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Impacts of changes in sewage disposal on populations of waterbirds wintering on the Northumbrian coast Report for 2004/05

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CONTENTS

Page No.

List of Tables

Page No.

List of Figures

Page No.

List of Appendices

EXECUTIVE SUMMARY

Background

1. Over the last decade Northumbrian Water Ltd (NWL) has implemented a series of major improvements to the treatment and discharge of sewage at sites along the coast between Berwick-upon-Tweed and Saltburn (from Northumberland to Cleveland), so as to comply with the EC's Urban Waste Water Treatment Directive.

2. The impact of these directives on coastal waterbirds has raised concern as waste water discharges from outfalls may provide considerable supplies of food for bird species, either as directly edible matter or by artificially enhancing concentrations of invertebrate food through nutrient enrichment.

3. This report reviews the latest results of an investigation, commissioned by NWL and begun in 1996/97 by the University of Durham, of the impacts of improvements to sewage discharges on waterbirds wintering on a 36 km stretch of the Northumbrian coast between the Coquet Estuary and St. Mary's Island (Figure 1.1). The area comprises extensive areas of rocky shore which are included in the Northumbria Coast Special Protection Area (SPA), which is designated for its importance for wintering Purple Sandpipers *Calidris maritima* and Turnstones *Arenaria interpres*. Between these rocky areas are the sandy (bathing) beaches of Druridge Bay, Cambois and South Blyth. The majority of improvements to sewage discharges in the area were completed by the end of the winter of 2000/01.

4. The report outlines work carried out by the British Trust for Ornithology (BTO) in the winter of 2004/05 and investigates how numbers of waterbirds wintering in the study area have changed since monitoring was begun by the University of Durham. Additional analyses investigate whether changes in Turnstone numbers following the improvements to sewage treatment might be explained by changes in this species' survival rates or movements.

   All waterbird species in the study area were included in counts, though analyses here are restricted to Purple Sandpiper and Turnstone. Analyses were carried out at two scales: firstly, for the whole coast from the Coquet Estuary to St. Mary's Island and secondly, for the Amble-Hauxley and Newbiggin areas alone. Two of the three largest outfalls in the study area discharge in these areas; both discharges received improved treatment from late in the winter of 2000/01.

Changes in Waterbird Numbers Following Improvements to Sewage Treatment

5. Across the study area as a whole, counts suggested that the changes to sewage treatment affected both of the species for which the SPA is designated in winter – Purple Sandpiper and Turnstone. These species showed declines following the winter of 2000/01, having previously risen in number.

   At a regional level, Wetland Bird Survey (WeBS) counts indicated that Purple Sandpipers were declining at least up to 2003/04, but that Turnstone numbers had stabilised after a decline between the mid-1980s and mid-1990s. However, for neither species were numbers in the study area related to regional numbers.

   At the more local scale, after a period of high stability in numbers, there was a clear decline (of >35%) in the numbers of Turnstone at Amble-Hauxley over the four years following the improvement to the Amble discharge. Purple Sandpiper numbers also fell here in 2003/04, having risen prior to the improvement to the discharge.

However, no significant declines were apparent in the numbers of either species, over the study area as a whole or at Amble-Hauxley, between the winters of 2003/04 and 2004/05.

Changes in Turnstone Survival Rates Following Improvements to Sewage Treatment

6. Analysis of data from resightings of colour-ringed Turnstone suggested that adult survival fell in 2002, from 0.769 (95% confidence limits = 0.723-0.810) to 0.615 (0.471-0.742), a rate similar to that of first-winter birds. However, the difference between these rates was not significant ($P = 0.0555$) and thus a constant annual survival rate (for adults and first-winter birds) of 0.747 (0.707-0.783) was estimated for the period 1997/98 to 2004/05. Nevertheless, it seems likely that the drop in Turnstone numbers seen at Amble-Hauxley following the improvements to the Amble discharge was in part a consequence of a fall in adult survival.

No evidence was found to suggest that the decline in Turnstone numbers at Amble-Hauxley was the result of individuals increasingly using other sites in the area.

Conclusions

7. Count data suggested that the changes to sewage treatment may have impacted numbers of both Purple Sandpiper and Turnstone, notably at Amble-Hauxley. For the latter species, analyses of the survival rates of colour-ringed birds suggested that the decline in numbers at that site may have been the result of an increase in adult mortality.

Recommendations

8. The declines of Purple Sandpiper and Turnstone in the study area – and, in particular, that of Turnstone at Amble-Hauxley – are of concern given that they began immediately following the changes to sewage treatment.

Although numbers of Turnstone and Purple Sandpiper over the study area as a whole and at Amble-Hauxley were similar in 2004/05 to those in the previous winter, it is still too early to affirm that numbers have now reached a new equilibrium.

The following recommendations are made with the aim of providing a more complete understanding of the impacts of the changes in sewage disposal on the waterbirds wintering on the Northumbrian coast:

9. Firstly, waterbird counts should continue during the winter of 2005/06. This would show whether numbers of Turnstone and Purple Sandpiper have now stabilised or whether there might be continued decline either over the study area as a whole or at Amble-Hauxley.

By collecting sightings of colour-ringed Turnstone for an additional winter it would also be possible to improve the accuracy of existing survival estimates and thus determine more fully the significance of the change in survival seen following the changes to sewage treatment at Amble. These data could be collected while undertaking waterbird counts.

10. Secondly, it is recommended that stable isotope analyses are undertaken in order to establish the importance of nutrient inputs from sewage along the Northumberland coast to invertebrates and the waterbirds that feed upon them and the extent to which these inputs have changed following the improvements to discharges.

1. INTRODUCTION

Over the last decade Northumbrian Water Ltd (NWL) has implemented a series of major improvements to the treatment and discharge of sewage at sites along the coast between Berwick-upon-Tweed and Saltburn (from Northumberland to Cleveland) so as to comply with the EC's Urban Waste Water Treatment Directive (Directive 91/271/EEC and its Amending Directive 98/15/EEC) (Anon 1991, 1998). Improvements have involved secondary treatment[1], and in some cases, the instillation of long offshore outfalls.

The impact of these directives on coastal waterbirds has raised concern as in many areas waste water discharges from outfalls may provide considerable supplies of food for bird species, either as directly edible matter or by artificially enhancing concentrations of invertebrate food (Green *et al.* 1990, Hill *et al.* 1993, Burton *et al.* 2002). For example, previous studies have highlighted the importance of outfalls in directly providing food for gulls (Ferns & Mudge 2000) and seaduck species such as Pochard *Aythya ferina*, Tufted Duck *A. fuligula*, Scaup *A. marila* and Goldeneye *Bucephala clangula* (e.g. Pounder 1976a, 1976b, Campbell 1978, 1984, Campbell *et al.* 1986, Campbell & Milne 1977). The changes in invertebrate and algal biomass found in the vicinity of outfalls are also likely to affect the densities of a number of other ducks and waders. Studies in Ireland (Fahy *et al.* 1975) and Holland (van Impe 1985), for example, have both linked increases in organic and nutrient inputs (from sewage, industrial and agricultural wastes) to increases in algae and invertebrates and thus to increased bird populations.

