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Impacts of changes in sewage disposal on populations of waterbirds wintering on the Northumbrian coast
Report for 2003/04

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CONTENTS

Page No.

List of Tables

Page No.

List of Figures

Page No.

Page No.

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 results of and extends the investigation, commissioned by NWL and begun in 1996/97 by the University of Durham, of the impacts of the 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 provides a summary of work carried out by the British Trust for Ornithology (BTO) and University of East Anglia (UEA) in the winter of 2003/04 and analyses of the changes to the invertebrate and wintering waterbird communities that have occurred since monitoring was begun by the University of Durham. Additional analyses investigate whether changes in Turnstone numbers might be explained by changes in this species' survival rates.

   In addition to Purple Sandpiper and Turnstone, analyses of waterbird count data were carried out for eight other waterbird species: Eider *Somateria mollissima*, Oystercatcher *Haematopus ostralegus*, Ringed Plover *Charadrius hiaticula*, Knot *Calidris canutus*, Sanderling *C. alba*, Dunlin *C. alpina*, Curlew *Numenius arquata* and Redshank *Tringa totanus*. 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 Invertebrate Abundance Following Improvements to Sewage Treatment

5. Comparison between (rocky shore and soft sediment) invertebrate data collected by the University of Durham between 1995/96 and 1997/98 and that collected in November 2003 showed no apparent declines in abundance following the improvements. However, particularly in the rocky shore data, there was considerable variability in invertebrate abundance both within and between transects and, as transects were not permanently marked, differences between years could have been the result of the heterogeneity within the sites, rather than actual changes over time. As a result of these factors and the limited size of the datasets, it was not possible to conclude that invertebrates had not been affected by the changes to sewage discharges.

Changes in Waterbird Numbers Following Improvements to Sewage Treatment

6. Across the study area as a whole, there were no clear trends in numbers across species following the completion of the majority of improvements to discharges in the winter of 2000/01. However, there was some evidence 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. No other species showed such clear declines following 2000/01.

At the more local scale, after a period of high stability in numbers, there was a clear decline (of >30%) in the numbers of Turnstone at Amble-Hauxley over the three 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. Sanderling likewise showed a decline in numbers at Amble-Hauxley after 2000/01 following an earlier increase. No other declines were noted at this scale that couldn't be attributed to longer-term trends (and thus potentially reflecting factors unrelated to sewage improvements).

Changes in Turnstone Survival Rates Following Improvements to Sewage Treatment

7. Analysis of data from resightings of colour-ringed Turnstone showed that the decline in Turnstone numbers at Amble-Hauxley following the winter of 2000/01 might have been the result of reduced survival among adults. Results suggested a drop in annual survival from 77% over the four years before the improvement to the Amble discharge to 68% over the following three years, though this change was not significant. The adult survival rate for Turnstone at Amble-Hauxley for the whole period from 1997/98 to 2003/04 was estimated to be 75.9% (95% confidence limits = 70.9-80.3).

Conclusions

8. There was some evidence, from analyses of changes in numbers (and survival rates) that the changes to sewage treatment affected Purple Sandpiper and Turnstone. However, it was not possible to determine whether invertebrate food supplies had been affected by the changes to sewage discharges and there were no clear indications that the improvements to sewage treatment might have affected other waterbird species, with the exception of Sanderling.

Recommendations

9. 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.

   It is thus recommended that waterbird counts continue for a minimum of two more winters. This would show whether numbers of Turnstone and Purple Sandpiper continue to decline across the study area as a whole and whether the decline recorded in Turnstone numbers at Amble-Hauxley continues or whether a new equilibrium has been reached.

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

11. Supplementary work that could be of benefit includes further invertebrate sampling (particularly of rocky shores), though only if the larger dataset collected by Mark Eaton was available for comparison.

12. In addition, it is recommended that the stable isotope analysis undertaken by Eaton (2001) be repeated. By sampling in the same locations it would be possible to examine how the proportion of sewage-derived Particulate Organic Matter has changed in the study area following the improvements to sewage treatment.

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 results of and extends the investigation, commissioned by NWL and begun in 1996/97 by the University of Durham, of the impacts of the 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:

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[1] 'Primary treatment' entails treatment of urban 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 (see Figure 1.1).

- 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). Reductions in the quantity of the organic matter from sewage discharges might be expected to have a noticeable impact on total POM 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 provides a summary of work carried out in the winter of 2003/04 and analyses of the changes to the invertebrate and wintering waterbird communities that have occurred 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).

Our report has four main aims:

1. To determine whether there have been changes in invertebrate abundance following the completion of the majority of improvements to sewage discharges late in the winter of 2000/01
2. To determine whether waterbird numbers have changed following the improvements to discharges
3. To determine whether changes in Turnstone numbers might be explained by changes in this species' survival rates
4. 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 (and survival rates) 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.

2. METHODS

2.1 Invertebrates

Invertebrate data were collected in early November 2003 at sites where samples had also been collected by the University of Durham prior to improvements to discharges. Data were collected from both soft sediments and rocky shores, following the same transects used in earlier studies (Robinson *et al.* 1996, Eaton 1997, 1998).

Soft sediment data had previously been collected by the University of Durham in autumn 1995, autumn 1996, autumn 1997 and spring 1998. Rocky shore data were also collected in the winter of 1995/96, autumn 1997 and spring 1998, though were only available from the former period for comparison with the data collected in November 2003.

It should be noted that as the transects were not permanently marked any differences observed between years may be the result of the heterogeneity (variability) within the sites, rather than actual changes over time. The actual lengths of the transects also differed between years for this reason and due to differences in the tides when samples were collected. In November 2003, data were collected over a period of spring low tides of c.1 m in height.

2.1.1 Soft sediments

The sampling programme involved collection of samples at five locations (See Table 2.1.1.1 and Figure 2.1.1.1). At each location, two 10 x 10 cm cores were taken to a depth of 15 cm (following the procedure used by previous University of Durham sampling). The two replicates were processed separately, giving a total of 218 samples.

Sediment samples were placed in polythene bags, labelled and immediately preserved with industrial methylated spirits. Samples were returned to the University of East Anglia (UEA) where they were sieved through a 0.5 mm sieve in tap water. Animals were then transferred to industrial methylated spirits for identification and long term storage. Invertebrates were identified under a dissecting microscope, using the identification keys of Hayward & Ryland (1990) and Lincoln (1979).

2.1.2 Rocky shores

Rocky shores were sampled at Amble (Wellhaugh Point), Hauxley and Seaton Sluice (see Figure 2.1.2.1). Based on a review of the University of Durham sampling programme, our intention was to sample four transects at Amble and three each at Seaton Sluice and Hauxley. This was feasible at Amble and Seaton Sluice, but not Hauxley, where the area of exposed rock was substantially less than indicated on the attached map. In consequence a single transect was sampled at Hauxley, corresponding to transect C on the University of Durham maps (see Figure 2.1.2.1).

The 1995/96 University of Durham report (Robinson *et al.* 1996) states that the following methods were used:

- Transects of the feeding areas were made and 0.25 m^2 quadrats were placed at 20 m intervals down the shore.
- The species present were recorded and were quantified either by percentage cover or by number if the cover was less than 5%.
- The lengths of *Mytilus edulis* along a transect were measured. Samples were measured at 20 m intervals down the shore.

The 1997/98 report (Eaton 1998) gives slightly different methods, including the collection of data on *Mytilus* percentage cover in ten randomly sited 0.25 m^2 quadrats within musselbeds. At the first site to be visited (Hauxley) it was immediately apparent that the animal and plant communities were too heterogeneous (variable) to characterise the fauna from a single quadrat at each location. In consequence, between 2 and 10 quadrats were sampled at each location. The number of quadrats sampled at each site was dictated by the time available, but where possible more samples were taken at spatially heterogeneous sites. Numbers of quadrats at each site are given in the results table. A total of 125 quadrats were sampled at Amble, 98 at Hauxley and 67 at Seaton Sluice.

Sampling sites were located at 20 m intervals along each transect, extending upwards to the top of the barnacle zone. Data were collected on percentage cover of *Mytilus,* and the mean abundance of limpets and dogwhelks in 0.25 m^2 quadrats. In addition, at 13 sites mean lengths of a sample of approximately 20 individuals of *Mytilus* were measured using Vernier callipers. Data were also collected on percentage cover of bare rock, barnacles and algae and numbers of individuals per quadrat for littorinid gastropods; *Gibbula*; *Patina* and hermit crabs, but these data are not reported here.

2.2 Waterbird Numbers

2.2.1 Count data

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.

2.2.2 Analysis of count data

Analyses of count data were carried out for the two wintering species for which the Northumbria Coast SPA is designated: Purple Sandpiper and Turnstone, as well as Eider *Somateria mollissima* and seven other species of wader: Oystercatcher *Haematopus ostralegus*, Ringed Plover, Knot, Sanderling, Dunlin, Curlew *Numenius arquata* and Redshank. 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. The estimated values of the model parameters α_i indicate how the numbers of birds varied each winter relative to 2003/04. These estimates are plotted in a series of graphs, for each species, to indicate trends in bird numbers.

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 model estimates so as to understand better how the actual numbers of each species changed over the study period and following improvements to discharges.

As the numbers 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 and Sanderling), 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.

Analyses of waterbird numbers 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.

Accounts for Purple Sandpiper and Turnstone are given first, followed by those for the other eight species. Comparison is made with the most recent national trends taken from Wetland Bird Survey (WeBS) data (Austin *et al.* 2004) for all species except for Purple Sandpiper and Eider which are poorly monitored by this scheme. Trend information from WeBS was only available up until the winter of 2000/01 and thus does not cover the period following the completion of the majority of improvements to sewage discharges on the Northumbrian coast. For Purple Sandpiper and Turnstone, 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).

2.3 Turnstone Survival Analyses

Between the winters of 1996/97 and 2000/01, 229 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 229 birds colour-ringed, 26 were classed as first-winter birds when marked, 95 as adults and 108 unaged.

Estimates of annual survival rates and recapture probabilities of Turnstone were calculated using mark-recapture methods. Too few first-winter Turnstone were caught to investigate age-specific survival rates and thus only data pertaining to birds known to be adults, i.e. in their second-winter or older, when caught or resighted were retained. This allowed calculation of survival rates for the period 1997/98 to 2003/04. Initial analysis used data from birds caught at every one of the catch sites (Table 2.3.1). A second analysis investigated the adult survival rates of just those Turnstone originally caught and ringed at Amble-Hauxley (though retaining resighting data from the whole study area). In both cases, analyses aimed to determine whether survival rates differed 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 seen 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 2.3.2). 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). Models looked at whether annual survival rates varied with time, either fully across every recapture period or before and after the winter of 2000/01, when the majority of improvements to discharges were completed. Similarly, the models also investigated whether or not the recapture probabilities also varied fully with time. Changes in survival rates are discussed in relation to the changes in numbers of Turnstone observed on the study area (see section 3.2.2).

3. RESULTS

3.1 Changes in Invertebrate Abundance Following Improvements to Sewage Treatment

3.1.1 Soft sediments

Preserved animals were in good condition when sieved from the sediment, and a greater diversity of taxa was identified than in reports produced by the University of Durham. Invertebrates have been retained in long term storage. The animals identified, and total numbers and maximum densities at any one site are given in Table 3.1.1.1.

The "other polychaetes" category include a range of species not identified further. The biggest recognisable subcategory within this were spionids other than *Scolelepis*. We did not systematically assess whether gastropod shells contained live animals, but the bivalves were intact individuals (largely juveniles) with their shells closed and were presumably all alive at the time of sampling.

Both samples from 50 m on St Mary's Island transect B contained large numbers of *Capitella* and *Scolelepis* and a substantial quantity of organic debris, which was intertwined and impossible to separate without damaging the animals. Counts for these samples are therefore estimated.

For the five species for which data from previous years were available, total counts across all samples from each site, with comparative data from autumn 1995 to autumn 1997 are given in Table 3.1.1.2.

Both within transects and between sites, there was considerable heterogeneity in the diversity and numbers of species present and this is also apparent over time. Examination of Table 3.1.1.2 shows no clear loss in invertebrate abundance between 1995 and 1997, prior to the improvements in sewage treatment, and 2003 following the improvements. Indeed, the abundance of *Scolelepis* appeared greater at Druridge Bay and St. Mary's Island in 2003 and the abundance of *Perioculoides* similarly greater at Druridge Bay and Cambois.

3.1.2 Rocky shores

Results from the sampling of rocky shores are summarised in Table 3.1.2.1. Mussel abundance varied greatly between the three shores. At Hauxley, mussels occurred only in small areas, with a mean percentage cover of 2.6% at one site, and a mean individual length of about 5 mm. At Amble there were two sites where the mean percentage cover of mussels was in the region of 40% and mussels were present at a number of other sites. Mean length was approximately 10 mm. Mussels were most abundant at Seaton Sluice, where percentage cover exceeded 70% on at least one site on each transect and mean individual lengths varied between 10 and 20 mm.

Limpet abundance showed a similar pattern, with mean numbers per quadrat of 2.2 at Hauxley; 9.2 at Amble and 23.3 at Seaton Sluice. Dogwhelk numbers were very low at all sites (mean abundance always less than one per quadrat).

Comparative figures on percentage cover of mussels and limpet abundance from February 1996 (taken from Robinson *et al.* 1996) are shown in Table 3.1.2.1. Results from both years show considerable heterogeneity in both the percentage cover of mussels and limpet abundance within transects and between sites. Comparison suggests greater abundance of both species in 2003, though as the samples were collected three months earlier than in 1996, numbers would have been less depleted by predation.

3.2 Changes in Waterbird Numbers Following Improvements to Sewage Treatment

Species for which the Northumbria Coast SPA is designated in winter

3.2.1 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 149 birds – but fell in 2002/03, two winters after the completion of the majority of improvements to sewage discharges in the area (Figure 3.2.1.1a). There was no significant difference in numbers between the four winters before these improvements and the three following winters ($\chi^2_1 = 1.14$, $P = 0.285$). Nationally, there was a decline in Purple Sandpiper numbers on non-estuarine coasts between 1984/85 and 1997/98 (Rehfisch *et al.* 2003c).

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 no significant difference in numbers before and after the improvement to the Amble discharge (Figure 3.2.1.1b; $\chi^2_1 = 0.40$, $P = 0.529$).

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 3.2.1.1c; $\chi^2_1 = 0.23$, $P = 0.630$).

