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The Effect of the Cardiff Bay Barrage on Waterbird Populations 12. Distribution and Movement Studies August 2000-May 2001

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EXECUTIVE SUMMARY

1. This report presents the results of the twelfth year of intensive monitoring of the wildfowl and waders of Cardiff Bay and adjacent areas. The report concentrates upon results from the winter of 2000/01, the second following the closure of the Cardiff Bay barrage. The programme of monitoring followed that used over the previous 11 years, thus allowing direct comparisons to be made between results from each year.

2. The Cardiff Bay barrage was closed on the morning of 4 November 1999, impounding the Bay with seawater. Thereafter, the Bay was drained overnight approximately once every week until September 2001, whereafter it was impounded permanently with freshwater.

3. The numbers of birds using Cardiff Bay in the two winters following barrage-closure have been greatly reduced. A few individuals of the four key species - Shelduck, Dunlin, Curlew and Redshank – have continued to use the Bay as a high tide roost site, but no Dunlin or Curlew were recorded at low tide. Only 16 species of wildfowl and wader, and an annual median of 15, have been recorded at the site since barrage-closure in comparison to an annual median of 23 and a total of 41 in the 10 years before. Only Pochard, Mute Swan and Lapwing were recorded in increased numbers in the winter of 2000/01 during the high and low tide counts, though the latter's numbers were still lower than those pre-closure.

4. Although numbers of Shelduck and Curlew rose at Orchard Ledges in the winter following barrage-closure and have since been maintained, neither increase matched the loss of birds from the Bay. Numbers of Shelduck were particularly high on the mudflat immediately adjacent to the Bay. There has been little change in the numbers of Curlew at Rhymney, whilst those of Shelduck fell sharply in the winter of 2000/01.

5. Numbers of both Dunlin and Redshank had declined on the main study sites in the 10 years prior to barrage-closure. Following closure, Dunlin numbers have fallen further at Rhymney whilst those of Redshank have risen in both years. The observed increase in the number of Redshank at Rhymney over the two winters subsequent to barrage-closure almost matches the loss of birds from the Bay.

6. Numbers of Dunlin and Curlew in the winter of 2000/01 at low tide at Peterstone and St. Brides were lower than in any previous winter, whilst those of Shelduck and Redshank were unchanged.

7. Information from colour-ringing confirmed that the increase in Redshank numbers at Rhymney in the two winters post-closure was largely due to an influx of birds from Cardiff Bay. In the winter following closure, colour-ringed Redshank were recorded as far as the River Usk in Newport and the River Axe in Somerset, but in 2000/01, colour-ringed birds were only seen as far from the Bay as Peterstone. In both years, the majority of birds were seen on the Rhymney Estuary and on the area of mudflats by Cardiff Heliport. Radio-tracking had shown that the latter area was formerly used only at night, probably due to disturbance.

8. Analysis of biometric data indicated that, in the winter of 1999/2000 post-closure, adult Redshank from Cardiff Bay were significantly lighter than those from Rhymney and those that had been recorded at both sites prior to barrage-closure.

9. Preliminary survival analysis indicated that the mortality rate of adult Redshank in the winter of 1999/2000, immediately post-closure, was greater than in each of the two previous winters.

10. Further monitoring at Cardiff over the winter of 2001/2002 will show whether Shelduck, Curlew and Redshank numbers can be maintained at their increased levels at Orchard Ledges and Rhymney. Observations of colour-ringed birds will also show whether Redshank from Cardiff Bay continue to experience increased mortality.

GENERAL INTRODUCTION

This report looks at the distribution and movements of waterbirds (wildfowl and waders, but excluding grebes, cormorants, herons and rails) in the winter of 2000/01, the second since the closure of the Cardiff Bay barrage. The barrage was closed early on the morning of 4 November 1999, impounding the Bay with seawater. The Bay was drained overnight approximately once every week until September 2000, but thereafter was impounded with freshwater.

The report is in two parts. The first describes how the densities and distributions of feeding waterbirds have changed in the two winters following the closure of the Cardiff Bay barrage and over the preceding 10 years. The second reports the study of the movements and survival of Redshank *Tringa totanus* following barrage-closure. Previous work has shown that individual Redshank were formerly highly faithful to the Bay both within and between winters (Burton 2000a). The results of the previous 11 years of monitoring of the wildfowl and wader populations of Cardiff Bay and nearby areas were reported by Evans *et al.* (1990), Donald and Clark (1991a), Toomer and Clark (1992a), Toomer *et al.* (1993, 1994, 1995) and Burton *et al.* (1997a, 1997b, 1998, 1999, 2001).

Data from the Wetland Bird Survey (WeBS) are used to show the importance of Cardiff Bay and the Severn Estuary for waterbirds in a British and a European context. Data for Cardiff Bay are given for the winters of 1998/99, 1999/2000 and 2000/01. As information concerning the Severn Estuary was not available for the 2000/01 winter at the time of writing, its importance will be referred to using data from the 1999/2000 winter (Musgrove *et al.* 2001).

PART 1: DISTRIBUTION STUDIES

1. INTRODUCTION

The first part of this report describes how the densities and distributions of feeding wildfowl and waders have changed in the two winters following the closure of the Cardiff Bay barrage. Changes are discussed in the light of long-term trends evident from the 10 years of study prior to barrage-closure, known regional trends in waterbird populations (Austin *et al.* 2000) and previous studies of habitat loss. Relative annual densities of four key species – Shelduck *Tadorna tadorna*, Dunlin *Calidris alpina*, Curlew *Numenius arquata* and Redshank – are presented graphically for Cardiff Bay and the two neighbouring sites, Orchard Ledges and Rhymney. Changes in the numbers of ten further species, which were regularly present on the main study sites at the beginning of the study, are also discussed.

The report concentrates on the second winter period following barrage-closure, i.e. November 2000 to March 2001. Maps indicate the distribution of the four key species on the Orchard Ledges and Rhymney study sites during this period. Distribution maps for the autumn (August to October 2000) and spring (April and May 2001) are not presented in this report.

2. METHODS

Survey methods used in this year of study were the same as those used in the 11 previous years. Two types of counts were carried out: all-day counts and low tide counts.

2.1 All-day Counts

All-day counts were carried out at three sites: Cardiff Bay (Figure 2.1.1), Orchard Ledges and Rhymney (Figure 2.1.2). At the beginning of the study, each of these sites was divided into several mudflat count areas to allow detailed analyses (Evans *et al.* 1990). The Cardiff Bay site was divided into 19 count areas, Orchard Ledges into two count areas and Rhymney into 17 count areas. After the closure of the barrage, Cardiff Bay was counted as one unit (excluding, as before, areas of saltmarsh).

Fieldwork was divided into three seasons: autumn (August - October 2000), winter (November 2000 - March 2001) and spring (April - May 2001). With the exception of Cardiff Bay, birds at each site were counted at hourly intervals through two complete tidal cycles per month (with the exception of April, when only a single count took place). Thus each month there were two counts every hour from six hours before to five hours after low tide. Cardiff Bay was only surveyed at low tide and high tide (i.e. 6 hours before low tide).

Feeding and roosting birds were counted separately and any disturbance to count areas or impaired visibility noted. All birds present on the exposed mudflats were counted. Wildfowl feeding on invertebrates or plants in the shallow water offshore were included in the counts for the respective count areas. Wildfowl roosting offshore on open water were excluded, however. Observations on the previous roosting behaviour of birds in Cardiff Bay have been covered in separate reports (Donald & Clark 1991a, Toomer & Clark 1992a, 1993, 1994).

2.2 Low Tide Counts

The distribution and numbers of waterbirds on the wider north-west Severn, east from Cardiff to the mouth of the River Usk, were monitored during winter (November to March) by counts made during the low tide period (*i.e.* from two hours before to two hours after low tide). As with the all-day counts, this study area was broken down into several smaller count areas (Figure 2.2.1). It should be noted that observations in this area were limited in March 2001, due to access restrictions associated with the Foot and Mouth Disease outbreak.

2.3 Data Analysis and Presentation of Results

The previous 11 years of study were reported in Evans *et al.* (1990), Donald & Clark (1991b), Toomer & Clark (1992b), Toomer *et al.* (1993, 1994, 1995) and Burton *et al.* (1997a, 1997b, 1998, 1999, 2001). Some figures from the latter report are reproduced here for comparison with this year's results.

Detailed analysis was carried out for four key species: Shelduck, Dunlin, Curlew and Redshank, all of which occurred on the Severn Estuary in internationally important numbers during the 11 year study period (Musgrove *et al.* 2001; Table 2.3.1).

For these species, analysis of all-day count data was undertaken to determine how densities of feeding birds at the three sites had changed over the 10 years prior to barrage closure and whether densities at Rhymney and Orchard Ledges had increased in the two winters following the displacement of birds from the Bay. Oystercatcher *Haematopus ostralegus* were also included in these analyses, as, although they do not occur on the Severn Estuary in nationally important number, they were numerous in the Bay prior to barrage-closure. For each of the three sites, generalized linear models (GLMs: McCullagh & Nelder 1989; SAS Institute Inc. 1996) were used to relate the density of feeding birds on each count (birds/ha) to the year, month (August to May), state of tide (hour relative

to low water at which the count was undertaken) and the mudflat count area, represented respectively by estimable factors α, β, γ and δ, and the interaction between state of tide and mudflat, represented by ε, i.e.

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

Models assumed a Poisson distribution for the number of feeding birds, specified a log link function and treated the natural logarithm of mudflat area (ha) as an offset. Month, state of tide, mudflat and year were 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. Only those variables that were significant in explaining the variation in densities were retained in the final models. Two model estimates were calculated for 1999/2000, one for the months prior to barrage-closure, i.e. August to October 1999, and one for the months afterwards, i.e. November 1999 to May 2000. For Rhymney and Orchard Ledges, the estimated values of the model parameters α_i indicate the densities of feeding birds each year relative to that for November 2000 to May 2001. For Cardiff Bay, these estimates indicate densities for each year relative to that for August to October 1999. These estimates are plotted in a series of graphs, for each species and site, to enable bird densities to be compared across years.

The fitted models were also used to calculate, for each species and site, the average number of feeding 'bird hours' per tidal cycle (i.e. the sum of the average number of feeding birds each hour) each winter (i.e. November to March). 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 barrage-closure.

For the four key species, maps are also presented indicating the average number of feeding bird hours on each of the mudflat count areas at the Orchard Ledges and Rhymney sites for the winter of 2000/01. Comparison maps are given for two previous winters, so as to indicate which areas were important for the species both before and after barrage-closure. In addition, for each species, graphs indicate the average number of birds and the proportion feeding at each hour through the tidal cycle at each of these sites in the winter of 2000/01.

Low tide counts of these five species along the shore of the north-west Severn to the east of Rhymney, i.e. on the eight mudflats of Peterstone and St. Brides (see Figure 2.2.1), were also analysed using GLMs. Models related the densities of feeding birds to the year, month and the mudflat count area, represented respectively by estimable factors α, β and δ, i.e.

$$\ln(count_{ijl}) = \mu + \alpha_i + \beta_j + \delta_l$$

Again, models assumed a Poisson distribution for the number of feeding birds, specified a log link function and treated the natural logarithm of mudflat area (ha) as an offset. Likewise, the problem of overdispersion was again 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. Month, mudflat and year were each treated as class variables. Month and mudflat were only retained in the final models if they were significant in explaining the variation in densities. The model parameters α_i indicate the densities of feeding birds each winter relative to that for 2000/01. These estimates are plotted in a series of graphs, for each species and site, to enable bird densities to be compared across years. Maps showing the mean number of feeding birds on each of the mudflats along the whole northwest Severn are additionally shown for each of these species.

For nine other waterbird species (which were also relatively numerous in the study areas when the study began), the main feeding areas are described and any changes in numbers noted. Those species recorded on the study sites only infrequently or in very small numbers are detailed in a table.

3. RESULTS

Appendix 1 lists all wildfowl and wader species seen at Cardiff Bay during counts from 1989 to 2001 and highlights those that have been recorded in the Bay since barrage-closure. An annual median of 15 species and a total of 16 have been recorded in the Bay in the two years since closure, in comparison to an annual median of 23 and a total of 41 in the 10 previous years.

3.1 Shelduck *Tadorna tadorna*

Shelduck breed in Britain at many coastal locations, but increasingly, at inland sites (Gibbons *et al.* 1993). Following breeding, most adult Shelduck move to moulting grounds on the German Wadden Sea and start to return to their wintering areas from September onwards. There is a small but important moulting population at Bridgewater Bay on the south side of the Severn. The British wintering population has remained relatively steady in recent winters and was estimated at 57,000 in 1999/2000 (Musgrove *et al.* 2001). The Severn Estuary is of international importance for Shelduck in winter.

Figure 3.1 shows that in the winters of 1999/2000 and 2000/01, after barrage closure, only a few Shelduck used Cardiff Bay. In the latter winter, averages of just 25.7 and 2.3 occurred at high tide and low tide respectively. Prior to barrage closure, an average of 150-200 used the Bay during the exposure period (Burton *et al.* 1999).

Densities of feeding Shelduck in Cardiff Bay prior to closure were significantly related to all factors considered in the GLM (Table 3.1.1). Annual estimates given by this model are shown in Figure 3.1.1a. Treating year as a continuous (rather than a class) variable in the model showed that there had been no significant long-term change in the densities of feeding Shelduck at Cardiff Bay over the 10 years prior to barrage closure ($F_{1,31833} = 0.00$, ns).

Densities at Orchard Ledges were significantly related to year, month, state of tide and mudflat (Table 3.1.1). Figure 3.1.1b indicates that densities at this site in the winter of 2000/01 were similar to those in the winter of 1999/2000 ($F_{1,1921} = 0.41$, ns) and slightly, though insignificantly, higher than those in the winter of 1998/99, prior to barrage closure ($F_{1,1921} = 3.75$, $P = 0.0529$). Numbers on the mudflat immediately adjacent to Cardiff Bay, which had risen following the closure of the barrage, remained above their pre-closure levels (Figure 3.1.2). A peak mean of 14 Shelduck was recorded at Orchard Ledges at low tide in 2000/01 (Figure 3.1.3a). Treating year as a continuous variable in the model showed that densities of feeding Shelduck at Orchard Ledges had significantly decreased over the 10 years prior to barrage closure ($F_{1,1569} = 44.12$, $P < 0.0001$).

At Rhymney, densities of feeding Shelduck were significantly related to all factors considered in the GLM (Table 3.1.1). Densities found at Rhymney in the winter of 2000/01 were lower than in 1999/2000 immediately post-closure ($F_{1,26295} = 15.99$, $P < 0.0001$) and those found in the 1998/99 winter prior to closure ($F_{1,26295} = 31.48$, $P < 0.0001$) (Figure 3.1.1c). As in the previous winter, Shelduck were most numerous on mudflats to the east of the Rhymney River (Figure 3.1.2). A peak mean of 483 Shelduck was recorded at Rhymney in the winter of 2000/01 (Figure 3.1.3b). In contrast to the situation at the other sites, treating year as a continuous variable indicated that densities of feeding Shelduck had significantly increased at Rhymney over the 10 years prior to barrage closure ($F_{1,21702} = 4.74$, $P = 0.0295$).

As results for the winter of 1999/2000 indicated, therefore, the loss of birds from Cardiff Bay has not been matched by an increase at the Orchard Ledges and Rhymney sites. There was a mean of 1022 bird hours per tidal cycle in the Bay in the winter of 1998/99, but an increase of only 26 bird hours at Orchard Ledges in the winter of 1999/2000 and a decrease of 300 at Rhymney (Figures 3.1.1a-c). In the winter of 2000/01, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was only 19 greater than that in the winter of 1998/99, whilst the mean recorded at Rhymney was 1091 less.

Feeding Shelduck were found on all of the eight low tide count sections to the east of Rhymney in the winter of 2000/01 (Figure 3.1.4). Densities of feeding birds in this area were significantly related to mudflat, year and month (Table 3.1.2). No significant differences were apparent between the densities found in 1999/2000 and 2000/01 and those in the winter of 1998/99 prior to barrage-closure (Figure 3.1.5).

3.2 Dunlin *Calidris alpina*

Almost 10,000 pairs of Dunlin breed in Britain (Reed 1985, Stone *et al.*1997), mainly in the flows of northern Scotland and on peaty bogs in the English and Scottish uplands (Stroud *et al.* 1987). In winter, these birds move south to Africa, whilst others that have bred in Scandinavia and Siberia, migrate to Britain. A total of 371,000 Dunlin wintered in Britain in 1999/2000 (Musgrove *et al.* 2001). The Severn Estuary holds internationally important numbers of Dunlin during the winter.

No Dunlin were recorded in Cardiff Bay at low tide in the two winters after barrage-closure and there were means of only 2.6 and 1.3 at high tide (Figure 3.1). In the winter prior to barrage closure, 150-170 Dunlin occurred in the Bay on the ebb and flood tides (Burton *et al.* 1999).

Densities of feeding Dunlin in the Bay prior to closure were significantly related to year, month, mudflat and state of tide (Table 3.2.1). The model did not converge if the interaction between the latter two terms was included. Annual estimates are given in Figure 3.2.1a and as this shows there was a significant decline in feeding densities in the 10 years prior to barrage-closure ($F_{1,31484}$ = 238.99, $P < 0.0001$).

Densities of feeding Dunlin at Orchard Ledges were also related to year, month, mudflat and state of tide, but not the interaction between the latter two variables (Table 3.2.1). Figure 3.2.1b shows that the densities of feeding Dunlin recorded at this site in the winter of 2000/01 were very low, though similar to those found in the preceding winter ($F_{1,1778}$ = 1.82, ns) and in the winter immediately prior to barrage-closure ($F_{1,1778}$ = 0.02, ns). A peak mean of just five Dunlin was recorded at Orchard Ledges at low tide (Figure 3.2.3a). Treating year as a continuous (rather than a class) variable in the model showed that there had been a highly significant decrease in the densities of feeding Dunlin at this site over the 10 years prior to barrage closure ($F_{1,1452}$ = 57.27, $P < 0.0001$).

At Rhymney, densities of Dunlin were also related to year, month, mudflat and state of tide (Table 3.2.1). The model did not converge if the interaction between the latter two terms was included. Densities found at Rhymney in the winter of 2000/01 were similar to those found in the preceding winter ($F_{1,22616}$ = 0.85, ns), but less than those in the winter of 1998/99 immediately prior to closure ($F_{1,22616}$ = 11.12, $P < 0.001$) (Figure 3.2.1c). Figure 3.2.2 shows this decline and also that Dunlin were most numerous in both winters on mudflats to the east of the Rhymney River. A peak mean of 492 Dunlin was recorded at Rhymney in the winter of 2000/01 (Figure 3.2.3b). As at the other two sites, treating year as a continuous variable indicated that densities of Dunlin decreased significantly over the 10 years prior to barrage closure ($F_{1,18592}$ = 30.42, $P < 0.0001$).

The continuing decline in Dunlin numbers meant that it was not possible to discern where birds displaced from the Bay settled in the two winters following barrage-closure. There was a mean of 454 bird hours per tidal cycle in Cardiff Bay in the winter of 1998/99, but an increase of only 49 bird hours at Orchard Ledges in the winter of 1999/2000 and a decrease of 3312 at Rhymney (Figures 3.2.1a-c). In the winter of 2000/01, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was 3 less than that in the winter of 1998/99, whilst the mean recorded at Rhymney was 2720 less.

Feeding Dunlin were found on all but two of the eight low tide count sections to the east of Rhymney in the winter of 2000/01 (Figure 3.2.4). Densities of feeding birds in this area were significantly related to mudflat, year and month (Table 3.2.2). Figure 3.2.5 indicates that densities of Dunlin have

also declined in this area and that the densities found in 2000/01 were lower than in any previous winter.

3.3 Curlew *Numenius arquata*

The Curlew characteristically breeds on damp upland moorlands, but this century has colonised many lowland regions, including agricultural habitats (Gibbons *et al.* 1993). The breeding population of Britain has been estimated at 33,000-38,000 pairs (Reed 1985). Some of this population winters in France, but many other Curlew from continental Europe, notably Scandinavia, migrate to Britain to winter (Prater 1981). A total of 99,000 wintered on the estuaries and shores of Britain in 1999/2000, an increase on the previous year (Musgrove *et al.* 2001). The Severn Estuary presently holds nationally important numbers of Curlew during winter.

No Curlew were recorded in Cardiff Bay at low tide in the two winters following barrage-closure and there were means of only 1.6 and 11.1 at high tide. In the winter of 1998/99, immediately prior to closure, 60-70 Curlew occurred in the Bay on flood tide (Burton *et al.* 1999).

Densities of feeding Curlew in Cardiff Bay prior to closure were significantly related to all factors considered in the GLM (Table 3.3.1). Annual estimates given by this model are shown in Figure 3.3.1a. Treating year as a continuous (rather than a class) variable in the model showed that there had been no significant long-term change in the densities of feeding Curlew at Cardiff Bay over the 10 years prior to barrage closure ($F_{1,34559} = 0.17$, ns).

Densities of feeding Curlew at Orchard Ledges were related to year, month, mudflat and state of tide, but not the interaction between the latter two variables (Table 3.3.1). Figure 3.3.1b shows that the densities of feeding Curlew recorded at this site in the winter of 2000/01 were similar to those found in the preceding winter ($F_{1,2790} = 2.06$, ns), but much greater than those recorded in the winter of 1998/99, prior to closure ($F_{1,2790} = 19.17$, $P < 0.0001$). A peak mean of 50 Curlew was recorded at Orchard Ledges on the flood tide (Figure 3.3.3a). Treating year as a continuous variable in the model showed that there had been no significant change in the densities of feeding Curlew at this site over the 10 years prior to barrage closure ($F_{1,2271} = 2.28$, ns)

At Rhymney, densities of Curlew were related to year, month, mudflat, state of tide and the interaction between the latter two variables (Table 3.3.1). Densities in the winter of 2000/01 were similar to those found in the preceding winter ($F_{1,29310} = 1.38$, ns) and those in the winter of 1998/99, immediately before barrage-closure ($F_{1,29310} = 1.82$, ns) (Figure 3.3.1c). Figure 3.3.2 shows that Curlew were most numerous on this site on mudflats adjacent to the Rhymney River and close to Orchard Ledges. A peak mean of 64 Curlew was recorded at Rhymney in the winter of 2000/01 (Figure 3.3.3b). Treating year as a continuous variable indicated a slight decrease in the densities of Curlew over the 10 years prior to barrage closure ($F_{1,24041} = 6.23$, $P = 0.0126$)

The change in the number of Curlew at Orchard Ledges only went some way to matching the loss of birds from the Bay. There was a mean of 186 bird hours per tidal cycle in the Bay in the winter of 1998/99, but an increase of only 36 bird hours at Orchard Ledges in the winter of 1999/2000 and a negligible increase at Rhymney (Figures 3.3.1a-c). In the winter of 2000/01, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was 63 greater than that in the winter of 1998/99, whilst the mean recorded at Rhymney was 26 greater.

