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The Effect of the Cardiff Bay Barrage on Waterbird Populations 13. Distribution and Movement Studies August 2001-May 2002

Authors

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EXECUTIVE SUMMARY

1. This report presents the results of the thirteenth year of intensive monitoring of the waterbirds of Cardiff Bay and adjacent areas. The report concentrates upon results from the winter of 2001/02, the third following the closure of the Cardiff Bay barrage. The programme of monitoring followed that used over the previous 12 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 three winters following barrage-closure have been greatly reduced. A very few individuals of the four key species - Shelduck, Dunlin, Curlew and Redshank – have continued to use the Bay, though primarily as a high tide roost site. A total of 28 species of waterbird, and an annual mean of 21.0, have been recorded at the site since barrage-closure in comparison to an annual mean of 26.5, and a total of 50, in the 10 years before.

4. The decline in waterbird species' diversity in Cardiff Bay since barrage-closure has been due, primarily, to a loss of waders. However, at the same time, there has been a slight increase in the numbers of 'other' waterbird species such as grebes and rails. Among waders and wildfowl, only the numbers of Mute Swan and two diving duck species – Pochard and Tufted Duck – have increased. There has thus been a change from a diverse waterbird community dominated by large numbers of estuarine specialists, to a less diverse community comprising relatively small numbers of freshwater species.

5. Although numbers of both Shelduck and Curlew increased at Orchard Ledges in the two winters following barrage-closure, they fell back to previous levels in 2001/02. In neither case could the increase account for the loss of birds displaced from the Bay. At Rhymney, densities of Shelduck have decreased since barrage-closure, whilst those of Curlew have remained the same. Whilst it seems probable, therefore, that some of the Shelduck and Curlew from the Bay initially settled at Orchard Ledges, it is likely that either many have been forced to disperse to more distant areas or that there has been increased mortality in their populations or reduced recruitment of young birds. Until the full programme of work has been completed, however, these conclusions should be treated with caution.

6. Numbers of both Dunlin and Redshank had declined on the main study sites in the 10 years prior to barrage-closure. Dunlin numbers fell further at Rhymney in the winter of 1999/2000, though no further over the following two winters. Redshank numbers, in contrast, have risen at Rhymney since barrage-closure. The observed increase in the number of Redshank at this site over the three winters subsequent to barrage-closure could account for the loss of birds from the Bay.

7. Numbers of Dunlin and Curlew in the winters of 2000/01 and 2001/02 at low tide at Peterstone and St. Brides were lower than in any previous winter, whilst those of Shelduck and Redshank were unchanged.

8. Information from colour-ringing confirmed that the increase in Redshank numbers at Rhymney in the three winters post-closure was largely due to an influx of birds from Cardiff Bay. In the winter following closure, Redshank originally colour-ringed in the Bay were recorded as far as the River Usk in Newport and the River Axe in Somerset. In contrast, only single colour-ringed birds were seen in Somerset in 2000/01 and 2001/02 and none any further east than Peterstone. In all three years, the majority of colour-ringed 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.

9. Preliminary survival analyses indicated that the survival rate of adult Redshank in the winter of 1999/2000, immediately post-closure, was lower than in each of the two previous winters. The survival rate of birds displaced from the Bay remained at a similar low level over the winter of 2000/01. Although winter survival rates thus did fall following barrage-closure, it should be noted that the annual survival rates of 80% and 72% calculated for the two years following closure are no lower than many other previous published estimates.

10. Further monitoring at Cardiff over the winter of 2002/2003 will help to further distinguish changes associated with the closure of the barrage from other underlying fluctuations in species' populations. Observations of colour-ringed birds will also show whether Redshank displaced from Cardiff Bay continue to experience increased mortality.

GENERAL INTRODUCTION

This report looks at the distribution and movements of waterbirds in the winter of 2001/02, the third since the closure of the Cardiff Bay barrage. The report concentrates upon wildfowl and waders, though also includes information concerning grebes, cormorants, herons, rails and kingfishers. 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 (these episodes are referred to as 'drawdowns' hereafter), after which the Bay was permanently impounded with freshwater.

The report is in two parts. The first describes how the densities and distributions of waterbirds have changed in the three 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 12 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, 2001a, 2001b).

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, 2000/01 and 2001/02. As information concerning the Severn Estuary was not available for the 2001/02 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 waterbirds have changed in the three 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 16 further species, which were regularly present on the main study sites at the beginning of the study or which have been recorded in Cardiff Bay in numbers of 10 or more since barrage-closure, are also discussed.

The report concentrates on the third winter period following barrage-closure, i.e. November 2001 to March 2002. 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 2001) and spring (April and May 2002) are not presented in this report.

2. METHODS

Survey methods used in this year of study were the same as those used in the 12 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 2001), winter (November 2001 - March 2002) and spring (April - May 2002). 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).

2.3 Data Analysis and Presentation of Results

The previous 12 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, 2001a, 2001b). Some figures from the latter three reports 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 12 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 three winters following the displacement of birds from the Bay. Oystercatcher *Haematopus ostralegus* were additionally included in these analyses, as, although they do not occur on the Severn Estuary in nationally important number, they were also 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.

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

Models assumed a Poisson distribution for the number of feeding birds, 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 2001/02. 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 2001/02. Comparison maps are given for three 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 2001/02.

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.

$$\ln(\text{count}_{ijl}) = \mu + \alpha_i + \beta_j + \delta_l$$

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 2001/02. 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.

Shorter accounts are also provided for 15 other waterbird species, which were either relatively numerous in the study areas when the study began or which have been recorded in numbers of 10 or more since barrage-closure. For these species and for three species of gull, information is provided on peak numbers recorded in the winter of 2001/02.

3. RESULTS

Appendix 1 lists all waterbird species seen at Cardiff Bay during counts from 1989 to 2002 and highlights those that have been recorded in the Bay since barrage-closure. An annual mean of 21.0 waterbird species and a total of 28 have been recorded in the Bay in the three years since closure, in comparison to an annual mean of 26.5 and a total of 50 in the 10 previous years. In total, 26 species were recorded in the Bay in 2001/02, including four not seen previously – Slavonian Grebe *Podiceps auritus*, Black-necked Grebe *Podiceps nigricollis*, Long-tailed Duck *Clangula hyemalis* and Moorhen *Gallinula chloropus*.

Figure 3.1 shows that the decline in waterbird species' diversity since barrage-closure has been due, primarily, to a loss of waders. However, at the same time, there has been a slight increase in the numbers of 'other' waterbird species such as grebes and rails.

Numbers of the four key species – Shelduck, Dunlin, Curlew and Redshank – at Cardiff Bay in the winters of 1999/2000, 2000/01 and 2001/02 are shown in Figure 3.2.

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 3.2 shows that, in contrast to the winters prior to barrage-closure, only a few Shelduck occurred in Cardiff Bay in 1999/2000, 2000/01 and 2001/02. In the winter of 2001/02, averages of just 4.4 and 1.6 Shelduck occurred in the Bay at high tide and low tide respectively, with a peak of 10 birds in March. Prior to barrage closure, an average of 150-200 used the Bay during the exposure period (Burton *et al.* 1999). At least one pair of Shelduck bred successfully in the Bay in 2001 and three pairs were also recorded in 2002.

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 rose in the year following barrage-closure (particularly on the mudflat immediately adjacent to Cardiff Bay – see Figure 3.1.2), but have since fallen back to the very low levels seen prior to barrage-closure. Densities in 2001/02 were significantly lower than those in 2000/01 ($F_{1,2102}$ = 12.89, P = 0.0003) and 1999/2000 ($F_{1,2102}$ = 17.70, P < 0.0001), though similar to those in 1998/99, prior to barrage closure ($F_{1,2102}$ = 2.85, P = 0.0918). A peak mean of just 3 Shelduck was recorded at Orchard Ledges in the winter of 2001/02. 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 also significantly related to year, month, state of tide and mudflat (Table 3.1.1). The model did not converge if the interaction between the latter two terms was included. Densities at Rhymney have fallen over the three years since barrage-closure (Figure 3.1.1c). Densities in 2001/02 were thus lower than those in 2000/01 ($F_{1,28657}$ = 51.37, P < 0.0001) and

1999/2000 ($F_{1,28657}$ = 120.76, P < 0.0001), as well as those in 1998/99 immediately prior to closure ($F_{1,28657}$ = 160.95, P < 0.0001). As in the previous years, Shelduck were most numerous on mudflats to the east of the Rhymney River (Figure 3.1.2). A peak mean of 290 Shelduck was recorded at Rhymney in the winter of 2001/02 (Figure 3.1.3). 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 previous results have 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 283 at Rhymney (Figures 3.1.1a-c). The increase noted at Orchard Ledges has not been sustained and in the winter of 2001/02, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was 11 less than that in the winter of 1998/99. The mean recorded at Rhymney was 2307 less than in the winter of 1998/99. It would appear, therefore, that the Shelduck displaced from Cardiff Bay have not been able to settle at either Rhymney or Orchard Ledges.

Feeding Shelduck were found on all but one of the eight low tide count sections to the east of Rhymney in the winter of 2001/02 (Figure 3.1.4). Densities of feeding birds in this area were significantly related to mudflat, year and month (Table 3.1.2). Densities have increased marginally, though not significantly, since 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.

Only one Dunlin has been recorded in Cardiff Bay at low tide in the three winters since barrage-closure and there have been means of only 2.6, 1.3 and 1.1 at high tide (Figure 3.2). A peak of just 3 occurred in the winter of 2001/02. In the year 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 have been exceedingly low since 1996/97 and a peak of just 3 birds was recorded in 2001/02. Densities in 2001/02 were similar to those in 1998/99, immediately prior to barrage-closure ($F_{1,1946}$ = 0.73, ns). 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 have declined greatly since 1996/97 (Figure 3.2.1c). Those in 2001/02 were similar to those found in the preceding year ($F_{1,24535}$ = 2.45, ns), but slightly less than those in 1999/2000 ($F_{1,24535}$ = 6.19, P = 0.0128). Densities in 2001/02, however, were similar to those in 1998/99 immediately prior to closure ($F_{1,24535}$ = 3.36, P = 0.0668). Figure 3.2.2 shows this decline and also that Dunlin were most numerous in all years on mudflats to the east of the Rhymney River. A peak mean of 672 Dunlin was recorded at Rhymney in the winter of 2001/02 (Figure 3.2.3). 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 ($F_{1,18592} = 30.42$, $P < 0.0001$).

Given the continuing decline in Dunlin numbers, it would seem that the birds displaced from the Bay found it difficult to settle at Rhymney (or Orchard Ledges) 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 2001/02, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was 14 less than that in the winter of 1998/99, whilst the mean recorded at Rhymney was 1577 less.

Feeding Dunlin were found on all but one of the eight low tide count sections to the east of Rhymney in the winter of 2001/02 (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 and 2001/02 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 have been recorded in Cardiff Bay at low tide in the three winters following barrage-closure and there have been means of only 1.6, 11.1 and 0.4 at high tide (Figure 3.2). A peak of just 3 occurred in the winter of 2001/02, though more were present in the preceding autumn. In 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 rose in the two years following barrage-closure, but that this increase was not sustained in 2001/02. Densities in 2001/02 were significantly lower than in 2000/01 ($F_{1,3055} = 41.83$, $P < 0.0001$) and 1999/2000 ($F_{1,3055} = 18.19$, $P < 0.0001$), and also slightly lower than those in 1998/99, prior to closure ($F_{1,3055} = 5.00$, $P = 0.0254$). A peak mean of just 18 Curlew was recorded at Orchard Ledges in the winter of 2001/02 (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 2001/02 were similar to those found in the preceding year ($F_{1,31901} = 2.25$, ns) and those in 1999/2000 ($F_{1,31901} = 0.09$, ns), as well as those in 1998/99, immediately before barrage-closure ($F_{1,31901} = 0.02$, 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 41 Curlew was recorded at Rhymney in the winter of 2001/02 (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 in the two winters following barrage-closure only went some way to matching the loss of birds from the Bay and this increase has apparently not been maintained. 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 42 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 2001/02, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was 28 less than that in the winter of 1998/99, whilst the mean recorded at Rhymney was 3 less.

Feeding Curlew were found on all but one of the eight low tide count sections to the east of Rhymney in the winter of 2001/02 (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 the winters of 2000/01 and 2001/02 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 primarily of birds from Britain, Ireland 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 small numbers of Redshank have been recorded in Cardiff Bay in the three years post-closure (Figure 3.2). An average of just 9.1 and a peak of 30 occurred at high tide in the winter of 2001/02 and none were recorded at low tide. 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).

Only one Redshank was observed at Orchard Ledges in 2001/02 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 at this site have risen significantly since barrage-closure. Densities in 2001/02 were higher than those found in the preceding year ($F_{1,24297}$ = 5.49, P = 0.0192) and in 1999/2000 ($F_{1,24297}$ = 23.42, P < 0.0001) and much greater than those in 1998/99, prior to barrage-closure ($F_{1,24297}$ = 48.62, P < 0.0001) (Figure 3.4.1b). Figure 3.4.2 shows that Redshank were most numerous in 2001/02 on mudflats adjacent to the Rhymney River. As in 1999/2000, they also used the mudflats adjacent to Cardiff Heliport, though unlike that year, usually only in small numbers on the ebb tide. A peak mean of 480 Redshank was recorded at Rhymney in the winter of 2001/02 (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 three winters subsequent to barrage-closure could account for the loss of birds from the Bay – though it cannot be concluded from this alone that the survival of displaced birds was not depressed. 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 298 bird hours at Rhymney in the winter of 1999/2000, there has been an overall increase of 1413 bird hours over the last three winters (Figures 3.4.1a-b). The initial 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 2001/02 (Figure 3.4.4). Densities of feeding birds in this area were significantly related to mudflat, year and month (Table 3.4.2). Those in the winter of 2001/02 were slightly lower than those in the two preceding winters which followed barrage-closure (Figure 3.4.5).

3.5 Other Waterbird Species

3.5.1 Great Crested Grebe *Podiceps cristatus*

Great Crested Grebes were recorded at Cardiff Bay in just four of the 10 years preceding barrage-closure and only ever in numbers of one or two. Only one was recorded in the winter and spring following closure, when the Bay was still affected by periodic drawdowns. Since the cessation of drawdowns and the change to freshwater conditions, however, this species has become firmly established in the Bay. Great Crested Grebes were recorded in the Bay every month during 2001/02. A peak of 17 birds was recorded during winter, this increasing to 22 in the spring when the species was noted to be nesting. At least two broods of young grebes were also noted in the preceding summer.

No Great Crested Grebes have been observed during the study at either Orchard Ledges or Rhymney.

3.5.2 Cormorant *Phalacrocorax carbo*

Cormorants have been recorded at Cardiff Bay every year since the study began in 1989/90 and their presence does not seem to have been affected by the change from saline to freshwater conditions. The species was recorded in the Bay in every month during 2001/02, with a peak of 42 birds recorded in December.

Cormorant also occur in small numbers at both Orchard Ledges and Rhymney.

3.5.3 Mute Swan *Cygnus olor*

As with Great Crested Grebe, Mute Swans were recorded only occasionally in small numbers at Cardiff Bay prior to barrage-closure and, in total, were observed in just five of the 10 years between 1989/90 and 1998/99. They have been recorded in each of the last two years, however, and have become more common with the change to freshwater conditions. Mute Swans were recorded in all but one month between August 2001 and May 2002. Up to seven birds were recorded during winter, though as with Great Crested Grebe, this figure increased in spring when a peak of 14 was noted. Two pairs of Mute Swans attempted to breed in spring 2002, but lost their nests as a result of high water levels on 30 April (V. Grantham, pers. comm.).

Only occasional Mute Swans have been observed during the course of the study at either Orchard Ledges or Rhymney.

3.5.4 Mallard *Anas platyrhynchos*

Mallard have continued to use Cardiff Bay in the three winters since barrage-closure, although in reduced numbers. A peak of 24 was recorded during the winter of 2001/02. In comparison, a peak of 127 was recorded in the winter of 1998/99 prior to closure. Mallard were recorded nesting in the Bay in 2002 (V. Grantham, pers. comm.).

No Mallard were seen at Orchard Ledges during the winter. The peak of 99 Mallard at Rhymney in January was similar to that recorded in the previous winter. Further large concentrations were present at low tide at St. Brides.

3.5.5 Teal *Anas crecca*

Teal numbers have been much reduced in the Bay since barrage-closure. A peak of 42 was recorded during the winter of 2001/02, in comparison to a peak of 121 in the winter of 1998/99 prior to closure.

A maximum of 34 Teal 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.

3.5.6 Pintail *Anas acuta*

As in most previous years no Pintail were recorded at Cardiff Bay in the winter of 2001/02. Numbers at Rhymney were slightly higher than in the previous winter, though similar to those in 1998/99, peaking at 381 in December. Large concentrations also occurred along the shoreline at Peterstone and St. Brides.

3.5.7 Pochard *Aythya ferina*

Pochard numbers have increased at Cardiff Bay since barrage-closure and the change to freshwater conditions, and the peak of 240 in the winter of 2001/02 was twice that in the preceding winter and four times that in the winter of 1999/2000. A peak of 48 was recorded in the winter of 1998/99, prior to barrage-closure.

Numbers have not just increased in the Bay, however. The peak of 350 recorded at Rhymney in the winter of 2001/02 also represented an increase in comparison to the preceding winter. Small numbers were also present on adjacent areas of Peterstone at low tide.

3.5.8 Tufted Duck *Aythya fuligula*

Only a single Tufted Duck was recorded in Cardiff Bay in the 10 years preceding barrage-closure, though the species occurs in large flocks at St. Brides and occasionally at Rhymney during winter. However, as with Pochard, another species of diving duck, the species has been recorded more regularly in the Bay since the change to freshwater conditions. A peak of 23 was recorded in November 2001 and again in May 2002. A single brood of Tufted Duck was observed in the Bay in August 2001.

A peak of 24 Tufted Duck was observed at Rhymney in January 2002.

3.5.9 Goosander *Mergus merganser*

Goosander have been recorded in Cardiff Bay annually since 1992/93 and, as with Cormorant (another piscivore), their presence does not seem to have been affected by the change from saline to freshwater conditions. Up to 14 Goosander were recorded in the Bay in the winters prior to barrage-closure and peaks of 7, 4 and 16 have been recorded in the three winters since.

No Goosander have been observed during the study at either Orchard Ledges or Rhymney.

3.5.10 Coot *Fulica atra*

Only a single Coot was recorded in Cardiff Bay in the 10 years preceding barrage-closure and the species was also absent in the winter and spring following closure, when the Bay was still affected by periodic drawdowns. Since the cessation of drawdowns and the change to freshwater conditions, however, this species has become firmly established in the Bay. Coot were recorded in the Bay every month during 2001/02, with a peak of 59 birds in January 2002. The species also bred successfully in small numbers in both 2001 and 2002.

No Coot have been observed during the study at either Orchard Ledges or Rhymney.

3.5.11 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. Numbers have declined dramatically since barrage-closure, however, and a peak of just two and a total of three Oystercatcher were observed in the Bay in 2001/02.

