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The Effect of the Cardiff Bay Barrage on Waterbird Populations Final Report

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EXECUTIVE SUMMARY

Background

1. This report presents the results of 14 years of intensive monitoring of the waterbirds of Cardiff Bay and adjacent areas which have aimed to determine the impacts of the impoundment of the Bay by the Cardiff Bay barrage. The work has attempted to answer four main questions:
   i. Were the numbers and distribution of birds within the Bay affected by construction work associated with the barrage?
   ii. Were birds displaced by the inundation of the bay following barrage-closure and how did the waterbird community change?
   iii. Were birds displaced from the Bay able to re-locate to other neighbouring sites?
   iv. Was there any impact on the condition and survival of birds that were forced to re-locate?

2. The report is thus in two parts. The first answers questions i-iii, and describes changes in the numbers and distributions of birds resulting from the Bay's inundation. Birds were monitored by all-day (hourly through-the-tide) counts at Cardiff Bay and the neighbouring intertidal areas of Orchard Ledges and Rhymney, and by low tide counts at the more distant areas of Peterstone and St. Brides (15 km from the Bay). The second part focuses on the fourth question and reports on a study of the movements, body condition and survival of one species – Redshank – following barrage-closure, using data from colour-ringed and radio-tagged birds. This species is known to be especially faithful to its wintering sites and thus may be particularly susceptible to habitat loss.

3. 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 2000, whereafter it was impounded permanently with freshwater. Prior to barrage-closure, the estuarine mudflats of Cardiff Bay supported sizeable winter populations of several species of waterbirds. The study presented here involved the collection of 10 years of data before barrage-closure and four years of data post-closure.

Changes within Cardiff Bay prior to Barrage-closure

4. Initial work indicated that the overall numbers of wintering waterbirds supported in the Bay had declined prior to barrage-closure, possibly due to changes in habitat quality. The distribution and behaviour of birds in the Bay were also affected by disturbance during the building works.

Changes in Species' Diversity and Abundance within Cardiff Bay following Barrage-closure

5. Following barrage-closure, the numbers of waterbirds using Cardiff Bay in the four winters were greatly reduced. A very few individuals of five key species – Shelduck, Oystercatcher, Dunlin, Curlew and Redshank – continued to use the Bay, though primarily as a high tide roost site.

6. A total of 31 species of waterbird and an annual mean of 22.0 were recorded in the Bay during the four years following barrage-closure, in comparison to a total of 50 and an annual mean of 26.5 over the 10 previous years. 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 Mute Swan and two diving duck species – Pochard and Tufted Duck – increased in number following barrage-closure. 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.

7. Although the size and diversity of the waterbird community using Cardiff Bay has been reduced, the Bay does now provide habitat for a range of freshwater species. Developing aquatic vegetation within the Cardiff Bay Wetlands Reserve, an area of 8 ha established on the Bay's northern shore, and elsewhere within the Bay attracts grebes, Coot, Teal and Mallard throughout the year and also now provides opportunities for nesting birds in spring. Seven species – Great Crested Grebe, Little Grebe, Mute Swan, Shelduck, Mallard, Tufted Duck and Coot – have bred in small numbers in the Bay since barrage-closure. The further development of this habitat on the reserve and around the Bay is likely to attract larger numbers of nesting waterbirds in the future.

Impacts on the Former Waterbird Community of the Bay

Shelduck

8. The majority of the Shelduck that formerly used Cardiff Bay have been displaced by its inundation. There was no evidence that Shelduck displaced from Cardiff Bay were able to settle on the adjacent coast at Rhymney or Orchard Ledges, or elsewhere on the north-west Severn. Although there was a small increase in Shelduck numbers at Orchard Ledges in the winter following closure, this was not sustained. Numbers also subsequently declined at Rhymney. It is thus likely that the Shelduck that were displaced from the Bay were either forced to disperse to more distant areas or that increased competition for food led to increased mortality in the population. It should also be noted, though, that for this and other species, the lack of increases in numbers outside Cardiff Bay (from the redistribution of birds from the Bay) may have been a consequence of reduced recruitment of young birds.

Oystercatcher

9. Oystercatcher have been almost entirely lost to Cardiff Bay as a result of its inundation and as with Shelduck, there was no evidence that Oystercatcher displaced from the Bay were able to settle at either Rhymney or Orchard Ledges, or elsewhere on the north-west Severn. An initial increase in numbers at Rhymney in the winter following barrage-closure would have accounted for the birds displaced from the Bay, but was not sustained. Prior to barrage-closure, numbers of Oystercatcher had increased on the study sites and might have been close to carrying capacity at the time birds were displaced from the Bay.

Dunlin

10. Only small numbers of Dunlin were recorded in the Bay following its inundation, only visiting the site to roost over high tide. Declines were recorded on all the study sites prior to closure and these have continued since. As these declines were likely to have been the result of external factors, there might have been spare capacity for the Dunlin displaced from the Bay. However, because of the continued decline in numbers of Dunlin on the Severn Estuary as a whole, it has not been possible to determine whether birds displaced from the Bay have been able to settle elsewhere.

Curlew

11. Curlew have only used Cardiff Bay for roosting since its inundation and in decreasing numbers. Prior to barrage-closure, Curlew numbers had been stable within the Bay, and at the neighbouring Orchard Ledges, though had shown a slight decline at Rhymney. Curlew numbers increased at Orchard Ledges in the two winters following closure. This increase would have only accounted for some of the displaced birds, but has not been sustained. An

increase at Peterstone and St. Brides in 2002/03 would have accounted for the birds that moved away from Orchard Ledges.

Redshank

12. Only small numbers of Redshank were recorded in Cardiff Bay following its inundation, primarily using the site as a high tide roost. Prior to barrage-closure, numbers of Redshank had decreased at both Cardiff Bay and Rhymney. Over the four subsequent winters, however, the numbers recorded at Rhymney increased significantly. The increase observed could account for the loss of birds from the Bay.

13. Information from colour-ringing and radio-tracking confirmed that the increase in Redshank numbers at Rhymney in the four 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 also recorded at Peterstone and the neighbouring Sluice House Farm (16 individuals) and as far east as the River Usk at Newport, and at least one bird moved to Somerset. Numbers increased further at Rhymney in the winters of 2000/01 and 2001/02, suggesting a further concentration of displaced birds into this site. In all four years, the majority of colour-ringed birds were seen on the mudflats by the River Rhymney and on the area of mudflats by Cardiff Heliport. Radio-tracking had shown that the Heliport mudflats were formerly used only at night, probably due to disturbance during the day.

14. Although count data suggest that the Redshank displaced from Cardiff Bay have been able to settle at Rhymney, analysis of biometric data revealed that adult Redshank from the Bay had difficulty maintaining their body condition in the first winter following closure. Birds that had only previously been caught (or seen) in the Bay were significantly lighter than those that had previously been caught (or seen) at Rhymney.

15. More significantly, the survival rates of displaced Redshank declined. The estimated annual survival rate of adult Redshank originally caught and ringed at Cardiff Bay fell from 0.846 in the two years prior to barrage-closure to 0.778 in the three following years, due to a significant decline in winter survival rates (P = 0.0006). In comparison, there was no significant difference before and after barrage-closure in the annual survival rate of adult Redshank originally caught and ringed at Rhymney. Estimated annual survival for these birds was 0.860, similar to that of Cardiff Bay birds before barrage-closure. Estimated survival rates for adult Redshank at a control site in north Wales varied annually, though the rates for 2000-2002 were actually higher than over the 11 years beforehand, suggesting that the drop in survival of Cardiff Bay birds was not due to regional weather patterns. It should be noted that the annual survival rate estimated for birds displaced from Cardiff Bay over the three years following barrage-closure is no lower than some other previously published estimates. However, the lack of decline in the survival rates of Redshank from Rhymney and north Wales in the years following the closure of the barrage and the similarity in the survival rate of Cardiff Bay birds pre-closure to that of Rhymney birds imply that the decline in the survival of Redshank displaced from Cardiff Bay was a direct consequence of barrage-closure. Thus, although there may have been some capacity for the increase in Redshank numbers seen at Rhymney, this decline in survival suggests that the area could not fully support the enlarged population. Our results also suggest that older Redshank may have been particularly at risk as, having been settled for many winters, they appeared to find it difficult to move from the Bay and adapt to alternative wintering sites.

Conclusions

16. Prior to barrage-closure, the overall numbers of wintering waterbirds supported by the Bay declined, perhaps due to changes in habitat quality or increased disturbance from construction work.

17. The majority of the former waterbird community of Cardiff Bay was displaced by its inundation and the change to freshwater conditions. The formerly diverse waterbird community of predominantly estuarine specialists (including Shelduck, Oystercatcher, Dunlin, Curlew and Redshank) has been replaced by a smaller community of freshwater species.

18. There was evidence from counts that some of the displaced Shelduck, Oystercatcher and Curlew settled at adjacent sites in the first winter following barrage-closure. However, these increases were not maintained and, with the exception of Curlew, there was no evidence that birds subsequently attempted to settle elsewhere. In the case of Dunlin, it was not possible to determine whether displaced birds were able to settle elsewhere due to an ongoing decline of the local population.

19. Detailed observation of colour-ringed and radio-tagged birds supported the evidence from counts that the majority of Redshank were displaced to the neighbouring Rhymney Estuary. However, many of these birds were forced to use a disturbed part of this site that had previously been used only at night. Most significantly, although counts suggested that displaced Redshank may have been able to settle at Rhymney, data from colour-ringed birds indicated that the winter survival rate of Cardiff Bay Redshank fell after their displacement.

GENERAL INTRODUCTION

This report presents the results of 14 years of intensive monitoring of the waterbirds of Cardiff Bay and adjacent areas which have aimed to determine the impacts of the impoundment of the Bay by the Cardiff Bay barrage. The report concentrates upon the impact on five estuarine species – Shelduck *Tadorna tadorna*, Oystercatcher *Haematopus ostralegus*, Dunlin *Calidris alpina*, Curlew *Numenius arquata* and Redshank *Tringa totanus* – though also includes information concerning other waterbirds (grebes, cormorants, herons, rails and kingfishers) and gulls.

The Cardiff Bay barrage was closed early on the morning of 4 November 1999, impounding the Bay with seawater. The Bay was then 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 investigates how the densities and distributions of waterbirds have changed in the winters following the closure of the Cardiff Bay barrage. The second reports the study of the movements and survival rates of Redshank following barrage-closure. Previous work has shown that individual Redshank were formerly highly faithful to the Bay both within and between winters (Burton 2000a).

Other reports and papers resulting from the 14 years of study are listed at the end of this report.

PART 1: DISTRIBUTION STUDIES

1. INTRODUCTION

The first part of this report investigates how the number and distributions of waterbirds changed as a result of 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, 2003) and previous studies of habitat loss.

The report concentrates upon the impact on five key estuarine species – Shelduck, Oystercatcher, Dunlin, Curlew and Redshank – which were numerous in the Bay at the start of the study. Through an intensive programme of monitoring the study aimed to determine how these species' use of the Bay changed as a result of its inundation and whether there was any evidence that neighbouring sites were able to accommodate displaced birds.

Changes in the numbers of 14 further waterbird species, which were regularly present in Cardiff Bay at the beginning of the study or which were recorded in Cardiff Bay in numbers of 10 or more following barrage-closure, are also discussed. In addition, the use of the Bay by gull species is also appraised.

2. METHODS

The same survey methodologies were followed throughout the course of the study. 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.

Fieldwork was divided into three seasons: autumn (August to October), winter (November to March) and spring (April to May). 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. Following barrage-closure 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 roosting behaviour of birds in Cardiff Bay prior to barrage-closure were covered in four earlier reports (Donald & Clark 1991, Toomer & Clark 1992, 1993, 1994).

In addition to waders and wildfowl, the presence of other waterbird species within Cardiff Bay was also noted throughout the course of the study, though these species were not counted until after barrage-closure.

2.2 Low Tide Counts

The distribution and numbers of waterbirds on the wider north-west Severn, east of Rhymney 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

Tables list all the waterbird species recorded during counts of Cardiff Bay between 1989/90 and 2002/03 and highlight those which have not been seen since barrage-closure. An additional figure indicates how the mean annual numbers of wildfowl species, waders and other waterbirds have changed since closure. For wader and wildfowl species, a further table indicates the peak numbers recorded in the Bay each year.

Detailed analysis was carried out for five key estuarine species: Shelduck, Oystercatcher, Dunlin, Curlew and Redshank, four of which occurred on the Severn Estuary in internationally important numbers during the study period (Pollitt *et al.* 2003). 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 winters following the displacement of birds from the Bay. 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 2002/03. 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 five 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 before barrage-closure and the four since.

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 2002/03. 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 the winter before barrage-closure and the four since for each of these species.

Shorter accounts are also provided for 14 other waterbird species, which were regularly present in Cardiff Bay at the beginning of the study or which have been recorded in Cardiff Bay in numbers of 10 or more since barrage-closure. In addition, the use of the Bay by gull species is also appraised.

3. RESULTS

3.1 Changes within Cardiff Bay prior to Barrage-closure

Prior to the barrage-closure the overall number of wintering waterbirds supported in the Bay had declined, perhaps in part due to changes in habitat quality. The distribution and behaviour of birds in the Bay were also affected by disturbance. As reported in Burton *et al.* (2002a), construction work significantly reduced the densities of five species – Teal *Anas crecca*, Oystercatcher, Dunlin, Curlew and Redshank – on adjacent mudflats, and thus the overall carrying capacity of the Bay. Construction work also reduced the feeding activity of Oystercatcher, Dunlin and Redshank on these mudflats.

3.2 Changes in Species' Diversity and Abundance within Cardiff Bay following Barrage-closure

Table 3.2.1 lists all waterbird species seen at Cardiff Bay during counts from 1989 to 2003 and shows those that have been recorded in the Bay since barrage-closure. Table 3.2.2 indicates the years in which each species was recorded. An annual mean of 22.0 waterbird species and a total of 31 (13 wildfowl, nine waders and nine other species) were recorded in the Bay in the four years following closure, in comparison to an annual mean of 26.5 and a total of 50 (20 wildfowl, 21 waders and nine others) in the 10 previous years.

In total, 23 of these 50 species (eight wildfowl, 12 waders and three others) have not been recorded in the Bay since barrage-closure. However, four new species were seen following closure – Slavonian Grebe *Podiceps auritus*, Black-necked Grebe *Podiceps nigricollis*, Long-tailed Duck *Clangula hyemalis* and Moorhen *Gallinula chloropus.*

Figure 3.2.1 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 average annual numbers of 'other' waterbird species such as grebes and rails.

Average numbers of the key species – Shelduck, Oystercatcher, Dunlin, Curlew and Redshank – recorded in Cardiff Bay in the winters following barrage-closure are shown in Figure 3.2.2. Peak annual numbers of each of the wader and wildfowl species discussed in the following accounts are given in Table 3.2.3, with thresholds for national and international also given to provide context. Tables 3.2.4 and 3.2.5 provide equivalent figures for the Orchard Ledges and Rhymney study sites.

3.3 Shelduck *Tadorna tadorna*

Shelduck breed at many coastal locations in Great Britain, but increasingly, also at inland sites (Gibbons *et al.* 1993). Following breeding, most adult Shelduck move to moulting grounds on the German Wadden Sea and start to move 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 of Shelduck has shown a slight decrease in recent winters (Austin *et al.* 2003) and has been estimated to total 78,200 birds (Kershaw *et al.* 2003). The Severn Estuary is currently of international importance for Shelduck in winter.

Changes in the Numbers of Shelduck using Cardiff Bay

Figure 3.2.2 and Table 3.2.3 show that, in contrast to the winters prior to barrage-closure, few Shelduck occurred in Cardiff Bay between 1999/2000 and 2002/03. Peaks of just 39, 61, 10 and 18 occurred in the four winters following barrage-closure in comparison to peaks of between 233 and 469 over the 10 years beforehand. Since barrage-closure, the largest numbers of Shelduck have occurred at high tide (Figure 3.2.2) – few birds now use the Bay at low tide.

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 3.3.1). Annual estimates and mean numbers derived from 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 Shelduck at Cardiff Bay over the 10 years prior to barrage closure ($F_{1,31833}$ = 0.00, ns).

Changes in the Numbers of Shelduck at Neighbouring Sites

Figure 3.3.2 shows the distribution of Shelduck on the neighbouring Orchard Ledges and Rhymney sites, as recorded by the all-day counts in each of the last five years of study. Large numbers of Shelduck used the intertidal mudflats of Rhymney study site throughout the 14 years, though relatively few were found on the rockier substrate at Orchard Ledges.

Densities of feeding Shelduck at Orchard Ledges were significantly related to year, month, state of tide and mudflat (Table 3.3.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.3.1b.

In contrast to other sites, densities at Orchard Ledges rose in the year following barrage-closure (particularly on the mudflat immediately adjacent to Cardiff Bay – see Figure 3.3.2), though have since fallen back to the very low levels seen prior to barrage-closure. Densities in 1999/2000 were thus significantly higher than those in 1998/99, the year immediately before barrage closure ($F_{1,2239}$ = 7.12, P = 0.0077). No difference was found between densities in 1998/99 and 2002/03, however ($F_{1,2239}$ = 0.67, ns). In comparison to a peak of 53 Shelduck in 1998/99, peaks of 101, 54, 20 and 21 were recorded in the four winters following closure (Table 3.2.4). 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 3.3.1). The model did not converge if the interaction between the latter two terms was included.

Densities at Rhymney fell each year following barrage-closure (Figure 3.3.1c). Thus, although densities in 1999/2000 were only slightly lower than those recorded in 1998/99, the winter immediately before barrage-closure ($F_{1,32284}$ = 1.72, ns), the densities found in 2002/03 were significantly less than those in 1998/99 ($F_{1,32284}$ = 223.15, P < 0.0001). In comparison to a peak of 1,309 Shelduck in 1998/99, peaks of 1,165, 921, 635 and 603 were recorded at Rhymney in the four winters following closure (Table 3.2.5). In contrast to the situation at the other sites, treating year as a continuous variable indicated that densities of feeding Shelduck had shown a slight increase at Rhymney over the 10 years prior to barrage closure ($F_{1,22940}$ = 5.00, P = 0.0254).

The results from the all-day counts show, therefore, that the loss of Shelduck from Cardiff Bay has not been matched by an increase at the Orchard Ledges and Rhymney sites. There was a mean of 1,022 feeding 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 269 at Rhymney (Figures 3.3.1a-c). The increase noted at Orchard Ledges was likely to have been caused by the displacement of birds from the Bay (no similar increases were seen at other sites), but has not been sustained and by 2002/03 numbers were no different to those in 1998/99. At Rhymney, the number of bird hours per tidal cycle was 2,601 lower in 2002/03 in comparison to 1998/99.

The Shelduck displaced from Cardiff Bay have clearly not been able to settle at either Rhymney or Orchard Ledges. It is also possible that the decline recorded at Rhymney could be a consequence of the loss of birds from the Bay, as many of the Shelduck that previously used the Bay were also likely to have used Rhymney (many Shelduck formerly left Cardiff Bay to feed elsewhere at low tide).

There is no evidence either that Shelduck were able to settle elsewhere on the north-west Severn. Figure 3.3.3 shows the distribution of Shelduck on low tide count sections at Peterstone and St. Brides to the east of Rhymney over the last six winters of study and Figure 3.3.4 the results of the GLM investigating changes in the numbers recorded here at low tide. Densities of feeding birds in this area were significantly related to mudflat, year and month (Table 3.3.2). As this figure shows, there was no clear change in Shelduck numbers in this area following barrage-closure.

3.4 Oystercatcher *Haematopus ostralegus*

A population of 33,000-43,000 pairs of Oystercatcher breeds in Great Britain, occupying both inland and coastal sites (Piersma 1986; Gibbons *et al.* 1993). In autumn and winter, the number of birds increases with an influx of migrants from northern Europe predominantly Scandinavia and Iceland. The British wintering population has shown a slight decrease in recent winters (Austin *et al.* 2003) and has been estimated to total 315,200 birds (Rehfisch *et al.* 2003). Although the Oystercatcher does not occur on the Severn in nationally important numbers, it was one of the most numerous species in Cardiff Bay prior to barrage-closure.

Changes in the Numbers of Oystercatcher using Cardiff Bay

The numbers of Oystercatcher using Cardiff Bay declined dramatically following barrage-closure. Peaks of just four, two and two were recorded in the winters of 1999/2000, 2000/01 and 2001/02 respectively and none in 2002/03 (Table 3.2.3). Prior to barrage-closure, there had been a rise in the numbers of Oystercatchers using the Bay, with a peak of 121 in the winter of 1998/99.

Densities of feeding Oystercatcher in Cardiff Bay prior to closure were significantly related to all factors considered in the GLM (Table 3.4.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.4.1a. Treating year as a continuous (rather than a class) variable in the model confirmed that there had been a significant increase in Oystercatcher densities over the 10 years prior to barrage-closure ($F_{1,31972}$ = 262.65, P < 0.0001).

Changes in the Numbers of Oystercatcher at Neighbouring Sites

Figure 3.4.2 shows the distribution of Oystercatcher on the neighbouring Orchard Ledges and Rhymney sites, as recorded by the all-day counts in each of the last five years of study. Large numbers of Oystercatcher used the intertidal mudflats of Rhymney study site and the rockier substrate at Orchard Ledges throughout the course of the study.

Densities of feeding Oystercatcher at Orchard Ledges were significantly related to all factors considered in the GLM (Table 3.4.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.4.1b.

Oystercatcher densities at Orchard Ledges showed no significant change following barrage-closure. Densities in 1999/2000 were similar to those in 1998/99, immediately prior to closure ($F_{1,3269}$ = 0.66, ns). Although, there was a decline in 2001/02, densities in 2002/03 were once again similar to those in 1998/99 ($F_{1,3269}$ = 1.40, ns). In comparison to a peak of 246 Oystercatcher in 1998/99, peaks of 276, 258, 244 and 183 were recorded at Orchard Ledges in the four winters following closure (Table 3.2.4). Treating year as a continuous variable in the model showed that, prior to barrage-closure, densities of Oystercatchers at Orchard Ledges had increased significantly ($F_{1,2265}$ = 231.04, P < 0.0001).

Densities of feeding Oystercatcher at Rhymney were also significantly related to all factors considered in the GLM (Table 3.4.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.4.1c.

Densities at Rhymney rose in the year following barrage-closure, but fell afterwards. Densities in 1999/200 were thus significantly greater than those in 1998/99, the winter immediately prior to barrage-closure ($F_{1,34296}$ = 27.88, P < 0.0001). Densities in 2002/03, in contrast, were only half those found in 1998/99 ($F_{1,34296}$ = 94.07, P < 0.0001). In comparison to a peak of 332 Oystercatcher in 1998/99, peaks of 399, 461, 453 and 239 were recorded in the four winters following closure (Table 3.2.5). Prior to barrage-closure, densities of Oystercatchers at Rhymney had increased significantly ($F_{1,24082}$ = 82.38, P < 0.0001).

The Oystercatcher displaced from Cardiff Bay, therefore, do not seem to have been able to settle at either Rhymney or Orchard Ledges. The initial increase in Oystercatcher densities at Rhymney in the winter following barrage-closure would have accounted for the birds displaced from the Bay. There was a mean of 153 feeding bird hours per tidal cycle in the Bay in the winter of 1998/99 and an increase of 528 bird hours at Rhymney the following winter (although a decrease of 34 bird hours at Orchard Ledges) (Figures 3.4.1a-c). However, by 2002/03, the number of bird hours recorded per tidal cycle at Rhymney was 685 less than in the winter immediately before barrage-closure.

There is no evidence either that Oystercatcher were able to settle elsewhere on the north-west Severn. Figure 3.4.3 shows the distribution of Oystercatcher on low tide count sections at Peterstone and St. Brides to the east of Rhymney over the last six winters of study and Figure 3.4.4 the results of the GLM investigating changes in the numbers recorded here at low tide. Densities of feeding birds in this area were significantly related to mudflat and year, though not month (Table 3.4.2). As this figure shows, numbers increased in this area prior to barrage-closure, but afterwards showed no significant change.

3.5 Dunlin *Calidris alpina*

Almost 10,000 pairs of Dunlin breed in Great 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 northern Scandinavia and Siberia migrate to Britain. Numbers of Dunlin wintering in Great Britain have declined since a high in the early 1990s (Austin *et al.* 2003) and the population has recently been estimated to total 555,800 birds (Rehfisch *et al.* 2003). The Severn Estuary holds internationally important numbers of Dunlin during the winter.

Changes in the Numbers of Dunlin using Cardiff Bay

As with other estuarine species, there was a sharp fall in the numbers of Dunlin using Cardiff Bay following barrage-closure. Peaks of just 12, seven, three and 50 were recorded in the winters of 1999/2000 to 2002/03. Prior to barrage-closure, peak numbers using the Bay had declined from 7,280 in the winter of 1989/90 to 786 Dunlin in the winter of 1998/99 (Table 3.2.3). Dunlin now only use the Bay to roost over high tide and in very small numbers (Figure 3.2.2). Only one Dunlin was recorded feeding in Cardiff Bay at low tide in the winters following barrage-closure.

Densities of feeding Dunlin in the Bay prior to closure were significantly related to year, month, mudflat and state of tide (Table 3.5.1). The model did not converge if the interaction between the latter two terms was included. Annual estimates and mean numbers derived from this model are shown in Figure 3.5.1a. Treating year as a continuous (rather than a class) variable in the model confirmed that there had been a significant decrease in feeding densities over the 10 years prior to barrage-closure ($F_{1,33413}$ = 247.56, P < 0.0001).

Changes in the Numbers of Dunlin at Neighbouring Sites

Figure 3.5.2 shows the distribution of Dunlin on the neighbouring Orchard Ledges and Rhymney sites, as recorded by the all-day counts in each of the last five years of study. Large numbers of Dunlin used the intertidal mudflats of Rhymney study site throughout the 14 years, though fewer used on the rockier substrate at Orchard Ledges.

Densities of feeding Dunlin at Orchard Ledges were significantly related to year, month, state of tide and mudflat (Table 3.5.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.5.1b.

Relatively few Dunlin were recorded at Orchard Ledges after 1996/97 and there was no significant change following barrage-closure. Peak numbers fell from 2,700 to just 55 between 1994/95 and 1998/99 and peaks of just 300, 45, three and two birds were recorded in the four winters following closure (Table 3.2.4). Densities at Orchard Ledges in 1999/2000 were similar to those in 1998/99 just before barrage-closure ($F_{1,2239}$ = 1.86, ns), as were those in the final year of study ($F_{1,2239}$ = 1.02, ns). Treating year as a continuous variable in the model confirmed 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 ($F_{1,1569}$ = 58.52, $P < 0.0001$).

At Rhymney, densities of feeding Dunlin were also significantly related to year, month, state of tide and mudflat (Table 3.5.1). The model did not converge if the interaction between the latter two terms was included. Annual estimates and mean numbers derived from this model are shown in Figure 3.5.1c.

Densities of Dunlin at Rhymney also declined greatly after 1996/97 and decreased further following barrage-closure (Figure 3.5.1c). Peak numbers fell from 15,600 in 1994/95 to 3,395 in 1998/99, the winter immediately before barrage-closure. In subsequent winters, peaks of 1,995, 1,640, 1,626 and 2,000 were recorded (Table 3.2.5). Densities at Rhymney in 1999/2000 were significantly lower than those in 1998/99, just before barrage-closure ($F_{1,32284}$ = 22.47, $P < 0.0001$), and were still lower in 2002/03 ($F_{1,32284}$ = 5.33, P = 0.00210). 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 ($F_{1,22940}$ = 64.97, $P < 0.0001$).

Given the continued decline in Dunlin numbers, it would seem that the birds displaced from the Bay may have 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 48 bird hours at Orchard Ledges in the winter of 1999/2000 and a decrease of 3,312 at Rhymney (Figures 3.5.1a-c). In the winter of 2002/03, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was 14 less than that in the winter of 1998/99, while the mean recorded at Rhymney was 1,789 less.

There is no evidence that Dunlin were able to settle elsewhere on the north-west Severn. Figure 3.5.3 shows the distribution of Dunlin on low tide count sections at Peterstone and St. Brides to the east of Rhymney over the last six winters of study and Figure 3.5.4 the results of the GLM investigating changes in the numbers recorded here at low tide. Densities of feeding Dunlin in this area were significantly related to mudflat, year and month (Table 3.5.2). As Figure 3.5.4 shows, densities of Dunlin have also declined in this area and were lower post-barrage than in previous winters..

3.6 Curlew *Numenius arquata*

The Curlew characteristically breeds on damp upland moorlands, but over the last century colonised many lowland regions, including agricultural habitats (Gibbons *et al.* 1993). The breeding population of Great 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). The British wintering population of Curlew has shown a steady increase over recent years and has been estimated to total 147,100 birds (Rehfisch *et al.* 2003). The Severn Estuary currently holds nationally important numbers of Curlew during winter.

Changes in the Numbers of Curlew using Cardiff Bay

In comparison to the winters prior to barrage-closure, few Curlew used in Cardiff Bay between 1999/2000 and 2002/03. Peaks of just 15, 62, three and six were recorded over these winters in comparison to peaks of between 98 and 186 over the 10 winters beforehand (Table 3.2.3). Since barrage-closure, Curlew have only used the Bay as a high tide roost site – no Curlew have been recorded in Cardiff Bay at low tide (Figure 3.2.2).

Densities of feeding Curlew in Cardiff Bay prior to closure were significantly related to all factors considered in the GLM (Table 3.6.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.6.1a. 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).

Changes in the Numbers of Curlew at Neighbouring Sites

Figure 3.6.2 shows the distribution of Curlew on the neighbouring Orchard Ledges and Rhymney sites, as recorded by the all-day counts in each of the last five years of study. Large numbers of Curlew used the intertidal mudflats of Rhymney study site and the rockier substrate at Orchard Ledges throughout the course of the study.

