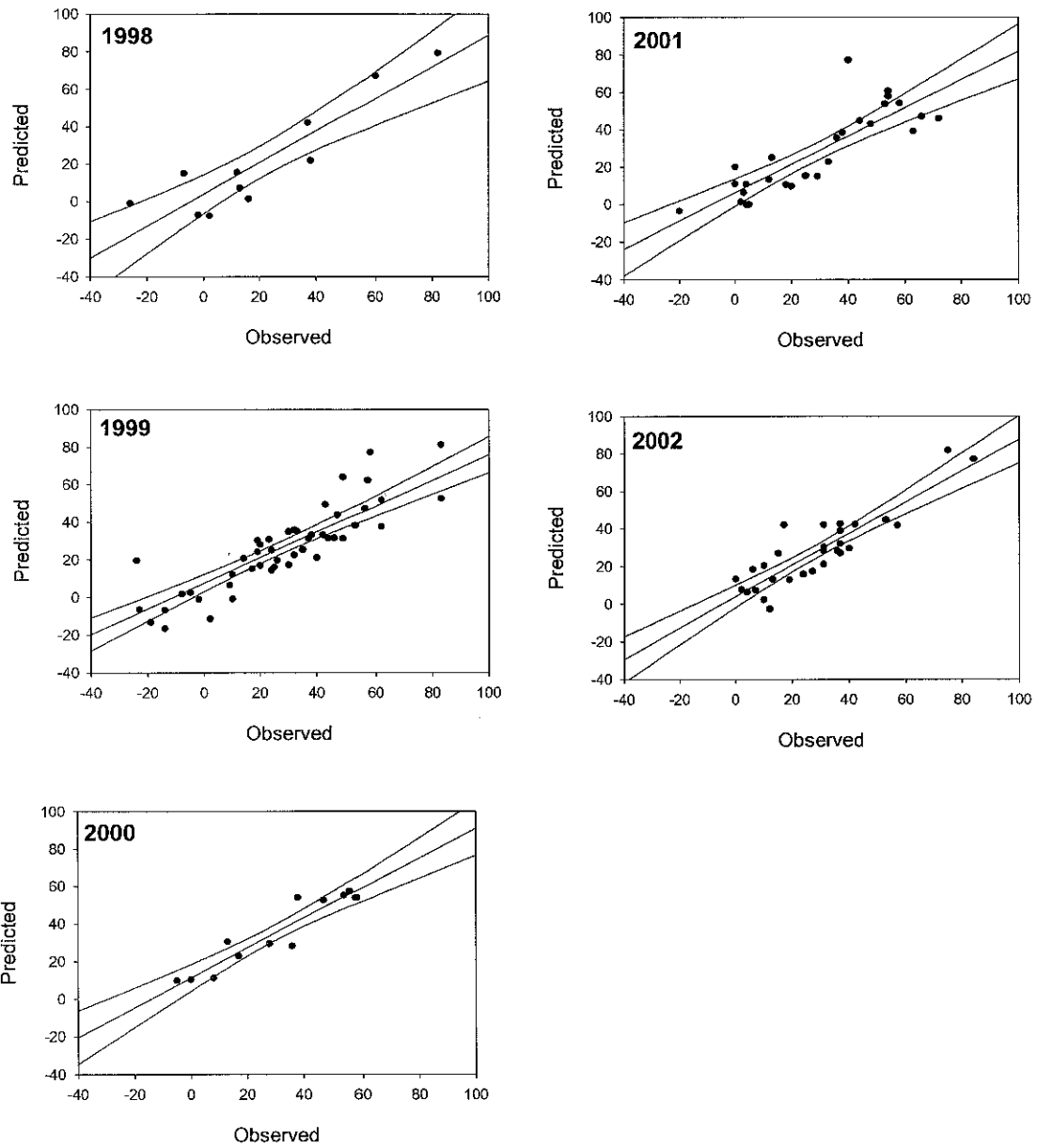


Figure 1.4. Observed weight gains vs those predicted from the GLM weight gain model. The line fitted through the data indicates the observed vs predicted relationship for each year \pm 95% CI.



1.4 Calculating survival rates in Delaware Bay Red Knot – is survival related to departure weight?

Delaware Bay, as a staging area and Horseshoe Crab eggs as a food resource, are likely to be an extremely critical resource for Red Knot as there are probably very few other areas, which have suitable conditions to allow Red Knots to stage in a suitable amount of time.

However to date, we do not know just what the demographic consequences of a reduction in the ability to reach a target weight are. If birds do not reach their departure weight in time then they may not have sufficient resources to make it back to the Arctic and would be destined either to try and fly north risking an increased chance of mortality, remain in Delaware Bay or return to South American wintering areas. We do not know which option birds would take. The question we are trying to answer in this analysis is: do birds which do not make target weight incur a survival cost?

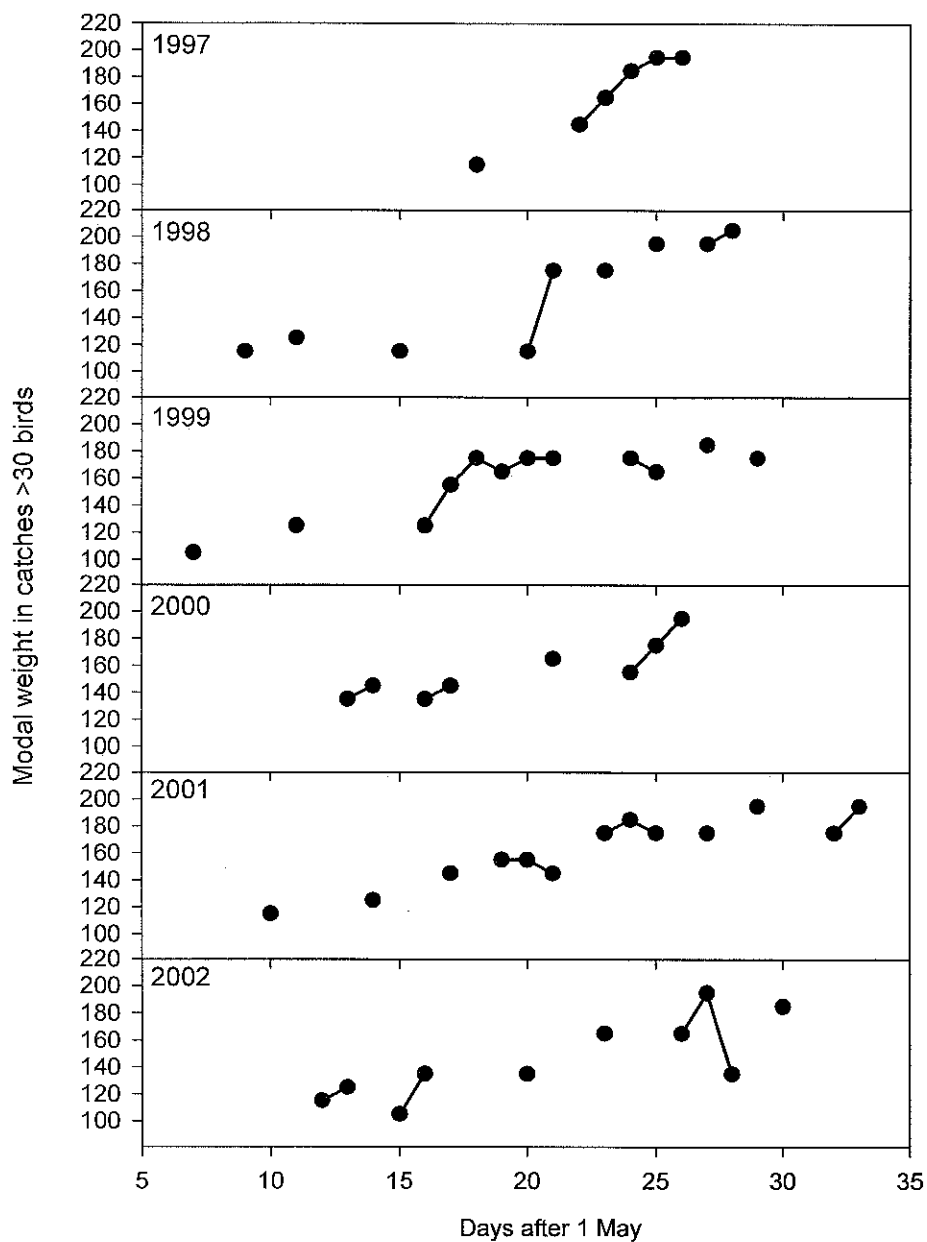
1.5 How to incorporate weight gain into the survival models?

In some years waves of birds pass through Delaware Bay and multi-modal weight distributions are observed in the catch data (see Robinson *et al.* 2003). It was not a simple task to deconstruct these and follow through each cohort (cohort in this sense = groups of birds arriving together), as the rate of weight gain is non-linear and depends on the initial weight of the bird and also the day it arrives in the Bay. To estimate the target weight that birds reach before departing we therefore transformed the weight data into 10 gram intervals [$\text{weight_interval} = 10 * (\text{weight} / 10) + 5$] and calculated the modal value of this weight interval for each catch which comprised more than 30 birds. We then plotted these over time on the grounds that birds will arrive and put on weight until they reach a maximum 'departure' weight. We would expect the pattern to be first of an increasing modal value over time, which would then level off as the earlier cohorts left and the later cohorts 'caught up' and reached their departure weights (Figure 1.5).