Figure 3.5.11.1 indicates the results of the modelling of Oystercatcher densities at Cardiff Bay, Orchard Ledges and Rhymney. All factors considered in the models were significant in explaining densities (Table 3.5.11.1). 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 were maintained over the two years following barrage-closure, but declined in 2001/02. Densities in the latter year were thus lower than both those in the preceding year ($F_{1,3049}$ = 33.11, P < 0.0001) and 1999/2000 ($F_{1,3049}$ = 23.34, P < 0.0001), as well as those in 1998/99 prior to barrage-closure ($F_{1,3049}$ = 36.68, P < 0.0001). Densities at Rhymney rose in the year following barrage-closure, but have since fallen back to previous levels. Densities in 2001/02 were similar to those in the preceding year ($F_{1,32110}$ = 0.14, ns), but significantly lower than those in 1999/2000 ($F_{1,32110}$ = 15.15, P < 0.0001). Densities were similar to those in 1998/99, however ($F_{1,32110}$ = 1.76, ns).

Densities of feeding Oystercatchers on low tide counts at Peterstone and St. Brides were significantly related to mudflat and year, but not month (Table 3..5.11.2). No significant difference was apparent between the densities of Oystercatchers found in these areas in 2001/02 and those in the winter of 1998/99 (Figure 3.5.11.2).

3.5.12 Ringed Plover *Charadrius hiaticula*

No Ringed Plover have been recorded in Cardiff Bay in the three years since barrage-closure. In the winter of 1998/99, immediately prior to closure, a peak of 44 Ringed Plover was recorded in November.

Numbers at Orchard Ledges and Rhymney in the winter of 2001/02 were similar to those in the previous winter – though higher than in the winter immediately before barrage-closure – peaking at 35 and 75 in November and January respectively. No Ringed Plover were observed at St. Brides Peterstone in the winter of 2001/02.

3.5.13 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 winters of 2000/01 and 2001/02. 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 fallen and a peak of just 21 birds was recorded in the winter of 2001/02.

3.5.14 Lapwing *Vanellus vanellus*

The numbers of Lapwing using Cardiff Bay have declined since barrage-closure. None were recorded in 1999/2000 and peaks of just 43 and 24 in 2000/01 and 2001/02 respectively. In comparison, a maximum of 73 was recorded during the winter of 1998/99.

A peak of 230 was recorded during the winter of 2001/02 at Rhymney, but none were recorded at Orchard Ledges or at Peterstone and St. Brides at low tide.

3.5.15 Knot *Calidris canutus*

Knot too have declined greatly in number at all sites in recent years and none have been recorded at Cardiff Bay since barrage-closure. Only a single flock of 90 birds was recorded at Rhymney in the winter of 2001/02 and none were seen at Orchard Ledges. A total of 475 Knot were observed at St. Brides in January 2002.

3.5.16 Turnstone *Arenaria interpres*

Turnstone formerly used Cardiff Bay primarily as a high tide roost site, but have rarely been recorded in the Bay since barrage-closure. The species was only recorded twice in the Bay in the winter of 1999/2000, not at all in 2000/01 and just a single bird was observed in 2001/02. A peak of 12 Turnstone used the Bay in the winter of 1998/99, prior to barrage-closure.

Peaks of 86 and 60 were recorded at Orchard Ledges and Rhymney respectively in the winter of 2001/02. No Turnstone were recorded at low tide at St. Brides or Peterstone.

3.6 Gulls

Three species of gull occur regularly in Cardiff Bay – Black-headed Gull *Larus ridibundus*, Lesser Black-backed Gull *L. fuscus* and Herring Gull *L. argentatus*. Numbers of Black-headed Gull rose through the winter of 2001/02. A total of 423 were recorded in March, though numbers peaked at 575 in April. Lesser Black-backed Gull numbers followed a similar pattern – 140 were recorded in February and a peak of 180 in May. At this time, birds would have been returning to breed around the Bay, as well as at their colonies on nearby Steep Holm and Flat Holm. Herring Gull numbers peaked at 103 during March.

The numbers of gulls recorded in Cardiff Bay tended to increase towards dusk as birds flew in to use the site as a night-time roost. Gulls typically roost on open water and thus the Bay has probably become a more attractive site for them since barrage-closure.

4. DISCUSSION

4.1 Changes in Species' Diversity and Abundance within Cardiff Bay

Only 28 species of waterbird, and an annual mean of 21.0, have been recorded during counts at Cardiff Bay over the three years since barrage-closure, in comparison to a total of 50 in the 10 previous years, and an annual mean of 26.5. The main cause of this change in waterbird species' diversity has been a loss of waders. However, since barrage-closure and the change to freshwater conditions resultant from the cessation of drawdowns, there has been a slight increase in the numbers of 'other' waterbird species such as grebes and rails – species more typical of freshwater habitats.

Not only has species' diversity been reduced, but so have the numbers of most species that still use Cardiff Bay. A few of the four key species – Shelduck, Dunlin, Curlew and Redshank – have continued to use the Bay as a high tide roost site, but very few remain to forage at low tide. All species of wader have fallen sharply in number since barrage-closure. Amongst wildfowl, the numbers of two common dabbling duck species – Teal and Mallard – have also been reduced. In contrast, the numbers of two diving duck species – Pochard and Tufted Duck – have increased, whilst those of two piscivores – Cormorant and Goosander – have remained the same. Other species more typical of freshwater habitats – grebes, Mute Swan, Moorhen and Coot – have also become more common. Seven species – Great Crested Grebe, Little Grebe, Mute Swan, Shelduck, Mallard, Tufted Duck and Coot – have additionally attempted to breed in small numbers in the Bay since barrage-closure, at least six successfully.

At Cardiff Bay, there has thus been a change from a diverse waterbird community dominated by large numbers of estuarine specialists, to a less diverse community comprising relatively small numbers of freshwater species. A previous study in The Netherlands looked at the consequences of the loss of 56 km^2 of intertidal habitat resultant from the construction of a storm-surge barrier and two dams in the country's Delta region (Schekkerman *et al.* 1994). This work similarly reported a decrease in the numbers of waders (Oystercatcher, Avocet, Kentish Plover, Grey Plover, Dunlin and Redshank), Shelduck and dabbling ducks (Pintail, Teal and Shoveler) and also an increase in the numbers of open water species (Great Crested Grebe, Cormorant and Goldeneye).

4.2 Impacts of Barrage-Closure on the Former Waterbird Community of Cardiff Bay

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.* 2001a, 2001b; 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 winters of 2000/01 and 2001/02, suggesting a further concentration of displaced birds into this site and indeed, the observed increase in the number of Redshank at Rhymney over the three winters subsequent to barrage-closure could account the loss of birds from the Bay. Without the analysis of data from resightings of colour-ringed birds, however, it cannot be concluded from this alone that the survival of displaced birds was not depressed.

In the winter immediately following barrage-closure, high densities of Redshank were noted 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 further over the following two winters. 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 winter following barrage-closure than in the year before. This increase could have accounted for the loss of birds from the Bay, but has not been sustained over the two subsequent winters. Likewise, while densities of Oystercatcher were maintained at Orchard Ledges in the two winters following barrage-closure, they declined in 2001/02.

Prior to barrage-closure, populations of Oystercatchers at both Rhymney and Orchard Ledges had been increasing – suggesting either that food supplies had 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). Partly due to the previous increasing trend, it is not possible to state with certainty that the increases seen at Rhymney and Orchard Ledges after 1999 were caused by an influx of birds from Cardiff Bay. Whatever the cause, however, these increases have not been maintained and it seems possible, therefore that the Oystercatcher displaced from the Bay may have suffered increased mortality due to increased competition resultant from the high densities at Rhymney and Orchard Ledges.

Densities of both Shelduck and Curlew increased at Orchard Ledges in the two winters following barrage-closure, but fell back to previous levels in 2001/02. In neither case could the increase account for the loss of birds displaced from the Bay. At Rhymney, densities of Shelduck have decreased since barrage-closure, whilst those of Curlew have remained the same. Whilst it seems probable, therefore, that some of the Shelduck and Curlew from the Bay initially settled at Orchard Ledges, it is likely that either many have been forced to disperse to more distant areas or that there has been increased mortality in their populations or reduced recruitment of young birds. There was no evidence that Curlew had increased in number at St. Brides or Peterstone, though numbers of Shelduck have increased marginally.

Until the full programme of work has been completed, these conclusions should be treated with caution. Future monitoring will help to further 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 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 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 total of 18 individuals moved as far as the River Usk at Newport and at least one crossed the Severn Estuary to Somerset. In the winter of 2000/01, colour-ringed Redshank were more concentrated at Rhymney and none were seen east of Peterstone. Results presented here show whether displaced Redshank continued to use the same areas in the winter of 2001/02.

Also in this part of the report, we investigate whether the survival of Redshank displaced from the Bay has been adversely affected since barrage-closure. Burton *et al.* (2001b) reported preliminary analyses that showed that the mortality of Redshank from Cardiff Bay was greater over the winter of 1999/2000 following barrage-closure than in the two preceding winters, perhaps due to starvation (body condition was reduced amongst Cardiff Bay Redshank that winter). Further results presented here aim to determine whether survival rates were also low in the winter of 2000/01 or whether the birds displaced from Cardiff Bay have been successful in relocating and adapting to their new wintering quarters. These analyses should be regarded as preliminary until fieldwork is completed after the winter of 2002/03.

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.

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 three 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 four 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 (November to February), 2000/01 (October to February) and 2001/02 (October to February) 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 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 2002. 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) (i.e. the proportion of birds surviving a period) and resighting probabilities (p) and whether these varied with time. Time dependent estimates are represented, respectively, by ϕ_t and p_t.

The validity of the CJS models depends 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 6.2.2.1). 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 (i.e. February and October 1996) was sufficient to overcome this violation (Table 6.2.2.1). Using Program MARK, we also estimated an overdispersion parameter for the data ($\hat{c}$) to adjust the models. A value of 1.42 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 a change in 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_s) 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_w) 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 Likelihood Ratio Test) to one where the ϕ_w for 1999/2000 was assumed to differ from that for the preceding two winters. This procedure was repeated in order to compare the ϕ_w for the winter of 2000/01 to those for the two winters prior to barrage-closure. 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. This procedure was similarly repeated in order to compare the ϕ_s for the summer of 2001 with those for summers prior to barrage-closure.

As these survival analyses depend upon calculating resighting probabilities, they should be regarded as preliminary until the full programme of fieldwork is completed after the winter of 2002/03.

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 three winters subsequent to barrage-closure, i.e. 1999/2000, 2000/01 and 2001/02. 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 (one 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 Estuary than the River Usk, in spite of good coverage of this area.

In comparison, in the winters of 2000/01 and 2001/02, colour-ringed Redshank were less dispersed. No colour-ringed birds were seen east of Peterstone and only single birds were seen each winter on the English side of the Severn Estuary. The bird seen at the River Axe in 2000/01 had been seen there in October 1999, prior to barrage-closure. The second bird was seen at Steart in November 2001.

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 declined slightly over the following two winters to 19% and 16% respectively (presumably due to the influx of juveniles into the population). However, these figures were still significantly higher than that recorded in the October prior to barrage-closure (for 2000/01: χ^2_1= 16.14, P < 0.0001; for 2001/02: χ^2_1= 5.13, P = 0.0235). In all three 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 immediately prior to closure (χ^2_1 = 0.74, ns). The area was used by fewer Redshank in the winters of 2000/01 and 2001/02 and primarily on the ebb tide. In the winter of 2000/01, approximately 45% of these birds were again colour-ringed, a similar percentage to that recorded in the Bay pre-closure (χ^2_1 = 1.20, ns). This figure had fallen significantly to 31% in the winter of 2001/02 (presumably also due to the influx of juveniles into the population) (χ^2_1= 11.02, P = 0.0009).

7.2 Survival Analyses

Table 7.2.1 indicates that the model that best fitted the Redshank resighting data was one where both the survival rate 'ϕ' and the resighting probability 'p' varied with time. Likelihood Ratio Tests (LRTs) showed that survival varied most significantly with time (χ^2_9 = 28.06, P = 0.0009), and that having accounted for this, p did also (χ^2_8 = 17.04, P = 0.0297).

Resulting survival and resighting probability estimates from this model are shown in Table 7.2.2.

Winter survival was estimated at 0.994 (s.e. = 0.021) and 0.993 (s.e. = 0.016) in the two winters prior to barrage-closure, but fell significantly (LRT: χ^2_1 = 6.27, P = 0.0123) to 0.918 (s.e. = 0.027) in the winter of 1999/2000, immediately after closure. The survival rate over the winter of 2000/01 of 0.897 (s.e. = 0.036) was also significantly lower than those over the two winters prior to barrage-closure (χ^2_1 = 7.10, P = 0.0077).

The return rates over the summers of 2000 and 2001 were calculated to be 0.867 (s.e. = 0.035) and 0.807 (s.e. = 0.046) respectively. These rates did not differ significantly from those over the three summers prior to barrage-closure (for 2000: χ^2_1 = 0.04, ns; for 2001: χ^2_1 = 0.95, ns).

Annual survival, calculated as the product of ϕ_{wt} and ϕ_{st}, was 0.818 over the winter of 1997/98 and the summer of 1998 and 0.864 the following year. However, annual survival fell to 0.796 the year after barrage-closure and further to 0.723 the next year.

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 – as far as the River Usk at Newport (18 individuals) or the River Axe in Somerset (one individual) across the mouth of the River Severn. In the winters of 2000/01 and 2001/02, colour-ringed Redshank were again most commonly seen at the Rhymney Estuary, though none were seen on the River Usk and only one each winter in Somerset. The proportions of colour-ringed birds observed in flocks of Redshank at Rhymney were slightly lower than in 1999/2000, probably due to the addition of unringed juvenile birds to the population, though still higher than prior to barrage-closure. These observations and the increase in counts of Redshank at Rhymney indicate 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 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 winters of 2000/01 and 2001/02, birds primarily used the Heliport area on the ebb tide whilst en route to the Rhymney River. A maximum of 42 Redshank was observed at the Heliport in the winter of 2001/02 in comparison to 68 in 2000/01 and 79 in 1999/2000. Results from 1999/2000 and 2000/01 indicated that approximately 45% of the Redshank that used the mudflats were colour-ringed, a similar percentage to that recorded in the Bay prior to closure, suggesting that almost all these birds were from the Bay.

The mudflats by the Heliport are situated by a sewage outfall pipe and due to the high organic and nutrient input from sewage are 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, previous analysis of biometric data revealed that adult Redshank from the Bay had difficulty maintaining their body condition in the first winter following closure (Burton *et al.* 2001b). 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 of 92% was significantly lower than the 99% recorded in each of the two winters preceding barrage-closure. Had the weather during the winter of 1999/2000 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, 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 (Appendix 2) and no colour-ringed birds detected. If birds did move to sites further afield, not covered by surveys, it is perhaps more probable that they would have done this after the 2000 breeding season. Return rates over the summer of 2000 were no lower than those over the three summers that preceded barrage-closure, however, and thus it seems that this did not happen.

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). Although the actual population of Redshank at Rhymney increased from 1999/2000 to 2000/01, as birds ceased using more distant areas, the estimated survival rate of birds displaced from the Bay remained at a similar level – also significantly lower than in the two winters preceding barrage-closure.

Although winter survival rates thus did fall following barrage-closure, it should be noted that the annual survival rates of 80% and 72% calculated for the two years following closure are 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.

Continued study will help to show whether or not the survival rate remained 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	Maximum WeBS count at Cardiff Bay - winter 2001/02
Shelduck *Tadorna tadorna*	2500	750	International	177	14	44	4
Teal *Anas crecca*	4000	1400	National	70	12	28	50
Mallard *Anas platyrhynchos*	20000	5000	-	155	37	67	38
Pintail *Anas acuta*	700	280	International	0	0	0	0
Pochard *Aythya ferina*	3500	440	National	33	2	64	350
Oystercatcher *Haematopus ostralegus*	9000	3600	-	60	0	2	0
Ringed Plover *Charadrius hiaticula*	500	290	-	5	0	0	0
Grey Plover *Pluvialis squatarola*	1500	430	National	0	0	0	0
Lapwing *Vanellus vanellus*	20000	20000	National	17	1	45	0
Knot *Calidris canutus*	3500	2900	-	0	0	0	0
Dunlin *Calidris alpina*	14000	5300	International	4500	0	55	1
Curlew *Numenius arquata*	3500	1200	National	137	8	30	0
Redshank *Tringa totanus*	1500	1100	International	352	0	0	3
Turnstone *Arenaria interpres*	700	640	-	48	21	37	0

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, 2000/01 and 2001/02.

	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	$F_{6,2102} = 32.4$ $P < 0.0001$	$F_{6,2102} = 6.2$ $P < 0.0001$	$F_{1,2102} = 9.7$ $P = 0.0019$	ns	$F_{12,2102} = 9.5$ $P < 0.0001$
Rhymney	$F_{8,28657} = 648.5$ $P < 0.0001$	$F_{11,28657} = 55.0$ $P < 0.0001$	$F_{16,28657} = 456.2$ $P < 0.0001$	-	$F_{13,28657} = 37.5$ $P < 0.0001$

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 2001/02. 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. '–' indicates that the model did not converge if this term was included.

Month	Mudflat	Year
$F_{4,459} = 5.1$ $P = 0.0005$	$F_{7,459} = 24.6$ $P < 0.0001$	$F_{9,459} = 2.8$ $P = 0.0032$

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 2001/02.

	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	$F_{6,1946}$ = 28.1 P < 0.0001	$F_{6,1946}$ = 11.0 P < 0.0001	$F_{1,1946}$ = 187.0 P < 0.0001	ns	$F_{12,1946}$ = 18.7 P < 0.0001
Rhymney	$F_{8,24535}$ = 377.3 P < 0.0001	$F_{11,24535}$ = 36.9 P < 0.0001	$F_{16,24535}$ = 172.5 P < 0.0001	-	$F_{13,24535}$ = 104.0 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 2001/02. 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. '–' indicates that models did not converge if this term was included.

Month	Mudflat	Year
$F_{4,459} = 17.6$ $P < 0.0001$	$F_{7,459} = 18.8$ $P < 0.0001$	$F_{9,459} = 22.0$ $P < 0.0001$

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 2001/02.

	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	$F_{9,3055}$ = 125.8 P < 0.0001	$F_{6,3055}$ = 52.4 P < 0.0001	$F_{1,3055}$ = 119.4 P < 0.0001	ns	$F_{13,3055}$ = 6.6 P < 0.0001
Rhymney	$F_{9,31901}$ = 107.0 P < 0.0001	$F_{11,31901}$ = 2.8 P = 0.0013	$F_{16,31901}$ = 28.8 P < 0.0001	$F_{117,31901}$ = 5.7 P < 0.0001	$F_{13,31901}$ = 34.1 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 2001/02.

Month	Mudflat	Year
$F_{4,459} = 3.8$ $P = 0.0048$	$F_{7,459} = 39.0$ $P < 0.0001$	$F_{9,459} = 9.9$ $P < 0.0001$

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 2001/02.