Densities of feeding Curlew at Orchard Ledges were significantly related to year, month, state of tide and mudflat (Table 3.6.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.6.1b.

Curlew densities at Orchard Ledges site rose in the two years following barrage-closure, but declined significantly afterwards. Densities in 1999/2000 were thus significantly greater than those in 1998/99, immediately prior to barrage-closure ($F_{1,3275} = 6.58$, $P = 0.0104$), but significantly lower in 2002/03 ($F_{1,3275} = 86.44$, $P < 0.0001$). Peak winter numbers at Orchard Ledges rose from 68 in 1998/99 to 114 in 1999/2000, but declined to just 36 in 2002/03 (Table 3.2.4). 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 3.6.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.6.1c.

Densities of Curlew at Rhymney in 1999/2000, immediately after barrage-closure, were similar to those found in the preceding year ($F_{1,34076} = 0.04$, ns). By 2002/03, however, densities had shown a slight decline (comparing 2002/03 with1999/2000: $F_{1,34076} = 5.01$, $P = 0.0252$). In comparison to a peak of 105 Curlew in the winter of 1998/99, peaks of 90, 178, 135 and 65 were recorded in the four winters following closure (Table 3.2.5). Treating year as a continuous variable indicated a slight decrease in the densities of Curlew over the 10 years prior to barrage closure ($F_{1,23924} = 7.05$, $P = 0.0079$).

Although the change in the number of Curlew at Orchard Ledges in the two winters following barrage-closure accounted for some of the birds lost from the Bay, this increase was not maintained. Indeed, four winters after the closure of the barrage, it seems that there has been a knock-on effect on the numbers of Curlew using this neighbouring site. There was a mean of 185 bird hours per tidal cycle in the Bay in the winter of 1998/99, but an increase of only 44 bird hours at Orchard Ledges in the winter of 1999/2000 and a negligible change at Rhymney (Figures 3.6.1a-c). In the winter of 2002/03, the mean number of bird hours recorded per tidal cycle at Orchard Ledges was 100 less than that in the winter of 1998/99, while the mean recorded at Rhymney was 41 less.

Figure 3.6.3 shows the distribution of Curlew at low tide at Peterstone and St. Brides over the last six winters of study and Figure 3.6.4 the results of the GLM investigating changes in the numbers recorded here at low tide. Densities of feeding Curlew in this area were significantly related to mudflat, year and month (Table 3.6.2). The numbers of Curlew recorded at low tide at Peterstone and St. Brides declined over the three winters following barrage-closure, but rose sharply in 2002/03 – average numbers were 39 greater than in the winter immediately prior to barrage-closure. This increase would account for the birds that moved away from Orchard Ledges.

3.7 Redshank *Tringa totanus*

A total of 30,000-34,000 pairs of Redshank was estimated to breed in Great 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 and Ireland, and Iceland (Summers *et al.* 1988). Wintering numbers in Great Britain rose during the 1980s, but have remained relatively stable since (Austin *et al.* 2003). The British wintering population has recently been estimated to total 116,100 birds (Rehfisch *et al.* 2003). The Severn Estuary is currently internationally important for Redshank in winter.

Changes in the Numbers of Redshank using Cardiff Bay

As with other estuarine species, only occasional flocks of Redshank were recorded in Cardiff Bay in the four winters post-closure. Peaks of 22, 91, 30 and three were recorded in the winters between 1999/2000 and 2002/03 (Table 3.2.3). Prior to barrage-closure, peak numbers of Redshank using the Bay had declined from 534 in the winter of 1989/90 to 296 in the winter of 1998/99. In the first two winters following closure, Redshank were recorded in similar numbers at high and low tide, though only occasional birds were seen feeding. In 2001/02 and 2002/03, Redshank were only recorded using the Bay as a high tide roost.

Densities of feeding Redshank in Cardiff Bay prior to closure were significantly related to all factors considered in the GLM (Table 3.7.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.7.1a. Treating year as a continuous (rather than a class) variable in the model confirmed 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 ($F_{1,32085} = 58.65$, $P < 0.0001$).

Changes in the Numbers of Redshank at Neighbouring Sites

Figure 3.7.2 shows the distribution of Redshank on the Rhymney study site, as recorded by the all-day counts in each of the last five years of study. Very few Redshank were observed at Orchard Ledges over the course of the study.

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 3.7.1). Annual estimates and mean numbers derived from this model are shown in Figure 3.7.1b.

Densities of Redshank at Rhymney increased following barrage-closure. Though they were only slightly greater in 1999/2000 than those in 1998/99, the winter prior to closure ($F_{1,31960} = 3.02$, $P < 0.10$), they rose significantly over each of the following two winters (Figure 3.7.1b). Densities in 2002/03 were thus significantly greater than those in 1998/99 ($F_{1,31960} = 57.12$, $P < 0.0001$). As Figure 3.7.2 shows, part of this increase was due to the use of the mudflats adjacent to Cardiff Heliport, which were previously only rarely used in the day (though use of this site had declined by 2002/03). However, Redshank were most numerous on the mudflats adjacent to the Rhymney River. In comparison to a peak of 625 Redshank in the winter of 1998/99, peaks of 611, 747, 861 and 730 were recorded in the four winters following closure (Table 3.2.5). 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 ($F_{1,22024} = 140.14$, $P < 0.0001$).

The observed increase in the number of Redshank at Rhymney over the four 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 (see Part 2). There was a mean of 1,050 bird hours per tidal cycle in the Bay in the winter of 1998/99 and although there was an increase of only 308 bird hours at Rhymney in the winter of 1999/2000, there was an overall increase of 1,473 bird hours by 2002/03 (Figures 3.7.1a-b). The initial increase recorded may have been underestimated as the population at Rhymney was 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. 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).

The impact of the increased density of Redshank at Rhymney on the survival of both those displaced from the Bay and those that previously resident used the area is investigated in Part 2 of this report.

Figure 3.7.3 shows the distribution of Redshank at low tide at Peterstone and St. Brides over the last six winters of study and Figure 3.7.4 the results of the GLM investigating changes in the numbers recorded here at low tide. Densities of feeding birds in this area were significantly related to mudflat and year, though not month (Table 3.7.2). The relatively low numbers recorded here showed no significant change in the first three winters following barrage-closure, though increased in the winter of 2002/03. However, it should be noted that the numbers of Redshank recorded on this stretch of coast were often underestimated because of the difficulties of seeing birds in the creeks at Peterstone Gout at low tide.

3.8 Other Waterbird Species

3.8.1 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. A peak of 12 Great Crested Grebes was recorded in Cardiff Bay during the winter of 2002/03. Higher numbers occur in spring, however, and a peak of 22 was recorded in May 2002. Great Crested Grebes successfully bred in the Bay in 2001 and 2002.

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

3.8.2 Cormorant *Phalacrocorax carbo*

Cormorants were 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. A peak of 18 Cormorants was recorded in the Bay in the winter of 2002/03 and up to 35 in the preceding autumn.

Cormorant also occurred in small numbers at both Orchard Ledges and Rhymney through the course of the study.

3.8.3 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 become more common with the change to freshwater conditions, with peaks of seven, seven and eight in the last three winters of study (Table 3.2.3). Numbers are greatest in the autumn, however, and a peak of 37 was recorded in August 2002. More recently, in June 2003, 73 Mute Swans were recorded in the Bay – the highest count ever recorded there (Reed 2003).

Two pairs of Mute Swans attempted to breed in spring 2002, but lost their nests as a result of high water levels (V. Grantham, pers. comm.). However, a pair of Mute Swans bred successfully in the Bay in 2003.

Only occasional Mute Swans were observed during the course of the study at either Orchard Ledges or Rhymney (Tables 3.2.4 & 3.2.5).

3.8.4 Teal *Anas crecca*

Although Teal may use both estuarine and freshwater wetlands in winter, numbers have been much reduced in the Bay since barrage-closure. Peaks of 20, 30, 42 and 45 were recorded in the four winters since barrage-closure, in comparison to peaks of between 103 and 354 over the 10 previous winters (Table 3.2.3).

There was no discernible change in Teal numbers at Rhymney in the years following barrage-closure that could account for the loss of birds from the Bay. Peaks of two, six, 34 and six were recorded over the four winters following closure (Table 3.2.5). Prior to closure, Teal numbers at Rhymney had shown a steep decline, from a peak of 165 birds in 1989/90 to just nine in 1998/99. More Teal used the upper tidal stretches of the River Rhymney and thus did not appear on the study site. Few Teal used the Orchard Ledges site (Table 3.2.4).

Large numbers of Teal were also recorded throughout the course of the study at Peterstone and at the mouth of the River Usk at St. Brides. The numbers of Teal recorded on these mudflats at low tide fluctuated over the study period and it was not possible to discern any clear trend in numbers following barrage-closure.

3.8.5 Mallard *Anas platyrhynchos*

As with Teal, Mallard continued to use Cardiff Bay following barrage-closure, although in reduced numbers. Peaks of 51, 21, 24 and 44 were recorded in the four winters post-closure, in comparison to peaks of between 91 and 147 over the 10 winters beforehand (Table 3.2.3). Mallard were recorded nesting in the Bay in 2002 (V. Grantham, pers. comm.).

Only occasional Mallard were seen at Orchard Ledges during the course of the study (Table 3.2.4). At Rhymney, peak numbers varied between 58 and 170 in the 10 winters prior to barrage-closure, with only 65 recorded in 1998/99. Numbers increased slightly from this following closure, with peaks of 79, 83, 99 and 107 in the four winters (Table 3.2.5), though this change would not account for the loss of birds from the Bay.

Large numbers of Mallard were also recorded throughout the course of the study at Peterstone and St. Brides. The numbers of Mallard recorded here at low tide did not change significantly following barrage-closure.

3.8.6 Pochard *Aythya ferina*

Pochard numbers at Cardiff Bay increased in the winters prior to barrage-closure and increased further over the following three winters to a peak of 240 in 2001/02 (Table 3.2.3). Numbers dropped in 2002/03, however, to a peak of just 25.

After considerable fluctuation in the winters prior to closure, numbers also increased at Rhymney over the three following winters to a peak of 350 in 2001/02. Numbers also dropped here in 2002/03, however, to a winter peak of just 19 (Table 3.2.5).

The recent declines may be linked to improvements in waste water treatment. The Pochard at Rhymney were typically found around the outfall of the Cardiff eastern sewer. Waste water from this and other discharges was transferred to a new pipe discharging offshore in 2001 and received improved treatment in 2002. Previous studies in Scotland have linked declines in duck populations to the cessation of sewage discharges (Campbell 1984).

Small numbers were also recorded at low tide at Peterstone through the course of the study.

3.8.7 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 was recorded more regularly in the Bay following the change to freshwater conditions. Peaks of one, two, 23 and 10 were recorded in the four winters following barrage-closure (Table 3.2.3). A single brood of Tufted Duck was observed in the Bay in August 2001.

3.8.8 Goosander *Mergus merganser*

Goosander were recorded annually in Cardiff Bay from the mid-1990s 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 seven, four, 16 and nine were recorded in the four subsequent winters (Table 3.2.3).

No Goosander were observed during the study at either Orchard Ledges or Rhymney (Tables 3.2.4 & 3.2.5).

3.8.9 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. A peak of 110 Coot was recorded in the Bay in the winter of 2002/03 and up to 142 in the preceding autumn. The species also bred successfully in the Bay in small numbers in both 2001 and 2002.

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

3.8.10 Ringed Plover *Charadrius hiaticula*

Numbers of Ringed Plover at Cardiff Bay varied considerably in the winters prior to barrage-closure, from peaks of just one to 48 (Table 3.2.3). No Ringed Plover were recorded in the Bay in the first three years following barrage-closure, however, and in 2002/03, when a peak of 22 birds was recorded, the species was only recorded roosting at high tide.

Peak numbers of Ringed Plover at Orchard Ledges fell from 150 in the winter of 1992/93 to just one in 1998/99 immediately prior to barrage-closure. Following barrage-closure, winter peaks of 64, 31, 35 and 41 were recorded (Table 3.2.4). A similar pattern was recorded at Rhymney. Peak winter numbers fell from 100 in 1989/90 to just two in 1998/99, whereas, in the four winters following barrage-closure, peaks of 46, 32, 75 and 36 were recorded (Table 3.2.5).

The loss of Ringed Plover from Cardiff Bay, therefore, seems to have been compensation for by increases at these two sites.

Only occasional flocks of Ringed Plover were observed at St. Brides and Peterstone during the study.

3.8.11 Grey Plover *Pluvialis squatarola*

The numbers of Grey Plover recorded in Cardiff Bay declined sharply in the winters prior to barrage-closure. Although a winter peak of 100 was recorded in 1989/90, none were seen in the Bay in 1997/98 and just one in 1998/99 (Table 3.2.3). No Grey Plover have been recorded in the Bay since barrage-closure.

Grey Plover were only intermittently recorded at Rhymney prior to barrage-closure, a peak of 21 birds being seen in 1995/96 (Table 3.2.5). As in the Bay, none have been seen since barrage-closure. Grey Plover were never recorded at Orchard Ledges during the course of the study.

The numbers of Grey Plover recorded at Peterstone and St. Brides at low tide also fell over the winters immediately before and after barrage-closure, though showed a partial recovery in 2002/03.

As a result of the local decline in its numbers, it is not possible to assess whether numbers of this estuarine wader have been affected by the loss of the mudflats in Cardiff Bay.

3.8.12 Lapwing *Vanellus vanellus*

The numbers of Lapwing using Cardiff Bay declined following barrage-closure. None were seen in the winter of 1999/2000 and peaks of only 43, 24 and one in the three following winters (Table 3.2.3). In comparison, peak numbers had varied between 73 and 175 over the 10 winters prior to barrage-closure.

Only occasional Lapwing were recorded at Orchard Ledges over the course of the study (Table 3.2.4). At Rhymney, numbers rose to a peak of 200 in 1993/94, though had declined to a peak of 96 by 1998/99. Although none were recorded here in the winter following barrage-closure, peaks of 24, 230 and 105 were recorded over the following three winters (Table 3.2.5).

Lapwing were also recorded intermittently at Peterstone and St. Brides at low tide throughout the course of the study. As at Rhymney, however, there has been no clear trend in the species' numbers that would clearly account for the loss of birds from the Bay.

Lapwing typically used Cardiff Bay (and the intertidal mudflats at Rhymney, Peterstone and St. Brides) for roosting. Given that larger numbers of Lapwing roost and feed on the grasslands of the Gwent Levels in winter, it seems probable that the impact of the Bay's loss to this species has been slight.

3.8.13 Knot *Calidris canutus*

The numbers of Knot recorded at Cardiff Bay in the winters prior to barrage closure showed considerable fluctuations, peaking at 850 in 1993/94 (Table 3.2.3). Only single birds were recorded from 1995/96, however. No Knot were recorded in the Bay following barrage-closure.

Knot were only intermittently recorded at Orchard Ledges through the course of the study (Table 3.2.4). At Rhymney, though none were recorded in the first four winters, a peak of 1,200 was recorded in 1993/94. Numbers declined thereafter to a peak of 240 in 1998/99. Peak numbers of one, 60, 90 and 14 were recorded in the four winters following barrage-closure (Table 3.2.5). The numbers recorded by the low tide counts at Peterstone and St. Brides also fluctuated greatly from year to year, though the species was more regularly recorded following barrage-closure than in the winters immediately preceding this.

At the time of barrage-closure, Knot rarely used Cardiff Bay and thus would not have been affected by the loss of the Bay's mudflats. However, given that numbers of this species tend to fluctuate over time, it is not possible to assess whether the loss of habitat will have a longer term impact.

3.8.14 Turnstone *Arenaria interpres*

Turnstone formerly used Cardiff Bay primarily as a high tide roost site, but were rarely recorded in the Bay following barrage-closure. Numbers had declined prior to barrage-closure, from a peak of 80 in 1990/91 to just 12 in 1998/99. In comparison, Turnstone were only recorded twice in the Bay in the winter of 1999/2000, numbers peaking at 18, and were not recorded over the following three winters (Table 3.2.3).

Numbers of Turnstone also declined at Orchard Ledges prior to barrage-closure, from up to 235 in 1993/94 to 84 in 1998/99. Numbers remained low over the following winters, peaking at 79, 97, 86 and 41 (Table 3.2.4). At Rhymney, numbers rose to a peak of 95 in 1995/96, before falling to a peak of 42 in the winter of 1998/99 immediately prior to barrage-closure. Peaks of only four and three were recorded in the first two winters following closure, but up to 60 and 67 were recorded in 2001/02 and 2002/03 respectively (Table 3.2.5).

Turnstone were only rarely recorded at low tide at St. Brides and Peterstone through the course of the study.

Although there are no clear increases in numbers elsewhere that would account for the loss of Turnstone from Cardiff Bay, as the Bay was formerly used primarily as a roost site, the impact on this species is likely to have been slight.

3.9 Gulls

Three species of gull occurred regularly in Cardiff Bay during the course of the study – Black-headed Gull *Larus ridibundus*, Lesser Black-backed Gull *L. fuscus* and Herring Gull *L. argentatus*. Numbers of Black-headed Gull peaked at 423 and 764 in the winters of 2001/02 and 2002/03 respectively. Lesser Black-backed Gull numbers peaked at 140 and 154 in the respective winters. More occur in spring – a peak of 180 was recorded in May 2002. 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 and 130 in 2001/02 and 2002/03 respectively.

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 following Barrage-closure

Only 31 species of waterbird, and an annual mean of 22.0, were recorded during counts at Cardiff Bay over the four years following 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 (estuarine) waders. However, following barrage-closure and the change to freshwater conditions resultant from the cessation of drawdowns, there was 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. Small numbers of the key species – Shelduck, Oystercatcher, 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. Numbers of all species of wader have fallen sharply 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 species of diving duck – Pochard and Tufted Duck – increased, at least over the first three winters, whilst those of two piscivores – Cormorant and Goosander – remained the same. Other species more typical of freshwater habitats – grebes, Mute Swan, Moorhen and Coot – have also become more common.

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).

Although the size and diversity of the waterbird community using Cardiff Bay has been reduced, the Bay does now provide habitat for a range of freshwater species. Since the cessation of drawdowns, the open water has attracted grebes, Tufted Duck, Pochard and roosting gulls, particularly in the winter months. The Cardiff Bay Wetlands Reserve, an area of 8 ha established on the Bay's northern shore, includes a central lagoon and three smaller ponds within an area of marsh, separated from the land by a moat (Reed 2003). The reedbeds, tall herb fen, willow and alder carr and other aquatic vegetation that has developed here and on the Bay's western shore attracts grebes, Coot, Teal and Mallard throughout the year and also now provides opportunities for nesting birds in spring. Seven waterbird species – Great Crested Grebe, Little Grebe, Mute Swan, Shelduck, Mallard, Tufted Duck and Coot – have bred in small numbers in the Bay since barrage-closure. The further development of this habitat within the reserve and around the Bay is likely to attract larger numbers of nesting waterbirds in the future.

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

Shelduck

The majority of the Shelduck that formerly used Cardiff Bay have been displaced by its inundation. Peaks of between 233 and 469 were recorded in the Bay in the 10 years prior to barrage-closure. In contrast, in the four years following closure peaks of just 39, 61, 10 and 18 were recorded (Table 3.2.3). Those few Shelduck that do still frequent the Bay, primarily use it as a roost site.

There was no evidence that Shelduck displaced from Cardiff Bay were able to settle at either Rhymney or Orchard Ledges, or elsewhere on the north-west Severn. Although there was a small increase in Shelduck numbers at Orchard Ledges in the winter following closure, this was not maintained. A decline recorded at Rhymney subsequent to barrage-closure may have also been a consequence of the loss of birds from the Bay, as many of the Shelduck that previously used the Bay were also likely to have used Rhymney.

Whilst it seems probable, therefore, that some of the Shelduck from the Bay initially settled at Orchard Ledges, it is likely that either many were forced to disperse to more distant areas or that increased competition for food led to increased mortality in the population. It should also be noted, though, that the lack of increases in numbers elsewhere may have been the result of reduced recruitment of young birds onto the local populations.

Oystercatcher

Oystercatcher have been almost entirely lost to Cardiff Bay as a result of its inundation. Peaks of just four, two and two were recorded in the winters of 1999/2000, 2000/01 and 2001/02 respectively and none in 2002/03, in contrast to a peak of 121 in 1998/99 (Table 3.2.3).

As with Shelduck, there was no evidence that Oystercatcher displaced from Cardiff Bay were able to settle at either Rhymney or Orchard Ledges, or elsewhere on the north-west Severn. An initial increase in numbers at Rhymney in the winter following barrage-closure would have accounted for the birds displaced from the Bay. However, not only was this increase not sustained, but by 2002/03 there had been a significant decrease in Oystercatcher numbers at this site.

In The Netherlands' Delta region, Oystercatcher were apparently able to survive an initial loss of intertidal mudflats in the 1970s, perhaps because the area was not at carrying capacity for the species at the time (Lambeck *et al.* 1989). However, later habitat loss led to the loss of substantial numbers of birds (Lambeck 1991, Meire 1991). In our study, numbers of Oystercatchers had increased at Cardiff Bay, Orchard Ledges, Rhymney and elsewhere on the north-west Severn prior to barrage-closure – 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). However, given that the increases seen in our study did not continue, it seems likely that at the time of barrage-closure, there was little spare capacity for the birds displaced from the Bay.

Dunlin

As with other estuarine species, Dunlin were only recorded in small numbers in Cardiff Bay following its inundation, only visiting the site to roost over high tide. Peaks of just 12, 7, three and 50 were recorded in the four winters following barrage-closure. Prior to closure, peak numbers using the Bay had declined from 7,280 in the winter of 1989/90 to 786 Dunlin in the winter of 1998/99 (Table 3.2.3).

Declines were recorded on all the other study sites prior to closure and these have continued since. Austin *et al.* (2000, 2003) reported that numbers of Dunlin 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 meant that wintering on the milder west coast of Britain has become less of a benefit 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. If local factors were not contributing to the decline, there would have been spare capacity for the Dunlin displaced from the Bay. However, because of the continued decline in numbers of Dunlin on the Severn Estuary as a whole, it has not been possible to determine whether birds displaced from the Bay have been able to settle elsewhere.

Curlew

Curlew have only used Cardiff Bay for roosting since its inundation and in decreasing numbers. In comparison to peaks of between 98 and 186 over the 10 winters before barrage-closure, peaks of just 15, 62, three and six were recorded over the four subsequent winters (Table 3.2.3).

There was only slight evidence that Curlew displaced from Cardiff Bay were able to settle elsewhere. Curlew numbers increased at Orchard Ledges in the two winters following closure. This increase would have only accounted for some of the displaced birds, but has not been maintained. An increase at Peterstone and St. Brides in 2002/03 would have accounted for the birds that were unable to settle at Orchard Ledges.

Whilst it seems probable, therefore, that some of the Curlew displaced from the Bay initially settled at Orchard Ledges, it is likely that either many were forced to disperse to more distant areas or that increased competition for food led to increased mortality in the population. It should also be noted, though, that the lack of increases in numbers on adjacent areas may have been the result of reduced recruitment of young birds.

Redshank

The majority of the Redshank that formerly used Cardiff Bay have been displaced by its inundation and now only use the site in very small numbers as a high tide roost. Peaks of 22, 91, 30 and three were recorded in the winters following barrage-closure. Prior to closure, peak numbers declined from 534 in 1989/90 to 296 in 1998/99 (Table 3.2.3).

The increase in Redshank numbers 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 (see 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 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.

As with Dunlin, Redshank numbers have also been in decline in recent winters across the whole of south Wales and southwest England (Austin *et al.* 2000, 2003). As with that species, it is possible that warmer winter weather over recent winters has meant that wintering on the milder west coast of Britain has become less of a benefit 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 are in decline due to habitat drainage and loss and increased nest predation rates (e.g. Fuller & Jackson 1999, Jackson & Green 2000). If the declines seen at Rhymney were thus a consequence of external factors and not simply due to reduced local food resources, there would have been some capacity for birds displaced from the Bay. If this were limited, however, the increased densities of Redshank observed would have led to increased mortality (Goss-Custard 1985, Goss-Custard *et al.* 2002). Studies in The Netherlands (Lambeck 1991, Meire 1991, Schekkerman *et al.* 1994) found that waders displaced by coastal engineering works in the 1980s were not able to settle in adjacent intertidal areas as these sites were close to their carrying capacity. This and severe winter weather are believed to have 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.

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 (Goss-Custard 1985, Goss-Custard *et al.* 2002) 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. 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.

The majority of applied studies of the impacts of habitat loss on local populations of waterbirds have been based largely on count data (e.g. Evans 1978/79, Laursen *et al.* 1981, Lambeck *et al.* 1989, Meire 1991, 1996, McLusky *et al* 1992, Schekkerman *et al.* 1994, Hötker 1997). This may provide information on how birds redistribute themselves or on changes in behaviour – Evans (1978/79), for example, reported 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. However, such studies may be limited in establishing impacts on survival.

To determine more clearly the fates of birds displaced by habitat loss, two recent studies used ringing to follow birds' movements and provide some limited information on relative survival rates. Lambeck (1991) used colour-ringing to determine where Oystercatcher were displaced to following habitat loss in the Delta region of The Netherlands. Recoveries of dead birds also suggested that displaced birds had experienced significantly higher mortality than those originally ringed elsewhere in the Delta. Approximately half the Oystercatchers from the former intertidal areas disappeared following the loss of habitat.

Colour-ringing was also used to determine the movements of Dark-bellied Brent Geese *Branta bernicla bernicla* following the loss of saltmarsh at Rodenäs Vorland on the German Wadden Sea (Ganter & Ebbinge 1997, Ganter *et al.* 1997). The study revealed that, following the loss of habitat, long-distance movements were more frequent among displaced birds than control birds and that many displaced birds moved to less preferred sites that were apparently below their carrying capacity for the species. Resighting rates suggested no difference in the survival rates of displaced and control birds, though sample sizes were small.

In addition to using count data, our study thus used information gathered from ringing and tracking studies to determine more closely the impacts of the closure of the Cardiff Bay Barrage on one species of wader, the Redshank. 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 inundation.

Observations of both colour-ringed and radio-tagged birds were used to determine the movements of Redshank displaced by the loss of the Bay and its mudflats. Additionally, in this part of the report, we investigate whether the body condition and survival of Redshank displaced from the Bay has been adversely affected since barrage-closure. The survival rates of Redshank from the Bay are compared to those of birds from the neighbouring Rhymney Estuary and from a control site in north Wales.

6. METHODS

6.1 Ringing and Radio-tagging

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 Cardiff Bay and at the Rhymney Estuary. Each bird was aged according to its plumage characteristics (Prater *et al.* 1977) as either adult or first-year and fitted with a metal BTO ring. To help analyse variation in the birds' body condition, the following measurements were taken: mass (g), wing length (maximum chord), foot length and bill length (to precisions of 1 mm, 0.5 mm and 0.1 mm respectively) (see Summers *et al.* 1988). The majority of measurements were taken by one observer (Steve Dodd).

In addition to these data, ringing data have also been collated from four adjacent sites (Bangor Harbour, Wig and two on the Ogwen Estuary) in north Wales, to provide control data for use in the survival analyses. As above, Redshank were aged as either adult or first-year and fitted with a metal BTO ring.

Colour-ringing

Colour-ringing was used 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.

Radio-tagging

The movements of samples of Redshank before and after barrage-closure were also monitored by radio-tagging. Twenty individuals (19 adults and one first-winter bird) were caught and tagged in catches in Cardiff Bay on 15 and 21 October 1999. Ten additional adults were additionally caught and tagged on the Rhymney Estuary on 13 October, so as to determine if their movements would have been affected by any increase in the Redshank population on the estuary following the inundation of the Bay. Transmitters (model TW-4, Biotrack Ltd, 52 Furzebrook Road, Wareham, Dorset, BH20 5AX) were 2.5 g in weight and were fitted with a small piece of gauze to aid attachment. Following the methods of Warnock & Warnock (1993), the transmitters were attached to a small area of clipped feathers on the birds' lower backs using a cyanoacrylate glue (Loctite® Super Glue). The birds weighed between 125 and 168 g and thus transmitters were between 1.5 and 2.0% of their body mass. The transmitters' signals could be detected up to 1.5 km away and their batteries had a life expectancy of up to three months.

Following the exhaustion of the batteries on these tags, a further 10 adult Redshank were fitted with transmitters at the Rhymney River between 20 and 24 January 2000. Seven of these birds had originally been caught and ringed at Cardiff Bay, whilst the other three had first been metal-ringed at Rhymney. These birds weighed between 134 and 173 g and transmitters were thus between 1.4 and 1.9% of their body mass. All 40 birds tagged were also individually colour-ringed.

6.2 Data Analysis and Presentation of Results

6.2.1 The Distribution of Redshank Displaced from Cardiff Bay

Data from Colour-ringed Birds

Both in October 1999 and in the winters post-closure, Cardiff Bay and other parts of the Severn Estuary previously known to support wintering Redshank were surveyed for colour-ringed birds. Sites surveyed are listed in Appendix 1; 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 in October 1999 and the subsequent three winters. No other studies have colour-ringed Redshank on the Severn Estuary and thus those colour-ringed birds seen would either have been from Cardiff Bay (with the exception of the few birds radio-tagged and thus colour-ringed at Rhymney) or been birds ringed on breeding grounds. Three Redshank colour-ringed on breeding grounds in the Outer Hebrides were seen in the Cardiff area in winter during the course of the study (Jackson 1999, Burton *et al.* 2002b).

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 investigated 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).

Data from Radio-tagged Birds

Movements of radio-tagged individuals were monitored using a three element hand-held Yagi antenna and either an Australis 26K scanning receiver (Titley Electronics, Ballina, NSW, Australia) or a Mariner 57 receiver (Mariner Radar, Lowestoft, Suffolk, UK). For those birds tagged in October 1999, data were collected during three periods:

1. 15 to 31 October, i.e. pre-barrage closure
2. 5 to 18 November, immediately post-closure
3. 26 November to 20 December.