Feeding Curlew were found on all of the eight low tide count sections to the east of Rhymney in the winter of 2000/01 (Figure 3.3.4). Densities of feeding birds in this area were significantly related to mudflat, year and month (Table 3.3.2). Densities in 2000/01 were lower than in any previous winter (Figure 3.3.5).

3.4 Redshank *Tringa totanus*

A total of 30,000-34,000 pairs of Redshank were estimated to breed in Britain in the mid-1980s, mainly on wet grasslands and on coastal saltmarshes (Reed 1985; Gibbons *et al.* 1993; Stone *et al.* 1997). The British wintering population is formed of birds from both Britain and Iceland (Summers *et al.* 1988). A total of 98,000 wintered on Britain's estuaries and shores in 1999/2000 (Musgrove *et al.* 2001). The Severn Estuary is internationally important for Redshank in winter.

Only a few Redshank were recorded in Cardiff Bay in the two winters post-closure (Figure 3.1). Averages of just 11.4 and 12.8 occurred at high tide and low tide respectively in the winter of 2000/01. In winters prior to barrage-closure, an average of 200-230 used the Bay during the exposure period (Burton *et al.* 1999).

Densities of feeding Redshank in Cardiff Bay prior to closure were significantly related to all factors considered in the GLM (Table 3.4.1). Annual estimates given by this model are shown in Figure 3.4.1a. Treating year as a continuous (rather than a class) variable in the model showed that there had been a highly significant decline in the densities of feeding Redshank at Cardiff Bay over the 10 years prior to barrage closure ($F_{1,32085} = 58.65$, $P < 0.0001$).

No Redshank were observed at Orchard Ledges in the winter of 2000/01 and only occasional birds have been seen there previously.

At Rhymney, densities of feeding Redshank were related to year, month, mudflat and state of tide, but not the interaction between the latter two variables (Table 3.4.1). Densities in the winter of 2000/01 were slightly higher than those found in the preceding winter ($F_{1,22234} = 5.86$, $P = 0.0155$), but much greater than those in the winter of 1998/99 prior to barrage-closure ($F_{1,22234} = 20.55$, $P < 0.0001$) (Figure 3.4.1b). Figure 3.4.2 shows that Redshank were most numerous in the winter of 2000/01 on mudflats adjacent to the Rhymney River. As in the winter of 1999/2000, they also used the mudflats adjacent to Cardiff Heliport, though unlike that winter, usually only on the ebb tide. A peak mean of 370 Redshank was recorded at Rhymney in the winter of 2000/01 (Figure 3.4.3). Treating year as a continuous variable indicated that, as at Cardiff Bay, there had been a highly significant decline in the densities of feeding Redshank at Rhymney over the 10 years prior to barrage closure ($F_{1,18045} = 134.73$, $P < 0.0001$).

The observed increase in the number of Redshank at Rhymney over the two winters subsequent to barrage-closure almost matches the loss of birds from the Bay. There was a mean of 1050 bird hours per tidal cycle in the Bay in the winter of 1998/99 and although there was an increase of only 326 bird hours at Rhymney in the winter of 1999/2000, there was a further increase of 524 bird hours in the following winter (Figures 3.4.1a-b). The increase recorded may have been tempered by a continuing fall in the existing Redshank population at Rhymney and by mortality in the displaced population. It probably also underestimates the true change in numbers, as the population at Rhymney is itself usually underestimated by the all-day counts and to a greater extent than was the population in the Bay. This is because as the tide falls many birds move out of sight into creeks and onto the lower river banks (Figure 3.4.3). It is also probable that, at times, much of the population at Rhymney frequented the upper tidal stretches of the river and thus did not appear on the study site (as defined in Figure 2.1.2).

Feeding Redshank were found on just four of the eight low tide count sections to the east of Rhymney in the winter of 2000/01 (Figure 3.4.4). Densities of feeding birds in this area were significantly related to mudflat and year, but not month (Table 3.4.2). No significant difference was apparent between the densities found in 2000/01 and those in the previous winter (Figure 3.4.5).

3.5 Other Species

3.5.1 Mallard *Anas platyrhynchos*

Mallard have continued to use Cardiff Bay in the two winters since barrage-closure, although in reduced numbers. A peak of 21 was recorded in the winter of 2000/01, less than half that in the previous winter and less than one quarter that recorded in the winter of 1998/99 prior to closure. No Mallard were recorded at Orchard Ledges during the winter. The peak of 83 at Rhymney in January was similar to that of the previous winter. Further large concentrations were present at low tide at St. Brides.

3.5.2 Teal *Anas crecca*

Teal numbers have been much reduced in the Bay since barrage-closure. A peak of 30 was recorded in November, compared to a peak of 121 in the winter of 1998/99. A maximum of six was recorded at Rhymney, although many more used the upper tidal stretches of the River Rhymney and thus did not appear on the study site. Further concentrations were present at low tide at St. Brides.

3.5.3 Pintail *Anas acuta*

As in most previous years no Pintail were recorded at Cardiff Bay in the winter of 2000/01. Five Pintail were seen at Orchard Ledges in November 2000, however - the first ever recorded there. Numbers at Rhymney were slightly higher than in the previous winter, though similar to those in 1998/99, peaking at 351 on 18 February. Large concentrations also occurred along the shoreline at Peterstone and St. Brides.

3.5.4 Pochard *Aythya ferina*

Pochard numbers have increased at Cardiff Bay over the past three winters and the post-barrage peak of 120 in February was almost twice that in the previous winter and four times that in the winter of 1998/99, prior to barrage-closure. The peak of 190 at Rhymney in March, in comparison, was slightly lower than that in the preceding winter. Small numbers were also present on adjacent areas of Peterstone at low tide.

3.5.5 Oystercatcher *Haematopus ostralegus*

Oystercatcher, although not present on the Severn in nationally important numbers, were one of the most numerous species in Cardiff Bay prior to barrage-closure. A total of just nine Oystercatcher have been observed at Cardiff Bay in the two winters since barrage-closure, however.

Figure 3.5.5.1 indicates the results of the modelling of densities at Cardiff Bay, Orchard Ledges and Rhymney. All factors considered in the models were significant in explaining densities (Table 3.5.5.1). Densities at all three sites had increased over the 10 years prior to barrage-closure (Cardiff Bay: $F_{1,31972} = 262.65$, $P < 0.0001$; Orchard Ledges: $F_{1,2265} = 231.04$, $P < 0.0001$; Rhymney: $F_{1,24082} = 82.38$, $P < 0.0001$). Densities at Orchard Ledges in the winter of 2000/01 were similar to those found in the preceding winter ($F_{1,2784} = 0.35$, ns) and those in the winter of 1998/99 prior to barrage-closure ($F_{1,2784} = 0.22$, ns). Densities at Rhymney, however, were less than those in the preceding winter ($F_{1,29502} = 12.62$, $P = 0.0004$), but still slightly higher, though not significantly, than those in the winter of 1998/99 ($F_{1,29502} = 2.85$, $P = 0.0916$).

No significant difference was apparent between the densities of Oystercatchers found on low tide counts at Peterstone and St. Brides in 2000/01 and those in the winter of 1998/99 (Figure 3.5.5.2).

3.5.6 Ringed Plover *Charadrius hiaticula*

No Ringed Plover have been recorded in Cardiff Bay in the two winters since barrage-closure. In the two preceding years, peak numbers over 40 had occurred in the autumn. Numbers at Orchard Ledges and Rhymney were slightly lower than in the previous winter – though higher than in the winter immediately before barrage-closure - peaking at 31 and 32 in November and January respectively. Only occasional Ringed Plover were observed at St. Brides, but none were recorded at Peterstone.

3.5.7 Grey Plover *Pluvialis squatarola*

Numbers of Grey Plover have declined sharply on the study sites in recent years and none were recorded at Cardiff Bay, Orchard Ledges or Rhymney in the winter of 2000/01. Indeed, no Grey Plover have been recorded in the Bay since barrage-closure. Numbers recorded at Peterstone and St. Brides at low tide have also fa1len and only one flock of 13 birds was recorded in the winter of 2000/01.

3.5.8 Lapwing *Vanellus vanellus*

In contrast to the winter of 1999/2000, Lapwing were observed several times at Cardiff Bay in the winter of 2000/01, averages of 6.0 and 5.1 being recorded at high and low tide respectively. Few birds were recorded feeding, however, and numbers were much lower than in winters prior to barrage-closure. (A maximum of 73 was recorded in the winter of 1998/99, for example.) A maximum of only 24 was recorded during the winter at Rhymney and none were recorded at Orchard Ledges or at low tide at Peterstone and St. Brides.

3.5.9 Knot *Calidris canutus*

Knot too have declined greatly in number at all sites in recent years and the species was recorded on only four dates at Rhymney in the winter of 2000/01, with a peak of 60 birds on 14 February. None have been recorded at Cardiff Bay since barrage-closure. Only one Knot was recorded at Orchard Ledges in the winter of 2000/01 and none at low tide at St. Brides or Peterstone.

3.5.10 Turnstone *Arenaria interpres*

Turnstone formerly used Cardiff Bay primarily as a high tide roost site and continued to do so in small numbers in the winter of 1999/2000 following the closure of the barrage. None were recorded in the winter of 2000/01, however. Peaks of 97 and 3 were recorded at Orchard Ledges and Rhymney in the winter of 2000/01, both less than those in 1998/99 prior to barrage-closure. No Turnstone were recorded at low tide at St. Brides or Peterstone.

3.6 Occasional Species

Several other species of wildfowl and wader were observed at Cardiff Bay, Orchard Ledges and Rhymney in 2000/01 but in numbers too small to be included in the separate species accounts. These are shown in Table 3.6.1. Goosander *Mergus merganser* continued to use the Bay in small numbers post-closure and occasional Whimbrel *Numenius phaeopus* and Common Sandpiper *Actitis hypoleucos* were also present. Mute Swan *Cygnus olor* which had only occasionally used the Bay prior to closure, were regularly present in small numbers in the winter of 2000/01, averages of 12.0 and 12.8 being recorded on high and low tide surveys respectively.

4. DISCUSSION

Only 16 species of wildfowl and wader (and an annual median of 15) have been recorded in Cardiff Bay in the two winters following barrage-closure, in comparison to a total of 41 in the 10 previous years (and an annual median of 23). The numbers of all but Pochard and Mute Swan have been much reduced. A few Shelduck, Dunlin, Curlew and Redshank continued to use the Bay as a high tide roost site, but no Dunlin or Curlew were recorded at low tide in either winter. Schekkerman *et al.* (1994) similarly reported a decrease in dabbling ducks and waders, but an increase in species that feed on open water in a study looking at the effects of the construction of a storm-surge barrier and two dams in The Netherlands. At Cardiff Bay, Coot and Great Crested Grebe bred in small numbers in the spring of 2001.

The increase in Redshank densities at Rhymney in the winter of 1999/2000 followed a long-term decline at this site. With the addition of evidence from colour-ringing and radio-tracking studies (Burton *et al.* 2001; see also Part 2), it is clear that this change was primarily due to the influx of birds from Cardiff Bay. Densities increased further in the winter of 2000/01, suggesting a further concentration of displaced birds into this site and indeed, the observed increase in the number of Redshank at Rhymney over the two winters subsequent to barrage-closure almost matches the loss of birds from the Bay. In both winters, the highest densities of Redshank were noted along the Rhymney River and by Cardiff Heliport, a disturbed site that in past winters was normally used only at night. In a similar study of habitat loss on the Forth Estuary, McLusky *et al.* (1992) also found that Redshank remained faithful to a neighbouring but formerly less favoured area.

Dunlin had been in decline at all three sites over the 10 years prior to barrage-closure and densities fell further at Rhymney in the winter of 1999/2000, though no more the following winter. Austin *et al.* (2000) reported that numbers of both Dunlin and Redshank have been in decline not just in this area but also across south Wales and southwest England. It is possible that warmer winter weather over recent winters has made it less essential for birds to winter on the milder west coast of Britain and as a result fewer first-winter birds have settled in these areas. Alternatively wintering populations may be falling due to declines in breeding populations. Breeding populations of Redshank in the UK, for example, are in decline due to habitat drainage and loss and increased nest predation rates (e.g. Fuller & Jackson 1999, Jackson & Green 2000). If, however, the populations of these species on the northwest Severn have been in decline due to reduced local food resources, there would be limited spare capacity for any birds displaced from Cardiff Bay. In the longer term this could be a particular problem for those Redshank displaced to Rhymney. A study in The Netherlands (Schekkerman *et al.* 1994), found that waders displaced by coastal engineering works were not able to settle in adjacent intertidal areas as these sites were close to their carrying capacity. This and severe winter weather led to an increase in mortality rates. Changes in the survival rates of Redshank following the closure of the barrage are investigated in Part 2 of this report.

Oystercatcher densities at Rhymney were greater in the two winters following barrage-closure than in the year before. Although this increase may in part have been due to the displacement of birds from the Bay, it may also just have been the continuation of a long-term upward trend. Densities at this (and the other two sites) had increased in the 10 years prior to closure. The causes of these increases are unclear, but suggest either that food supplies have increased or that the local populations were below carrying capacity in previous years. A previous study, which found that an increase in Oystercatcher numbers on part of the Exe was not linked to an increase in food supply, indicated that Oystercatcher populations do sometimes occur below local carrying capacity (Goss-Custard *et al.* 1998). It remains difficult to say, therefore, whether Oystercatcher displaced from the Bay settled at Rhymney, have dispersed over a much larger area or have suffered increased mortality.

Densities of both Curlew and Shelduck increased at Orchard Ledges in the winter following barrage-closure and these higher densities were maintained in the winter of 2000/01. Those of Shelduck were significantly greater on the mudflat immediately adjacent to Cardiff Bay than in winters prior to barrage-closure and it is reasonable to suppose that this was solely a result of birds being displaced

from the Bay. Neither increase matched the loss of birds from the Bay, however. Curlew numbers have increased marginally at Rhymney following barrage-closure, but those of Shelduck have declined sharply. Whilst it seems probable, therefore, that some of the Curlew and Shelduck from the Bay have settled at Orchard Ledges, it remains difficult to ascertain the fate of the rest.

Until the full programme of work has been completed, these conclusions should be treated with caution. Future monitoring will help to distinguish changes associated with the closure of the barrage from other underlying fluctuations in species' populations.

PART 2: REDSHANK STUDIES

5. INTRODUCTION

The impact of habitat loss on local bird populations is largely dependent upon the availability of suitable habitat elsewhere, how close these alternative sites are to their carrying capacity and whether displaced birds are able to learn about the spatial characteristics of the new sites in periods when they are not under food stress (Goss-Custard 1985). The effects may also vary between species due to their site-faithfulness. Wader species, such as Knot, Dunlin 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), may be less affected by the loss of any one site. However, more site-faithful species, such as Redshank, Turnstone and Purple Sandpiper *C. maritima* (Metcalfe & Furness 1985, Symonds & Langslow 1986, Symonds *et al.* 1984, Rehfisch *et al.* 1996, Burton & Evans 1997, Dierschke 1998) could be at greater risk. A previous study (McLusky *et al.* 1992) suggested that the effects of habitat loss on a local Redshank population were initially delayed, as birds remained faithful to neighbouring (though formerly less favoured) areas. In the longer term, such a population would be greatly threatened, unless these alternative sites were below their carrying capacity for the species and thus were able to support additional birds.

This chapter reports on the distribution, condition and survival rates of Redshank displaced as a result of the closure of the Cardiff Bay barrage. Burton (2000a) found that Redshank were previously highly faithful to Cardiff Bay, both within and between winters and concluded that the species would be among the most at risk from its loss if no other suitable habitat was available nearby. Results from observations of colour-ringed and radio-tagged birds in the first winter post-closure revealed that the majority of displaced Redshank remained in the immediate vicinity of the Bay, using mudflats by Cardiff Heliport and around the Rhymney Estuary. A few individuals moved as far as the River Usk at Newport and at least one crossed the Severn Estuary to Somerset. Results presented here show whether displaced Redshank continued to use the same areas in the winter of 2000/01.

Also in this part of the report, we investigate whether the condition and survival of Redshank displaced from the Bay were adversely affected in the first year following barrage-closure. Burton (2000a) reported adult survival rates for two years prior to barrage-closure that were slightly higher than those found in most previous studies (Jackson 1988; Thompson & Hale 1993; Insley *et al.* 1997). Survival may vary between years and sites according to weather conditions and predation pressure (Cresswell & Whitfield 1994; Insley *et al.* 1997). Redshank are known to suffer particularly high mortality in cold winters (Davidson 1982; Davidson & Evans 1982; Clark *et al.* 1993, Insley & Swann 1996). The results presented will help to determine whether the loss of the Bay resulted in increased mortality in the Redshank population from Cardiff Bay or whether the displaced birds have been successful in relocating to new wintering quarters.

6. METHODS

6.1 Ringing

Ringing activities associated with the project began in January 1991. Redshank were caught by cannon- or mist netting at high tide roosts both within the Bay and at the Rhymney Estuary. 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. To help analyse variation in the birds' body condition, the following measurements were taken: mass (g), wing length (maximum chord), foot length and bill length (to precisions of 1 mm, 0.5 mm and 0.1 mm respectively) (see Summers *et al.* 1988). The majority of measurements were taken by one observer (Steve Dodd).

Colour-ringing has helped in the study of the movements and survival of Redshank. Initially, in January 1991, October 1993 and September 1994, Redshank were fitted just with single yellow and white Darvic plastic rings on the right or left tarsus. Thereafter, from November 1994 to October 1999, the majority of Redshank caught at Cardiff Bay and some of those originally metal-ringed in the Bay and then retrapped at Rhymney were given unique combinations of colour-rings so that they could be subsequently identified in the field. In total, 454 birds were individually colour-ringed - 396 in the Bay (322 adults, 69 first-winter birds and 5 birds whose age could not be determined) and 58 adults caught at Rhymney (39 of which had previously been caught in the Bay).

For the first colour-ringing scheme used (from November 1994 to February 1995), three colours had to be determined on the left tibia and tarsus for an individual to be identified (two constant scheme colours of yellow over white additionally being placed on the right tibia). In contrast, for the second (used from October 1995), colours only had to be determined on the tibias (the constant scheme colours being placed on the right tarsus). Subsequent analysis revealed that birds of the first scheme were identified less frequently, as rings on the tarsus were often covered with mud or water (Burton 2000b). To avoid any bias, it was decided that these individuals should not be used in survival analyses.

6.2 Data Analysis and Presentation of Results

6.2.1 The Distribution of Redshank Displaced from Cardiff Bay

Both in October 1999 and in the two winters post-closure, Cardiff Bay and other parts of the Severn Estuary previously known to support wintering Redshank have been surveyed for colour-ringed birds. Sites surveyed are listed in Appendix 2; no sites were surveyed on the coast immediately west of Cardiff as the narrow, rocky shore in this area supports few Redshank. Mudflats by the Rhymney River and Cardiff Heliport, both counted as part of the larger Rhymney all-day site, are here treated as separate areas. In addition to details of any colour-ringed birds sighted, the proportions of colour-ringed birds in flocks of Redshank were also recorded. No other studies have colour-ringed Redshank on the Severn Estuary and thus those colour-ringed birds seen would either have been from Cardiff or been birds ringed on breeding grounds. Three Redshank colour-ringed on breeding grounds in the Outer Hebrides have previously been seen in the Cardiff area in winter (Burton *et al.* 1999, Jackson 1999).

The results of these surveys are shown in three figures that indicate the proportion of colour-ringed birds in flocks of Redshank in October 1999, prior to the closure of the Cardiff Bay barrage, and the winters of 1999/2000 and 2000/01 subsequent to barrage-closure. Differences in the proportions of colour-ringed Redshank (p) seen in flocks in different periods were tested for using GLMs, e.g.

$$\text{logit}(p) = \mu + \text{period}_i$$

A binomial error distribution was assumed in these models, with a logit link function used to ensure valid proportion estimates in the range (0,1). Differences in the proportions of colour-ringed

Redshank seen between periods were tested for using likelihood ratio tests (see Wetherill 1981, pp. 350-353).

6.2.2 Analysis of the Body Condition of Redshank in the Winter of 1999/2000

To determine whether displacement from Cardiff Bay adversely affected the body condition of the Redshank that wintered there, it was initially necessary to classify individuals into three groups. There were those that had only ever been caught (or having first been colour-ringed, then seen) at Cardiff Bay prior to its flooding, those that had only ever been caught (or seen) at Rhymney and those that had been recorded at both sites. Comparison was then made of the masses of adults from each of these three categories in the winter of 1999/2000 using a GLM. The model controlled for month of capture and measures of body-size – i.e. wing-length, bill-length and foot-length – and only used one observation for each bird. Previous work has shown that the Redshank that formerly wintered in the Bay were predominantly from the British breeding population, whilst those that were found at Rhymney came from both the British and Icelandic populations (Burton *et al.* in prep.). Thus birds from the Bay tended to have shorter wings and feet, but longer bills (Summers *et al.* 1988). The model assumed a normal distribution and treated month and origin as class variables. The problem of overdispersion in the mass (i.e. weight) data 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. Only those variables that were significant in explaining the variation in mass were retained in the final models. Likelihood ratio tests were used to investigate differences in the masses of Redshank from each category. Sample sizes were too small to investigate whether the masses of individuals were lower in the winter of 1999/2000 than in preceding winters.

6.2.3 Survival Analyses

Estimates of survival and return rates of adult Redshank were calculated using mark-recapture methods. Cardiff Bay and other areas used by wintering Redshank were searched extensively for colour-ringed birds (originally caught and ringed in the Bay) twice a year, in February and October, from February 1996 to February 2001. Resighting data were analysed using Program MARK (White & Burnham 1999). Following Burton (2000a), Cormack-Jolly-Seber (CJS) models (Lebreton *et al.* 1992, Seber 1982) were developed to estimate average survival rates (ϕ) and resighting probabilities (p) and time-varying annual rates (ϕ_t and p_t).