	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	$F_{8,24297} = 110.0$ $P < 0.0001$	$F_{11,24297} = 7.1$ $P < 0.0001$	$F_{16,24297} = 130.1$ $P < 0.0001$	ns	$F_{13,24297} = 23.6$ $P < 0.0001$

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 2001/02. 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
$F_{4,395} = 2.6$ $P = 0.0377$	$F_{6,395} = 9.2$ $P < 0.0001$	$F_{9,395} = 2.1$ $P = 0.0287$

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 2001/02.

	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	$F_{9,3049}$ = 107.3 P < 0.0001	$F_{6,3049}$ = 41.8 P < 0.0001	$F_{1,3049}$ = 88.9 P < 0.0001	$F_{6,3049}$ = 17.4 P < 0.0001	$F_{13,3049}$ = 30.4 P < 0.0001
Rhymney	$F_{9,32110}$ = 73.8 P < 0.0001	$F_{11,32110}$ = 18.0 P < 0.0001	$F_{16,32110}$ = 63.9 P < 0.0001	$F_{118,32110}$ = 15.0 P < 0.0001	$F_{13,32110}$ = 37.6 P < 0.0001

Table 3.5.11.1 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 2001/02.

Month	Mudflat	Year
ns	$F_{7,463} = 33.5$ $P < 0.0001$	$F_{9,463} = 2.4$ $P = 0.0113$

Table 3.5.11.2 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 2001/02.

	Test 2	Test 3
A	$\chi^2_{10} = 33.9$, $P = 0.0002$	$\chi^2_{14} = 14.5$, ns
B	$\chi^2_{8} = 12.9$, ns	$\chi^2_{10} = 12.7$, ns

Table 6.2.2.1 Results of goodness-of-fit tests carried out on the Redshank mark-recapture data.
A – using data from February 1996 to February 2002.
B – using data from February 1997 to February 2002.
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	1073.9	0.003	280.4
$\phi\, p_t$	11	1068.5	0.044	256.8
$\phi_t\, p$	11	1064.1	0.409	252.3
$\boldsymbol{\phi_t\, p_t}$	**19**	**1063.5**	**0.545**	**235.3**

Table 7.2.1 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 2002. 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
PRE-CLOSURE			
1997	Over-summer return rate	43	0.885 (0.058)
1997/98	Over-winter survival rate	55	0.994 (0.021)
1998	Over-summer return rate	73	0.823 (0.053)
1998/99	Over-winter survival rate	77	0.993 (0.016)
1999	Over-summer return rate	122	0.870 (0.038)
POST-CLOSURE			
1999/2000	Over-winter survival rate	193	0.918 (0.027)
2000	Over-summer return rate	167	0.867 (0.035)
2000/01	Over-winter survival rate	129	0.897 (0.036)
2001	Over-summer return rate	131	0.807 (0.046)

Table 7.2.2. 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.

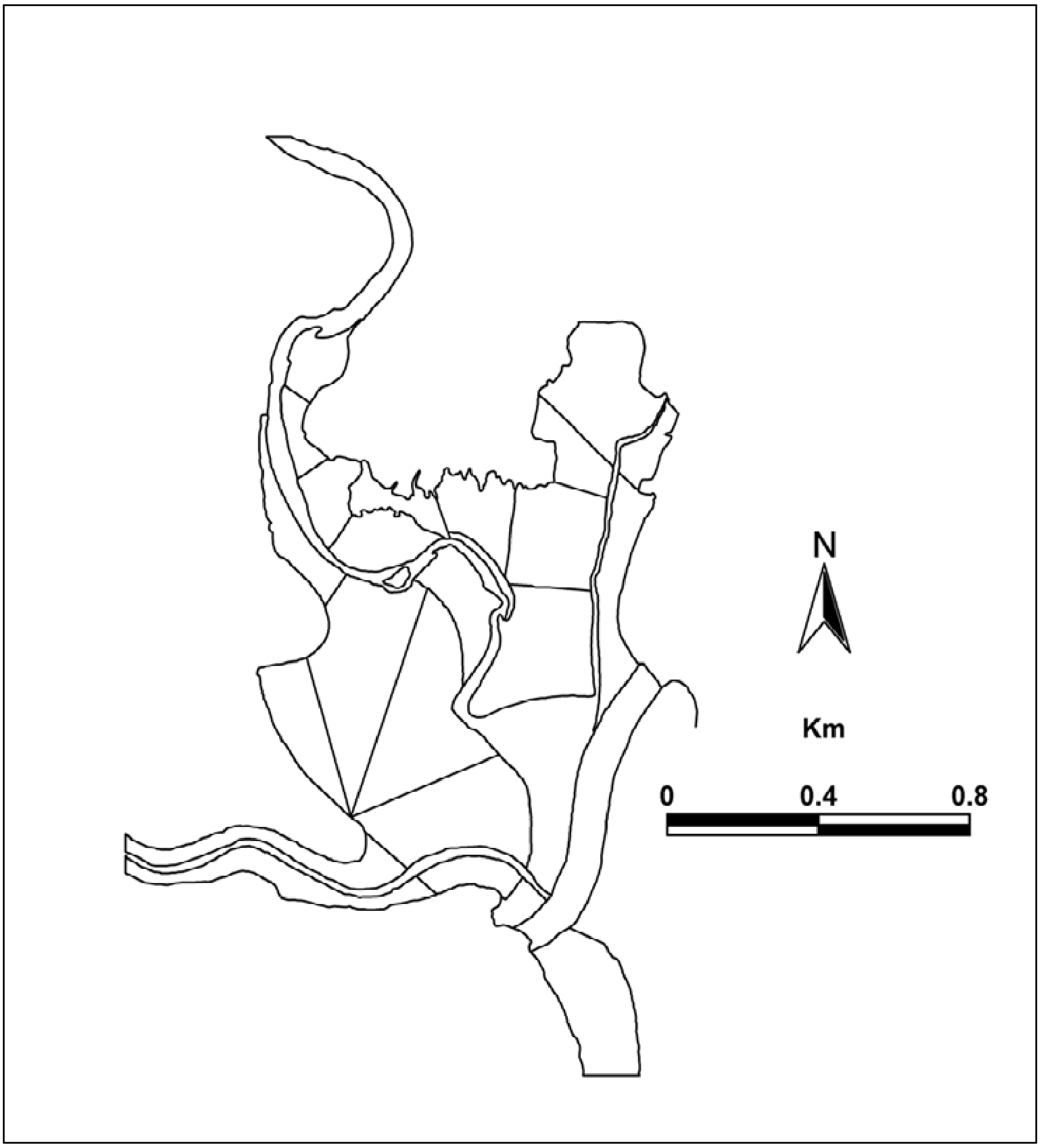


Figure 2.1.1 The Cardiff Bay study site showing mudflat areas counted in autumn 1999, prior to barrage-closure.

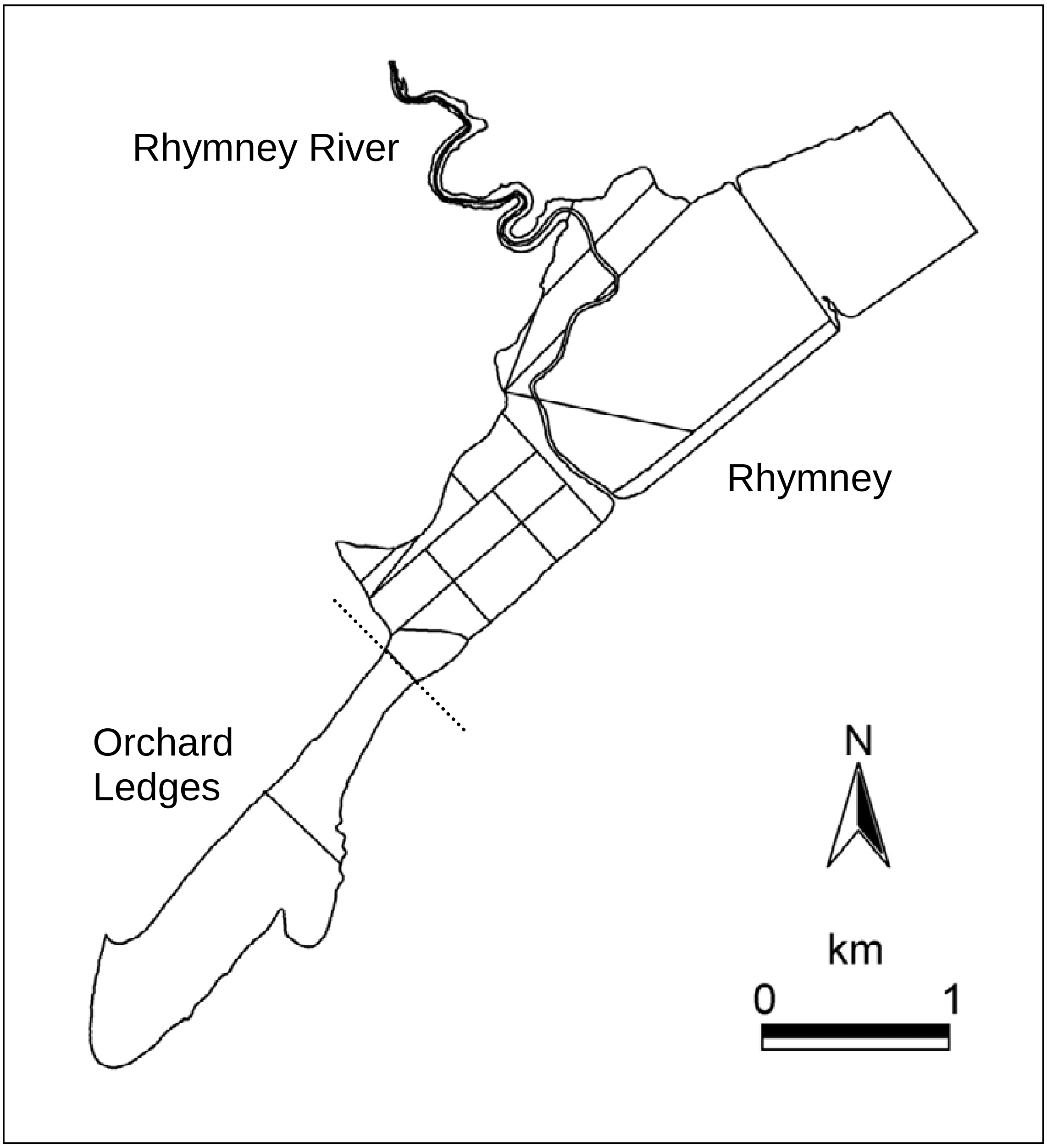


Figure 2.1.2 The Rhymney and Orchard Ledges study sites showing mudflat count areas.

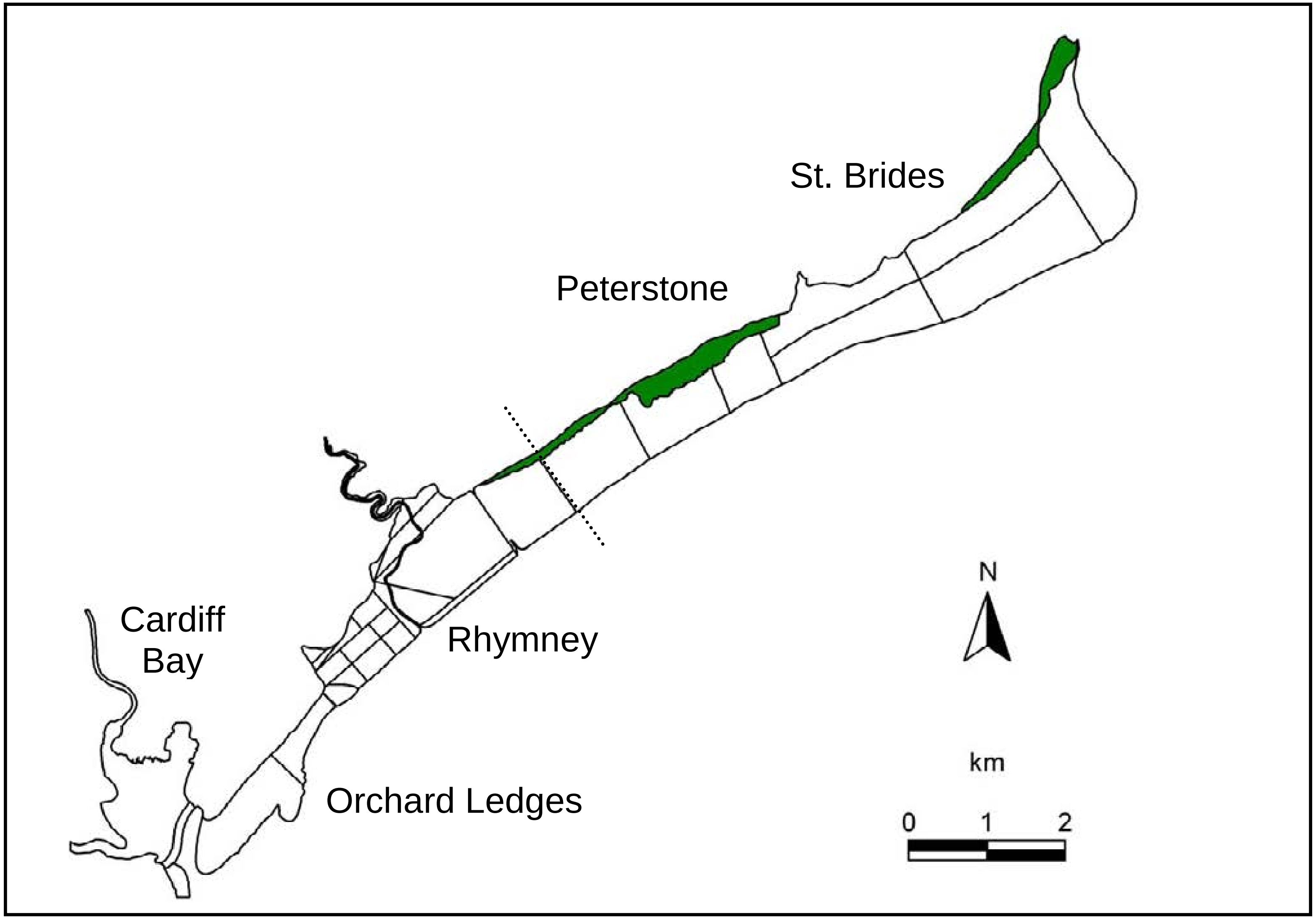


Figure 2.2.1 The low tide count areas on the northwest Severn. Areas of saltmarsh not included in the counts are shaded grey.

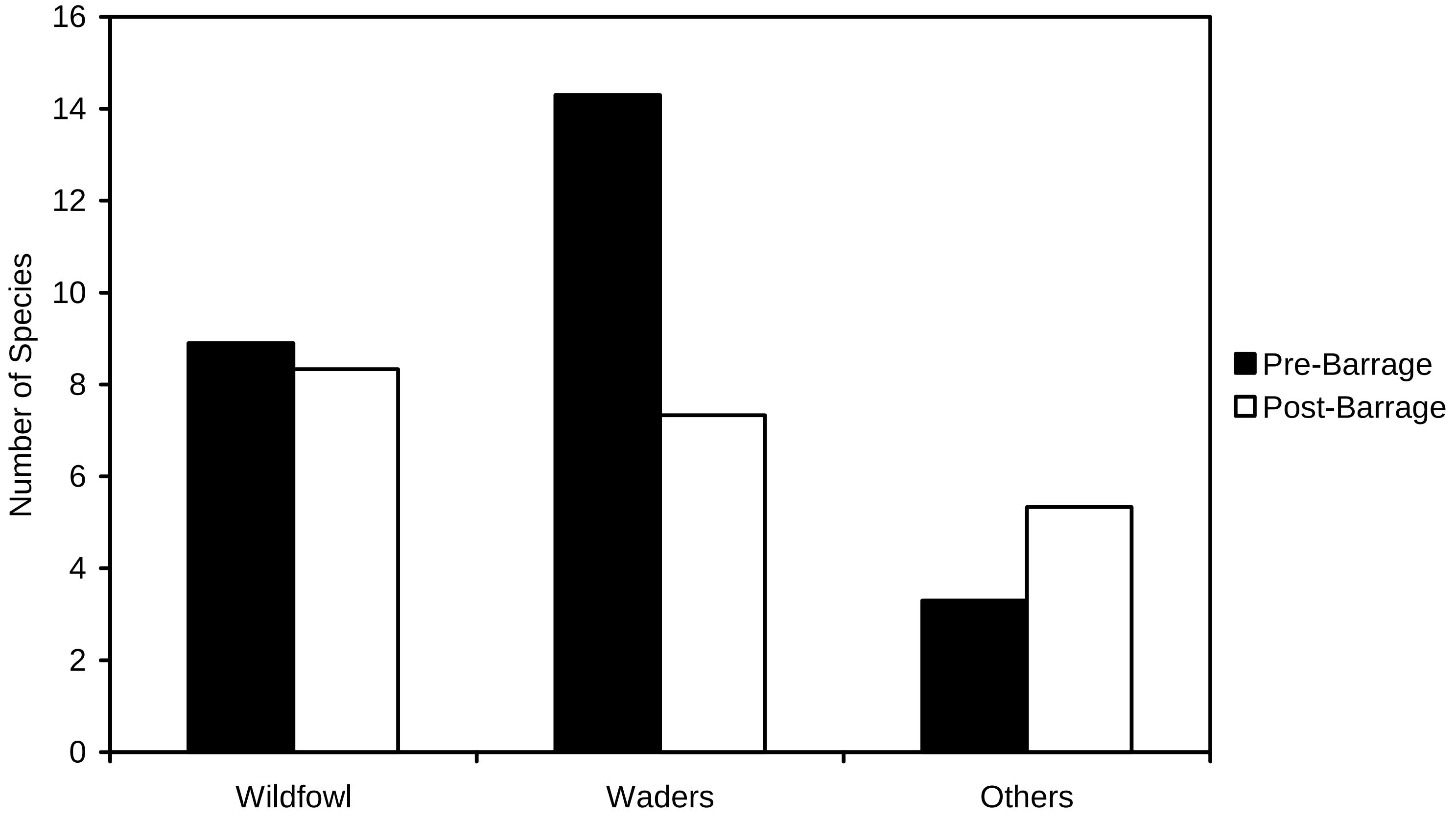


Figure 3.1 Mean numbers of wildfowl, wader and other waterbird species recorded annually at Cardiff Bay before barrage-closure (1989/90 to 1998/99) and after barrage-closure (1999/2000 to 2001/02).