During each of these periods, triangulation was used to record the location of each bird three times, diurnally and nocturnally, each hour of the intertidal period, i.e. from four hours before low tide to four hours after (a total of 27 data points for each bird both day and night). The locations recorded indicate the extent of the areas that the birds used for feeding.

The time spans over which these data were collected covered different phases of the lunar cycle and neap and spring tides. The interval of one hour between recording successive radio-locations was long enough for birds to traverse the study area. This interval was thus sufficient to reduce the effects of autocorrelation, though not so great that biologically relevant data would have been omitted in subsequent analyses (de Solla *et al.* 1999; Otis & White 1999).

For the three periods, graphs indicate the proportion of birds tagged at Cardiff Bay and Rhymney that used different sites, both during the daytime and at night. Data are only presented for those individuals for which 27 points were obtained. Data points for period 2, i.e. immediately post-closure, were only collected once individuals were first recorded away from the Bay during daylight hours.

In addition to this, we also investigated whether the maximum distance between points – a measure of the extent of the areas that the birds used – differed between the day and night prior to barrage-closure and over the three periods.

The above analyses excluded data collected during 'drawdowns', i.e. periods when the Bay was temporary drained to maintain water quality. The use of the Bay by radio-tagged Redshank was recorded during six such periods between December 1999 and February 2000. This analysis used data only from those birds originally ringed in Cardiff Bay (i.e. the 20 caught and tagged there in October 1999 and the seven tagged at Rhymney in January 2000 that had originally been ringed in the Bay). Drawdowns were usually timed to occur outside of daylight hours.

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

To determine whether displacement from Cardiff Bay adversely affected the body condition of the Redshank that wintered there, it was initially necessary to classify individuals into three groups – those that had only ever been caught (or having been colour-ringed, seen) at Cardiff Bay prior to its flooding, those that had only ever been caught (or seen) at Rhymney and those that had been recorded at both sites. Comparison was then made of the masses of adults from each of these three categories in the winter of 1999/2000 using a GLM. The model controlled for month of capture and measures of body-size – i.e. wing-length, bill-length and foot-length – and only used one observation for each bird. Previous work has shown that the Redshank that formerly wintered in the Bay were predominantly from the British breeding population, whilst the birds that were found at Rhymney included a significantly larger number of birds from the Icelandic population (Burton *et al.* 2002b). Thus birds from the Bay tended to have shorter wings and feet, but longer bills (Summers *et al.* 1988). The model assumed a normal distribution and treated month and site group as class variables. The problem of overdispersion in the mass data was addressed by the application of a scale factor estimated from the square root of the Pearson's Chi-squared statistic divided by its degrees of freedom. Only those variables which were significant in explaining the variation in mass were retained in the final models. Likelihood ratio tests were used to investigate differences in the masses of Redshank from each group. Sample sizes were too small to investigate whether the masses of individuals were lower in the winter of 1999/2000 than in preceding winters.

6.2.3 Survival Analyses

Estimates of survival rates and recapture probabilities of adult Redshank were calculated using mark-recapture methods. Survival rates were calculated separately for a) birds originally caught and ringed at Cardiff Bay, using information from resightings of colour-ringed birds, b) birds originally ringed at Rhymney, using information from the recapture of ringed birds and c) birds from the north Wales control site, also using information from the recapture of ringed birds.

a) Survival Rates of Adult Redshank from Cardiff Bay

To determine the survival rates of Redshank from Cardiff Bay, the 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 2003. The use of data from resightings of colour-ringed birds was preferred to using data from the recapture of ringed birds, as it provided higher 'resighting' (i.e. recapture) rates (see also Sandercock 2003, Bearhop *et al.* in press). Importantly, it also allowed the inclusion of data from sites away the Bay and Rhymney, thus allowing for the movement of birds following the closure of the barrage. This allowed for better estimation of true survival, rather than just the measure of survival and site-fidelity to the Cardiff/Rhymney area (see Sandercock 2003).

Data were only included for birds originally caught and ringed in Cardiff Bay and were restricted to those first caught as adults, or subsequently seen, in one of the February or October resighting periods. There were insufficient data to look at the survival rates of first-winter Redshank, notably over the year following barrage-closure, though data from birds originally ringed in the Bay as first-winter birds but subsequently resighted (in October or February) as adults were included from the first point they were seen as adults. As no new birds were captured in the Bay following barrage-closure (i.e. from 1999/2000 onwards) and because we wanted to measure the impact of the closure on birds that had formerly used the Bay, the data set only contained resighting data for individuals first encountered as adults between February 1996 and October 1999.

Resighting data were analysed using Program MARK (White & Burnham 1999). Cormack-Jolly-Seber (CJS) models (Lebreton *et al.* 1992, Seber 1982) were developed to estimate monthly survival rates (ϕ) (i.e. the proportion of birds surviving a month within a period) and resighting probabilities (p).

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 6.2.3.1). This was thought to be because in the first year of data collection the River Ely was not surveyed for colour-ringed birds. Thus birds that were largely resident there at this time were subsequently seen to have 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 6.2.3.1). Using Program MARK, we also estimated an overdispersion parameter for the data ($\hat{c}$) to adjust the final selected model (following White & Burnham 1999).

A combination of likelihood ratio tests and Akaike's Information Criterion (AIC), adjusted for overdispersion and sample size ($QAIC_c$; Burnham & Anderson 1998), was used to select the model that best described the data (typically that with the lowest $QAIC_c$ value). Reduced models looked at whether p varied with time, either fully across every recapture period, between the October and February recapture periods or before and after barrage-closure. Similarly, the models also investigated whether the monthly survival rates ϕ also varied fully with time, between summer (February to October) and winter (October to February) or before and after barrage-closure.

b) Survival Rates of Adult Redshank from Rhymney

Survival rates were calculated for those adult Redshank originally caught and ringed at Rhymney using ringing-recapture data from catches undertaken at both Rhymney and Cardiff Bay between December 1991 and February 2003. Data were only included from catches undertaken between October and February each year. In part this was to match the winter period defined for the survival analyses of Cardiff Bay birds, though also to exclude birds only caught on autumn and spring passage (following Insley *et al.* 1997). Data were only included for individuals first encountered as adults between 1991/92 and October 1999. This was firstly in order to exclude data from Redshank that had been displaced from the Bay and, secondly, because we wanted to measure the impact of this possible influx of birds on those that had used the Rhymney Estuary prior to the closure of the barrage.

Data were again analysed using Program MARK to estimate annual survival rates (ϕ) and resighting probabilities (p) and to determine whether these varied with time. As above, likelihood ratio tests and Akaike's Information Criterion (AIC), adjusted for overdispersion and sample size ($QAIC_c$; Burnham & Anderson 1998), were used to select the model that best described the data. In addition to the models investigating whether ϕ and p varied with time, we also investigated whether the survival rate ϕ of Redshank from Rhymney differed before and after barrage-closure.

c) Survival Rates of Adult Redshank from North Wales

Survival rates were calculated for adult Redshank using ringing-recapture data from catches undertaken at Bangor Harbour, Wig and two sites on the Ogwen Estuary between November 1988 and February 2003. These sites were all within 4.3 km of each other. As above, data were only included from catches undertaken between October and February each year.

Models investigated whether ϕ and p varied with time and also whether the survival rate ϕ for north Wales Redshank differed in 2000-2002 to the 11 years before, so as to see whether any change in survival of Cardiff Bay birds following barrage-closure might have been simply a reflection of a regional trend, perhaps associated with a change in weather conditions.

7. RESULTS

7.1 The Distribution of Redshank Displaced from Cardiff Bay

7.1.1 Colour-ringing Studies

Figure 7.1.1.1 shows the how the distribution of colour-ringed Redshank on the lower Severn Estuary changed between October 1999, prior to barrage-closure, and 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 a total of 198 colour-ringed individuals was recorded in the Bay. In comparison, at Rhymney, a mean of 10% of Redshank were colour-ringed and a total of 56 colour-ringed individuals was recorded. 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 Severn.

The closure of the barrage displaced the majority of Redshank from the Bay and just 14 colour-ringed Redshank were recorded there over the following winter (this total excludes data from radio-tracking). These birds primarily used the Bay as a high tide roost. The majority of colour-ringed Redshank were recorded at the Rhymney River (219 individuals) and the mudflats by Cardiff Heliport (111 individuals) during the winter following barrage-closure. Colour-ringed Redshank were also seen at Sluice House Farm and Peterstone (16 individuals) and as far east as the River Usk at Newport (18 individuals). In addition to the bird seen on the River Axe in October, two colour-ringed individuals were also seen (at separate sites) on the English side of the Severn Estuary. Two of the three birds were believed to have been 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 (see Appendix 1).

Interestingly, there was an inverse relationship between the ages of individually colour-ringed Redshank and the maximum distances that they were recorded away from Cardiff Bay in the winter following closure (Table 7.1.1.1; Jonckheere Test $z = 2.12$, $P = 0.017$ – see Siegel & Castellan 1988 for methods). Of 42 individuals of known age (i.e. those that had originally been caught and ringed as first-winter birds), those that only moved as far as the Heliport mudflats were on average the oldest, whilst those that moved as far as Newport were the youngest. Only birds in their first or second winter were recorded at sites more than 4 km away from Cardiff Bay.

In subsequent winters, colour-ringed Redshank displaced from the Bay became more concentrated at the Rhymney River. Only 12 different colour-ringed Redshank were recorded in the Bay and 65 at the Heliport mudflats over these winters. No colour-ringed Redshank were seen on the River Usk in 2000/01 and 2001/02 and only one in 2002/03. Similarly, only two individuals were seen on the English side of the Severn over these winters. The bird seen at the River Axe in 2000/01 had been seen there in October 1999, prior to barrage-closure. A second bird was seen at Steart in November 2001.

The increased use of Rhymney was reflected by an increase in the proportion of colour-ringed individuals recorded in flocks of Redshank at the site. In the winter of 1999/2000, following barrage-closure, the percentage of colour-ringed birds in flocks at the Rhymney River increased significantly to 21% ($\chi^2_1 = 28.97$, $P < 0.0001$). 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: $\chi^2_1 = 16.14$, $P < 0.0001$; for 2001/02: $\chi^2_1 = 5.13$, $P = 0.0235$).

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 recorded in the Bay immediately prior to closure (χ^2_1 = 0.74, ns), suggesting that the majority of Redshank using this area were birds displaced from the Bay. 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).

7.1.2 Radio-tracking

In October 1999, prior to barrage-closure, radio-tagged Redshank showed a high degree of fidelity to the sites where they were caught (Figure 7.1.2.1). Only two of 17 birds (18%) caught at Cardiff Bay were recorded at the Rhymney River in the daytime and none anywhere else. At night, individuals were more mobile, with 10 of 13 birds (77%) recorded on the mudflats by Cardiff Heliport and five (46%) at the Rhymney River. Only two of eight Redshank radio-tagged at Rhymney were recorded away from that site in the daytime. Three (38%) were recorded by the Heliport and one (13%) in the Bay at night.

Post-closure, radio-tagged Redshank continued to be recorded in the Bay at both high and low tide for at least eight days (Figure 7.1.2.2). Thereafter the Bay was primarily used by radio-tagged Redshank as a high tide roost site.

Radio-tracking confirmed the results from observations of colour-ringed birds, that most Redshank from Cardiff Bay were displaced to the Rhymney River and the Heliport mudflats following barrage-closure. During the first two weeks post-closure, Cardiff Bay tagged Redshank were recorded during the intertidal period between the Bay and the River Usk at Newport (Figure 7.1.2.1). Twelve (71%) of 17 were recorded in the Bay at least once during the day in this period, nine (53%) by Cardiff Heliport, fourteen (82%) at the Rhymney River, one (6%) at Peterstone and five (29%) on the River Usk. All these sites were also used at night, with the area by the Heliport being especially favoured. Redshank radio-tagged at Rhymney were recorded only there during the day in this period, but also at the Heliport and Peterstone at night – a similar pattern to that recorded prior to closure.

By late November / early December, the movements of the Redshank originally radio-tagged in the Bay were already becoming more limited. Eight (57%) of 14 birds were recorded by Cardiff Heliport during the day and 13 (93%) at the Rhymney River. Only two individuals (14%) still used the Bay during the intertidal period and just one was recorded at Peterstone and one on the River Usk. A higher proportion of birds used the Heliport mudflats at night. Redshank radio-tagged at Rhymney were again primarily found at this site in the day. Use of the Heliport mudflats and Peterstone was again greater amongst these birds at night.

The analyses of the maximum distances between observations of individuals showed that, pre-closure, individuals from both Cardiff Bay and Rhymney ranged more widely at night than in the day (for Cardiff Bay birds: $T = 0$, $n = 13$, $P < 0.001$; for Rhymney birds: $T = 1$, $n = 8$, $P < 0.05$).

In the first two weeks following closure, the maximum distances separating diurnal observations of individual Redshank from Cardiff Bay increased, as birds ranged more widely ($T = 6$, $n = 16$, $P < 0.001$). Two individuals were recorded both at Cardiff Bay and on the River Usk at Newport in this first fortnight – a distance of over 15 km. No significant difference was found for nocturnal observations ($T = 16$, $n = 9$, ns). In late November / early December, radio-tagged Redshank from Cardiff Bay continued to range more widely than pre-closure during the day ($T = 11$, $n = 13$, $P < 0.05$), though, again, not at night ($T = 12$, $n = 9$, ns).

The distances separating observations of Redshank originally radio-tagged at Rhymney post-closure were not significantly different to those pre-closure (for diurnal observations in early November: T = 7, n =7 , ns; in late November / early November: T = 4, n = 5, ns; for nocturnal observations in early November: T = 7, n = 5 , ns; in late November / early November: T = 7, n = 5 , ns).

Examples of the radio-locations of two Redshank tagged at Cardiff Bay are shown in Figures 7.1.2.3-7.1.2.6. Prior to closure the first, bird 'RD05', was recorded primarily in the Bay during the daytime and only occasionally at the Rhymney River. At night this bird was recorded at these two sites and also by Cardiff Heliport (Figure 7.1.2.3). In early November, after barrage-closure, this bird was recorded only at Rhymney (Figure 7.1.2.4). The second individual, bird 'RD11', was never recorded away from the Bay during daylight hours in the first period prior to closure, but was found to use the mudflats by the Heliport at night (Figure 7.1.2.5). In the fortnight after closure, this bird was recorded almost exclusively by the Heliport, with only occasional observations at the Rhymney River and back in the Bay in the daytime (Figure 7.1.2.6).

The above analyses excluded data collected during 'drawdowns', i.e. periods when the Bay was temporarily drained to maintain water quality. During six such periods between December 1999 and February 2000, an average of 14% of radio-tagged Redshank was found to use the Bay (Table 7.1.2.1). Only those birds originally ringed in Cardiff Bay and with still active tags were included in this analysis. Although drawdowns were usually timed to occur outside of daylight hours, it was possible to count Redshank as the Bay was filled by the incoming tide on two mornings in February 2000. Totals of 55 and 56 Redshank were recorded in the Bay on 3 and 25 February respectively.

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

The GLM used to analyse adult Redshank biometric data indicated that mass was significantly and positively related to wing-length ($F_{1,225}$ = 37.2, P < 0.0001) and foot-length ($F_{1,225}$ = 41.6, P < 0.0001), but not to bill-length ($F_{1,224}$ = 0.18).

Mass in the winter of 1999/2000 was also significantly related to month ($F_{1,225}$ = 32.5, P < 0.0001) and notably, the group to which an individual had been categorised ($F_{1,225}$ = 3.5, P = 0.0336). 'Cardiff Bay' Redshank were significantly lighter, controlling for body-size and month, than those classified as 'Rhymney' birds ($F_{1,225}$ = 5.4, P = 0.0214) and those that had been recorded at both sites prior to barrage-closure ($F_{1,225}$ = 6.8, P = 0.0095). Those from the latter two categories did not differ in mass ($F_{1,225}$ = 0.6, ns).

7.3 Survival Analyses

a) Survival Rates of Adult Redshank from Cardiff Bay

Models describing the survival rates and resighting probabilities for adult Redshank originally caught and ringed in Cardiff Bay are shown in Table 7.3.1. Resighting probabilities were high, equal to 0.862 (95% confidence limits = 0.840-0.882) in the base model in which both ϕ and p were assumed to be constant over time.

Refinement of initial models indicated that, rather than vary fully with time, resighting probabilities varied between October and February and also before and after barrage-closure. The most parsimonious model (that with the lowest $QAIC_c$ value) needed only three survival parameters, one relating to the summer, one for the two winters before barrage-closure and one for the four winters following barrage-closure. A likelihood ratio test showed that the difference between winter survival before and after barrage-closure was highly significant (χ^2_1 = 11.86, P = 0.0006).

Using the 'best-fit' model, the monthly winter survival (ϕ_W) of adult Redshank from Cardiff Bay in the two winters before barrage-closure was thus estimated to be 0.998 (95% confidence limits = 0.966-

1.000). In the four winters following barrage-closure, the monthly survival rate of these birds fell to 0.978 (0.968-0.984). Monthly summer survival (ϕ_S) was estimated to be 0.980 (0.975-0.984).

Annual survival, calculated as the product of the survival rate over the whole winter (ϕ_W^4) and the over-summer return rate (ϕ_S^8) was thus 0.846 for the two years prior to barrage-closure, but fell to 0.778 in the three years thereafter.

b) Survival Rates of Adult Redshank from Rhymney

Models describing the survival rates and recapture probabilities for adult Redshank originally caught and ringed at Rhymney are shown in Table 7.3.2. Recapture probabilities for these birds were much lower than the equivalent resighting probabilities for Cardiff Bay Redshank, equal to 0.086 (95% confidence limits = 0.069-0.107) in the base model in which both ϕ and p were assumed to be constant over time.

The most parsimonious model indicated that recapture probabilities varied fully with time, but that survival was constant over the study period. A likelihood ratio test also indicated that for these birds there was no significant difference in survival in the eight years before the closure of the Cardiff Bay barrage and the three years (2000-2002) afterwards ($\chi^2_1 = 0.03$, ns).

The annual survival rate for adult Redshank originally caught and ringed at Rhymney was estimated to be 0.860 (95% confidence limits = 0.813-0.897) – a similar rate to that of Cardiff Bay birds prior to barrage-closure.

c) Survival Rates of Adult Redshank from North Wales

Models describing the survival rates and recapture probabilities for adult Redshank caught at the control site in north Wales are shown in Table 7.3.3. The recapture probability for these birds equalled 0.142 (95% confidence limits = 0.124-0.162) in the base model in which both ϕ and p were assumed to be constant over time, again much lower than the resighting rates for Cardiff Bay birds.

The most parsimonious model indicated that both recapture probabilities and survival varied fully with time. This 'best-fit' model indicated that the annual survival rate for adult Redshank in north Wales varied between 0.389 and 1.000.

A likelihood ratio test indicated that for these birds, survival was actually greater in the years 2000-2002 (i.e. the period following the closure of the Cardiff Bay barrage) in comparison to the 11 beforehand ($\chi^2_1 = 4.93$, $P = 0.0263$). The annual survival rate across the first 11 years was estimated to equal 0.730 (95% confidence limits = 0.696-0.761). In comparison, the estimated rate for 2000-2002 equalled 0.932 (95% confidence limits = 0.402-0.996).

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 River and the mudflats by Cardiff Heliport. Although a number of Redshank continued to frequent the Bay, after the first two weeks they primarily used the site to roost over high tide. A number of birds moved further than Rhymney – to Peterstone (16 colour-ringed individuals) and as far as the River Usk at Newport (18 individuals), though evidence from radio-tracking suggested that use of the latter site decreased after November. At least one individual also crossed the mouth of the Severn to the estuary of the River Axe. This individual had been seen in Cardiff Bay in October 1999, but notably had also previously been reported as a breeding bird on the Somerset Levels in April 1996.

Older birds appeared more faithful to the Bay in the winter following closure, only moving to those sites closest by. Previous studies of Dunlin (Baccetti *et al.* 1995, 1999) have also suggested that adult birds may be more attached to wintering sites than first-year birds, but that the latter become more attached to wintering sites as winter progresses. Our results suggest that, for Redshank, an individual's attachment to a winter site may develop more gradually.

In spite of their attachment to Cardiff Bay, radio-tracking revealed that displaced Redshank ranged more widely in the winter following barrage-closure than they had done previously. In part this may have been due to a lack of knowledge of the most profitable local foraging locations outside of the Bay, though was also perhaps a result of competition for food. In their study in Germany, Ganter *et al.* (1997) similarly found that Brent Geese displaced by a loss of saltmarsh ranged more widely than a group of control birds.

Subsequent observations of colour-ringed birds and the increase in counts of Redshank at Rhymney indicated that the distribution of Redshank displaced from the Bay became even more concentrated into this area over the following three winters. Redshank continued to use the mudflats at the Heliport, though in reduced numbers. Observations from 2000/01 and 2001/02 revealed that the Redshank that used this site during the day included a number of individuals that continued to use the Bay as a high tide roost and which stopped at the Heliport en route to the Rhymney River. Colour-ringed Redshank from the Bay also continued to frequent Peterstone, but after 1999/2000, only one colour-ringed individual was seen on the River Usk after 1999/2000 and just two on the English side of the Severn.

Results from 1999/2000 indicated that approximately 45% of the Redshank that used the mudflats by the Heliport 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 at this site are situated by a sewage outfall pipe and due to the high organic and nutrient input from sewage are rich in invertebrates, notably very high densities of *Corophium* (N.A.C. pers. obs.; Pearson & Rosenberg 1978). In spite of this, disturbance from landing helicopters probably discouraged Redshank from using the site prior to barrage-closure, at least during the day – the heliport's usual operating hours are from 0900 to 1700. Previous studies have indicated that helicopters typically cause more disturbance than any other type aircraft (Smit & Visser 1993). Birds had previously used the site at night, however, when no helicopters took off or landed.

It seems probable that Redshank displaced from the Bay have been forced to use this disturbed site by an inability to find food elsewhere. The displaced Redshank are likely to have faced intense competition for food with those birds already resident at Rhymney and many adults would have turned to the Heliport site due to their familiarity of it as a nocturnal feeding site. In spite of this, analysis of biometric data revealed that adult Redshank from the Bay had difficulty maintaining their body condition in the first winter following closure. In The Netherlands, Oystercatcher displaced by a loss of mudflats in the Delta region were similarly significantly lighter than those originally ringed at other neighbouring sites (Lambeck 1991).

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 displaced from Cardiff Bay not only lost body condition but the population as a whole also suffered increased mortality in the winters following barrage-closure. The estimated annual survival rate of adult Redshank originally caught and ringed at Cardiff Bay fell from 0.846 in the two years prior to barrage-closure to 0.778 in the three following years, due to a significant decline in winter survival rates (P = 0.0006). As a result of this decline, an additional 13% of the Redshank displaced from the Bay were apparently lost over these three years. In comparison, there was no significant difference before and after barrage-closure in the annual survival rate of adult Redshank originally caught and ringed at Rhymney. Estimated annual survival for these birds was 0.860, similar to that of Cardiff Bay birds before barrage-closure. Estimated survival rates for adult Redshank at a control site in north Wales varied annually, though the rates for 2000-2002 were actually higher than over the 11 years beforehand, suggesting that the drop in survival of Cardiff Bay birds was not due to poor weather regionally.

The survival rate of Cardiff Bay Redshank over the winters subsequent to barrage-closure may have been underestimated if birds had not been detected once displaced. However, the selected model accounted for a lower resighting rate following barrage-closure and there is little evidence that birds moved to sites not surveyed. As Figure 7.1.1.1 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 1) 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 first (2000) breeding season following the barrage's closure. Over-summer return rates were found to be constant over the study period, however, and thus it seems that this did not happen.

Although winter survival rates thus did fall following barrage-closure, it should be noted that the annual survival rate estimated for birds displaced from Cardiff Bay over the three years following barrage-closure is no lower than some other previously 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. However, the lack of decline in the survival rates of Redshank from Rhymney and north Wales in the years following the closure of the barrage and the similarity in the survival rate of Cardiff Bay birds pre-closure to that of Rhymney birds imply that the decline in the survival of Redshank displaced from Cardiff Bay is nevertheless of significance.

Numbers of Redshank at Rhymney had fallen over the seven years preceding the closure of the barrage (see Section 3.5). As there had also been a regional decline in the species' numbers over this period (Austin *et al.* 2000, 2003), it seems likely that this was not solely the result of local factors and consequently the site may have been below its carrying capacity for the species at the time of the Bay's loss. Certainly, the high winter survival rates of Redshank at Rhymney (and at Cardiff Bay prior to closure) suggest that birds were not previously dying because of competition for food.

However, although there may have been some capacity for the increase in Redshank numbers that has been seen at Rhymney since barrage-closure, the increase in mortality among the birds displaced from Cardiff Bay suggests that the area could not fully support the enlarged population. Our results suggest that older birds may have been particularly at risk as, having been settled for many winters, they found it difficult to move far and adapt to alternative wintering sites. If the size of the population at Rhymney is above the area's carrying capacity for the species (Goss-Custard 1985, Goss-Custard *et al.* 2002), mortality among the displaced Redshank is likely to remain at this increased level.

9. CONCLUSIONS

The aim of this study has been to assess changes in the numbers, distribution and survival of waterbirds in Cardiff Bay and surrounding areas during construction of the barrage and following barrage-closure. The work has attempted to answer four main questions:

i. Were the numbers and distribution of birds within the Bay affected by construction work associated with the barrage?
ii. Were birds displaced by the inundation of the bay following barrage-closure and how did the waterbird community change?
iii. Were birds displaced from the Bay able to re-locate to other neighbouring sites?
iv. Was there any impact on the condition and survival of birds that were forced to re-locate?

Initial work indicated that the overall numbers of wintering waterbirds supported in the Bay had declined prior to barrage-closure, perhaps due to changes in habitat quality. The distribution and behaviour of birds in the Bay were also affected by disturbance.

Following barrage-closure, the majority of the former waterbird community of Cardiff Bay was displaced by its inundation and the change to freshwater conditions. Prior to barrage-closure, the Bay supported a diverse waterbird community, dominated by large (winter) numbers of estuarine specialists. Over the four subsequent years, however, this has been replaced by a smaller community comprising smaller numbers of freshwater species. At least seven of these species have bred. Very small numbers of Shelduck, Oystercatcher, Dunlin, Curlew and Redshank – formerly the most numerous waterbird species to occur in the Bay – have continued to use the Bay as a high tide roost site during winter, though only occasional individuals remain to forage at low tide.

For three of these five key species – Shelduck, Oystercatcher and Curlew – there was evidence from counts that some of the birds displaced from Cardiff Bay settled at adjacent sites in the first winter following barrage-closure. However, these increases were not maintained and, with the exception of Curlew, there was no evidence that birds subsequently attempted to settle elsewhere. In the case of Dunlin, it was not possible to determine whether displaced birds were able to settle elsewhere due to an ongoing decline of the local population. Counts indicated that the majority of Cardiff Bay Redshank were displaced to the neighbouring Rhymney Estuary

Detailed observation of colour-ringed and radio-tagged birds supported the evidence from counts that most of the Redshank from the Bay were displaced to Rhymney. However, many of these birds were forced to use a disturbed part of this site that had previously been largely used only at night. Although count data suggested that the Redshank displaced from Cardiff Bay were able to settle at Rhymney, analysis of biometric data revealed that adult Redshank from the Bay had difficulty maintaining their body condition in the first winter following closure. Most significantly, data from colour-ringed birds indicated that the winter survival rate of adult Redshank from Cardiff Bay fell after their displacement, suggesting that the Rhymney area could not fully support the enlarged population. Older Redshank also appeared more attached to the Bay and perhaps had difficulty in adapting to alternative wintering sites.

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	Winters before barrage-closure	Winters following barrage-closure
WILDFOWL		
Mute Swan *Cygnus olor*	5	4
Canada Goose *Branta canadensis*	2	2
Barnacle Goose *Branta leucopsis*	1	0
Dark-bellied Brent Goose *Branta bernicla bernicla*	5	0
Shelduck *Tadorna tadorna*	10	4
Wigeon *Anas penelope*	3	0
Gadwall *Anas strepera*	5	1
Teal *Anas crecca*	10	4
Mallard *Anas platyrhynchos*	10	4
Pintail *Anas acuta*	3	0
Shoveler *Anas clypeata*	4	1
Pochard *Aythya ferina*	10	4
Tufted Duck *Aythya fuligula*	1	4
Scaup *Aythya marila*	1	0
Eider *Somateria mollissima*	1	0
Long-tailed Duck *Clangula hyemalis*	0	1
Common Scoter *Melanitta nigra*	2	1
Goldeneye *Bucephala clangula*	5	2
Red-breasted Merganser *Mergus serrator*	2	0
Goosander *Mergus merganser*	7	4
Ruddy Duck *Oxyura jamaicensis*	2	0
WADERS		
Oystercatcher *Haematopus ostralegus*	10	4
Avocet *Recurvirostra avosetta*	2	0
Ringed Plover *Charadrius hiaticula*	10	1
Golden Plover *Pluvialis apricaria*	2	0
Grey Plover *Pluvialis squatarola*	10	0
Lapwing *Vanellus vanellus*	10	3
Knot *Calidris canutus*	10	0
Curlew Sandpiper *Calidris ferruginea*	3	0
Dunlin *Calidris alpina*	10	4
Ruff *Philomachus pugnax*	3	0
Snipe *Gallinago gallinago*	6	0
Black-tailed Godwit *Limosa limosa*	8	0
Bar-tailed Godwit *Limosa lapponica*	8	0
Whimbrel *Numenius phaeopus*	9	2
Curlew *Numenius arquata*	10	4
Spotted Redshank *Tringa erythropus*	2	0
Redshank *Tringa totanus*	10	4
Greenshank *Tringa nebularia*	3	0
Green Sandpiper *Tringa ochropus*	1	0
Common Sandpiper *Actitis hypoleucos*	6	4
Turnstone *Arenaria interpres*	10	3
OTHER WATERBIRD SPECIES		
Little Grebe *Tachybaptus ruficollis*	1	4
Great Crested Grebe *Podiceps cristatus*	4	4
Red-necked Grebe *Podiceps grisegena*	1	0
Slavonian Grebe *Podiceps auritus*	0	1
Black-necked Grebe *Podiceps nigricollis*	0	2
Cormorant *Phalacrocorax carbo*	10	4
Little Egret *Egretta garzetta*	1	0
Grey Heron *Ardea cinerea*	9	2
Water Rail *Rallus aquaticus*	1	0
Moorhen *Gallinula chloropus*	0	2
Coot *Fulica atra*	1	3
Kingfisher *Alcedo atthis*	6	2

Table 3.2.1 Waterbird species recorded on all-day counts at Cardiff Bay between 1989/90 and 2002/03. The table indicates how many of the 10 winters before barrage-closure and the four following that species were seen in the Bay.