3.2.2 Turnstone *Arenaria interpres*

Mean winter numbers of Turnstone in the study area as a whole rose to a peak of 430 birds in 2000/01 just prior to the completion of the majority of improvements to sewage discharges in the area (Figure 3.2.2.1a). There was no significant difference in numbers between the four winters before these improvements and the three following winters ($\chi^2_1 = 2.98$, $P = 0.084$). Nationally, the wintering numbers of Turnstone recorded by WeBS counts declined between the mid-1980s and mid-1990s, but have since been more stable (Austin *et al.* 2004). A decline was also recorded on non-estuarine coasts between 1984/85 and 1997/98 (Rehfisch *et al.* 2003c).

At Amble-Hauxley, Turnstone numbers were very stable over the four winters prior to the improvement to the Amble discharge, but declined over the three following winters (Figure 3.2.2.1b). Numbers in 2001/02 to 2003/04 were significantly lower than those in the four preceding winters ($\chi^2_1 = 13.22$, $P < 0.001$).

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 three following winters (Figure 3.2.2.1c; $\chi^2_1 = 0.65$, $P = 0.420$).

Other species

3.2.3 Eider *Somateria mollissima*

Mean winter numbers of Eider across the study area have shown cyclical changes across the study period. Numbers rose to a peak of 592 birds in the winter of 1998/99, declined and then rose again to another peak of 726 in 2003/04 (Figure 3.2.3.1a). Numbers in the three winters following the completion of the majority of improvements to sewage discharges in the area were significantly greater than those in the preceding four winters ($\chi^2_1 = 30.43$, $P < 0.0001$).

The peak in 1998/99 was apparent at Amble-Hauxley, but numbers dropped sharply the following winter and have remained low since (Figure 3.2.3.1b). Here, numbers were thus significantly higher in the four winters preceding the improvement to the Amble discharge ($\chi^2_1 = 17.03$, $P < 0.0001$).

At Newbiggin, numbers fluctuated over the first six winters of study before rising to a peak in 2003/04 (Figure 3.2.3.1c). Numbers here were thus significantly greater in the three winters following the improvement to the Newbiggin discharge than in the four preceding winters ($\chi^2_1 = 22.62$, $P < 0.0001$).

3.2.4 Oystercatcher *Haematopus ostralegus*

Mean winter numbers of Oystercatcher in the study area have risen since the completion of the majority of improvements to sewage discharges, peaking at 626 birds in 2003/04 (Figure 3.2.4.1a). Numbers between 2001/02 and 2003/04 were thus significantly greater than those in the four preceding winters ($\chi^2_1 = 20.62$, $P < 0.0001$). Nationally, wintering numbers of Oystercatcher have been largely stable since the early 1990s (Austin *et al.* 2004).

At Amble-Hauxley, numbers have fluctuated, but shown no clear trend and no significant change following the improvements to the discharge at Amble (Figure 3.2.4.1b: $\chi^2_1 = 1.41$, $P = 0.236$).

In contrast, at Newbiggin, there has been a steady increase in numbers across the entire study period and thus have been greater in the three winters since the improvement to the Newbiggin discharge than before (Figure 3.2.4.1c; $\chi^2_1 = 16.33$, $P < 0.0001$).

3.2.5 Ringed Plover *Charadrius hiaticula*

Mean winter numbers of Ringed Plover in the study area rose to a peak of 135 birds in 1999/2000, but since then have remained stable at a slightly lower level (Figure 3.2.5.1a). There was no significant difference in numbers between the four winters before these improvements and the three following winters ($\chi^2_1 = 1.34$, $P = 0.247$). Nationally, there has been a decline in the wintering numbers of Ringed Plovers since the mid-1980s (Austin *et al.* 2004).

Numbers at Amble-Hauxley were highest in 1997/98 and 1999/2000, but as in the study area as a whole have remained stable at a lower level since 2000/01 (Figure 3.2.5.1b). Numbers in 2001/02 to 2003/04 were significantly lower than those in the four preceding winters ($\chi^2_1 = 6.91$, $P = 0.009$).

At Newbiggin, numbers fell between 1997/98 and 2000/01, showed a small recovery the following winter but then declined again over the following two winters (Figure 3.2.5.1c). The difference in numbers between the four winters before the improvement to the Newbiggin discharge and the three following winters was almost significant ($\chi^2_1 = 3.59$, $P = 0.058$).

3.2.6 Knot *Calidris canutus*

Mean winter numbers of Knot in the study area rose to a peak of 1,039 birds in 1999/2000, and as with Ringed Plover have remained stable at a slightly lower level since (Figure 3.2.6.1a). The difference in numbers between the four winters before these improvements and the three following winters was almost significant ($\chi^2_1 = 3.75$, $P = 0.053$). Nationally, numbers of Knot have shown considerable fluctuations in recent years, though no clear trend (Austin *et al.* 2004).

At Amble-Hauxley, numbers peaked in 1998/99, but dropped sharply the following winter and have remained low since (Figure 3.2.6.1b). Numbers were thus significantly higher in the four winters preceding the improvement to the Amble discharge ($\chi^2_1 = 18.98$, $P < 0.0001$).

In contrast, at Newbiggin there was a sharp rise in numbers of Knot in 2000/01 and this higher level has been maintained over the subsequent winters (Figure 3.2.6.1c). Numbers were thus significantly higher following the improvement to the Newbiggin discharge ($\chi^2_1 = 7.07$, $P = 0.008$).

3.2.7 Sanderling *Calidris alba*

Mean numbers of Sanderling in the study area in winter rose to a peak of 217 birds in 2003/04 and thus numbers in the three winters following the completion of the majority of improvements to sewage discharges in the area were significantly greater than those in the preceding four winters (Figure 3.2.7.1a; $\chi^2_1 = 17.30$, $P < 0.0001$). Nationally, wintering numbers of Sanderling rose during the 1990s (Austin *et al.* 2004).

At Amble-Hauxley, numbers peaked in 2000/01, but declined over the following winters (Figure 3.2.7.1b). There was no significant difference in numbers between the four winters before the improvement to the Amble discharge and the three following winters ($\chi^2_1 = 0.03$, $P = 0.868$).

At Newbiggin, numbers dropped to very low levels in 1998/99 but have since recovered (Figure 3.2.7.1c). However, there was no significant difference in numbers before and after the improvement to the Newbiggin discharge ($\chi^2_1 = 2.85$, $P = 0.091$).

3.2.8 Dunlin *Calidris alpina*

Mean winter numbers of Dunlin in the study area peaked at 534 birds in 1997/98, declined over the next two winters, but have since stabilised (Figure 3.2.8.1a). However, there was no significant difference in numbers between the four winters before the completion of the majority of improvements to sewage discharges in the area and the three following winters ($\chi^2_1 = 0.80$, $P = 0.372$). The earlier decline mirrors a recent decline nationally (Austin *et al.* 2004).

The decline in Dunlin numbers since 1997/98 is evident at both Amble-Hauxley (Figure 3.2.8.1b) and Newbiggin (Figure 3.2.8.1c), where only low numbers now occur in winter. The majority of Dunlin found in the study area are found on estuaries rather than on rocky shores. Numbers in the three winters following the completion of improvements to sewage discharges were significantly lower than those in the preceding four winters at both sites (Amble-Hauxley: $\chi^2_1 = 30.49$, $P < 0.0001$; Newbiggin: $\chi^2_1 = 12.97$, $P < 0.001$).

3.2.9 Curlew *Numenius arquata*

Mean winter numbers of Curlew in the study area as a whole have shown only small fluctuations and there has thus been no change following the completion of the majority of improvements to sewage discharges in the area in 2000/01 (Figure 3.2.9.1a: $\chi^2_1 = 0.50$, $P = 0.480$). A peak mean of 95 birds was recorded in 2000/01. Nationally, wintering numbers of Curlew rose over the 1980s and 1990s (Austin *et al.* 2004).

At Amble-Hauxley, numbers peaked in 1998/99 before dropping to a much lower level, but have since slowly increased (Figure 3.2.9.1b). There was no significant difference in numbers between the four winters before the improvement to the Amble discharge and the three following winters ($\chi^2_1 = 1.66$, $P = 0.198$).

At Newbiggin, Numbers rose to a peak in 2000/01 (Figure 3.2.9.1c). Again, there was no significant difference in numbers between the four winters before the improvement to the Newbiggin discharge and the three following winters ($\chi^2_1 = 0.64$, $P = 0.424$).

3.2.10 Redshank *Tringa totanus*

Redshank numbers in the study area in winter rose from previously stable levels to a peak mean of 727 birds in 2003/04 (Figure 3.2.10.1a). Numbers in the three winters following the completion of the majority of improvements to sewage discharges in the area were significantly greater than those in the preceding four winters ($\chi^2_1 = 8.84$, $P = 0.003$). Nationally, numbers of wintering Redshank have been relatively stable over the last decade (Austin *et al.* 2004).

At Amble-Hauxley there was no clear trend across the study period and thus there was no significant change between the years before and after the improvements to the discharge at Amble (Figure 3.2.10.1b: $\chi^2_1 = 1.53$, $P = 0.216$).

The trend at Newbiggin reflects that in the study area as a whole, with numbers rising to a peak in 2000/04 (Figure 3.2.10.1c) Numbers were thus significantly higher following the improvement to the Newbiggin discharge ($\chi^2_1 = 7.43$, $P = 0.006$).

3.3 Changes in Turnstone Survival Rates Following Improvements to Sewage Treatment

Results using data from birds from all catching sites within the study area

Models describing the adult survival rates 'ϕ' and resighting probabilities 'p' for Turnstone caught at all six catching sites within the study area are shown in Table 3.3.1. The most parsimonious model (that with the lowest $QAIC_c$ value) was that in which p varied significantly between years, but in which ϕ was constant. Resighting probabilities were mostly high, varying between 0.682 and 0.986 in five of six winters, but falling to 0.148 in 2002/03. A likelihood ratio test confirmed that there was no significant difference in survival before and after the winter of 2000/01 when the majority of improvements to sewage discharges were completed ($\chi^2_1 = 0.70$, $P = 0.404$). The survival rate for the period 1997/98 to 2003/04 was estimated to be 0.770 (95% confidence limits = 0.722-0.812).

Results using data for just those birds caught at Amble-Hauxley

Models describing the adult survival rates and resighting probabilities of just those Turnstone caught at Amble-Hauxley are described in Table 3.3.2. Again, the most parsimonious models indicated that p varied significantly between years, though the model in which ϕ also varied between years did not improve on the model with constant ϕ.

A reduced model suggested that annual survival decreased from 0.771 (0.720-0.816) in the four years before the improvement to the Amble discharge to 0.683 (0.607-0.750) over the following three years. Despite this trend, this model did not differ significantly from that in which survival was assumed to be constant over the study period (LRT: $\chi^2_1 = 2.15$, $P = 0.143$), largely because the error in the survival estimates was increased by the low resighting rate in 2002/03.

The survival rate for the period 1997/98 to 2003/04 was estimated to be 0.759 (95% confidence limits = 0.709-0.803). Resighting probabilities varied between 0.705 and 1.000 over five of the six winters, but dropped to 0.138 in the winter of 2002/03.

Although 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. Despite generally high site-fidelity in the species (Metcalfe & Furness 1985, Burton & Evans 1997) some individuals may thus move wintering area between years – though the reasons for these movements are not clear. Thus it is possible that the estimates reported here may underestimate true survival (Sandercock 2003).

4. DISCUSSION

Changes in waterbird numbers in relation to sewage improvements and national 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 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 were no clear trends in numbers across species following the completion of the majority of improvements to discharges in the winter of 2000/01 (Table 4.1). However, 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). However, WeBS counts show that since the mid-1990s, Turnstone numbers have been more stable at a national level (Austin *et al.* 2004). 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. No other species showed such clear declines across the study area as a whole following 2000/01.

At the more local scale, after a period of high stability in numbers, there was a clear decline (of >30%) in the numbers of Turnstone at Amble-Hauxley over the three 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. Sanderling likewise showed a decline in numbers at Amble-Hauxley after 2000/01 following an earlier increase. No other declines were noted at this scale that couldn’t be attributed to longer-term trends (and thus potentially reflecting factors unrelated to sewage improvements).

The immediate decline in Turnstone numbers at Amble-Hauxley following improvements to the discharge here 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).

Changes in invertebrate abundance following improvements to sewage treatment

The time taken for changes in sewage treatment and disposal to impact upon waterbirds will vary between species. Those species which feed on matter directly discharged from outfalls, such as gulls and some species of duck, such as Scaup, Goldeneye, Pochard and Tufted Duck will be most at risk and the impacts on local populations of these species may be seen soon after changes (Campbell 1984, Raven & Coulson 2001). In contrast, the impacts on species which feed on the invertebrates that proliferate around outfalls might be expected to be delayed. However, early impacts on mussel spatfall, for example, would be more likely seen in small wader species, such as Purple Sandpiper and Turnstone, that feed on smaller size classes of mussels than species such as Eider that take larger prey

(Dunthorn 1971, Bustnes & Erikstad 1990, Eaton 2001). Such an impact might explain the immediate decline seen in Turnstone numbers at Amble-Hauxley.

Invertebrate data were collected by the University of Durham from 1995/96 to 1997/98, though not during the period when the majority of improvements to discharges were being completed. Thus it was not possible to determine how soon there might have been impacts on invertebrates because of these changes.

Comparison between invertebrate data collected between 1995/96 and 1997/98 and that collected in November 2003 showed no apparent declines in abundance following the improvements. However, particularly in the rocky shore data, there was considerable variability in invertebrate abundance both within and between transects and, as transects were not permanently marked, differences between years could have been the result of the heterogeneity within the sites, rather than actual changes over time. Mussels show huge year to year variability in settlement, and limpets also show year to year variation in recruitment success. As a result of these factors and the limited size of the datasets, it was not possible to conclude that invertebrates had not been affected by the changes to sewage discharges. The larger dataset on rocky shore invertebrates collected by Mark Eaton was not available at the time of writing this report, though comparison with this dataset would also have been limited by the fact that transects were not permanently marked.

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

The annual survival rate of 77% calculated for Turnstone for the study area as a whole 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 Turnstone wintering in south-western Scotland. Evans & Pienkowski (1984) recorded a return rate of 85% for colour-ringed Turnstones 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 Turnstone wintering at Hartlepool.

At Amble-Hauxley, the drop in Turnstone numbers following the winter of 2000/01 might have been the result of reduced survival among adults (or perhaps movements of some individuals out of the study area). 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 is likely to lessen, allowing survival rates to return to their previous levels. However, it is unclear at this stage whether the numbers of Turnstone in this area have now reached an equilibrium 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. However, it was not possible to determine whether invertebrate food supplies had been affected by the changes to sewage discharges and there were no clear indications that the improvements to sewage treatment might have affected other waterbird species, with the exception of Sanderling.