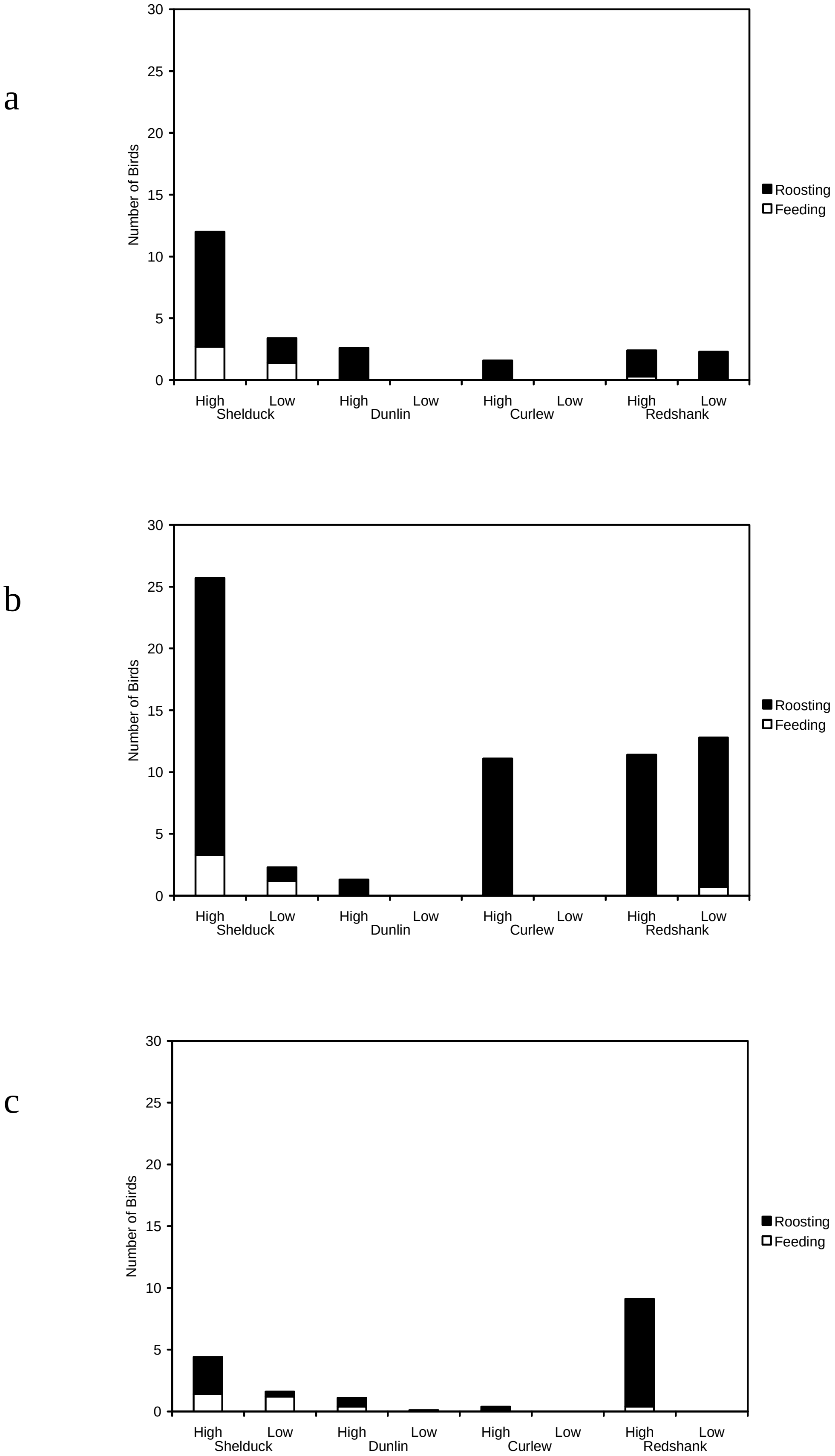


Figure 3.2 Mean numbers of Shelduck, Dunlin, Curlew and Redshank recorded roosting (black sections of columns) and feeding (white sections) in Cardiff Bay at high tide and low tide in the winters of **a.** 1999/2000 **b.** 2000/01 and **c.** 2001/02, following barrage-closure.

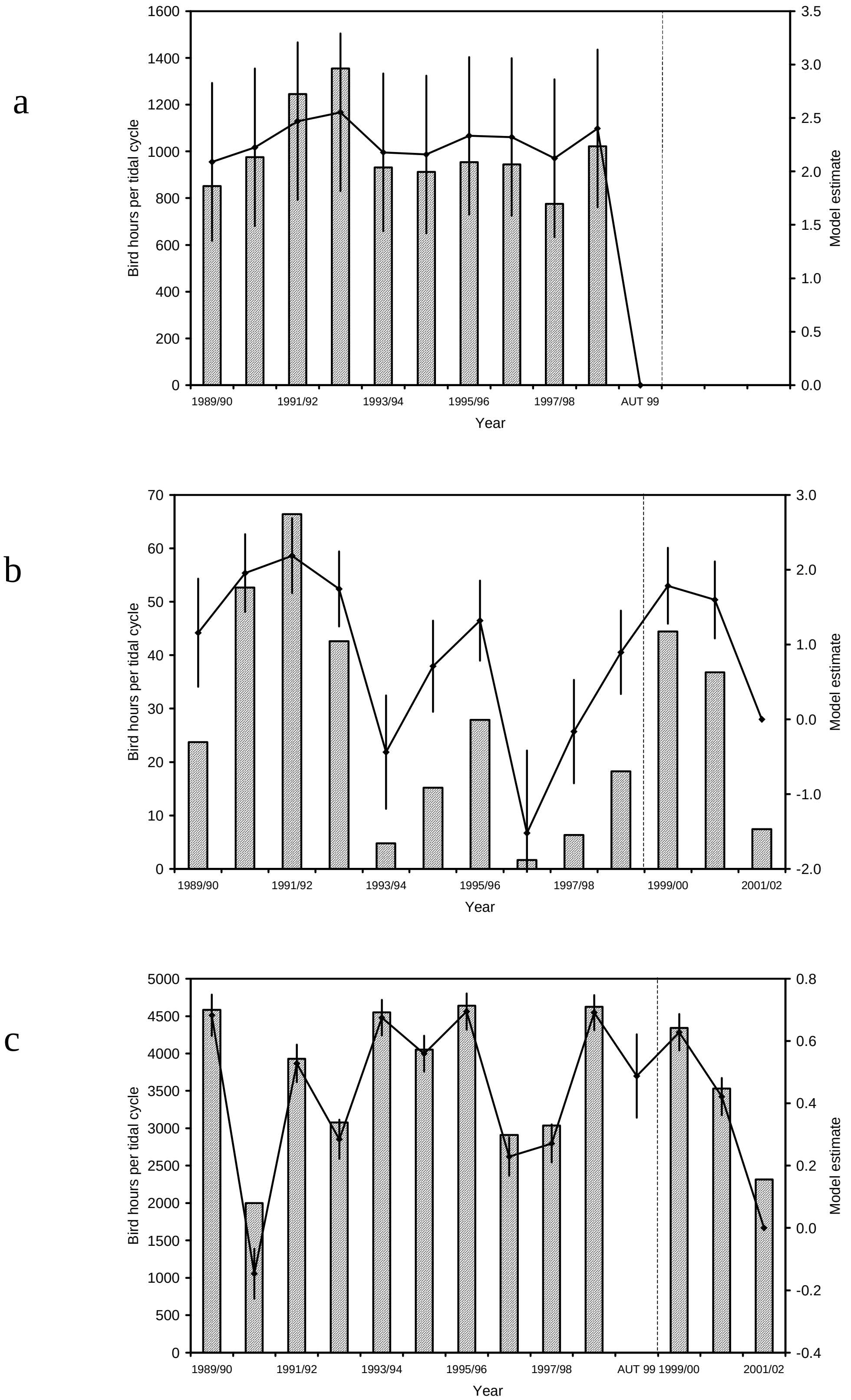


Figure 3.1.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Shelduck at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure;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

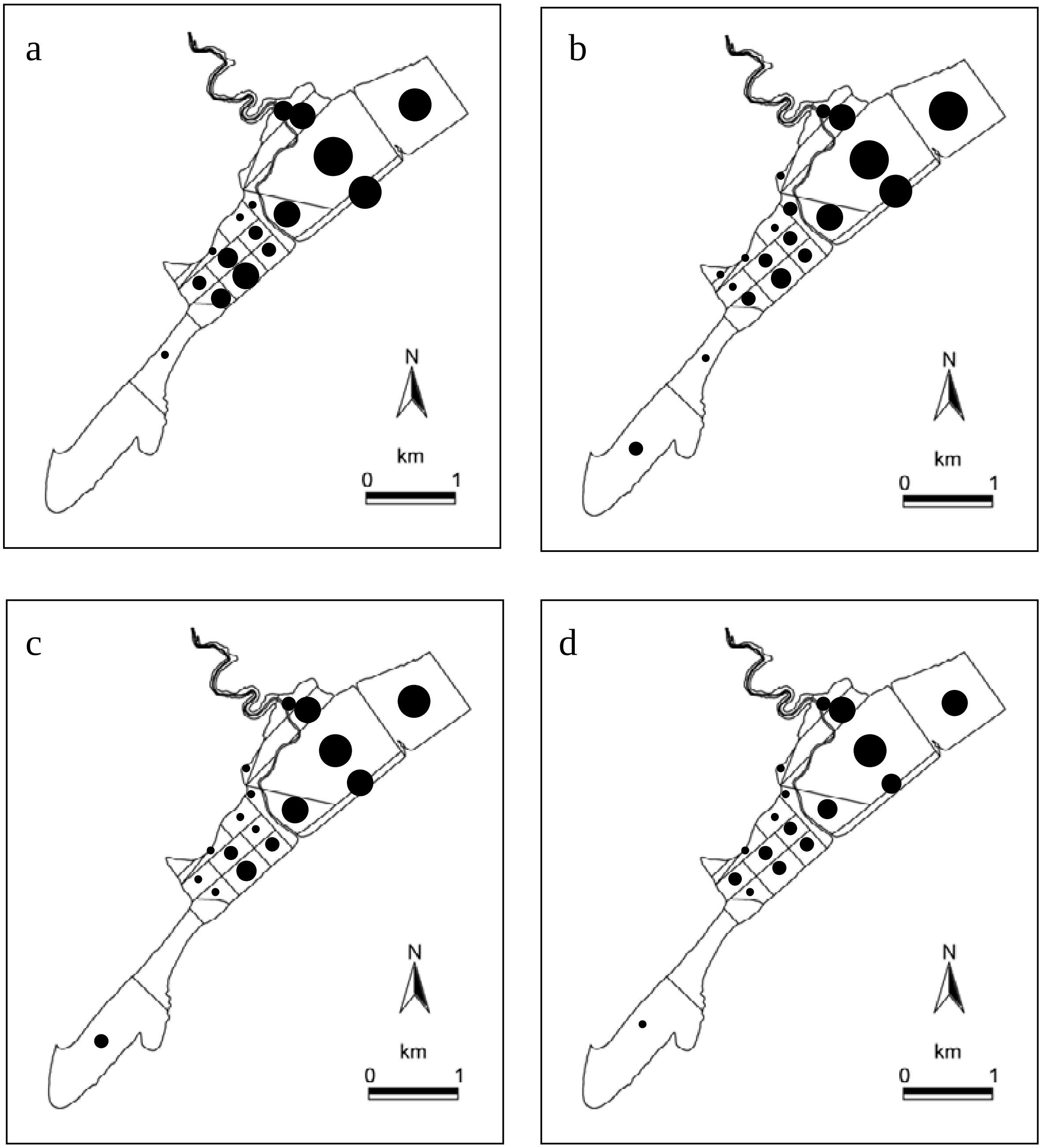


Figure 3.1.2 The distribution of feeding Shelduck on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted.

a = 1998/99; b = 1999/2000; c = 2000/01; d= 2001/02.

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

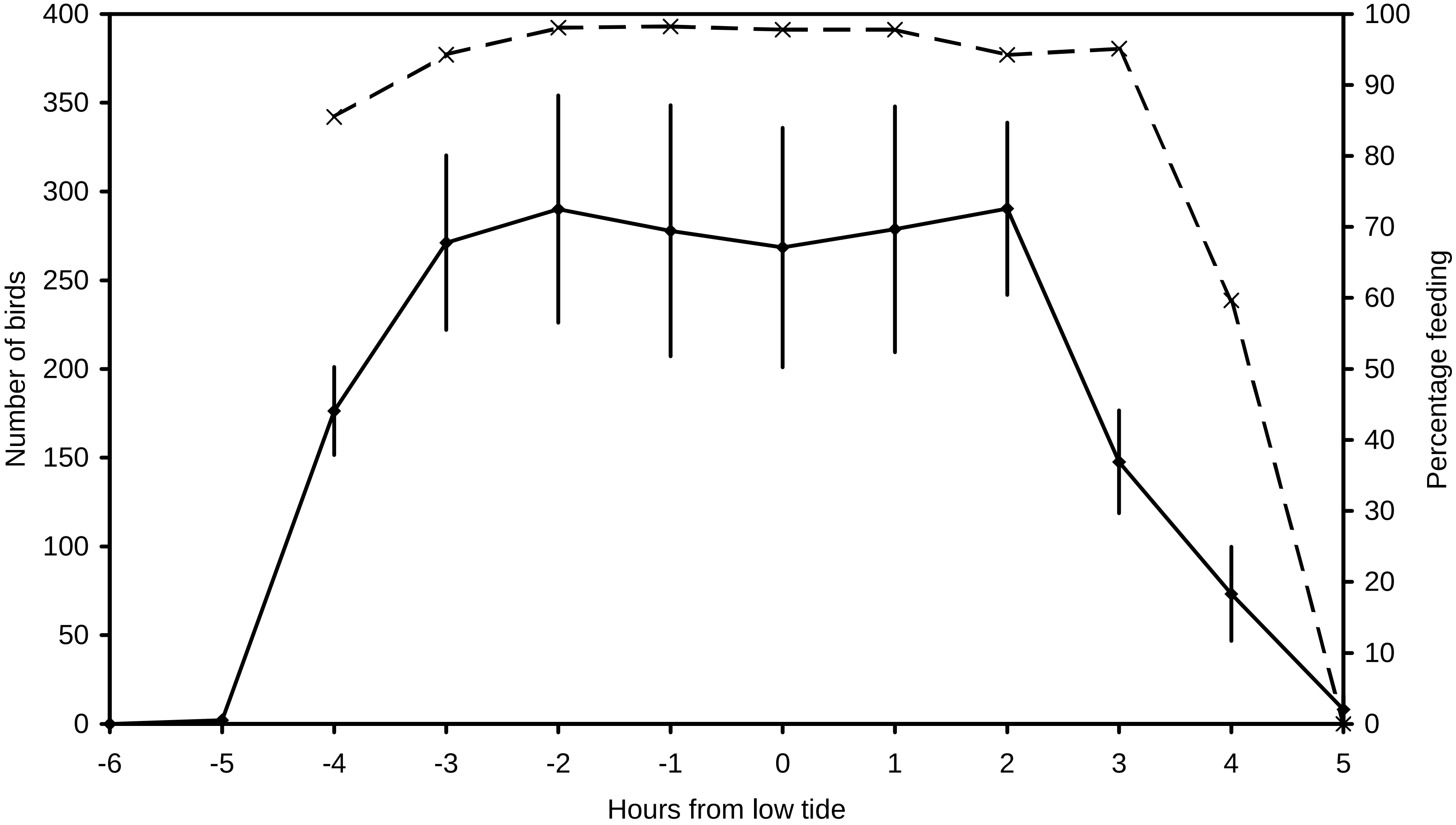


Figure 3.1.3 The total number of Shelduck present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at Rhymney during the winter of 2001/02.

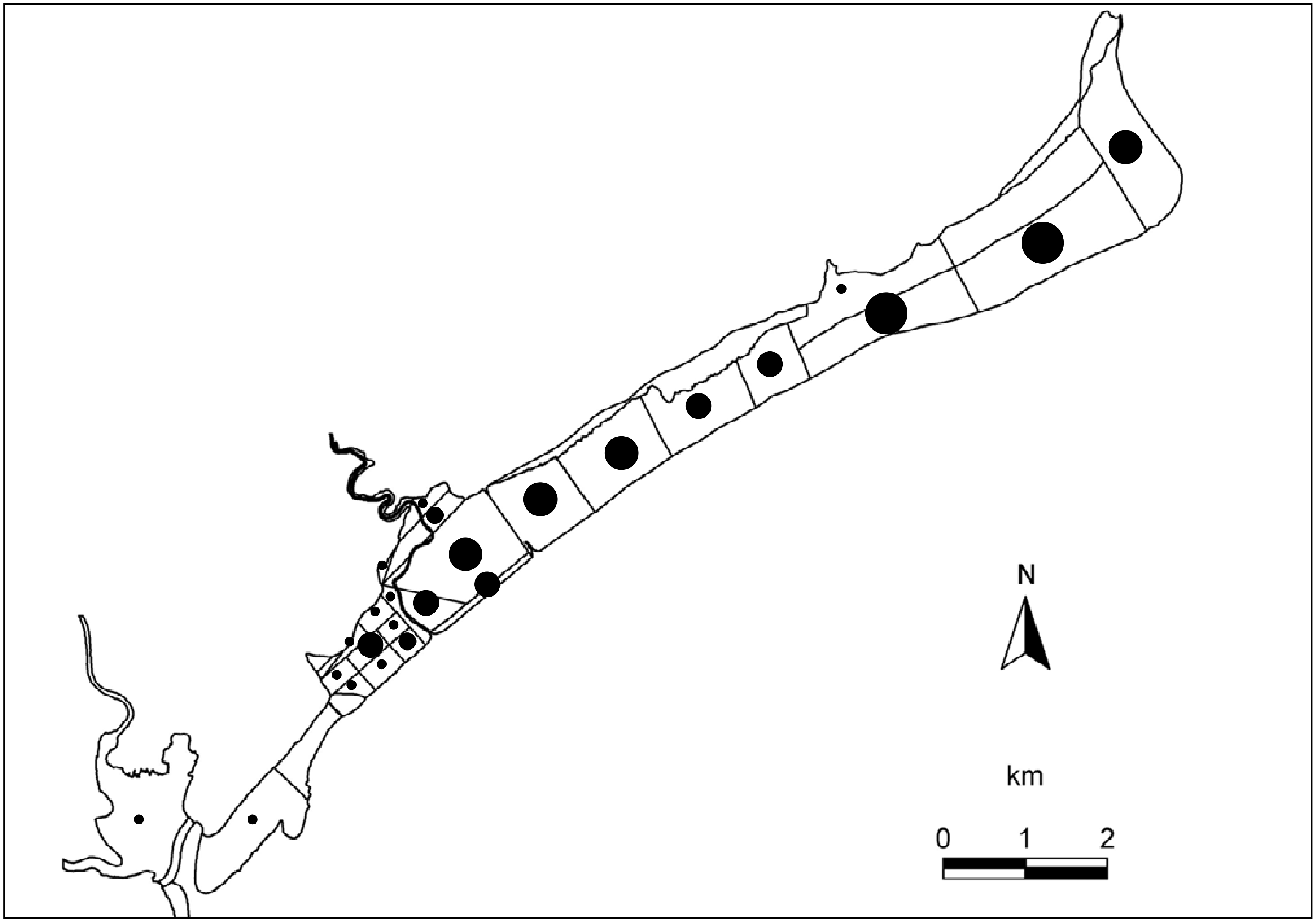


Figure 3.1.4 The low tide distribution of feeding Shelduck on the northwest Severn during the winter of 2001/02.