The validity of the CJS models depend upon the equal catchability (or in this case 'sightability') of each marked individual. Initial goodness-of-fit tests (of the model in which ϕ and p were assumed to vary with time) indicated that this assumption was not valid (Table 6.2.3.1). This was thought to be because in the first year of data collection the River Ely was not surveyed for colour-ringed birds and thus birds that were largely resident there had a lower catchability than those resident in the main part of the Bay. Further goodness-of-fit tests indicated that the exclusion of data from the first year of study was sufficient to overcome this violation (Table 6.2.3.1). Using Program MARK, we also estimated an overdispersion parameter for the data ($\hat{c}$) to adjust the models. A value of 1.440 for $\hat{c}$ was calculated by dividing the deviance of the actual data by the average deviance calculated from 100 simulated data sets produced by bootstrapping (White & Burnham 1999).

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 (i.e. that with the lowest $QAIC_c$ value). If the selected model indicated that survival did not vary with time, then clearly there would be no evidence that Redshank had suffered increased mortality as a result of displacement from the Bay. It was expected, however, that survival would vary with time, at least between seasons. This was partly because birds face varying pressures in different parts of their annual cycle, but also because the period over which estimates for over-summer return rates to the study site (ϕ_{st}) were calculated (February to October, covering migrations from and back to the study area and the

breeding season) was twice that over which estimates for winter survival (ϕ_{wt}) were calculated (October to February).

To determine whether survival fell following barrage-closure, a model in which estimates of ϕ_w for the winters of 1997/98, 1998/99 and 1999/2000 were assumed to be equal was compared (using a LRT) to one where the ϕ_w for 1999/2000 was assumed to differ from that for the preceding two winters. Likewise, to determine whether the over-summer return rate fell in the summer following barrage-closure, a model in which estimates of ϕ_s for the summers of 1997, 1998 and 1999 and 2000 were set equal was compared to one where the ϕ_s for the summer of 2000 and for the summers of 1997-1999 were estimated separately.

7. RESULTS

7.1 The Distribution of Redshank Displaced from Cardiff Bay

Figure 7.1.1 shows the proportions of colour-ringed individuals in flocks of Redshank on the lower Severn Estuary in October 1999, prior to barrage-closure, and in the two winters subsequent to barrage-closure, i.e. 1999/2000 and 2000/01. Prior to closure, a mean of 49% of Redshank at Cardiff Bay were colour-ringed and at Rhymney, a mean of 10%. The comparatively low proportion of marked birds in the population at Rhymney emphasises individuals' fidelity to the Bay - birds were only colour-ringed when caught at Cardiff Bay or if they had been previously metal-ringed there. No Redshank were recorded on the area of mudflats adjacent to Cardiff Heliport during daylight hours during October. No colour-ringed birds were seen to the east of Rhymney and only one individual on the English side of the Estuary.

In the winter of 1999/2000, immediately after barrage-closure, colour-ringed Redshank were seen as far east as the River Usk at Newport (18 individuals) and as far south as the River Brue in Somerset (1 individual). Three colour-ringed individuals were seen on the English side of the Severn Estuary (at two sites), two of which were probably colour-ringed at Cardiff on autumn passage to these sites. No colour-ringed birds were seen further up the Severn than the River Usk, in spite of good coverage of this area.

In comparison, in the winter of 2000/01, colour-ringed Redshank were less dispersed. No colour-ringed birds were seen east of Peterstone and only one bird was seen on the English side of the Severn Estuary (that which had been seen there on October 1999 prior to barrage-closure).

In the winter of 1999/2000, following barrage-closure, the percentage of colour-ringed birds in flocks of Redshank at Rhymney increased significantly to 21% (χ^2_1= 28.97, $P < 0.0001$). This figure had declined slightly by the following winter to 19% (presumably due to the influx of juveniles into the population), though this figure was still significantly higher than that recorded prior to barrage-closure (χ^2_1= 16.14, $P < 0.0001$). In both winters, colour-ringed Redshank were also recorded at Sluice House Farm and Peterstone, immediately to the east of Rhymney.

The area of mudflats by Cardiff Heliport, which was only used nocturnally by Redshank prior to barrage-closure, was used intensively both during the day and night in the winter after barrage-closure. Approximately 45% of the Redshank that used this area between November 1999 and February 2000 were colour-ringed, a similar percentage to that which was recorded in the Bay prior to closure ($\chi^2_1 = 0.74$, ns). The area was used by fewer Redshank in the winter of 2000/01 and primarily on the ebb tide. Again, approximately 45% of these birds were colour-ringed, a similar percentage to that recorded in the Bay pre-closure ($\chi^2_1 = 1.20$, ns).

7.2 Analysis of the Body Condition of Redshank in the Winter of 1999/2000

The GLM used to analyse adult Redshank biometric data indicated that mass was significantly and positively related to wing-length ($F_{1,225} = 37.2$, $P < 0.0001$) and foot-length ($F_{1,225} = 41.6$, $P < 0.0001$), but not to bill-length ($F_{1,224} = 0.18$). Mass in the winter of 1999/2000 was also significantly related to month ($F_{1,225} = 32.5$, $P < 0.0001$) and the group to which an individual had been categorised ($F_{1,225} = 3.5$, $P = 0.0336$).

Controlling for body-size and month, 'Cardiff Bay' Redshank were significantly lighter than those classified as 'Rhymney' birds ($F_{1,225} = 5.4$, $P = 0.0214$) and those that had been recorded at both sites prior to barrage-closure ($F_{1,225} = 6.8$, $P = 0.0095$). Those from the latter two categories did not differ in mass ($F_{1,225} = 0.6$, ns). (The sample of 'Cardiff Bay' Redshank included birds seen at Cardiff Heliport, Rhymney and Peterstone in the winter of 1999/2000)

7.3 Survival Analyses

Table 7.3.1 indicates that the model that best fitted the Redshank resighting data was one where the survival rate 'ϕ' varied with time, but with a constant value for the resighting probability '*p*'. Likelihood Ratio Tests (LRTs) showed that survival varied significantly with time ($\chi^2_7 = 20.25$, $P = 0.0051$), but that having accounted for this, *p* did not ($\chi^2_6 = 11.16$, $P = 0.0837$).

Resulting survival estimates from this model are shown in Table 7.3.2. A constant value of 0.889 (s.e. = 0.015) was calculated for *p*.

Winter survival was estimated at the boundary value $\phi = 1.000$ for each of the two winters prior to barrage-closure, but fell significantly (LRT: $\chi^2_1 = 9.29$, $P = 0.0023$) to 0.907 (s.e. = 0.028) in the winter immediately after closure. The return rate over the summer of 2000 did not differ from those over the three previous years however (LRT: $\chi^2_1 = 0.0$, ns).

Annual survival, calculated as the product of ϕ_{wt} and ϕ_{st} was 0.819 over the winter of 1997/98 and the summer of 1998, 0.860 the following year and 0.773 the year after barrage-closure.

8. DISCUSSION

Data from observations of colour-ringed and radio-tagged birds indicated that in the winter of 1999/2000 following barrage-closure the majority of Redshank from Cardiff Bay were displaced to the Rhymney Estuary and the mudflats by Cardiff Heliport. Only a few birds moved further – to the River Usk at Newport or the River Axe in Somerset across the mouth of the River Severn. In the winter of 2000/01, colour-ringed Redshank were again most commonly seen at the Rhymney Estuary, though none were seen on the River Usk and only one in Somerset. The proportions of colour-ringed birds observed in flocks of Redshank at Rhymney were only a little lower than the previous winter, despite the addition of unringed juvenile birds to the population. These observations and the slight increase in counts of Redshank at Rhymney suggest that the distribution of Redshank displaced from the Bay has become even more concentrated into this area.

Redshank continued to use the mudflats at the Heliport, as they had in the winter following barrage-closure. Observations from both 1999/2000 and 2000/01 revealed that those Redshank that did use the site during the day included a number of individuals that continued to use the Bay as a high tide roost. In the winter of 2000/01, birds primarily used the area on the ebb tide whilst en route to the Rhymney River. A maximum of 68 Redshank was observed at the Heliport in the winter of 2000/01 in comparison to 79 in the winter before. In both winters, approximately 45% of the Redshank that used the mudflats were colour-ringed, a similar percentage to that recorded in the Bay prior to closure.

The mudflats by the Heliport are situated by a sewage outfall pipe and due to the high organic and nutrient input from sewage are thus likely to be rich in invertebrates (N.A.C. pers. obs.; Pearson & Rosenberg 1978). In spite of this, disturbance from landing helicopters probably discouraged Redshank from using the site prior to barrage-closure, at least during the day – the heliport's usual operating hours are from 0900 to 1700. Previous studies have indicated that helicopters typically cause more disturbance than any other type aircraft (Smit & Visser 1993). Birds had previously used the site at night, however, when no helicopters took off or landed.

It seems probable that Redshank displaced from the Bay have been forced to use this disturbed site by an inability to find food elsewhere. The displaced Redshank are likely to have faced intense competition for food with those birds already resident at Rhymney and many adults would have turned to the Heliport site due to their familiarity of it as a nocturnal feeding site. In spite of this, analysis of biometric data revealed that adult Redshank from the Bay had difficulty maintaining their body condition in the first winter following closure. A previous study (Evans 1978/79) found that, following the loss of an area of intertidal mudflats, Redshank were forced to use supratidal feeding areas over high tide in order to meet their daily food requirements.

The redistribution of Redshank following the closure of the barrage mirrors that reported by McLusky *et al.* (1992) following a similar loss of intertidal habitat in Scotland. They too found that Redshank tended to remain in the vicinity of their lost wintering grounds and also used areas formerly less favoured. In our study, adult Redshank not only lost body condition but also, according to preliminary analysis, apparently experienced increased mortality in the winter of 1999/2000 following barrage-closure. The estimated winter survival rate was lower than in each of the previous two winters and annual survival only 77% in comparison to 82% and 86% in the two preceding years. Had the weather during the winter been more severe, a higher mortality rate would have been expected.

The survival rate over the winter of 1999/2000 may have been underestimated if birds had not been detected once displaced. However, although it is known that one individual was missed during surveys – it was seen at a breeding site in Somerset in May 2000 – there is little reason to suppose that actual (rather than estimated) resighting rates were lower following closure than before. As Figure 7.1.1 shows, the majority of Redshank were displaced to sites close to Cardiff that were intensively surveyed for birds, whilst many other sites beyond these were also surveyed and no colour-ringed birds detected (Appendix 2). It should also be noted that the annual survival rate of 77% calculated

for the year following closure is no lower than many other previous published estimates. Großkopf (1959, 1964 – see also Boyd 1962), for example, reported survival rates of 71 and 75% for adult Redshank and Jackson (1988) rates of 77 and 75% for adult males and females respectively, in studies based on colour-ring sightings in the breeding season. Thompson and Hale (1993), likewise, reported rates of 75 and 72% for males and females in a mark-recapture study of breeding birds and Insley *et al.* (1997) a rate of 74% for birds at least three winters old.

The longer term future of the remaining Redshank displaced from the Bay depends upon whether the area to which they have moved, primarily the Rhymney Estuary, contains enough food resources to support an enlarged population (Goss-Custard 1977). If it does not, winter mortality amongst the displaced Redshank will remain high until such time that the size of the population falls below the area's carrying capacity for the species (Goss-Custard 1985). Continued study will help to show whether or not survival rates were also low in the winter of 2000/01 and whether they remain low in the winter of 2001/02.

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Species	Level for International Importance	Level for National Importance	Importance of Severn Estuary	Maximum WeBS count at Cardiff Bay - winter 1998/99	Maximum WeBS count at Cardiff Bay - winter 1999/2000	Maximum WeBS count at Cardiff Bay - winter 2000/01
Shelduck *Tadorna tadorna*	2500	750	International	177	14	44
Teal *Anas crecca*	4000	1400	National	70	12	28
Mallard *Anas platyrhynchos*	20000	5000	-	155	37	67
Pintail *Anas acuta*	700	280	International	0	0	0
Pochard *Aythya ferina*	3500	440	National	33	2	64
Oystercatcher *Haematopus ostralegus*	9000	3600	-	60	0	2
Ringed Plover *Charadrius hiaticula*	500	290	-	5	0	0
Grey Plover *Pluvialis squatarola*	1500	430	National	0	0	0
Lapwing *Vanellus vanellus*	20000	20000	National	17	1	45
Knot *Calidris canutus*	3500	2900	-	0	0	0
Dunlin *Calidris alpina*	14000	5300	International	4500	0	55
Curlew *Numenius arquata*	3500	1200	National	137	8	30
Redshank *Tringa totanus*	1500	1100	International	352	0	0
Turnstone *Arenaria interpres*	700	640	-	48	21	37

Table 2.3.1 The importance of the Severn Estuary and Cardiff Bay for waterbirds in a British and international context. A wetland site is considered internationally important for a species if it regularly holds at least 1% of the individuals in a population of that species. Britain's wildfowl belong to the northwest European population (Pirot *et al.* 1989), and the waders to the east Atlantic flyway population (Smit & Piersma 1989). A wetland site in Britain is considered nationally important for a species if it regularly holds 1% or more of the estimated British population of that species. The Severn Estuary also holds internationally important numbers of Bewick's Swan *Cygnus columbianus bewickii* and nationally important numbers of European White-fronted Goose *Anser albifrons albifrons*, Wigeon *Anas penelope*, Gadwall *Anas strepera*, Shoveler *Anas clypeata*, Tufted Duck *Aythya fuligula* and Black-tailed Godwit *Limosa limosa* (Musgrove *et al.* 2001). WeBS data for Cardiff Bay are from the winters (November to March) of 1998/99, 1999/2000 and 2000/01.

	Month	State of Tide	Mudflat	State of Tide * Mudflat	Year
Cardiff Bay	$F_{8,32624} = 918.4$ $P < 0.0001$	$F_{11,32624} = 10.6$ $P < 0.0001$	$F_{17,32624} = 107.4$ $P < 0.0001$	$F_{171,32624} = 6.7$ $P < 0.0001$	$F_{10,32624} = 27.4$ $P < 0.0001$
Orchard Ledges	$F_{6,1921} = 31.1$ $P < 0.0001$	$F_{6,1921} = 5.7$ $P < 0.0001$	$F_{1,1921} = 8.2$ $P = 0.0042$	ns	$F_{11,1921} = 8.9$ $P < 0.0001$
Rhymney	$F_{8,26295} = 647.7$ $P < 0.0001$	$F_{11,26295} = 5.5$ $P < 0.0001$	$F_{16,26295} = 90.3$ $P < 0.0001$	$F_{114,26295} = 8.6$ $P < 0.0001$	$F_{12,26295} = 31.3$ $P < 0.0001$

Table 3.1.1 Likelihood ratio statistics and associated probabilities for month, state of tide, mudflat, state of tide*mudflat and year in generalised linear models describing densities of feeding Shelduck at Cardiff Bay from 1989/90 to 1998/99 and Orchard Ledges and Rhymney from 1989/90 to 2000/01. All models excluded data from August and that for Orchard Ledges data from September and October too, as too few birds were present on the study sites at these times for their inclusion to be biologically meaningful.

Month	Mudflat	Year
$F_{4,414} = 4.9$ $P = 0.0007$	$F_{7,414} = 24.7$ $P < 0.0001$	$F_{8,414} = 2.4$ $P = 0.0153$

Table 3.1.2 Likelihood ratio statistics and associated probabilities for month, mudflat and year in a generalized linear model describing densities of feeding Shelduck at low tide on eight mudflats at Peterstone and St. Brides from 1992/93 to 2000/01.

	Month	State of Tide	Mudflat	State of Tide * Mudflat	Year
Cardiff Bay	$F_{8,32263} = 112.1$ $P < 0.0001$	$F_{11,32263} = 65.2$ $P < 0.0001$	$F_{18,32263} = 35.4$ $P < 0.0001$	-	$F_{10,32263} = 51.1$ $P < 0.0001$
Orchard Ledges	$F_{6,1778} = 25.7$ $P < 0.0001$	$F_{6,1778} = 10.1$ $P < 0.0001$	$F_{1,1778} = 171.2$ $P < 0.0001$	ns	$F_{11,1778} = 16.3$ $P < 0.0001$
Rhymney	$F_{8,22616} = 353.3$ $P < 0.0001$	$F_{11,22616} = 34.5$ $P < 0.0001$	$F_{16,22616} = 165.3$ $P < 0.0001$	-	$F_{12,22616} = 92.8$ $P < 0.0001$

Table 3.2.1 Likelihood ratio statistics and associated probabilities for month, state of tide, mudflat, state of tide*mudflat and year in generalized linear models describing densities of feeding Dunlin at Cardiff Bay from 1989/90 to 1998/99 and Orchard Ledges and Rhymney from 1989/90 to 2000/01. All models excluded data from August and that for Orchard Ledges data from September and October too, as too few birds were present on the study sites at these times for their inclusion to be biologically meaningful.

Month	Mudflat	Year
$F_{4,414} = 17.0$ $P < 0.0001$	$F_{7,414} = 18.2$ $P < 0.0001$	$F_{8,414} = 20.5$ $P < 0.0001$

Table 3.2.2 Likelihood ratio statistics and associated probabilities for month, mudflat and year in a generalized linear model describing densities of feeding Dunlin at low tide on eight mudflats at Peterstone and St. Brides from 1992/93 to 2000/01.

	Month	State of Tide	Mudflat	State of Tide * Mudflat	Year
Cardiff Bay	$F_{9,35750} = 285.8$ $P < 0.0001$	$F_{11,35750} = 7.5$ $P < 0.0001$	$F_{18,35750} = 143.0$ $P < 0.0001$	$F_{170,35750} = 4.5$ $P < 0.0001$	$F_{10,35750} = 31.3$ $P < 0.0001$
Orchard Ledges	$F_{9,2790} = 120.8$ $P < 0.0001$	$F_{6,2790} = 48.8$ $P < 0.0001$	$F_{1,2790} = 105.8$ $P < 0.0001$	ns	$F_{12,2790} = 5.8$ $P < 0.0001$
Rhymney	$F_{9,29310} = 103.2$ $P < 0.0001$	$F_{11,29310} = 2.3$ $P = 0.0091$	$F_{16,29310} = 29.6$ $P < 0.0001$	$F_{117,29310} = 5.0$ $P < 0.0001$	$F_{12,29310} = 36.3$ $P < 0.0001$

Table 3.3.1 Likelihood ratio statistics and associated probabilities for month, state of tide, mudflat, state of tide*mudflat and year in generalized linear models describing densities of feeding Curlew at Cardiff Bay from 1989/90 to 1998/99 and Orchard Ledges and Rhymney from 1989/90 to 2000/01.

Month	Mudflat	Year
$F_{4,414} = 4.0$ $P = 0.0035$	$F_{7,414} = 38.5$ $P < 0.0001$	$F_{8,414} = 8.7$ $P < 0.0001$

Table 3.3.2 Likelihood ratio statistics and associated probabilities for month, mudflat and year in a generalized linear model describing densities of feeding Curlew at low tide on eight mudflats at Peterstone and St. Brides from 1992/93 to 2000/01.

	Month	State of Tide	Mudflat	State of Tide * Mudflat	Year
Cardiff Bay	$F_{8,33330} = 56.4$ $P < 0.0001$	$F_{11,33330} = 2.8$ $P < 0.01$	$F_{18,33330} = 44.4$ $P < 0.0001$	$F_{179,33330} = 4.6$ $P < 0.0001$	$F_{10,33330} = 10.6$ $P < 0.0001$
Rhymney	$F_{8,22234} = 94.5$ $P < 0.0001$	$F_{11,22234} = 5.6$ $P < 0.0001$	$F_{16,22234} = 110.1$ $P < 0.0001$	ns	$F_{12,22234} = 22.6$ $P < 0.0001$

Table 3.4.1 Likelihood ratio statistics and associated probabilities for month, state of tide, mudflat, state of tide*mudflat and year in generalized linear models describing densities of feeding Redshank at Cardiff Bay from 1989/90 to 1998/99 and Rhymney from 1989/90 to 2000/01. Both models excluded data from May, as too few birds were present on the study sites at this time for their inclusion to be biologically meaningful.

Month	Mudflat	Year
ns	$F_{6,362} = 6.2$ $P < 0.0001$	$F_{8,362} = 1.5$ $P = 0.1626$

Table 3.4.2 Likelihood ratio statistics and associated probabilities for mudflat and year in a generalized linear model describing densities of feeding Redshank at low tide on eight mudflats at Peterstone and St. Brides from 1992/93 to 2000/01.

	Month	State of Tide	Mudflat	State of Tide * Mudflat	Year
Cardiff Bay	$F_{9,33073} = 36.1$ $P < 0.0001$	$F_{11,33073} = 7.5$ $P < 0.0001$	$F_{18,33073} = 44.7$ $P < 0.0001$	$F_{155,33073} = 5.0$ $P < 0.0001$	$F_{10,33073} = 62.2$ $P < 0.0001$
Orchard Ledges	$F_{9,2784} = 100.0$ $P < 0.0001$	$F_{6,2784} = 38.5$ $P < 0.0001$	$F_{1,2784} = 91.3$ $P < 0.0001$	$F_{6,2784} = 17.1$ $P < 0.0001$	$F_{12,2784} = 34.3$ $P < 0.0001$
Rhymney	$F_{9,29502} = 75.0$ $P < 0.0001$	$F_{11,29502} = 18.9$ $P < 0.0001$	$F_{16,29502} = 67.0$ $P < 0.0001$	$F_{118,29502} = 13.3$ $P < 0.0001$	$F_{12,29502} = 38.8$ $P < 0.0001$

Table 3.5.5.1 Likelihood ratio statistics and associated probabilities for month, state of tide, mudflat, state of tide*mudflat and year in generalized linear models describing densities of feeding Oystercatcher at Cardiff Bay from 1989/90 to 1998/99 and Orchard Ledges and Rhymney from 1989/90 to 2000/01.

Month	Mudflat	Year
ns	$F_{7,418} = 32.5$ $P < 0.0001$	$F_{8,418} = 2.6$ $P = 0.0079$

Table 3.5.5.2 Likelihood ratio statistics and associated probabilities for month, mudflat and year in a generalized linear model describing densities of feeding Oystercatcher at low tide on eight mudflats at Peterstone and St. Brides from 1992/93 to 2000/01.