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 (despite the stability or increases in most other species' numbers).

It is thus recommended that waterbird counts continue for a minimum of two more winters. This would show whether numbers of Turnstone and Purple Sandpiper continue to decline across the study area as a whole and, in particular, whether the decline recorded in Turnstone numbers at Amble-Hauxley continues or whether a new equilibrium has been reached.

Although the majority of changes to sewage treatment were completed in 2000/01, the discharge at Cresswell only received improved treatment in April 2003. Additional monitoring would be needed to fully evaluate the impact of this change and that planned at Hadston.

With further monitoring it would also be possible make a better comparison with national or regional trends for the period following the improvements to sewage discharges (e.g. from WeBS data), once these data become available.

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

Supplementary work that could be of benefit includes further invertebrate sampling (particularly of rocky shores), though only if the larger dataset collected by Mark Eaton was available for comparison.

In addition, it is recommended that the stable isotope analysis undertaken by Eaton (2001) be repeated. By sampling in the same locations it would be possible to examine how the proportion of sewage-derived POM has changed following the improvements to sewage treatment. Additional studies could look at the importance of sewage-derived material in the diet of waterbirds by examining δ^{13} C and δ^{15} N values in mussels.

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Site location	Transects sampled	Distances from High Water mark (m)	Comments
Whitley Bay (St. Mary's Island)	A, B, C, D, E located 100 m apart	0, 10, 20, 30, 40, 50 & 60	
North Blyth	A, B, C located 200m apart	20, 40, 60, 80, 100, 150, 200 & 250	Sampling only possible to 150 m on transects A and B and to 200 m on transect C
Cambois	D, E, F located 200 m apart	20, 40, 60, 80, 100, 150, 200 & 250	D100X, D150Y and F250Y missing
Druridge Bay	A, B, C located 200 m apart	20, 40, 60, 80, 100 & 150	
Amble	A, B, C located 200 m apart	20, 40, 60, 80 and 100	A40Y missing

Table 2.1.1.1 Soft sediment invertebrate sampling sites, with details of transect locations and sites sampled on each transect.

	1996/97	1997/98	1998/99	1999/2000	2000/01	Total
Amble	25	35	50	0	6	116
Hauxley	30	5	0	0	0	35
Cresswell	0	15	2	0	0	2
Newbiggin	0	0	0	0	3	3
St. Mary’s Island	0	0	0	26	0	26
Total	55	55	52	26	9	197

Table 2.3.1 Numbers of Turnstone ringed at each site and in each year (totals only include those birds used in adult survival analyses).

	Test 2	Test 3
A	$\chi^2_4 = 1.29$, $P = 0.863$	$\chi^2_8 = 3.42$, $P = 0.905$
B	$\chi^2_2 = 1.75$, $P = 0.418$	$\chi^2_7 = 2.37$, $P = 0.936$

Table 2.3.2 Results of goodness-of-fit tests carried out on adult Turnstone mark-recapture (mark-resighting) data.
A – using data from birds caught at all six catching sites within the study area.
B – using data for 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).

Taxon	Total number found	Maximum density m^{-2}
Bathyporeia sp.	356	3,250
Haustorius sp	105	1,300
Eurydice sp	89	650
Perioculoides longimanus	354	1,600
Scolelepis sp	1,032	11,050
Cumaceans	28	350
Hyperia sp	3	50
Nematodes	438	6,100
Bivalves	480	3,200
Gastropods	2,171	13,400
Capitella sp	1,163	11,950
Arenicola sp	1	50
Other polychaetes	526	9,000
Oligochaetes	7	250
Insects	30	150

Table 3.1.1.1 Details of taxa identified in soft sediment samples in November 2003, total numbers found in the whole study and maximum density recorded at any one site.

Site	*Bathyporeia*				*Haustorius*				*Scolelepis*				*Perioculoides*				*Eurydice*			
Year	1995	1996	1997	2003	1995	1996	1997	2003	1995	1996	1997	2003	1995	1996	1997	2003	1995	1996	1997	2003
Amble	76	320	14	27	3	29	9	7	71	11	27	79	1	54	48	24	0	9	0	5
Druridge Bay	780	508	28	226	31	13	11	29	22	30	39	100	12	71	61	127	0	77	2	15
Cambois	0	118	-	77	18	2	-	51	10	0	-	28	0	6	-	157	2	1	-	59
North Blyth	115	20	-	6	45	23	-	13	19	1	-	35	0	21	-	44	7	2	-	6
St. Mary’s Island	27	5	0	20	1	0	0	5	6	26	70	790	2	0	6	2	27	5	2	4
Total	998	971	42	356	98	67	20	105	128	68	136	1032	15	152	115	354	36	94	4	89

Table 3.1.1.2 Total numbers of individuals collected at each site for five species for which data from previous years are available. '-' indicates that the site was not sampled in the year in question.

a. Amble (Wellhaugh Point)

Site	Number of quadrats	Mean percentage cover of mussels	Mean length (mm)	Standard deviation (mm)	Number of mussels measured	Mean abundance of limpets	Mean abundance of dogwhelks
A 0	5	44.0	10.0	1.1	9	4.6	0
A 20	5	22.0	9.1	1.9	20	5.4	0
A 40	5	0				10.8	0
A 60	5	0				2.6	0
A 80	5	0				1.0	0.2
A 100	5	0				2.2	0.4
A 120	5	0				9.2	0
A 140	5	0				10.4	0
B 0	5	0				3.2	0.2
B 20	5	0				3.2	0
B 40	5	0				3.6	0
B 60	5	0				5.4	0
B 80	5	0				0	0
C 0	3	11.7				19.3	0
C 20	3	5.0				5.2	0
C 40	3	3.3				16.7	0
C 60	3	6.0				11.7	0
C 80	3	0.3				18.0	0
C 100	3	2.7	10.9	1.2	20	12.3	0.3
C 120	3	0				3.0	0
C 140	3	0				0.7	0
C 160	3	0				0.3	0
D 0	3	38.3				13.7	0
D 20	3	11.7				23.0	0
D 40	3	10.0				8.0	0
D 60	3	6.7				26.7	0
D 80	3	7.7				24.7	0
D 100	3	1.3				10.3	0
D 120	3	1.7				12.7	0
D 140	3	0.7				15.7	0
D 160	3	0.3				5.7	0
D 180	3	0				13.3	0
D 200	3	0				1.7	0

Table 3.1.2.1 Numbers of quadrats sampled at each site in November 2003; mean percentage cover of mussels, length of mussels and abundance of limpets and dogwhelks.

b. Hauxley

Site	Number of quadrats	Mean percentage cover of mussels	Mean length (mm)	Standard deviation (mm)	Number of mussels measured	Mean abundance of limpets	Mean abundance of dogwhelks
0	10	0				4.7	0.6
20	10	0				3.9	0.6
40	10	0				2.6	0.5
60	10	0				1.6	0.1
80	10	0				3.5	0
100	10	2.6	5.41	2.04	22	2.5	0
120	10	0				1.6	0
140	10	0				1.5	0
160	10	0				0	0
180	8	0				0.15	0

c. Seaton Sluice

Site	Number of quadrats	Mean percentage cover of mussels	Mean length (mm)	Standard deviation (mm)	Number of mussels measured	Mean abundance of limpets	Mean abundance of dogwhelks
A 0	5	24.0	11.8	3.6	20	38.4	0.4
A 20	5	34.0	9.5	1.9	20	41.8	0
A 40	5	0				101.0	0.2
A 60	5	0				22.4	0
A 80	5	0				4.4	0
A 100	3	58.0	17.4	2.1	20	4.0	0
A 120	3	71.7	12.9	2.0	20	2.7	0
A 140	3	0				38.3	0
A 160	3	0				43.7	0
A 180	3	0				15.3	0
B 0	3	59.0	22.0	2.8	18	4.0	0
B 20	2	81.0	14.75	2.7	20	0	0
B 40	3	12.7	12.6	2.6	20	18.0	0
B 60	3	0				33.0	0
B 80	3	8.3	15.7	2.2	20	75.3	0
B 100	3	0				8.7	0
C 0	2	75.0	19.1	4.8	20	4.0	0.5
C 20	2	47.5	19.1	3.2	20	11.5	0
C 40	2	65.0	16	3.0	20	0	0
C 60	2	72.5	14.1	2.0	20	0	0
C 80	2	65.0	13.4	2.8	20	4.5	0

Table 3.1.2.1 Continued. Numbers of quadrats sampled at each site in November 2003; mean percentage cover of mussels, length of mussels and abundance of limpets and dogwhelks (in 0.25 m^2 quadrat).

a. Amble (Wellhaugh Point)

Site	Mean percentage cover of mussels	Mean abundance of limpets (in 0.25 m^2 quadrat)
A 0	0	0
A 20	0	0
A 40	0	2.5
A 60	0	5.0
A 80	0	3.0
A 100	0	1.5
A 120	0	2.5
A 140	0	2.5
A 160	40.0	5.0
B 0	0	0
B 20	0	0
C 0	0	1.0
C 20	0	1.0
C 40	0	0.9
C 60	0	4.0
D 0	0	0.5
D 20	0	3.0
D 40	0	0
D 60	0	0.5
D 80	0	0.5
D 100	0	1.5

b. Hauxley

Site	Mean percentage cover of mussels	Mean abundance of limpets (in 0.25 m^2 quadrat)
0	0	0
20	0	0
40	0	0
60	0	0
80	0	0
100	0	0
120	0	5.0
140	0	0

Table 3.1.2.2 Mean percentage cover of mussels and abundance of limpets in February 1996 (from Robinson *et al.* 1996).

c. Seaton Sluice

Site	Mean percentage cover of mussels	Mean abundance of limpets (in 0.25 m^2 quadrat)
A 0	0	0
A 20	0	2.5
A 40	1.0	15.5
A 60	30.0	12.0
A 80	80.0	0
B 0	0	0
B 20	0	1.0
B 40	0	7.0
B 60	40.0	1.0
B 80	55.0	0.5
B 100	60.0	4.0
B 120	45.0	0
C 0	0	0.5
C 20	5.0	4.0
C 40	5.0	2.5
C 60	30.0	3.5

Table 3.1.2.2 Continued.

Model	$QAIC_c$	Parameters	Model deviance
$\phi_c\ p_c$	818.4	2	194.6
$\phi_t\ p_c$	798.4	7	164.4
$\phi_t\ p_t$	692.6	12	48.3
$\phi_{pre\text{-}post}\ p_t$	686.1	8	50.1
$\boldsymbol{\phi_c\ p_t}$	**684.7**	**7**	**50.8**

Table 3.3.1 Evaluation of mark-resighting models for adult Turnstone originally caught and colour-ringed at all six catching sites within the study area, using data from 1997/98 to 2003/04.

Different models evaluated whether resighting rates p were constant (c) or varied fully with time (t) and whether survival rates ϕ were constant (c), varied fully with time (t) or before and after the majority of improvements to sewage discharges in 2000/01 (pre v post). Bold type indicates the model that best fitted the data.

Model	$QAIC_c$	Parameters	Model deviance
ϕ_c p_c	745.4	2	159.1
ϕ_t p_c	720.7	7	124.1
ϕ_t p_t	644.4	12	37.3
ϕ_c p_t	**638.5**	**7**	**41.9**
$\phi_{pre\ v\ post}$ p_t	638.4	8	39.8

Table 3.3.2 Evaluation of mark-resighting models for adult Turnstone originally caught and colour-ringed at Amble-Hauxley, using data from 1997/98 to 2003/04.

Different models evaluated whether resighting rates p were constant (c) or varied fully with time (t) and whether survival rates ϕ were constant (c), varied fully with time (t), or before and after the majority of improvements to sewage discharges in 2000/01 (pre v post) or differed in some, but not all years following 2000/01. Bold type indicates the model that best fitted the data.

Species	Site	Trend from 1997/98 to 2000/01	Trend from 2000/01 to 2003/04
Purple Sandpiper	Whole study area	Increasing	Decreasing
	Amble-Hauxley	Fluctuating	Fluctuating
	Newbiggin	Increasing	Decreasing
Turnstone	Whole study area	Increasing	Decreasing
	Amble-Hauxley	Stable	Decreasing
	Newbiggin	Increasing	Fluctuating
Eider	Whole study area	Fluctuating	Increasing
	Amble-Hauxley	Decreasing	Decreasing
	Newbiggin	Fluctuating	Increasing
Oystercatcher	Whole study area	Stable	Increasing
	Amble-Hauxley	Fluctuating	Fluctuating
	Newbiggin	Increasing	Increasing
Ringed Plover	Whole study area	Fluctuating	Stable
	Amble-Hauxley	Decreasing	Stable
	Newbiggin	Decreasing	Decreasing
Knot	Whole study area	Fluctuating	Stable
	Amble-Hauxley	Decreasing	Decreasing
	Newbiggin	Increasing	Stable
Sanderling	Whole study area	Increasing	Increasing
	Amble-Hauxley	Increasing	Decreasing
	Newbiggin	Fluctuating	Stable
Dunlin	Whole study area	Decreasing	Stable
	Amble-Hauxley	Decreasing	Fluctuating
	Newbiggin	Decreasing	Fluctuating
Curlew	Whole study area	Increasing	Stable
	Amble-Hauxley	Fluctuating	Increasing
	Newbiggin	Increasing	Stable
Redshank	Whole study area	Stable	Increasing
	Amble-Hauxley	Stable	Stable
	Newbiggin	Fluctuating	Increasing

Table 4.1 Trends in waterbird numbers before and after the completion of the majority of improvements to sewage discharges in 2000/01. (See also Figures 3.2.1.1 to 3.2.10.1).