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

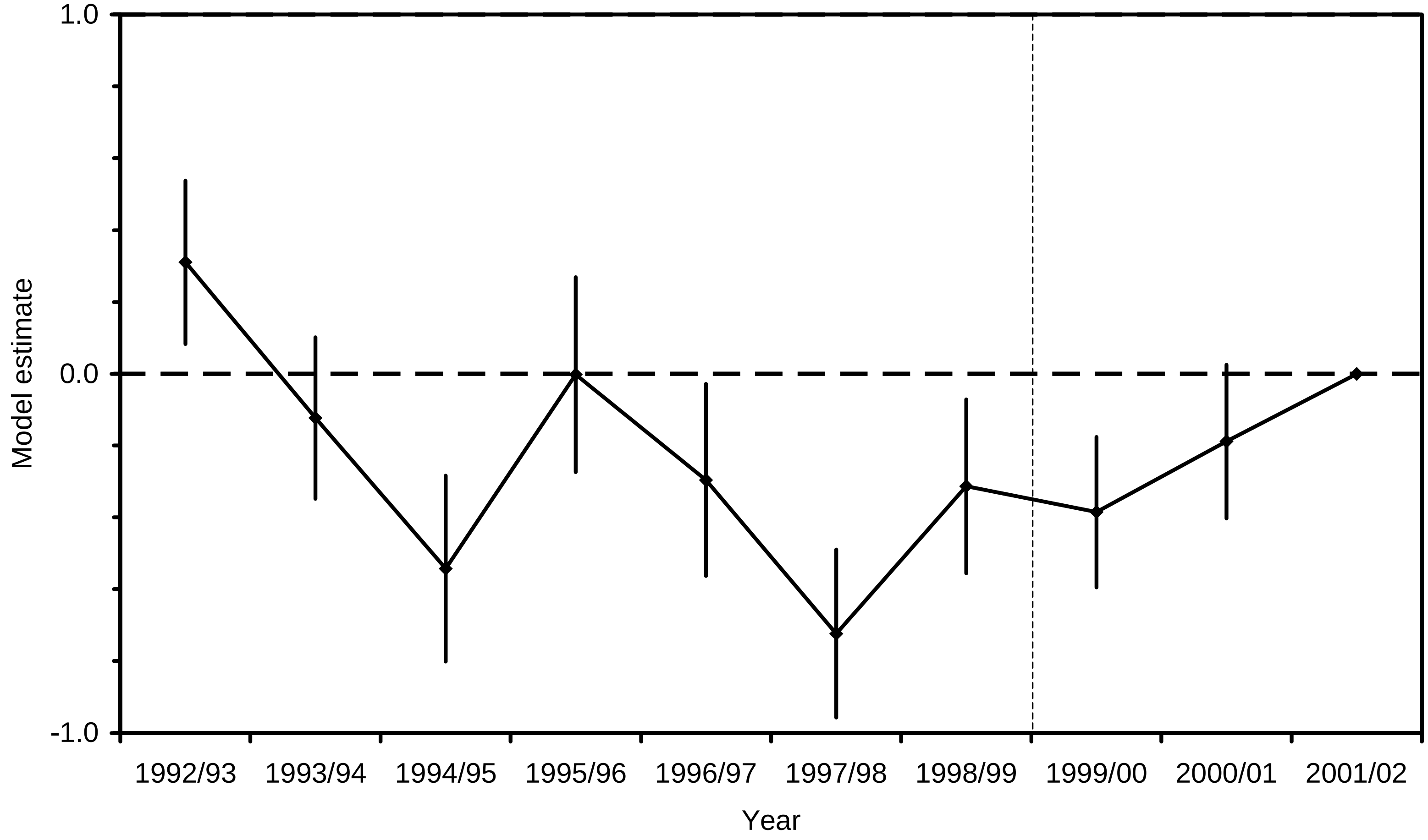


Figure 3.1.5 Estimates for ‘year’ (± 1 SE) in a model relating the densities of feeding Shelduck at low tide at Peterstone and St. Brides to year, month and mudflat.

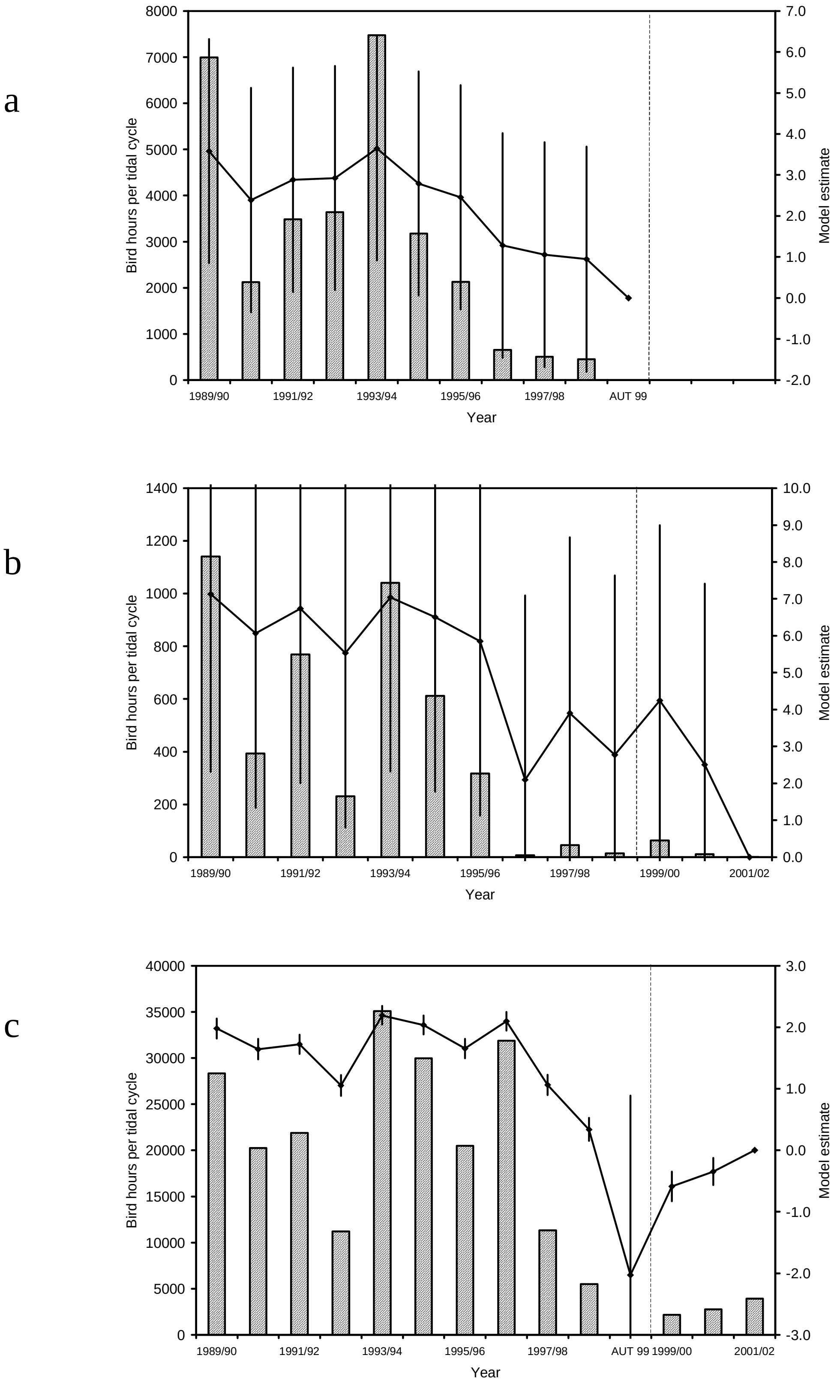


Figure 3.2.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Dunlin at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure;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

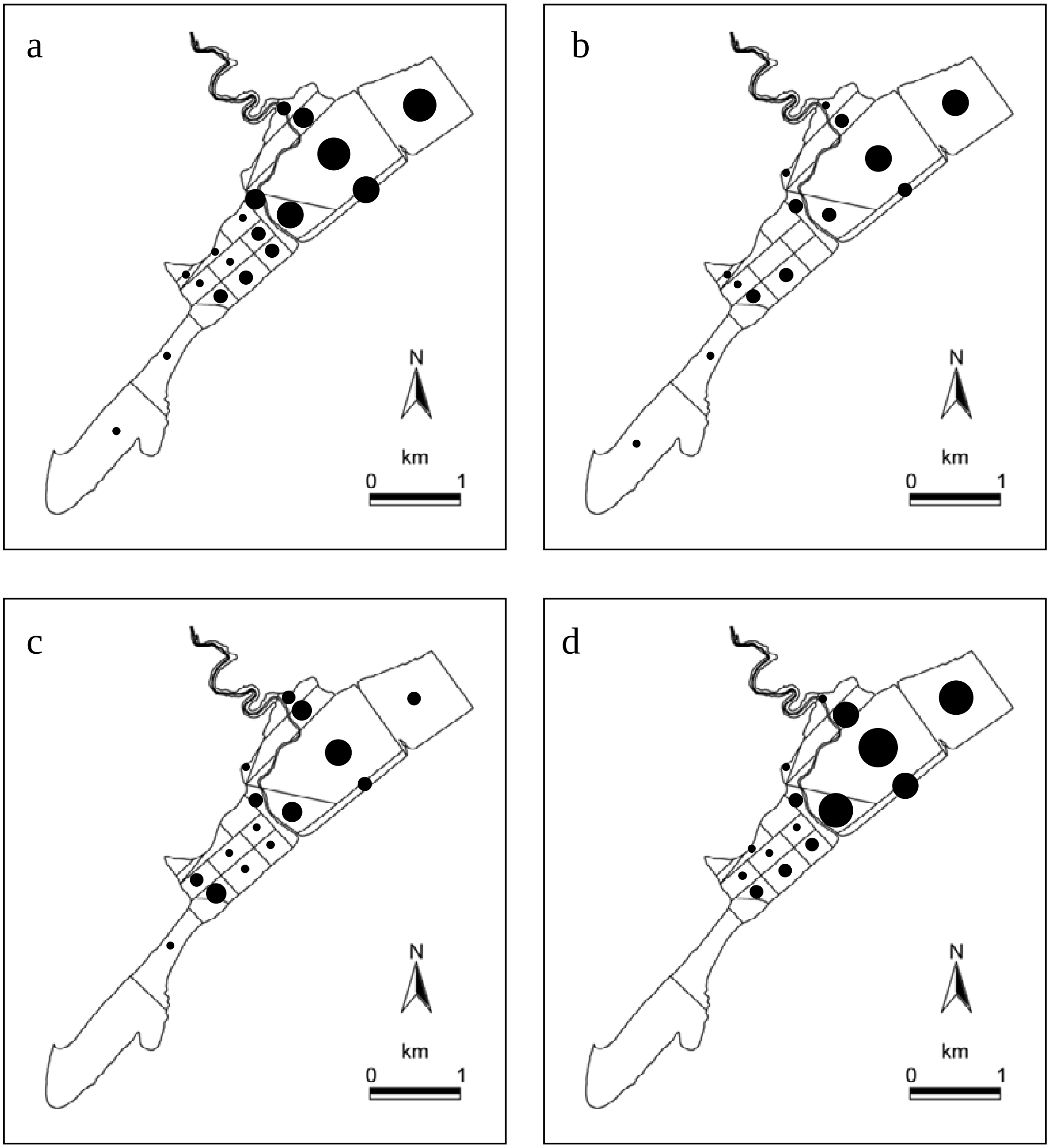


Figure 3.2.2 The distribution of feeding Dunlin on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted.

a = 1998/99; b = 1999/2000; c = 2000/01; d= 2001/02.

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

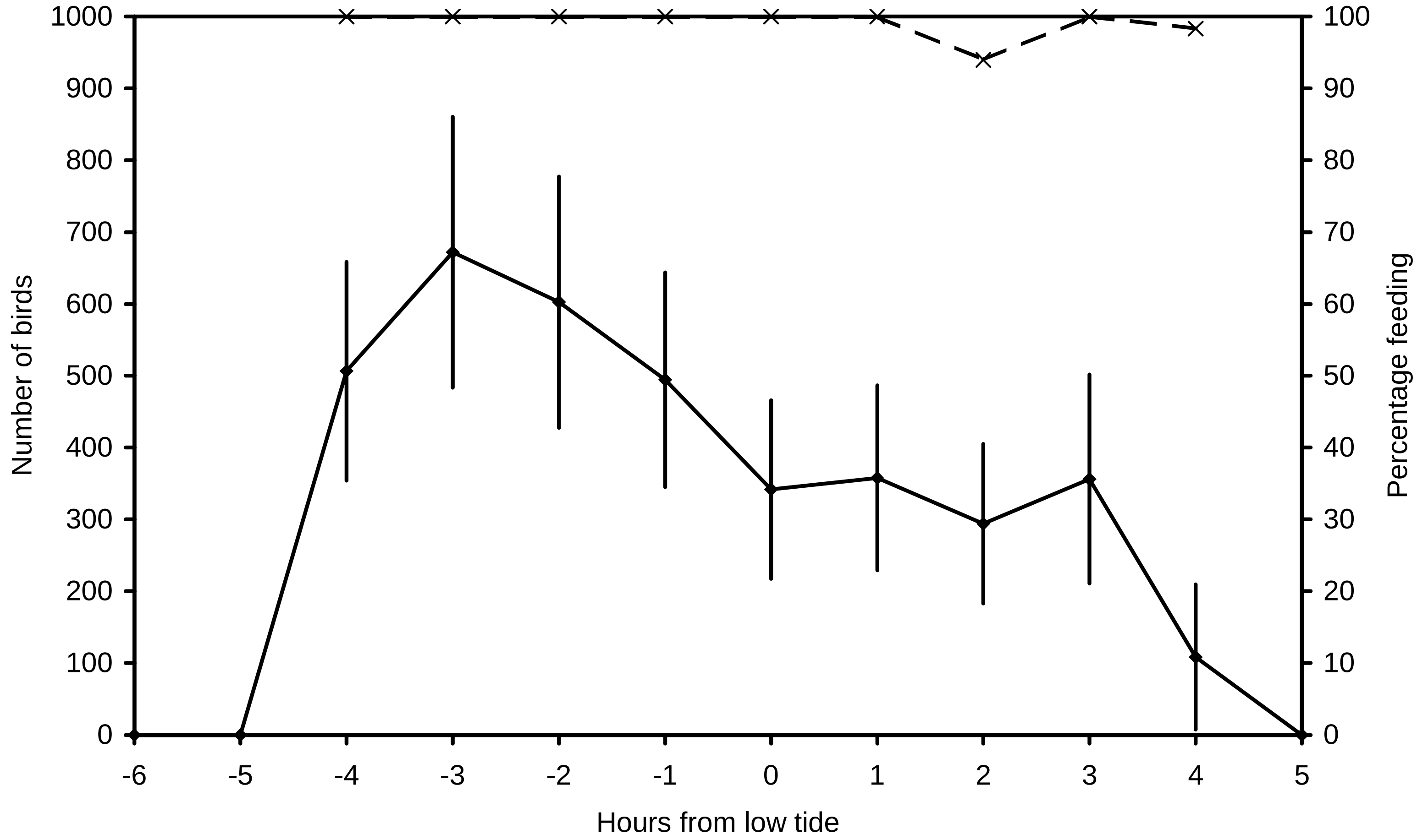


Figure 3.2.3 The total number of Dunlin present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at Rhymney during the winter of 2001/02.

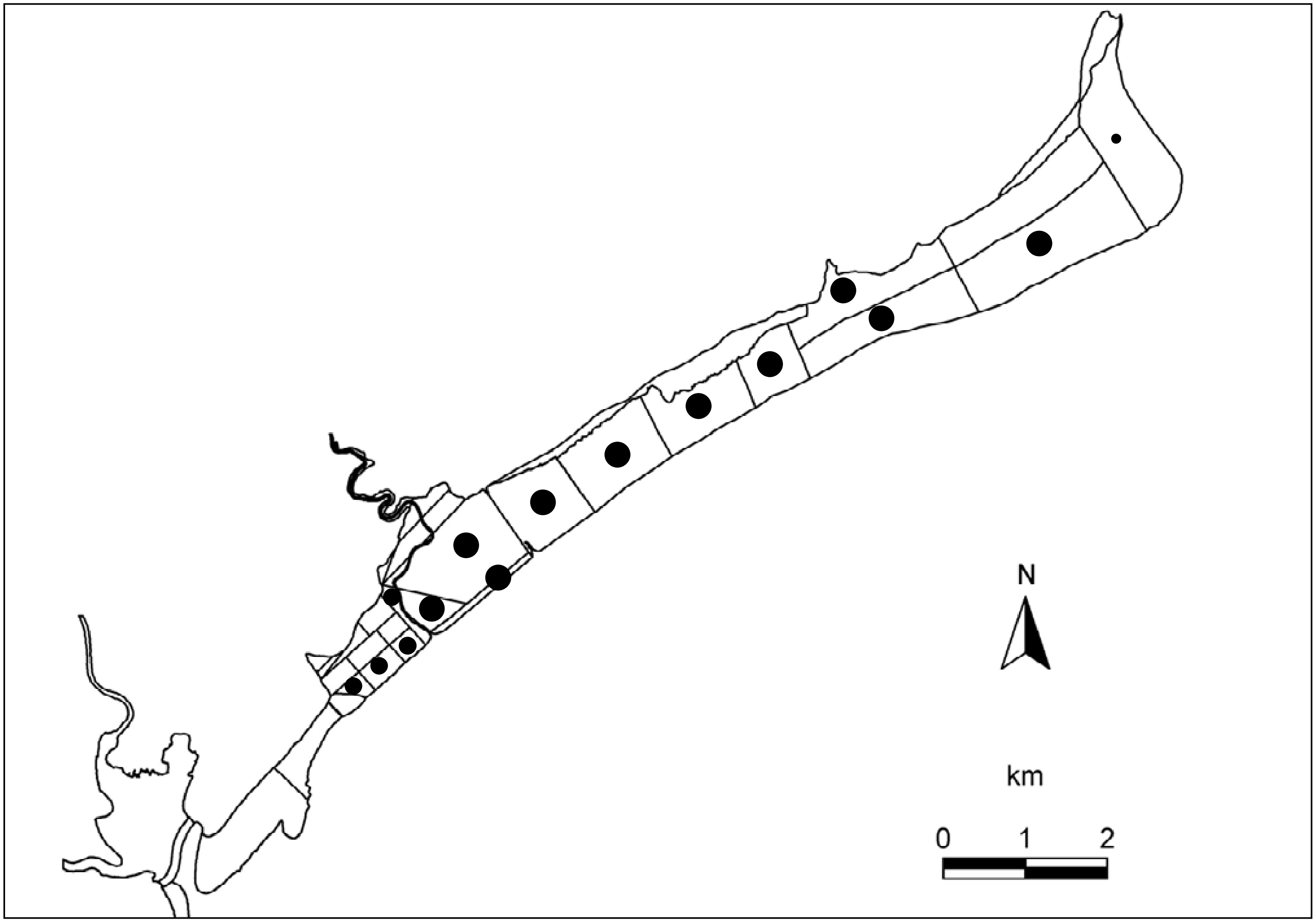


Figure 3.2.4 The low tide distribution of feeding Dunlin on the northwest Severn during the winter of 2001/02.