	Cardiff Bay	Orchard Ledges	Rhymney
Mute Swan *Cygnus olor*	▒	▒	
Canada Goose *Branta canadensis*	▒		
Shoveler *Anas clypeata*			▒
Tufted Duck *Aythya fuligula*	▒		▒
Scaup *Aythya marila*			▒
Goosander *Mergus merganser*	▒		
Black-tailed Godwit *Limosa limosa*			▒
Whimbrel *Numenius phaeopus*	▒	▒	
Spotted Redshank *Tringa erythropus*			▒
Common Sandpiper *Actitis hypoleucos*	▒	▒	

Table 3.6.1 Species of wildfowl and wader seen only occasionally on the three all-day sites during 2000/01 and not included in the separate species accounts.

	Test 2	Test 3
A	$\chi^2_8 = 35.4$, $P < 0.0001$	$\chi^2_{14} = 15.8$, ns
B	$\chi^2_6 = 12.5$, ns	$\chi^2_{10} = 14.8$, ns

Table 6.2.3.1 Results of goodness-of-fit tests carried out on the Redshank mark-recapture data.
A – using data from February 1996 to February 2001.
B – using data from February 1997 to February 2001.
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	Parameters	$QAIC_c$	$QAIC_c$ weight	Model deviance
$\phi\, p$	2	769.3	0.029	152.6
$\boldsymbol{\phi_t\, p}$	**9**	**763.3**	**0.598**	**132.4**
$\phi\, p_t$	9	768.5	0.045	137.6
$\phi_t\, p_t$	15	764.5	0.328	121.2

Table 7.3.1 Evaluation of mark-resighting models of survival rates (ϕ) and resighting probabilities (p) for adult Redshank at Cardiff, using data from February 1997 to February 2001. ϕ_t indicates a model in which survival varies with time, p_t one in which resighting varies with time. $QAIC_c$ weight indicates the weight of evidence in favour of a given model (see Burnham & Anderson 1998). Weights for all models sum to 1 and thus provide relative weights for each considered. Bold type indicates the most parsimonious model (i.e. that with the lowest $QAIC_c$ value), which was used in further tests.

		Number of Marked Birds Seen	ϕ_t
1997	Over-summer return rate	43	0.886 (0.059)
1997/98	Over-winter survival rate	61	1.000 (0.000)
1998	Over-summer return rate	73	0.819 (0.053)
1998/99	Over-winter survival rate	78	1.000 (0.000)
1999	Over-summer return rate	123	0.860 (0.039)
1999/2000	Over-winter survival rate	194	0.907 (0.028)
2000	Over-summer return rate	167	0.852 (0.035)

Table 7.3.2. Estimates for return and survival rates (ϕ_t) for adult Redshank wintering at Cardiff. Estimates are given with standard errors in parentheses. The table also shows the number of marked birds present at the start of each period.

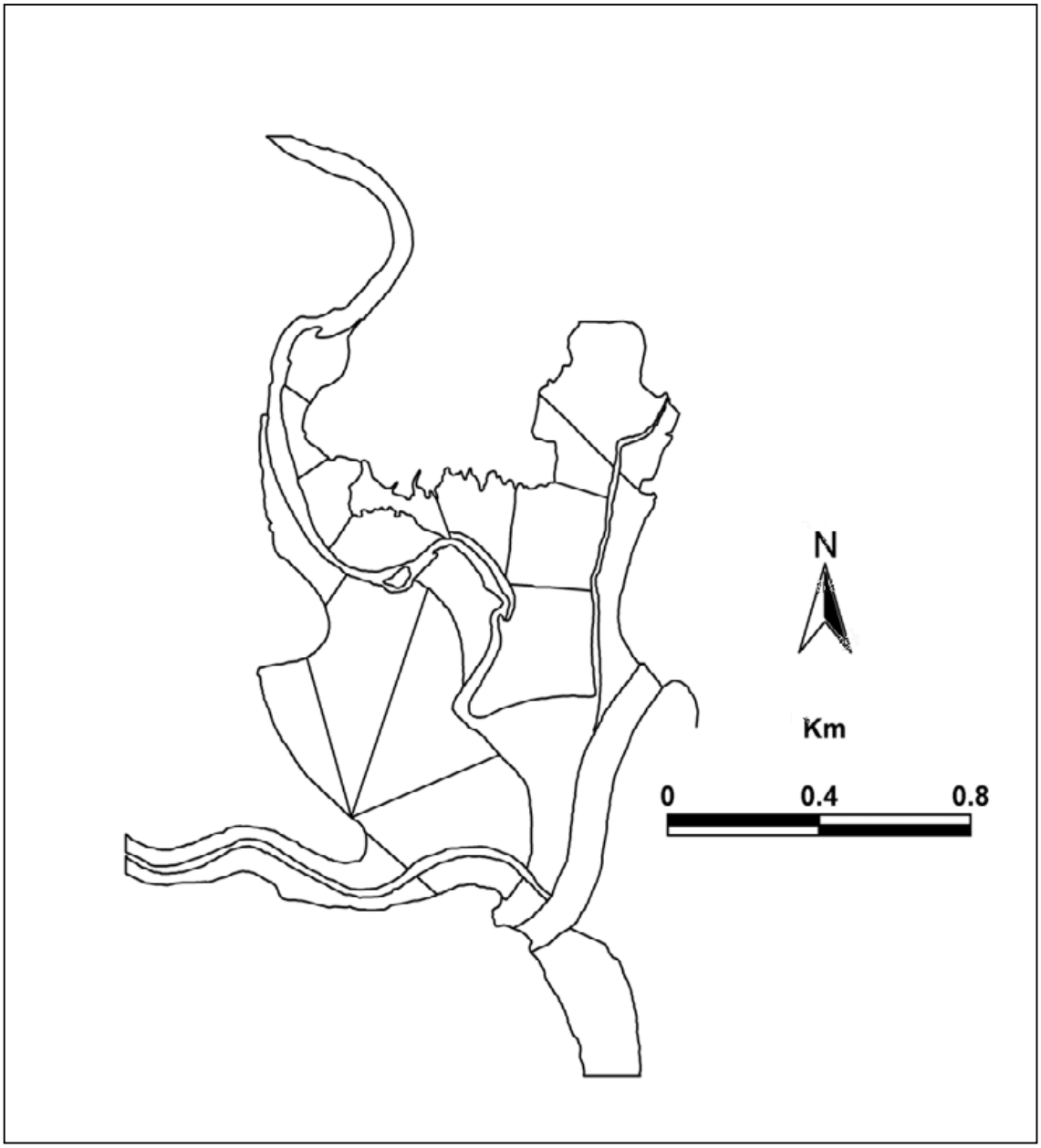


Figure 2.1.1 The Cardiff Bay study site showing mudflat areas counted in autumn 1999, prior to barrage-closure.

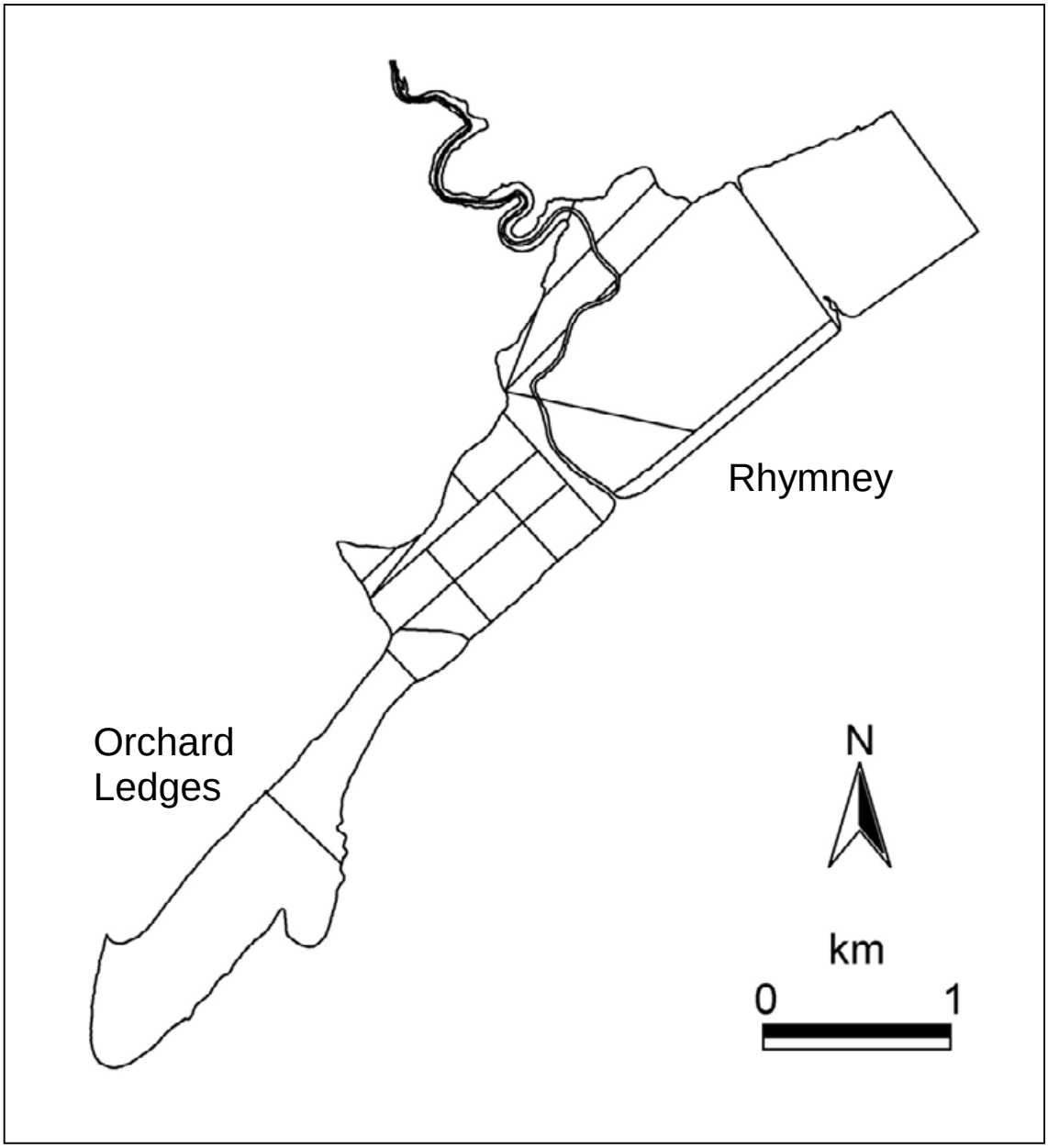


Figure 2.1.2 The Rhymney and Orchard Ledges study sites showing mudflat count areas.

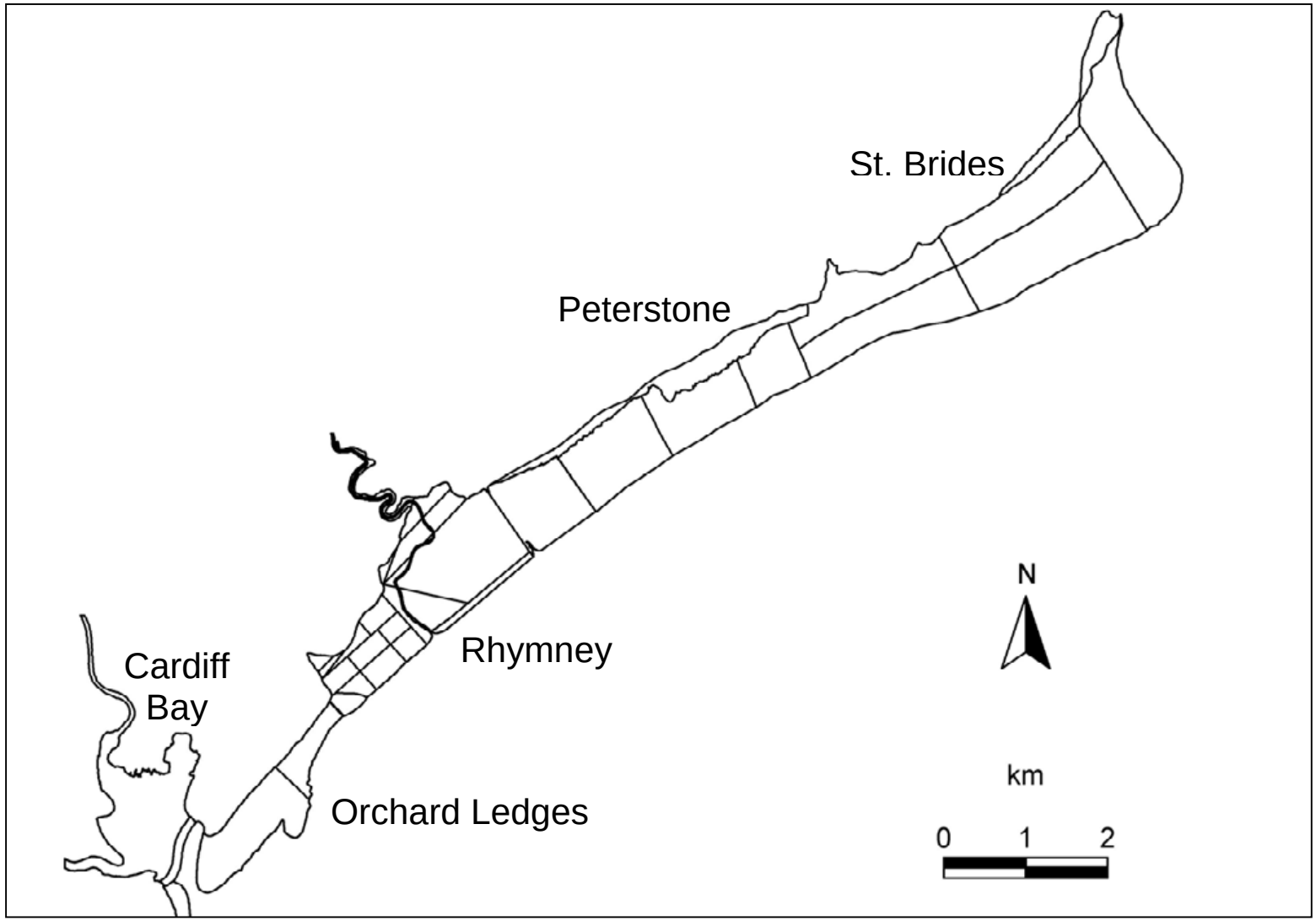


Figure 2.2.1 The low tide count areas on the northwest Severn.

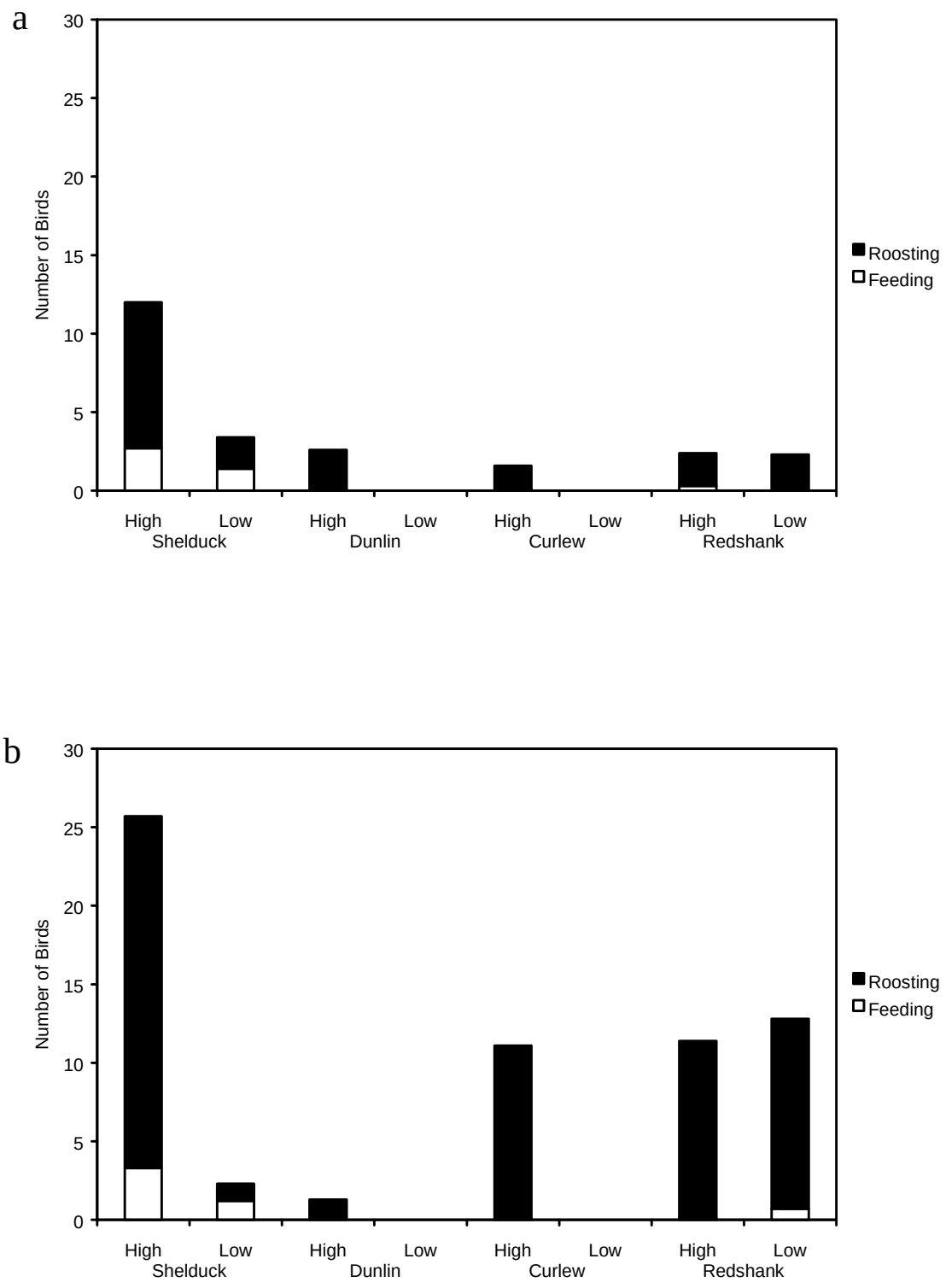
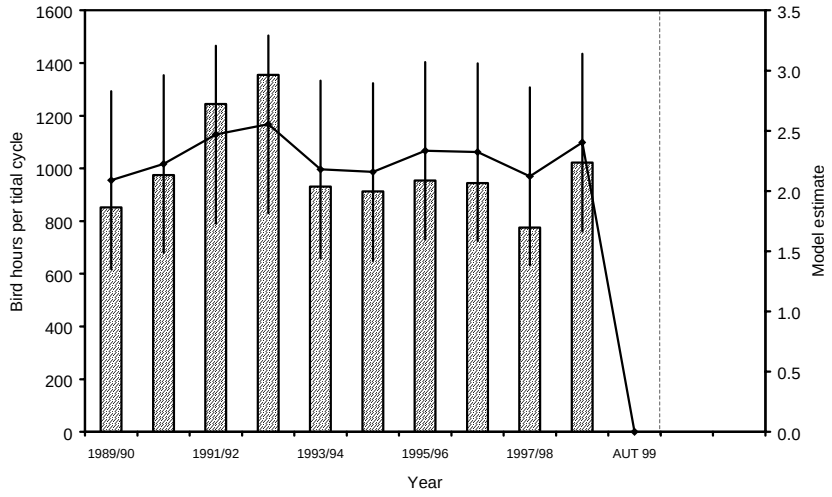
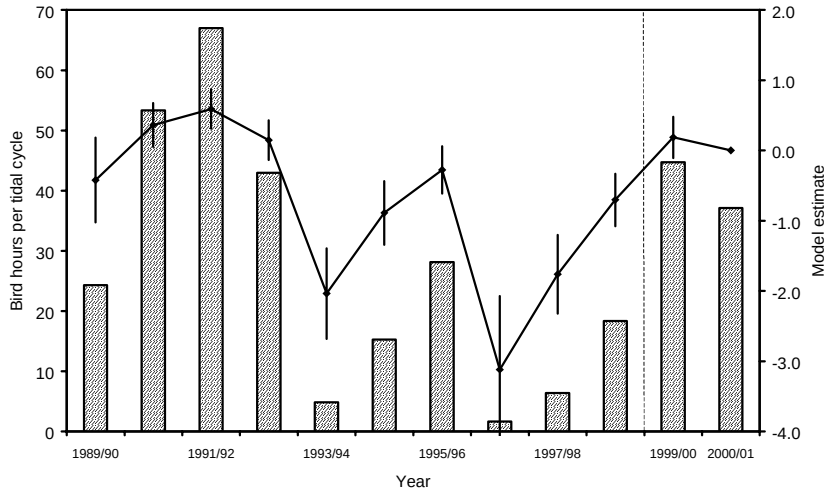


Figure 3.1 Mean numbers of Shelduck, Dunlin, Curlew and Redshank recorded roosting (black sections of columns) and feeding (white sections) in Cardiff Bay at high tide and low tide in the winters of **a.** 1999/2000 and **b.** 2000/2001, following barrage-closure.

a



b



c

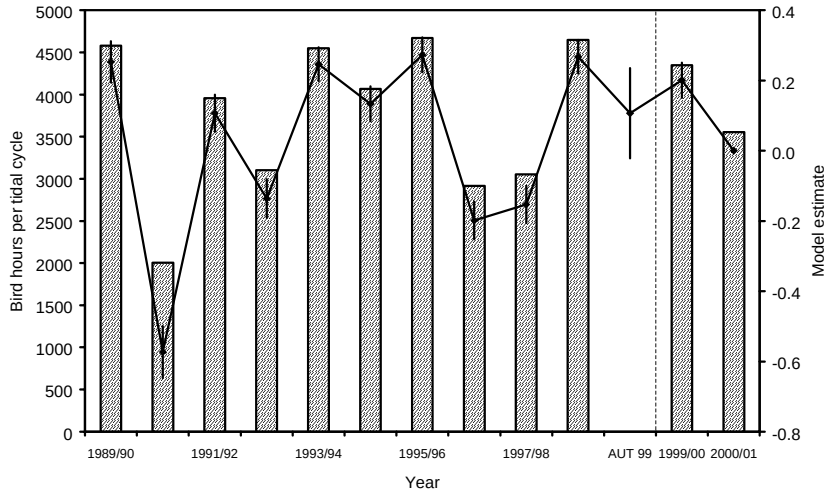


Figure 3.1.1 Estimates for 'year' (shown by lines with ± 1 SE) and the mean number of bird hours per tidal cycle (shown as bars) derived from models relating the number of feeding Shelduck at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; for Rhymney, points immediately before and after are estimates for autumn 1999 and for the winter of 1999/2000 together with spring 2000 respectively.