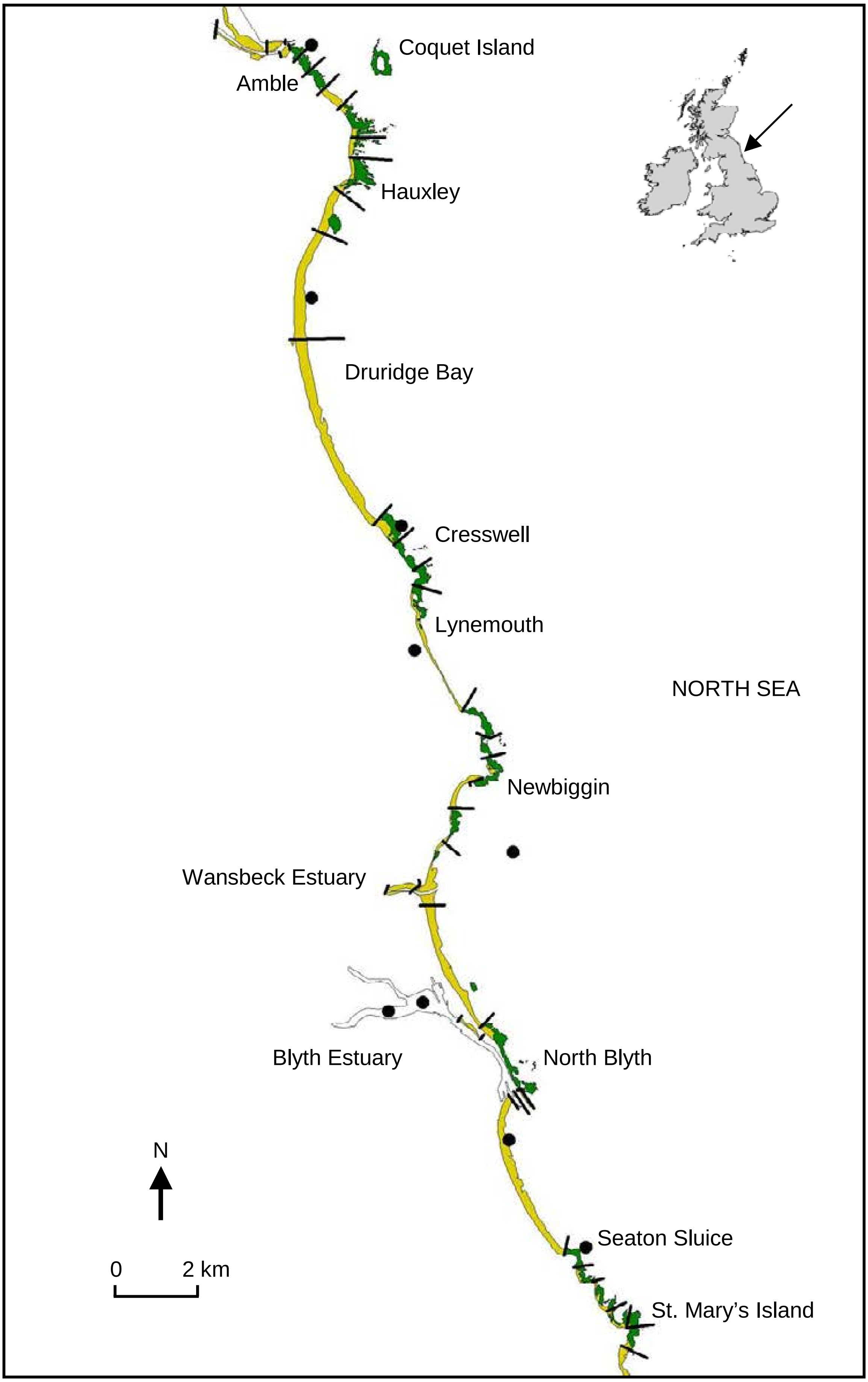


Figure 1.1 The study area, showing areas of rocky and soft sediment intertidal shore, sewage outfalls (shown by black dots) and the sections used for counting waterbirds. Amble (55˚20' N, 1˚34' W), St. Mary's Island (55˚04' N, 1˚27' W).

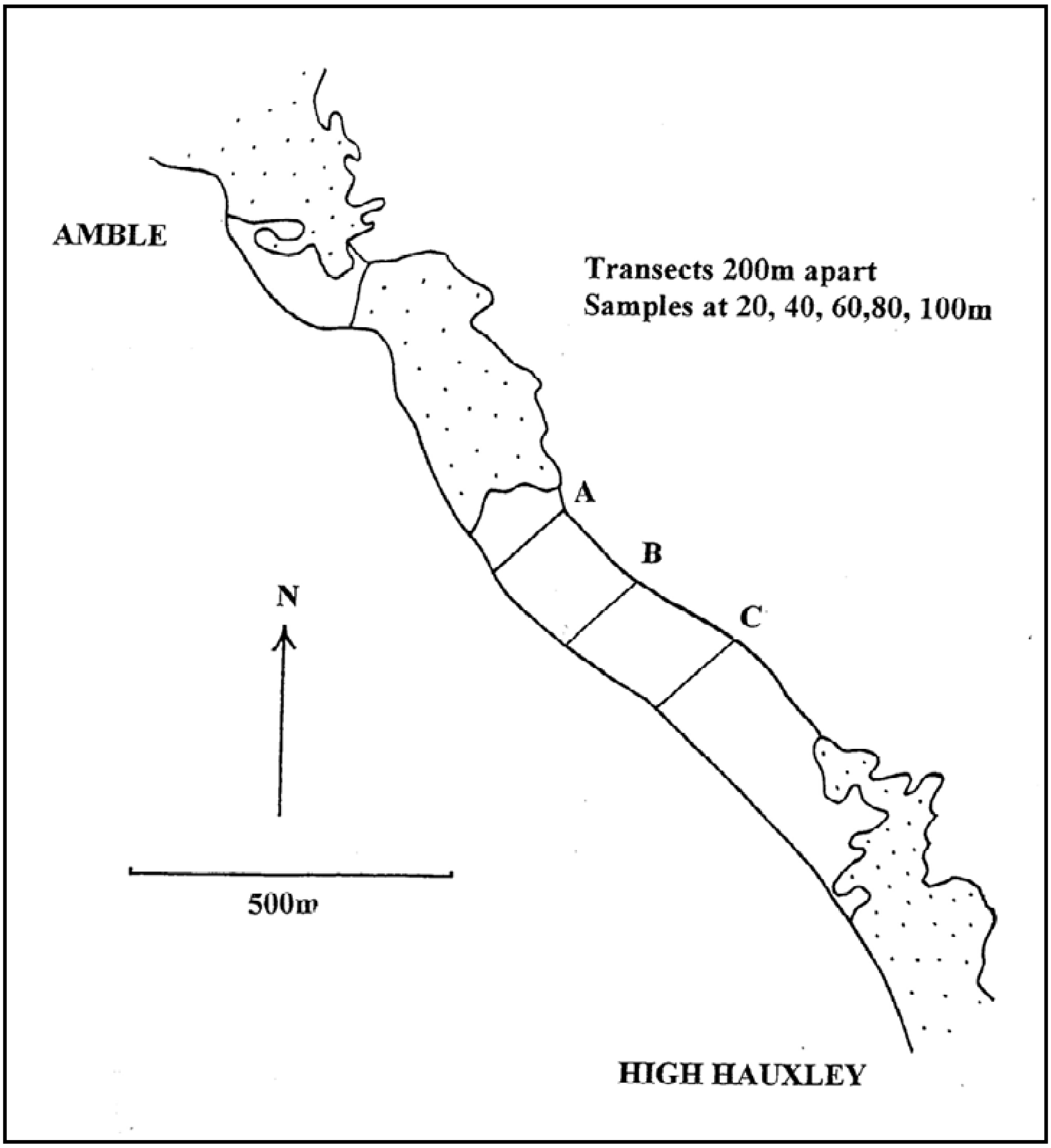
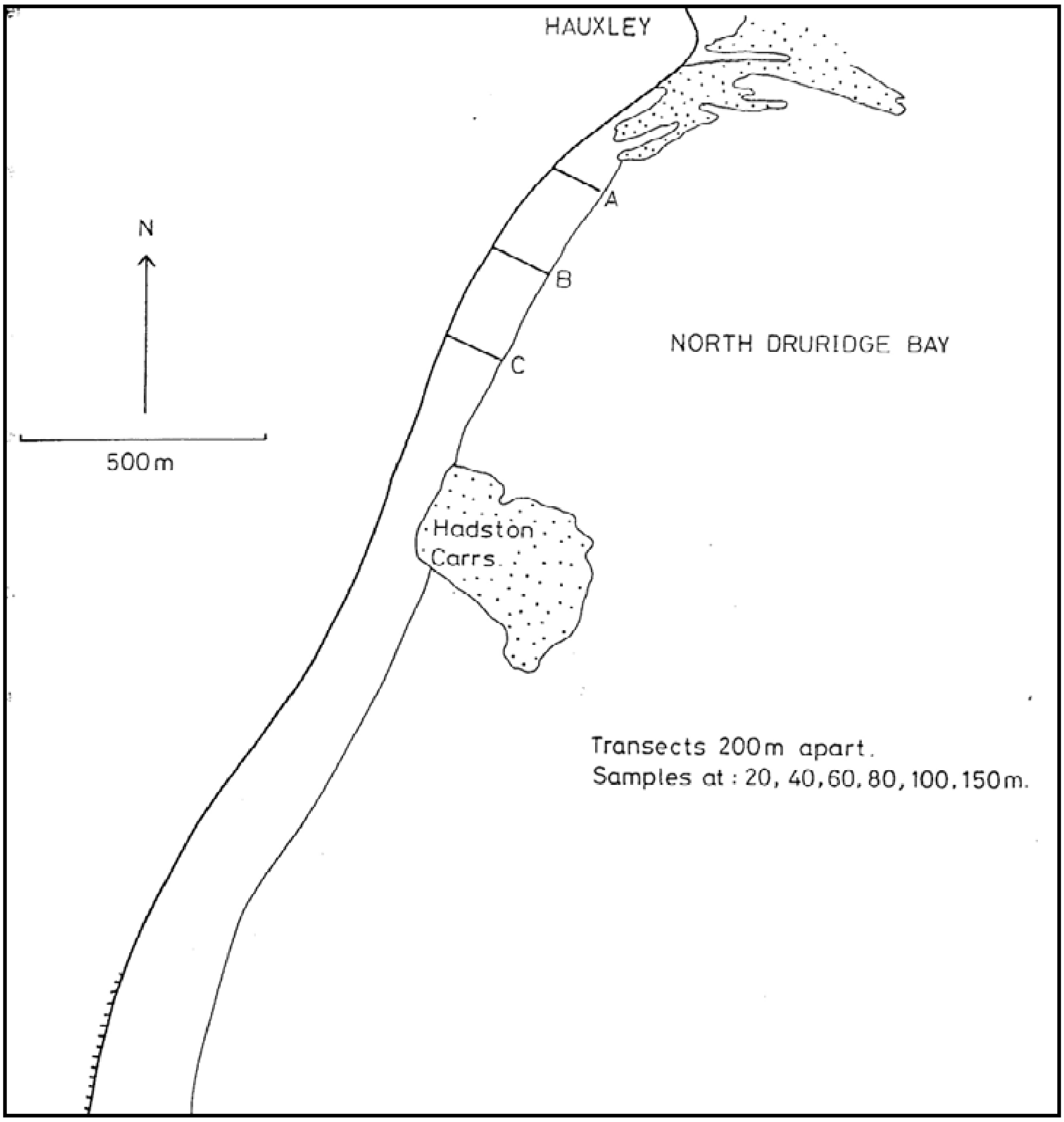
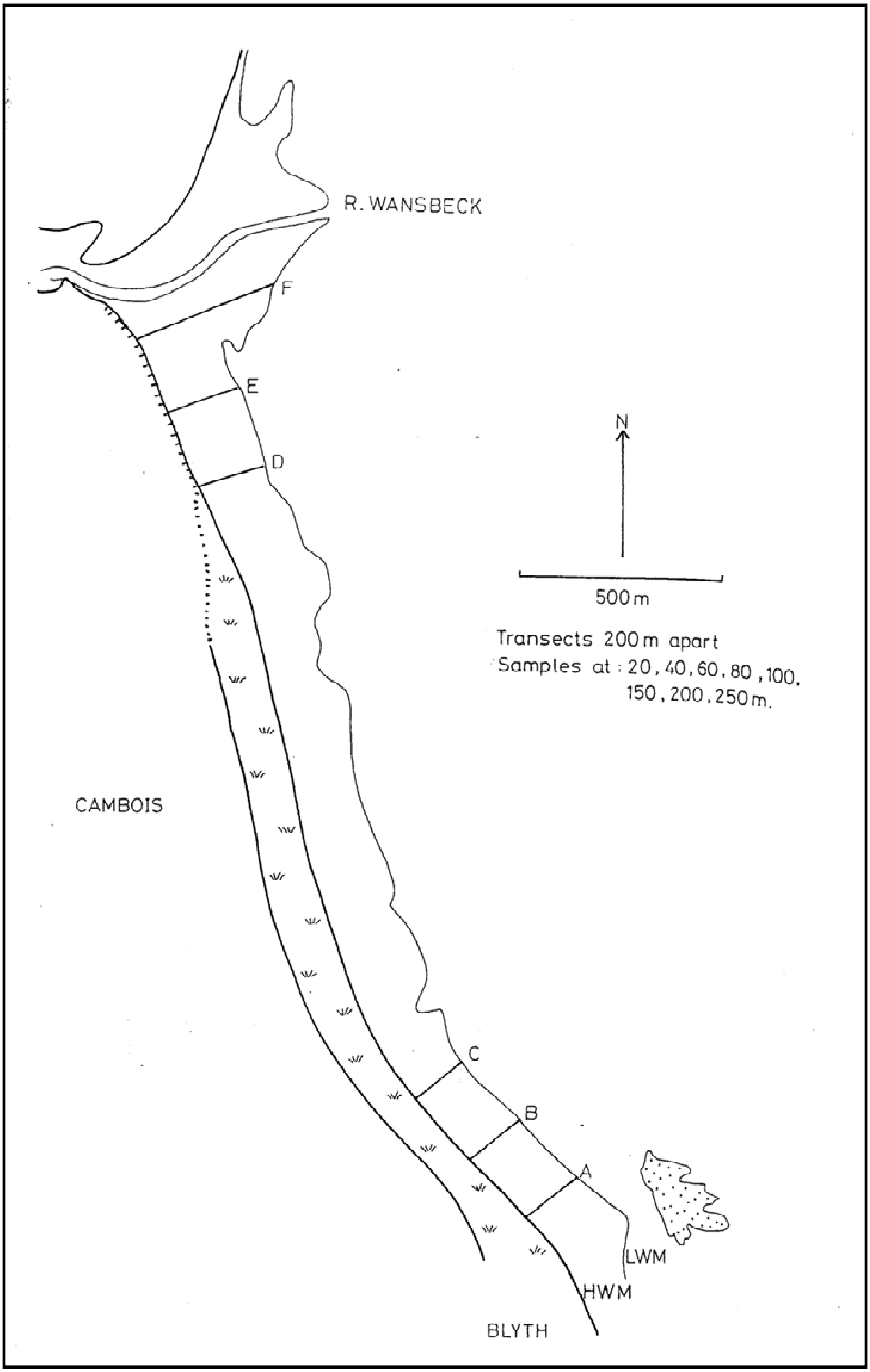


Figure 2.1.1.1 Transects used for sampling invertebrates in soft sediments (following Robinson *et al.* 1996, Eaton 1997).