There is reasonable evidence that the modal weights do indeed level off in some years (*e.g.* 1997, 1999, 2001) but not in others (1998, 2000 and 2002) and it may be that, in the second group of years, birds were not caught late enough to see this levelling off, late arrivals depressed the modal value or indeed that all birds reached target weight together and departure was synchronised across the population. There are obvious biases in the data in that catching effort varied between years but a mean departure weight averaged across years was between 190 and 200g (Fig 1.5) and this modal value was on average first observed on 27 May across the six years (range = 25 to 29 May).

This is the first date at which birds reach target weight. If we are to look at the impact of weight on departure on subsequent survival then it is necessary to pick an 'average' day on which birds leave. Counts have shown that the greatest proportion of birds leave in the last few days of May and first few days in June. We have therefore picked an 'average' date of departure of 31 May. As some birds will have left the bay by then we have truncated the expected weights - any over 195g were given a value of 195g.

Figure 1.5. Model weight of Red Knot in catches in Delaware Bay during May and June where a sample of >30 birds were available.



1.6 Survival modelling

The data were first run through U-CARE v1.4 to perform goodness of fit tests. Using the six years of data there was some evidence of transience in the data, *i.e.* testing for an excess of newly marked birds never seen again ($z = 1.58$ one-sided $P=0.056$). This was likely to be due to the mixing of populations in Delaware Bay and uneven catching effort throughout the different migration seasons. One of the main anomalies was the catching regime in 1997 as over 90% of the birds were caught over five consecutive days late on in the season and it is unlikely that these catches would have sampled the full range of birds (*i.e.* from the different wintering populations) passing through the bay. After removing 1997 from the data, this problem was reduced ($z= 1.2$, one sided $P = 0.12$). However, we decided to use the 1997 data but also included a check by running concurrent analyses omitting it and just using 1998-2002 data. These gave very similar results and so we present results from the whole dataset only.

With the 1997-2002 metal band data for all birds caught in Delaware Bay, four basic models were constructed which included time-dependent and constant reporting and survival rates (Table 1.2). Based on a lowest value of AICc, the model $\phi_t \rho_t$ was the most parsimonious.

Table 1.2. Results of Red Knot survival models, based on recaptures of birds in Delaware Bay 1997-2002 for. The models are ranked by the Akaike Information Criterion (AIC), with the most parsimonious model at the top.

Model notation: ϕ = annual survival, ρ = annual reporting rate. Parameters: . = constant (*i.e.* time-independent) parameter, t = time dependent, W = linear function of the predicted weight at 31 May in year of capture, ($W, .$) = Survival in first year set to a logistic function of weight, constant rate in year after, AGE - Transient model, *i.e.* survival parameter calculated individually in year 1 and constant thereafter

The model number is indicated on the left hand side of the tables and is referred to as such in the text.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	No of parms	Deviance
1 $\phi_{(.+w)} \rho_{(t)}$	3484.672	0.34	0.40883	0.8454	7	3470.659
2 $\phi_{(w,.)} \rho_{(t)}$	3487.402	2.73	0.20219	0.2554	8	3471.385
3 $\phi_{(.)} \rho_{(t)}$	3496.206	11.87	0.00128	0.0026	6	3484.196
4 $\phi_{(t)} \rho_{(t)}$	3499.062	14.73	0.00031	0.0006	10	3479.035
5 $\phi_{(t)} \rho_{(.)}$	3501.117	16.78	0.00011	0.0002	5	3491.11
6 $\phi_{(.)} \rho_{(.)}$	3502.337	18	0.00006	0.0001	2	3498.336

To test whether body condition of each bird at its first capture was related to its subsequent survival we incorporated a measure of body condition into the input data files into MARK. Survival was set to a logistic function of the predicted weight at 31 May using the exponential model described above and incorporated into the $\phi_t \rho_t$ model. The model was therefore $\phi_{(.+w)} \rho_t$, where W is the body condition parameter. The need for time dependent weight parameters was also tested, *i.e.* did the relationship between body condition and survival vary over time.

Our hypothesis that birds with lower departure weights have lower survival rates tends to be well supported by the data. A comparison of a model with weight included as individual covariates compared with one without showed a Δ AICc of -11.87 indicating a great deal of support for the covariate model (comparing models 1 and 4 in Table 1.2). Birds with lower weights at 31 May tended to have much lower survival rates (logit transformed parameters from Model 1 in Table 1.2: Intercept = 3.31, slope = 1.42). There is some evidence that predicted survival has changed over time, or at least a greater spread of survivals has been recorded, especially later on in the season. If the median (and 5, 25, 75 and 95% confidence intervals) predicted survival rates are calculated for each catch using the growth equation it can be seen that there has been a decrease in the survival over time (Figure 1.6). In

1997 and 1998 the early arrival of birds meant that they were able to leave at a suitable weight whereas in later years an increasing proportion has failed to meet the target weight and so towards the end of the season a higher proportion of birds have had lower predicted survivals.

1.7 Discussion

1.7.1 Changes in apparent survival

The apparent change in survival observed in the birds caught in the bay might be explained in several ways. Survival for birds caught in the Bay between May 10 and May 20 does not seem to have changed and it is consistently high. After 20 May the range of survivals is much higher and many birds are predicted to have higher mortality rates. This suggests that either (a) some birds are not able to put on weight at a sufficiently high rate or that (b) some birds are arriving later and despite putting on weight do not make the required weight by 31 May, the time at which the rate of departure over the past six years has been highest.

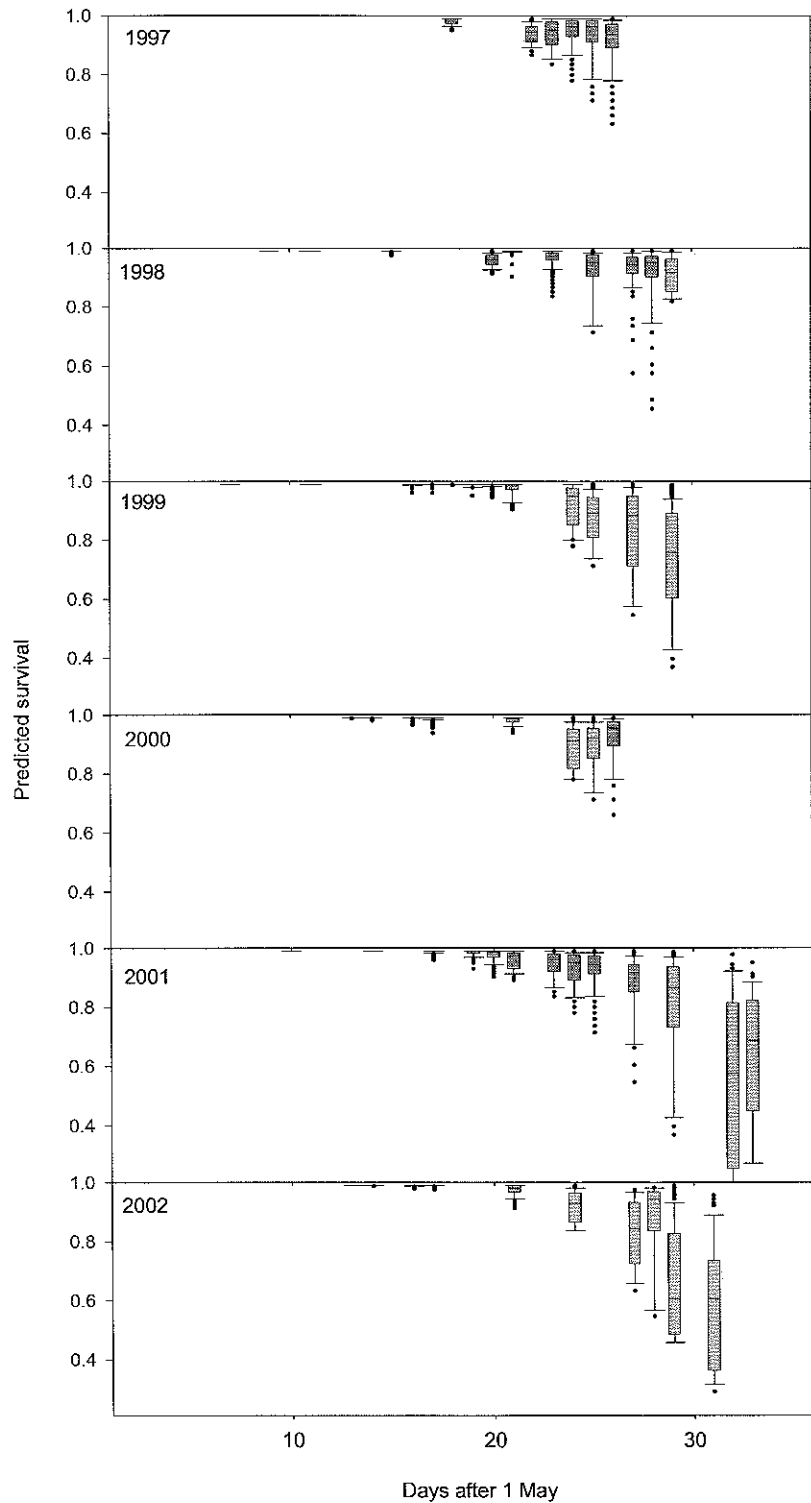
The weight models however indicate that the rates of weight gain over the six (or five given that the number of retraps in 1997 was very low) years of data have not changed significantly. This leaves late arrival as a probable explanation for the increased mortality in the later birds. Birds which arrive later tend to be the birds that winter in the southern Argentina and Chile and therefore it is likely that this population is likely to suffer greater mortality compared with earlier arriving birds which are from more northerly wintering areas.