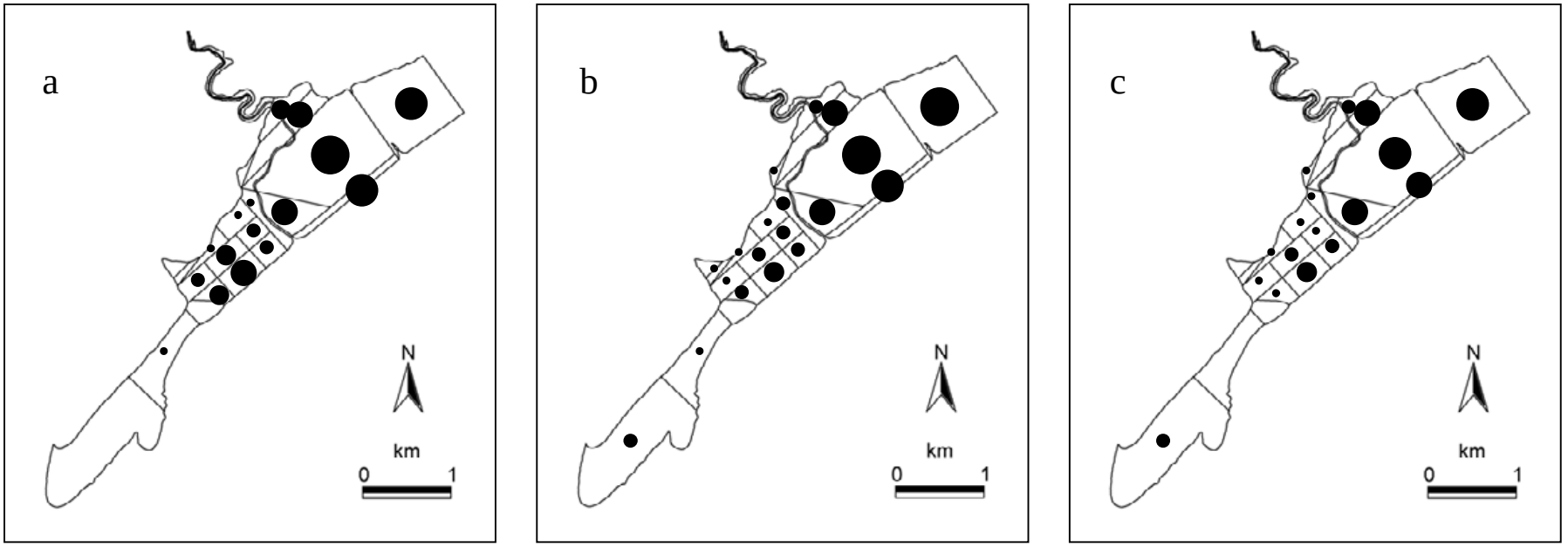
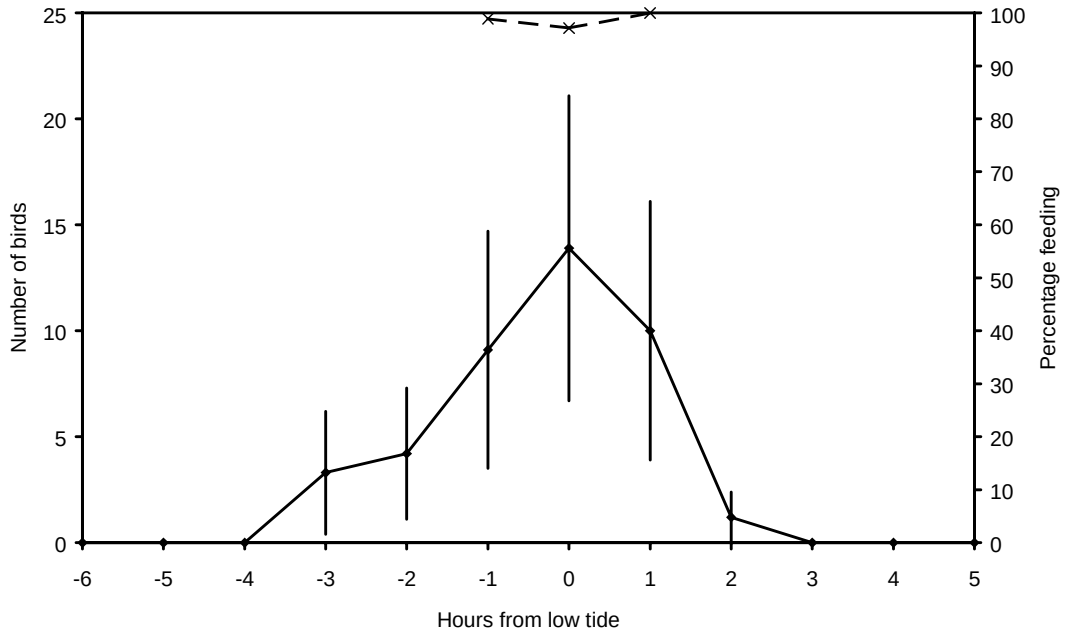


Figure 3.1.2 The distribution of feeding Shelduck on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01.

1-24 • 25-99 ● 100-249 ● 250-499 ● 500-999 ● >1000 ●

a



b

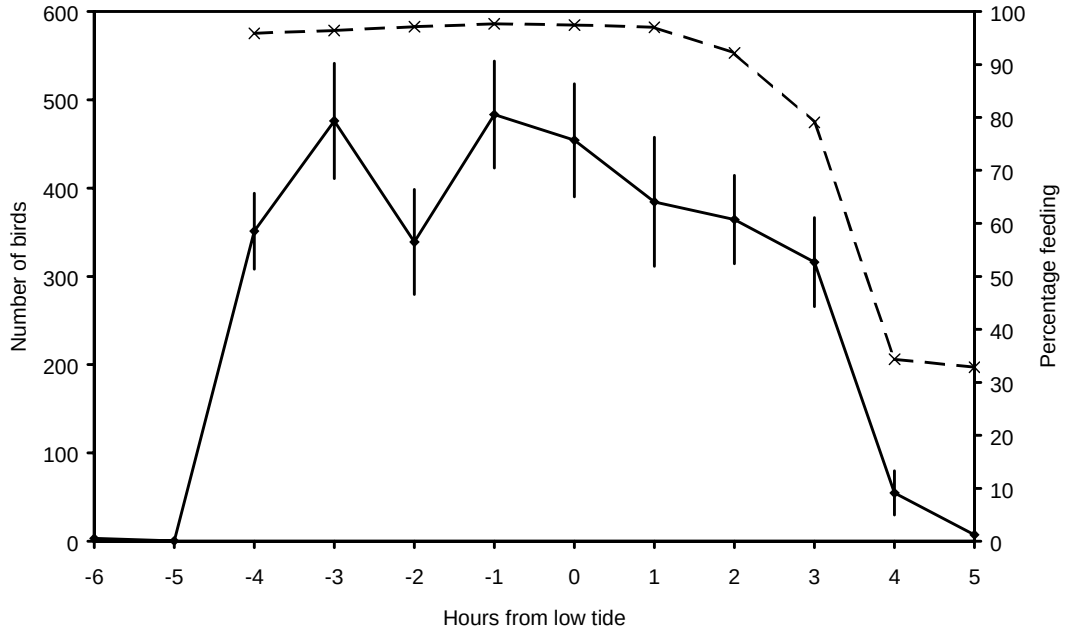


Figure 3.1.3 The total number of Shelduck present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at **a.** Orchard Ledges and **b.** Rhymney during the winter of 2000/2001.

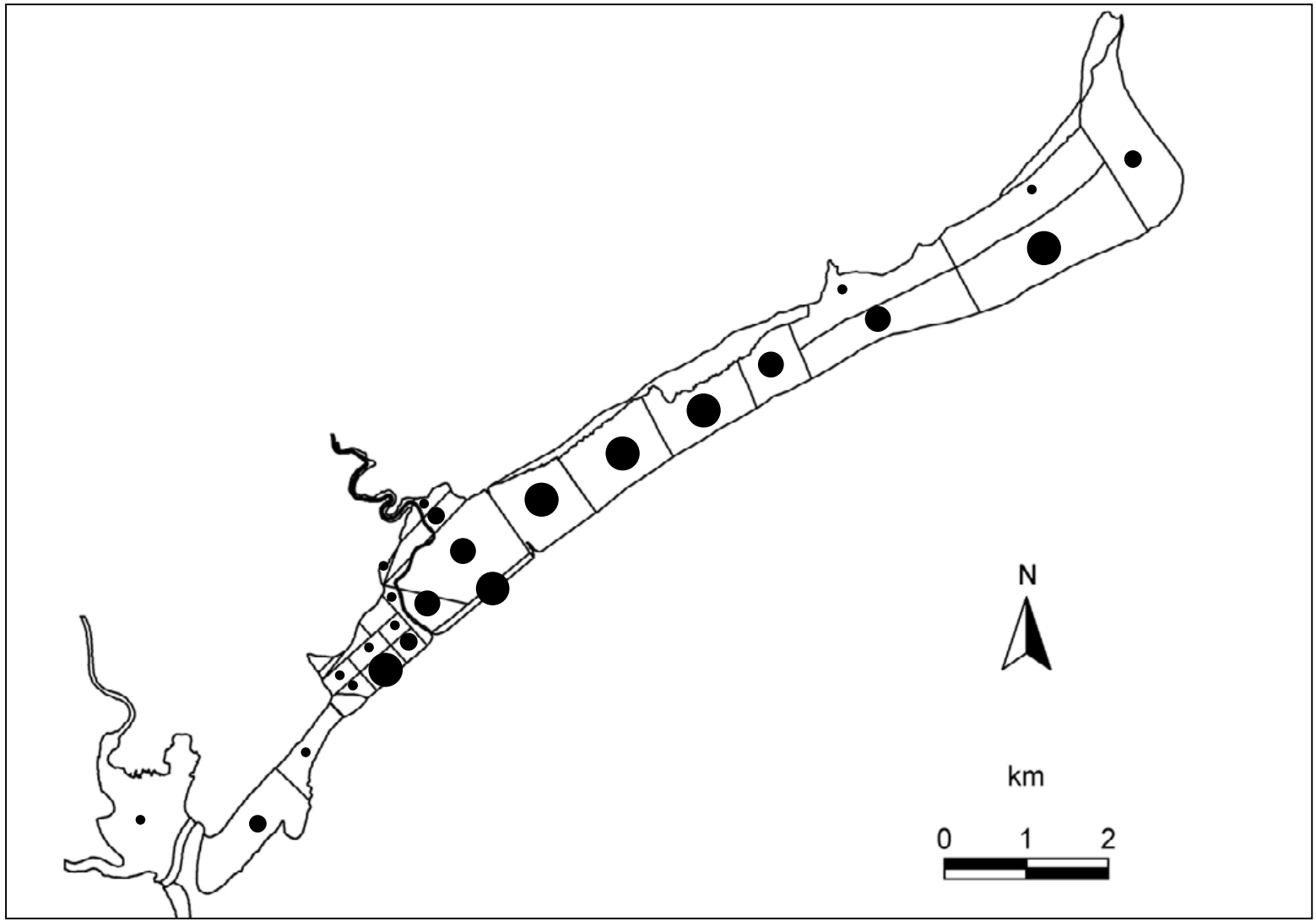


Figure 3.1.4 The low tide distribution of feeding Shelduck on the northwest Severn during the winter of 2000/2001.

1-9 10-24 25-49 50-99 100-199 >200

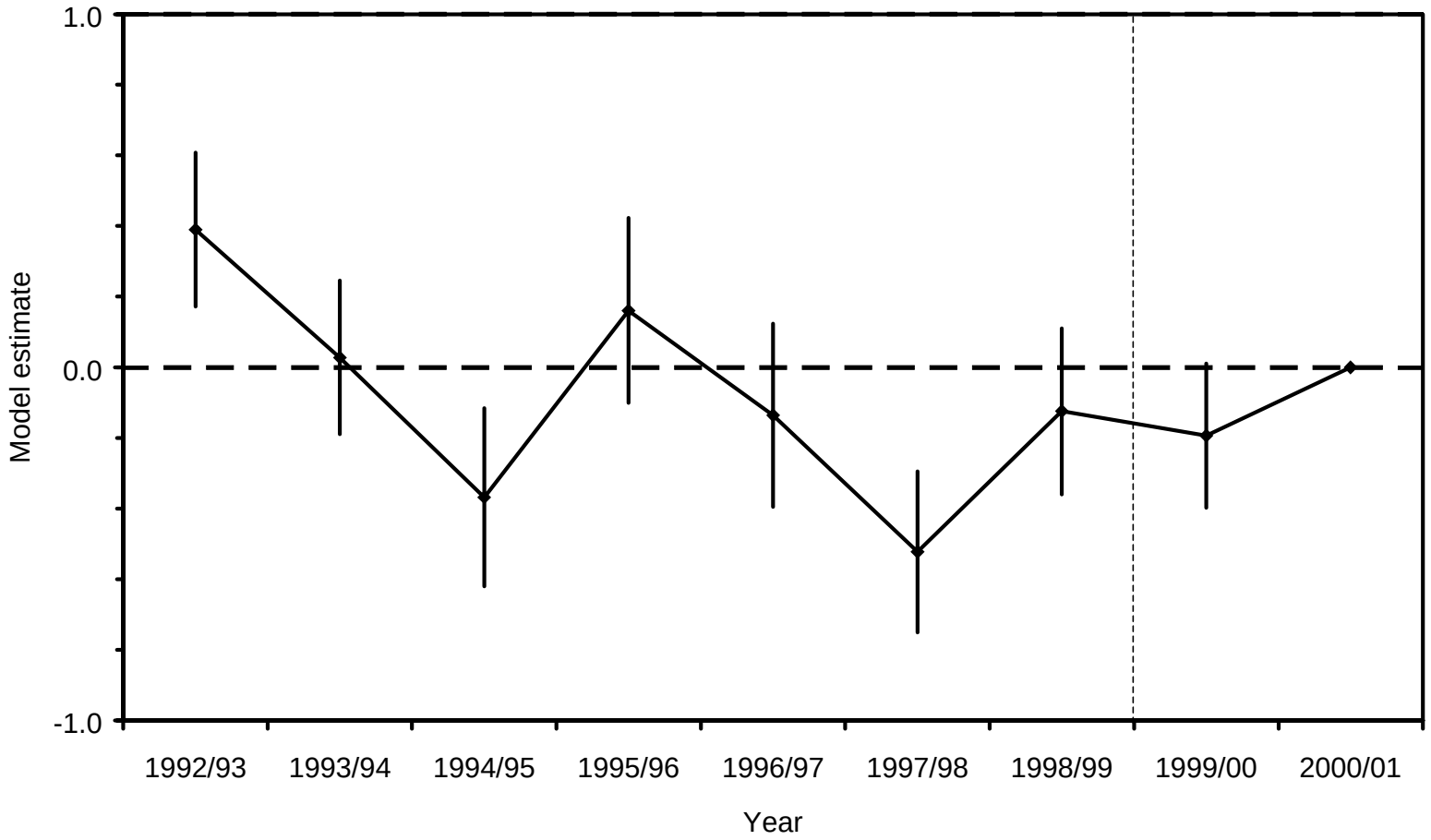
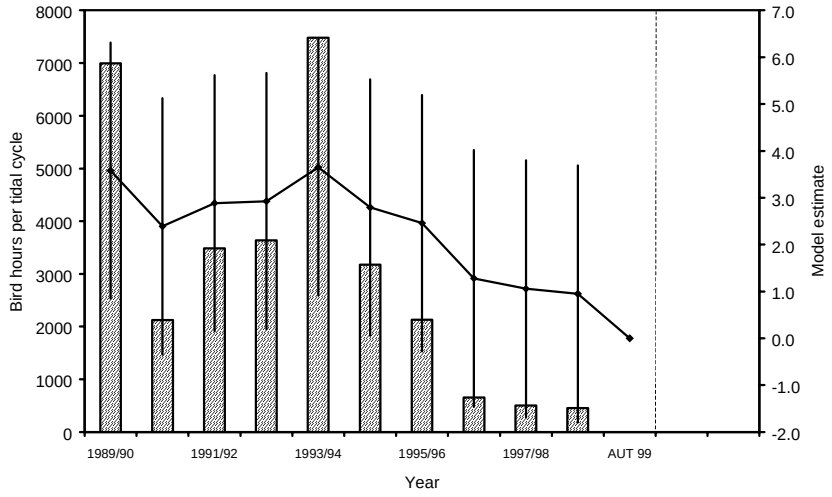
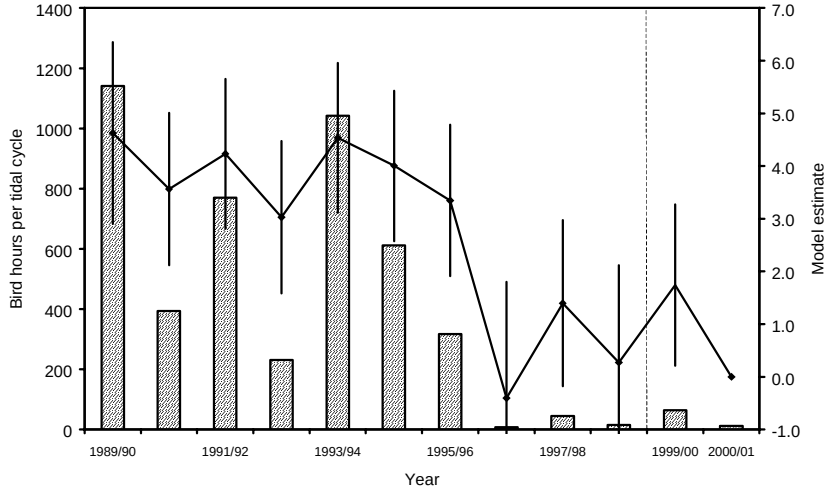


Figure 3.1.5 Estimates for 'year' (± 1 SE) in a model relating the densities of feeding Shelduck at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b



c

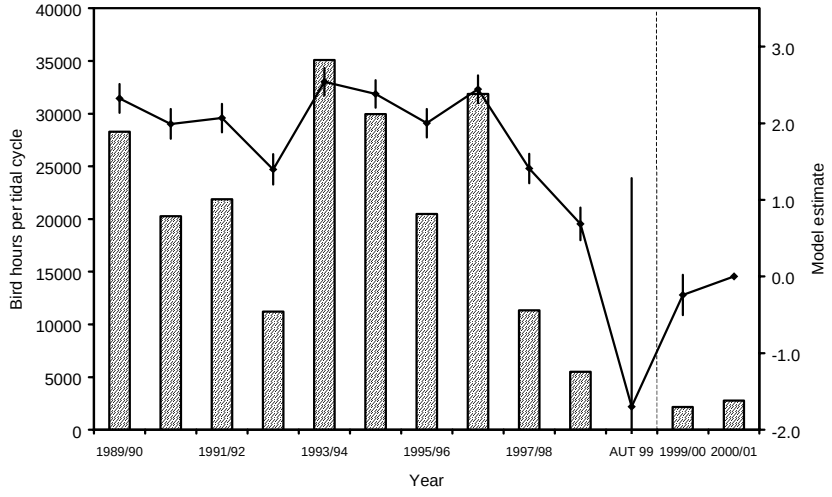


Figure 3.2.1 Estimates for 'year' (shown by lines with ± 1 SE) and the mean number of bird hours per tidal cycle (shown as bars) derived from models relating the number of feeding Dunlin at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; for Rhymney, points immediately before and after are estimates for autumn 1999 and for the winter of 1999/2000 together with spring 2000 respectively.

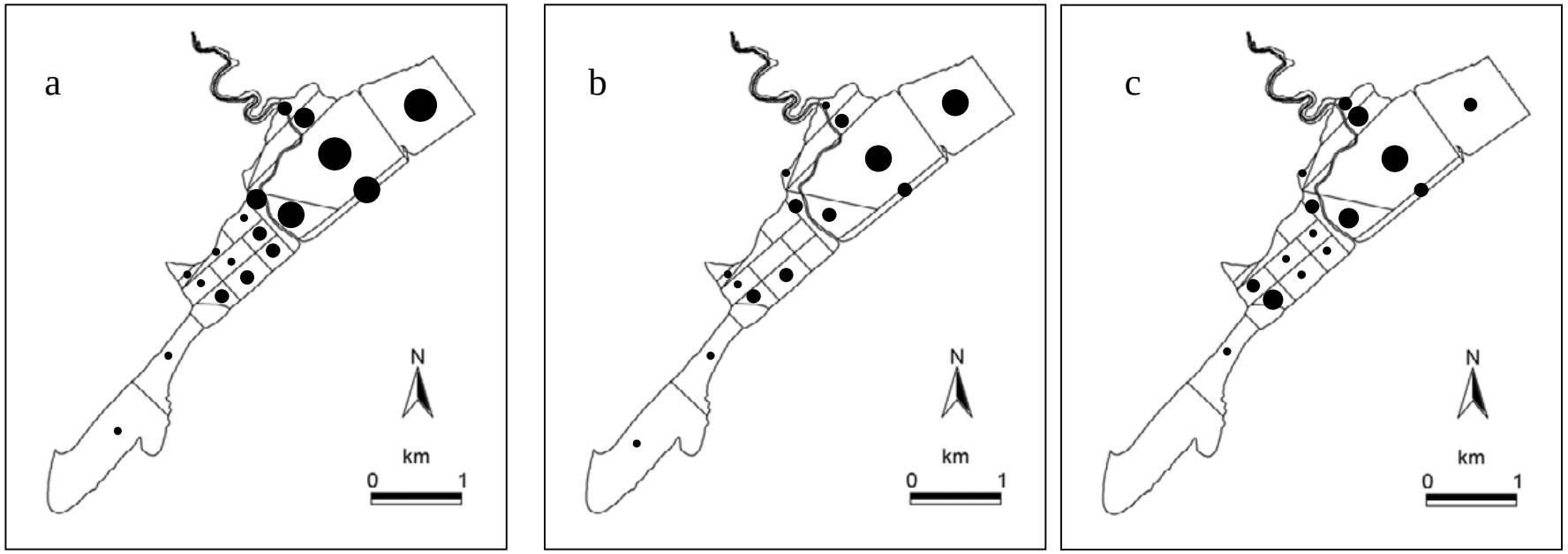
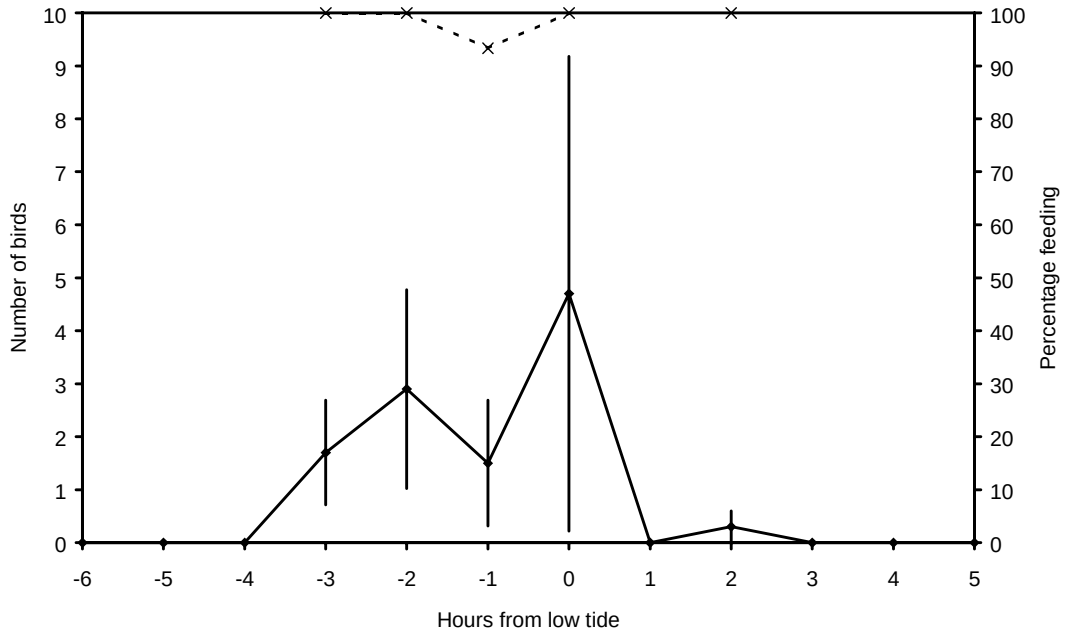


Figure 3.2.2 The distribution of feeding Dunlin on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01.