The coast between Berwick and Saltburn comprises two Special Protection Areas (SPAs) designated under EC Directive 79/409 for their importance for birds. The Teesmouth and Cleveland Coast SPA is noted for its importance for breeding Little Terns *Sterna albifrons*, passage Sandwich Terns *S. sandvicensis* and Ringed Plover *Charadrius hiaticula*, and wintering Knot *Calidris canutus* and Redshank *Tringa totanus* and an assemblage of other wintering waterbirds. The Northumbria Coast SPA was designated for its internationally important populations of wintering Purple Sandpipers *Calidris maritima* and Turnstones *Arenaria interpres*, as well as the small, but nationally important population of Little Terns that breeds in the north of the region (Stroud *et al.* 2001). Both sites are also designated as Ramsar Sites under the Convention of Wetlands of International Importance.

This report reviews the latest results of an investigation, commissioned by NWL and begun in 1996/97 by the University of Durham, of the impacts of improvements to sewage discharges on waterbirds wintering on a 36 km stretch of the Northumbrian coast between the Coquet Estuary and St. Mary's Island (Figure 1.1). The area comprises extensive wave-cut platforms and rocky headlands at Amble-Hauxley, Cresswell, Newbiggin, North Blyth and Seaton Sluice-St. Mary's Island, which are included in the Northumbria Coast SPA. These areas support high proportions of the SPA's populations of Purple Sandpipers and Turnstones (Anthony 1999). Between these rocky areas are the sandy (bathing) beaches of Druridge Bay, Cambois and South Blyth. Mining at Lynemouth has left the beach there covered with spoil. The Coquet, Wansbeck and Blyth rivers all form small estuaries; there are also harbours at Blyth and at Amble on the Coquet. The Northumbria Coast SPA supported a peak mean of 763 Purple Sandpipers and 1,456 Turnstones between 1991/92 and 1995/96 (1.5% of the Eastern Atlantic wintering population and 2.1% of the Western Palearctic wintering population respectively: Stroud *et al.* 2001). The British wintering populations of Purple Sandpipers and Turnstones are currently estimated to be 17,530 and 49,550 respectively (Rehfisch *et al.* 2003a).

A number of improvements have been made to sewage discharges within the study area:

[1] 'Primary treatment' entails treatment of waste water by a physical and/or chemical process involving settlement of suspended solids, or other processes in which the BOD5 (five-day biochemical oxygen demand) of the incoming waste water is reduced by at least 30-40% before discharge and the total suspended solids of the incoming waste water are reduced by at least 50-65%. 'Secondary treatment' generally involves biological treatment with a secondary settlement or equivalent process and removes 65-95% of the BOD and 60-90% of the suspended solids in the waste water (Anon 1999).

- At Amble, a new sewage works providing primary and secondary treatment was completed in January 2001. There was no change in the location of this outfall, between the Amble foreshore and Coquet Island (see Figure 1.1). This discharge is one of the three largest in the study area with a population equivalent value of 24,143 (Environment Agency 2000).

- At Newbiggin, primary and secondary treatment was also completed in January 2001. Sewage here is discharged offshore by a long outfall completed in 1993. The discharge has a population equivalent value of 36,231 (Environment Agency 2000).

- A new 1 km outfall was completed at Cambois in September 1997 and sewage with secondary treatment diverted through it from 2001. The discharge has a population equivalent value of 40,607 (Environment Agency 2000).

- Sewage discharged into the Blyth Estuary and at Blyth Link House on South Beach was also diverted to the Blyth Sewage Treatment Works in January 2001 to receive secondary treatment prior to discharge into the river.

- Other changes have also affected smaller discharges in the area. Sewage previously discharged at Seaton Sluice was diverted to the Howdon Sewage Treatment Works on the Tyne in January 2001. Sewage discharged at Cresswell was diverted to the Lynemouth Sewage Treatment Works in April 2003. Secondary treatment is also planned for a small discharge at Hadston at the north of Druridge Bay.

Earlier stable carbon isotope analyses indicated that a high proportion (up to 60%) of the Particulate Organic Matter (POM) in waters along this coast was derived from sewage (Eaton 2001). Improvements to sewage treatment might be expected to have a noticeable impact on nutrient loading and total POM (Savage & Elmgren 2004, Costanzo *et al.* 2005) and thus primary productivity of plankton and macroalgae (Hamer *et al.* 2002). This in turn may affect mussels *Mytilus edulis*, which are planktoniverous, and other invertebrate species. Mussels are important prey items for Purple Sandpipers (Feare 1966, Summers *et al.* 1990) and Eaton (2001) found that Purple Sandpiper densities on the Northumbrian coast were correlated to the densities of small mussels. Turnstones are more omnivorous (Cramp & Simmons 1983, Whitfield 1990), but could also be affected by the improvements to sewage discharges through reductions in the invertebrate populations that feed on macroalgae as well as any loss of mussels. Alternatively, reductions in the growth of *Enteromorpha* spp. and *Ulva* spp., both of which proliferate in nutrient-enriched waters, might increase the area of foraging substrate available by Turnstones and other waders (Cabral *et al.* 1999, Lopes *et al.* 2000, Lewis & Kelly 2001). Eaton (2001) previously found that the area of suitable foraging substrate was a good predictor of Turnstone densities.

Any loss of food resources is likely to affect the densities of birds that an area can support. Whether there is an actual reduction in bird numbers, though, will depend on whether the area was close to carrying capacity prior to the change (Goss-Custard 1985, Goss-Custard *et al.* 2002). If it was, either the increased competition for food resources will force birds to move to new feeding grounds or, if such areas do not exist or are also close to carrying capacity, lead to reduced survival. Impacts may also vary between species. Waders such as Knot, Dunlin *Calidris alpina* and Sanderling *Calidris alba* which may regularly move between sites to exploit varying food resources (Evans 1981, Myers 1984, Symonds & Langslow 1986, Symonds *et al.* 1984, Roberts 1991, Rehfisch *et al.* 1996, 2003b) may be less affected by reduced food supplies than more site-faithful species, such as Redshank, Turnstone and Purple Sandpiper. Both in the Northumberland study area and elsewhere, Turnstones and Purple Sandpipers typically return to the same stretches of shore each year and remain faithful to them through the winter (Metcalfe & Furness 1985, Rehfisch *et al.* 1996, 2003b, Burton & Evans 1997, Dierschke 1998, Burton 2000, Eaton 2001).

This report outlines work carried out in the winter of 2004/05 and provides analyses of the changes in the numbers of waterbirds wintering in the area since monitoring was begun by the University of Durham in 1996/97. Companion studies have also been undertaken by the University of Durham to look at the impacts of the improvements to sewage discharges on the breeding performance and numbers of terns in the area (Hamer *et al.* 2002, Booth & Hamer 2003).

This report has three main aims:

1. To determine whether waterbird numbers have changed following the improvements to discharges.
2. To determine whether changes in Turnstone numbers might be explained by changes in this species' survival rates or movements.
3. To suggest what work still needs to be done to determine whether the improvements to discharges have had an impact on waterbirds wintering on the Northumbrian coast.

Analyses of changes in wintering waterbird numbers are carried out at two scales: firstly, for the whole coast from the Coquet Estuary to St. Mary's Island and secondly, for the Amble-Hauxley and Newbiggin areas alone. Two of the three largest outfalls in the study area discharge in these areas; both discharges received improved treatment from late in the winter of 2000/01. Survival (and movement) analyses are undertaken for Turnstone caught in the Amble-Hauxley area.