There is evidence from the catch data that more 'pulses' of light weight birds are passing through the bay between 20 and 30 May in later years. This is discussed further in Robinson *et al.* 2003.

1.7.2 Issues with survival analyses

It is perhaps not surprising that there are transient problems with the Delaware Bay data as there is a relationship between date of capture in the Bay and consequent survival. As the catching regime (*i.e.* when birds are caught) has differed between years, we have not catching been random samples from each year and there will be issues with temporal & possibly spatial autocorrelation. As Delaware Bay is our best opportunity to view these birds, it is necessary to understand how birds arrive and depart and determine turnover to get any reasonable idea of what 'mean' survival is – the annual estimates from Mark are not likely to reflect the 'mean' survival of the population as a whole do not mean we are sampling the population in anything like a random manner in some years. As this is the case we need to substantially increase the recapture/resighting rate for birds to understand turnover, the effects of arrival dates on the population as a whole and estimate 'mean' survival rates.

Figure 1.6. Box plot (median, 5,25,75 & 95% confidence intervals) of the predicted survivals of birds caught in catches in Delaware Bay using the exponential growth model described in the text. Only catches of >30 birds have been used.



Chapter 2. Functional responses of shorebirds feeding on Horseshoe Crab eggs.

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1. Introduction

During May 2002 the British Trust for Ornithology, Centre for Ecology and Hydrology and Delaware Department of Natural Resources and Environmental Control measured the relationship between the density of horseshoe crab eggs on the sediment surface and the feeding rates of shorebirds (*i.e.* the functional response). This report describes the fieldwork and data analysis methods and presents the functional responses of semipalmated sandpiper *Calidris pusilla*, dunlin *Calidris alpina* and red knot *Calidris canutus*.

2. Methods

2.2.1 Fieldwork methods

Fieldwork was conducted between 18 May and 27 May 2002 on the west coast of Delaware Bay on beaches with high densities of foraging shorebirds. A shallow tray (area = 0.435 x 0.635 = 0.276m², depth = 2cm) was buried in an area in which birds had been actively foraging so that the lip of the tray was level with the surface of the sand on the beach. The tray was filled with egg-free sand so that the surface of the sand was level with the surface of the sand on the surrounding beach. Horseshoe crab eggs were mixed with dry sand and the sand / egg mixture spread uniformly over the surface of the sand within the tray. The dry sand separated the eggs (which tended to clump together when damp), meaning that individual eggs, rather than clumps of eggs were spread over the sand surface. A small amount of water was sprayed over the surface of the tray to dampen the dry sand so that the colour of sand within the tray was uniform and close to that of surrounding sand. Birds were disturbed during this procedure, but usually returned within a few minutes afterwards. The foraging behaviour of shorebirds was videoed (Canon 3CCD digital camera and 100-300mm zoom lens) from a distance of 10-25m for five minutes from the time at which the first bird started to feed in the tray. Videos were either taken from a concealed position in dunes or from a beached boat. We had no reason to suspect that videoing had any influence of the behaviour of the birds as they returned so quickly after being disturbed, spent virtually all of the time foraging rather than vigilant and often approached the boat to within 2m during experiments. The camera lens magnification was adjusted so that the tray almost filled the camera field of view. During experiments the number of birds of each species within the tray was counted every 15s. After the five minutes had elapsed the birds were disturbed to prevent any further consumption of eggs from the tray. The surface sand from the tray was then removed to a depth which ensured that no eggs were remaining within the tray and stored. Eggs were later separated from these samples by elutriation with tap water and counted to determine the number remaining at the end of each experiment.

Egg density in the different experiments was varied from *circa* 300m⁻² (87 per tray) to *circa* 25000m⁻² (7000 per tray). Eggs for the lowest density were counted individually, while the numbers for the higher densities were estimated from a relationship between total volume and egg number. The sequence of different egg densities was randomised within each day.

2.2.2 Video analysis

Videos were analysed using the Observer video analysis package (Noldus Information Technology; www.noldus.com). Observations were made by following a focal bird from the time it first entered the tray, or appeared from behind another bird, until it moved off of the tray, or disappeared behind another bird. Birds fed by moving across the substrate making rapid pecking movements. As the horseshoe crab eggs are so small and birds' did not make consistent, obvious swallowing movements, it was not possible to determine whether an egg was swallowed after each peck. Therefore the videos were analysed by recording the rate at which focal bird made pecking movements. A peck was recorded each time a bird's bill made contact with the substrate. Any aggressive interactions between birds were also recorded. Up to 10 focal birds of each species were followed for each experiment. As pecking rates were rapid, videos were watched at half speed. Observations were concentrated within the first 60 s of experiments to minimize the effect of egg depletion. Although six shorebird species (ruddy turnstone *Arenaria interpres*, short-billed dowitcher *Limnodromus griseus*, sanderling *Calidris alba*, dunlin *Calidris alpina*, red knot *Calidris canutus* and semipalmated sandpiper *Calidris pusilla*) and laughing gull *Larus atricilla* fed in the experiment trays, sufficient data were only recorded for semipalmated sandpiper, dunlin and red knot. The analysis was therefore restricted to these species.

2.3. Results

High densities of birds fed on the experimental trays, up to 50 semipalmated sandpiper (180 m⁻²), 12 dunlin (43 m⁻²) and 10 knot (36 m⁻²). Similar, high densities of birds fed on the surrounding substrate, and we had no reason to believe that the birds avoided the feeding tray or altered their behaviour when on the tray. The combined density of the three bird species throughout the five minute experiments was positively related to the initial density of eggs, ranging from 4 to 37 birds m⁻² (linear regression; bird density = 3.99 + 0.00127 Egg density; n = 27; p < 0.001; Fig. 2.1a). This occurred because the higher density experiments attracted higher densities of birds for longer periods than the lower density experiments. Although the combined densities are shown, a similar relationship was found for each species.

Egg density was greatly depleted during the course of experiments. The percentage depletion of eggs was unrelated to the wide range of initial egg densities, with approximately 80% of eggs being consumed during each experiment (linear regression; n = 36; ns; Fig. 2.1b). Birds were still actively feeding at the end of the higher density experiments, and so it is possible that a higher percentage of eggs would have been consumed in these experiments had they continued for longer. Although the same in percentage terms, more eggs were consumed in the higher egg density experiments.

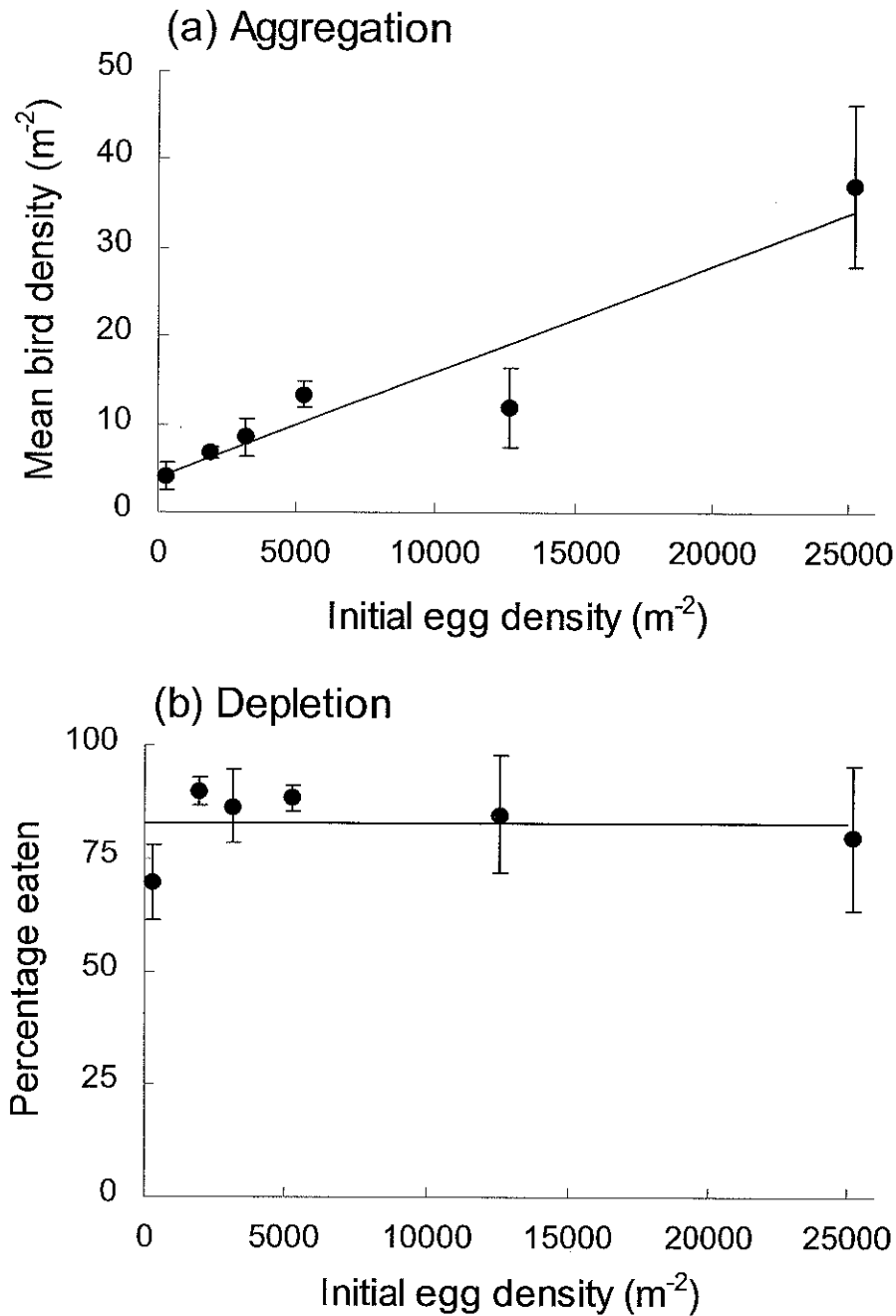


Figure 2.1. Aggregation of shorebirds (a) and depletion of eggs (b) during the experiments. (a) shows the density of semipalmated sandpiper, dunlin and red knot (mean \pm standard error) and (b) shows the percentage of eggs consumed within 5 minutes of the first bird entering the feeding tray (mean \pm standard error).