1-24 • 25-99 ● 100-249 ● 250-499 ● 500-999 ● >1000 ●

a



b

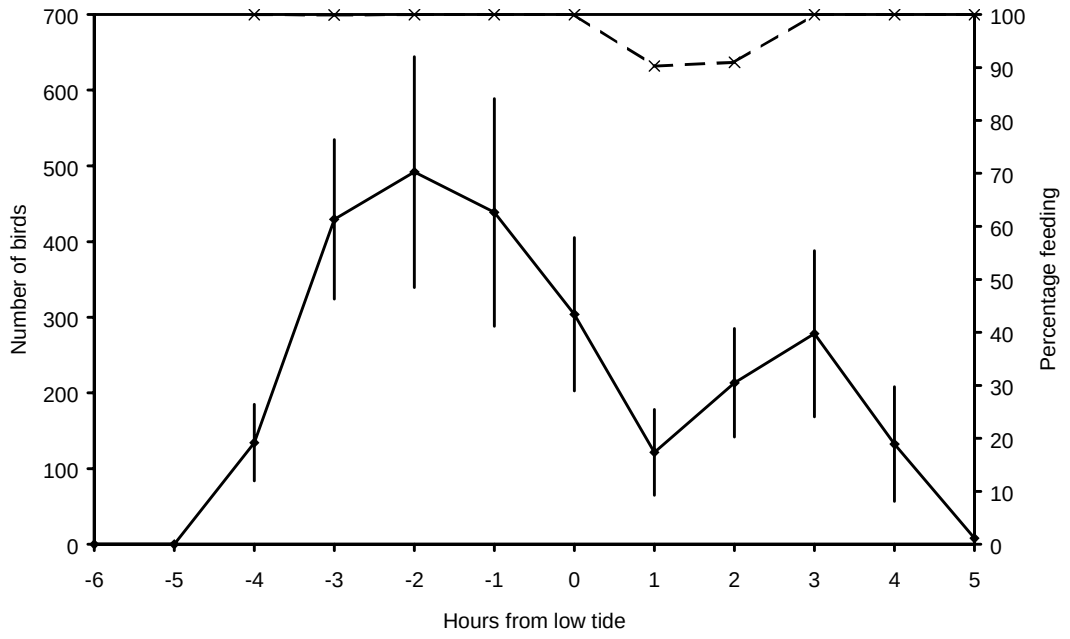


Figure 3.2.3 The total number of Dunlin present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at **a.** Orchard Ledges and **b.** Rhymney during the winter of 2000/2001.

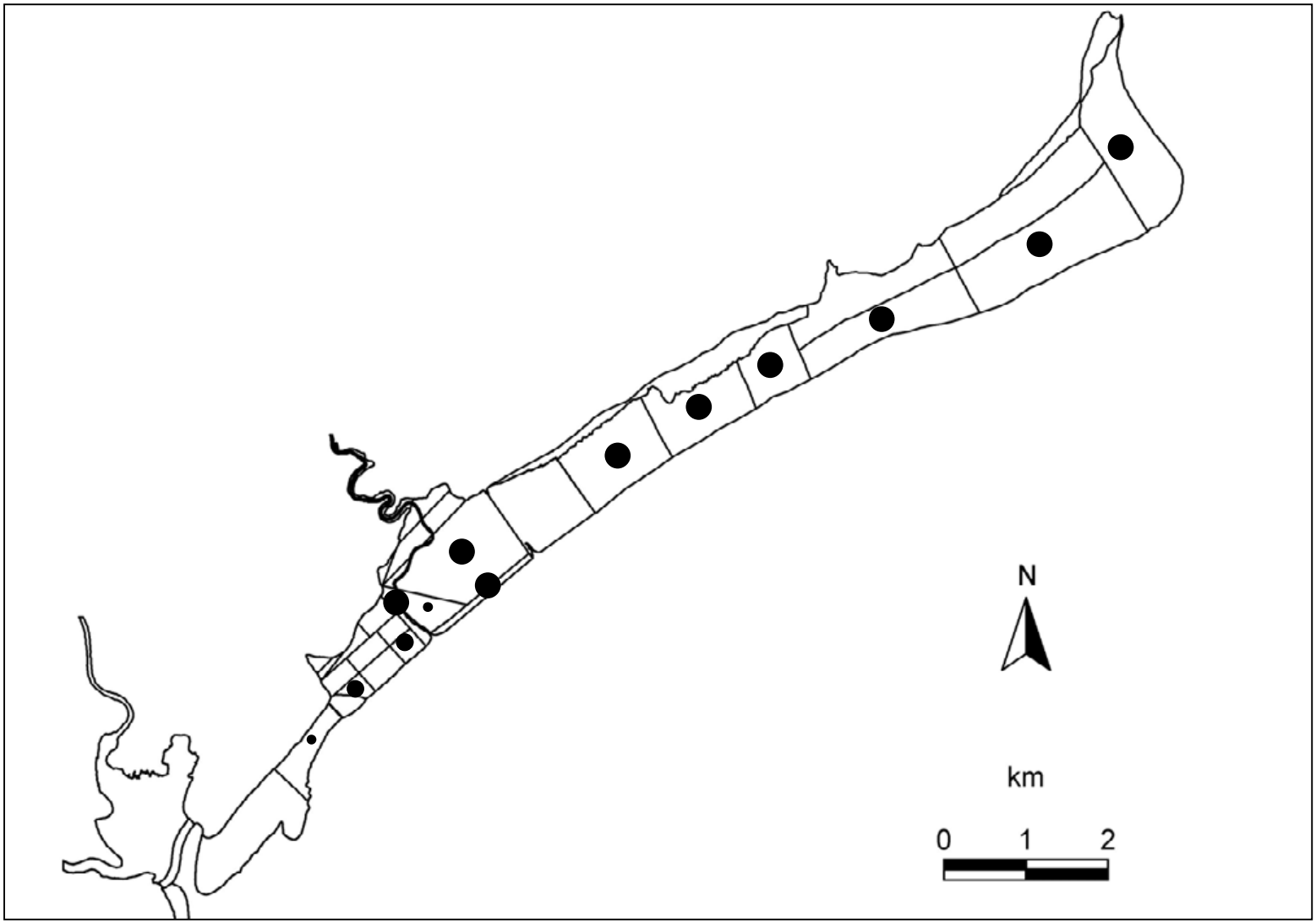


Figure 3.2.4 The low tide distribution of feeding Dunlin on the northwest Severn during the winter of 2000/2001.

1-9 10-49 50-249 250-749

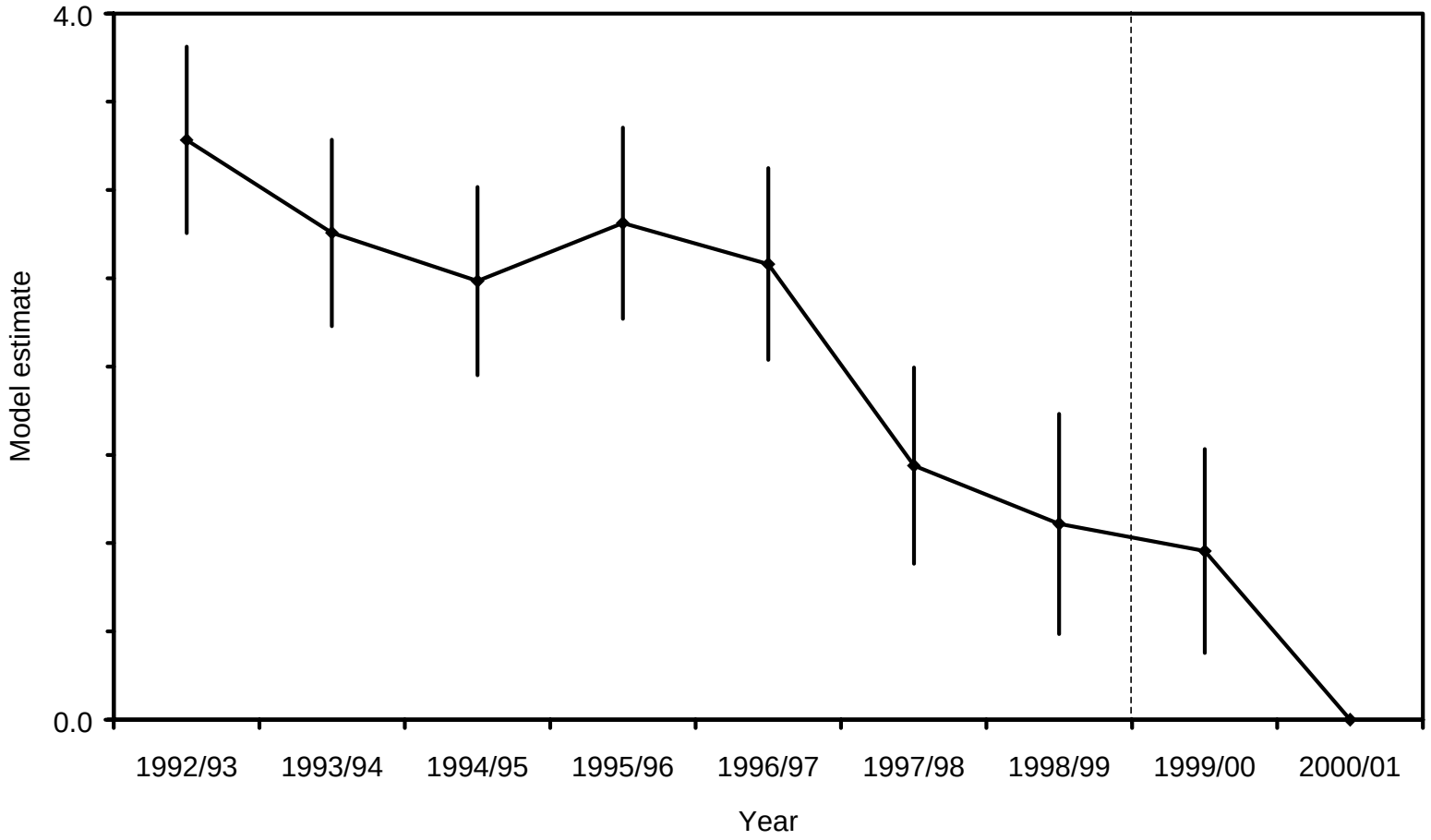
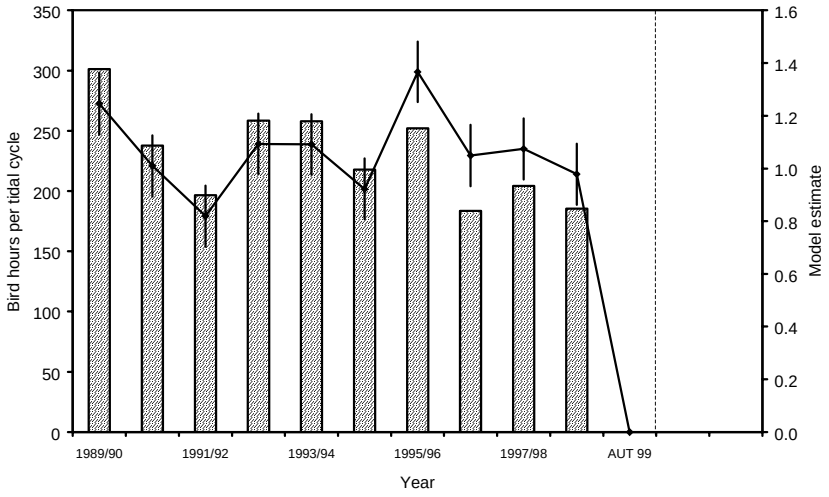
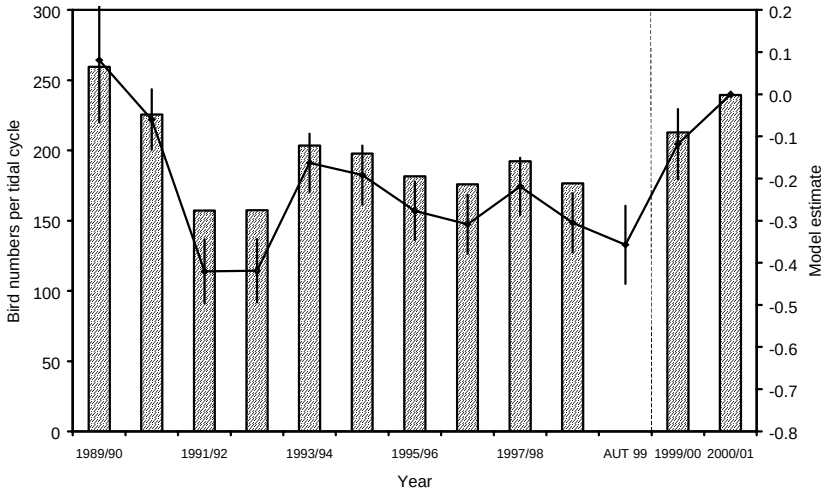


Figure 3.2.5 Estimates for 'year' (± 1 SE) in a model relating the densities of feeding Dunlin at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b



c

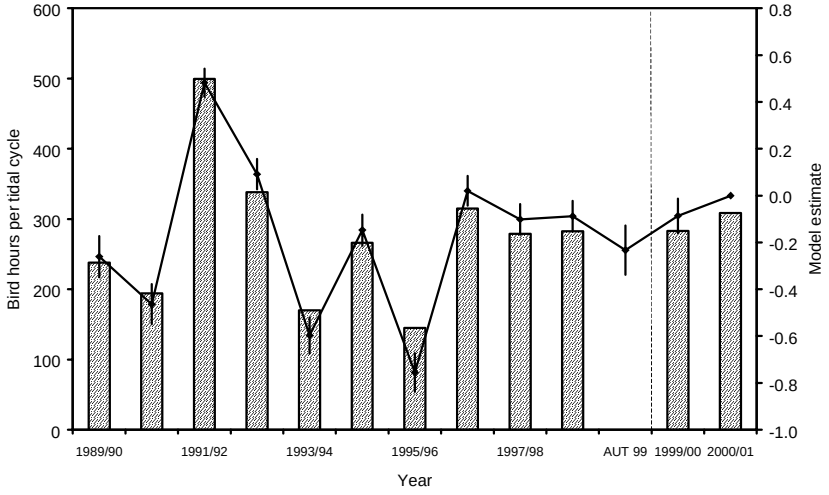


Figure 3.3.1 Estimates for 'year' (shown by lines with ± 1 SE) and the mean number of bird hours per tidal cycle (shown as bars) derived from models relating the number of feeding Curlew at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; points immediately before and after are estimates for autumn 1999 and for the winter of 1999/2000 together with spring 2000 respectively.

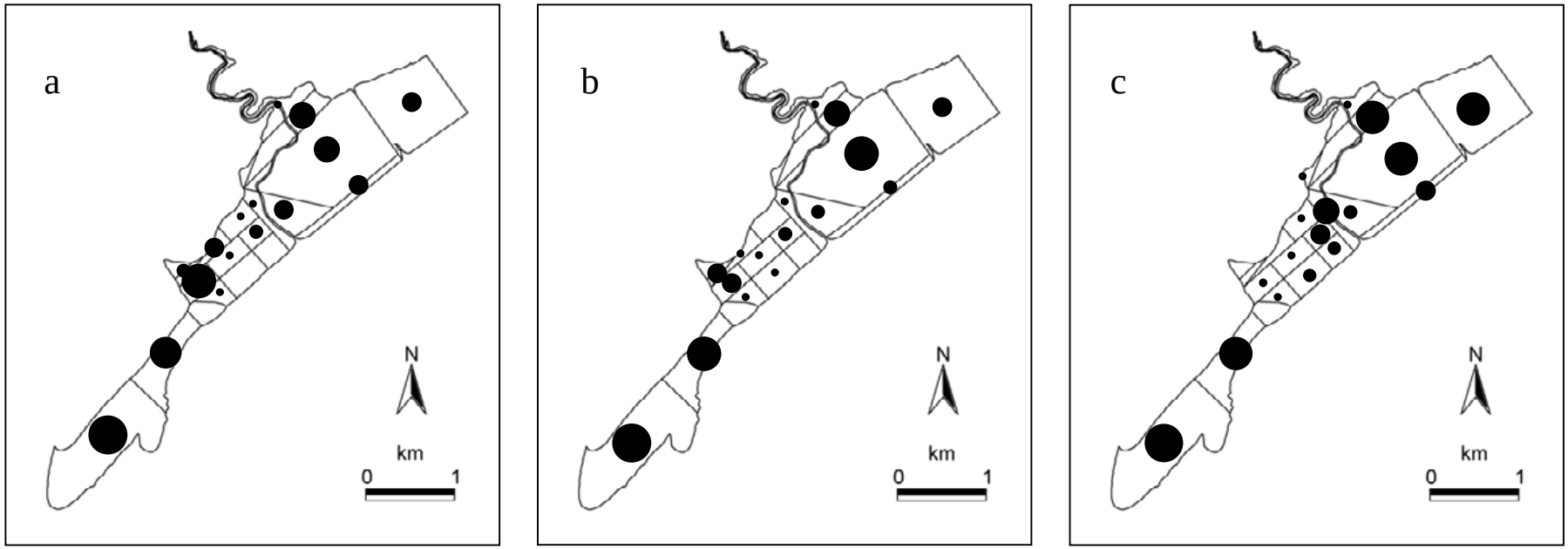
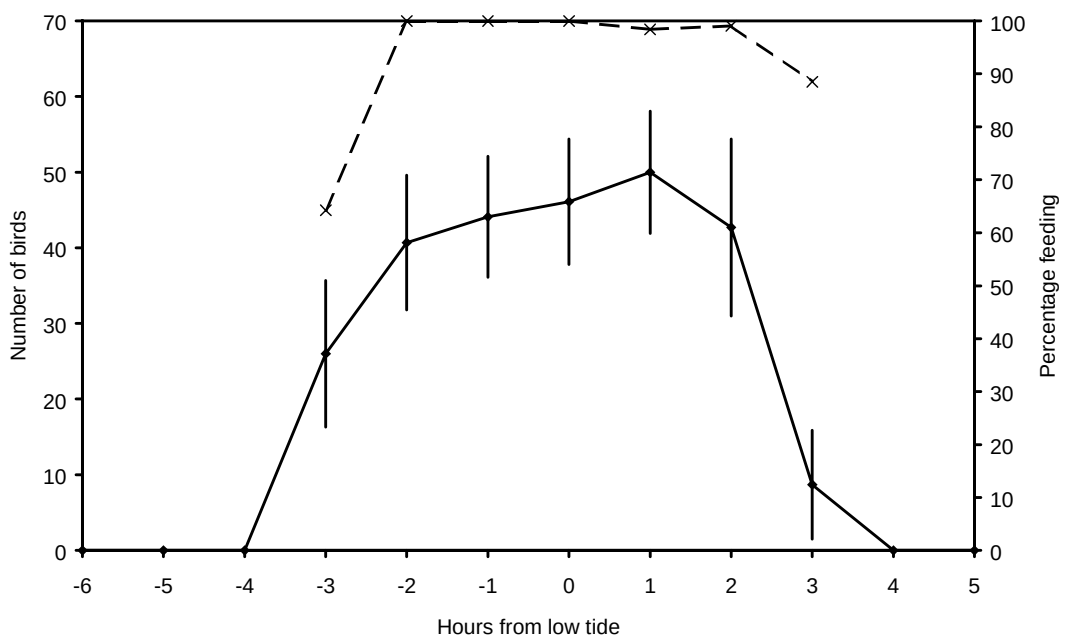


Figure 3.3.2 The distribution of feeding Curlew on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01.