2. METHODS

2.1 Waterbird Counts

2.1.1 Field methodology

Counts of waterbirds on the coast between the Coquet Estuary and St. Mary's Island were begun by the University of Durham in the winter of 1996/97. The study area was split into sections (see Figure 1.1) and the whole coast surveyed twice a month, with the aim that each section should be covered once over the high tide period (i.e. > 3.7 m OD) and once over the low tide period. Count sections included the lower Coquet, Wansbeck and Blyth estuaries (and the North Blyth Staithes roost site within the latter estuary). This programme of counts was continued until March 2003, with only occasional gaps during the summer months (Eaton 1997, 1998, Hamer *et al.* 2002, Fuller 2003a).

Monitoring was resumed in October 2003 by the British Trust for Ornithology (BTO), with counts of every section at high and low tide each half-month until the end of March 2004. Counts were continued following this regime in the winter of 2004/05.

2.1.2 Analysis of count data

Analyses of waterbird count data were carried out for the whole coast from the Coquet Estuary to St. Mary's Island and also separately for the Amble-Hauxley (count sections A01-A08) and Newbiggin (sections A14-A19) areas.

Although all waterbird species in the study area were included in counts, analyses are here restricted to Purple Sandpiper and Turnstone, the two wintering species for which the Northumbria Coast SPA is designated. Due to the potential for poor quality counts in the first winter of study (M. Eaton pers. comm.), data from that winter have been excluded. Counts of areas above the intertidal (e.g. Hauxley Haven, Druridge Pools and Cresswell Pond) were also excluded from all analyses, though St. Mary's Wetland, an important high tide roost site, was included as part of the southernmost count section.

For each species, generalized linear models (GLMs) (McCullagh & Nelder 1989; SAS Institute Inc. 2001) were used to relate the number of birds on each count to the winter, month (October to March), state of tide (high or low) and count section, represented respectively by estimable factors α, β, γ and δ, and the interaction between the state of tide and count section, represented by ε, i.e.

$$\ln(\text{count}_{ijkl}) = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \varepsilon_{kl}$$

Models assumed a Poisson distribution for the number of feeding birds and specified a log link function. Month, state of tide, count section and winter were all treated as class variables. The problem of overdispersion caused by a combination of a large number of zero counts with several very high counts, typical of flocking species, was addressed by the application of a scale factor estimated from the square root of the Pearson's Chi-squared statistic divided by its degrees of freedom. With the exception of winter, only those variables that were significant in explaining the variation in densities were retained in the final models.

Model results were used to produce and graph indices relating how the numbers of birds varied each winter relative to 2004/05. The fitted models were also used to calculate, for each species and site, the mean recorded number of birds present each winter (i.e. October to March) averaged between high and low tide. These figures are plotted on the same graphs as the indices so as to understand better how the actual numbers of each species changed over the study period and following improvements to discharges.

As the figures plotted on these graphs are averages of the numbers recorded across the winter, they may underestimate the total populations of some species. For example, Purple Sandpipers which forage on the Amble-Hauxley shore often roost over high tide on Coquet Island; this species' roost site at North Blyth may also be difficult to survey (though all visible parts of the piers where the species roosts were consistently surveyed across years). Also, although some species' populations are relatively stable over the defined winter period (e.g. Turnstone), those of other species show monthly variation. The population of Purple Sandpipers in the study area, for example, rises to a peak in mid-winter following the arrival of a second breeding population (thought to be from Canada: Summers 1994). The total population of Purple Sandpipers using the study area will thus be underestimated from the mean winter value.

The mean winter numbers in the study area are compared statistically with regional data taken from the Wetland Bird Survey (WeBS) Alerts report for winters up to 2003/04 (Maclean *et al.* 2005). In this, trends in WeBS data are presented for an area corresponding to the Environment Agency's North-East Region. Mean numbers (in WeBS recording areas within the region) are calculated for the three month period from December to February, having first taken into account missing counts in the dataset. Comparison is also made with the changes reported between two surveys of the country's non-estuarine coast in 1984/85 and 1997/98 (Rehfisch *et al.* 2003c), for which the Northumberland coast counts had also been supported by NWL.

It was not possible to determine whether changes in numbers reflected variation in annual breeding success, as data on the proportions of juveniles in the populations had not previously been collected and broader information on the annual breeding success of these species, which mostly breed in the Arctic, is limited.

Although they are typically faithful to the same areas within and between winters (Metcalfe & Furness 1985, Rehfisch *et al.* 2003b, Burton & Evans 1997, Eaton 2001), the local distribution of Turnstones may be affected by the availability of tidal wrack, due to the invertebrate populations that these wrack beds support (Fuller 2003b). Such wrack beds occur often within the study area within winter. However, no data was or had previously been collected to determine whether their availability had changed over time and so perhaps influenced the distribution and numbers of Turnstones (or other species).

2.2 Analyses of Data from Colour-ringed Turnstones

2.2.1 Turnstone survival analyses

Between the winters of 1996/97 and 2000/01, 226 Turnstone were caught and individually colour-ringed on the Northumbrian coast by Mark Eaton, Rich Fuller and colleagues from the University of Durham. The information collated from the marking and subsequent resighting of these birds (collected during the course of monitoring) has provided an ideal dataset to investigate temporal variations in the survival rate of this species.

Turnstone were caught within six different parts of the study area: Amble, Hauxley, Cresswell, Newbiggin, Blyth and St. Mary's Island. Birds were caught by cannon-netting, with the exception of one individual caught by dazzling on the night of 11 February 1997 at Blyth. Each bird was aged according to its plumage characteristics (Prater *et al.* 1977) as either adult or first-year and fitted with a metal BTO ring and an unique combination of colour-rings so that they could be subsequently identified in the field. Of the 226 birds colour-ringed, 26 were classed as first-winter birds when marked, 94 as adults and 106 unaged (Table 2.2.1.1).

Estimates of annual survival rates and recapture probabilities of Turnstone were calculated using mark-recapture methods. Data were only included from birds known to be either in their first-winter or adults, i.e. in their second-winter or older, when caught or resighted. This allowed calculation of survival rates for the period 1997/98 to 2004/05.

Following the initial work undertaken by Burton *et al.* (2004), analyses were restricted to estimating the survival rates of those Turnstone originally caught and ringed at Amble-Hauxley (though retaining resighting data from the whole study area). Comparatively few Turnstone were caught at any one other site (Table 2.2.1.1). Analyses aimed to determine whether survival rates differed between adults and first-winter birds and following the completion of the majority of improvements to sewage discharges late in the winter of 2000/01.

To determine the survival rates of Turnstone, the study area was searched extensively for colour-ringed birds during regular counts. The use of data from resightings of colour-ringed birds may be preferable to using data from the recapture of ringed birds, as it usually provides higher 'resighting' (i.e. recapture) rates (see also Sandercock 2003, Bearhop *et al.* 2003).

Data were analysed using Program MARK (White & Burnham 1999). Cormack-Jolly-Seber (CJS) models (Lebreton *et al.* 1992, Seber 1982) were developed to estimate annual survival rates 'ϕ' (i.e. the proportion of birds surviving each year) and resighting probabilities 'p'.