	Winters before barrage-closure										Winters following barrage-closure			
	89/90	90/91	91/92	92/93	93/94	94/95	95/96	96/9	97/98	98/99	99/00	00/01	01/02	02/03
WILDFOWL														
Mute Swan			1		1	1			1	1	1	1	1	1
Canada Goose		1					1					1		1
Barnacle Goose								1						
Brent Goose	1	1		1	1			1						
Shelduck	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Wigeon				1			1	1						
Gadwall			1	1	1		1	1					1	
Teal	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mallard	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Pintail					1		1	1						
Shoveler					1		1	1		1				1
Pochard	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tufted Duck								1			1	1	1	1
Scaup								1						
Eider					1									
Long-tailed Duck													1	
Common Scoter				1	1									1
Goldeneye		1		1		1	1		1				1	1
Red-breasted Merganser							1	1						
Goosander				1	1	1	1	1	1	1	1	1	1	1
Ruddy Duck		1					1							
WADERS														
Oystercatcher	1	1	1	1	1	1	1	1	1	1	1	1	1	
Avocet		1				1								
Ringed Plover	1	1	1	1	1	1	1	1	1	1				1
Golden Plover		1	1											
Grey Plover	1	1	1	1	1	1	1	1	1	1				
Lapwing	1	1	1	1	1	1	1	1	1	1		1	1	1
Knot	1	1	1	1	1	1	1	1	1	1				
Curlew Sandpiper			1					1		1				
Dunlin	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ruff								1	1	1				
Snipe	1		1		1	1		1		1				
Black-tailed Godwit			1	1	1	1	1	1	1	1				
Bar-tailed Godwit		1	1	1	1	1	1	1	1					
Whimbrel		1	1	1	1	1	1	1	1	1	1	1		
Curlew	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Spotted Redshank								1	1					
Redshank	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Greenshank						1			1	1				
Green Sandpiper		1												
Common Sandpiper		1			1	1	1		1	1	1	1	1	1
Turnstone	1	1	1	1	1	1	1	1	1	1	1	1	1	
OTHERS														
Little Grebe										1	1	1	1	1
Great Crested Grebe		1	1		1			1			1	1	1	1
Red-necked Grebe								1						
Slavonian Grebe													1	
Black-necked Grebe													1	1
Cormorant	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Grey Heron	1	1	1	1	1		1	1	1	1			1	1
Water Rail			1											
Moorhen													1	1
Coot										1		1	1	1
Kingfisher		1	1	1			1	1	1				1	1
Wildfowl	5	8	6	10	12	7	13	14	7	7	7	8	10	11
Waders	10	15	15	12	14	16	13	16	16	16	7	8	7	6
Other Waterbirds	5	6	6	7	9	5	9	10	5	6	5	6	6	7
TOTAL	20	29	27	29	35	28	35	40	28	29	19	22	23	24

Table 3.2.2 Waterbird species recorded on all-day counts at Cardiff Bay each year between 1989/90 and 2002/03. Note, a single Little Egret was also seen in the Bay in autumn 1999, just prior to barrage closure.

				Winters before barrage-closure										Winters following barrage-closure			
Species	a	b	c	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03
MS	2400	260	N	0	0	0	0	0	2	0	0	0	0	0	7	7	8
SU	3000	750	I	233	381	408	469	297	387	391	298	320	307	39	61	10	18
T.	4000	1400	N	175	210	303	352	354	225	125	124	103	121	20	30	42	45
MA	20000	5000	-	137	141	110	131	144	130	95	147	91	127	51	21	24	44
PO	3500	440	N	4	16	9	25	6	8	30	90	24	48	69	120	240	25
TU	10000	600	N	0	0	0	0	0	0	0	1	0	0	1	2	23	10
GD	2000	90	-	0	0	0	0	0	2	3	6	14	12	7	4	16	9
OC	9000	3600	-	29	35	76	93	66	82	114	206	83	121	4	2	2	0
RP	500	290	-	25	6	6	13	17	21	9	1	48	44	0	0	0	22
GV	1500	430	-	100	30	5	9	11	11	32	17	0	1	0	0	0	0
L.	20000	20000	-	115	83	175	133	161	125	156	150	115	73	0	43	24	1
KN	3500	2900	-	750	2	320	0	850	300	1	0	1	1	0	0	0	0
DN	14000	5300	I	7280	1149	2640	3526	7000	4973	2270	1584	1384	786	12	7	3	50
CU	3500	1200	N	186	98	120	168	157	116	143	126	143	122	15	62	3	6
RK	1500	1100	I	534	311	549	509	479	457	258	309	333	296	22	91	30	3
TT	700	640	-	51	80	20	35	25	45	36	40	12	12	18	0	0	0

Table 3.2.3 The importance of the Severn Estuary and Cardiff Bay for wildfowl and waders in a British and international context and peak numbers recorded in Cardiff Bay in the winters of 1989/90 to 2002/03. MS = Mute Swan *Cygnus olor*, SU = Shelduck *Tadorna tadorna*, T. = Teal *Anas crecca*, MA = Mallard *Anas platyrhynchos*, PO = Pochard *Aythya ferina*, TU = Tufted Duck *Aythya fuligula*, GD = Goosander *Mergus merganser*, OC = Oystercatcher *Haematopus ostralegus*, RP = Ringed Plover *Charadrius hiaticula*, GV = Grey Plover *Pluvialis squatarola*, L. = Lapwing *Vanellus vanellus*, KN = Knot *Calidris canutus*, DN = Dunlin *Calidris alpina*, CU = Curlew *Numenius arquata*, RK = Redshank *Tringa totanus* and TT = Turnstone *Arenaria interpres*. 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 Pintail *Anas acuta* and nationally important numbers of European White-fronted Goose *Anser albifrons albifrons*, Wigeon *Anas penelope*, Gadwall *Anas strepera*, Shoveler *Anas clypeata* and Black-tailed Godwit *Limosa limosa* (Pollitt *et al.* 2003). a – threshold for international importance; b – threshold for national importance; c – importance of the Severn Estuary: I = International; N = National.

	Winters before barrage-closure										Winters following barrage-closure			
Species	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03
MS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SU	13	71	240	83	14	25	83	6	9	53	101	54	20	21
T.	0	8	0	0	0	0	0	0	0	0	0	0	0	0
MA	0	4	2	2	2	0	3	4	0	1	5	0	0	5
PO	0	0	0	0	0	0	0	0	0	13	0	0	0	0
TU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OC	110	83	83	73	70	63	192	163	174	246	276	258	244	183
RP	25	40	18	150	82	34	4	5	13	1	64	31	35	41
GV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L.	1	0	0	0	0	4	12	0	0	0	0	0	0	0
KN	0	0	0	0	100	0	0	0	1	0	0	1	0	0
DN	200	400	975	1500	1800	2700	370	16	130	55	300	45	3	2
CU	55	105	52	76	80	85	59	65	90	68	114	107	53	36
RK	1	1	1	0	1	0	7	0	0	0	1	0	1	0
TT	170	176	152	220	235	215	170	116	181	84	79	97	86	41

Table 3.2.4 Peak winter numbers recorded of wildfowl and waders recorded at Orchard Ledges between 1989/90 and 2002/03. MS = Mute Swan *Cygnus olor*, SU = Shelduck *Tadorna tadorna*, T. = Teal *Anas crecca*, MA = Mallard *Anas platyrhynchos*, PO = Pochard *Aythya ferina*, TU = Tufted Duck *Aythya fuligula*, GD = Goosander *Mergus merganser*, OC = Oystercatcher *Haematopus ostralegus*, RP = Ringed Plover *Charadrius hiaticula*, GV = Grey Plover *Pluvialis squatarola*, L. = Lapwing *Vanellus vanellus*, KN = Knot *Calidris canutus*, DN = Dunlin *Calidris alpina*, CU = Curlew *Numenius arquata*, RK = Redshank *Tringa totanus* and TT = Turnstone *Arenaria interpres*.

	Winters before barrage-closure										Winters following barrage-closure			
Species	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03
MS	0	0	0	0	0	0	0	0	0	0	0	0	1	0
SU	1000	752	1376	1150	1449	1051	1820	893	892	1309	1165	921	635	603
T.	165	90	61	108	74	110	96	23	4	9	2	6	34	6
MA	170	58	100	84	100	84	82	110	90	65	79	83	99	107
PO	63	10	98	116	300	190	55	142	212	173	216	195	350	19
TU	0	0	0	1	1	0	0	1	125	50	0	35	24	0
GD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OC	255	159	420	554	415	328	407	416	506	332	399	461	453	239
RP	100	50	66	42	65	51	45	12	25	2	46	32	75	36
GV	2	2	0	1	20	0	21	14	0	0	0	0	0	0
L.	0	40	30	125	200	170	86	150	52	96	0	24	230	105
KN	0	0	0	0	1200	900	350	600	140	240	1	60	90	14
DN	9500	8200	8950	6100	13900	15600	8600	13615	7100	3395	1995	1640	1626	2000
CU	116	119	163	105	69	117	74	117	198	105	90	178	135	65
RK	712	566	950	828	790	700	744	712	491	625	611	747	861	730
TT	77	68	72	77	75	82	95	90	64	42	4	3	60	67

Table 3.2.5 Peak winter numbers recorded of wildfowl and waders recorded at Rhymney between 1989/90 and 2002/03. MS = Mute Swan *Cygnus olor*, SU = Shelduck *Tadorna tadorna*, T. = Teal *Anas crecca*, MA = Mallard *Anas platyrhynchos*, PO = Pochard *Aythya ferina*, TU = Tufted Duck *Aythya fuligula*, GD = Goosander *Mergus merganser*, OC = Oystercatcher *Haematopus ostralegus*, RP = Ringed Plover *Charadrius hiaticula*, GV = Grey Plover *Pluvialis squatarola*, L. = Lapwing *Vanellus vanellus*, KN = Knot *Calidris canutus*, DN = Dunlin *Calidris alpina*, CU = Curlew *Numenius arquata*, RK = Redshank *Tringa totanus* and TT = Turnstone *Arenaria interpres*.

	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	$F_{6,2239} = 34.9$ $P < 0.0001$	$F_{6,2239} = 6.9$ $P < 0.0001$	$F_{1,2239} = 11.5$ $P = 0.0007$	ns	$F_{13,2239} = 9.5$ $P < 0.0001$
Rhymney	$F_{8,32284} = 697.6$ $P < 0.0001$	$F_{11,32284} = 57.4$ $P < 0.0001$	$F_{16,32284} = 472.1$ $P < 0.0001$	-	$F_{14,32284} = 49.1$ $P < 0.0001$

Table 3.3.1 Likelihood ratio statistics and associated probabilities for month, state of tide, mudflat, state of tide*mudflat and year in 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 2002/03. 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
$F_{4,634} = 6.3$ $P < 0.0001$	$F_{7,634} = 30.9$ $P < 0.0001$	$F_{13,634} = 3.9$ $P < 0.0001$

Table 3.3.2 Likelihood ratio statistics and associated probabilities for month, mudflat and year in a generalized linear model describing densities of feeding Shelduck at low tide on eight mudflats at Peterstone and St. Brides from 1989/90 to 2002/03.

	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	$F_{9,3269}$ = 111.4 $P < 0.0001$	$F_{6,3269}$ = 49.9 $P < 0.0001$	$F_{1,3269}$ = 101.5 $P < 0.0001$	$F_{6,3269}$ = 20.1 $P < 0.0001$	$F_{14,3269}$ = 30.6 $P < 0.0001$
Rhymney	$F_{9,34296}$ = 73.8 $P < 0.0001$	$F_{11,34296}$ = 18.4 $P < 0.0001$	$F_{16,34296}$ = 63.6 $P < 0.0001$	$F_{118,34296}$ = 15.3 $P < 0.0001$	$F_{14,34296}$ = 42.0 $P < 0.0001$

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 Oystercatcher at Cardiff Bay from 1989/90 to 1998/99 and Orchard Ledges and Rhymney from 1989/90 to 2002/03.

Month	Mudflat	Year
ns	$F_{7,650} = 26.0$ $P < 0.0001$	$F_{13,650} = 1.9$ $P = 0.0311$

Table 3.4.2 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 1989/90 to 2002/03.

	Month	State of Tide	Mudflat	State of Tide * Mudflat	Year
Cardiff Bay	$F_{8,34240} = 115.5$ $P < 0.0001$	$F_{11,34240} = 67.6$ $P < 0.0001$	$F_{18,34240} = 37.9$ $P < 0.0001$	-	$F_{10,34240} = 52.7$ $P < 0.0001$
Orchard Ledges	$F_{6,2239} = 31.1$ $P < 0.0001$	$F_{6,2239} = 13.5$ $P < 0.0001$	$F_{1,2239} = 205.1$ $P < 0.0001$	ns	$F_{13,2239} = 21.3$ $P < 0.0001$
Rhymney	$F_{8,32284} = 452.9$ $P < 0.0001$	$F_{11,32284} = 49.9$ $P < 0.0001$	$F_{16,32284} = 220.0$ $P < 0.0001$	-	$F_{14,32284} = 131.4$ $P < 0.0001$

Table 3.5.1 Likelihood ratio statistics and associated probabilities for month, state of tide, mudflat, state of tide*mudflat and year in generalized linear models describing densities of feeding Dunlin at Cardiff Bay from 1989/90 to 1998/99 and Orchard Ledges and Rhymney from 1989/90 to 2002/03. 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
$F_{4,646} = 11.6$ $P < 0.0001$	$F_{7,646} = 23.3$ $P < 0.0001$	$F_{13,646} = 15.0$ $P < 0.0001$

Table 3.5.2 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 1989/90 to 2002/03.

	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	$F_{9,3275} = 133.1$ $P < 0.0001$	$F_{6,3275} = 56.3$ $P < 0.0001$	$F_{1,3275} = 130.0$ $P < 0.0001$	ns	$F_{14,3275} = 18.0$ $P < 0.0001$
Rhymney	$F_{9,34076} = 108.4$ $P < 0.0001$	$F_{11,34076} = 2.9$ $P = 0.0008$	$F_{16,34076} = 27.5$ $P < 0.0001$	$F_{117,34076} = 6.2$ $P < 0.0001$	$F_{14,34076} = 32.6$ $P < 0.0001$

Table 3.6.1 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 2002/03.

Month	Mudflat	Year
$F_{4,646} = 6.8$ $P < 0.0001$	$F_{7,646} = 49.9$ $P < 0.0001$	$F_{13,646} = 7.4$ $P < 0.0001$

Table 3.6.2 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 1989/90 to 2002/03.

	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 = 0.0013	$F_{18,33330}$ = 44.4 P < 0.0001	$F_{179,33330}$ = 4.6 P < 0.0001	$F_{10,33330}$ = 10.6 P < 0.0001
Rhymney	$F_{8,31960}$ = 123.1 P < 0.0001	$F_{11,31960}$ = 8.1 P < 0.0001	$F_{16,31960}$ = 186.3 P < 0.0001	ns	$F_{14,31960}$ = 25.5 P < 0.0001

Table 3.7.1 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 2002/03. Both models excluded data from May, as too few birds were present on the study sites at this time for their inclusion to be biologically meaningful.

Month	Mudflat	Year
ns	$F_{6,560} = 8.4$ $P < 0.0001$	$F_{13,560} = 3.2$ $P = 0.0001$

Table 3.7.2 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 1989/90 to 2002/03.

	Test 2	Test 3
A	$\chi^2_{12} = 36.9$, $P = 0.0002$	$\chi^2_{14} = 14.5$, ns
B	$\chi^2_{10} = 15.8$, ns	$\chi^2_{10} = 12.7$, ns
C	$\chi^2_{14} = 8.1$, ns	$\chi^2_{13} = 2.3$, ns
D	$\chi^2_{32} = 26.9$, ns	$\chi^2_{23} = 28.3$, ns

Table 6.2.3.1 Results of goodness-of-fit tests carried out on adult Redshank mark-recapture (mark-resighting) data.
A – for Cardiff Bay birds using data from February 1996 to February 2003.
B – for Cardiff Bay birds using data from February 1997 to February 2003.
C – for Rhymney birds.
D – for north Wales birds.
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).

Site	Distance from Cardiff Bay (km)	Age (years)							Mean Age	Median Age	*n*
		1	2	3	4	5	6	7			
Heliport	2.5	0	2	1	0	0	0	1	3.50	2.5	4
Rhymney River	4	1	22	0	0	3	3	1	2.83	2.0	30
Peterstone	11	0	4	0	0	0	0	0	2.00	2.0	4
Newport	18	2	2	0	0	0	0	0	1.50	1.5	4
Total		3	30	1	0	3	3	2			42

Table 7.1.1.1 The furthest distances that Redshank colour-ringed at Cardiff Bay were seen away from the Bay in the winter after barrage-closure (November 1999 to February 2000) in relation to their age.

Date	Birds with active Tags	Number in bay	Percentage in bay
19.12.99	14	8	57.1
12.01.00	8	0	0.0
26.01.00	7	0	0.0
03.02.00	7	2	28.6
10.02.00	7	0	0.0
25.02.00	7	0	0.0

Table 7.1.2.1 The number of Redshank with still active radio-tags that were recorded in Cardiff Bay during periods of temporary drainage.

Model	$QAIC_c$	Parameters	Model deviance
$\phi_c\ p_c$	1742.2	2	516.4
$\phi_t\ p_c$	1738.5	10	496.6
$\phi_t\ p_t$	1732.5	23	463.9
$\phi_c\ p_{O\text{-}F}$	1728.4	3	500.6
$\phi_c\ p_t$	1727.1	13	479.1
$\phi_c\ p_{O\text{-}Fpre\text{-}Fpost}$	1722.7	4	492.9
$\phi_c\ p_{Opre\text{-}Opost\text{-}F}$	1719.2	4	489.4
$\phi_{Spre\text{-}Spost\text{-}W}\ p_{Opre\text{-}Opost\text{-}Fpre\text{-}Fpost}$	1715.8	7	480.0
$\phi_{S\text{-}W}\ p_{Opre\text{-}Opost\text{-}Fpre\text{-}Fpost}$	1714.5	6	480.7
$\phi_c\ p_{Opre\text{-}Opost\text{-}Fpre\text{-}Fpost}$	1713.3	5	481.4
$\phi_{S\text{-}Wpre\text{-}Wpost}\ p_{Opre\text{-}Opost\text{-}Fpre\text{-}Fpost}$	**1704.7**	**7**	**468.8**

Table 7.3.1 Evaluation of mark-resighting models for adult Redshank originally caught and ringed at Cardiff Bay, using data from February 1997 to February 2003.

Different models evaluated whether resighting rates p were constant (c), varied fully with time (t), between the October and February observation periods (O-F) or pre- and post-closure of the Cardiff Bay Barrage (pre-post). Likewise, we also evaluated whether monthly survival rates ϕ were constant (c), varied fully with time (t), between the summer and winter periods (S-W) or pre- and post-closure (pre-post). Bold type indicates the most parsimonious model (i.e. that with the lowest $QAIC_c$ value), which was significantly better in a likelihood ratio test than the nested model in which ϕ was assumed to be the same in winters before and after barrage-closure ($\chi^2_1 = 11.86$, $P = 0.0006$).

Model	$QAIC_c$	Parameters	Model deviance
$\phi_c\ p_c$	1358.8	2	252.8
$\phi_t\ p_c$	1339.1	8	220.8
$\phi_t\ p_t$	1282.3	17	145.2
$\phi_{pre\text{-}post}\ p_t$	1278.2	13	149.6
$\phi_c\ p_t$	**1276.1**	**12**	**149.6**

Table 7.3.2 Evaluation of mark-resighting models for adult Redshank originally caught and ringed at Rhymney, using data from 1991/92 to 2002/03.

Different models evaluated whether resighting rates p were constant (c) or varied fully with time (t) and whether survival rates ϕ were constant (c), varied fully with time (t) or pre- and post-closure of the Cardiff Bay Barrage (pre-post). Bold type indicates the most parsimonious model (i.e. that with the lowest $QAIC_c$ value).

Model	$QAIC_c$	Parameters	Model deviance
$\phi_c\ p_c$	2969.5	2	538.0
$\phi_t\ p_c$	2862.8	9	417.2
$\phi_c\ p_t$	2822.2	15	364.4
$\phi_{pre\text{-}post}\ p_t$	2819.3	16	359.4
$\phi_t\ p_t$	**2814.9**	**25**	**336.7**

Table 7.3.3 Evaluation of mark-resighting models for adult Redshank originally caught and ringed in north Wales, using data from 1988/89 to 2002/03.

Different models evaluated whether resighting rates p were constant (c) or varied fully with time (t) and whether survival rates ϕ were constant (c), varied fully with time (t) or pre- and post-closure of the Cardiff Bay barrage (pre-post). Bold type indicates the most parsimonious model (i.e. that with the lowest $QAIC_c$ value).

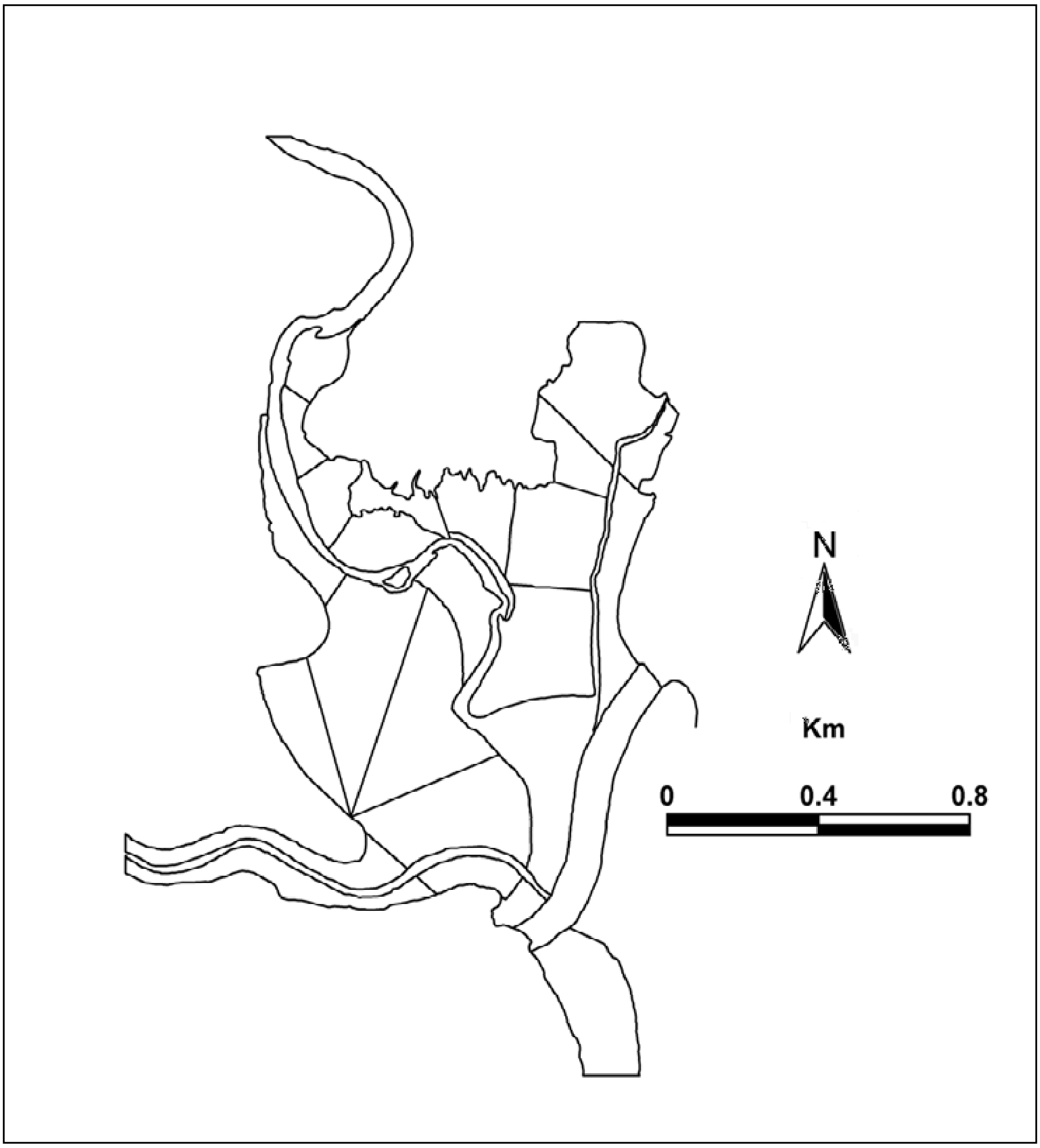


Figure 2.1.1 The Cardiff Bay study site showing mudflat areas counted in autumn 1999, prior to barrage-closure.

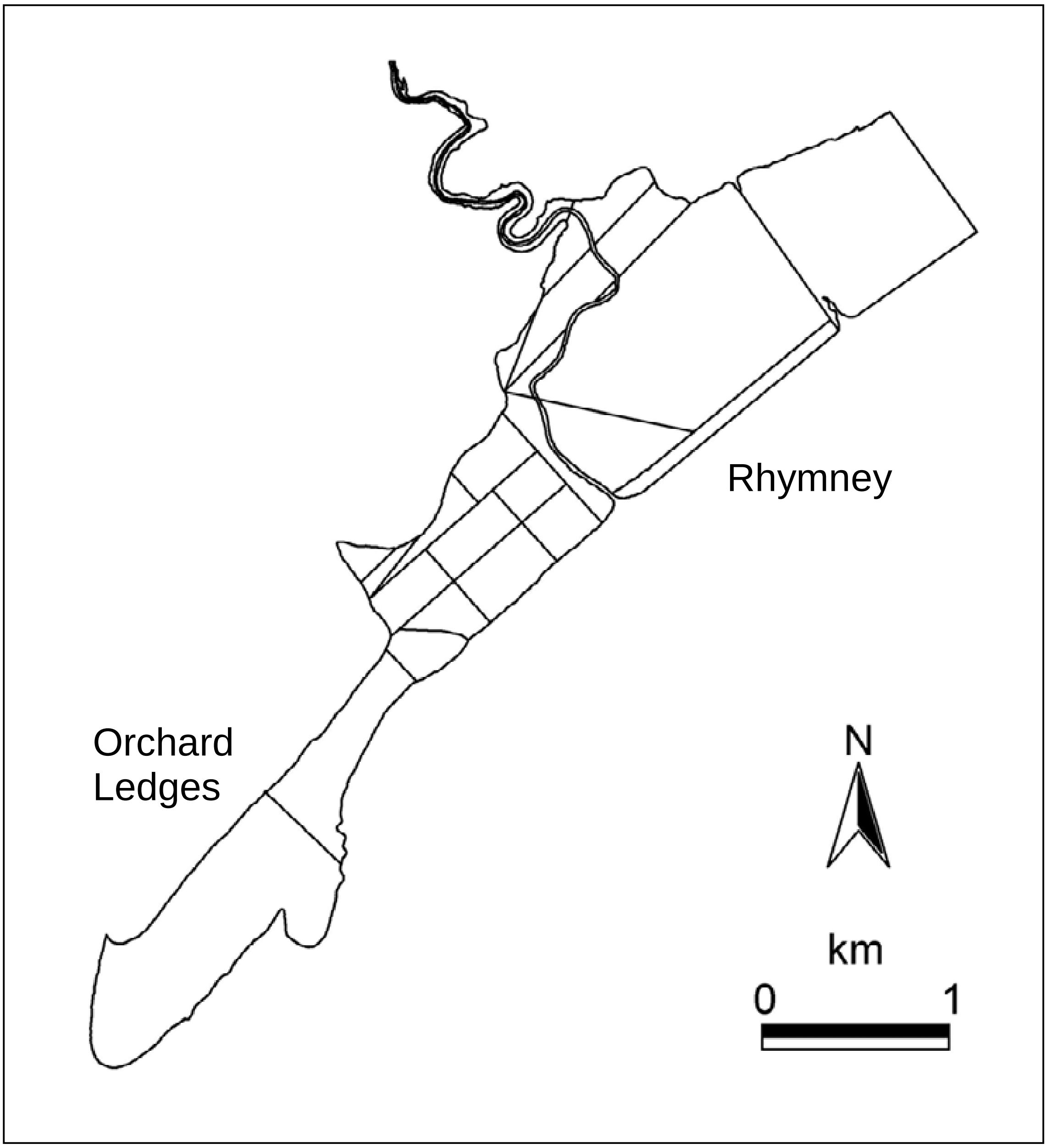


Figure 2.1.2 The Rhymney and Orchard Ledges study sites showing mudflat count areas.