1-9 10-49 50-249

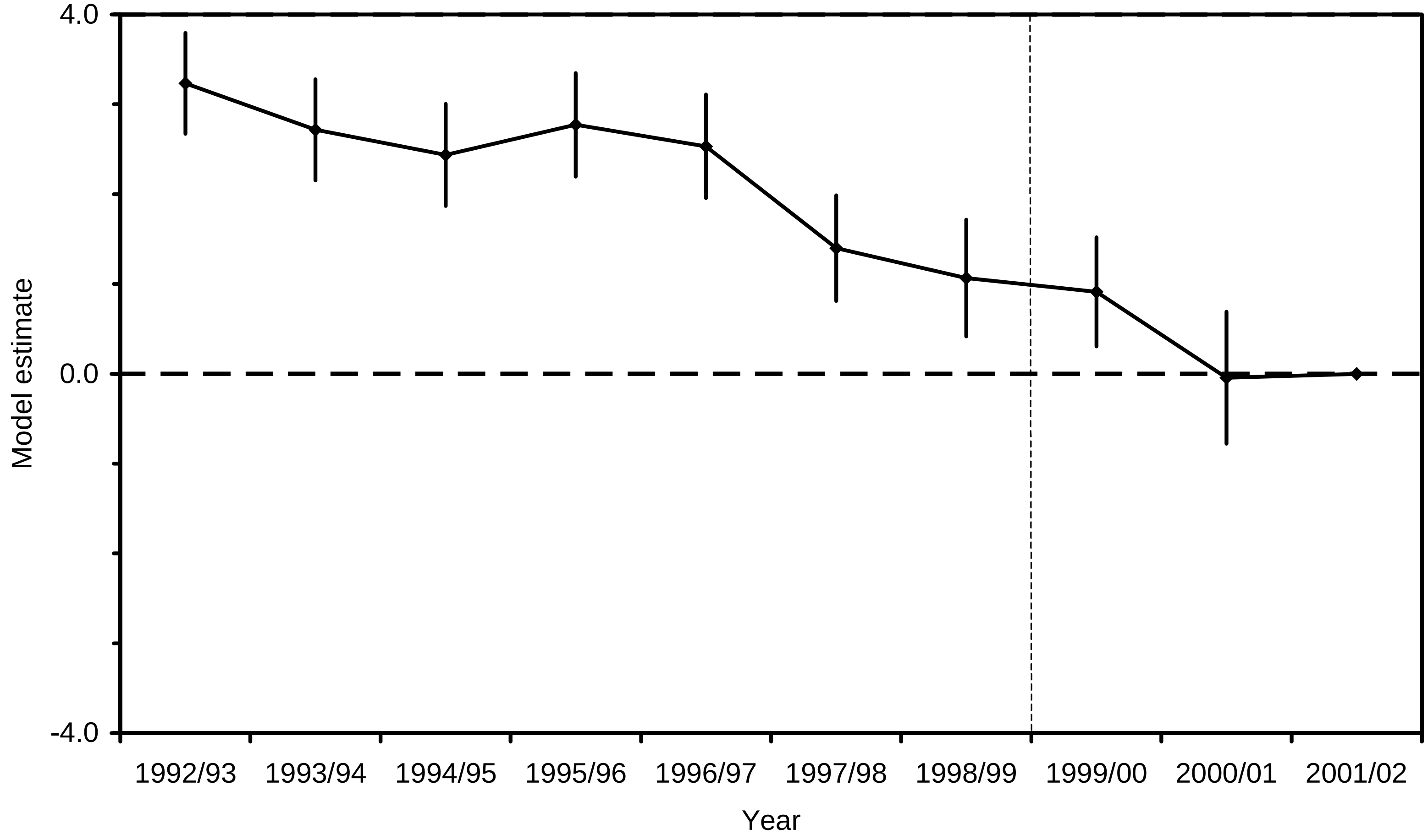
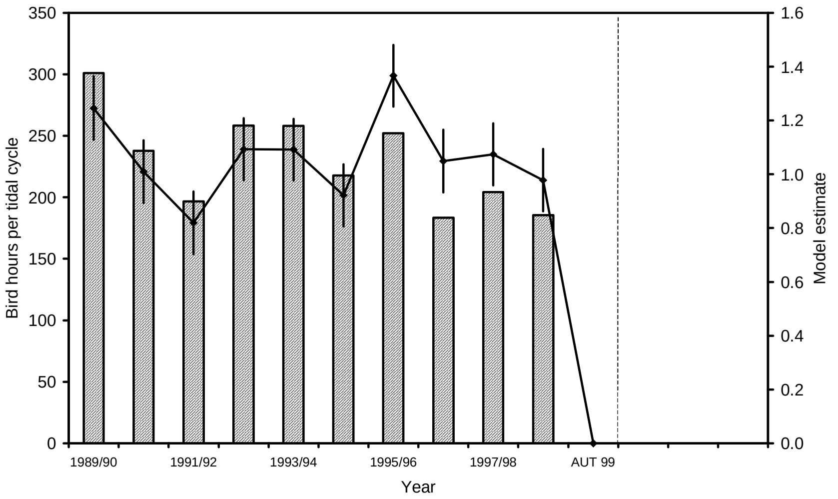
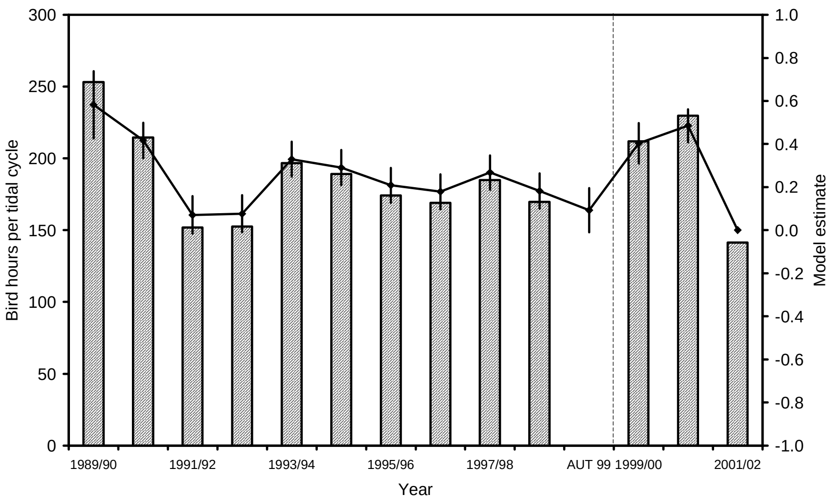


Figure 3.2.5 Estimates for 'year' (± 1 SE) in a model relating the densities of feeding Dunlin at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b



c

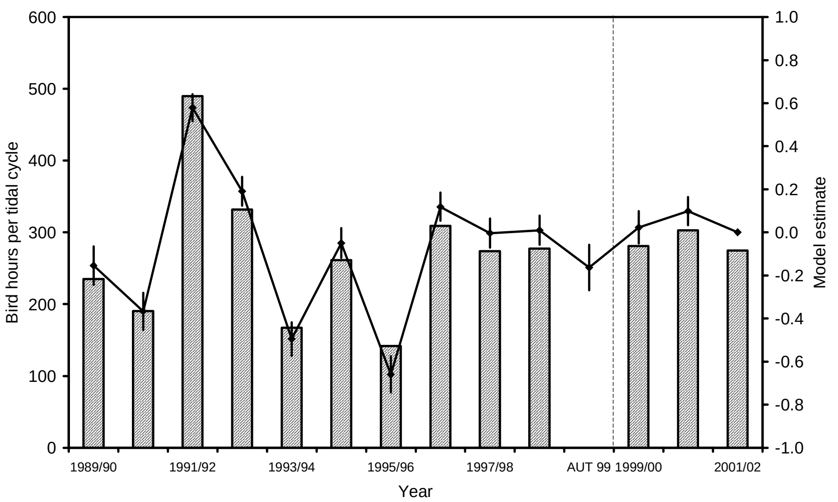


Figure 3.3.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Curlew at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure;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

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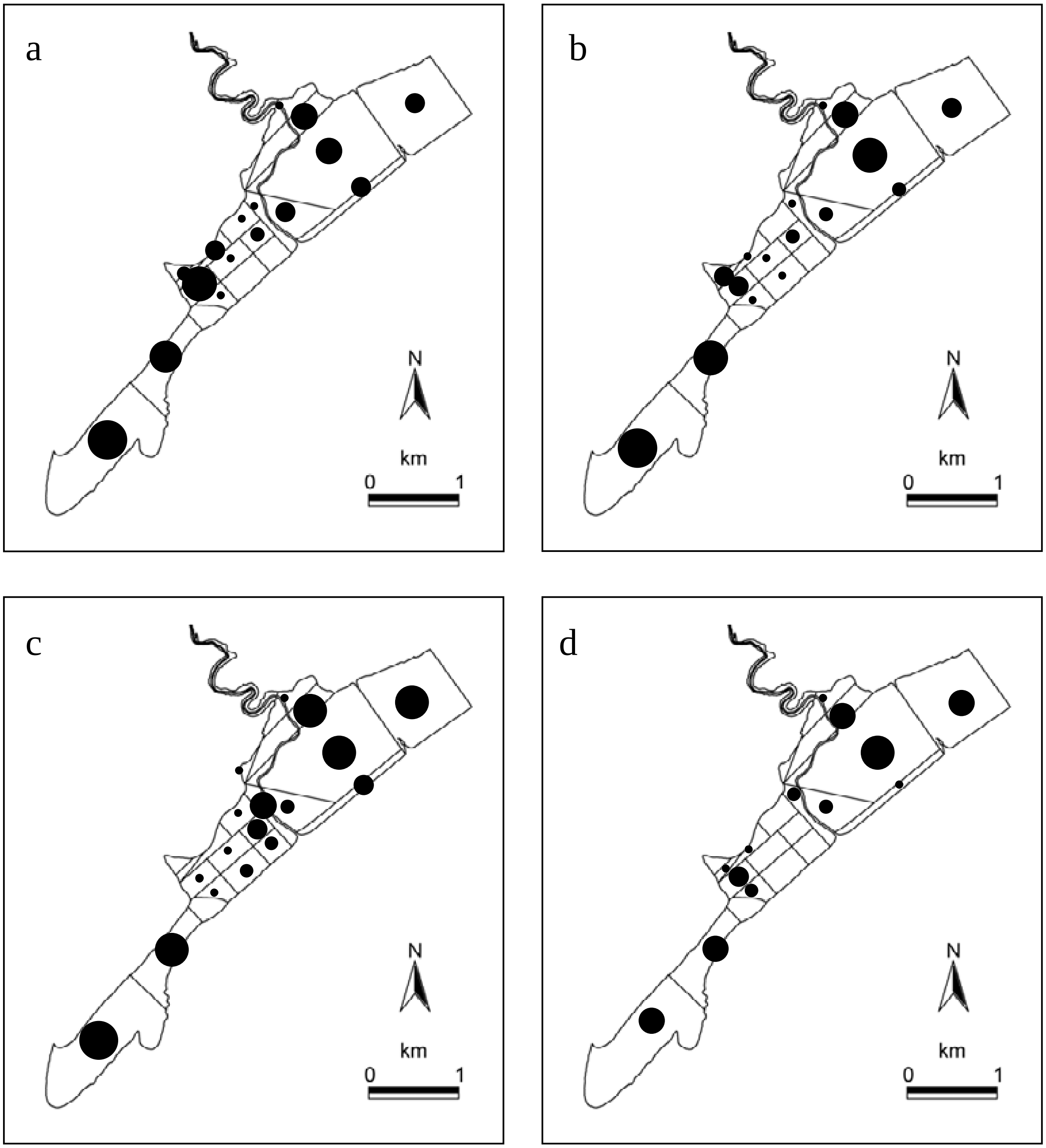


Figure 3.3.2 The distribution of feeding Curlew on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted.

a = 1998/99; b = 1999/2000; c = 2000/01; d= 2001/02.

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

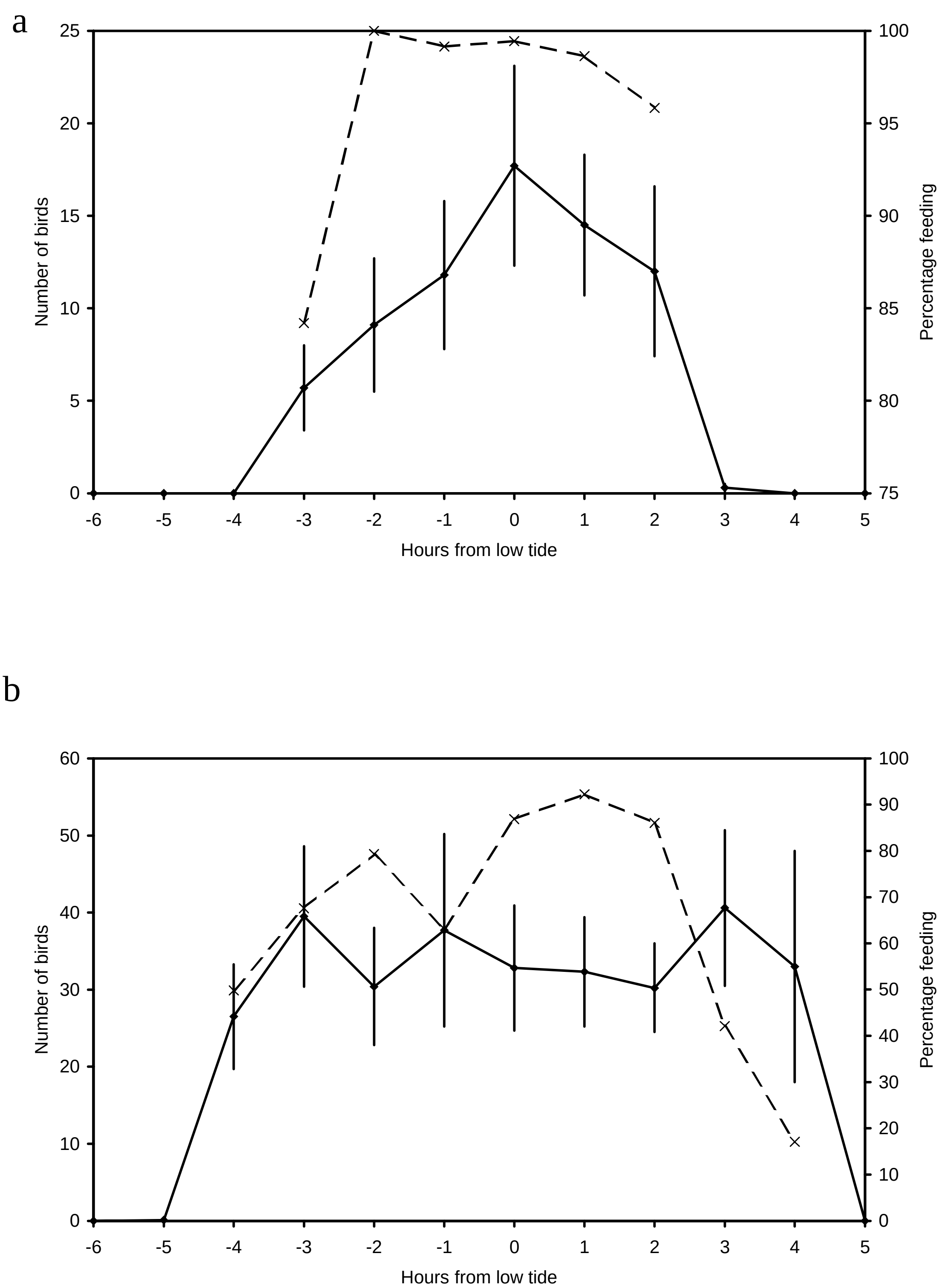


Figure 3.3.3 The total number of Curlew present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at **a.** Orchard Ledges and **b.** Rhymney during the winter of 2001/02.

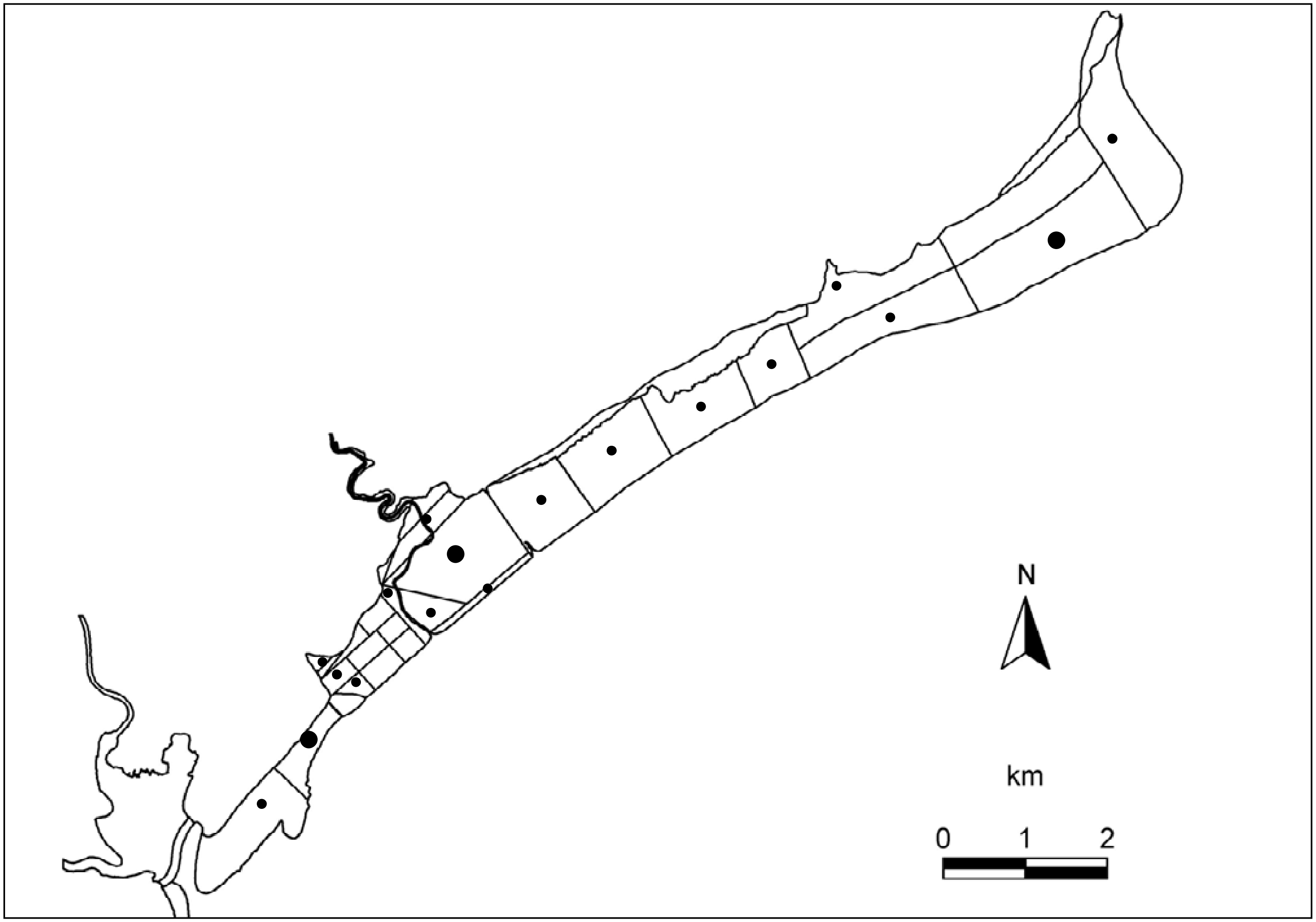


Figure 3.3.4 The low tide distribution of feeding Curlew on the northwest Severn during the winter of 2001/02.