The validity of the CJS models depends upon a number of assumptions being upheld, notably the equal "catchability" (a bird was considered caught if it was resighted) of each marked individual. By only using data from birds caught or resighted between October and March (thus matching the analyses of count data) we restricted the numbers of passage birds that would have been included in our analyses. Inequality in catchability between birds and years was also reduced by the regular surveying of the entire study area and by excluding sightings of birds from outside the study area. (Some individuals were observed on Coquet Island and at Boulmer between 1996/97 and 2000/01, but these areas were not surveyed in latter years.) Goodness-of-fit tests (provided through Program MARK by the program RELEASE – Burnham *et al.* 1987) indicated that model assumptions were not violated (Table 2.2.1.2). Using Program MARK, we also estimated an overdispersion parameter for the data ($\hat{c}$) to adjust the final selected model (following White & Burnham 1999).

A combination of likelihood ratio tests (LRTs) and Akaike's Information Criterion (AIC), adjusted for overdispersion and sample size ($QAIC_c$: Burnham & Anderson 1998), was used to select the model that best described the data (typically that with the lowest $QAIC_c$ value). Different models evaluated whether resighting rates p were constant or varied fully with time and whether survival rates ϕ were constant, differed between adults and first-year birds (adult v 1st-year), varied fully with time or (for adults) differed in the first full year after improvements to the Amble discharge, i.e. 2002.

The estimated values for 'ϕ' will underestimate true survival if birds moved away from the study area (Sandercock 2003). The movements of colour-ringed Turnstone were thus examined to determine whether any such movements might have occurred (see below). The impacts of changes in 'apparent survival' on the numbers of Turnstone recorded in the Amble-Hauxley study area are discussed.

2.2.2 Movements of colour-ringed Turnstones

Sightings of colour-ringed Turnstone were examined to investigate whether there was any change in the winter ranging behaviour of the species over the course of the study. For those Turnstone originally colour-ringed at Amble-Hauxley, a graphical comparison was made of the proportions of birds seen at other sites within the study area each winter (October to March). A GLM, with a logit link function and binomial errors, was used to determine whether this proportion showed any trend with time or differed between winters before and after the completion of the improvements to the Amble discharge. By doing this, we aimed to determine whether any changes in the numbers or apparent survival of Turnstones at this site following the improvement to the discharge might have been the result of an exodus of birds.

3. RESULTS

3.1 Changes in Waterbird Numbers Following Improvements to Sewage Treatment

3.1.1 Purple Sandpiper *Calidris maritima*

Mean winter (October to March) numbers of Purple Sandpiper in the study area as a whole rose between 1997/98 and 1999/2000 – peaking at an estimated 148 birds – but fell in 2002/03, two winters after the completion of the majority of improvements to sewage discharges in the area (Figure 3.1.1.1a). Numbers of Purple Sandpipers in the study area in the four winters following these improvements were significantly lower than those in the four preceding winters ($F_{1,3004}$ = 4.23, P = 0.0398).

At Amble-Hauxley, trends reflected those over the study area as a whole, numbers increasing to a peak in 2000/01, but declining afterwards. There was a notable decline in numbers between 2002/03 and 2003/04. Despite this, there was no significant difference in numbers before and after the improvement to the Amble discharge (Figure 3.1.1.1b; $F_{1,787}$ =1.47, P = 0.2259).

At Newbiggin, there was considerable fluctuation in numbers and no significant difference between winters before and after the completion of the improvement to the Newbiggin discharge (Figure 3.1.1.1c; $F_{1,567}$ = 1.70, P = 0.1926).

The regional trend in Purple Sandpiper numbers, as shown by WeBS count data (Maclean *et al.* 2005) is shown in Figure 3.1.1.2. These data suggest considerable fluctuations in the numbers in the region – though this may be because the index is based on only three counts during the winter and for some sections, numbers will have been estimated due to missing counts. Nevertheless, it is clear that there has been a decline in regional numbers of the species since the late 1980s. A regression analysis suggested that, over the period from 1997/98 to 2003/04, the mean winter numbers of Purple Sandpipers recorded in the study area were unrelated to mean regional numbers ($F_{1,5}$ = 3.06, P = 0.1408).

Nationally, there was a decline in Purple Sandpiper numbers on non-estuarine coasts between 1984/85 and 1997/98 (Rehfisch *et al.* 2003c).

3.1.2 Turnstone *Arenaria interpres*

Mean winter numbers of Turnstone in the study area as a whole rose to an estimated peak of 435 birds in 2000/01 just prior to the completion of the majority of improvements to sewage discharges in the area (Figure 3.1.2.1a). As with Purple Sandpipers, numbers of Turnstone in the study area in the four winters following these improvements were significantly lower than those in the four preceding winters ($F_{1,3502}$ = 7.87, P = 0.0050).

At Amble-Hauxley, Turnstone numbers were very stable over the four winters prior to the improvement to the Amble discharge, but declined over the four following winters (Figure 3.1.2.1b). Numbers in 2001/02 to 2004/05 were significantly lower than those in the four preceding winters ($F_{1,901}$ = 21.60, P < 0.0001).

At Newbiggin, Turnstone numbers were more variable between winters with no significant difference between the four winters prior to the improvement to the discharge here and the four following winters (Figure 3.1.2.1c; $F_{1,622}$ = 0.18, P = 0.6716).

The regional trend in Turnstone numbers, as shown by WeBS count data (Maclean *et al.* 2005) is shown in Figure 3.1.2.2. As with Purple Sandpiper, there was a decline in the numbers of Turnstone in the region from the late 1980s, although numbers appear to have stabilised since the winter of 1996/97. A regression analysis suggested that, over the period from 1997/98 to 2003/04, the mean winter numbers of Turnstone recorded in the study area were unrelated to mean regional numbers ($F_{1,5}$ = 0.89, P = 0.3881).

Nationally, the wintering numbers of Turnstone declined on non-estuarine coasts between 1984/85 and 1997/98 (Rehfisch *et al.* 2003c).

3.1.3 Other waterbird species

A total of 46 waterbird species were recorded during counts in the winter of 2004/05, including 21 species of wildfowl and 16 species of wader (Appendix 1).

3.2 Analyses of Data from Colour-ringed Turnstones

3.2.1 Changes in Turnstone survival rates following improvements to sewage treatment

Models describing the survival rates and resighting probabilities of Turnstone caught and colour-ringed at Amble-Hauxley are described in Table 3.2.1.1. Resighting probabilities were generally high, equal to 0.785 (95% confidence limits = 0.733-0.829) in the base model in which both ϕ and p were assumed to be constant over time.

In the model with the lowest $QAIC_c$ value, two separate survival rates were estimated. This suggested that the annual survival of adult Turnstones was constant at 0.769 (95% confidence limits = 0.723-0.810) over the years 1998-2001 and 2003-2004 but fell to 0.615 (0.471-0.742) in 2002 – a level equal to that of first-winter birds. This model also indicated that p varied significantly between years.

Although this was the most parsimonious model, a likelihood ratio test indicated that it did not differ significantly from that in which survival was assumed to be constant over the study period (LRT: χ^2_1 = 3.67, P = 0.0555) – largely because the error in the survival estimates was increased by a low resighting rate in 2002/03.

A constant annual survival rate (for adults and first-winter birds) of 0.747 (95% confidence limits = 0.707-0.783) was thus estimated for the period 1997/98 to 2004/05. Resighting probabilities varied between 0.681 and 1.000 over six of the seven winters, but dropped to 0.142 in the winter of 2002/03.