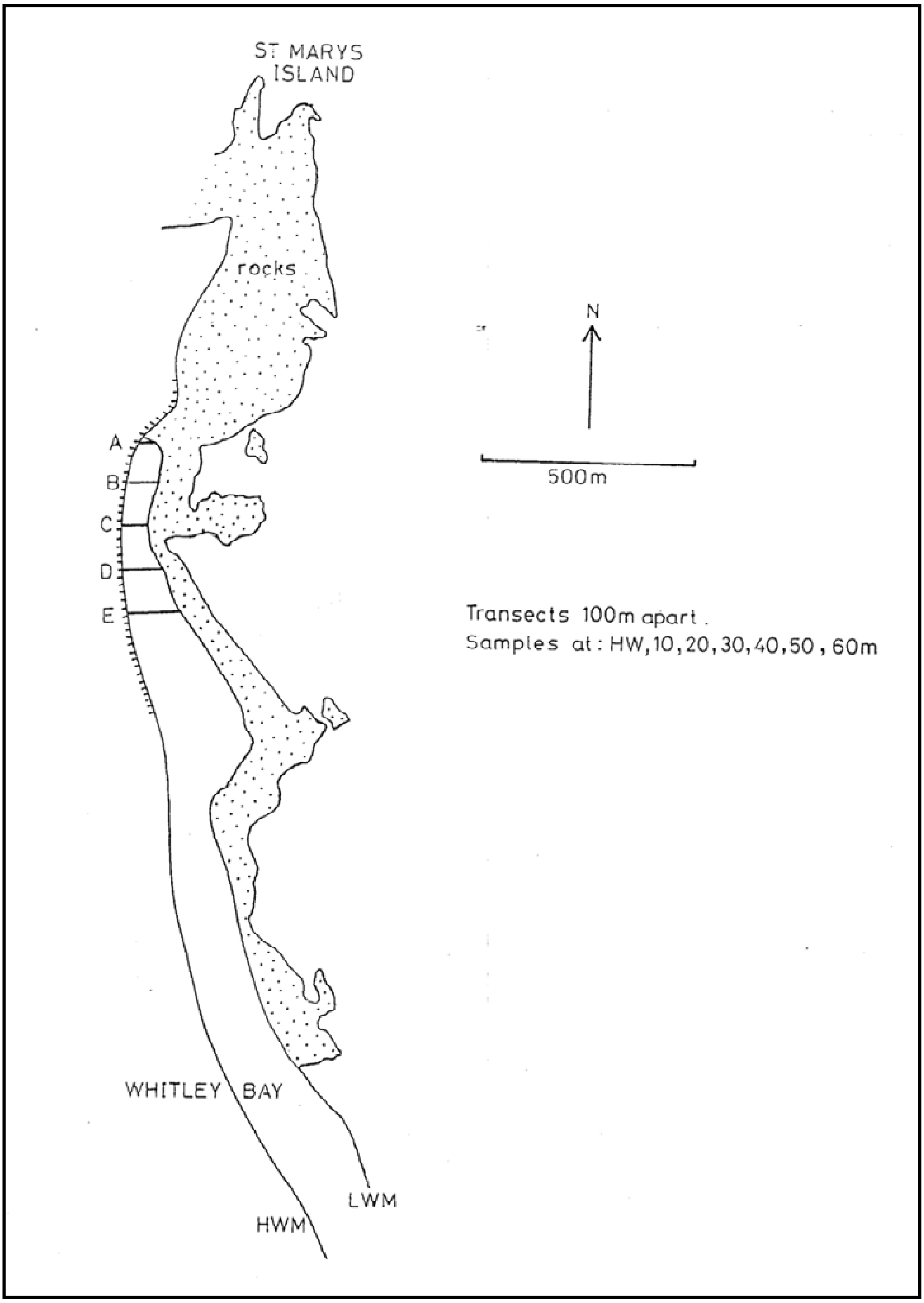
a. Amble



b. Druridge Bay



c. North Blyth and Cambois



d. St. Mary’s Island

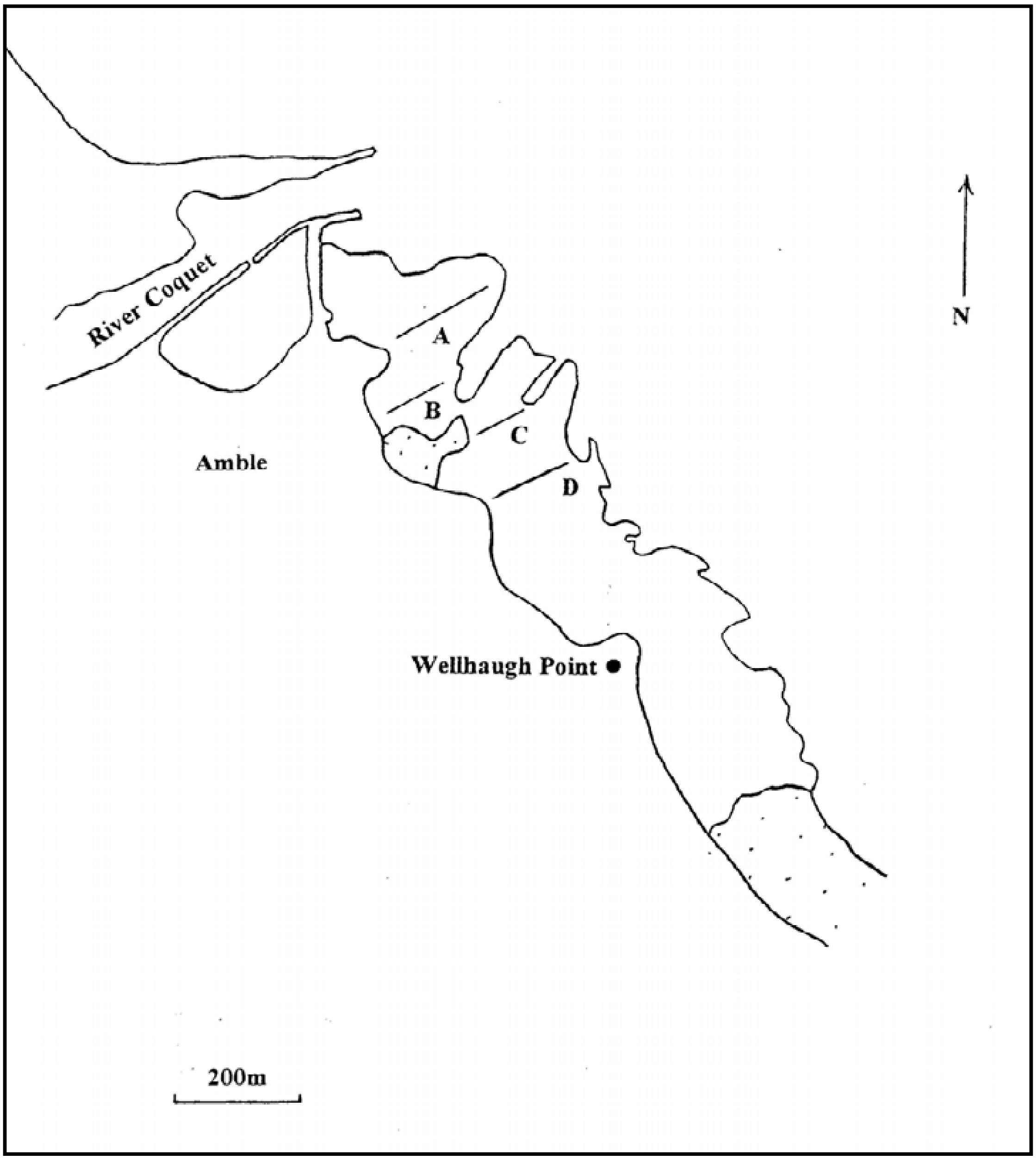
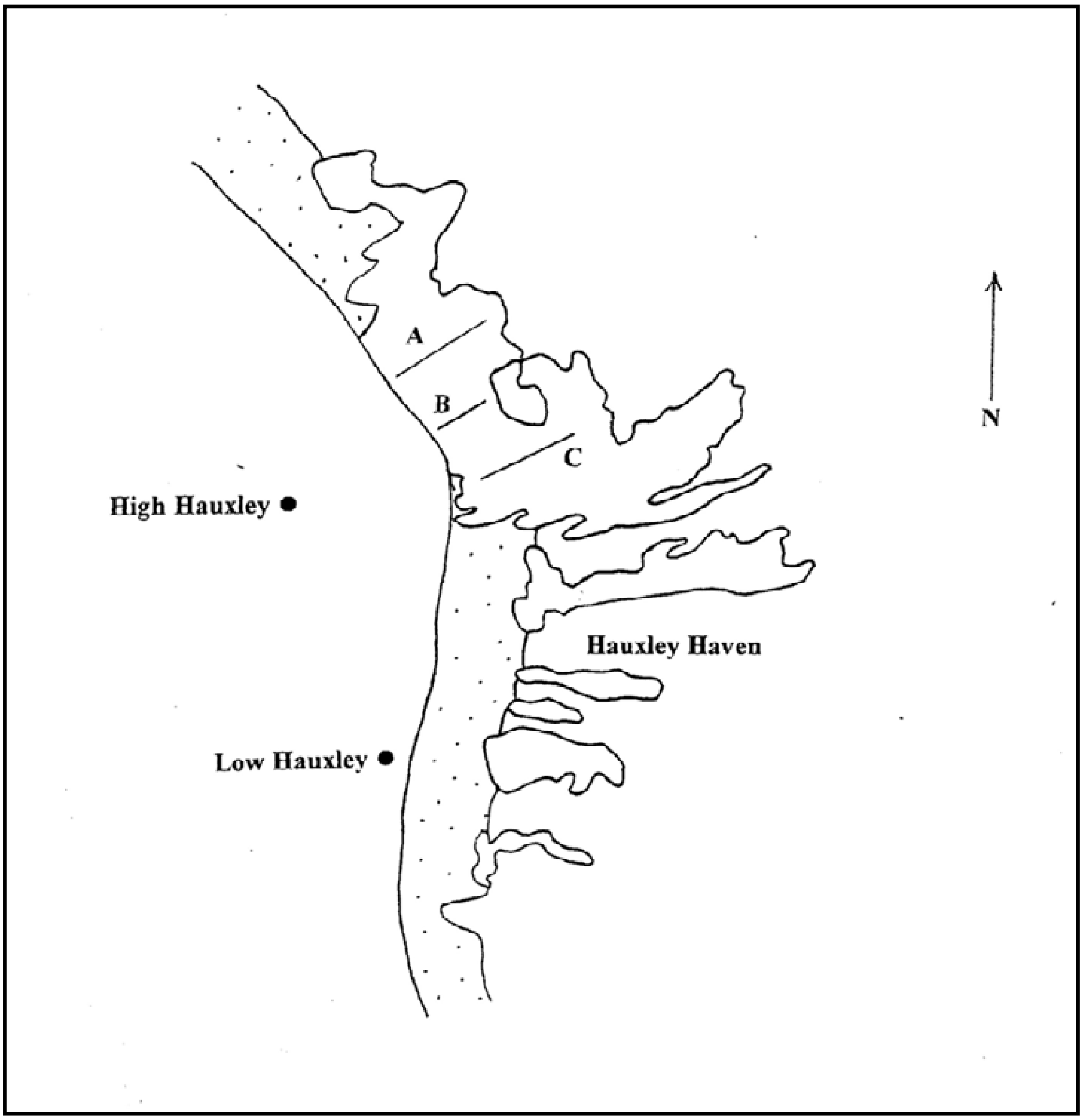
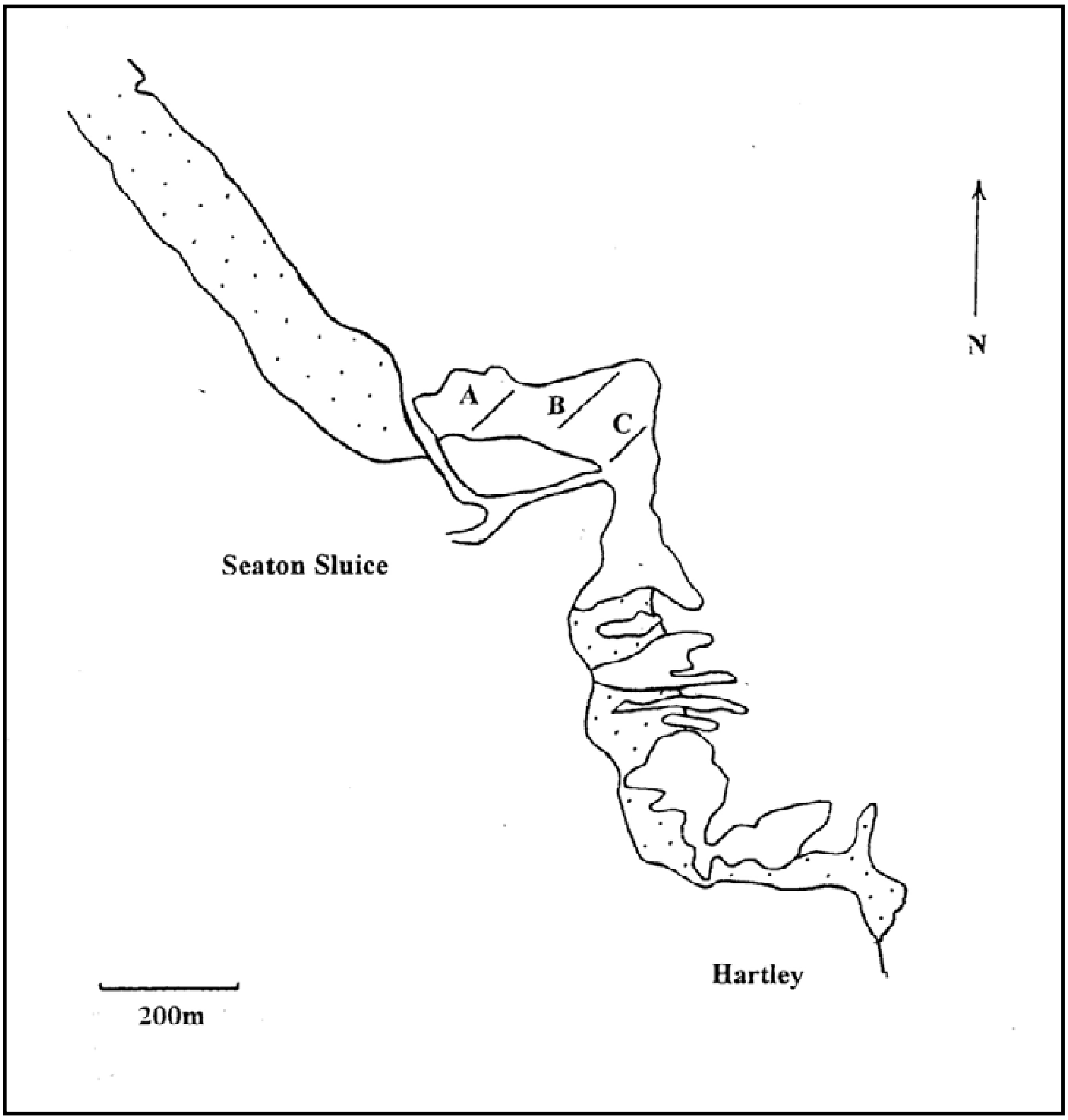