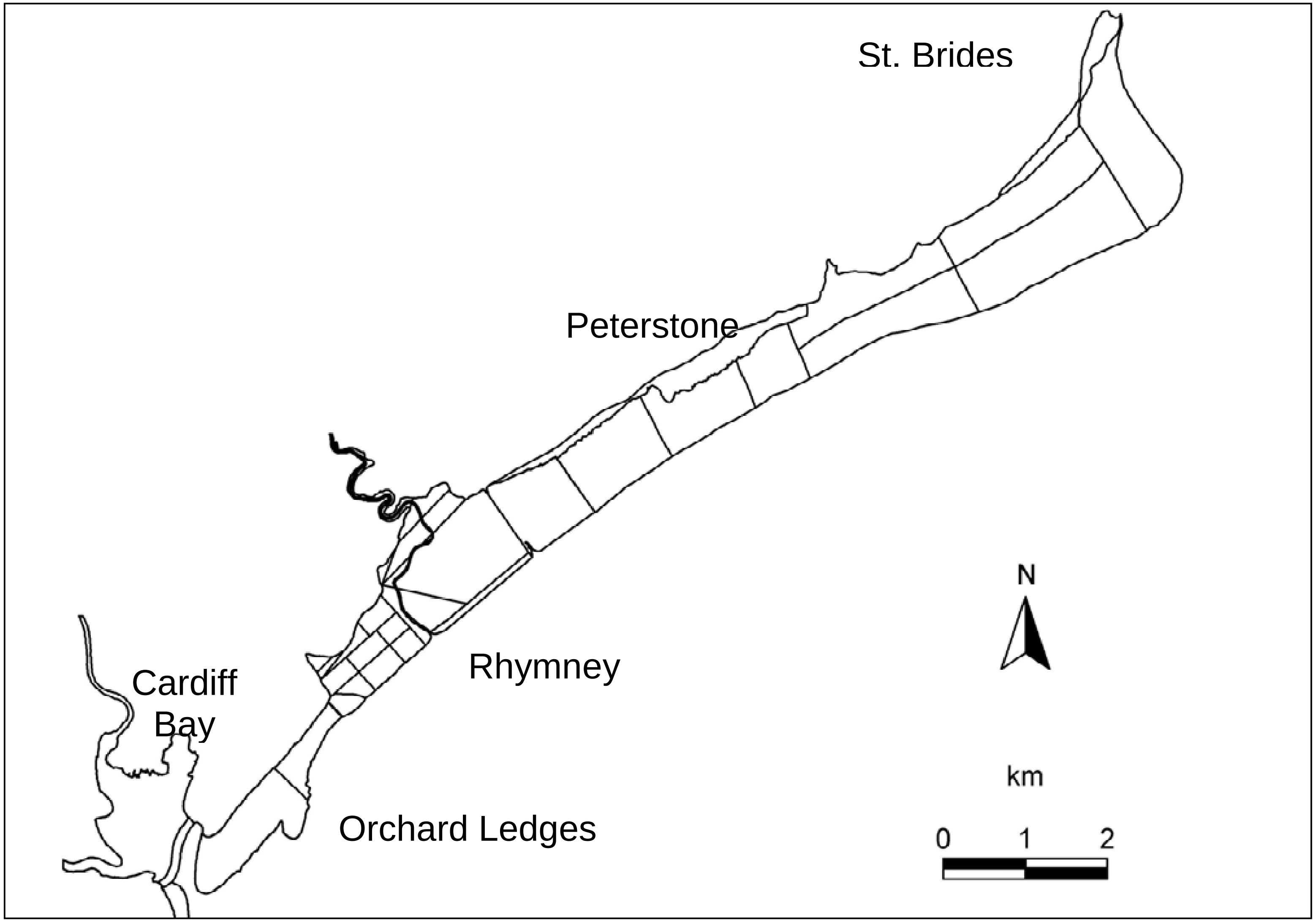


Figure 2.2.1 The low tide count areas on the northwest Severn.

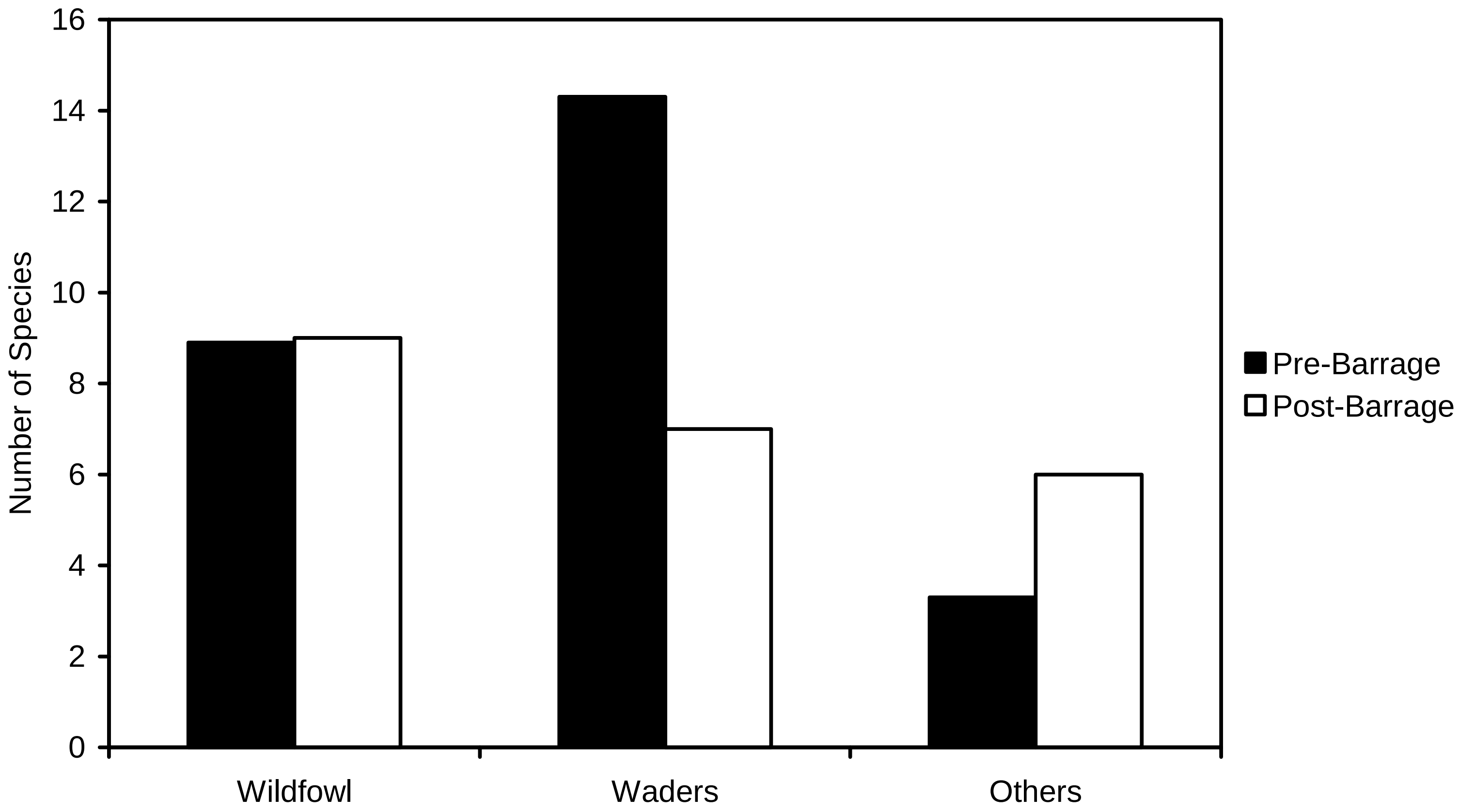


Figure 3.2.1 Mean numbers of wildfowl, wader and other waterbird species recorded annually at Cardiff Bay before barrage-closure (1989/90 to 1998/99) and after barrage-closure (1999/2000 to 2002/03).

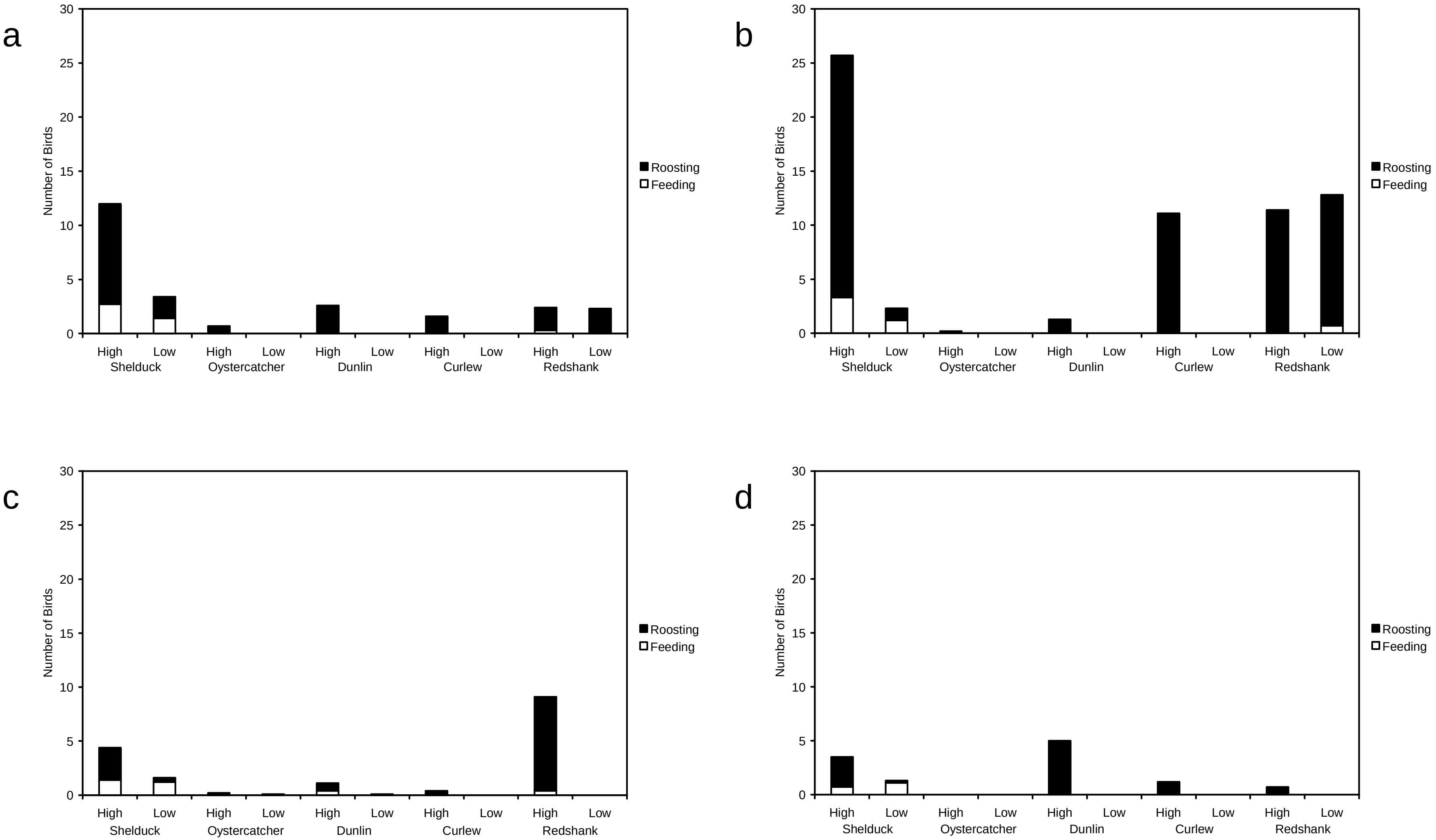


Figure 3.2.2 Mean numbers of Shelduck, Oystercatcher, Dunlin, Curlew and Redshank recorded roosting (black sections of columns) and feeding (white sections) in Cardiff Bay at high tide and low tide in the winters of **a.** 1999/2000 **b.** 2000/01 **c.** 2001/02 and **d.** 2002/03, following barrage-closure.

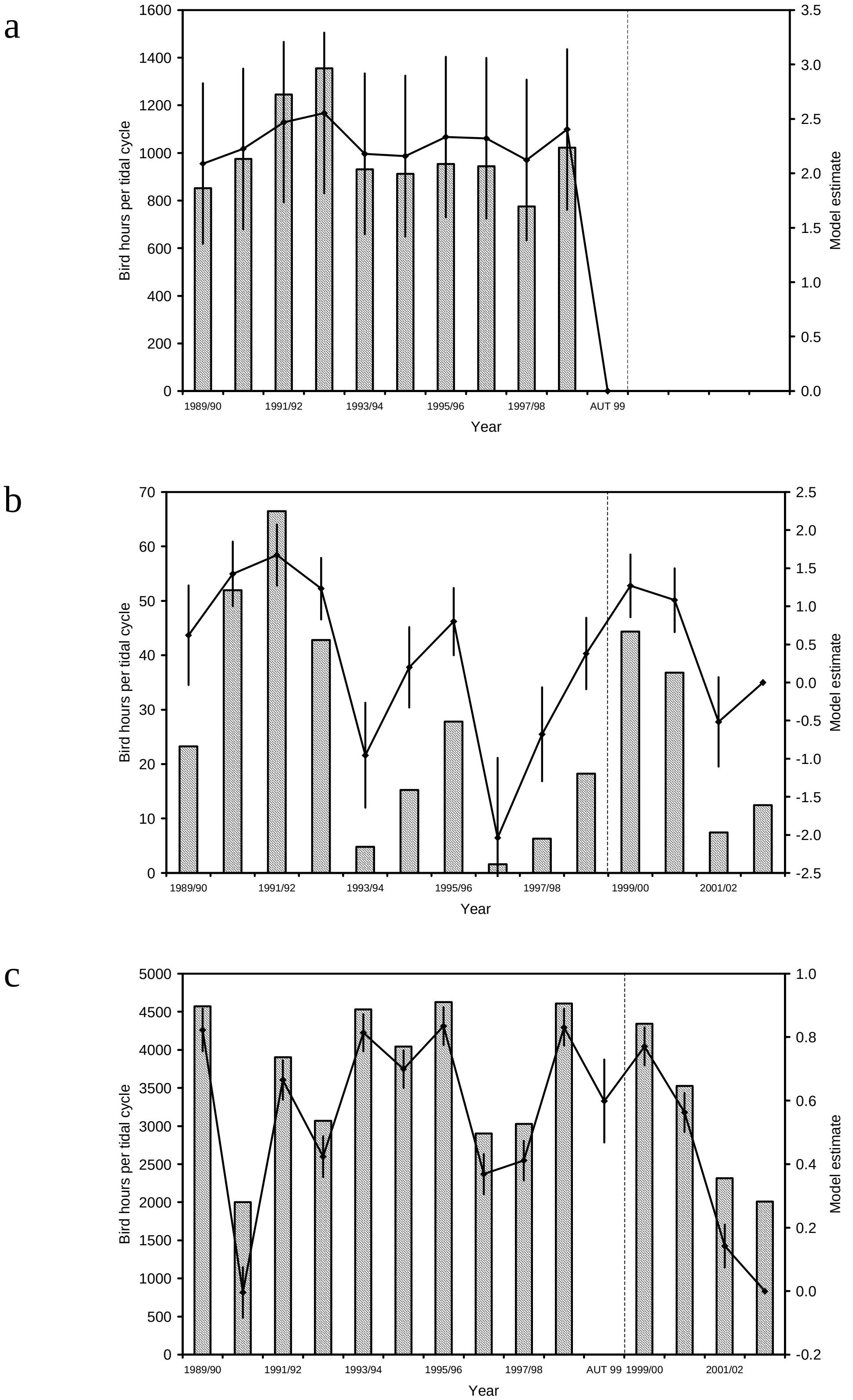


Figure 3.3.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Shelduck at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure;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

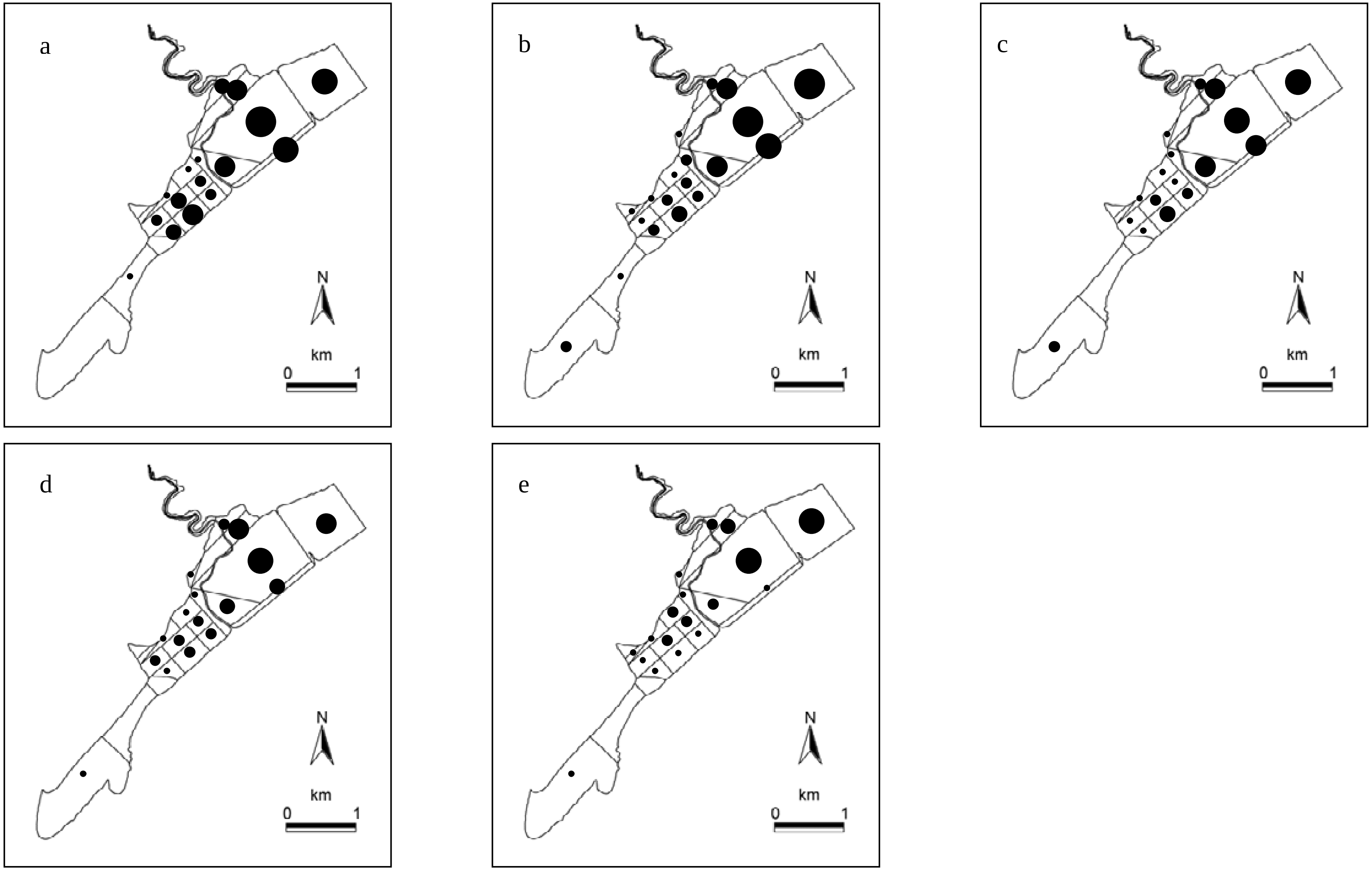


Figure 3.3.2 The distribution of feeding Shelduck on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

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

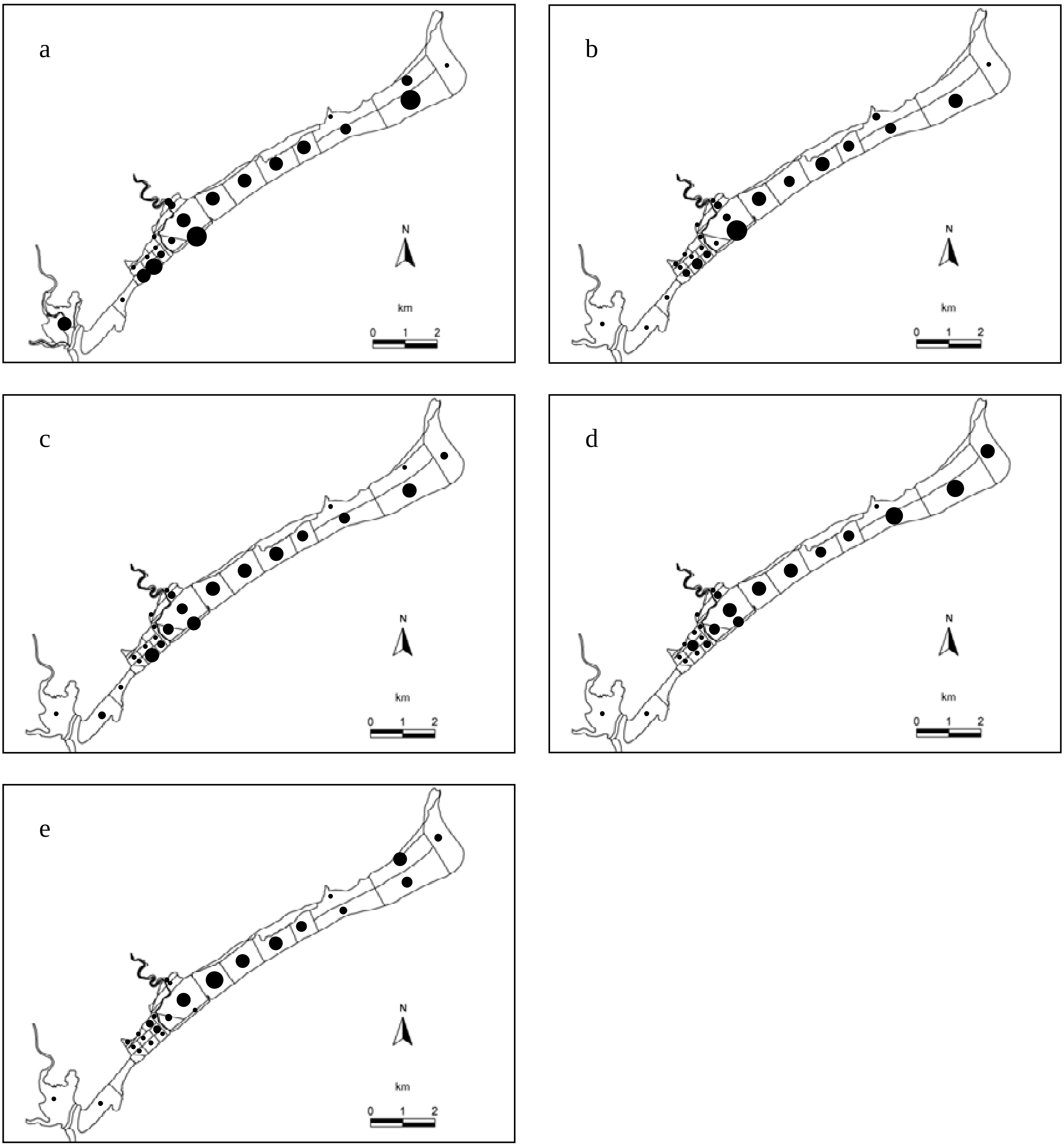


Figure 3.3.3 The low tide distribution of feeding Shelduck on the northwest Severn during winter. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

1-9 • 10-24 • 25-49 ● 50-99 ● 100-199 ● 200+ ●

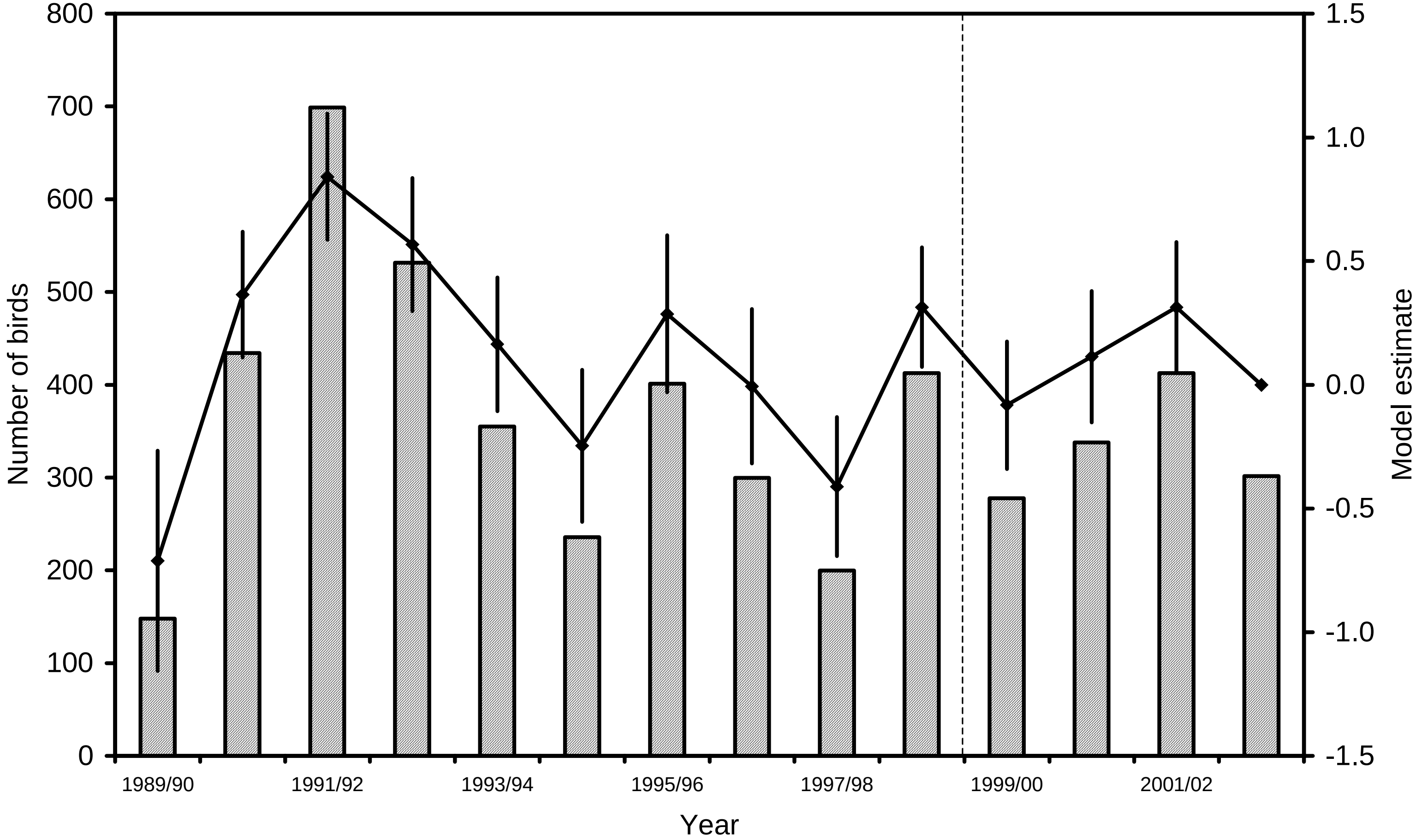
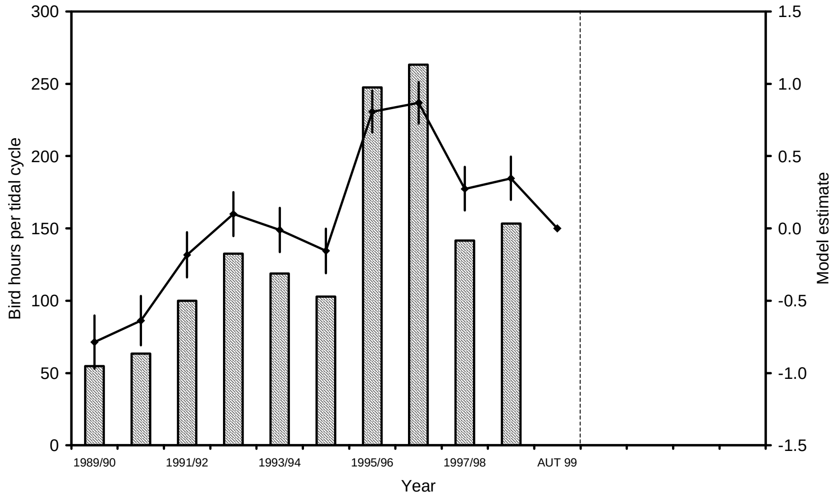
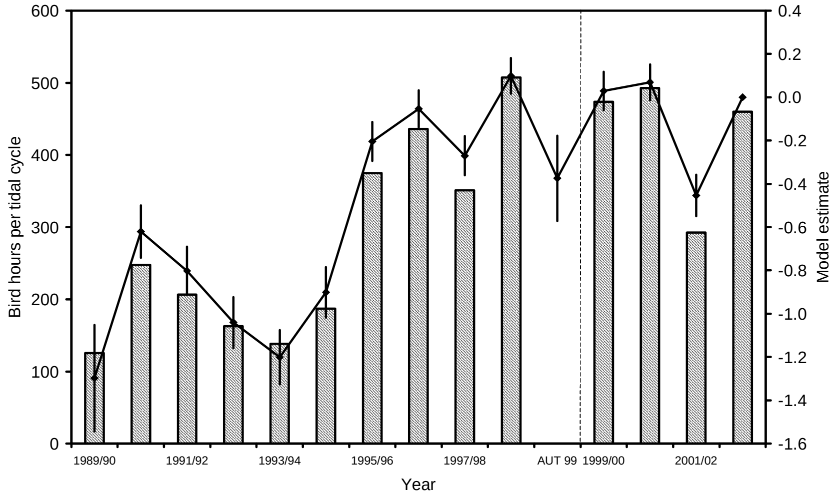