3.2.2 Movements of colour-ringed Turnstones

Turnstone are typically site-faithful during winter and, among those colour-ringed at Amble-Hauxley, only between 5 and 17% were recorded elsewhere in the study area in any one winter (Figure 3.2.2.1). Despite this, some individuals were recorded at St. Mary's Island over 30 km to the south.

The proportion of Turnstone colour-ringed at Amble-Hauxley that used other sites showed no trend across winters (χ^2_1 = 0.90, P = 0.3438) and also did not differ between winters before and after the improvement to the Amble discharge (χ^2_1 = 0.16, P = 0.6919).

4. DISCUSSION

Changes in waterbird numbers in relation to sewage improvements and regional trends

The influence of coastal sewage discharges on intertidal ecosystems is dependent on a number of factors, in addition to the size of discharge and the treatment the sewage has received, notably the distance of outfalls from shore and currents. On the Northumberland coast, there is a net southward flow of currents. Thus the sewage outfall which discharges at the north of the Amble-Hauxley area may have had a larger effect on intertidal communities than that at Newbiggin, which discharges to the south of this headland (though Eaton (2001) found no clear pattern of decline in the percentage of POM derived from sewage with increasing distance southward of outfalls). The impact of discharges on communities across the study area may thus be highly variable and the impacts of recent improvements correspondingly localised.

Across the study area as a whole, there was evidence that the changes to sewage treatment affected both of the two species for which the SPA is designated in winter – Purple Sandpiper and Turnstone. Both these species showed declines following the winter of 2000/01, having previously risen in number.

Purple Sandpiper and Turnstone both declined on non-estuarine coasts of Great Britain between surveys in 1984/85 and 1997/98 (Rehfisch *et al.* 2003c), in part possibly due to climate change (Rehfisch *et al.* 2004). At a regional level, WeBS counts indicated that Purple Sandpipers were still declining up to 2003/04, but that Turnstone numbers had stabilised after a decline between the mid-1980s and mid-1990s (Maclean *et al.* 2005). However, for neither species were numbers in the study area related to regional numbers. Indeed, the fact that both Turnstone and Purple Sandpiper were increasing in the study area up until 2000/01, suggests that local factors were important in their recent declines.

At the more local scale, after a period of high stability in numbers, there was a clear decline (of >35%) in the numbers of Turnstone at Amble-Hauxley over the four years following the improvement to the Amble discharge. Purple Sandpiper numbers also fell here in 2003/04, having risen prior to the improvement to the discharge. However, no significant declines were apparent in the numbers of either species at this site – or in the study area as a whole – between the winters of 2003/04 and 2004/05.

In contrast, at Newbiggin where the sewage outfall may have had less influence on intertidal communities, no significant trends were apparent in the numbers of either species following the improvements to the discharge there.

The immediate decline in Turnstone numbers at Amble-Hauxley following improvements to the discharge at Amble-Hauxley is in contrast to an earlier study at Hartlepool. Here, Eaton (2000) reported no change in Turnstone numbers between the winters of 1991/92 to 1993/94 and 1999/2000, the second winter following the diversion of discharges away from important feeding grounds on Hartlepool Headland to a new offshore outfall to the south. Purple Sandpiper numbers had fallen between these periods, though this decline followed an earlier local trend and may have reflected the national population trend for the species over this period (Rehfisch *et al.* 2003c). Since Eaton's study, however, numbers of Turnstone at Hartlepool have declined, suggesting that the impacts on birds of the changes in sewage disposal there may have been delayed (Burton *et al.* 2005).

Changes in Turnstone numbers in relation to changes in their survival rates

The present study is the first to use standard mark-recapture analyses to estimate annual survival rates (and resighting probabilities) for Turnstone. The rate of 75% calculated for (adult and first-winter) Turnstone caught at Amble-Hauxley is lower than many rates previously reported for the species, though not dissimilar to those for many other waders (Evans & Pienkowski 1984, Burton 2000, Sandercock 2003). Metcalfe & Furness (1985), for example, reported a minimum annual survival rate of 86% for a population of colour-ringed adult Turnstone wintering in south-western Scotland and Pearce-Higgins (2001) a similar rate for adults and first-winter birds wintering in north Wales. Evans & Pienkowski (1984) recorded a return rate of 85% for colour-ringed Turnstone on the coast south of Teesmouth and Bergmann (1946) a minimum annual survival rate of 78% in a study of breeding Turnstone in Finland. In contrast, Burton & Evans (1997) reported a minimum annual survival rate of 71-72% for colour-ringed adult and first-winter Turnstone wintering at Hartlepool.

Although survival analyses only included data for birds originally caught and ringed in the study area, four other Turnstones originally ringed in the Hartlepool / Teesmouth area (between 1986 and 1993) were seen in the study area in 2001, possibly due to the changes in sewage disposal there (Burton *et al.* 2005). Despite generally high site-fidelity in the species (Metcalfe & Furness 1985, Burton & Evans 1997) some individuals may thus move wintering area between years – indeed one Turnstone colour-ringed in Northumberland was also seen at Hartlepool only to subsequently return to its original wintering area. It is possible, therefore, that the apparent decline in survival in 2002 may have been in part due to movements of birds away from the area following the improvements to the Amble discharge and that true survival was underestimated. The analysis of Turnstone movements, though, suggests that this is unlikely. There was no change in the proportion of Amble-Hauxley ringed birds that were seen at other sites in the study area following the improvements to the discharge and thus no reason to suppose that individuals may have moved to other sites outwith the study area.

It is likely that the drop in Turnstone numbers seen at Amble-Hauxley following the improvements to the Amble discharge was in part a consequence of the fall in the apparent survival of adults (as suggested by the survival analyses). If this were the case, this would strongly suggest that the improved treatment of sewage had an impact on food supplies thus increasing competition between individuals. Following the decline in local densities, competition would have lessened, allowing survival rates to return to their previous levels. Although numbers of Turnstone, and Purple Sandpiper, at Amble-Hauxley were indeed similar in 2004/05 to those in the previous winter, it remains too early to affirm that numbers have now reached a new equilibrium. More study is thus needed to determine whether numbers have stabilised or whether there might be continued decline here and over the study area as a whole.

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, there was some evidence, from analyses of changes in numbers and survival rates, that the changes to sewage treatment affected Purple Sandpiper and Turnstone – the two wintering species for which the Northumbria Coast SPA is designated.

Both Purple Sandpiper and Turnstone declined across the study area following 2000/01 and the completion of the majority of improvements to sewage discharges. Although, in both cases, these declines followed earlier increases in numbers, the coincidence in timing with the changes to sewage treatment is of concern.

The following recommendations are made with the aim of providing a more complete understanding of the impacts of the changes in sewage disposal on the waterbirds wintering on the Northumbrian coast:

- Firstly, it is recommended that waterbird counts continue during the winter of 2005/06. This would show whether numbers of Turnstone and Purple Sandpiper have now stabilised or whether there might be continued decline either over the study area as a whole or at Amble-Hauxley.

  By collecting sightings of colour-ringed Turnstone for an additional winter it would also be possible to improve the accuracy of existing survival estimates and thus determine more fully the significance of the change in survival seen following the changes to sewage treatment at Amble. These data could be collected while undertaking waterbird counts.