Figure 2.1.2.1 Transects used for sampling invertebrates on rocky shores (following Robinson *et al.* 1996, Eaton 1997).

a. Amble (Wellhaugh Point)



b. Hauxley



c. Seaton Sluice

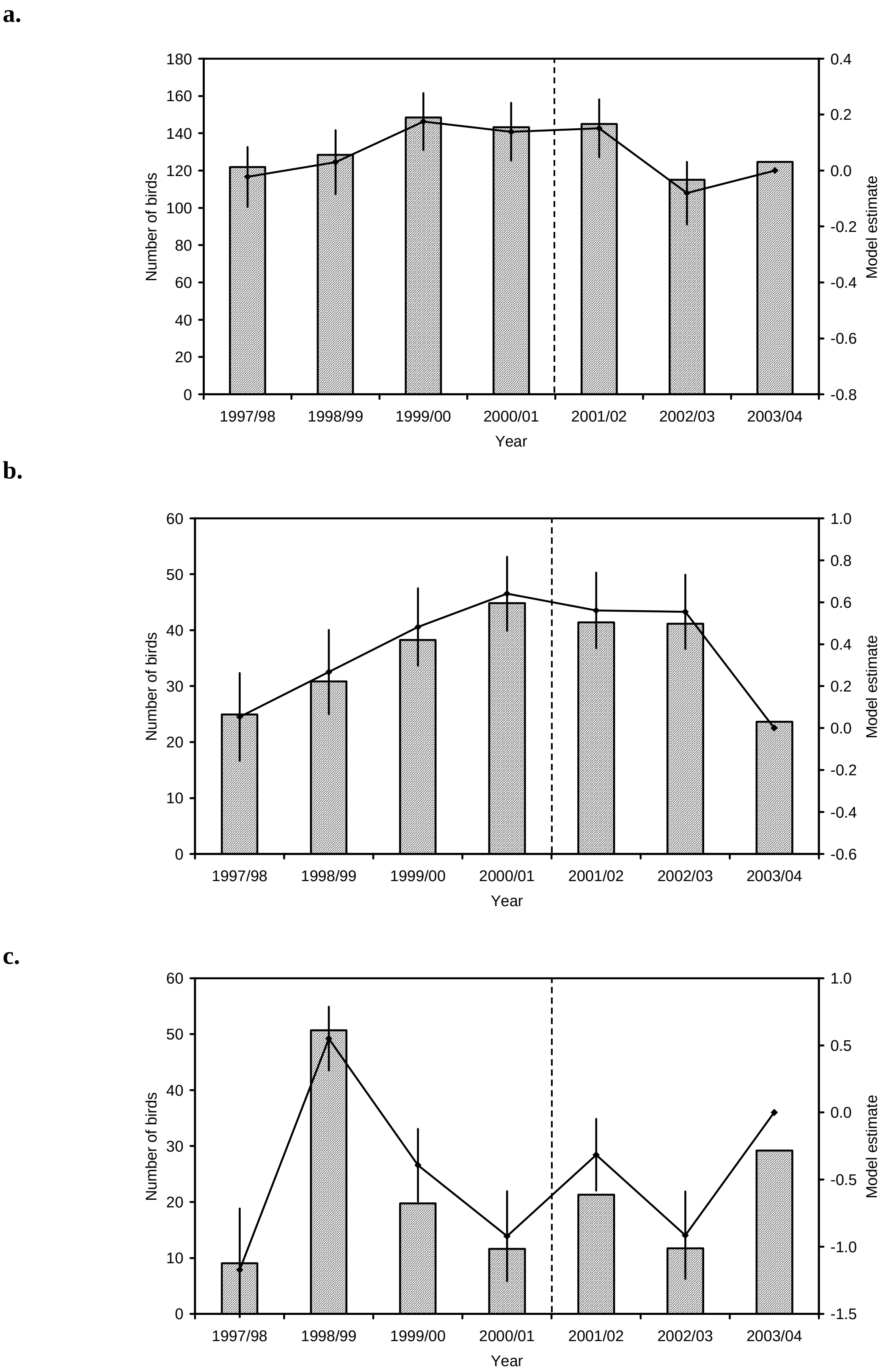


Figure 3.2.1.1 Estimates for 'year' (± 1 SE) and mean numbers of birds derived from models relating the numbers of Purple Sandpiper on **a.** the whole coast between the Coquet Estuary* and St. Mary's Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast to year, month, state of tide and 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.

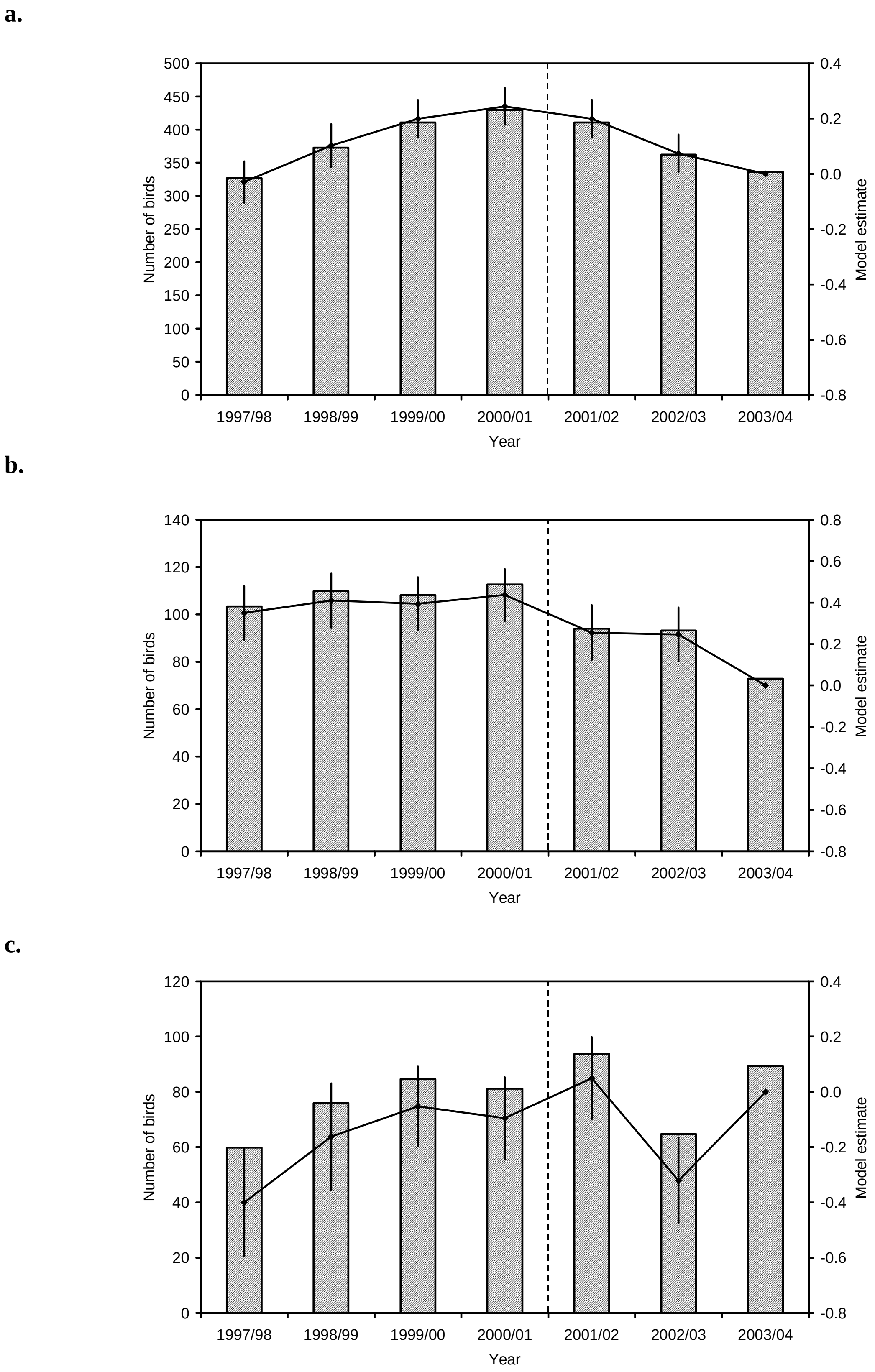


Figure 3.2.2.1 Estimates for ‘year’ (± 1 SE) and mean numbers of birds derived from models relating the numbers of Turnstone on **a.** the whole coast between the Coquet Estuary and St. Mary’s Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast* to year, month, state of tide and count 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.

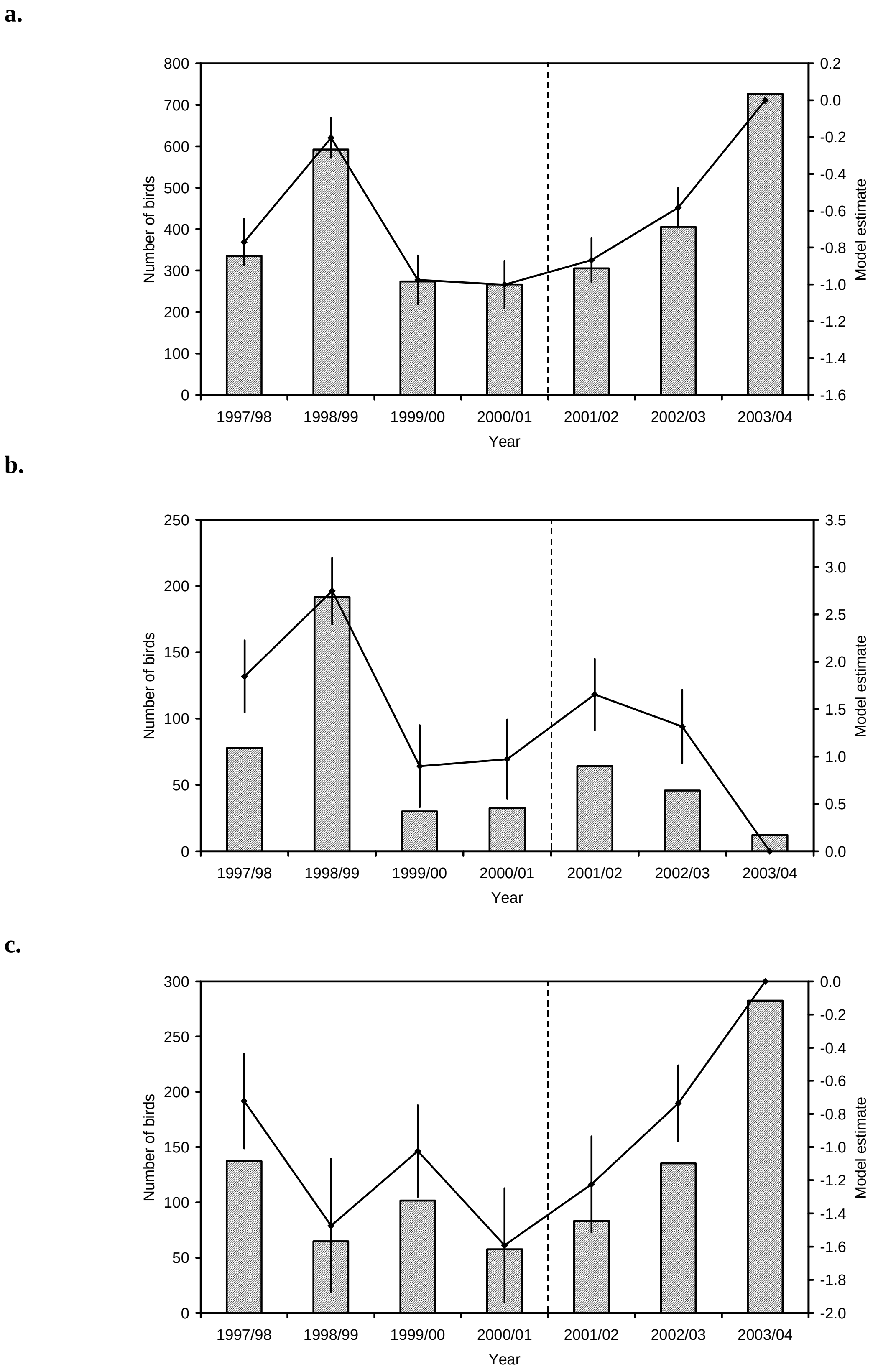


Figure 3.2.3.1 Estimates for 'year' (± 1 SE) and mean numbers of birds derived from models relating the numbers of Eider on **a.** the whole coast between the Coquet Estuary and St. Mary's Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast to year, month, state of tide and count section. The dotted line indicates the date when the majority of improvements to discharges (including those at Amble-Hauxley and Newbiggin) were completed.