1-4 • 5-9 • 10-24 ● 25-49 ● 50-99 ● >100 ●

a



b

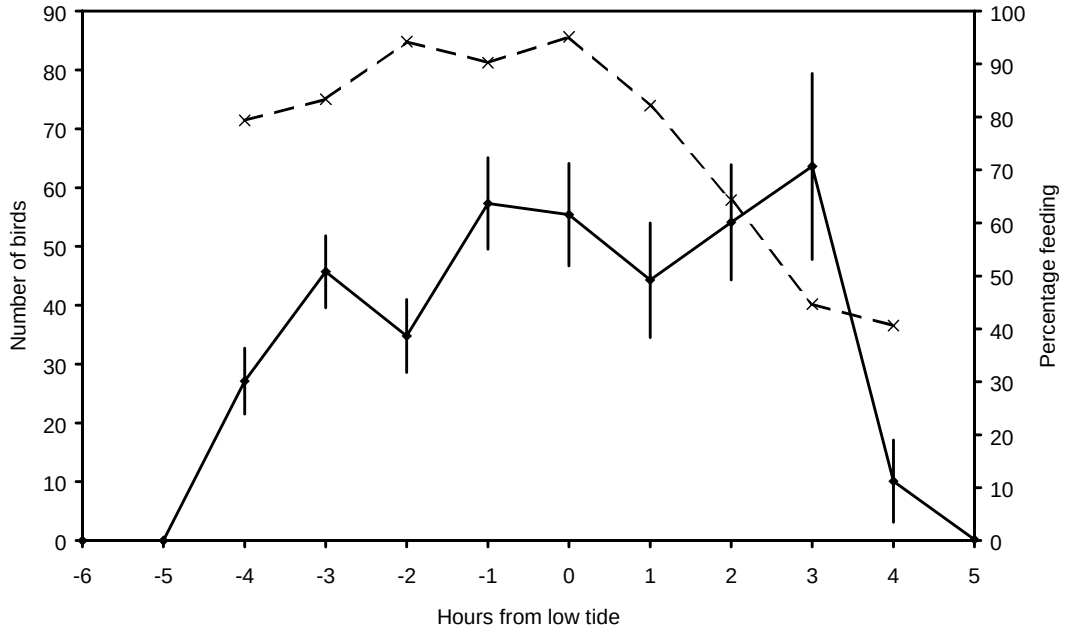


Figure 3.3.3 The total number of Curlew present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at **a.** Orchard Ledges and **b.** Rhymney during the winter of 2000/2001.

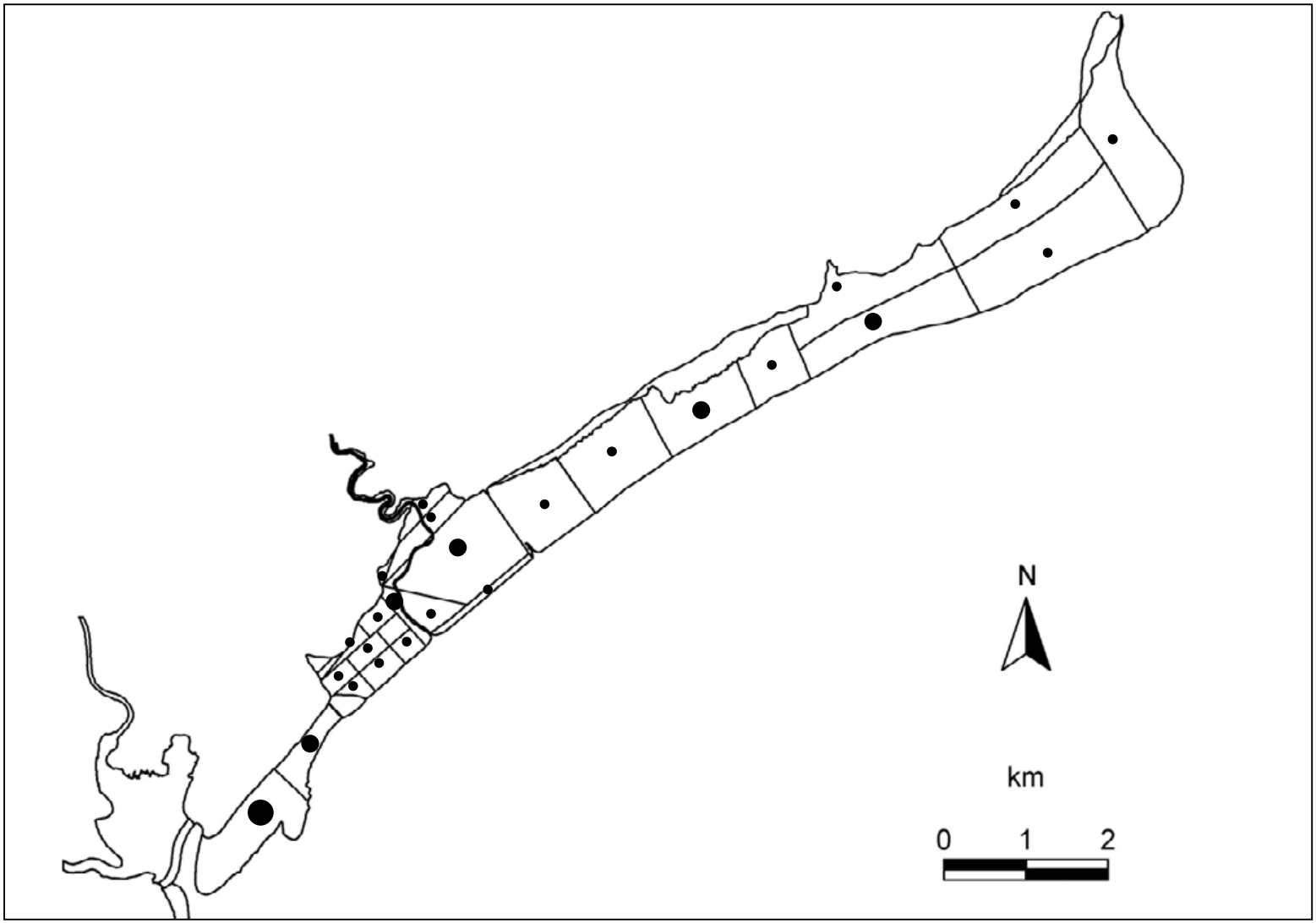


Figure 3.3.4 The low tide distribution of feeding Curlew on the northwest Severn during the winter of 2000/2001.

1-9 • 10-24 ● 25-49 ●

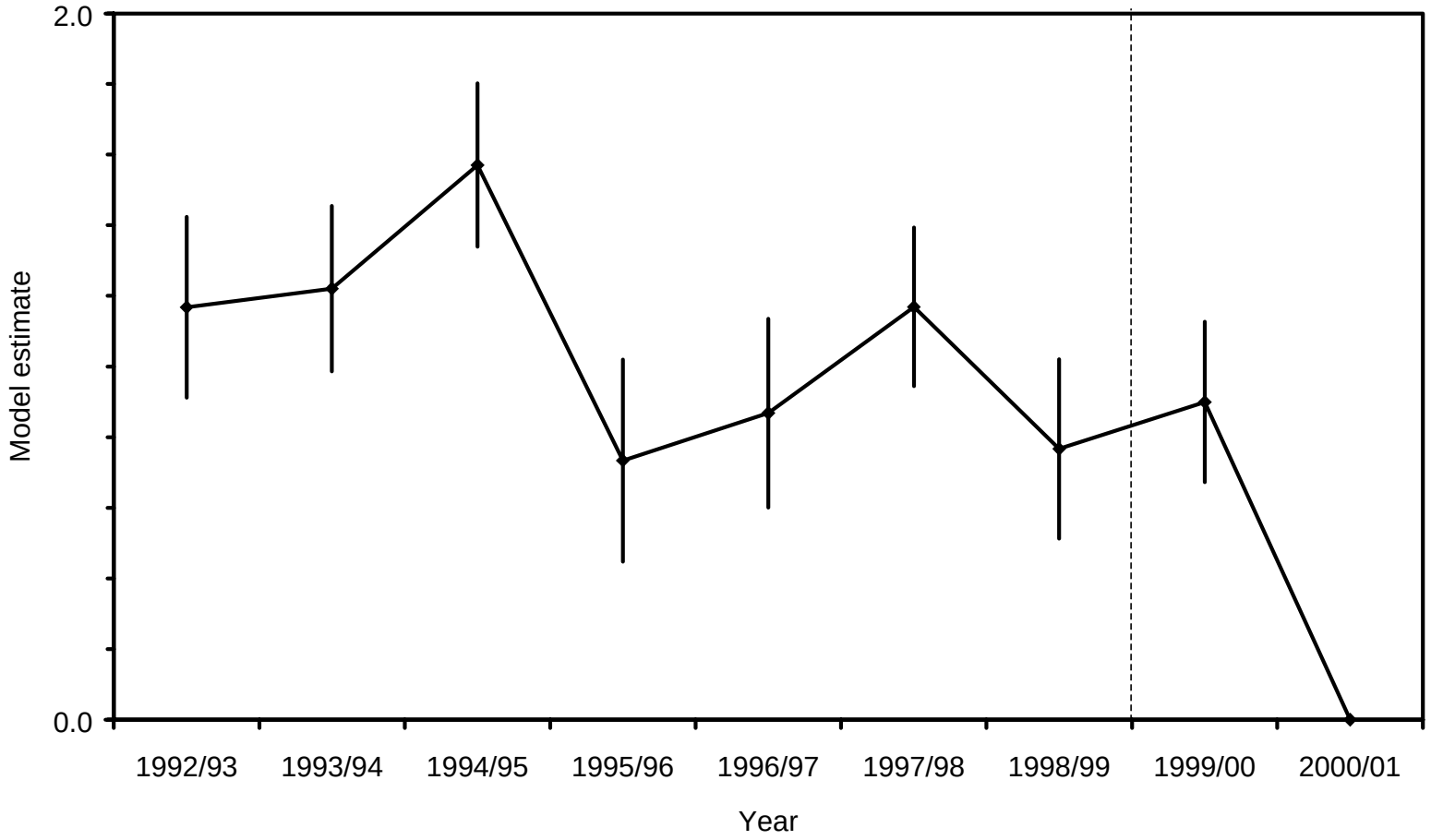
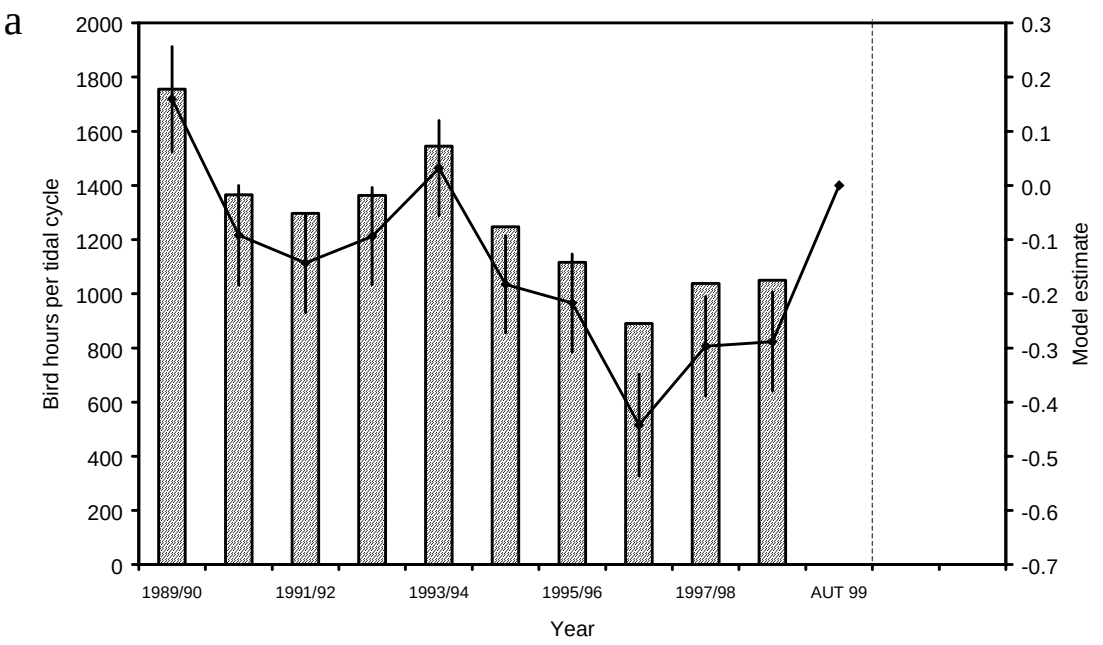


Figure 3.3.5 Estimates for 'year' (± 1 SE) in a model relating the densities of feeding Curlew at low tide at Peterstone and St. Brides to year, month and mudflat.



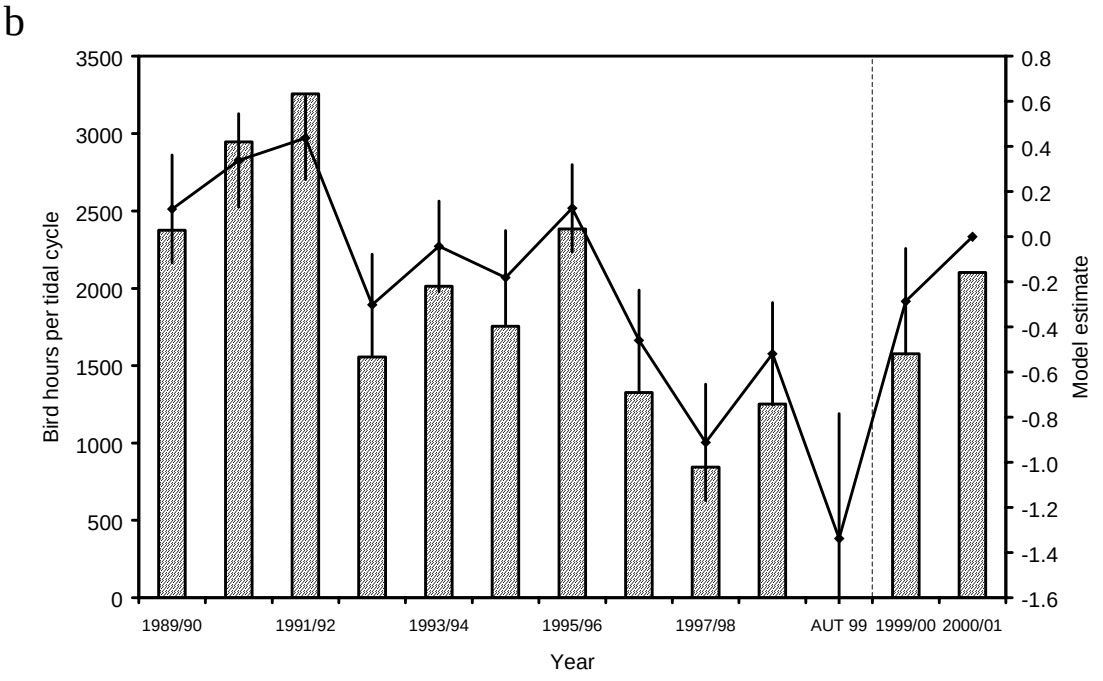


Figure 3.4.1 Estimates for 'year' (shown by lines with ± 1 SE) and the mean number of bird hours per tidal cycle (shown as bars) derived from models relating the number of feeding Redshank at **a.** Cardiff Bay and **b.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; points immediately before and after are estimates for autumn 1999 and for the winter of 1999/2000 together with spring 2000 respectively.

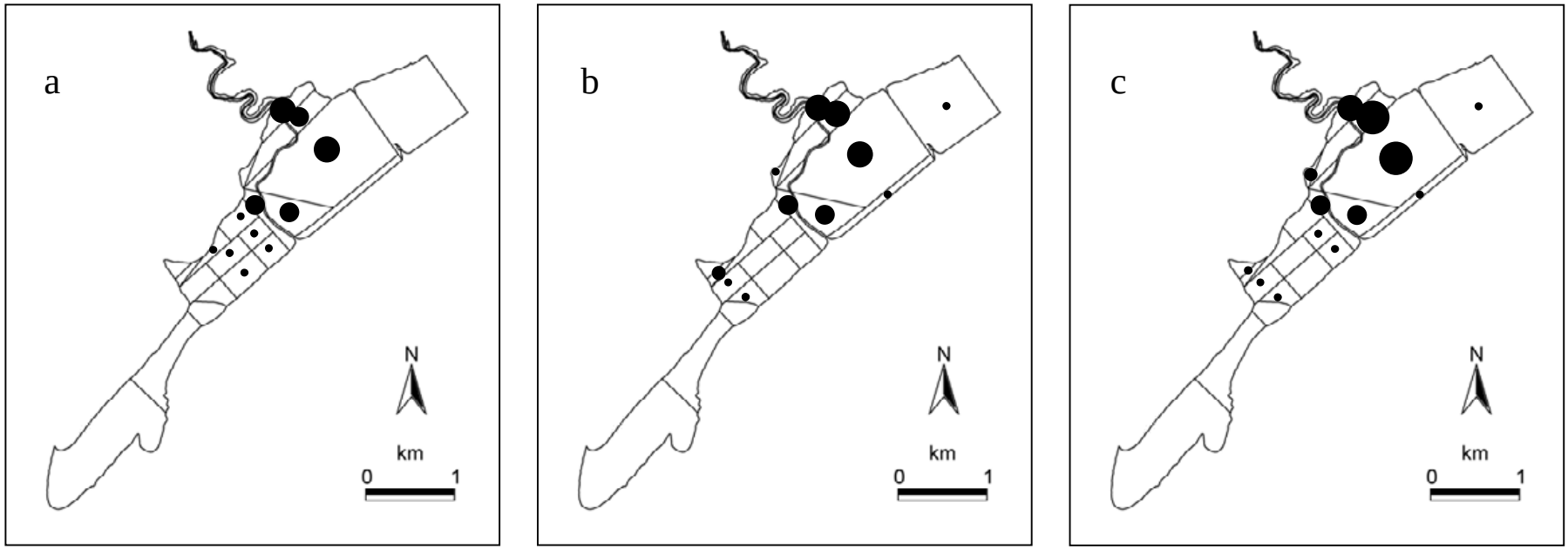


Figure 3.4.2 The distribution of feeding Redshank on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01.

1-24 • 25-99 ● 100-249 ● 250-499 ● 500-999 ● >1000 ●

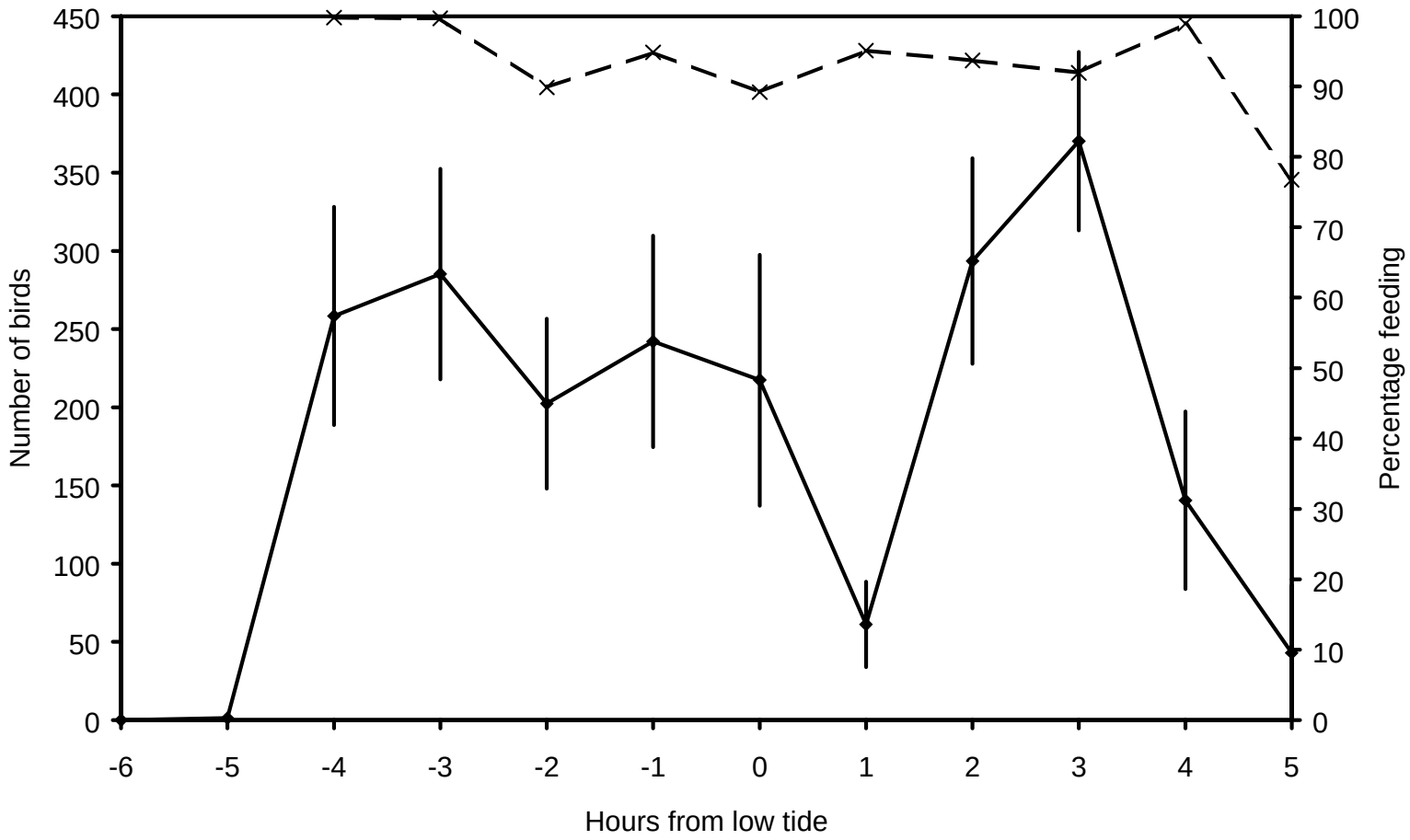


Figure 3.4.3 The total number of Redshank present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at Rhymney during the winter of 2000/2001.