Pecking rates were similar in each species, 1.7 s^{-1} in semipalmated sandpiper, 2.0 s^{-1} in dunlin and knot, and were unrelated to initial egg density (linear regression; $n = 30, 28$ and 11 for semipalmated sandpiper, dunlin and knot; ns for each species) (Fig. 2.2). As it was not possible to directly measure whether or not an egg was swallowed after each peck, the probability of consuming an egg after each peck was calculated using the following procedure. First, the total number of pecks made by each species in each experiment was estimated by multiplying the number of bird seconds each was present for by the species-specific mean pecking rate. Second, the number of eggs per peck was estimated in each experiment by dividing the total number of eggs consumed by the total number of pecks by all species. The number of eggs per peck increased from close to zero at low egg densities to approximately one when egg density exceeded 10000 m^{-2} (Fig. 2.3), and was described by

$$p = \frac{p_{\max} E}{E_{50} + E}, \quad \text{eqn 1}$$

where p = number of eggs consumed per peck, p_{\max} = maximum number of eggs consumed per peck, E = initial egg density and E_{50} = egg density at which p is 50% of p_{\max} . The values of p_{\max} and E_{50} were estimated as 1.3 and 3355 m^{-2} respectively using non-linear regression ($p < 0.05$ for both parameters). The above procedure assumed that the number of eggs per peck was the same across all species. To test this assumption the residuals after fitting equation 1 were regressed against the proportion of each species feeding in the experiment. No significant effects were found showing that the number of eggs per peck was not influenced by the composition of species feeding in the experiment.

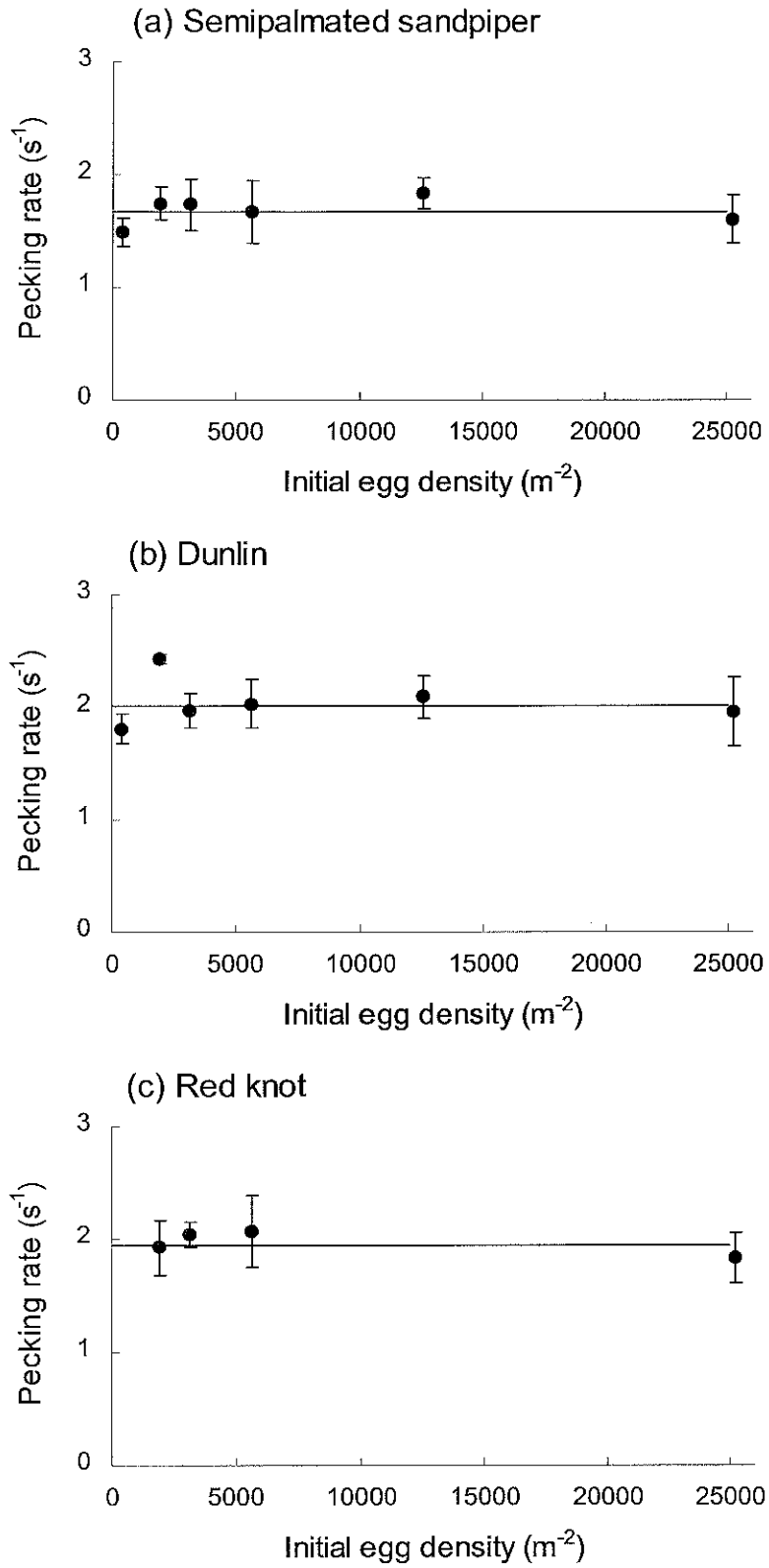


Figure 2.2. Pecking rates (mean \pm standard error) of semipalmated sandpiper, dunlin and red knot during the first minute of experiments.

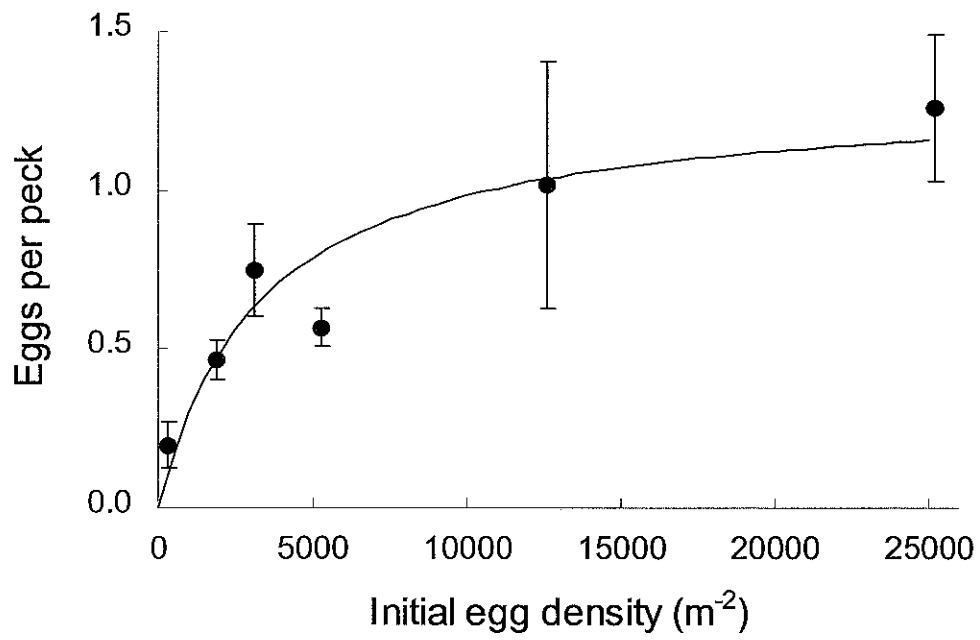


Figure 2.3. Relationship between the number of eggs consumed per peck (mean \pm standard error) and initial egg density. See text for the method used to calculate eggs per peck and the equation used to describe the relationship.