Figure 3.3.4 Estimates for ‘year’ (± 1 SE) and the mean number of birds derived from a model relating the number of feeding Shelduck at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b



c

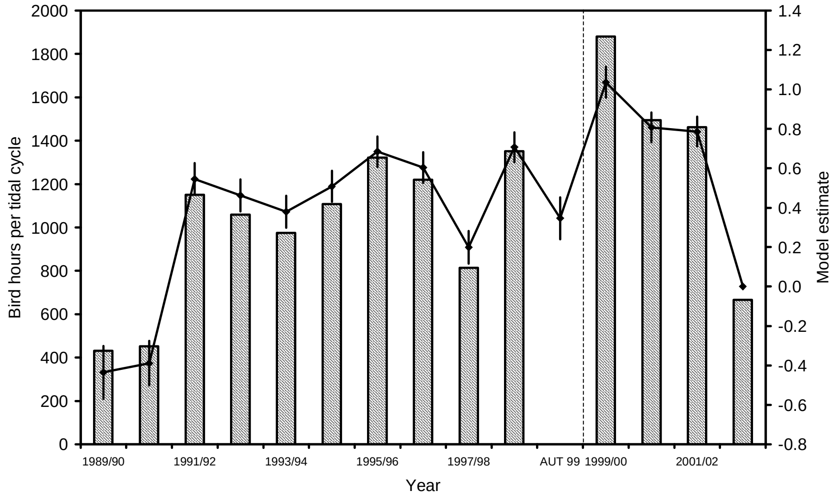


Figure 3.4.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Oystercatcher at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of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

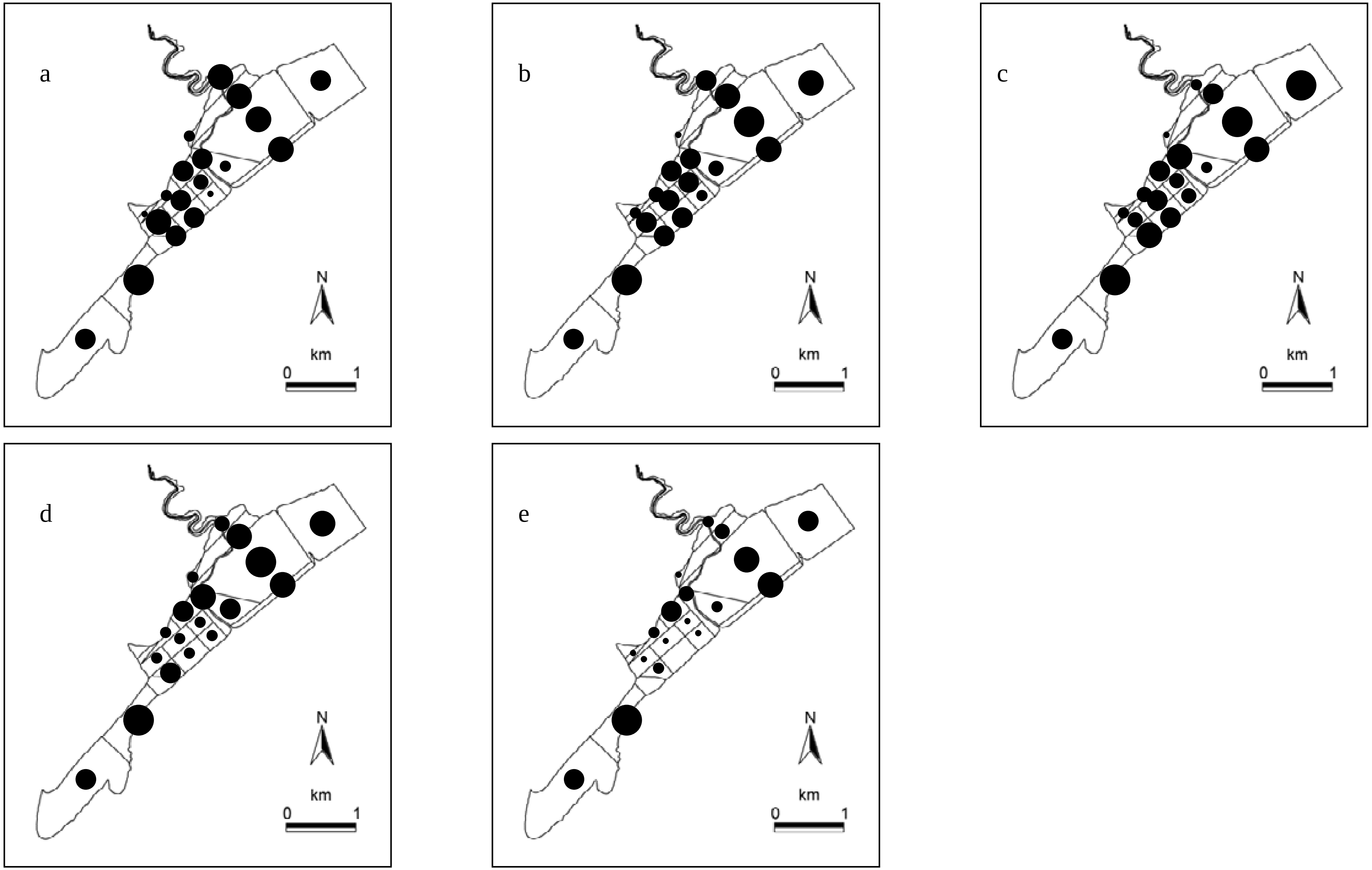


Figure 3.4.2 The distribution of feeding Oysterctatcher on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

1-9 • 10-24 ● 25-49 ● 50-99 ● 100-249 ● >250 ●

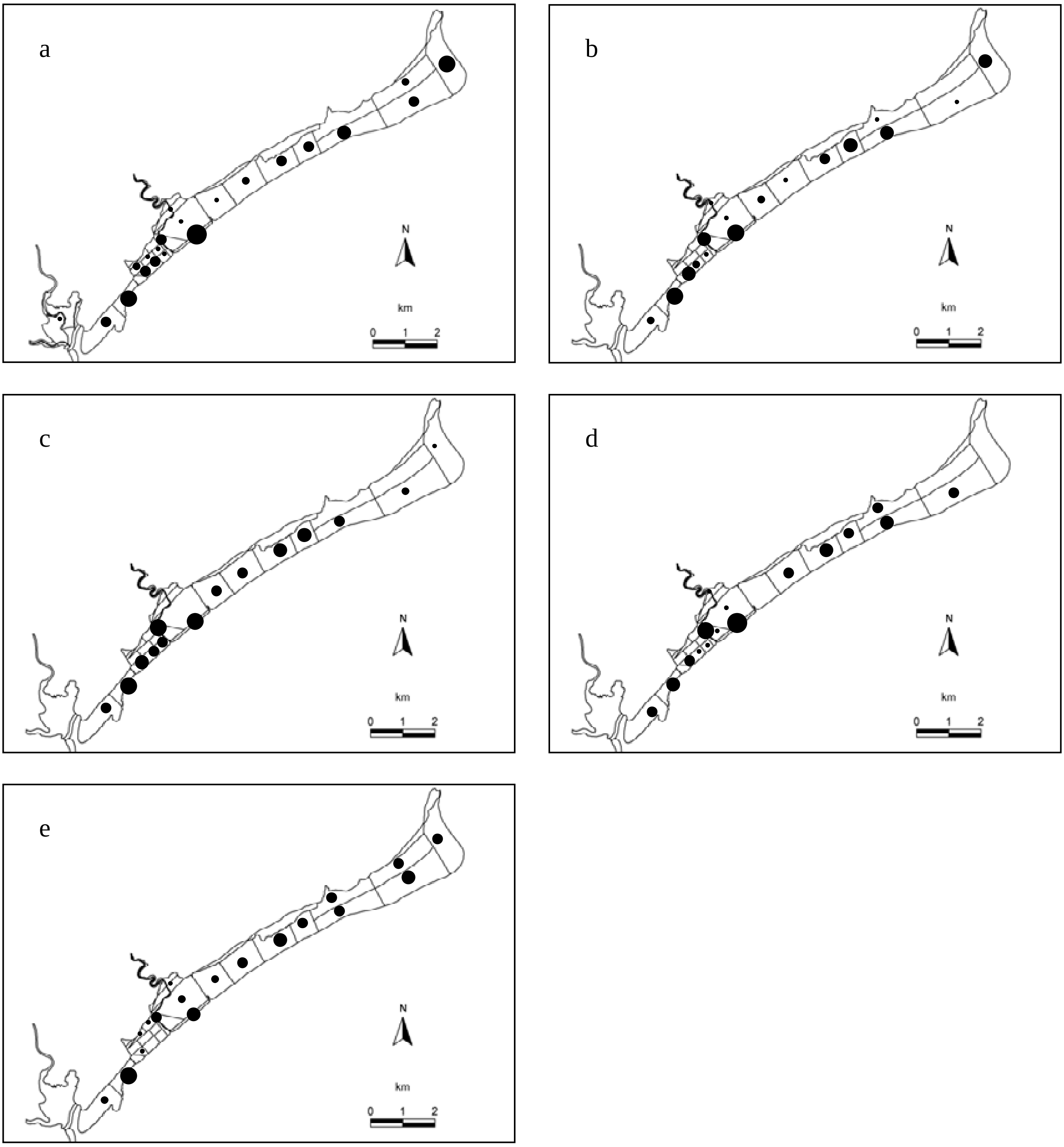


Fig. 3.4.3 The low tide distribution of feeding Oystercatcher on the northwest Severn during winter. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

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

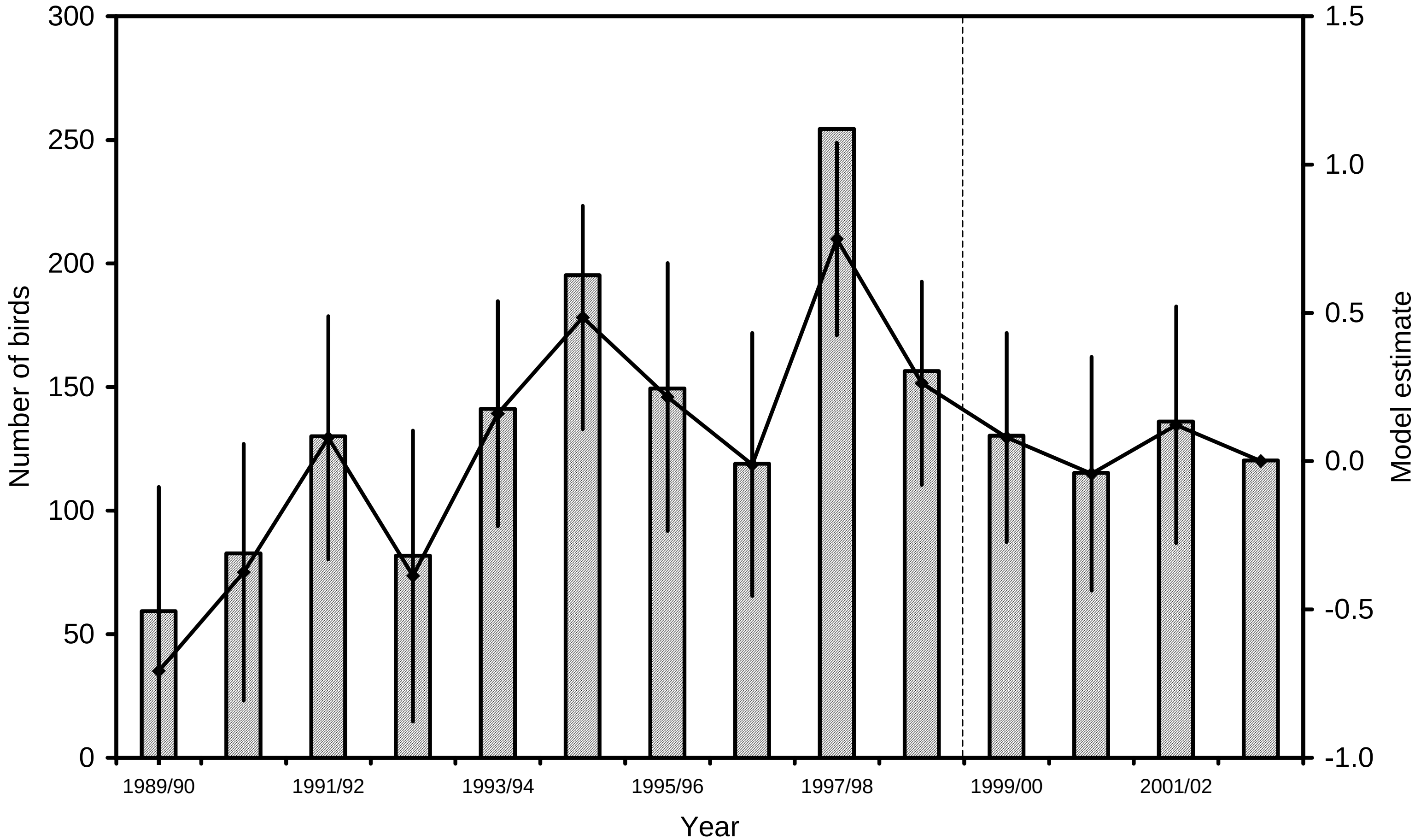


Figure 3.4.4 Estimates for 'year' (± 1 SE) and the mean number of birds derived from a model relating the number of feeding Oystercatcher at low tide at Peterstone and St. Brides to year, month and mudflat.

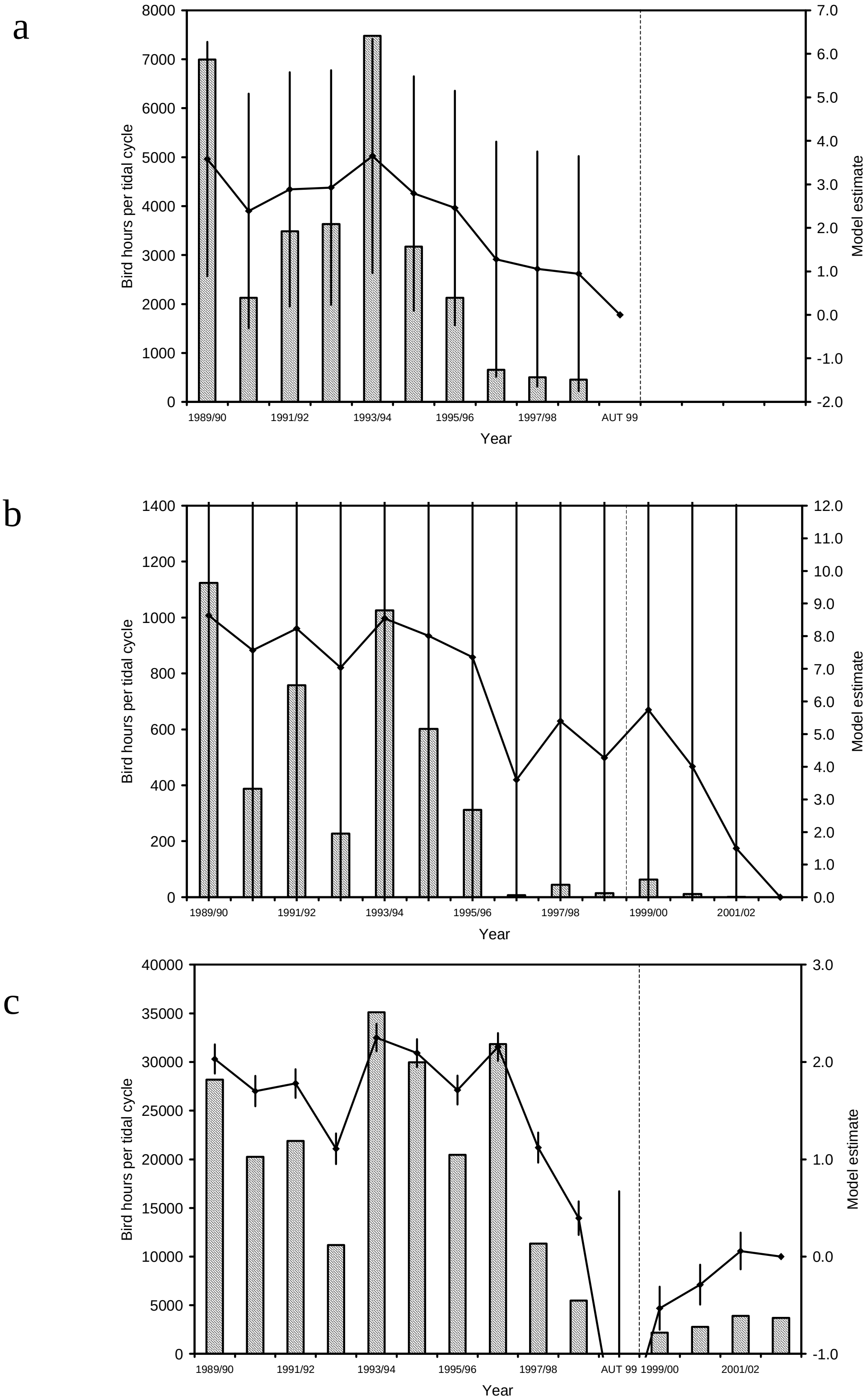


Figure 3.5.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Dunlin at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; for Rhymney, points immediately before and after are estimates for autumn 1999 and for the winter of 1999/2000 together with spring 2000 respectively.

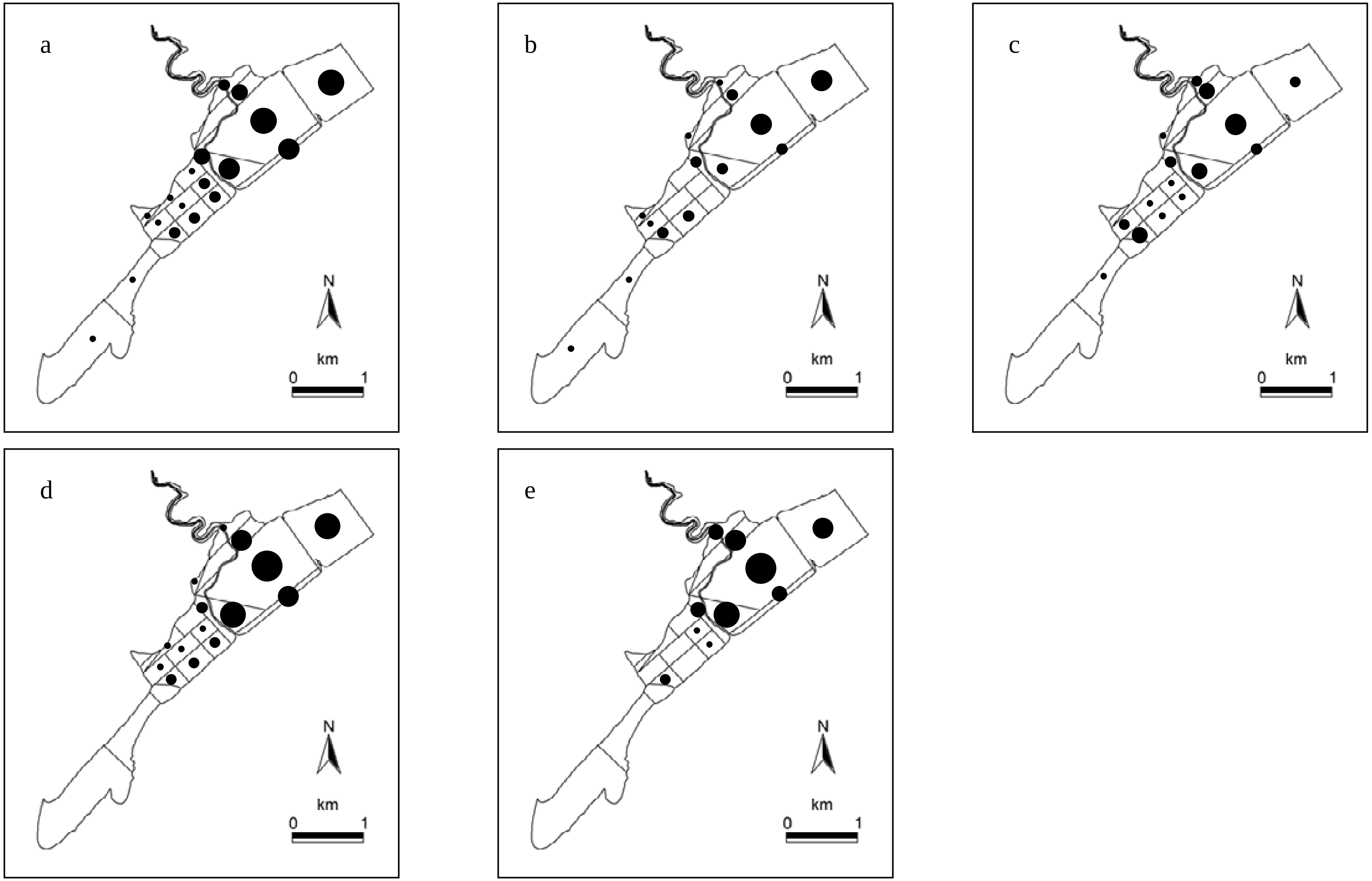


Figure 3.5.2 The distribution of feeding Dunlin on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

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

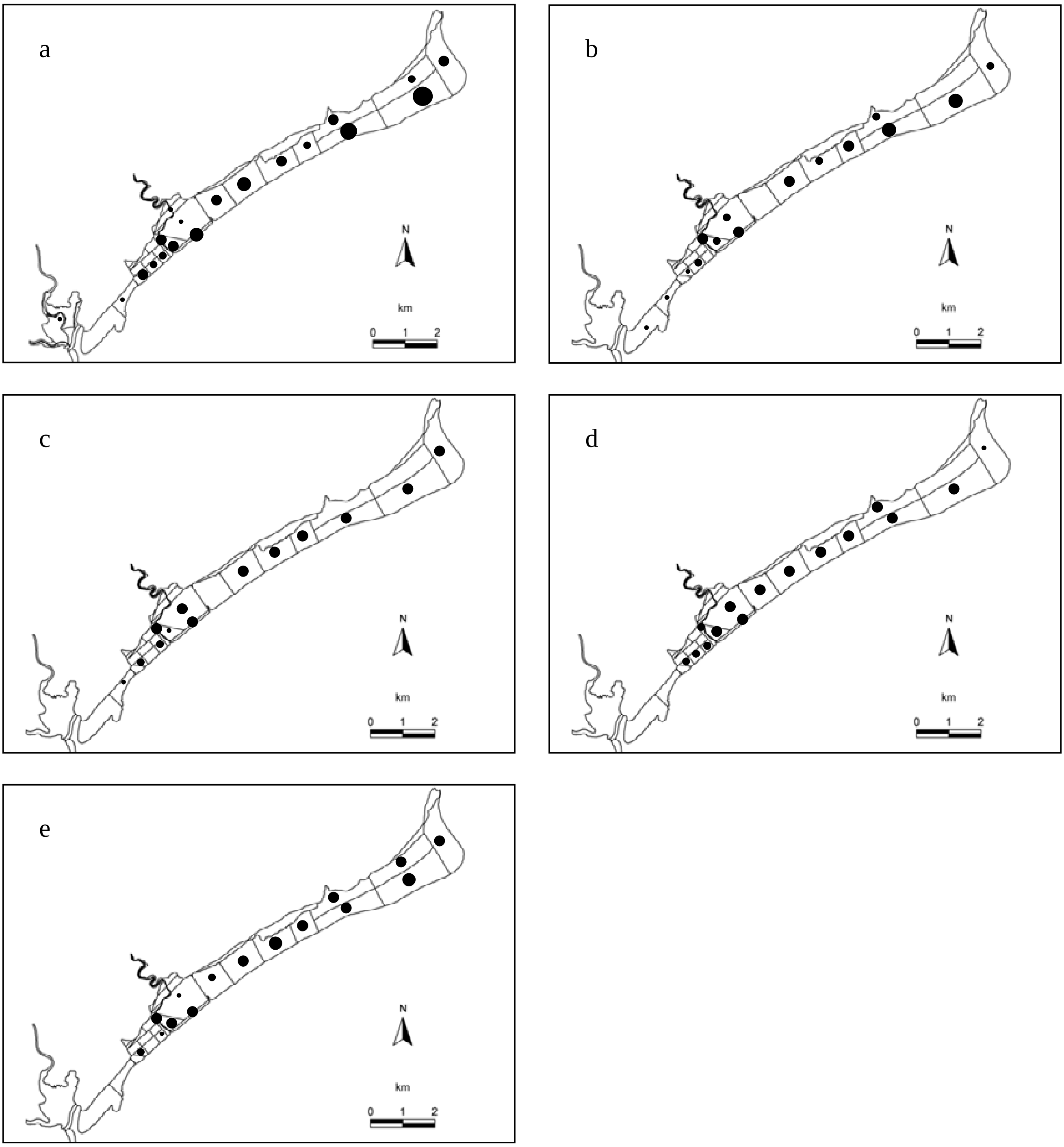


Figure 3.5.3 The low tide distribution of feeding Dunlin on the northwest Severn during winter. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

1-9 • 10-49 • 50-249 ● 250-749 ● 750-1499 ● 1500+ ●

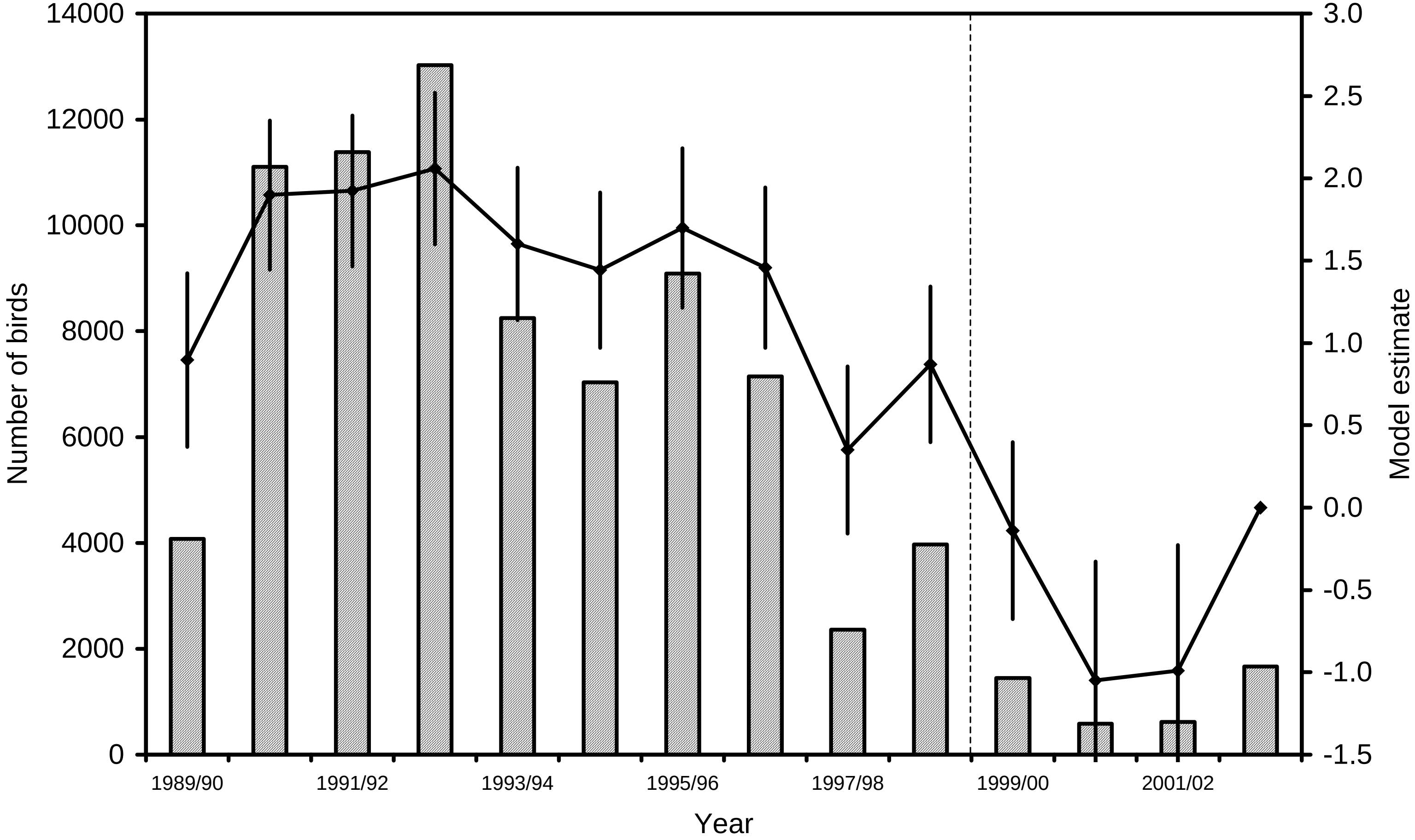


Figure 3.5.4 Estimates for ‘year’ (± 1 SE) and the mean number of birds derived from a model relating the number of feeding Dunlin at low tide at Peterstone and St. Brides to year, month and mudflat.