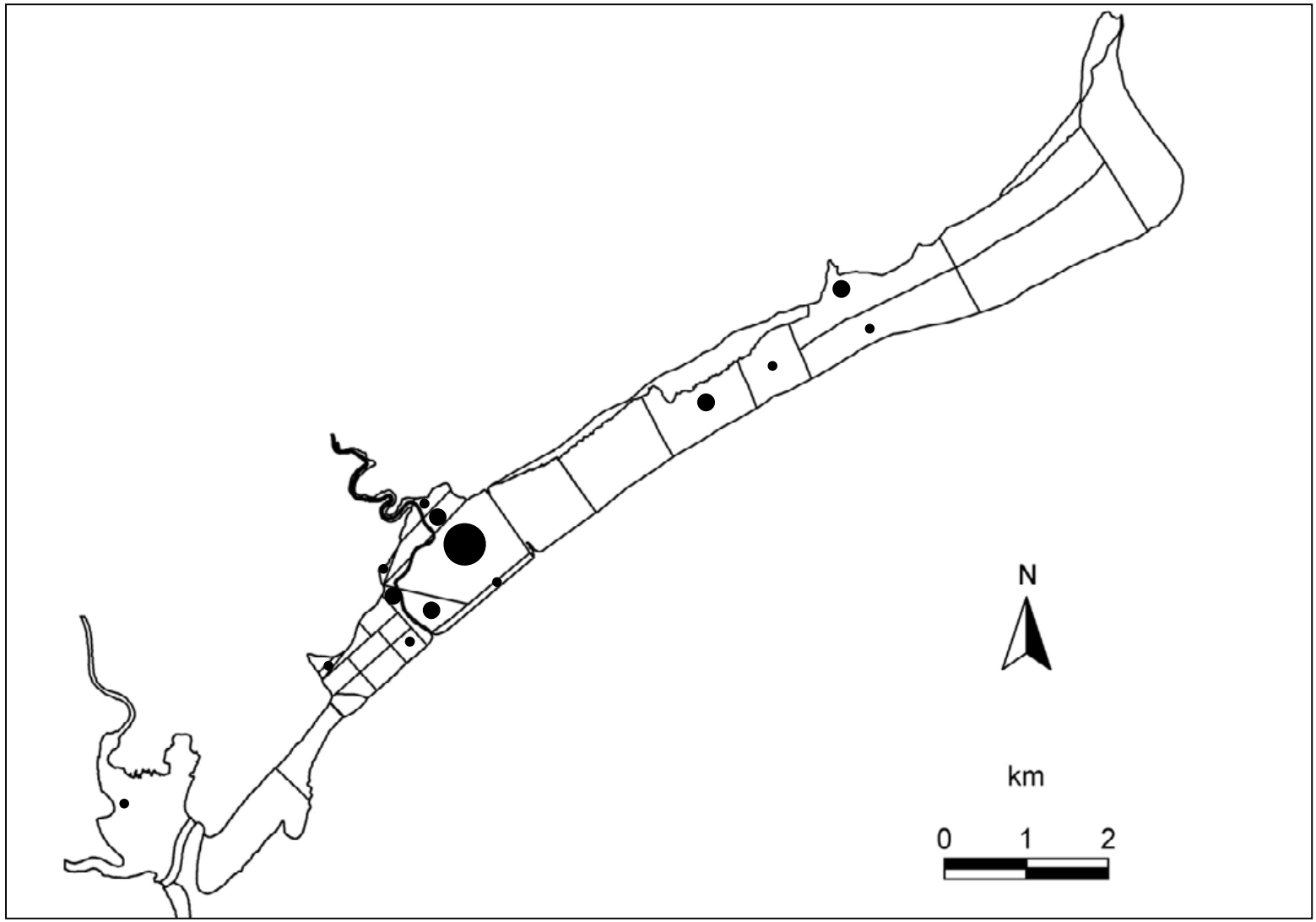


Figure 3.4.4 The low tide distribution of feeding Redshank on the northwest Severn during the winter of 2000/2001.

1-9 10-24 25-49 50-99 100-199

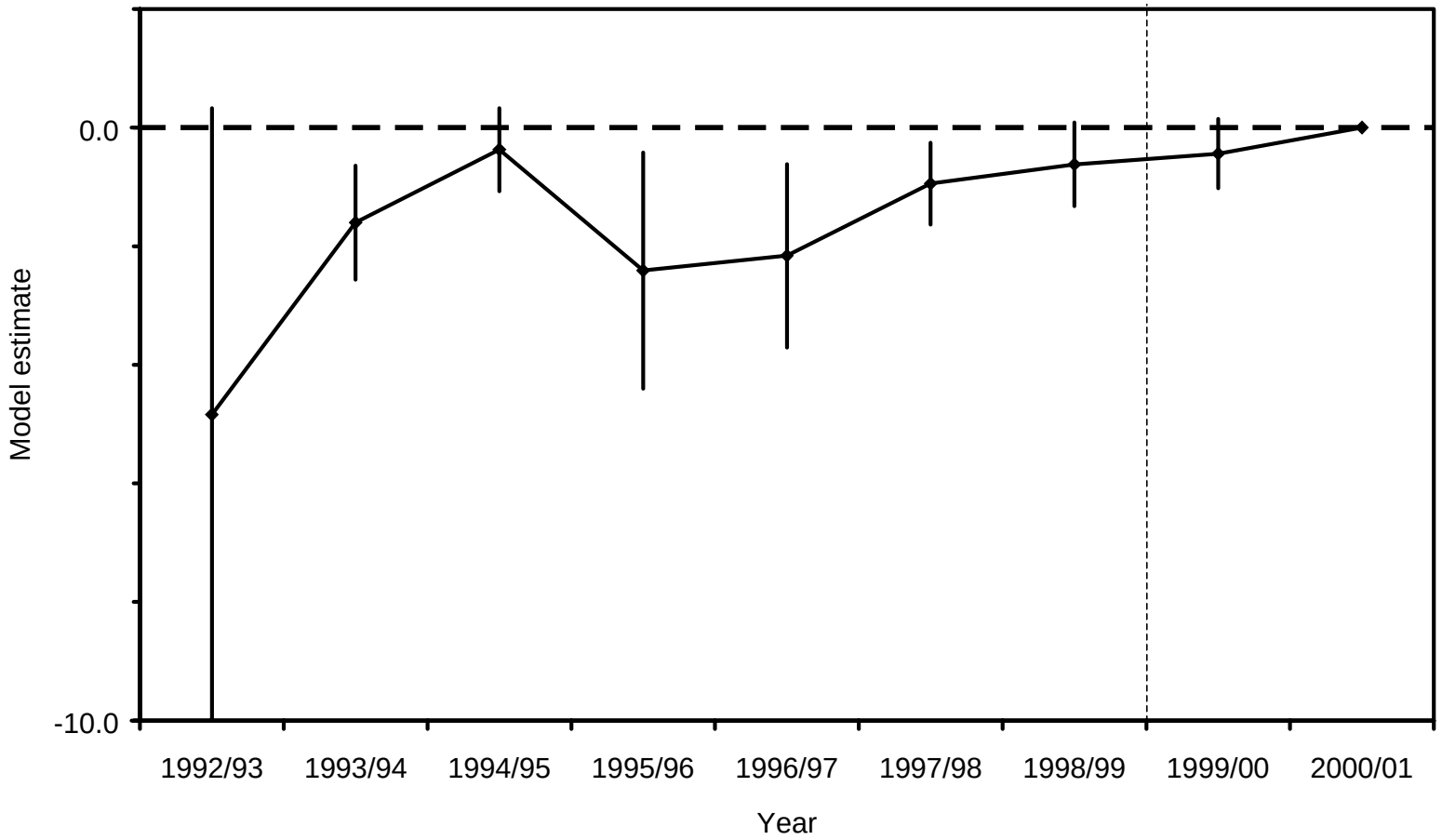
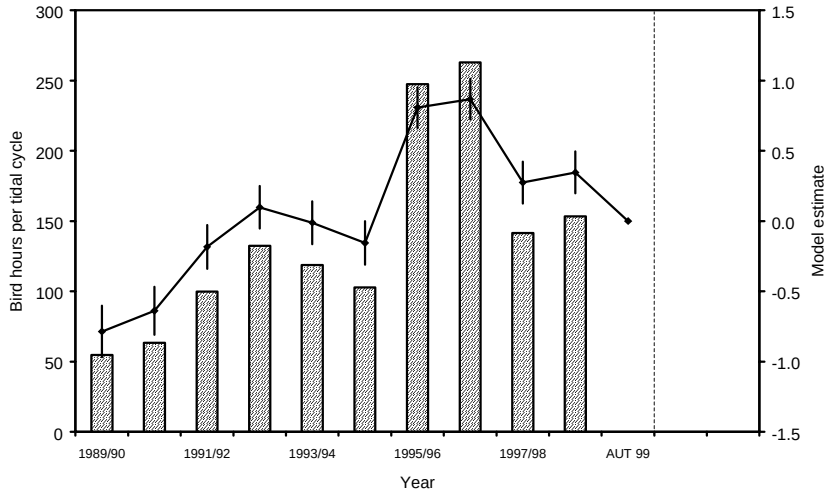
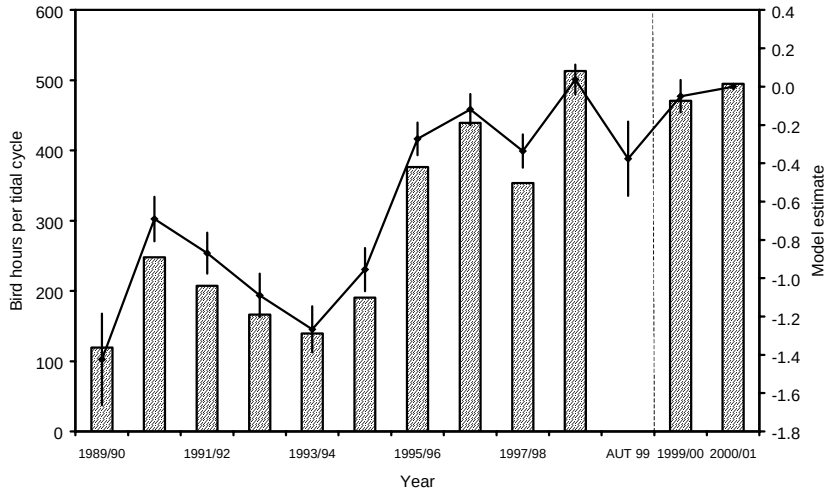


Figure 3.4.5 Estimates for 'year' (± 1 SE) in a model relating the densities of feeding Redshank at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b



c

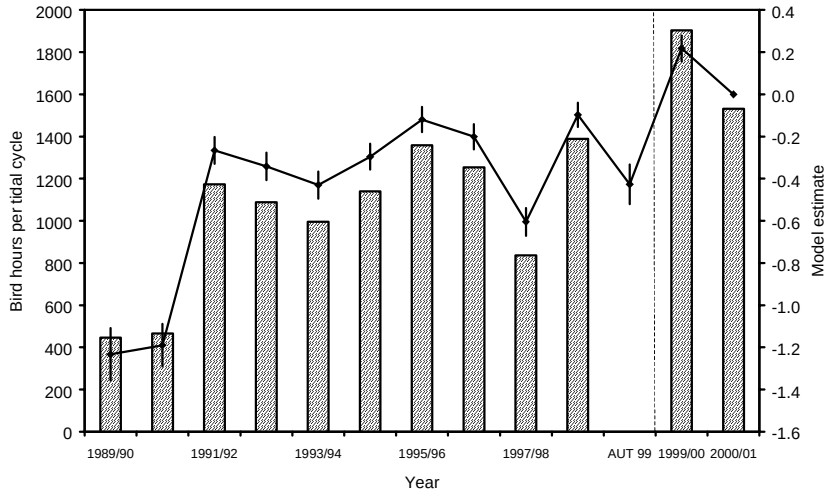


Figure 3.5.5.1 Estimates for 'year' (shown by lines with ± 1 SE) and the mean number of bird hours per tidal cycle (shown as bars) derived from models relating the number of feeding Oystercatcher at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; points immediately before and after are estimates for autumn 1999 and for the winter of 1999/2000 together with spring 2000 respectively.

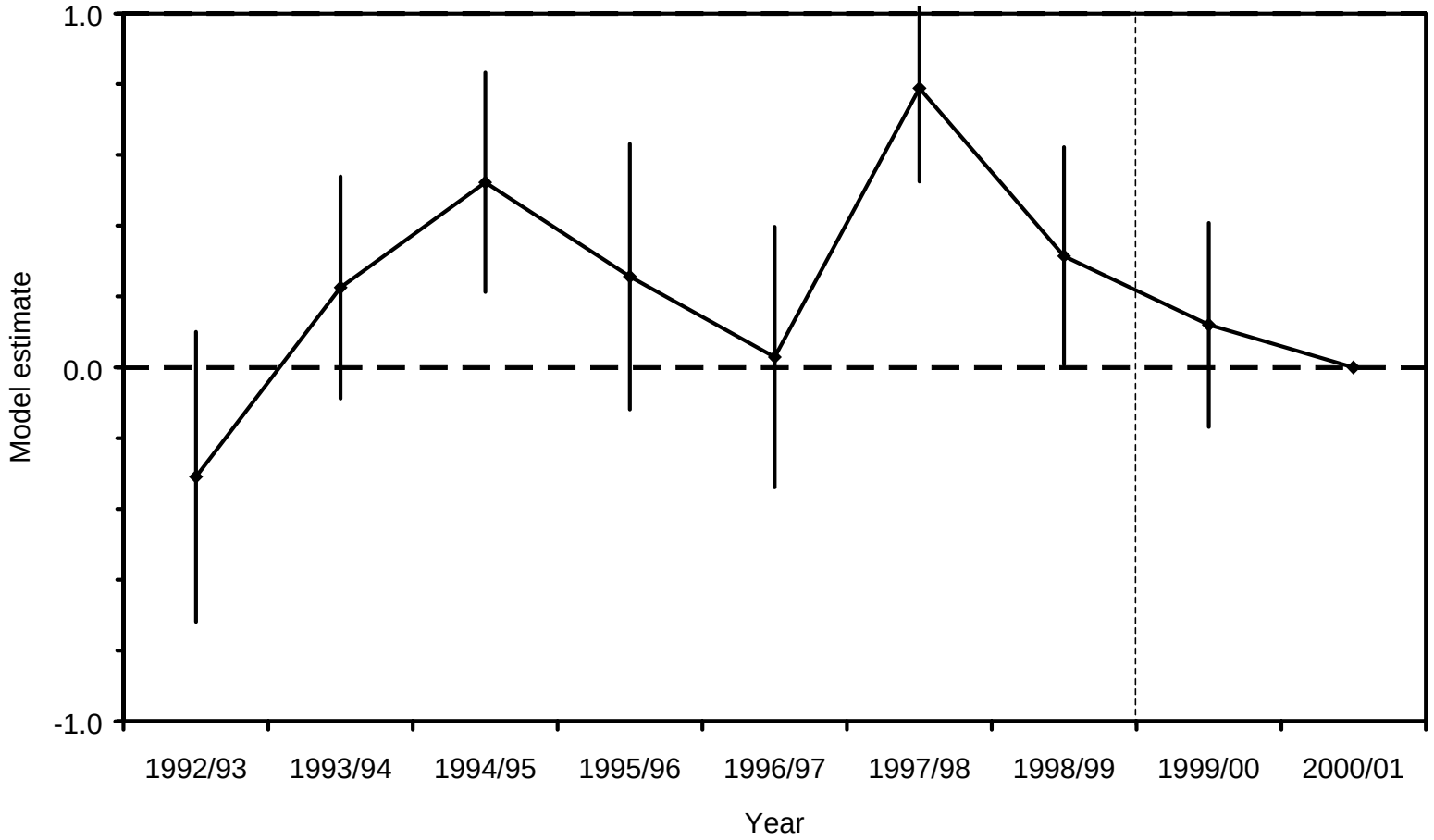


Figure 3.5.5.2 Estimates for 'year' (± 1 SE) in a model relating the densities of feeding Oystercatcher at low tide at Peterstone and St. Brides to year, month and mudflat.

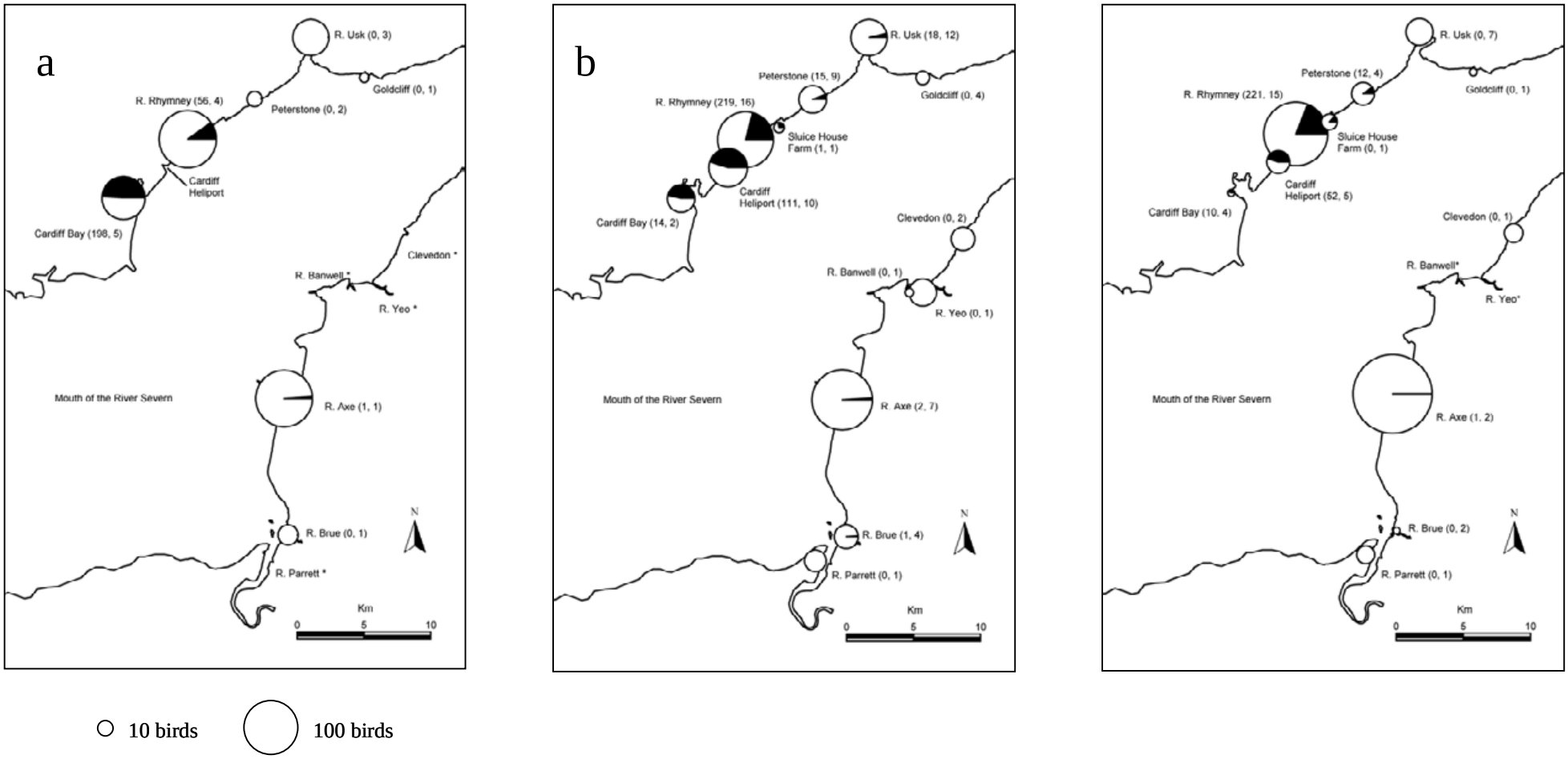


Figure 7.1.1 Proportions of colour-ringed individuals in flocks of Redshank in **a**. October 1999, immediately prior to the closure of the Cardiff Bay barrage, **b**. November 1999 to February 2000, the winter immediately post-closure and **c**. October 2000 to February 2001. Proportions are indicated by the black segments. Circle area reflects the mean size of flocks surveyed. Figures in parentheses indicate the number of individuals identified at a site and the number of surveys undertaken. * - site not surveyed. No colour-ringed Redshank were seen east of the area shown during these periods.

WILDFOWL
Mute Swan *Cygnus olor*
Canada Goose *Branta canadensis*
Barnacle Goose *Branta leucopsis*
Dark-bellied Brent Goose *Branta bernicla bernicla*
Shelduck *Tadorna tadorna*
Wigeon *Anas penelope*
Gadwall *Anas strepera*
Teal *Anas crecca*
Mallard *Anas platyrhynchos*
Pintail *Anas acuta*
Shoveler *Anas clypeata*
Pochard *Aythya ferina*
Tufted Duck *Aythya fuligula*
Scaup *Aythya marila*
Eider *Somateria mollissima*
Common Scoter *Melanitta nigra*
Goldeneye *Bucephala clangula*
Red-breasted Merganser *Mergus serrator*
Goosander *Mergus merganser*
Ruddy Duck *Oxyura jamaicensis*
Oystercatcher *Haematopus ostralegus*

WADERS
Avocet *Recurvirostra avosetta*
Ringed Plover *Charadrius hiaticula*
Golden Plover *Pluvialis apricaria*
Grey Plover *Pluvialis squatarola*
Lapwing *Vanellus vanellus*
Knot *Calidris canutus*
Curlew Sandpiper *Calidris ferruginea*
Dunlin *Calidris alpina*
Ruff *Philomachus pugnax*
Snipe *Gallinago gallinago*
Black-tailed Godwit *Limosa limosa*
Bar-tailed Godwit *Limosa lapponica*
Whimbrel *Numenius phaeopus*
Curlew *Numenius arquata*
Spotted Redshank *Tringa erythropus*
Redshank *Tringa totanus*
Greenshank *Tringa nebularia*
Green Sandpiper *Tringa ochropus*
Common Sandpiper *Actitis hypoleucos*
Turnstone *Arenaria interpres*

Appendix 1 Wildfowl and wader species recorded on all-day counts at Cardiff Bay between 1989 and 2001. Species highlighted in bold have been recorded in the Bay since barrage-closure.

Site	National Grid Reference
Cardiff Bay, South Glamorgan	ST1873
Cardiff Heliport, South Glamorgan	ST2175
Rhymney Estuary, South Glamorgan	ST2277
Sluice House Farm, Gwent	ST2578
Peterstone Gout, Gwent	ST2780
River Usk, Newport, Gwent	ST3285
Goldcliff Pill & Reserve, Gwent	ST3682
Nedern flood, Gwent	*ST4889*
River Wye, Chepstow, Gwent/Gloucestershire	ST5492
Berkeley Pill, Gloucestershire	*SO6600*
Oldbury, S Gloucestershire	*ST5992*
New Passage / Severn Beach, S Gloucestershire	*ST5486*
River Avon / Portbury Docks	*ST5078*
Clevedon, N Somerset	ST3970
River Yeo, N Somerset	*ST3666*
River Banwell, N Somerset	*ST3566*
River Axe, Somerset	ST3058
River Brue, Somerset	ST3047
River Parrett at Steart, Somerset	ST2846

Appendix 2 Sites on the Severn Estuary surveyed for colour-ringed Redshank in October 1999, immediately prior to barrage-closure and the winters of 1999/2000 and 2000/01, post-closure. Sites not surveyed in the latter winter are italicised.