The feeding rate of each species in each experiment was calculated by multiplying the species-specific pecking rate by the number of eggs per peck predicted by equation 1. In each species, feeding rate increased up to a maximum value as initial egg density increased (Fig. 2.4). The relationship between feeding rate and egg density was described by fitting the following functional response

$$F = \frac{aE}{1 + aEH}, \quad \text{eqn 2}$$

where F = feeding rate (eggs s^{-1}), a = area search rate (m^2s^{-1}) and H = time to consume an egg (= handling time) (s). The values of a and H were estimated using non-linear regression (NLIN procedure of SAS) as 0.00069 m^2s^{-1} and 0.45 s for semipalmated sandpiper, 0.00083 m^2s^{-1} and 0.38 s for dunlin and 0.00094 m^2s^{-1} and 0.38 s for knot ($p < 0.05$ for all species).

The above analysis ignored the possible effect of interference competition on the intake rate of birds, but as bird densities were so high, intake rates could have been reduced by either direct or indirect competitive interactions between birds. However, aggressive interactions between birds were very rare; across the three species an average of only 3 aggressive interaction occurred every 10000 s, meaning that this potential mechanism for interference was extremely rare. Additionally, the residual feeding rate after fitting equation 2 was not related to variation in the density of birds on the feeding tray (linear regression; ns for all species), indicating that competitor density was not influencing feeding rate.

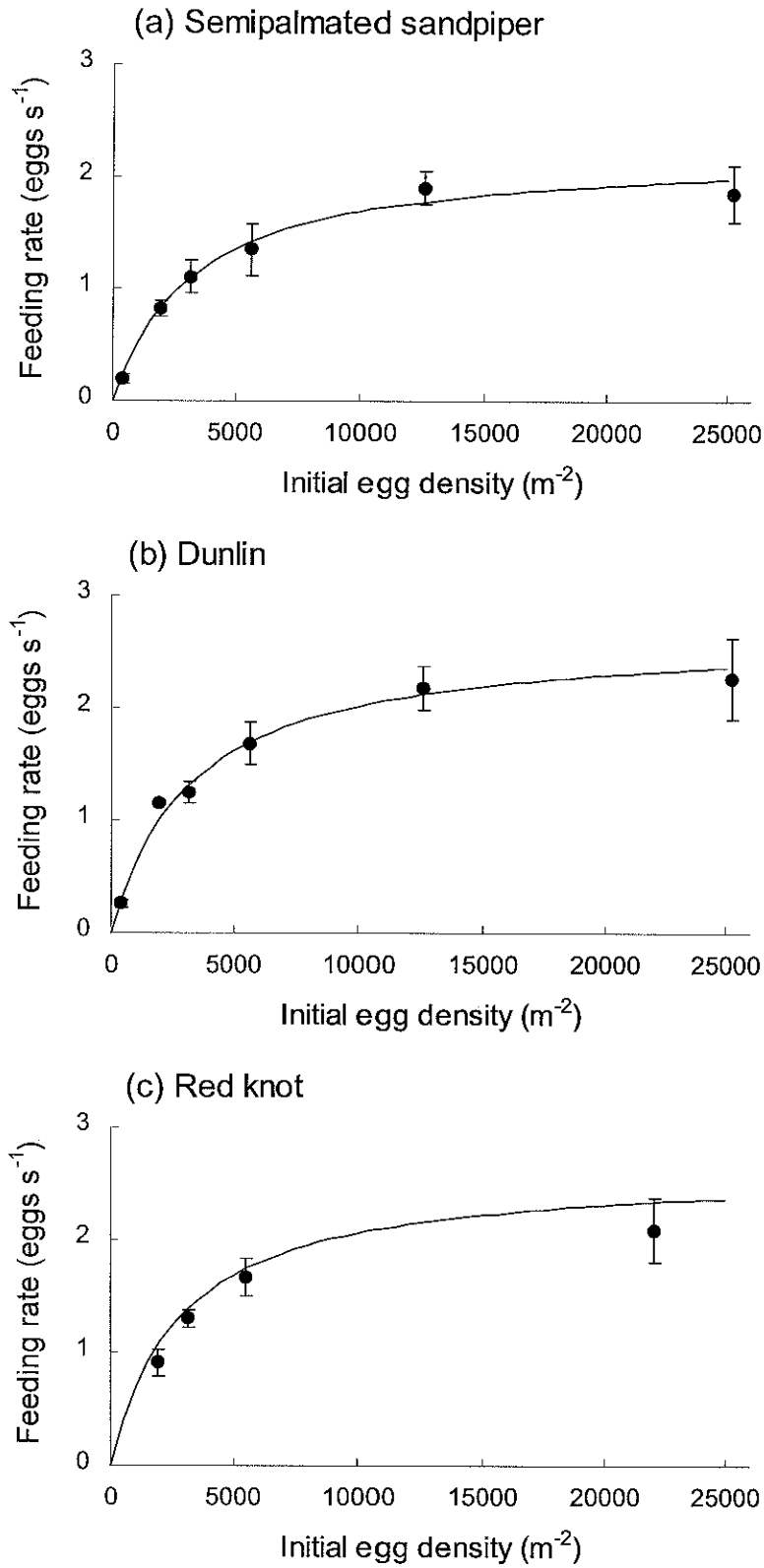
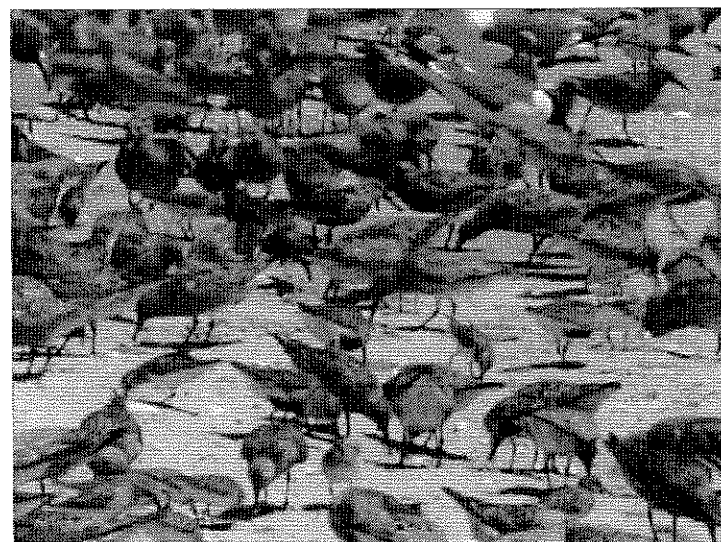
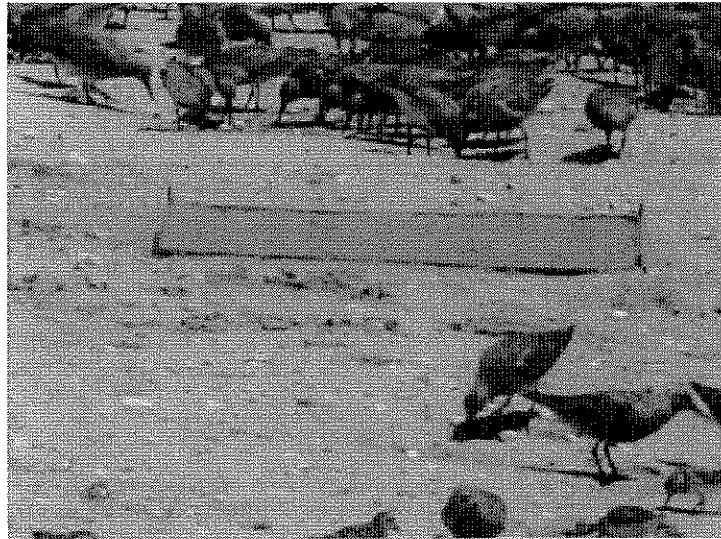


Figure 2.4. Feeding rates (mean \pm standard error) of semipalmated sandpiper, dunlin and red knot during the first minute of experiments. See text for the equations used to describe the relationships.

Figure 2.5. Example of one of the videoed feeding experiments



2.4. Summary

The three species had very similar functional responses, even though they varied considerably in the size. Each maintained high pecking rates down to very low egg densities, meaning that feeding rate decreased at low egg density because the probability of consuming an egg after each peck decreased as egg density decreased. The species had similar functional responses because they had similar pecking rates and consumed a similar number of eggs per peck. These similarities are perhaps not surprising as the species are closely related and had similar foraging behaviour.

The similarity of the functional responses may have consequences for the abilities of the different species to gain mass. The functional responses showed that, at a given egg density, each species consumed eggs at the same rate. The consequences of this for mass gain depend on the relative rates at which the species expend energy. The rate of energy expenditure, in the absence of thermoregulation, is positively related to body mass. Assuming that thermoregulation was insignificant, this indicates that the net rate of mass gain may decrease with body size (*i.e.* all species consume eggs at the same rate but knot have a higher energy expenditure than dunlin which have a higher expenditure than semipalmated sandpiper). To test this idea the thermoregulatory costs of each species would need to be estimated from the maximum and minimum air temperatures during the period that these birds feed in Delaware Bay. The consequences of these differences for migration will depend on the relative distances the species migrate and how much weight they need to put on.

The experiments estimated the intake rates of birds feeding on eggs on the substrate surface. In the natural situation birds can also feed on eggs buried below the surface. To determine the shape of functional responses for this situation further experiments are required in which eggs are mixed within the sand in the feeding tray.

Chapter 3. Resightings of color-marked birds in Delaware Bay in 2002. Are cohort based re-sightings useful to determine survival.