1-9 • 10-24 ●

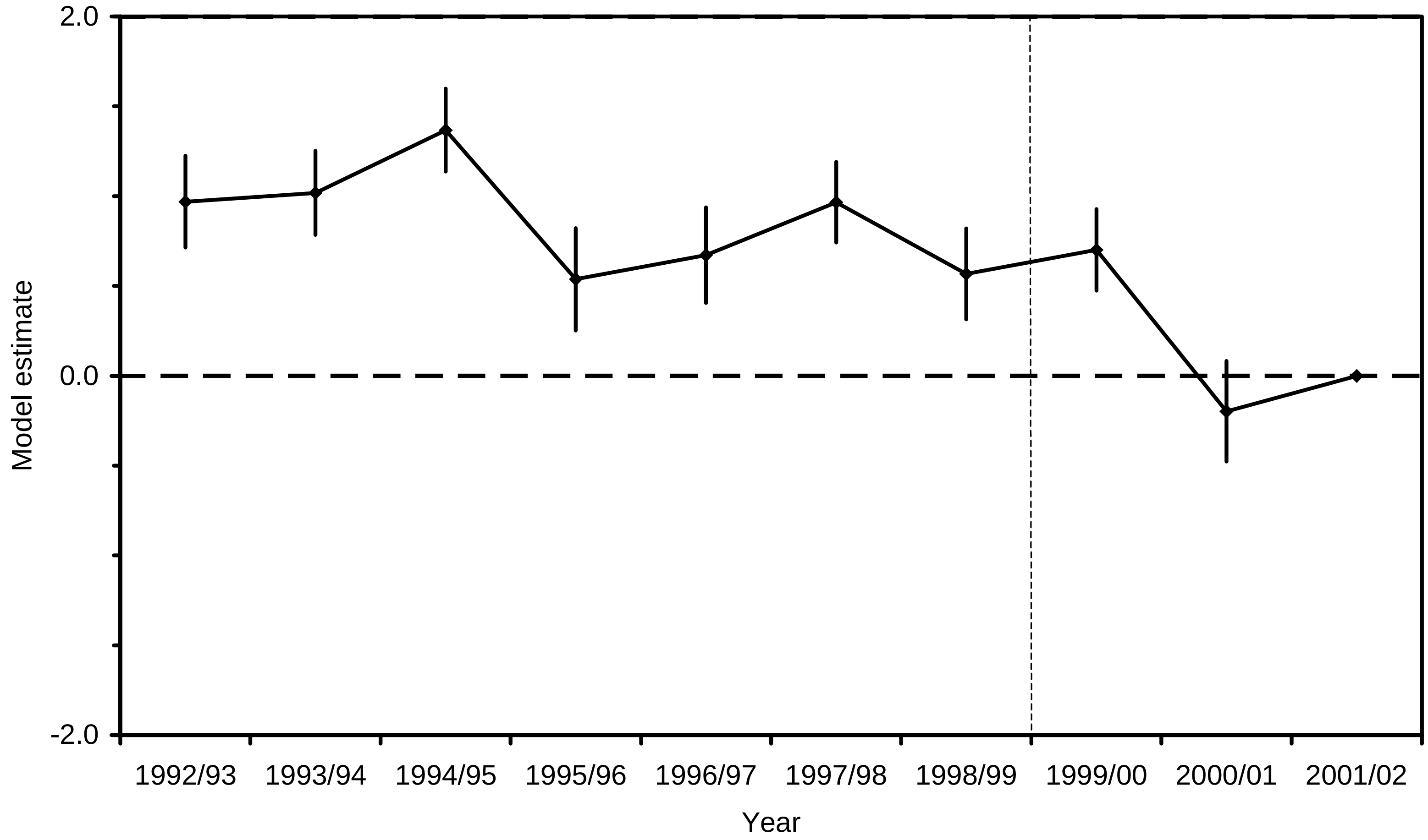
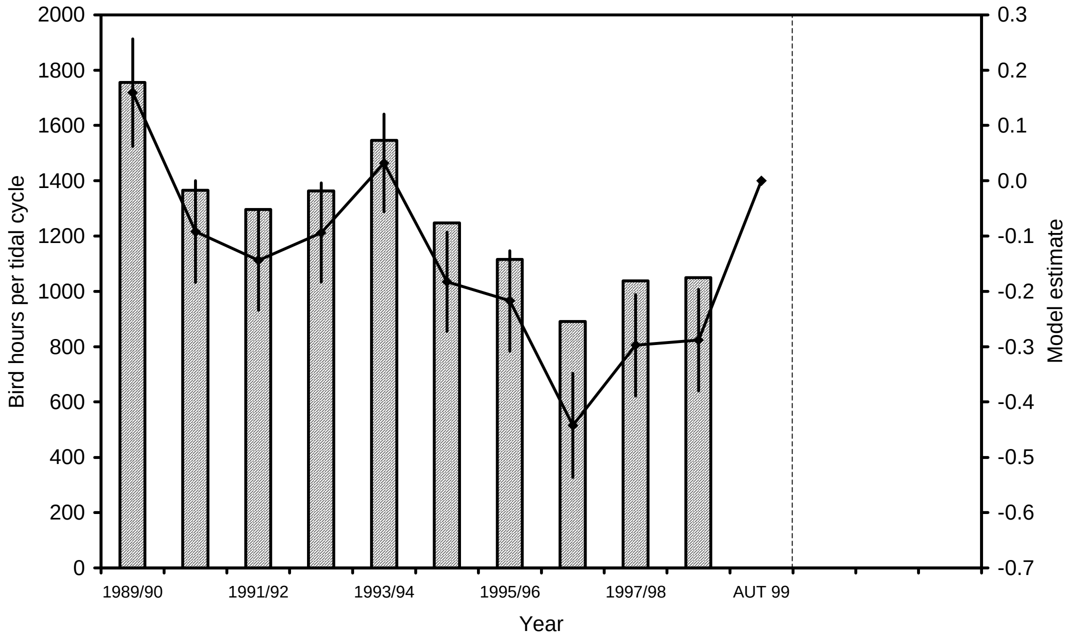


Figure 3.3.5 Estimates for 'year' (± 1 SE) in a model relating the densities of feeding Curlew at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b

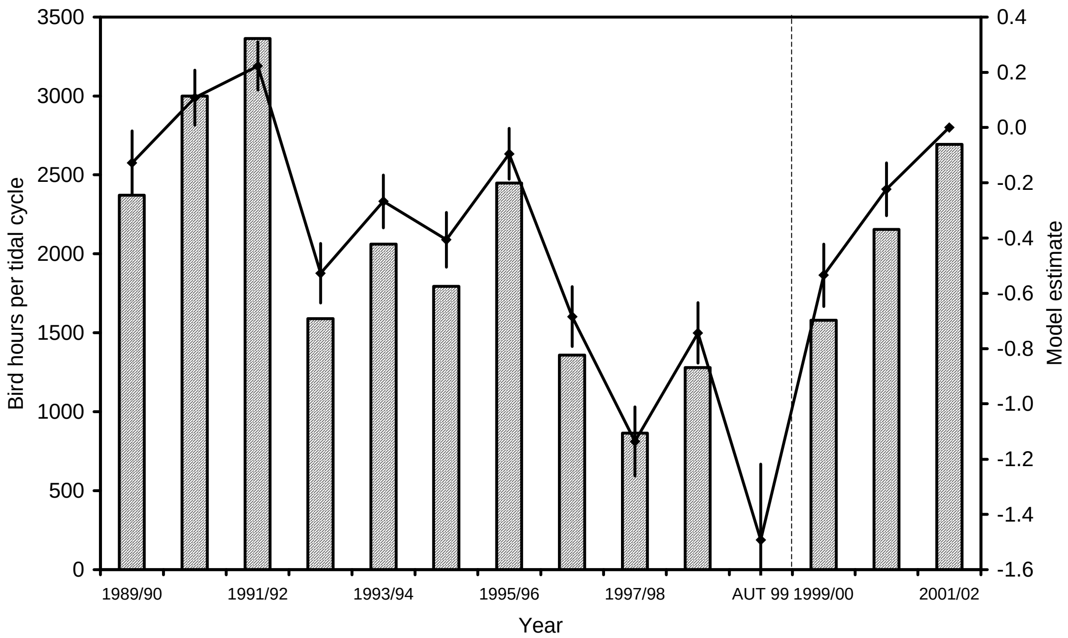


Figure 3.4.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Redshank at **a.** Cardiff Bay and **b.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; points immediately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

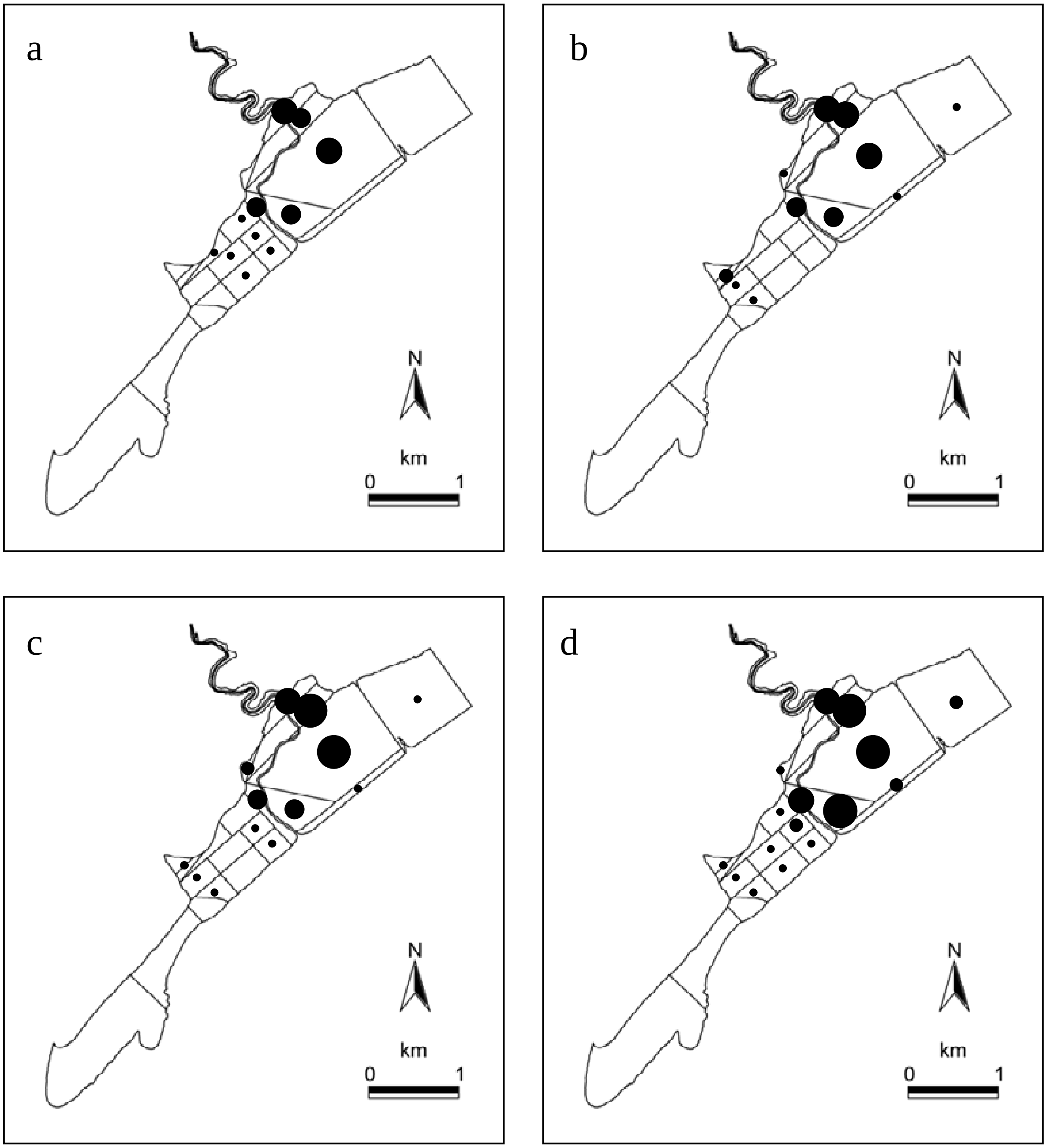


Figure 3.4.2 The distribution of feeding Redshank on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted.

a = 1998/99; b = 1999/2000; c = 2000/01; d= 2001/02.

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

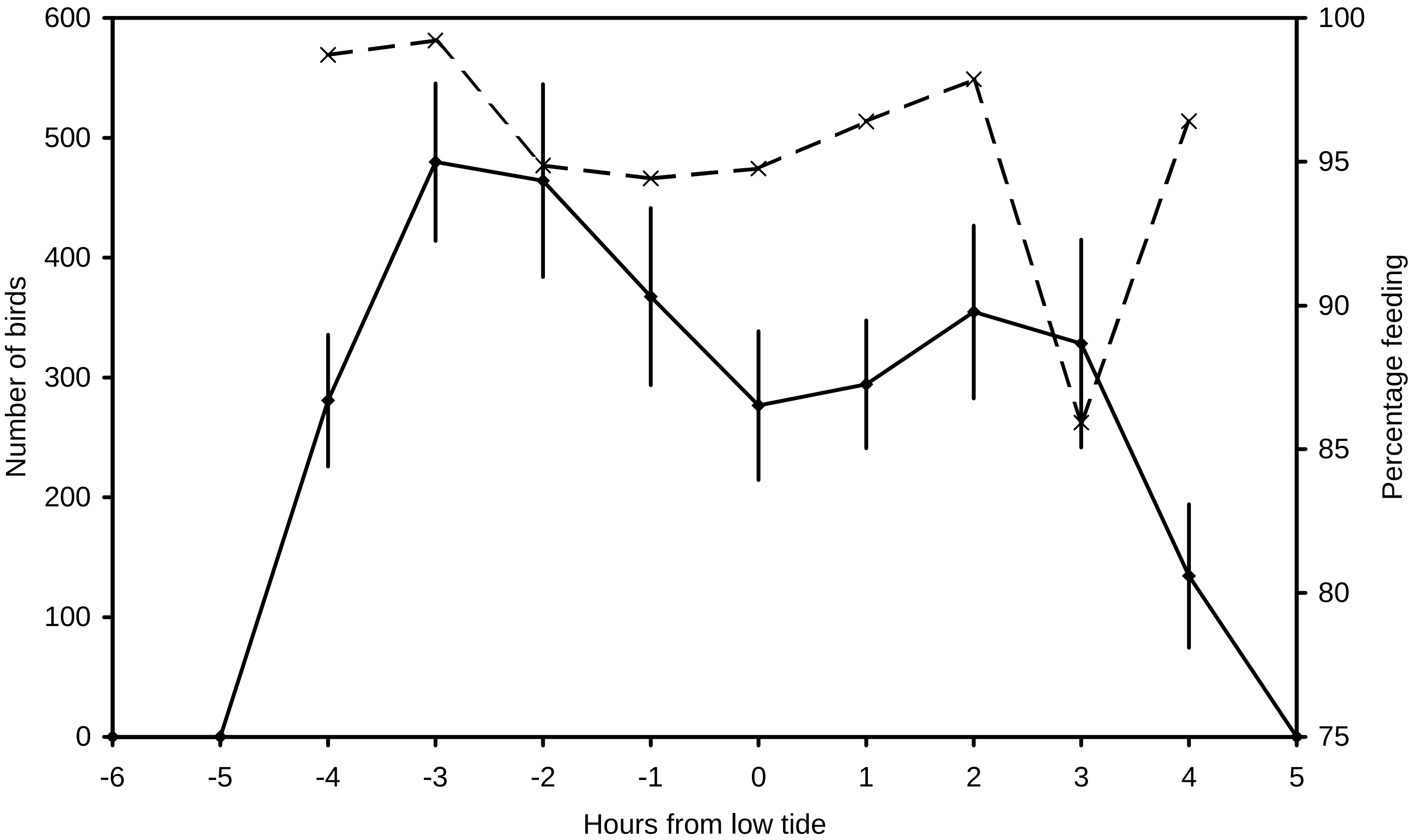


Figure 3.4.3 The total number of Redshank present (solid line) and the percentage feeding (dashed line) during each hour of the tidal cycle at Rhymney during the winter of 2001/02.

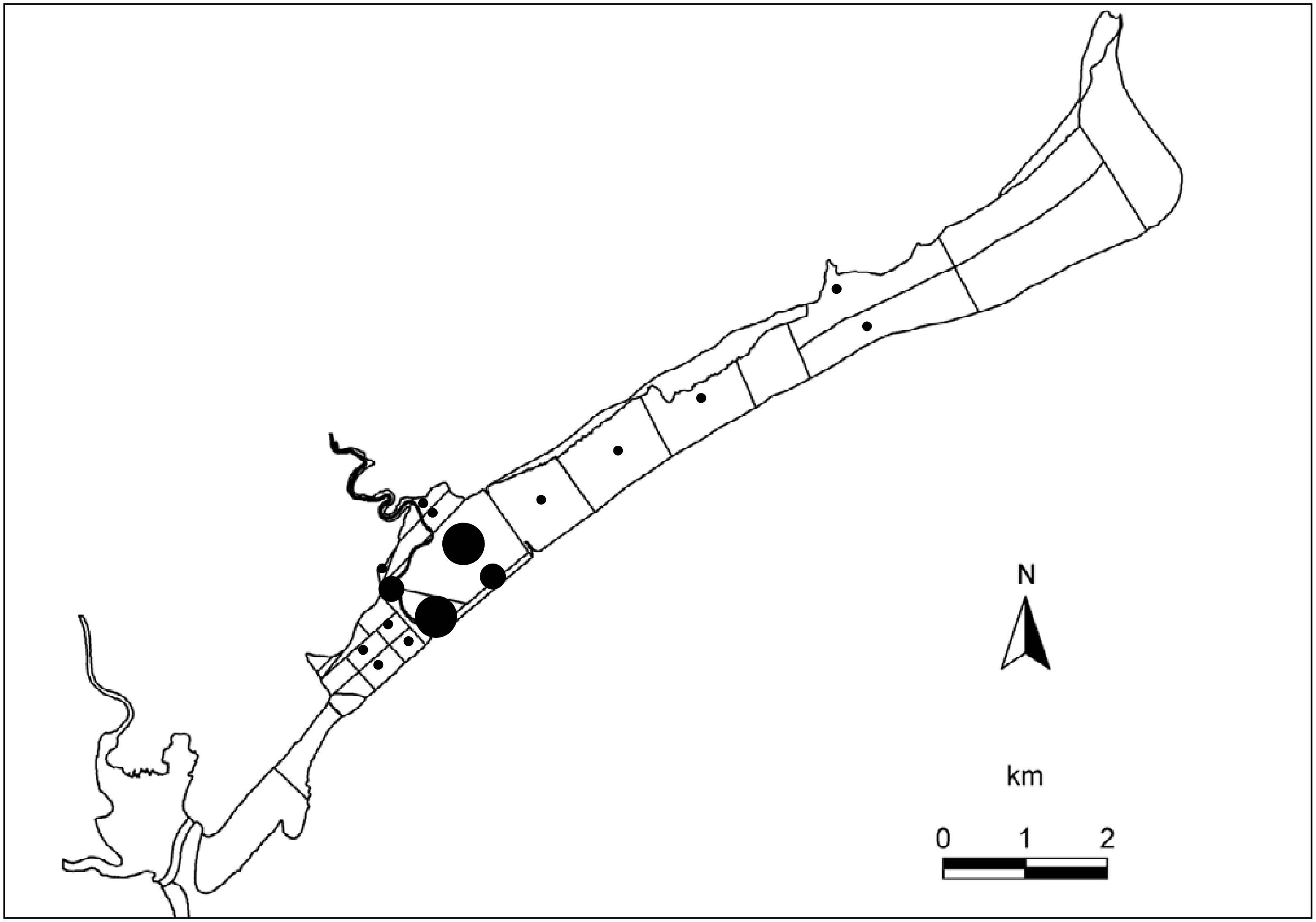


Figure 3.4.4 The low tide distribution of feeding Redshank on the northwest Severn during the winter of 2001/02.