- Secondly, it is recommended that stable isotope analyses are undertaken in order to establish the current importance of nutrient inputs from sewage for birds foraging within the study area. This may be achieved by looking at $\delta^{13}C$ (the ratio of ^{13}C to ^{12}C) and $\delta^{15}N$ (the ratio of ^{15}C to ^{14}C) values in different species of invertebrates and in the feathers of Turnstones.

  Stable isotope analyses should also be used to determine the degree to which nutrient loading in waters has changed along the Northumberland coast since 2001 and, through comparison with the results obtained by Eaton (2001), to measure change in the POM attributable to sewage.

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This report builds on the work on the waterbirds of the Northumbrian coast, initiated and commissioned by NWL, and undertaken by a team of researchers at the University of Durham. The project was initiated and overseen by Chris Spray of NWL and we owe a particular debt to both Chris and the late Peter Evans of the University of Durham for developing the project. We would also like to thank Keith Hamer for overseeing the University of Durham's recent work. Other NWL funded work on the impacts on waterbirds of changes to sewage disposal at Hartlepool and their support of the national Non-estuarine Coastal Waterfowl Survey was also of great benefit in providing background information for this study. Mark Eaton and Rich Fuller supplied their original counts and ringing data from their PhD work and provided considerable advice over the course of our work. We also thank all those from the University of Durham who helped Mark and Rich with counts over the course of their studies. We thank Stuart Pudney, Chris Jones and Les Hall (NWL) for their help in the continuation of this important long-term study; Mark Woolley (NWL) provided information on the changes to sewage treatment along the Northumbrian coast. Nigel Clark and Mark Rehfisch at the BTO were of considerable help over the course of our work and provided comments on the draft report.

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Site	1996/97			1997/98			1998/99			1999/2000			2000/01			Total
	A	1	U	A	1	U	A	1	U	A	1	U	A	1	U	
Amble	0	0	30	34	1	0	33	18	10	0	0	0	0	0	12	138
Hauxley	0	0	31	3	2	0	0	0	0	0	0	0	0	0	0	36
Cresswell	0	0	0	0	1	17	0	0	2	0	0	0	0	0	0	20
Newbiggin	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	5
N Blyth	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
St. Mary's	0	0	0	0	0	0	0	0	0	21	2	3	0	0	0	26
Total	0	0	62	37	4	17	33	18	12	21	2	3	3	2	12	226

Table 2.2.1.1 Numbers of Turnstone ringed at each site and in each year.

Test 2	Test 3
$\chi^2_3 = 2.01$, $P = 0.5701$	$\chi^2_{10} = 4.32$, $P = 0.9319$

Table 2.2.1.2 Results of goodness-of-fit tests carried out on Turnstone mark-recapture (mark-resighting) data, using information from birds caught at Amble-Hauxley.

Tests 2 and 3 from the program RELEASE (run through Program MARK) check the validity of the Cormack-Jolly-Seber model. Test 3 checks whether previous capture history affects the future probability of survival or recapture, whilst Test 2 checks that survival rates and recapture probabilities are the same for different cohorts of birds (see Burnham *et al.* 1987).

Model	QAIC$_c$	Parameters	Model deviance
$\phi_c\ p_c$	932.74	2	229.90
$\phi_t\ p_c$	906.06	8	190.91
$\phi_t\ p_t$	816.73	14	88.94
$\phi_{2002\ v\ other\ years}\ p_t$	811.13	9	93.90
$\phi_{adult\ v\ 1st\text{-}year}\ p_t$	810.28	9	93.05
$\phi_c\ p_t$	**809.78**	**8**	**94.63**
$\phi_{adult2002\ \&\ 1st\text{-}year\ v\ adult\ other\ years}\ p_t$	808.19	9	90.96

Table 3.2.1.1 Evaluation of mark-resighting models for Turnstone originally caught and colour-ringed at Amble-Hauxley, using data from 1997/98 to 2004/05.

Different models evaluated whether resighting rates p were constant (c) or varied fully with time (t) and whether survival rates ϕ were constant (c), differed between adults and first-year birds (adult v 1st-year), varied fully with time (t) or differed in the first full year after improvements, i.e. 2002. Bold type indicates the model that best fitted the data.

