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DISPERSION OF WATERFOWL ON THE MERSEY IN RELATION TO THEIR PREY

A report from the British Trust for Ornithology to the Mersey Barrage Company

by

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EXECUTIVE SUMMARY

The 1991/92 winter was the fourth consecutive winter of intensive data collection from the Mersey Estuary. Four major objectives were set for this winter:

I) to monitor the low tide distribution of waders and wildfowl on the Mersey, Alt and North Wirral shores;

II) to continue long-term monitoring, through the tidal cycle, of selected sites around the Mersey;

III) to continue night-time monitoring of selected sites, at a low level, to assess the between-year variability in night-time activity patterns;

IV) to monitor the distribution patterns of Pintail, using radio-telemetry, both day and night, focusing on the Pintail concentration at Stanlow Bay.

These objectives were met by the continued collection of field data using Birds of Estuaries Enquiry (BoEE), low tide, and all-day count techniques. Pintail and Teal were caught and radio-tagged, and their movements followed by day and by night. Observations were made of areas used particularly by Pintail and Teal. After consultations with the British Trust for Ornithology, Environmental Resources Limited continued a sampling programme of both the invertebrates and seeds of the Mersey Estuary. The sampling effort during the 1991/92 winter was more closely targeted at areas used by high densities of birds than the previous winter.

The report is presented in four sections:

Section 1 records numerical changes that occurred in the total waterfowl populations of the Mersey Estuary, the Alt and the North Wirral shore, in the four winters of extensive monitoring. The low tide feeding distributions of waterfowl in the inner Mersey Estuary are assessed, and the relative importance of the various Mersey mudflats over the four winters of study is derived. The waterfowl most likely to be affected by the proposed tidal barrage are identified.

Section 2 compares the day and night distributions of waterfowl at several all-day sites. Most species fed actively through most of the tidal cycle. In 1991/92, Grey Plover, Dunlin, Curlew and Redshank fed for longer on the rising tide, while Shelduck and Curlew fed for longer at night, than they did during the colder 1990/91 winter. In 1991/92, Teal and Pintail were opportunistic, feeding on saltmarshes when flooded by high spring tides, though these ducks fed mostly on mudflats. Teal fed at night on some mudflats that were avoided during the day because of human disturbance. Redshank also showed changes in their day and night roosting behaviour that could be related to disturbance. Sediment type affected the distribution of several waterfowl species.

Section 3 concentrates on the movements of radio-tagged Teal and Pintail around the Mersey Estuary. No radio-tagged Teal nor Pintail were located outside the estuary. The distribution of Teal caught at Mount Manisty was different from that of Teal caught at Hale and Bromborough during the previous winter. Pintail were tracked more frequently on mudflats than any other habitat type, indicating that this habitat is essential to the species. During the day but not at night, Pintail avoided areas disturbed by human activity. They used Mount Manisty, an area free of human disturbance, as a day-time refuge. The Mersey Estuary was essential for both feeding and roosting Pintail. Loss of intertidal habitat, a possible result of the proposed tidal-barrage, or increased disturbance could lead to reduced Pintail populations.

Section 4 compares invertebrate densities and biomasses to bird densities over the two winters of 1990/91 and 1991/92. Invertebrate densities did not help predict bird numbers but Shelduck, Teal, Dunlin and total bird densities, were correlated with oligochaete biomass. The most common constituent of the oligochaete fauna was *Tubificoides benedeni*, a species that is resistant to pollution. The proposed tidal barrage will limit the intertidal areas that the birds feed on but may not affect *Tubificoides benedeni* numbers.

It was recommended that further work include:

i) studies of the winter movements of waterfowl, both within the Mersey Estuary and away from the estuary;

ii) waterfowl time budgets;

iii) studies of any possible mitigation measures to compensate for the loss of feeding areas post-barrage;

iv) an estimation of the proportion of available food taken by waterfowl under the present conditions;

v) an assessment of the impact of human disturbance to waterfowl;

vi) the monitoring of the effects of barrage construction and operation on birds.

GENERAL INTRODUCTION

Large engineering projects can have an impact on the environment **(Gray 1992)** and the proposed Mersey Barrage may affect the large populations of waterfowl that winter on the estuary. The Mersey is currently the thirteenth most important site for wildfowl and the fourteenth most important site for waders in the United Kingdom **(Kirby *et al.* 1991)**. It holds over 100,000 waterfowl in total, including over 1% of the north-west European populations of Shelduck, Teal and Pintail and over 1% of the east Atlantic flyway populations of Dunlin and Redshank. As a result, the estuary qualifies as a candidate for the Ramsar Convention designation as an Internationally Important Wetland. The Mersey also holds nationally important numbers of Wigeon, Grey Plover, Black-tailed Godwit and Curlew.