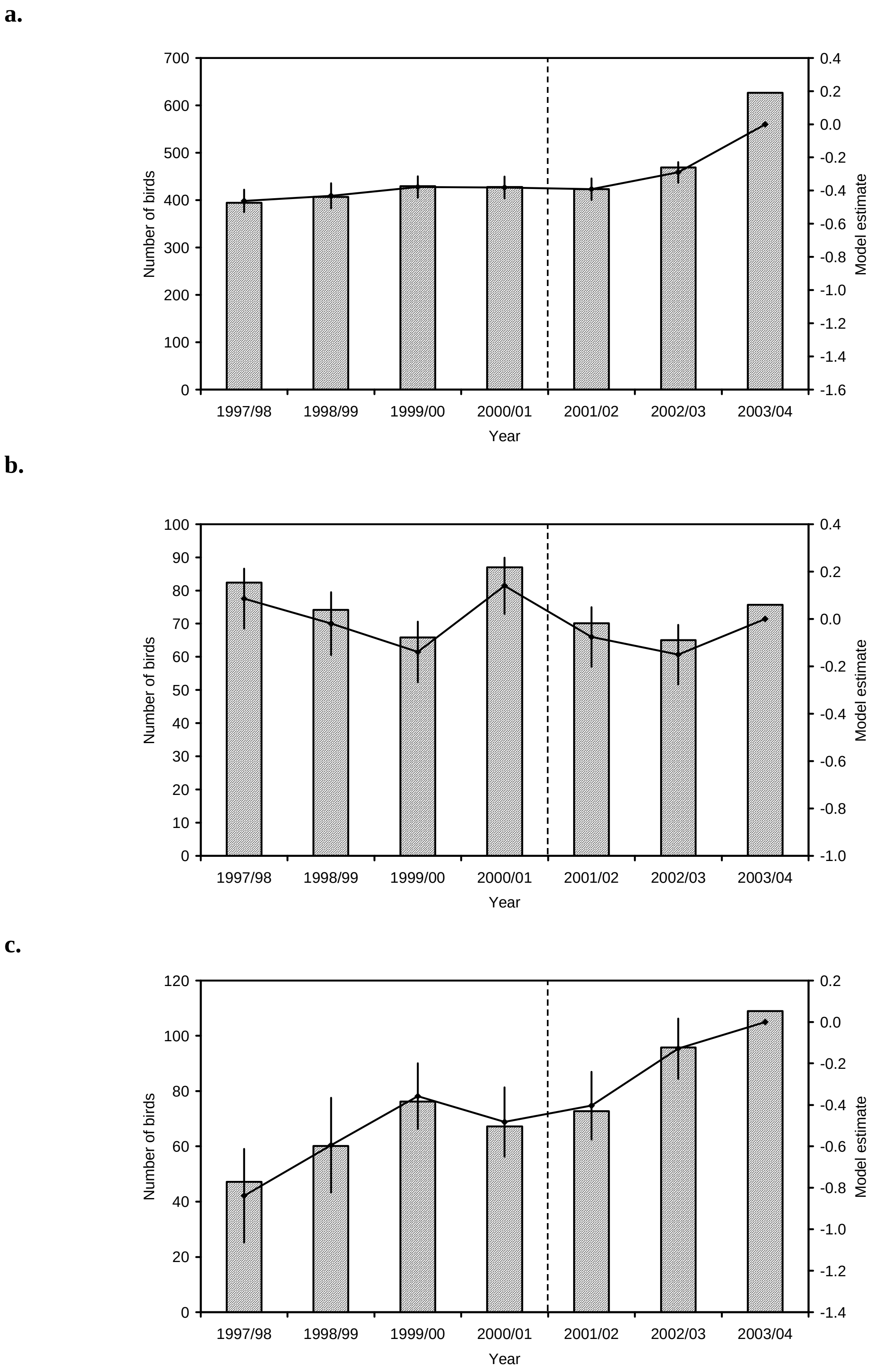


Figure 3.2.4.1 Estimates for 'year' (± 1 SE) and mean numbers of birds derived from models relating the numbers of Oystercatcher on **a.** the whole coast between the Coquet Estuary and St. Mary's Island **b.** the Amble-Hauxley coast* and **c.** the Newbiggin coast to year, month, state of tide and 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.

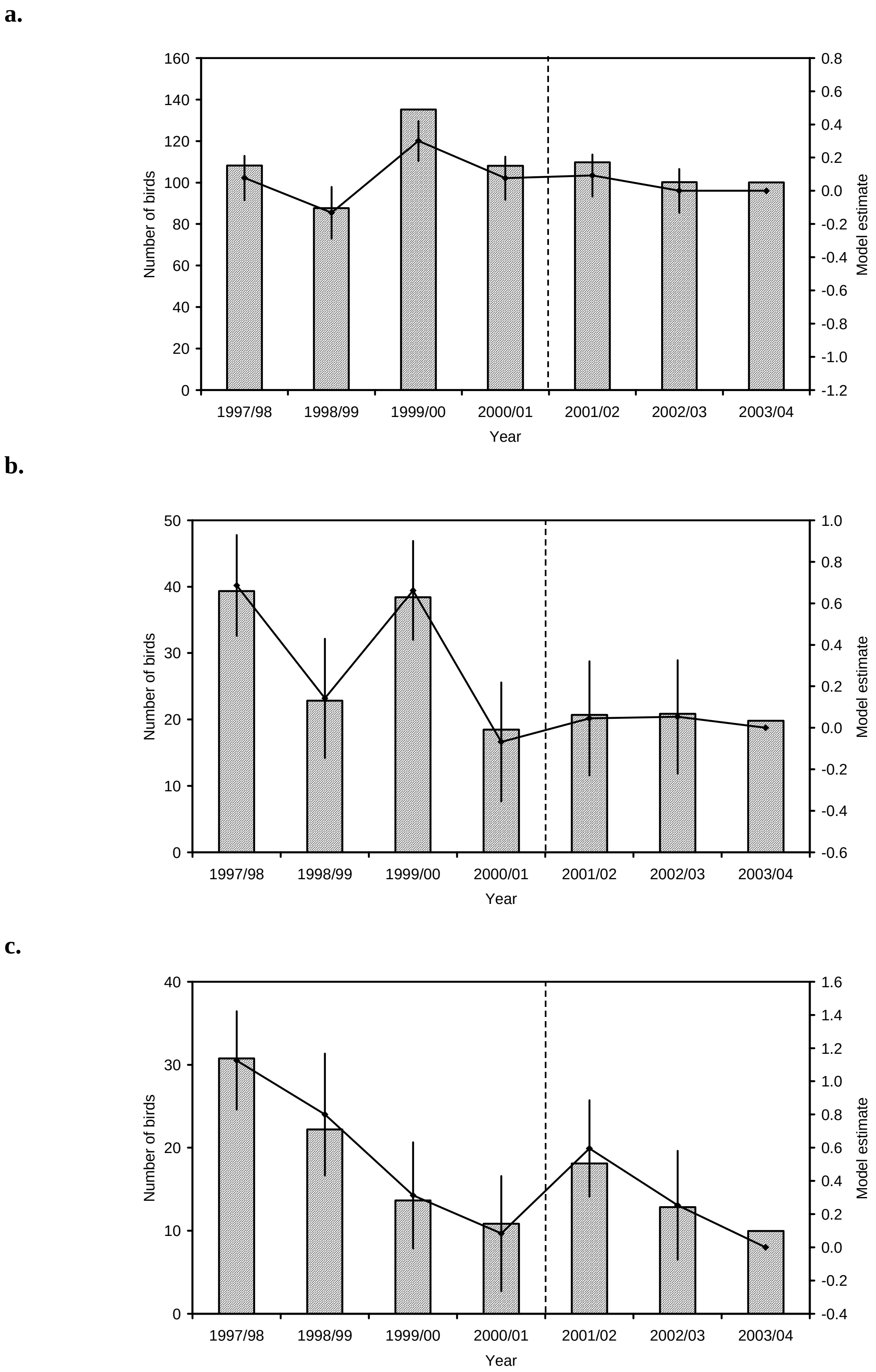


Figure 3.2.5.1 Estimates for 'year' (± 1 SE) and mean numbers of birds derived from models relating the numbers of Ringed Plover on **a.** the whole coast between the Coquet Estuary* and St. Mary's Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast to year, month, state of tide and 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.

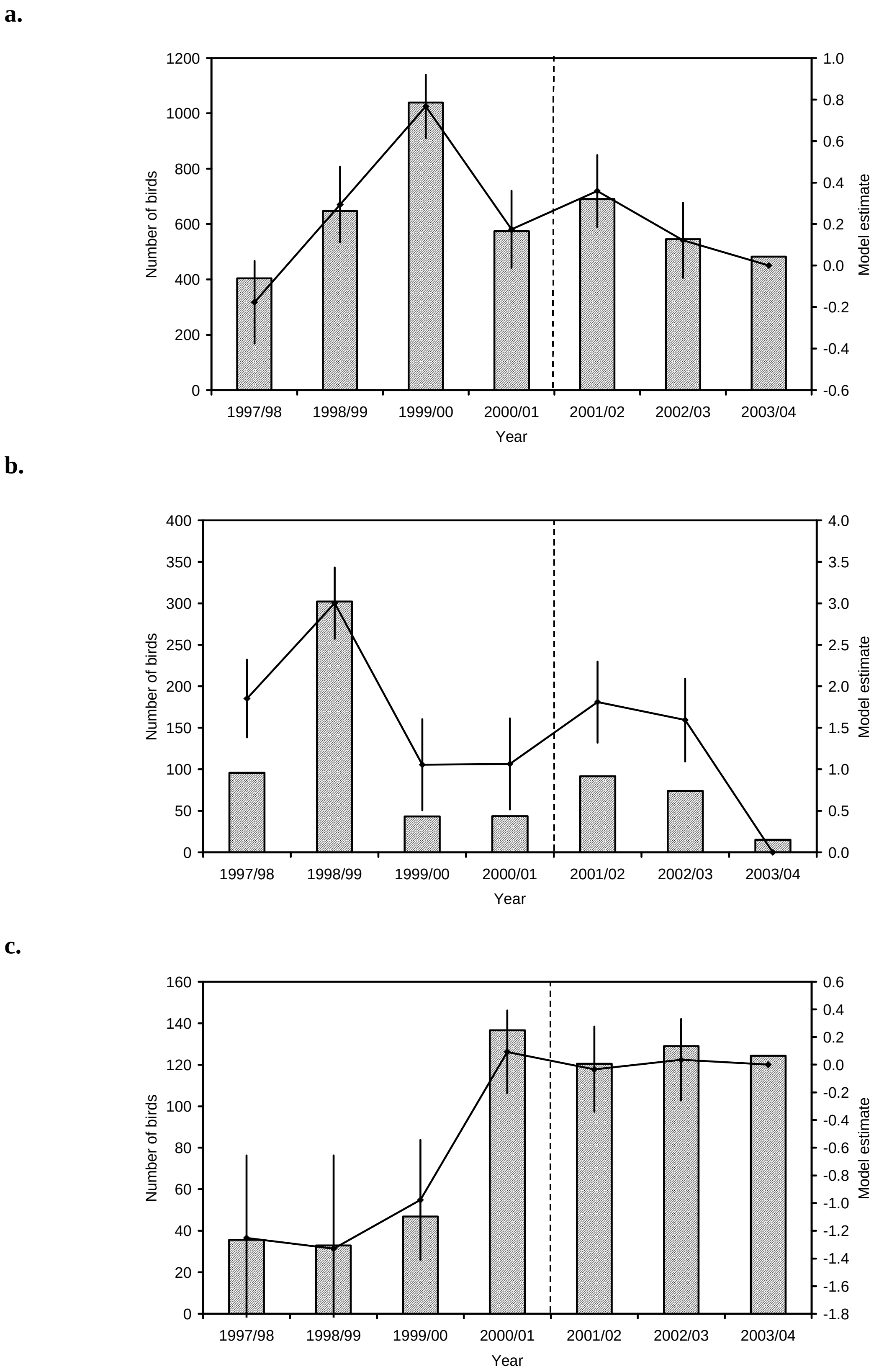


Figure 3.2.6.1 Estimates for ‘year’ (± 1 SE) and mean numbers of birds derived from models relating the numbers of Knot on **a.** the whole coast between the Coquet Estuary and St. Mary’s Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast to year, month, state of tide and count section. The dotted line indicates the date when the majority of improvements to discharges (including those at Amble-Hauxley and Newbiggin) were completed.

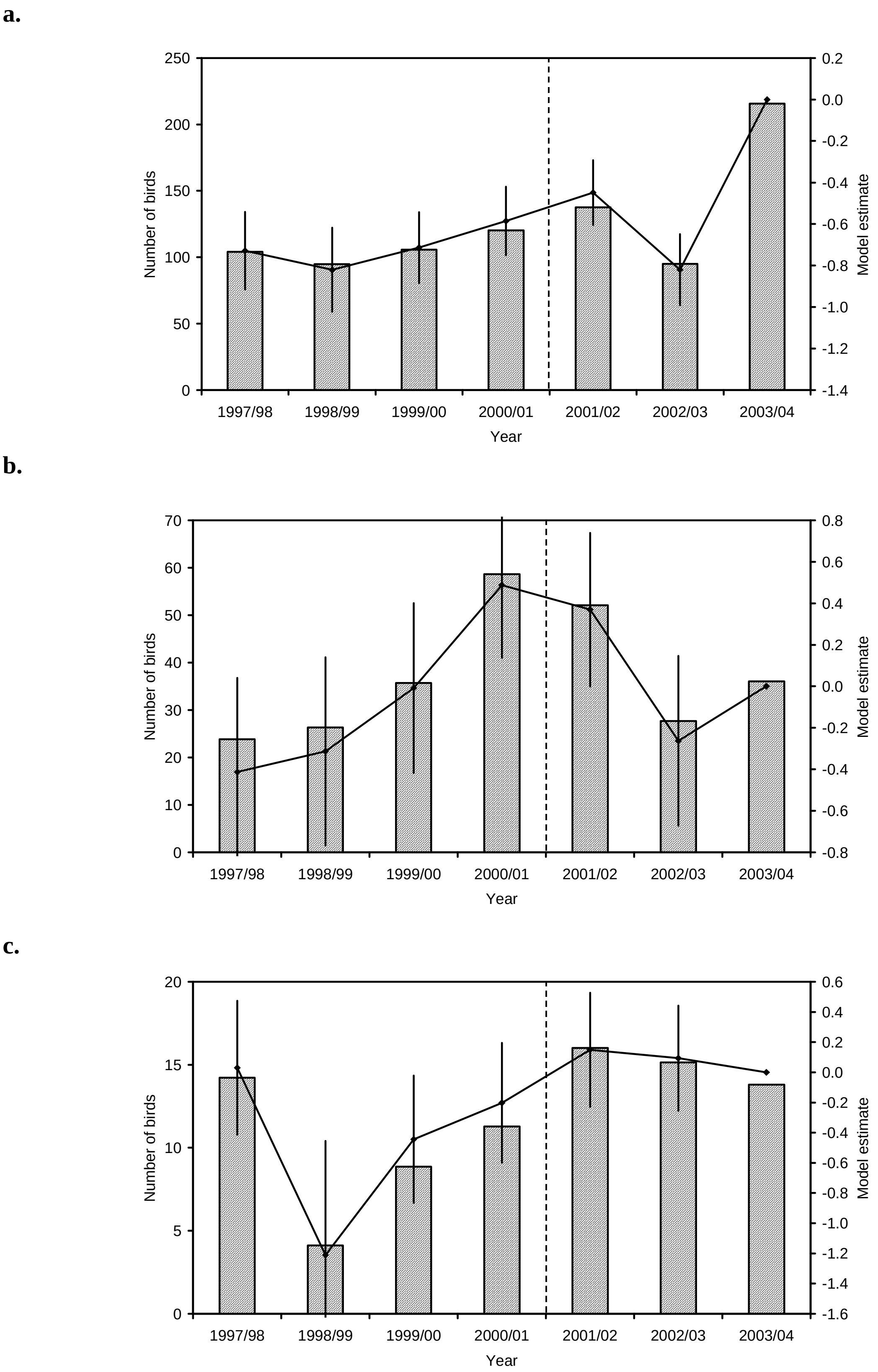


Figure 3.2.7.1 Estimates for 'year' (± 1 SE) and mean numbers of birds derived from models relating the numbers of Sanderling on **a.** the whole coast between the Coquet Estuary and St. Mary's Island **b.** the Amble-Hauxley coast* and **c.** the Newbiggin coast* to year, month, state of tide and count 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.