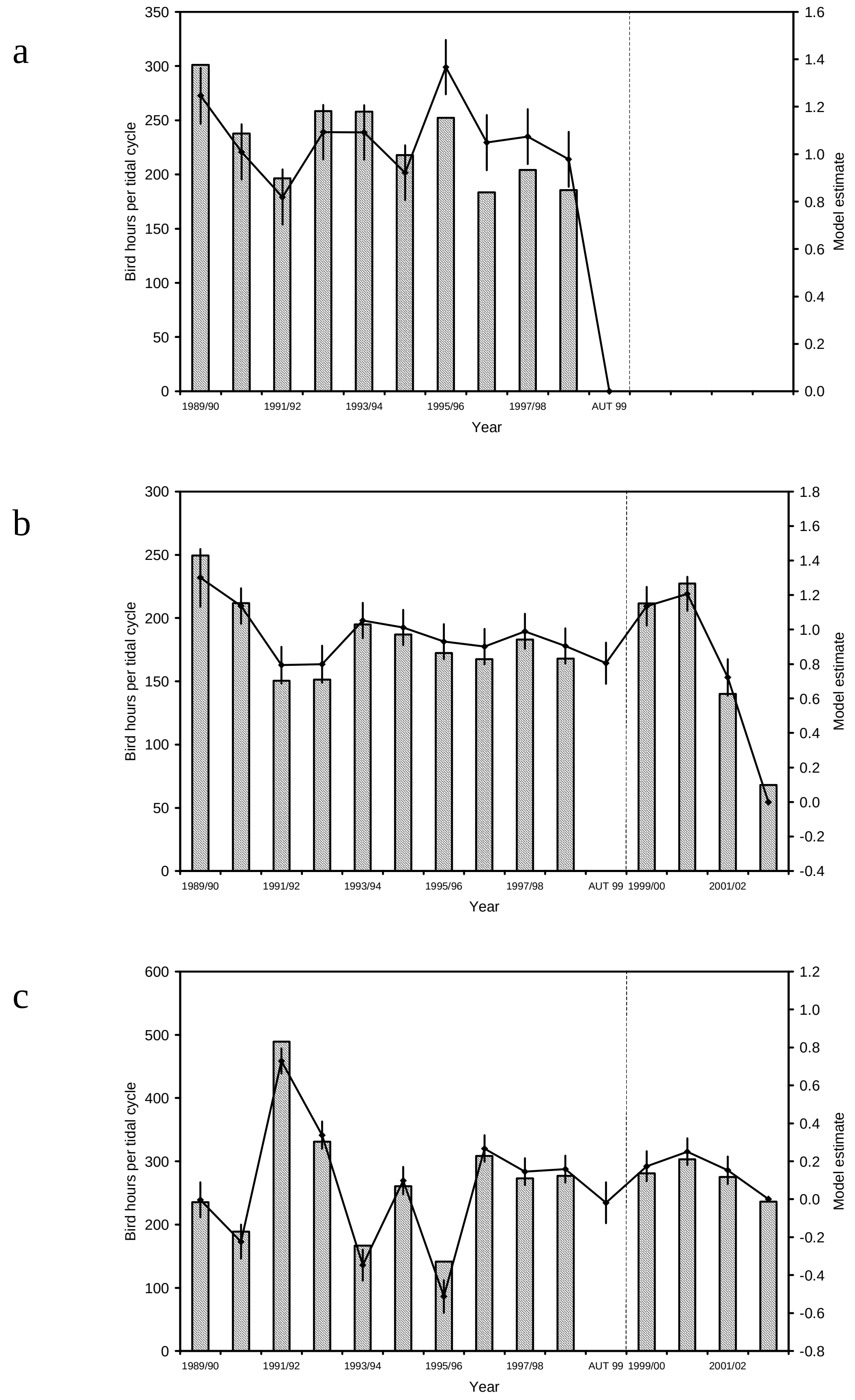


Figure 3.6.1 Estimates for ‘year’ (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Curlew at **a.** Cardiff Bay **b.** Orchard Ledges and **c.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; 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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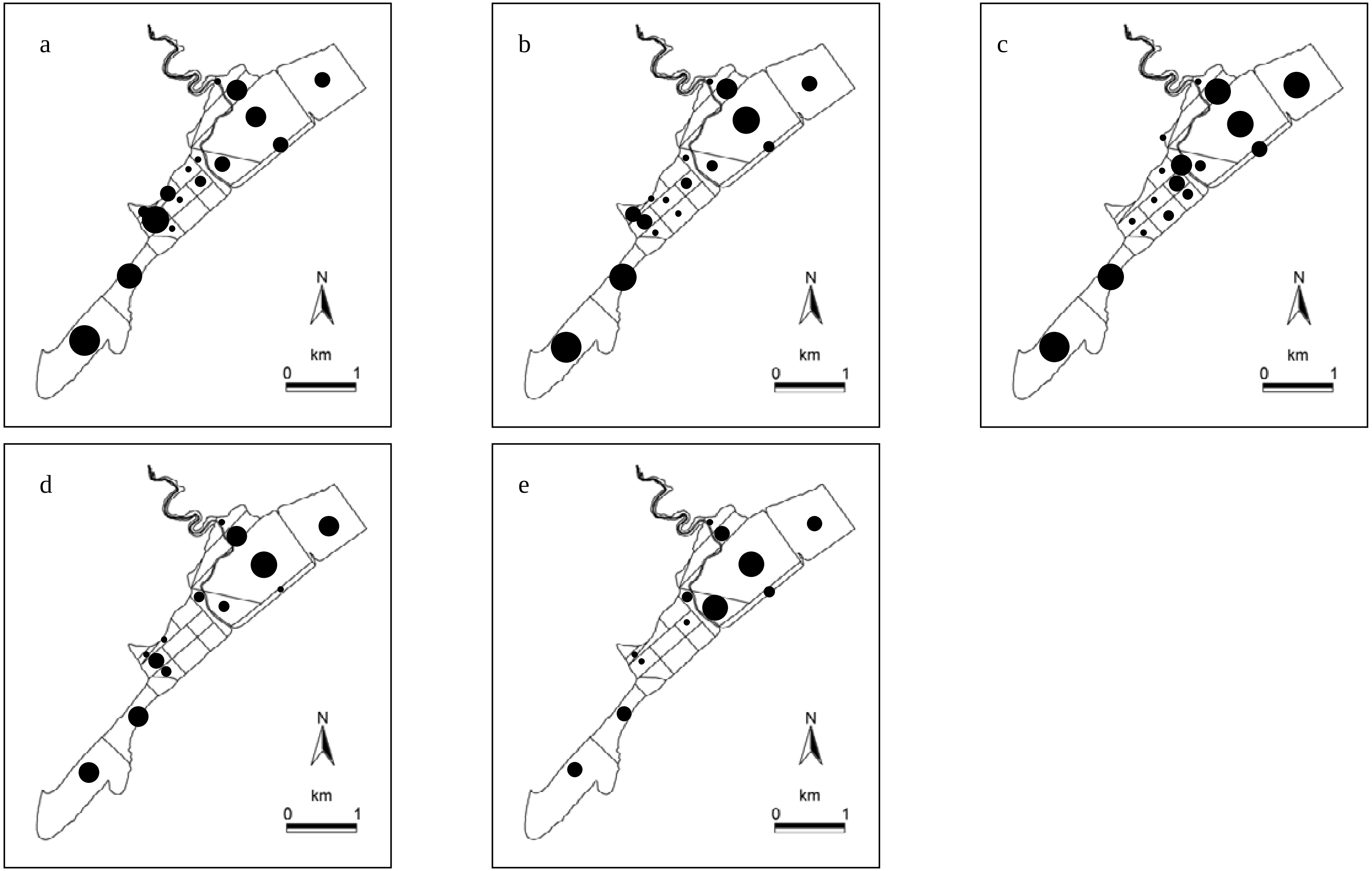


Figure 3.6.2 The distribution of feeding Curlew on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

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

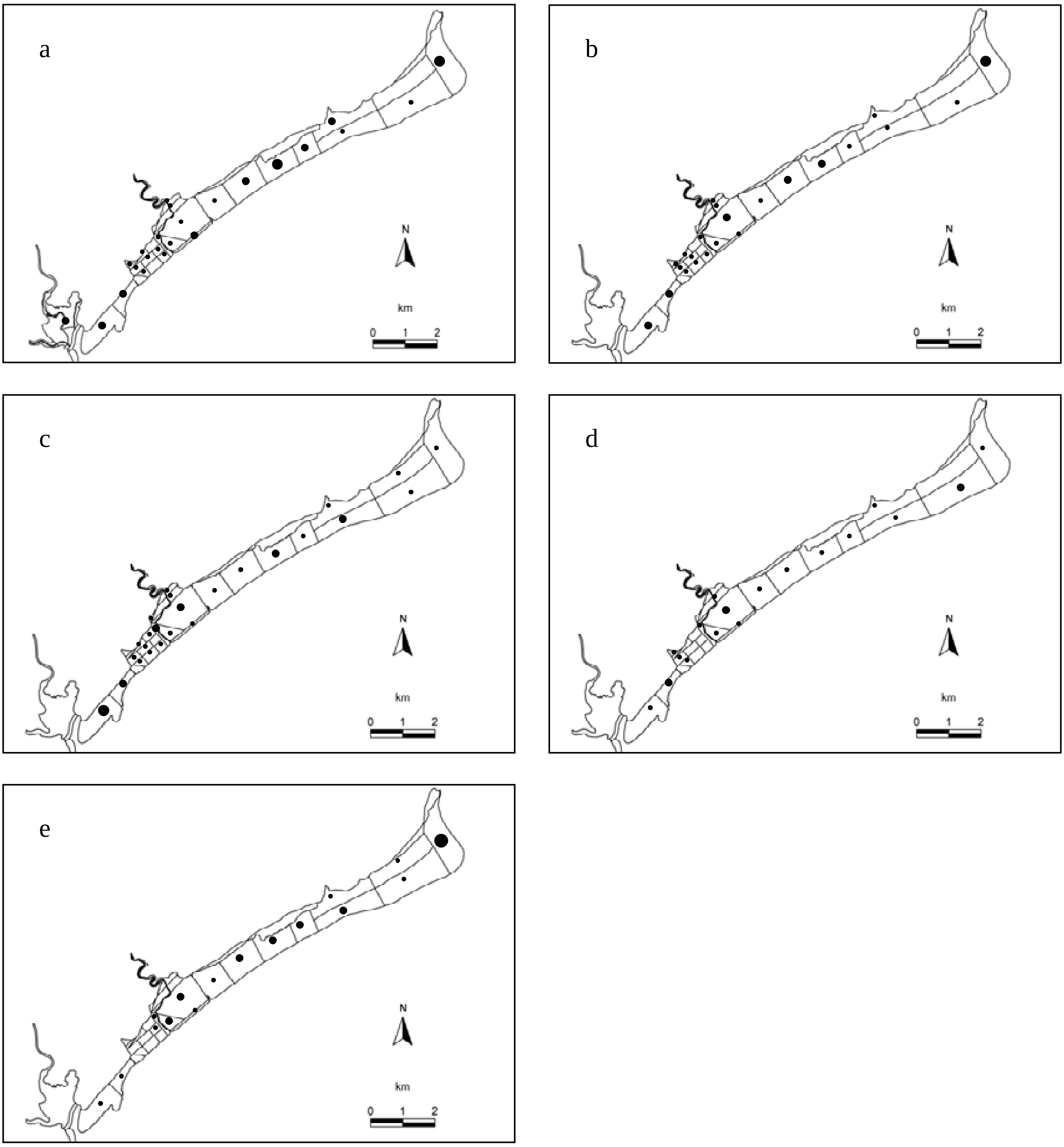


Figure 3.6.3 The low tide distribution of feeding Curlew on the northwest Severn during winter. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

1-9 · 10-24 • 25-49 ● 50-99 ● 100-199 ● 200+ ●

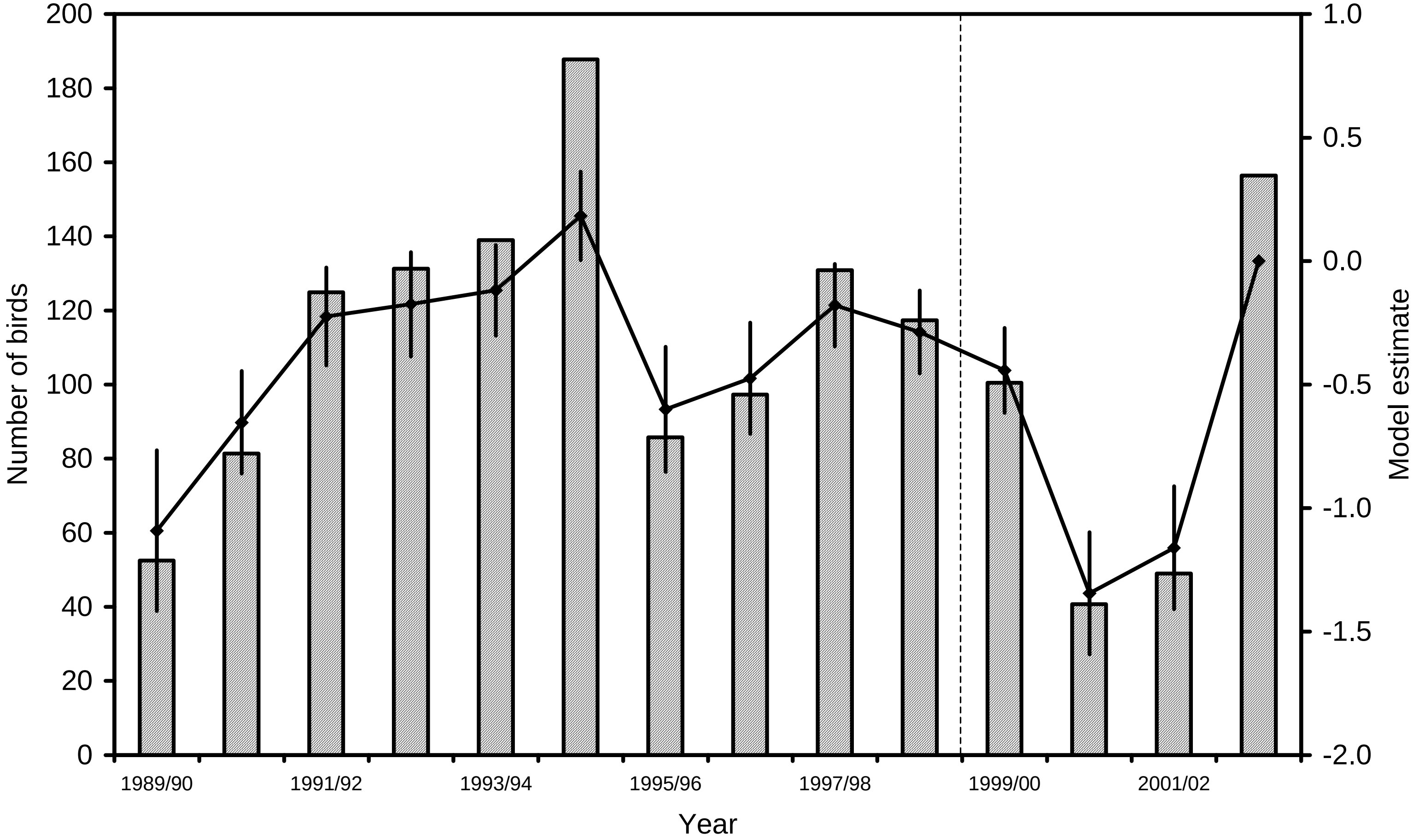
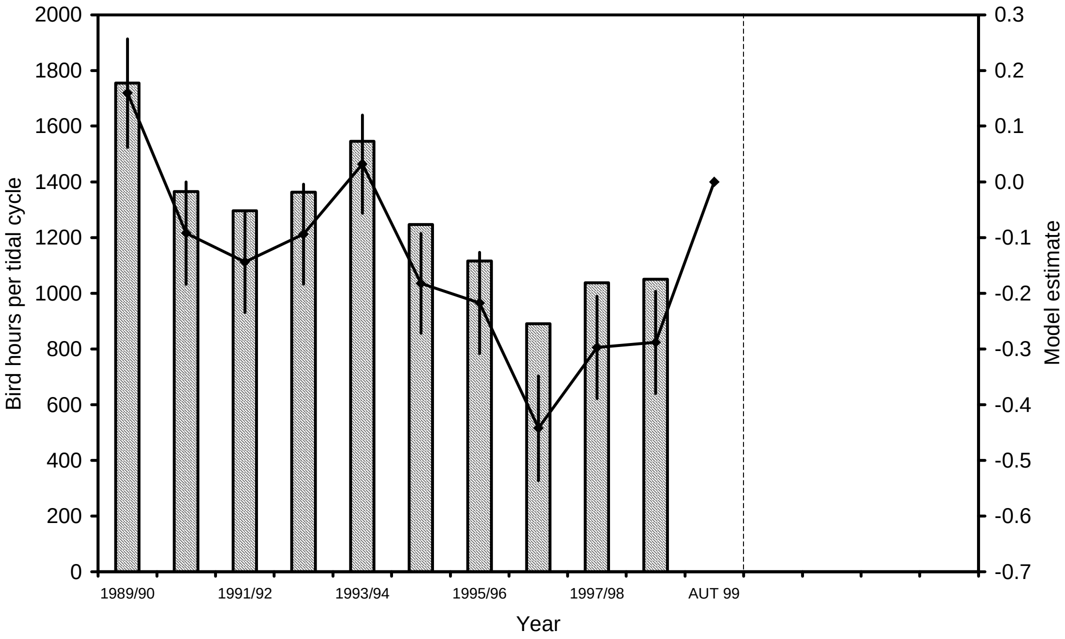


Figure 3.6.4 Estimates for 'year' (± 1 SE) and the mean number of birds derived from a model relating the number of feeding Curlew at low tide at Peterstone and St. Brides to year, month and mudflat.

a



b

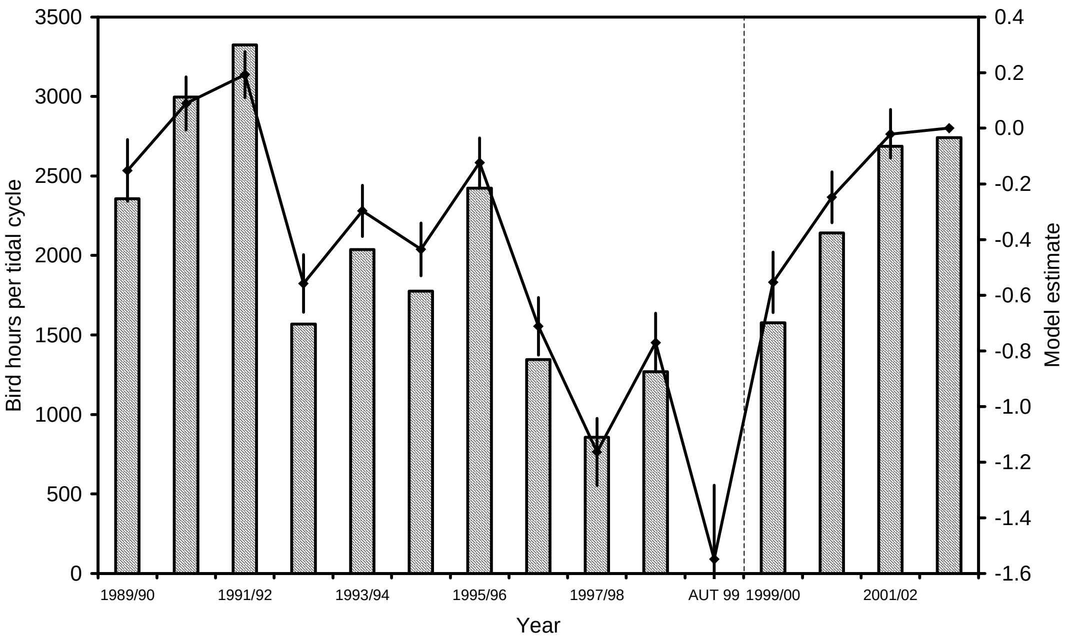


Figure 3.7.1 Estimates for 'year' (± 1 SE) and the mean number of bird hours per tidal cycle derived from models relating the number of feeding Redshank at **a.** Cardiff Bay and **b.** Rhymney to year, month, mudflat and state of tide. The dotted line indicates the date of barrage-closure; points immediately before and after are estimates for autumn 1999 and for the winter of 1999/2000 together with spring 2000 respectively.

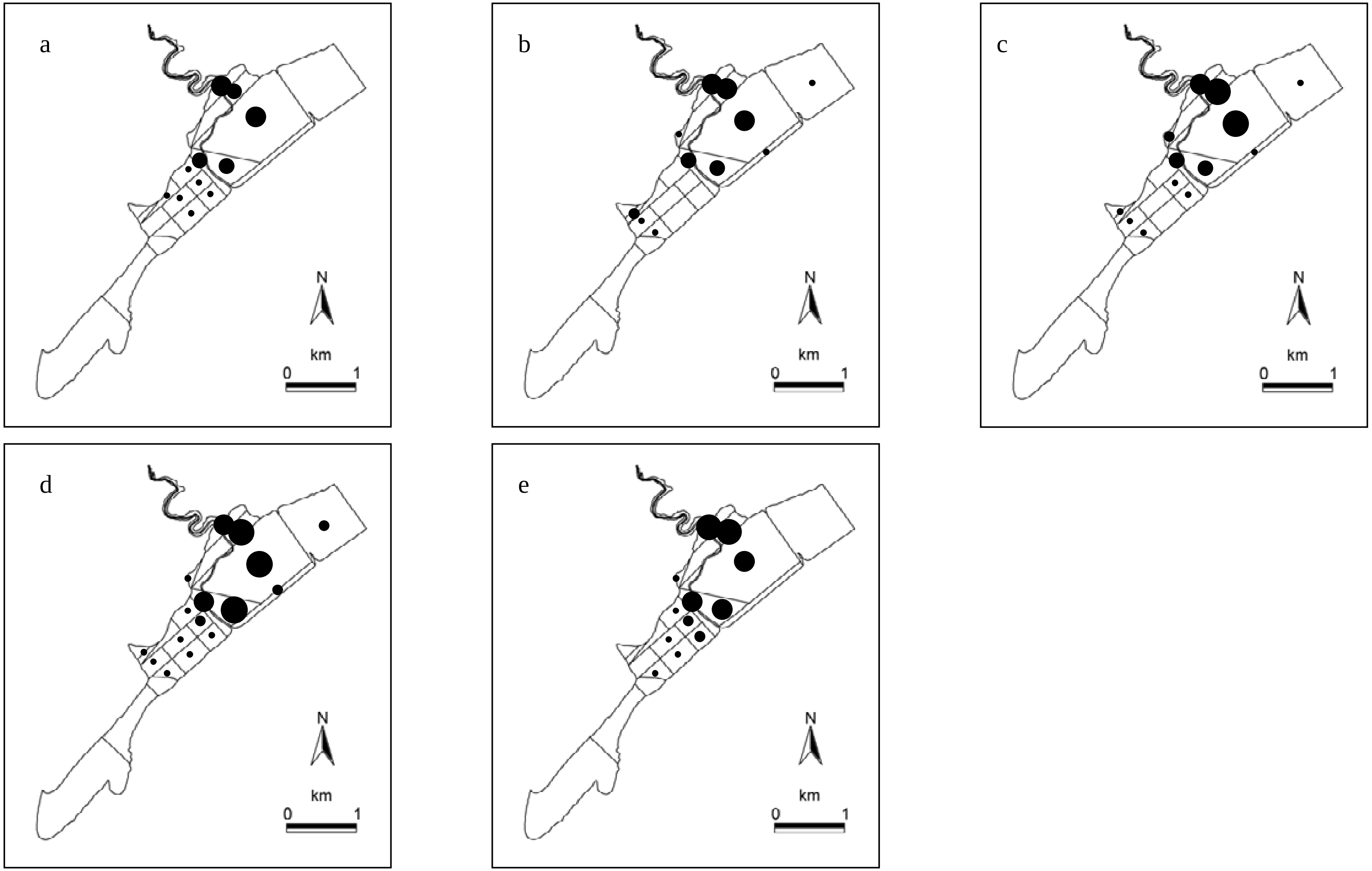


Figure 3.7.2 The distribution of feeding Redshank on the Rhymney and Orchard Ledges all-day sites during winter. The average number of bird hours per tidal cycle is depicted. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

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

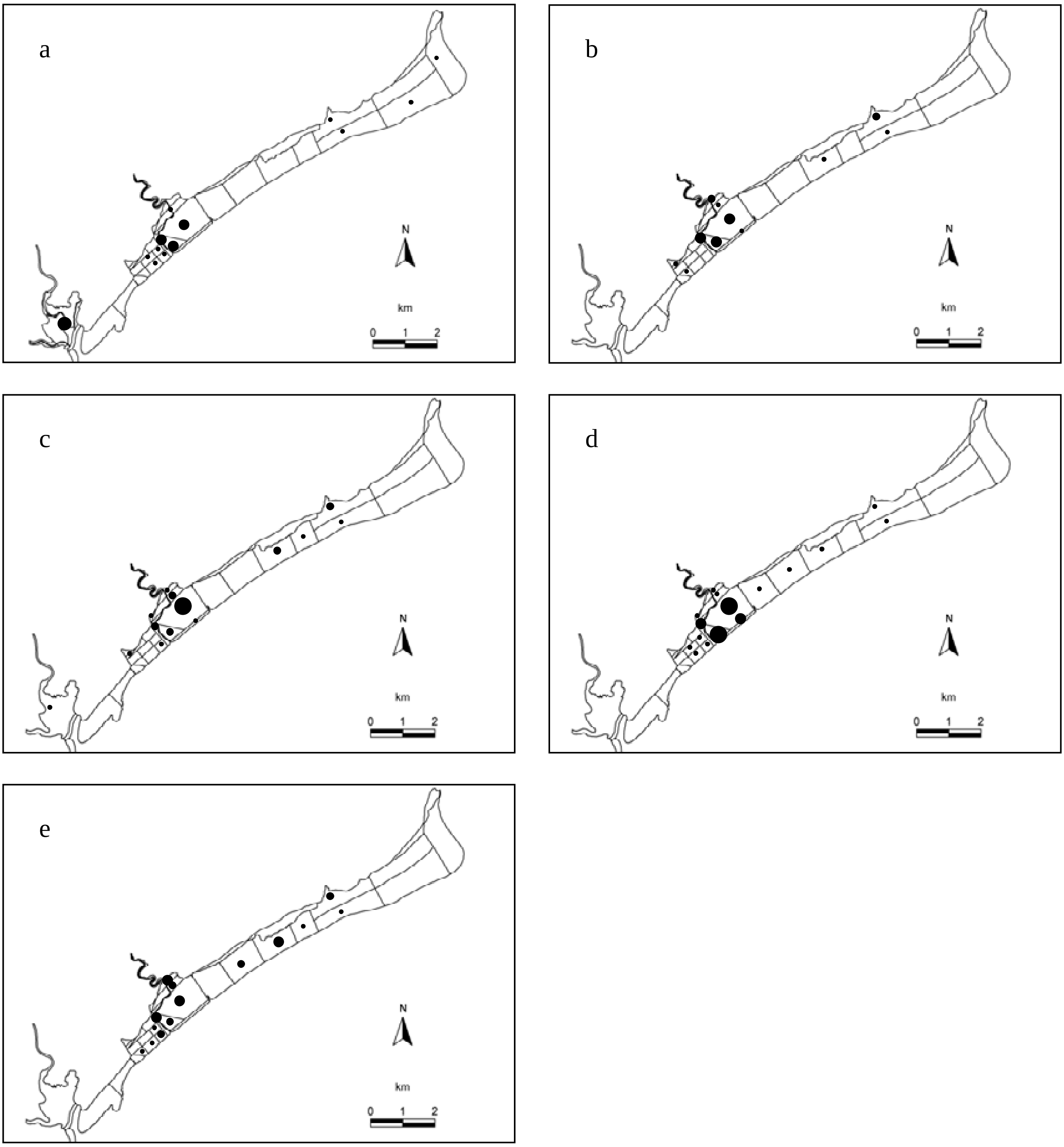


Figure 3.7.3 The low tide distribution of feeding Redshank on the northwest Severn during winter. a = 1998/99; b = 1999/2000; c = 2000/01; d = 2001/02; e = 2002/03.

1-9 • 10-24 • 25-49 ● 50-99 ● 100-199 ● 200+ ●

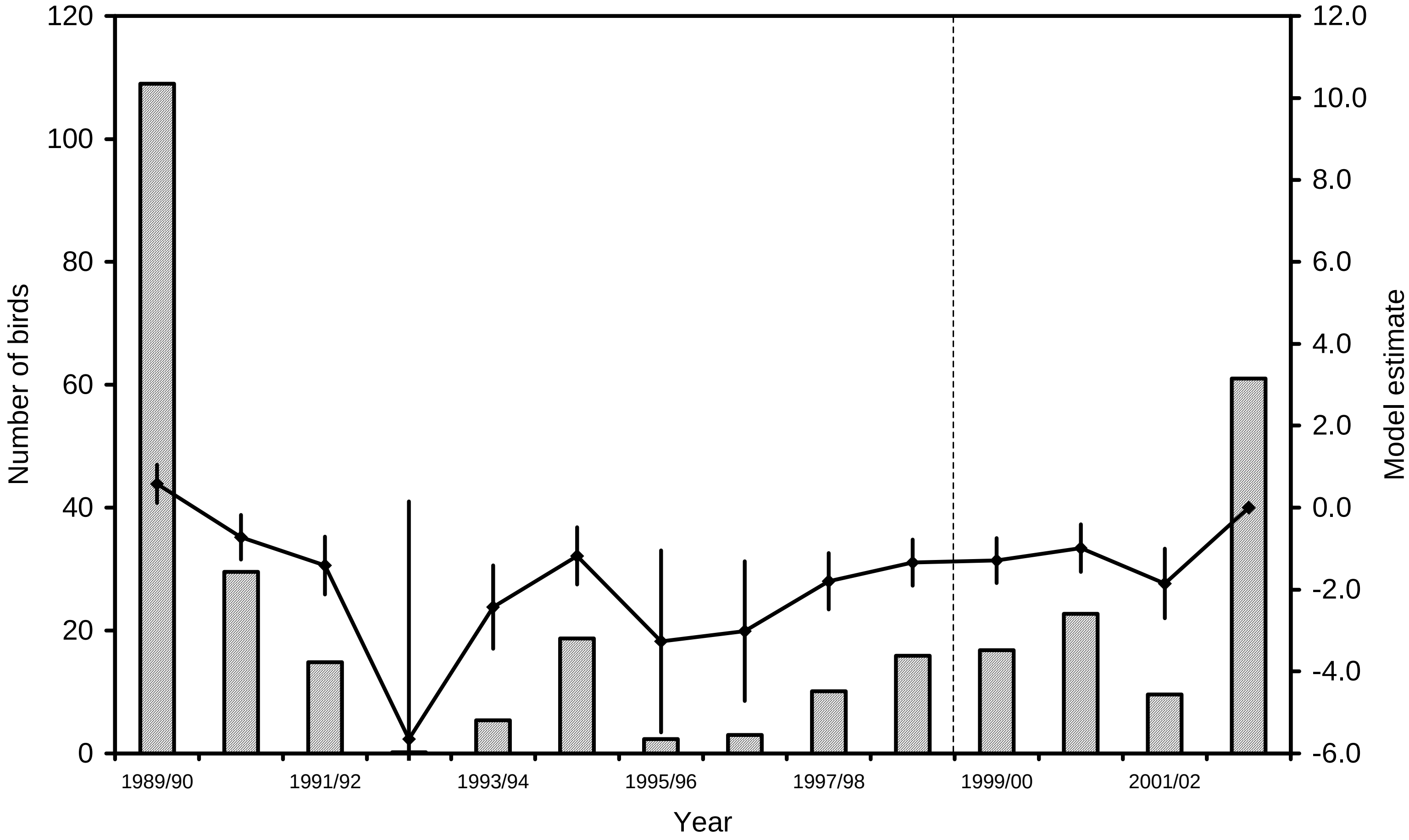


Figure 3.7.4 Estimates for 'year' (± 1 SE) and the mean number of birds derived from a model relating the number of feeding Redshank at low tide at Peterstone and St. Brides to year, month and mudflat.