3.1 Introduction and methods

Following the mass scanning of Red Knot and Turnstone in the Bay in 2001, it was decided to repeat the sampling in 2002. The intra-cohort inter-bird distance method described by Atkinson et al(2002) was used. Briefly, this involves scanning through flocks of birds recording the number of unmarked birds (inter-bird distance, IBD) until a color-banded bird is found. The color-combination is recorded, and a new inter-bird distance is begun until the next marked bird or the end of the flock is reached. Taking the reciprocal of one plus the mean intra-cohort IBDs gives an estimate of the proportion of each cohort in the population

3.2 Results

3.2.1 Knot

In total 11,527 Red Knot were scanned for color-bands between 11th and 30th May 2002, yielding 675 IBDs. Randomising the flock observations using 300 bootstraps produced approximately normally distributed IBDs for some but not all cohorts (Figure 3.1). There is considerable skew for some cohorts, which may be due to small numbers of caught birds (*e.g.* cohort NJ97), misread band combinations, due to staining or ring loss, or differences between observers. Quite why the NJ00 cohort has such a skewed distribution is not clear. Due to this skew median, rather than mean IBDs were calculated across the resamples for each cohort and these are presented in Figure 3.2.

Figure 3.2 shows median intra-cohort IBDs for each cohort after 300 bootstraps of the flock observations. In 2001 intra-cohort IBDs declined in more recent years as expected whereas in 2002 IBDs did not change with year.

3.2.2 Individually-marked Ruddy Turnstone resightings

In total 15,817 Ruddy Turnstone were scanned for combinations, revealing 440 birds with colour bands. Note that this includes some duplication where the same flock was counted repeatedly following mixing.

One hundred Ruddy Turnstone were marked with individual colour combinations at Port Mahon on 13th May 2002 (39 individuals) and 17th May 2002 (61 individuals) to see if it is possible to use resightings of individuals to monitor survival of individuals without having to retrap a high proportion of the population each year. 31 individuals that were marked in 2002 were resighted on subsequent dates in 2002. All were resighted at Port Mahon with the exception of one bird resighted at Slaughter Beach - a bird ringed on 17th and resighted on 23rd. Of the 31 individuals observed 27 were from scans - the other four being incidental records. From 13th to 17th 5154 Ruddy Turnstones were scanned, and a further 7698 were scanned after the 17th. Thirteen individuals from the 13th May catch were resighted prior to 17th in 5154 birds scanned

Table 3.1. Resightings of individually marked Ruddy Turnstone at Port Mahon in May 2002.

Number of Individuals	Date of Catch	Observation Period	Number of birds Scanned
13	13 th	pre-17 th	5154
8	13 th	post-17 th	7698
10	17 th	post-17 th	7698
19	13 th	all	12852

Resighting rates of individuals

In order to estimate how many birds need to be scanned in future years to ensure sufficient individual resightings it is necessary to know how often the same individual is repeatedly resighted- *i.e.* if 1000 birds are scanned, how many will be different birds.

During color-band scans in May 2002 17 Red Knot individuals banded in New Jersey in 2002 were resighted and of these two were resighted twice. Therefore, of 19 individually marked birds located, 17 were true individuals. Therefore flock sizes to be scanned need to be inflated by a factor of $19/17 = 1.12$. Performing the same calculation for Ruddy Turnstone seen during scans (excluding incidentals), results in 27 individuals in 40 individually marked birds, and an inflation factor of 1.48.

3.3 Discussion

The Red Knot cohort re-sighting studies have now been going on since 1997 and we are now in a position to assess their long-term value in monitoring Red Knot populations passing through Delaware bay in spring. There were three main reasons why the cohort marking was set up;

1. To assess the movement patterns of birds using Delaware Bay in spring throughout the rest of the flyway.
2. To assess the extent of cross bay movement within and between years.
3. To see if it is possible to monitor survival through re-sighting color-marked birds.

There is no doubt that the marking has yielded a large amount of data about the movement patterns throughout the flyway, which is of considerable conservation value on its own. It has also confirmed the high degree of movement across the bay both within and between years. The data collected in 2002 strongly suggests that it is unlikely that cohort marking will enable survival to be monitored effectively at the present time. The main reason for this is the staining that affects some of the colors very badly, most notably white, yellow and orange. This staining rubs off after the birds have been in the Bay for a week or two. However, this gives very little time for observations to be taken before the birds leave. In addition some of the rings used in the early years were made from cellulose, which is not color fast. These factors are likely to have lead to the anomalous results obtained in 2002. An alternative method of marking individuals is now available and the value of this is explored in Chapter 4.

The individual color-marking studies on Ruddy Turnstone in 2002 showed promising results. It will not be possible to work out the level of colour-ringed birds in the population that is needed to give survival estimates until the work in 2003 has been analysed. All the Ruddy Turnstone have been marked with overlapped Darvic rings that are color fast and do not fall off. In addition Turnstone do not winter in areas where their rings stain in the way that those on Red Knot do.

Figure 3.1. Frequency distributions of median intra-cohort inter-bird distances from 300 resamples of flock observations for Delaware cohorts (left graphs) and New Jersey cohorts (right graphs). Letters (left leg, right leg) indicate tarsal color-bands used in each year: W = white, Y = yellow, O = orange, G = green, B = blue, R = red, X = any.

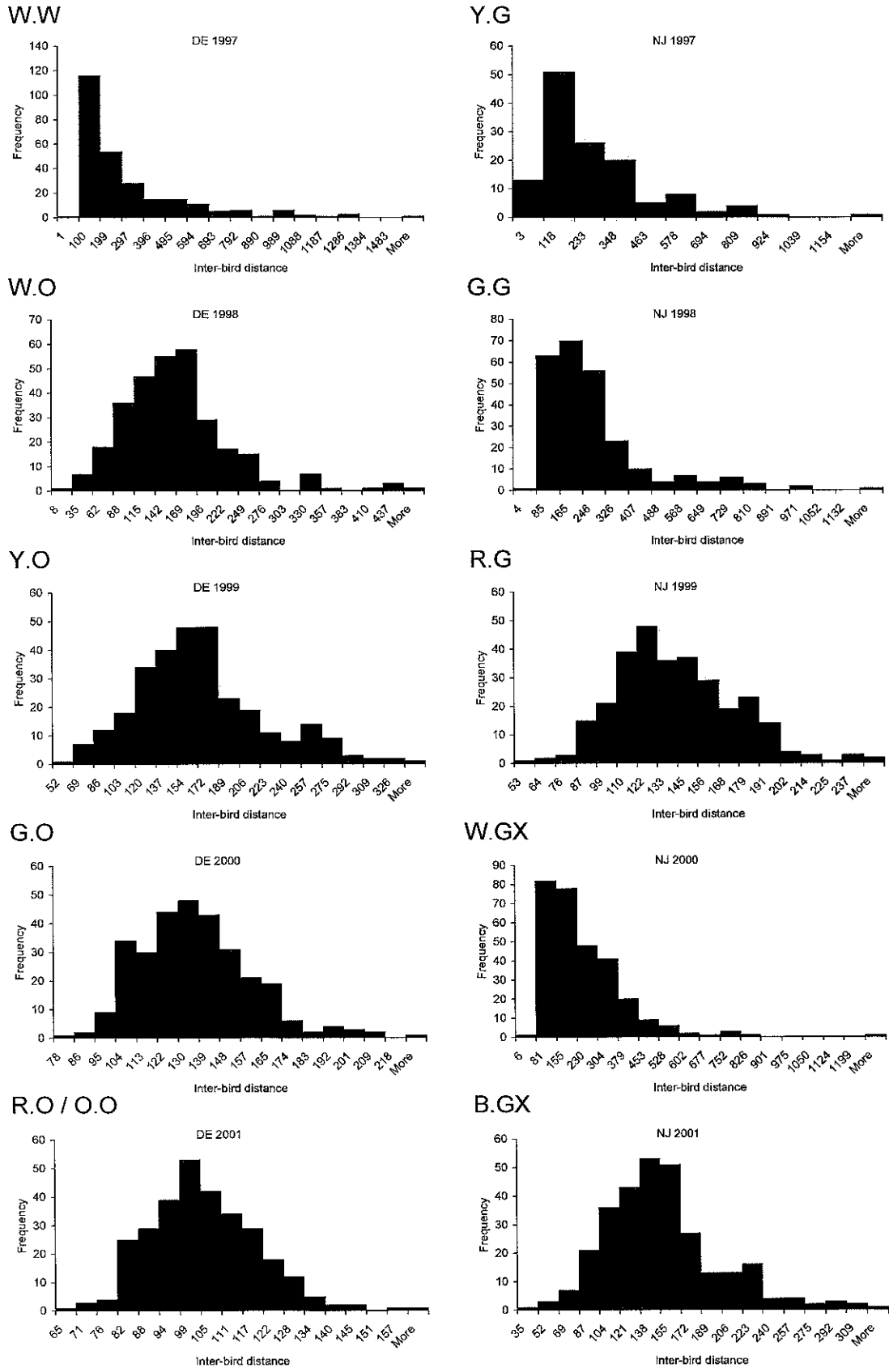
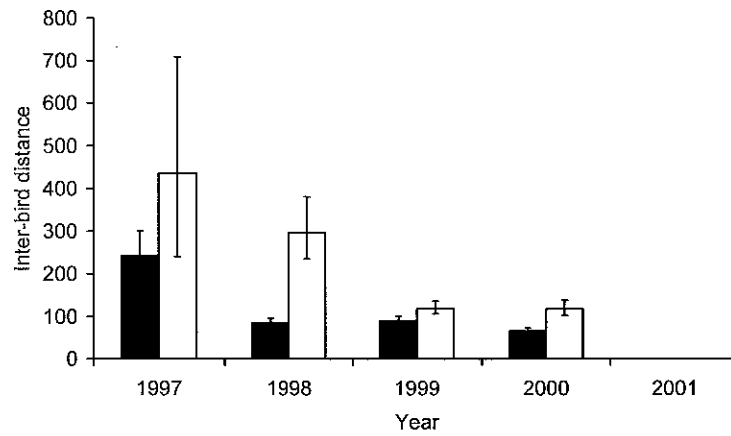
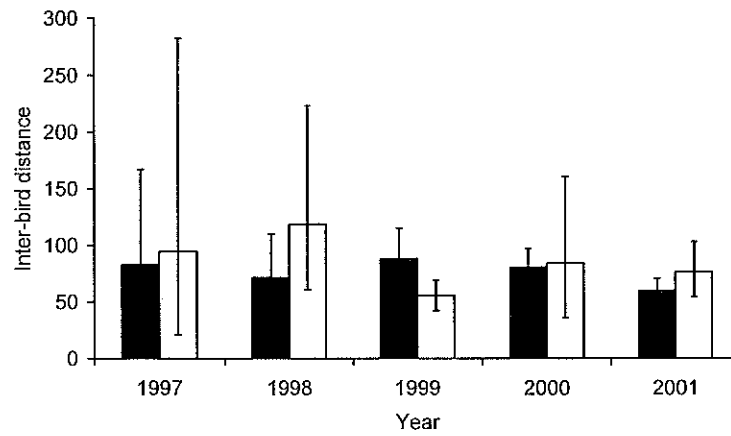