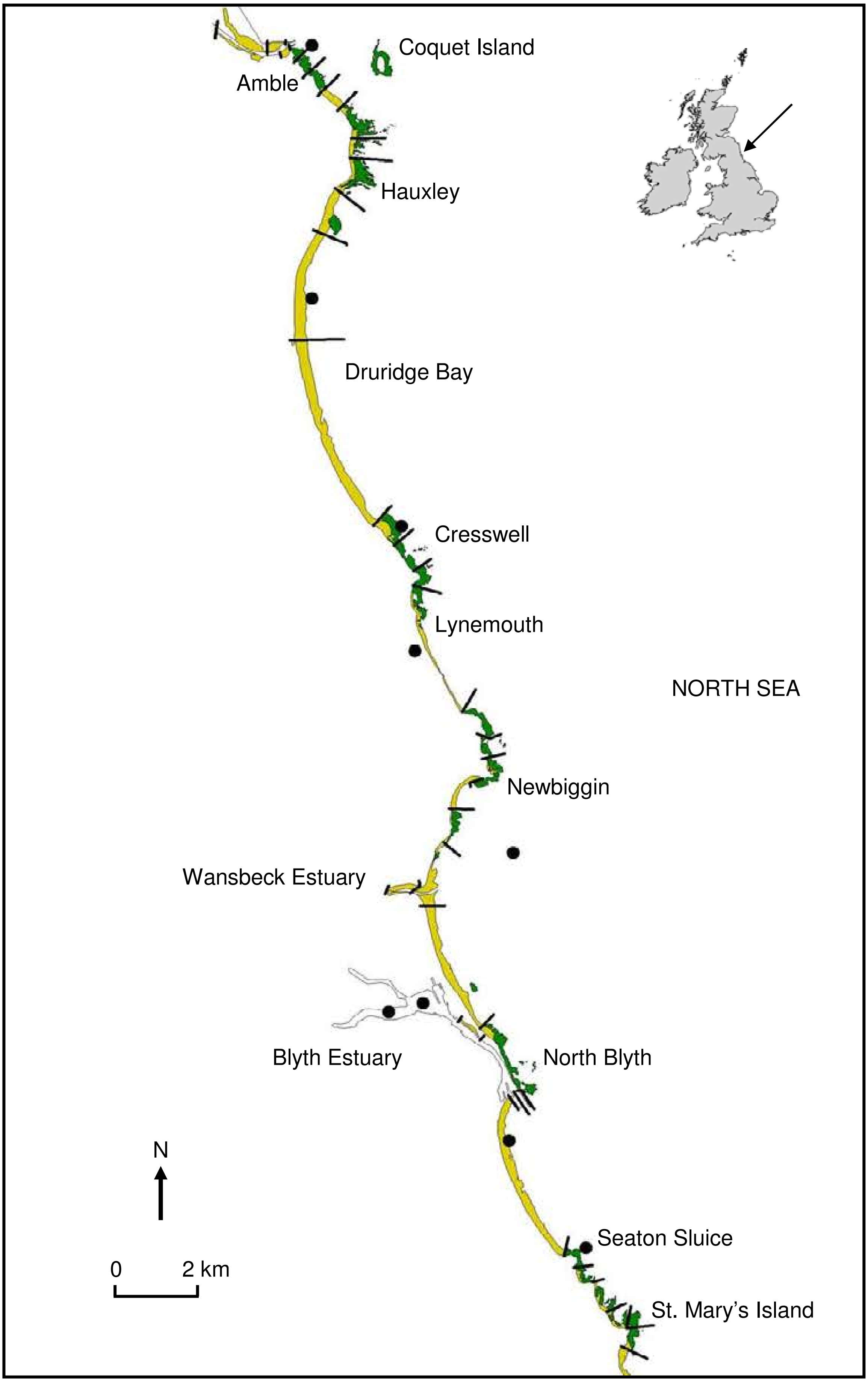
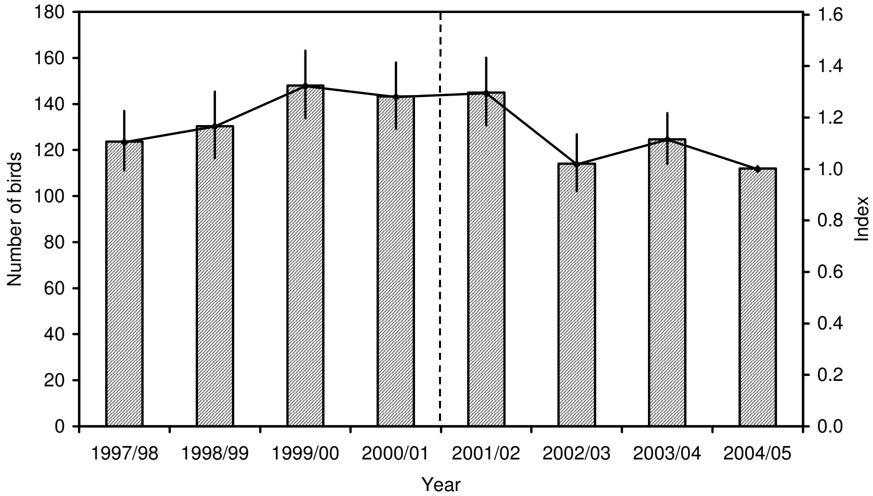
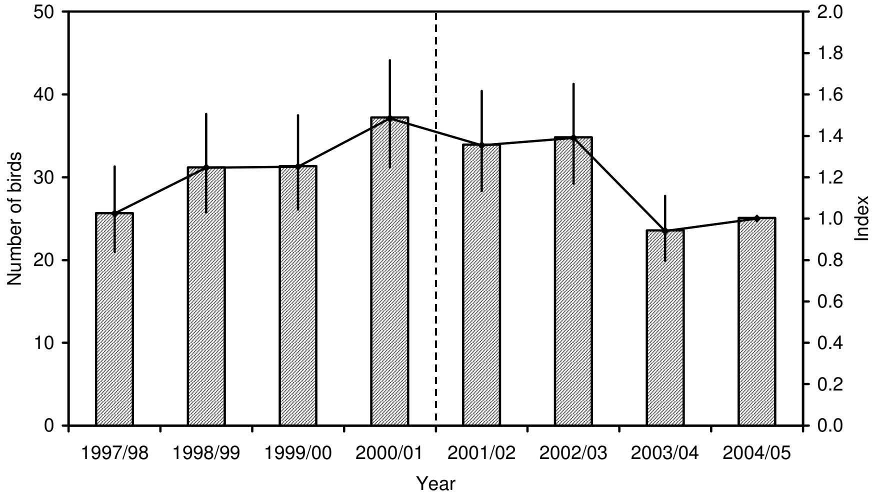


Figure 1.1 The study area, showing areas of rocky and soft sediment intertidal shore, sewage outfalls (shown by black dots) and the sections used for counting waterbirds. Amble (55˚20' N, 1˚34' W); St. Mary's Island (55˚04' N, 1˚27' W).

a.



b.



c.

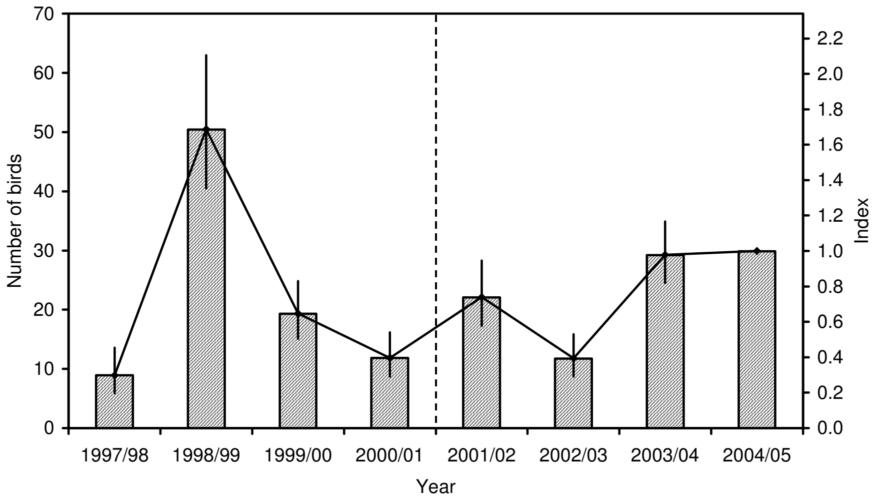
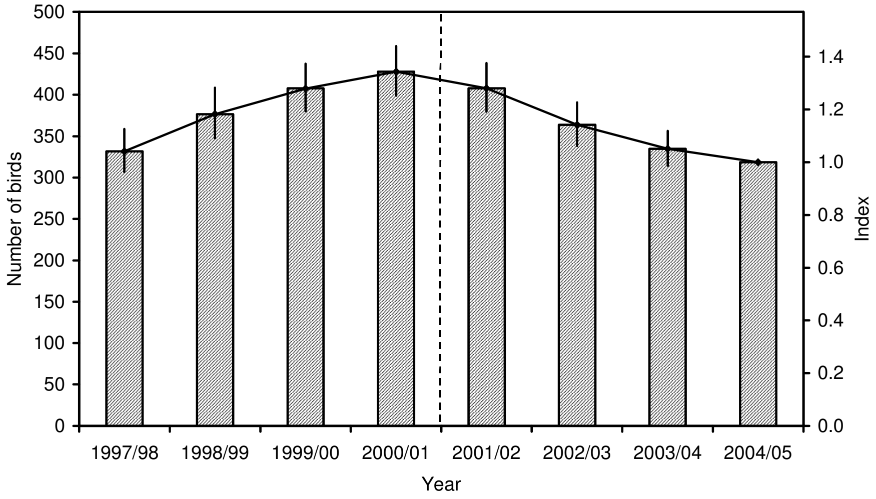