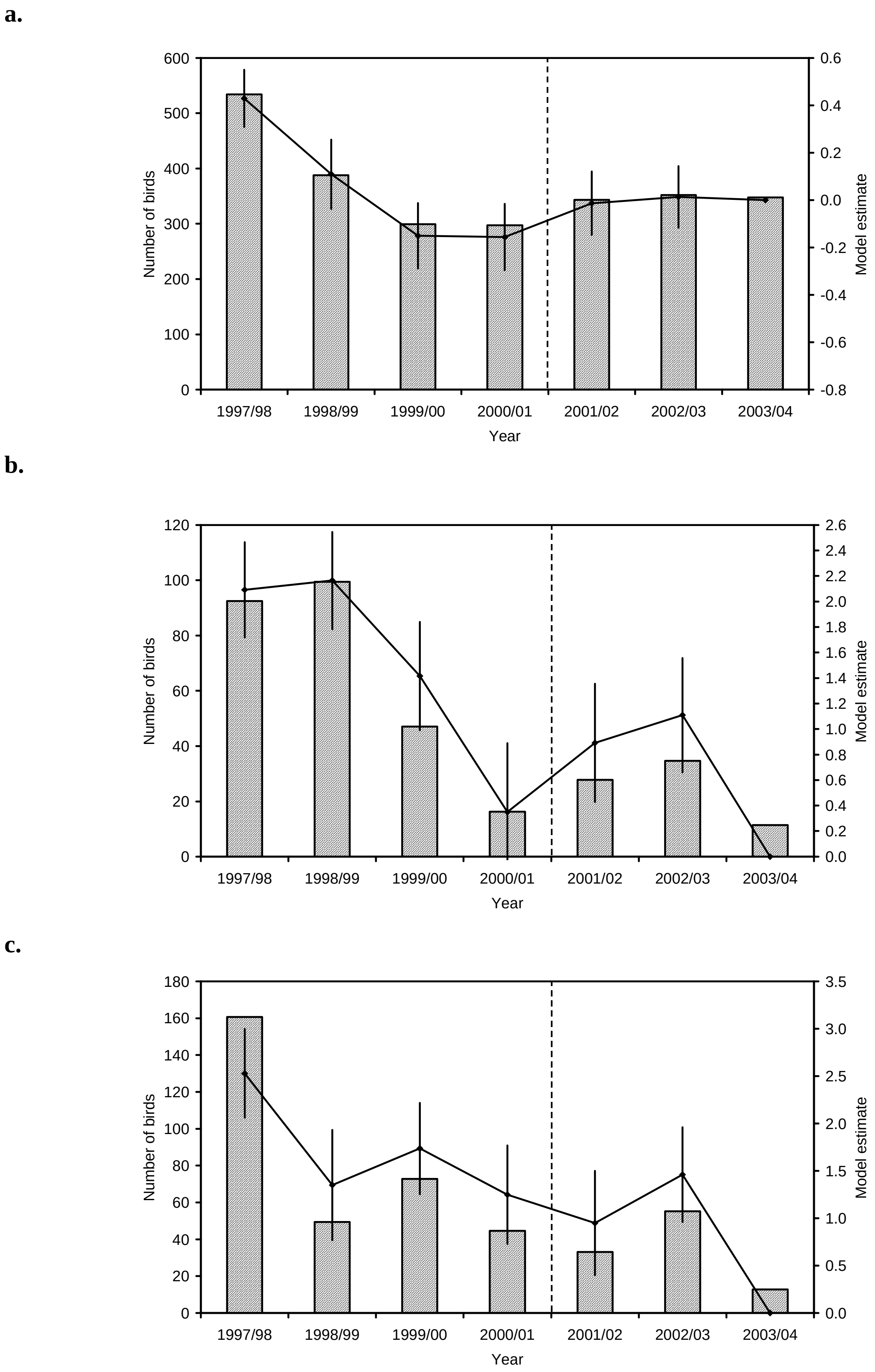
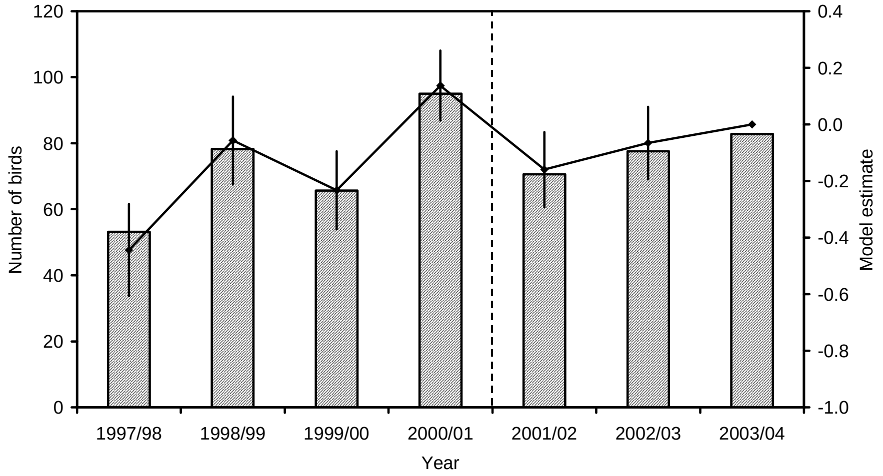
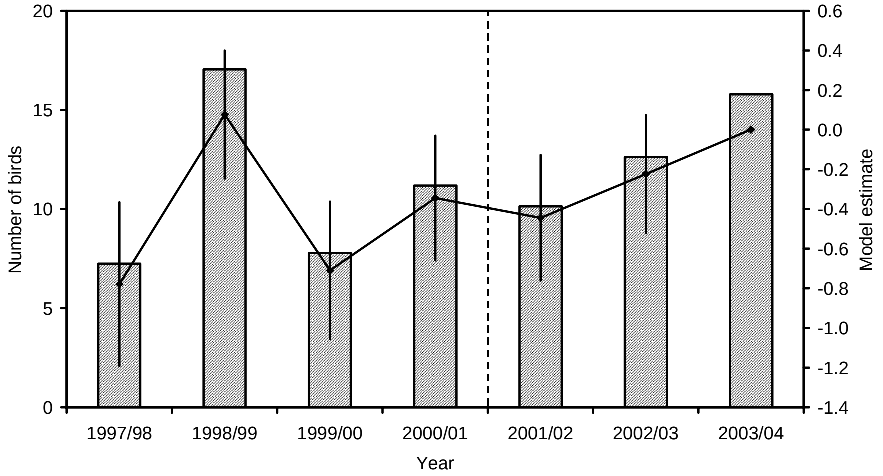


Figure 3.2.8.1 Estimates for 'year' (± 1 SE) and mean numbers of birds derived from models relating the numbers of Dunlin on **a.** the whole coast between the Coquet Estuary and St. Mary's Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast to year, month, state of tide and count section. The dotted line indicates the date when the majority of improvements to discharges (including those at Amble-Hauxley and Newbiggin) were completed.

a.



b.



c.

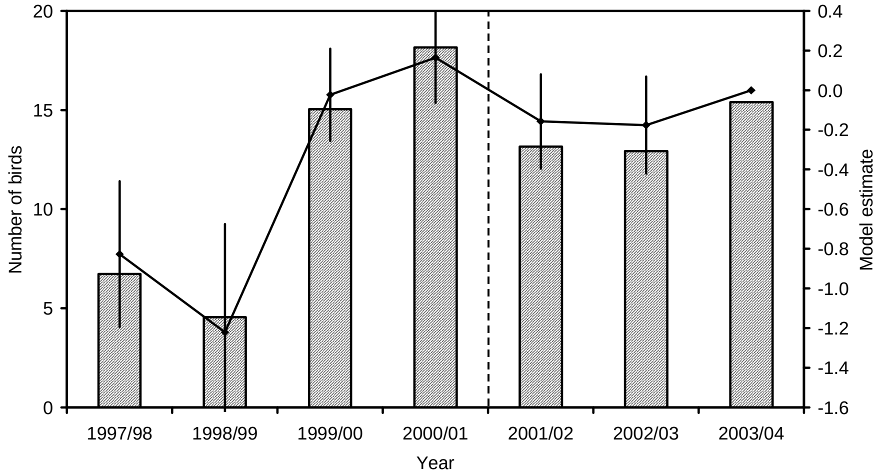
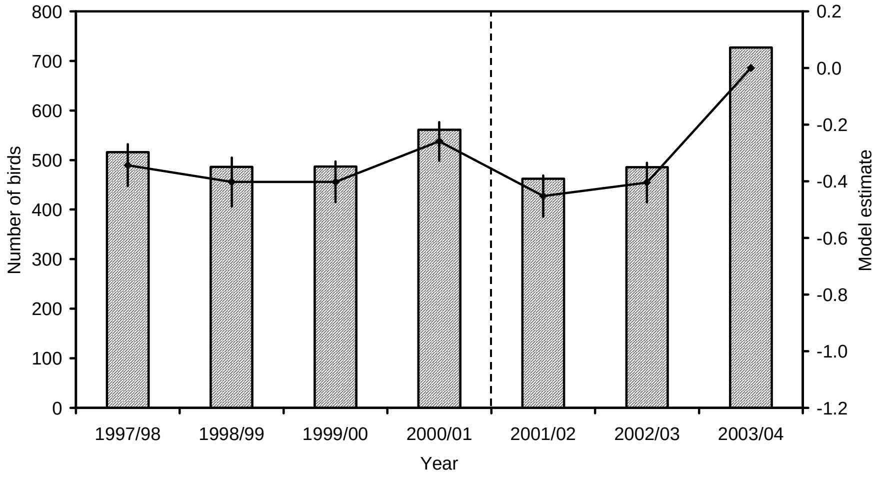
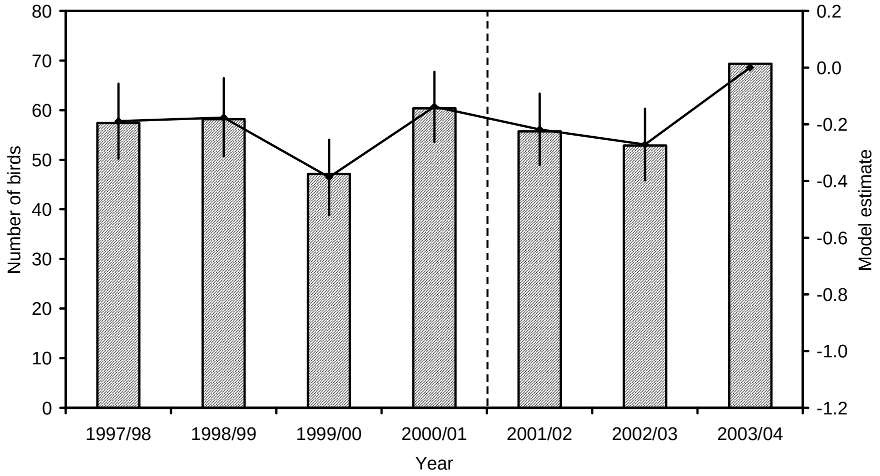


Figure 3.2.9.1 Estimates for ‘year’ (± 1 SE) and mean numbers of birds derived from models relating the numbers of Curlew on **a.** the whole coast between the Coquet Estuary and St. Mary’s Island **b.** the Amble-Hauxley coast and **c.** the Newbiggin coast to year, month, state of tide and count section. The dotted line indicates the date when the majority of improvements to discharges (including those at Amble-Hauxley and Newbiggin) were completed.

a.



b.



c.

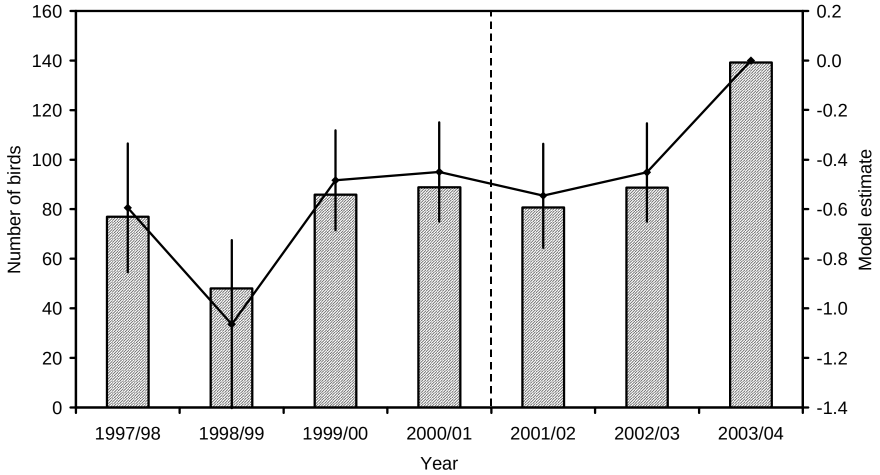


Figure 3.2.10.1 Estimates for 'year' (± 1 SE) and mean numbers of birds derived from models relating the numbers of Redshank on **a.** the whole coast between the Coquet Estuary and St. Mary's Island **b.** the Amble-Hauxley coast* and **c.** the Newbiggin coast to year, month, state of tide and count 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.