Figure 3.2. Median (and inter-quartiles range) intra-cohort inter-bird distances in the State of Delaware in A) May 2001 and B) May 2002. Solid bars are Delaware cohorts and open bars are New Jersey cohorts.

A) May 2001



B) May 2002



Chapter 4. Individually marking birds with colored bands or inscribed flags - rationale and approaches.

Philip W. Atkinson & Graham F. Appleton

4.1 Introduction

Cohort marking groups of animals is useful to infer information about migration routes and timing of migration for different groups of birds. However it is not sufficient to enable researchers to determine survival rates or turnover estimates (*i.e.* how long do individual birds remain in the bay). For this type of information birds will need to be marked as individuals. There have been moves to individually mark birds in DB from 2003 onwards. This document aims to set out the rationale for doing this and also to determine the numbers of birds that would need to be marked each year.

There are two options open to the International Shorebird Team in Delaware Bay. Birds could be banded using a unique series of color bands or using inscribed flags similar to those that have been used on birds caught in Argentina. Some of these were seen in Delaware Bay in 2002 and were thought to be an excellent way of marking birds as individuals.

4.2 Is there a need to individually mark birds?

One of the key questions about shorebirds in Delaware Bay is to determine changes in survival rates between years. Delaware Bay is really the best place to study survival as a vast proportion of Nearctic population of Red Knot pass through the bay each year. It is also possible to get relatively close to them in reasonable weather conditions (unlike in Patagonia where it is often windy) thus making resightings easy. As a standard monitoring project, individually marking birds in DB (rather than cohort-marking) is the most sensible way forward.

The other key question is also to look at the impacts of changing conditions in DB on the rates of weight gain in the birds. By having a good population of marked birds it will be possible to determine year-specific turnover rates – *i.e.* look at how long individuals remain in the bay and when they depart. This kind of information is essential if you need to know how many birds are using the bay. Though it is widely believed that peak aerial counts are close to the total flyway population, this cannot be assumed without establishing the turnover rate. Regular resightings of individually marked birds will give that information and allow total numbers to be estimated with better accuracy.

4.3 Can this information be obtained from using retraps of metal-banded birds?

Survival rates can be obtained from metal-banded birds. However reporting rates are low (generally 0.01-0.02) and so to obtain a large sample of recaptured individuals, a very large number of birds would need to be captured. This has obvious disadvantages. By having a larger sample of individual birds recaptured or resighted each year, the confidence intervals of the survival estimates would be reduced and it would be possible to look for more subtle changes in survival from year to year. Catching more birds than present, although possible, is not thought to be a good idea on welfare grounds. Individual marking would make each bird much more valuable in terms of data without increasing the need for larger numbers of birds to be caught.

Turnover rates cannot realistically be obtained from using metal band recapture data as it would require regular catching of the same flock of birds, which would require too much effort on the part of the team and also cause unacceptable disturbance to the birds.

4.4 How many birds would need to be individually marked each year?

This is an extremely tricky question to answer. The number of individual birds you will see the following year will be determined by the rate at which birds die, whether birds pass through the bay each year and when people are out scanning, as some birds may arrive early and leave early or vice versa. In these calculations, I've assumed that people are out scanning for the entire period birds are present and that birds pass through the bay each year, which I think is a fairly reasonable assumption to make. I will assume an 80% survival rate from year to year.

Given the proportion of birds individually color-banded in a particular year, together with an estimate of the survival rate between years, it is possible to estimate the probability p of encountering a particular individual in the following year. Any flock of n scanned birds will consist of x birds with color bands and $n - x$ without. Hence the probability of seeing x color-banded individuals is given by the probability:

$$P(x) = {}^n C_x p^x q^{n-x} \text{ where } q = 1 - p$$

(Equation 1)

Using the Normal approximation to the Binomial distribution, it is possible to work out the number of individual birds which it is necessary to see in a flock (or flocks) to have a 90% probability of seeing at least y individually marked birds. I've calculated this figure so that we can be reasonably sure of seeing the target number of birds in the scans.

This number is the number of INDIVIDUAL birds that must be scanned. One problem with scans is that they are not randomised in picking out birds from the population. Additionally, the whole population does not distribute itself at random either – *i.e.* there is likely to be spatial and temporal autocorrelation. If a big flock is being scanned it is likely that some birds will be scanned twice. Therefore, it will be necessary to multiply the estimate by an 'inflation' factor. The only realistic way to estimate this without trying to work out the autocorrelation (which in any case will vary from year to year) is to run some field tests. We ran some tests in 2002 with flocks which contained individually marked Red Knot and Ruddy Turnstones. The required inflation factor was approximately 1.2 for Red Knot and 1.5 for Ruddy Turnstone and these seem a reasonable range of values to work with.

Figure 4.1 shows that number of birds one would need to scan (vertical axis) to be 90% sure of seeing varying numbers of individuals the following year. Four different population size/banding scenarios are shown. The results are reassuring in that, even with an inflation factor (not included in the graphs), if 1000 birds were marked each year and you wanted to see say 100 of them the following year one would need to scan approximately 7,500 birds which is feasible during a season. In 2002, 12,000 Red Knot were scanned in Delaware and so the figures are in the right order of magnitude.

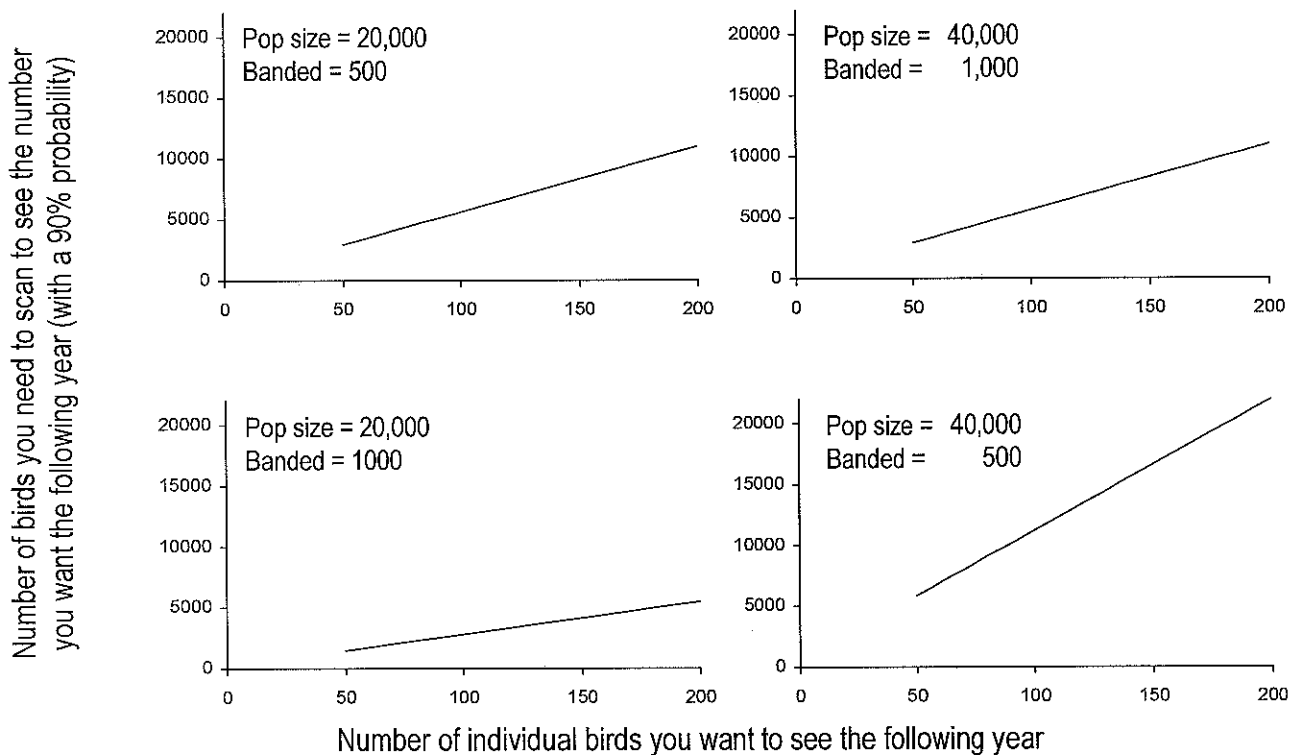
In terms of survival estimation – the higher the resighting rate (without errors – see notes on (dis)advantages of bands & flags below!) the better. At BTO we have worked on projects with a 50-90%+ reporting rate and this makes survival estimation fairly robust. At present reporting rates of metal bands in DB Red Knot are in the order of 0.02. Assume a population of 40,000, marking at least 1000 a year and scanning 15,000 birds: this would bring reporting rates up to approximately 0.2-0.25 which would make survival estimation much more robust. If we assumed a population of 80,000 then this would bring it down to 0.1. By doubling population size we approximately halve the reporting rate. As we do not know the true population size of Red Knot in the flyway (although it may well be in the 20-80K range) we should try and be conservative and definitely try to individually mark in excess of 1000 birds a year.