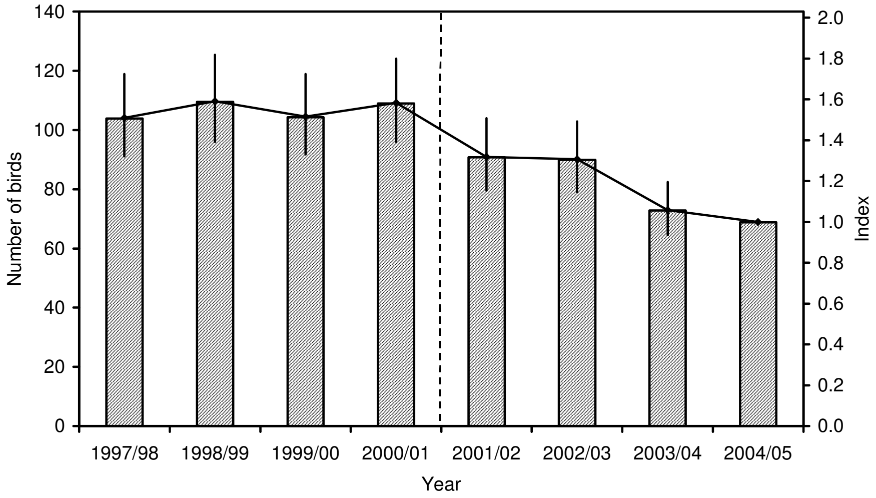
Figure 3.1.1.1 Indices (± 1 SE) and mean numbers of birds derived from models relating the numbers of Purple Sandpiper on **a.** the whole coast between the Coquet Estuary and St. Mary's Island **b.** the Amble-Hauxley coast* and **c.** the Newbiggin coast to year, month, state of tide and count section. The dotted line indicates the date when the majority of improvements to discharges (including those at Amble-Hauxley and Newbiggin) were completed. * - year not significant in this model.

Figure 3.1.1.2 Mean winter numbers of Purple Sandpiper in WeBS recording areas within the North-east Environment Agency region for the 25-year period from 1978/79 to 2003/04, taken from Maclean *et al.* (2005).

a.



b.



c.

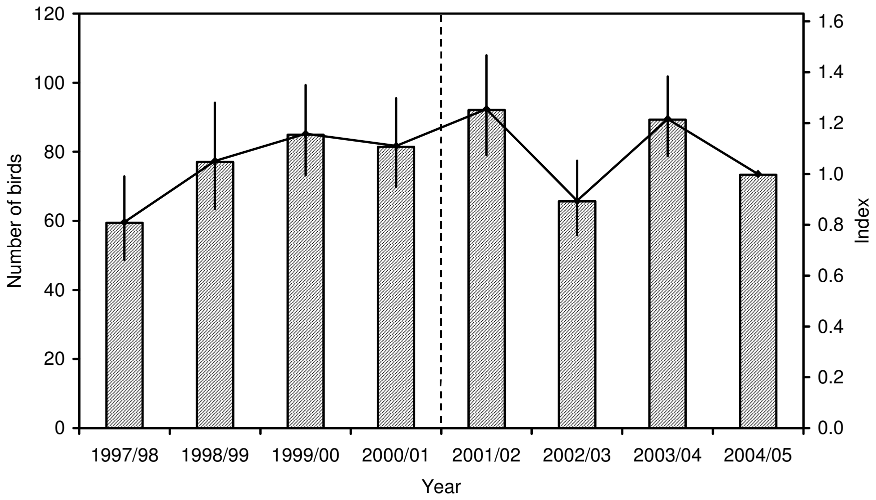


Figure 3.1.2.1 Indices (± 1 SE) and mean numbers of birds derived from models relating the numbers of Turnstone on **a.** the whole coast between the Coquet Estuary and St. Mary's Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast* to year, month, state of tide and count section. The dotted line indicates the date when the majority of improvements to discharges (including those at Amble-Hauxley and Newbiggin) were completed. * - year not significant in this model.

Figure 3.1.2.2 Mean winter numbers of Turnstone in WeBS recording areas within the North-east Environment Agency region for the 25-year period from 1978/79 to 2003/04, taken from Maclean *et al.* (2005).

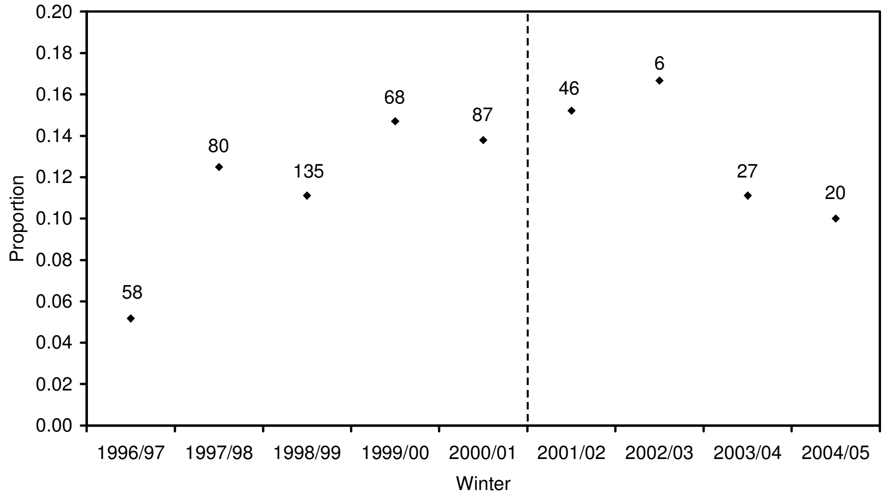


Figure 3.2.2.1 The proportions of Turnstone colour-ringed at Amble-Hauxley that were seen at other sites in the study area each winter. The total numbers of Turnstone colour-ringed at Amble-Hauxley that were seen each winter are indicated by data points. The dotted line indicates the date when the improvements to the Amble discharge were completed.

Appendix 1. Waterbird species recorded in the study area during the winter of 2004/05.

Red-throated Diver *Gavia stellata*
Black-throated Diver *Gavia arctica*
Great Crested Grebe *Podiceps cristatus*
Cormorant *Phalacrocorax carbo*
Shag *Phalacrocorax aristotelis*
Grey Heron *Ardea cinerea*
Mute Swan *Cygnus olor*
Whooper Swan *Cygnus cygnus*
Greylag Goose *Anser anser*
Dark-bellied Brent Goose *Branta bernicla bernicla*
Shelduck *Tadorna tadorna*
Mandarin *Aix galericulata*
Wigeon *Anas penelope*
Gadwall *Anas strepera*
Teal *Anas crecca*
Green-winged Teal *Anas carolinensis*
Mallard *Anas platyrhynchos*
Pintail *Anas acuta*
Tufted Duck *Aythya fuligula*
Scaup *Aythya marila*
Eider *Somateria mollissima*
Long-tailed Duck *Clangula hyemalis*
Common Scoter *Melanitta nigra*
Velvet Scoter *Melanitta fusca*
Goldeneye *Bucephala clangula*
Red-breasted Merganser *Mergus serrator*
Goosander *Mergus merganser*
Moorhen *Gallinula chloropus*
Coot *Fulica atra*
Oystercatcher *Haematopus ostralegus*
Ringed Plover *Charadrius hiaticula*
Golden Plover *Pluvialis apricaria*
Grey Plover *Pluvialis squatarola*
Lapwing *Vanellus vanellus*
Knot *Calidris canutus*
Sanderling *Calidris alba*
Little Stint *Calidris minuta*
Purple Sandpiper *Calidris maritima*
Dunlin *Calidris alpina*
Ruff *Philomachus pugnax*
Snipe *Gallinago gallinago*
Bar-tailed Godwit *Limosa lapponica*
Curlew *Numenius arquata*
Redshank *Tringa totanus*
Turnstone *Arenaria interpres*
Kingfisher *Alcedo atthis*