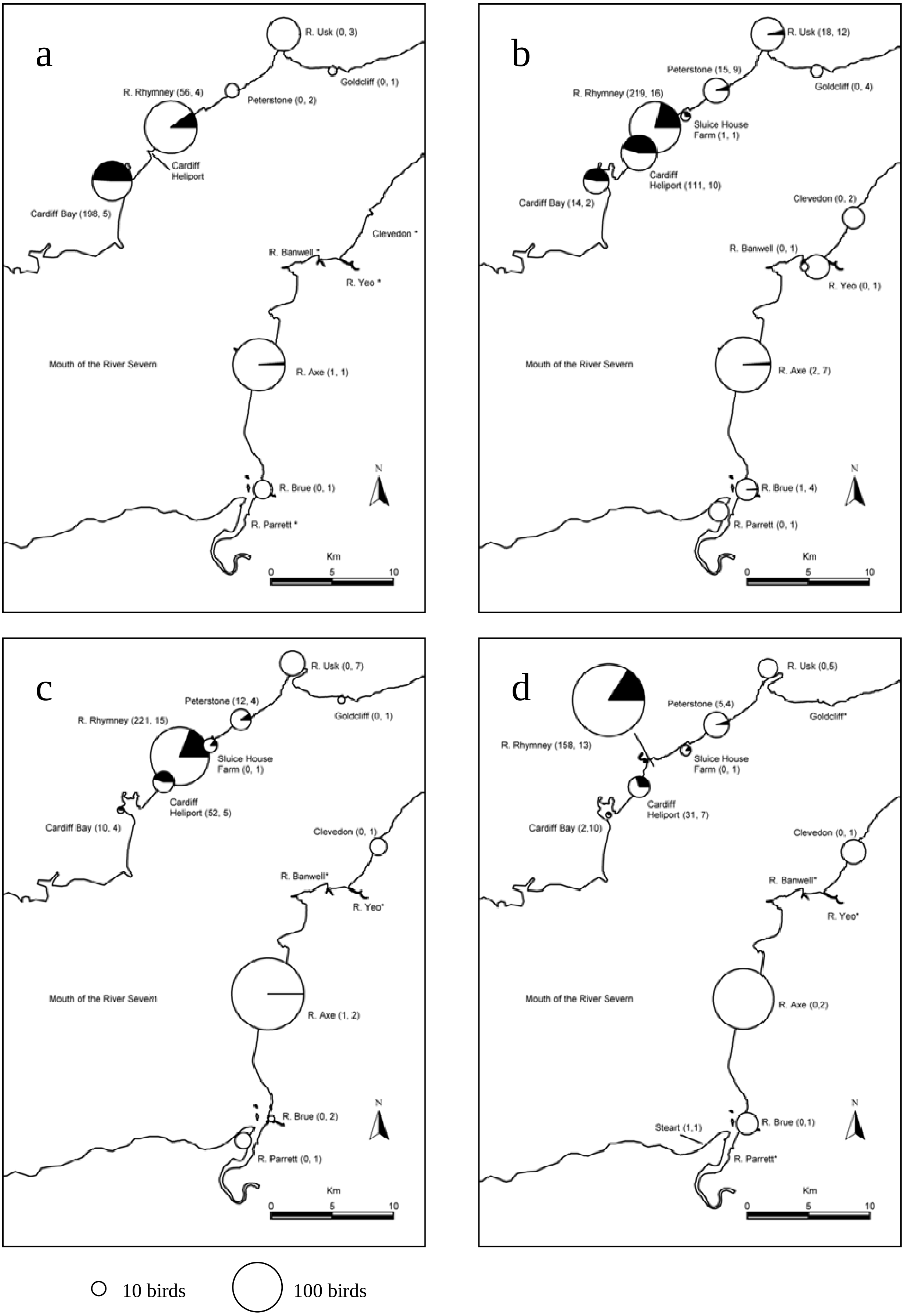


Figure 7.1.1.1 Proportions of colour-ringed individuals in flocks of Redshank in **a**. October 1999, immediately prior to the closure of the Cardiff Bay barrage, **b**. November 1999 to February 2000, the winter immediately post-closure, **c**. October 2000 to February 2001 and **d.** October 2001 to 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.

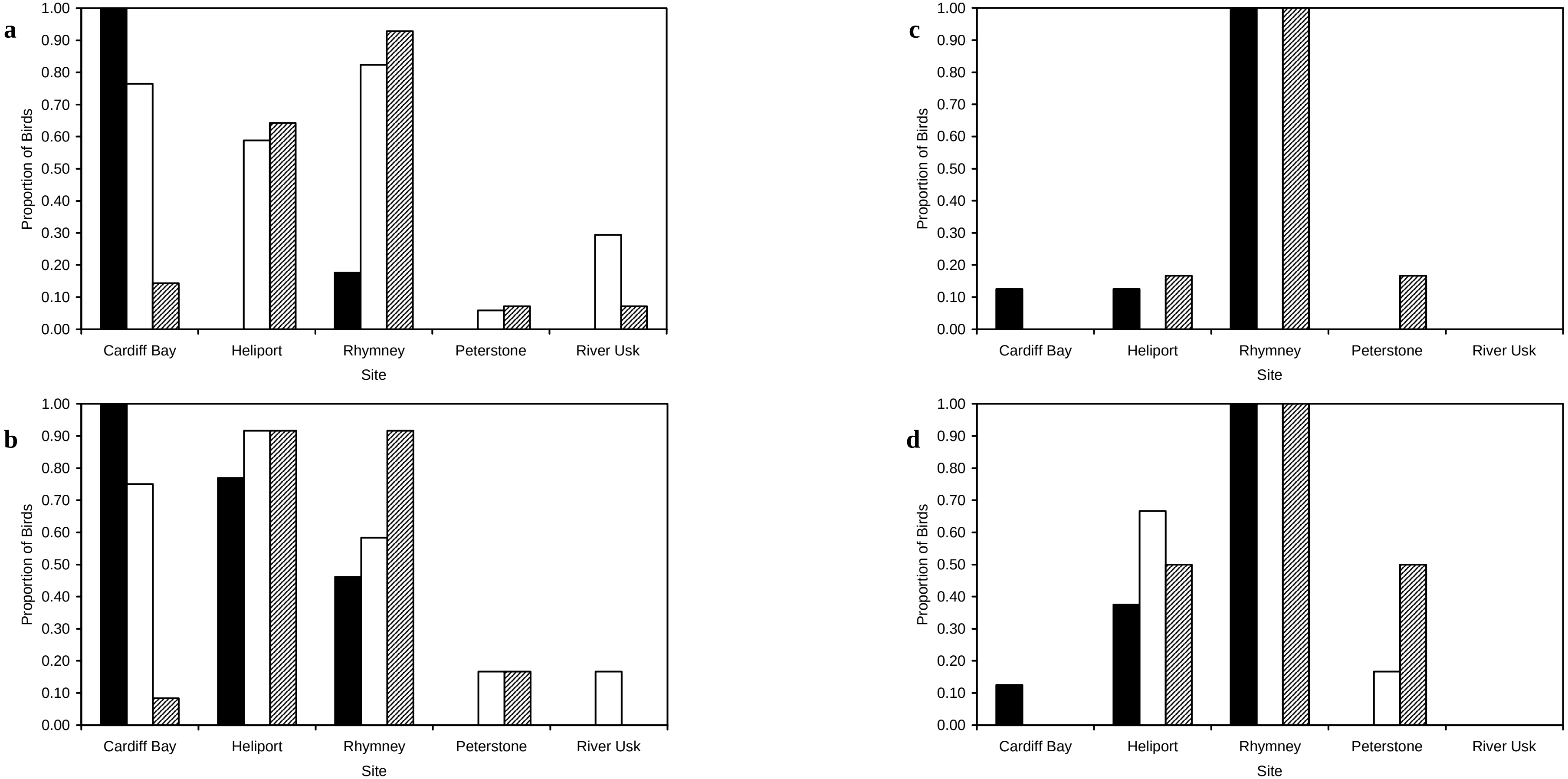


Figure 7.1.2.1 The proportion of radio-tagged Redshank recorded at each site diurnally and nocturnally between **1.** 15 and 31 October 1999, immediately prior to barrage-closure (black columns) **2.** 5 and 18 November 1999, immediately post-closure (white columns) and **3.** 26 November and 20 December 1999 (shaded columns).

a. Diurnal observations of individuals radio-tagged at Cardiff Bay (n_1 = 17; n_2 = 17; n_3 = 14).
b. Nocturnal observations of individuals radio-tagged at Cardiff Bay (n_1 = 13; n_2 = 12; n_3 = 12).
c. Diurnal observations of individuals radio-tagged at Rhymney (n_1 = 8; n_2 = 8; n_3 = 6).
d. Nocturnal observations of individuals radio-tagged at Rhymney (n_1 = 8; n_2 = 6; n_3 = 6).

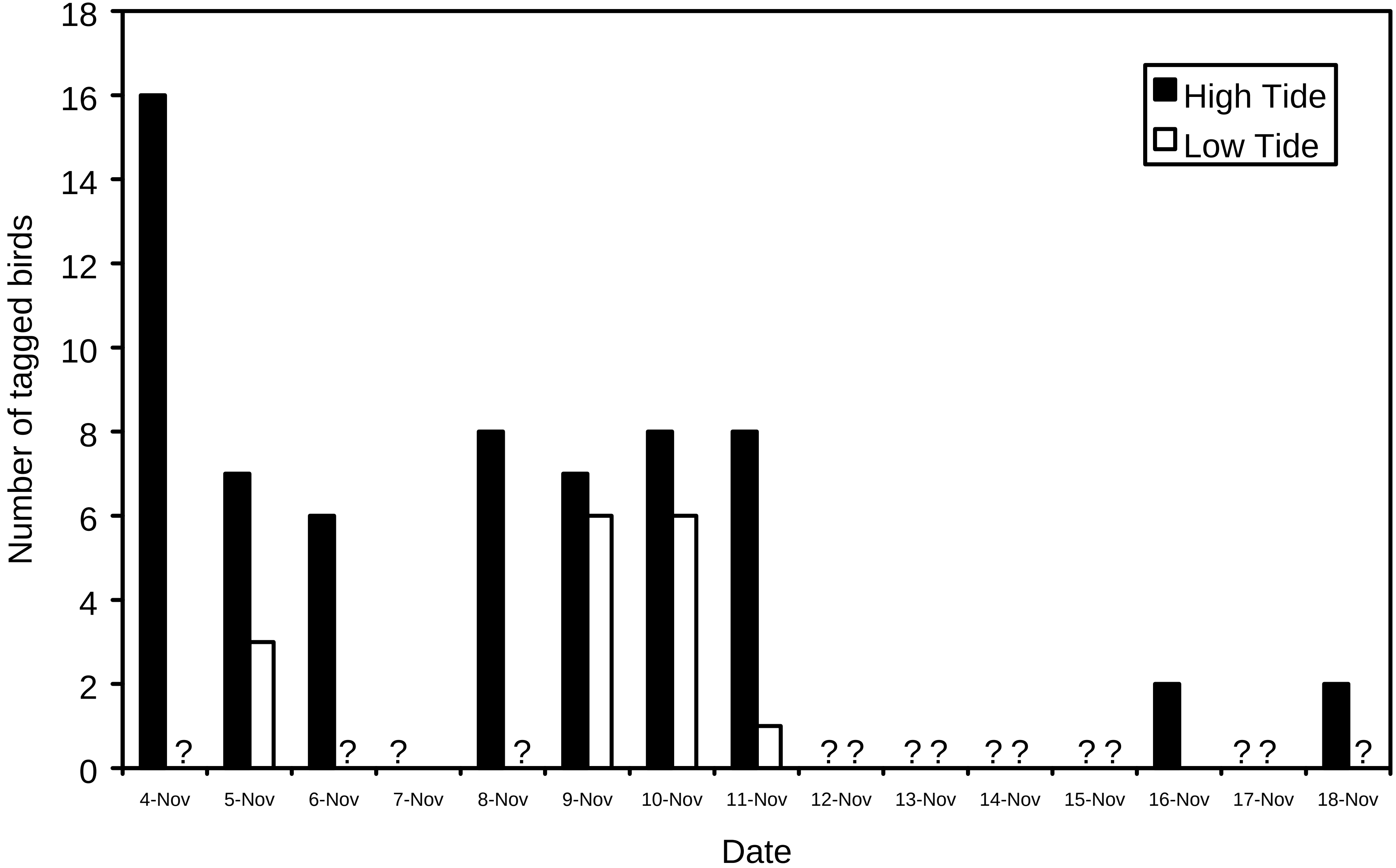


Figure 7.1.2.2 Numbers of Redshank originally radio-tagged at Cardiff Bay in October that were recorded there at high and low tide in the fortnight after barrage-closure.

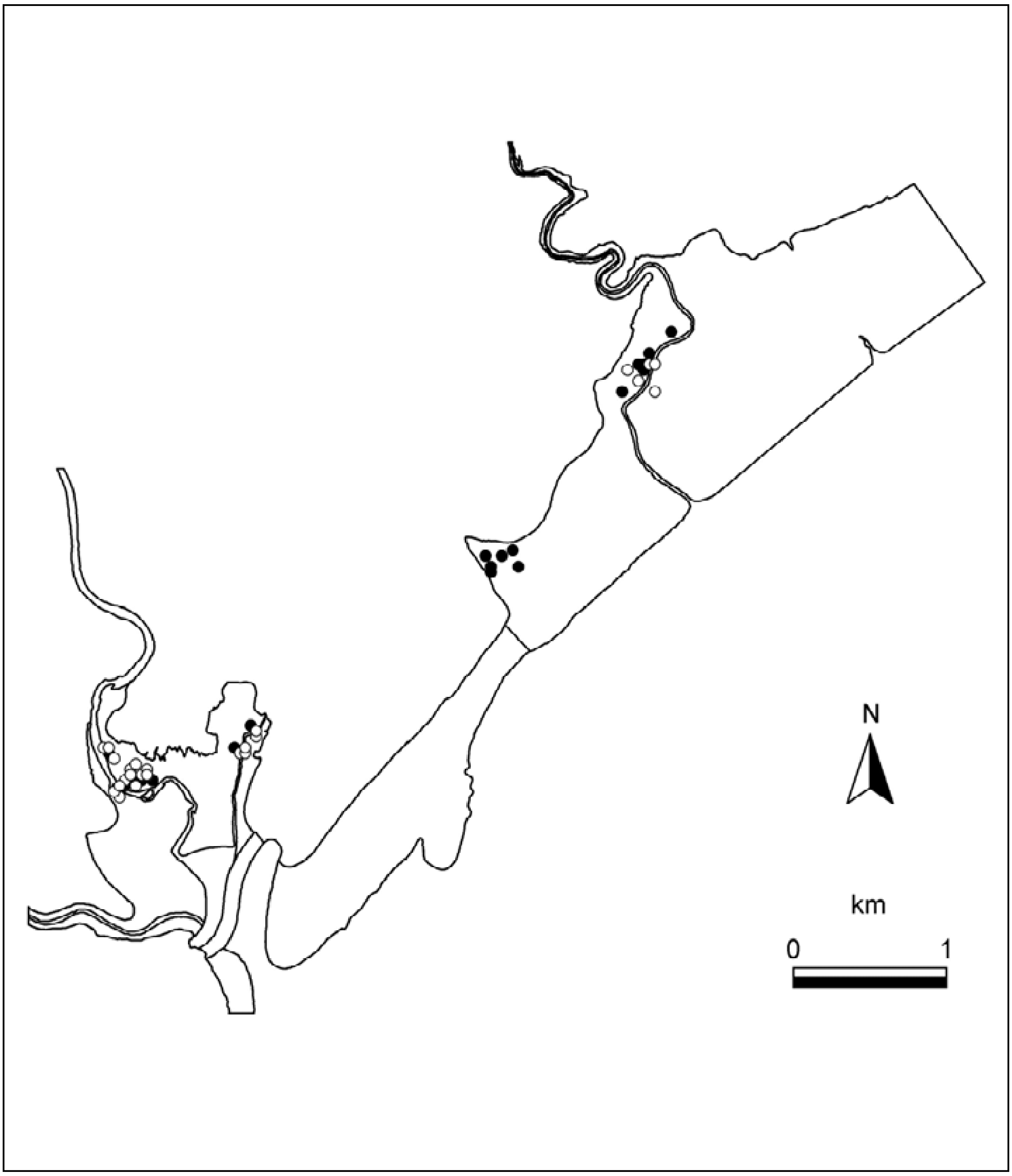


Figure 7.1.2.3 Radio-locations of Redshank RD05 in October 1999, immediately prior to barrage-closure. Open circles = day-time; closed circles = night-time.

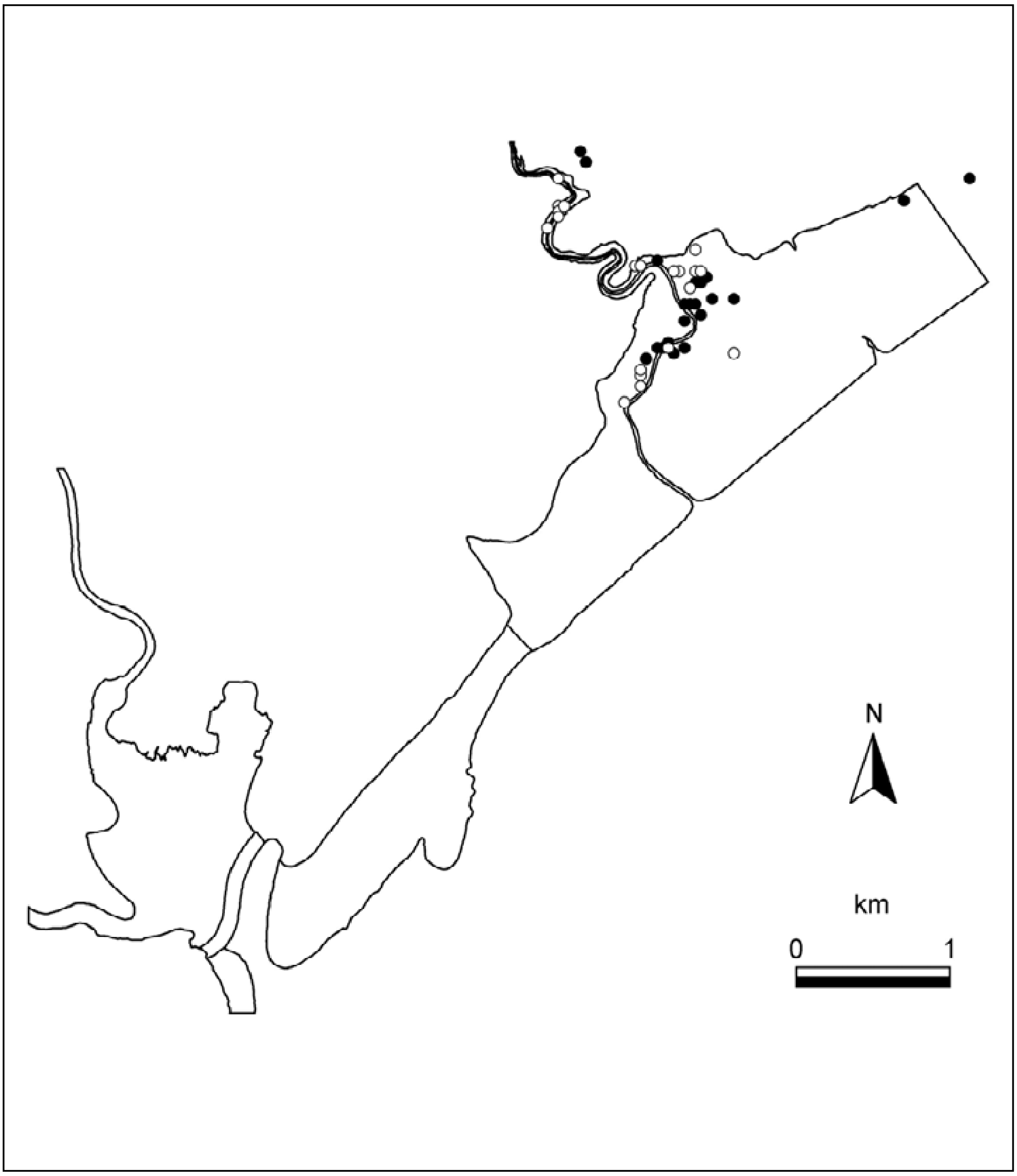


Figure 7.1.2.4 Radio-locations of Redshank RD05 in early November 1999, immediately after barrage-closure. Open circles = day-time; closed circles = night-time.

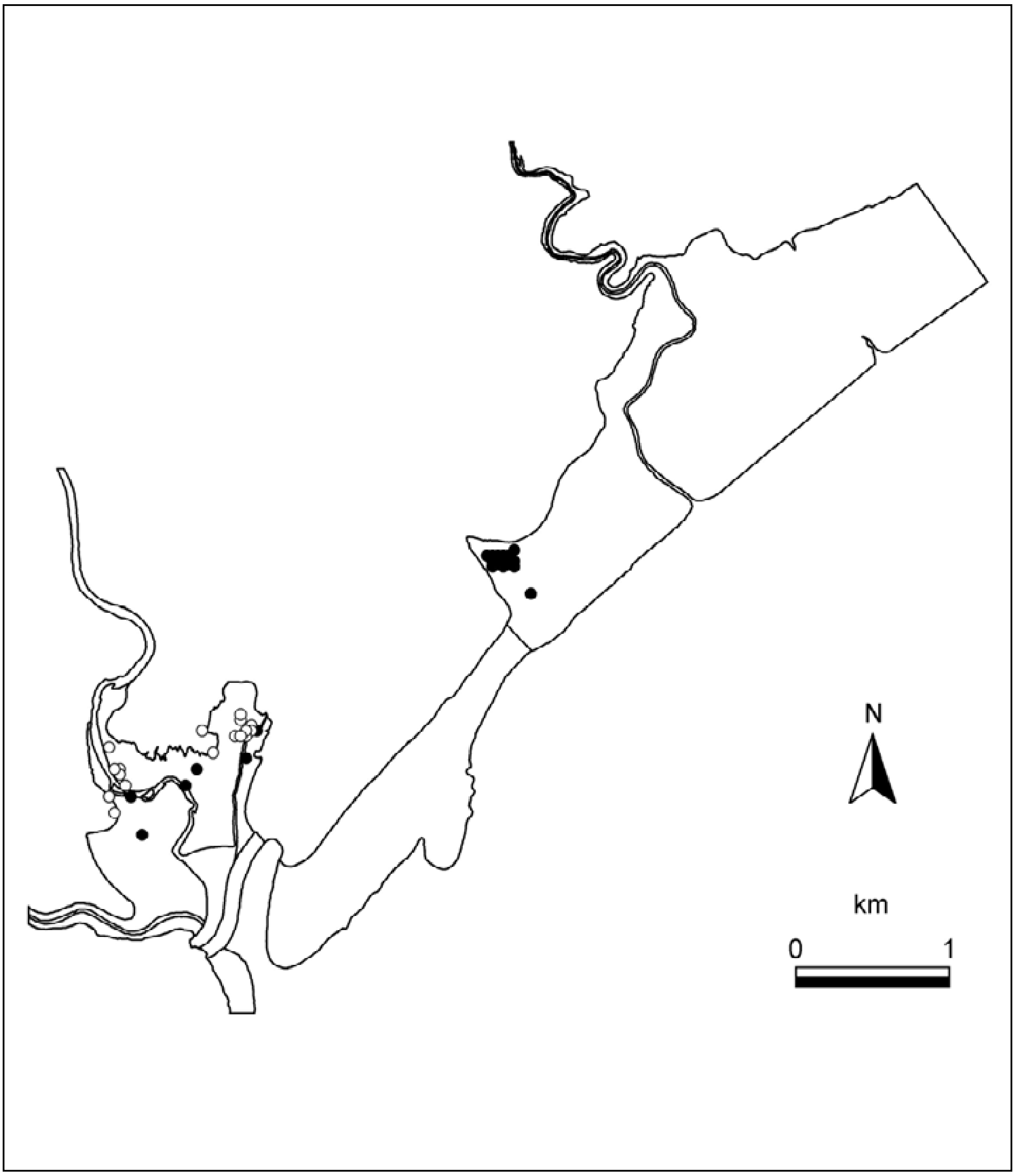


Figure 7.1.2.5 Radio-locations of Redshank RD11 in October 1999, immediately prior to barrage-closure. Open circles = day-time; closed circles = night-time.

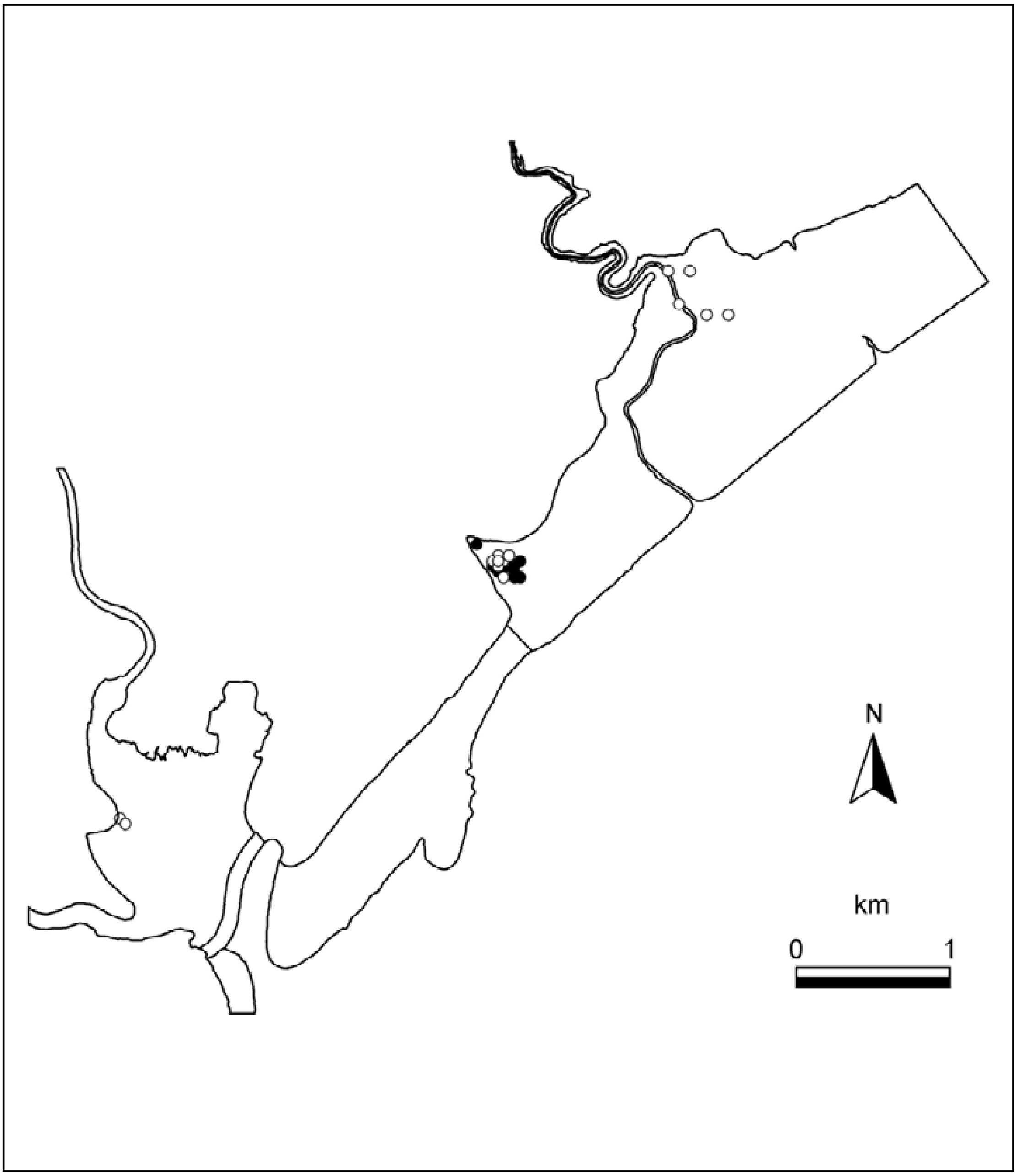


Figure 7.1.2.6 Radio-locations of Redshank RD11 in early November 1999, immediately after barrage-closure. Open circles = day-time; closed circles = night-time.

Site	National Grid Reference	Oct 99	1999/2000-2002/03
Cardiff Bay, South Glamorgan	ST1873	✓	✓
Cardiff Heliport, South Glamorgan	ST2175	✓	✓
Rhymney River, 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 1 Sites on the Severn Estuary surveyed for colour-ringed Redshank in October 1999, immediately prior to barrage-closure, and between 1999/2000 and 2002/03, post-closure.