For estimation of turnover, the calculation is also fraught with difficulties with spatial and temporal correlation. If we want to see some birds twice then instead of p in Equation 1 above being the

probability of seeing an individual it will be the probability of seeing an individual squared (p^2). If we take the worst case scenario in that birds distribute at random, there is no spatial or temporal autocorrelation, then the math suggests it will be possible. In DB, an average of 1,600 birds have been marked each year and assume that the population size is 40,000 and all 1,600 birds had been flagged. If we wanted to see 10 of these twice then the number that would have to be scanned would be approximately 15,000-20,000. This is an extremely conservative figure as in reality it is highly unlikely that birds behave in a random fashion and that birds are probably more likely to stay in one place from day to day than to move. Therefore repeated daily scans of the same flock are likely to find more birds at least twice than Equation 1 would suggest. This is likely to lead to over-dispersion in the survival models and the probabilities for these would need to be adjusted accordingly.

This brief analysis really shows that to get a reasonable number of birds resighted each year, individually-marking 400-500 birds each year will not be sufficient to get the kind of information we need. A figure of at least 1,000 birds is much more reasonable and if we are to get turnover rates then it therefore seems reasonable to try and individually mark all of these we catch if we can get the individual's weight and other mensural data as well.

Figure 4.1. Numbers of individual birds needed to be scanned to be 90% sure of seeing varying numbers of individual birds. This is uncorrected for seeing the same bird more than once – multiply by an inflation factor of 1.2-1.5 to obtain the number need to be scanned.



4.5 How should birds be individually marked – flags or bands?

ADVANTAGES	DISADVANTAGES
COLOR BANDS	
We have permission from BBL to use them	We would have to use 4 bands + flag + metal band to have sufficient combinations.
	The colors used are sometimes difficult to read (<i>e.g.</i> grey, brown/ pale blue <i>etc.</i>)
	We know pale-colored color bands stain further south and can be impossible to identify correctly, even in the hand
	The extra handling of the bird needed to put all the marks on is considerable
	Bad public relations if birds are “lit up like Christmas trees”.
	Experienced color band readers are required to read the combinations
	To read the combinations you will need to get the full combination which appears on left and right, above and below.
	Birds are often caught with an incomplete set of color bands.
	Not a huge number of combinations when only using ‘good’ colors.
INSCRIBED FLAGS	
Ideally we would use one pale-colored flag with a 2 or 3 letter character inscription with a metal band and perhaps one other color band	We need permission to use them (not a disadvantage but something we would need to sort out)
This reduces the number of marks we are attaching to each bird which makes handling quicker and also for better public relations	Untried in the US although successfully used in Argentina. We do know that flags do not stain and that uninscribed flags are resistant to wear and also have a very low rate of falling off.
The flag would be on the tibia (<i>i.e.</i> above the knee joint) and would not wear or suffer from the same staining problems	
Color band readers would only need to look in one place. In a flock of Red Knot it is often difficult to see the lower part of the legs anyway.	
The consistent use of 2 or 3 letter/number digits would make the whole color band reading much much easier.	
We do know that flags do not stain and that uninscribed flags are resistant to wear and also have a very low rate of falling off whereas birds with an incomplete set of color bands are often caught.	
20-30K+ individual combinations using 3 digits without repeating a set of digits and removing any possible confusion combinations.	
Error in reading is likely to be lower (extremely important for survival estimation)	

The advantages of flags outweigh the use of color bands. Flags are much more likely to have a lower error rate in reading, will be quicker to put on and better for the birds. The only question mark is their

durability. As cohort marking is not telling us anything new and that ordinary flags are durable this is a reasonable risk to take.

4.6 What codes should be used on flags?

Assumptions:

Flags would be made of 7mm high and 0.5mm thick DARVIC and be 40 mm long

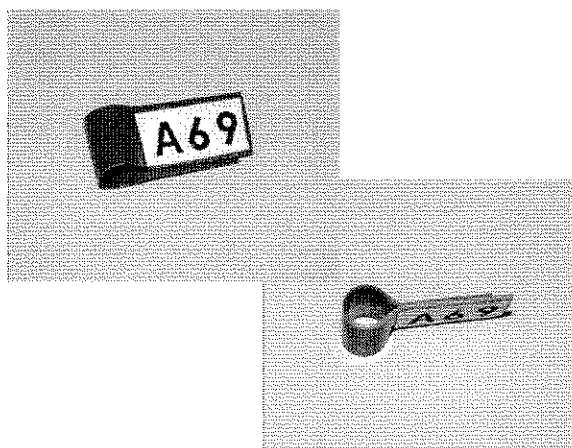
They would go above the knee joint.

They would be inscribed with letters or digits. Assuming that some characters/numbers are unsuitable there would be (26 letters + 10 numbers – 6 unsuitable) = 30 possibilities in each position. The number of unique combinations for a 2 letter/digit flag would be $30^2 = 900$ or for a three letter/digit flag $30^3 = 27,000$.

2 letter/digit flag plus a color band	3 letter/digit flag
ADVANTAGES	ADVANTAGES
Smaller flag possible but this will be a small difference	Many more unique combinations (27,000)
Fewer digits to read	Lower error rate in reading
	Scanner need only look in one place on the leg.
DISADVANTAGES	DISADVANTAGES
Fewer unique combinations (900) would mean that flags would have to be placed on left/right legs and have color band (s) to identify years <i>etc.</i>	Increased flag size compared with 2 letter/digit.
Having a color band in addition will mean that scanners would have to look at several different places on the leg – often difficult when scanning flocks of birds..	Three digits/letters to read.
Color bands suffer from staining and therefore the colors to be used to identify years would be severely limited.	
There would be several copies of the same flag in the population. Scanners (even supposedly experienced ones) are notorious for mixing up left/right and misreading the color of color bands	

4.7 What size flags and how many characters?

The three character combination, in our opinion is preferable. We made up some flags to Mark Peck's 7mm x 40 mm x .5 mm size specification with BOLDED 16 POINT lettering with 50% EXTRA SPACING. Pictures of one appear below. We used a highly involved technique to label it (paper, scissors & glue!). At this size the flag with three characters seems to work well using Arial Narrow letters and New Century Gothic numbers. We prefer the latter font for numbers, as the sixes and nines stand out much better. Ideally we would find a font with flat-topped threes as well to avoid confusion with eights.



Arial Narrow letters + Century gothic numbers

A83 A68 A89

The sixes and nines in Century are more readable.

Arial Narrow letters + numbers

A83 A68 A89

Threes, sixes and nines can be confused when using Arial Narrow.....

4.8 Recommendations

Therefore, I suggest that we use three-digit flags with or without an additional color band [might make identification easier in places other than DB and also draw attention to birds], that we plan to individually mark a MINIMUM of 1,000 Red Knots each year and that all birds caught that are in addition to this minimum shall be similarly marked, especially where mensural data are available. 1,500-2,000 birds marked, which is our present level, would make the analyses much more robust.

If possible birds should be caught at periods throughout the season but in a smaller number of larger catches rather than large numbers of small catches. This avoids issues of representativeness of small samples and also reduces disturbance on the beaches.

Acknowledgements

The monitoring of shorebirds in Delaware Bay has been a collaboration of many individuals, all of whose efforts have contributed indirectly to the results this report and we are extremely grateful for their time and enthusiasm. In particular, the monitoring programme was begun by Alan Baker and efforts have been co-ordinated by Dave Carter (DNREC) and Larry Niles (New Jersey FWS), we thank them for their continued support.

Many professionals and volunteers, from all parts of the globe, have willingly and freely given up their time to help catch the birds, in particular Clive Minton, who helped start the international catching efforts, and Phil Ireland of the Wash Wader Ringing Group. A number of other people deserve thanks for their contributions to the monitoring, in particular Kathy Clark, Kimberley Cole, Jim Hewes, Humphrey Sitters and Mark Peck. We would also like to thank Jacquie Clark, Simon Gillings and Kimberley Cole (on behalf of DNREC) for their comments on the report and the analyses presented.

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