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

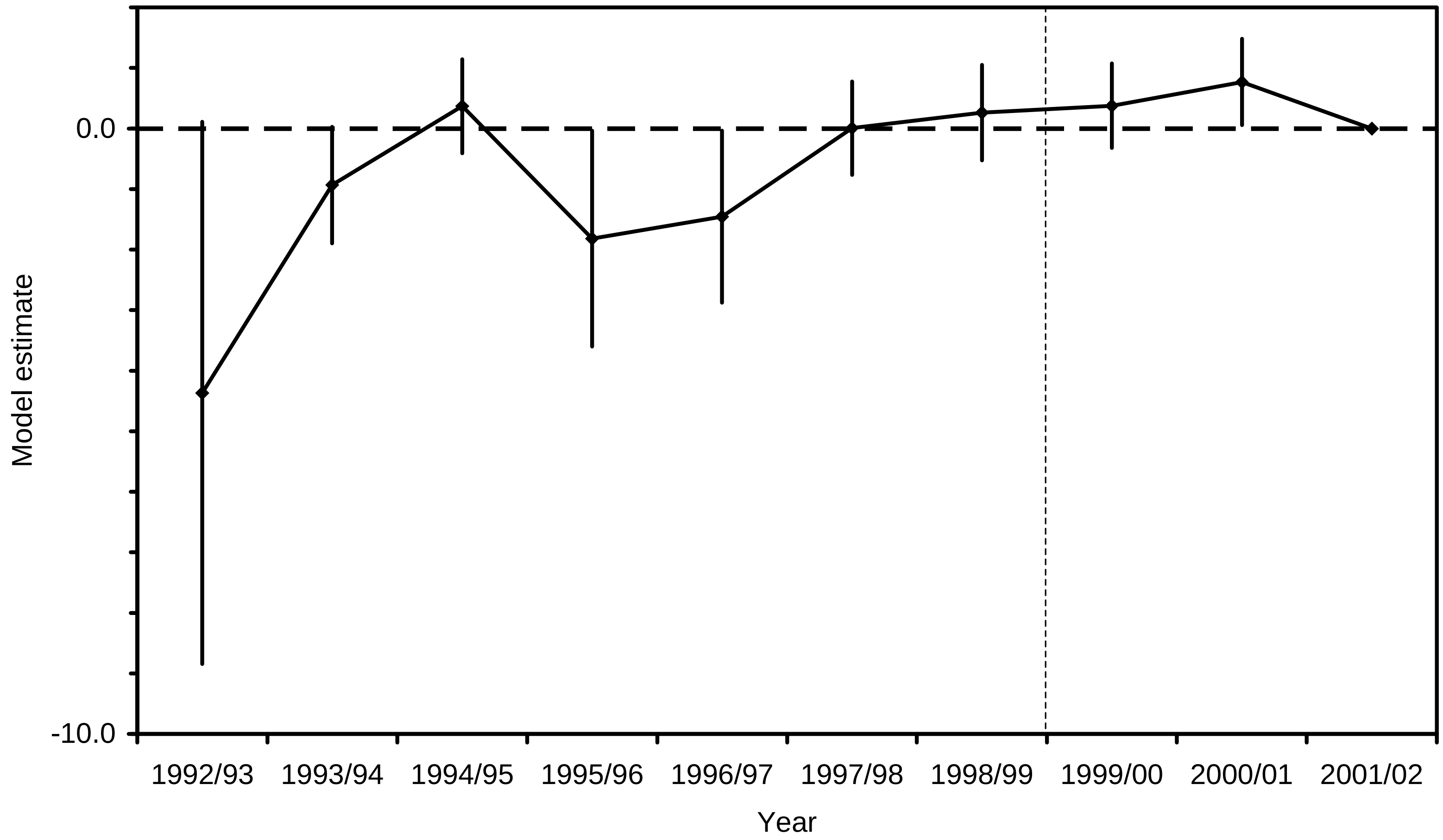
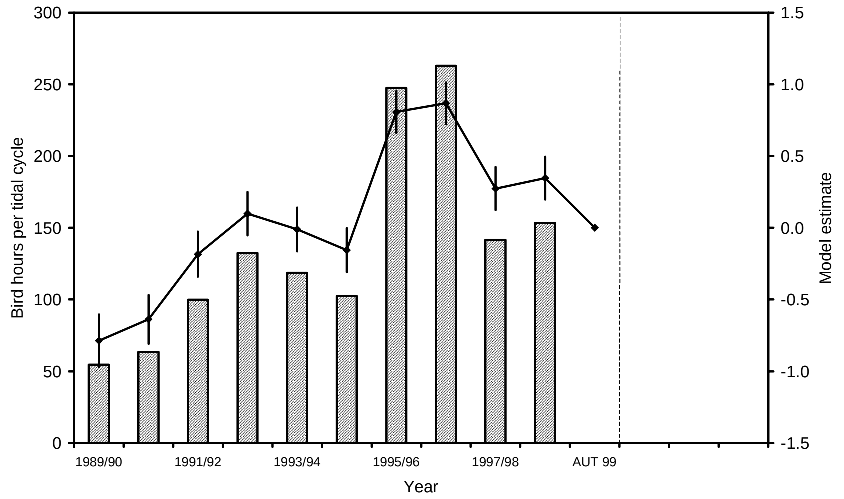
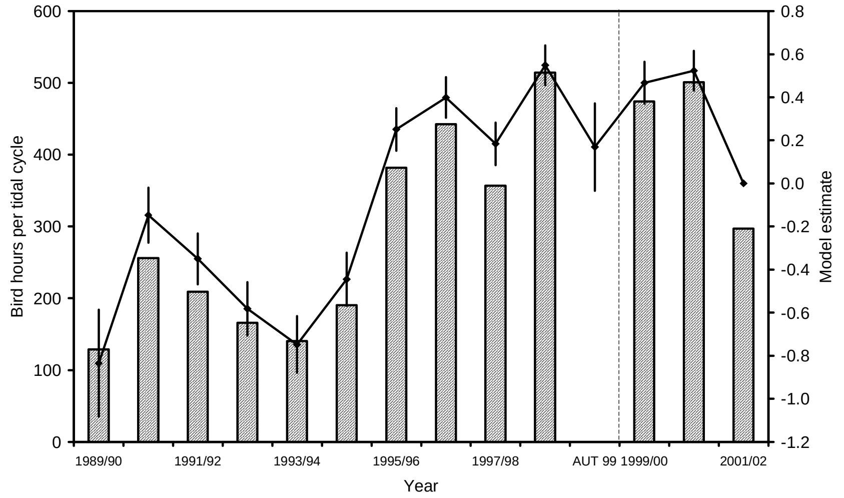


Figure 3.4.5 Estimates for ‘year’ (± 1 SE) in a model relating the densities of feeding Redshank at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b



c

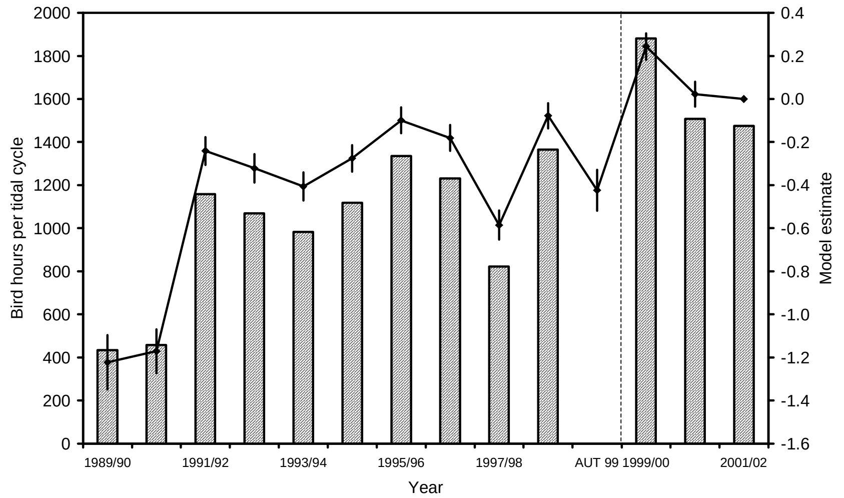


Figure 3.5.11.1 Estimates for ‘year’ (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Oystercatcher at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date 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.

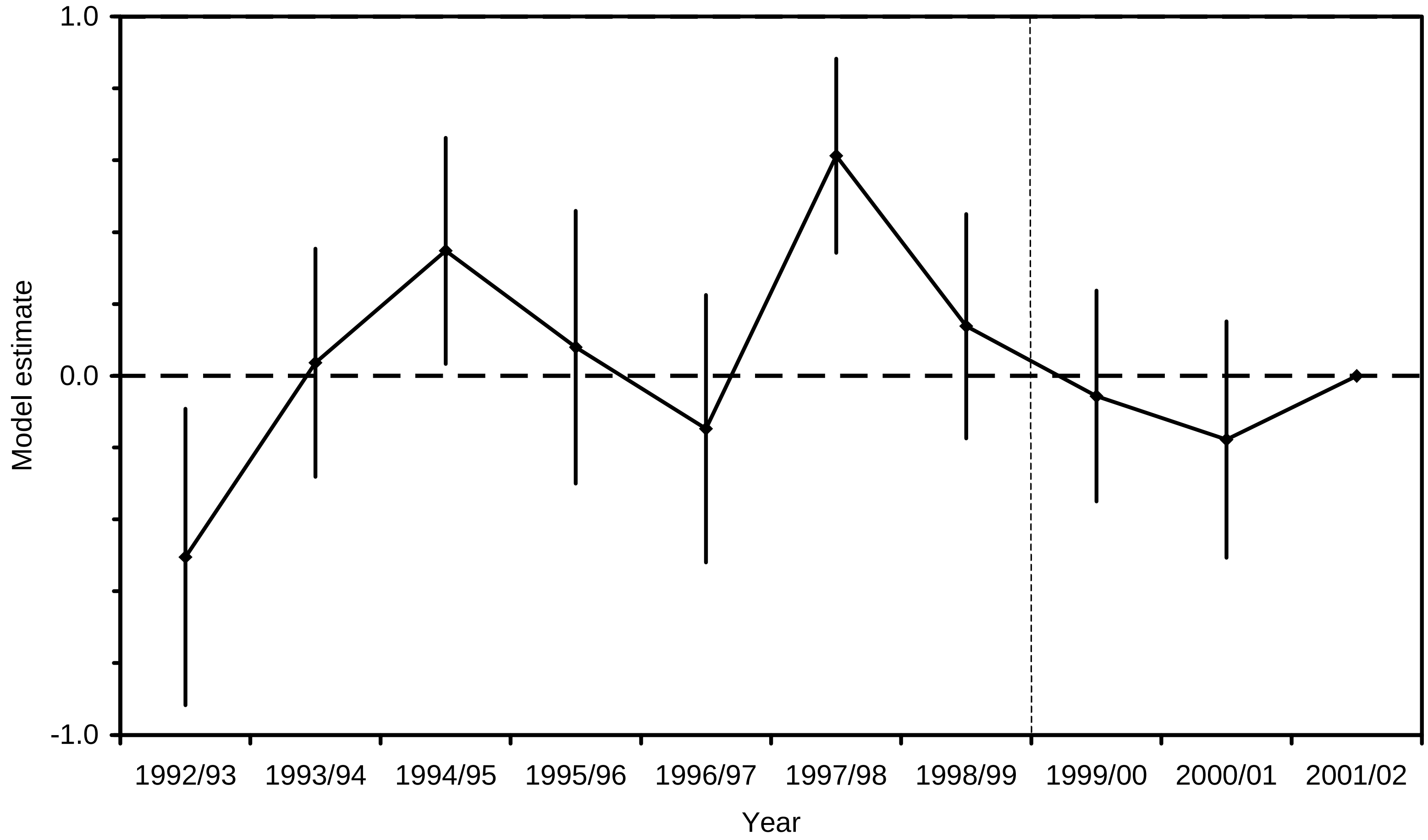


Figure 3.5.11.2 Estimates for ‘year’ (± 1 SE) in a model relating the densities of feeding Oystercatcher at low tide at Peterstone and St. Brides to year, month and mudflat.

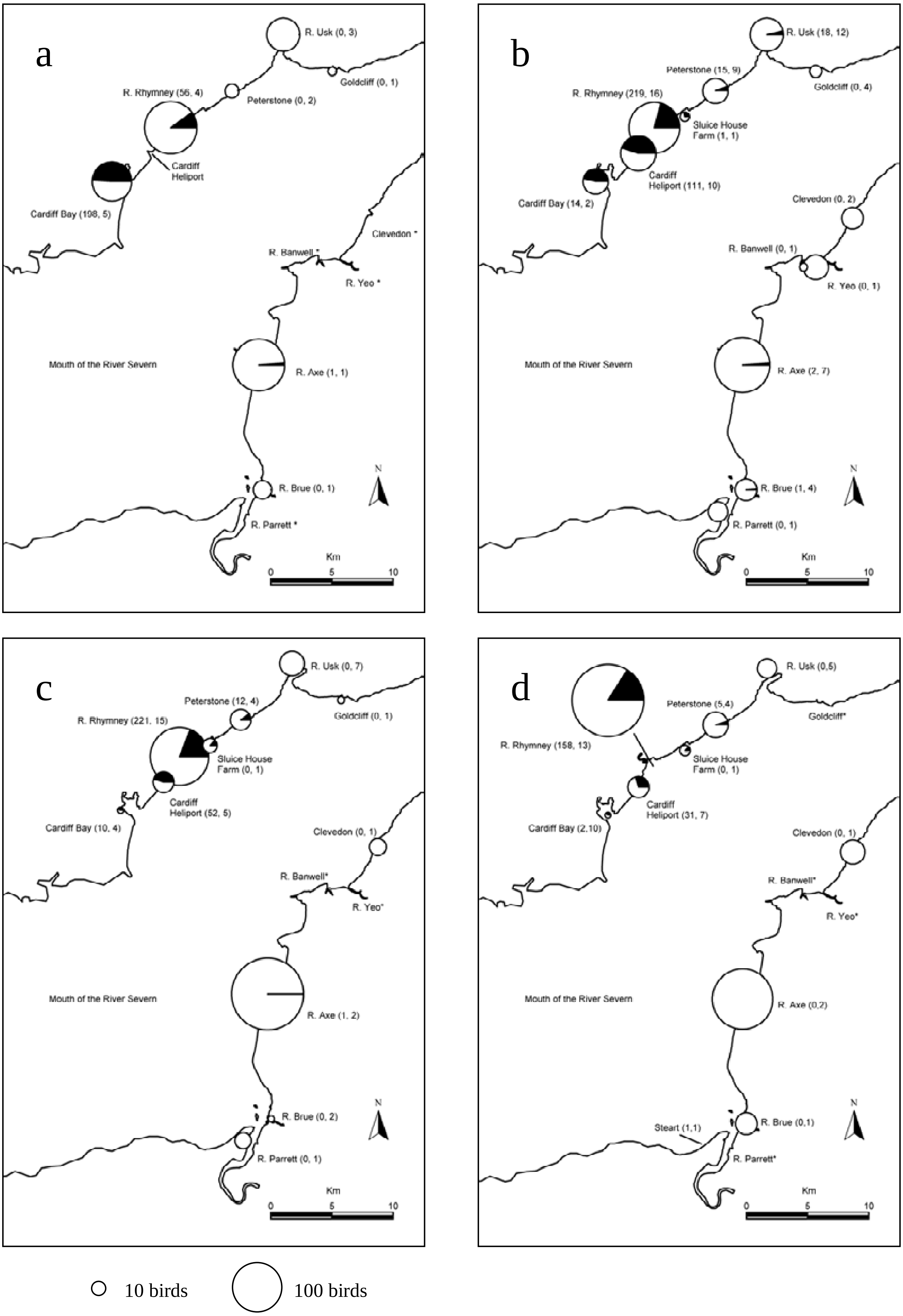


Figure 7.1.1 Proportions of colour-ringed individuals in flocks of Redshank in **a**. October 1999, immediately prior to the closure of the Cardiff Bay barrage, **b**. November 1999 to February 2000, the winter immediately post-closure, **c**. October 2000 to February 2001 and **d.** October 2001 to February 2002. Proportions are indicated by the black segments. Circle size 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*
<u>Long-tailed Duck *Clangula hyemalis*</u> *
Common Scoter *Melanitta nigra*
Goldeneye *Bucephala clangula* *
Red-breasted Merganser *Mergus serrator*
Goosander *Mergus merganser* *
Ruddy Duck *Oxyura jamaicensis*

WADERS
Oystercatcher *Haematopus ostralegus* *
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* *

OTHER WATERBIRD SPECIES
Little Grebe *Tachybaptus ruficollis* *
Great Crested Grebe *Podiceps cristatus* *
Red-necked Grebe *Podiceps grisegena*
<u>Slavonian Grebe *Podiceps auritus*</u> *
<u>Black-necked Grebe *Podiceps nigricollis*</u> *
Cormorant *Phalacrocorax carbo* *
Little Egret *Egretta garzetta*
Grey Heron *Ardea cinerea* *
Water Rail *Rallus aquaticus*
<u>Moorhen *Gallinula chloropus*</u> *
Coot *Fulica atra* *
Kingfisher *Alcedo atthis* *

Appendix 1 Waterbird species recorded during all-day counts at Cardiff Bay between 1989/90 and 2001/02. Species highlighted in bold have been recorded in the Bay since barrage-closure. Those underlined were not seen prior to barrage-closure. Species indicated with an asterisk were recorded in 2001/02.

Site	National Grid Reference	Oct 99	99/00	00/01	01/02
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 in the winters of 1999/2000, 2000/01 and 2001/02, post-closure.