The proposed Mersey tidal barrage will reduce the tidal range and the length of time that the intertidal areas are exposed **(Mersey Barrage Company 1992)**. This will decrease the intertidal area and the amount of time that waterfowl can feed. A diminution of feeding area can be expected to lead to a decrease in waterfowl populations **(Goss-Custard & Moser 1988; Lambeck 1991; Meire 1991)**, though this will largely depend on whether the site is now fully used by birds (at carrying capacity) or not. To assess the implications of the barrage on the waterfowl a thorough understanding of how the Mersey is used by birds is necessary.

The large bird populations found on estuaries are there because of very high invertebrate densities and biomass **(Prater 1981; McLusky 1981; Wilson 1988)**. It is important to know what prey the Mersey waterfowl are utilizing, and to what extent potential prey resources are being exploited, as the effect of the proposed Mersey tidal barrage will vary with the invertebrate and plant species.

Relatively long-term studies of the year to year variability in the usage made of estuaries by waterfowl are uncommon because of their relatively high cost. Long-term monitoring is required to predict the impact of the barrage on the Mersey Estuary. For example, the dynamic nature of the Mersey Estuary leads to changes in the characteristics of its intertidal areas but the impact of such physical changes on the waterfowl can only be measured through extended periods of study. Studies of the variations in the use waterfowl have made of such areas have led to a better understanding of what constitutes preferred feeding and roosting areas. Long-term studies have the secondary advantage of being invaluable when it comes to assessing the impact of such incidents as the accidental Mersey oil spill of 1989 **(Clark *et al.* 1990c)**.

The 1991/92 winter was the fourth consecutive winter of monitoring. The study continued to focus on year to year variability, the most regularly important intertidal areas, and waterfowl activity budgets. This necessitated both diurnal and nocturnal observations, as birds feed at night **(*eg* Wood 1983 & 1986; Clark *et al.* 1990b; Rehfisch *et al.* 1991)**. During the 1991/92 winter work was concentrated on one particular internationally important species, Pintail, the nocturnal distribution and feeding behaviour of which was still poorly understood on the Mersey.

SECTION 1

ANNUAL VARIABILITY IN WATERFOWL NUMBERS

1.1 INTRODUCTION

The 1991/92 winter was the fourth consecutive winter of waterfowl monitoring on the Mersey Estuary and adjacent areas. It saw a return to the pattern of mild conditions that characterised the 1988/89 and 1989/90 winters **(Clark *et al.* 1990c)**. These were in marked contrast to the 1990/91 winter, when severe cold weather affected much of Britain, including Merseyside **(Rehfisch *et al.* 1991)**. The 1991/92 winter's data allowed further comparison between population peaks and movements relative to the prevailing mild weather conditions.

This extended study of the wintering bird populations of the Mersey was started because of a proposed tidal power barrage across the estuary, which would alter the character of the habitat. In the context of the proposed tidal barrage, it is particularly important to know what bird species are present on the Mersey and in what numbers. Knowledge of the distribution of these birds, and their usage of the various habitats on the estuary, is essential to assessing the potential impact of the barrage. Such information could only be gathered over the course of several winters, using techniques perfected by the British Trust for Ornithology.

The Birds of Estuaries Enquiry (BoEE) counts recorded birds monthly at high tide during the winter, when the majority were roosting. The low tide counts were made twice a month and censused mainly feeding birds. Taken together these counts allowed the continued monitoring of the use made of the estuary by waterfowl and any associated population changes during the course of the winter. As previously, the Alt and North Wirral Shore were also covered by low tide counts. The distribution of the waterfowl over the four winters was compared and the most important mudflat feeding areas mapped (Figure 1.3.19.2).

Five species of birds were present in internationally important numbers on the Mersey this winter (Shelduck, Teal, Pintail, Dunlin and Redshank), while Wigeon, Grey Plover and Black-tailed Godwit were of national importance (Table 1). The estuary is becoming increasingly important for wintering Black-tailed Godwit with continuing evidence of some redistribution from other estuaries **(Kirby *et al.* 1990)**.

1.2 DATA COLLECTION, PRESENTATION AND ANALYSIS

In continuing the last three years of ornithological studies on the Mersey Estuary, extensive low tide counts covered the whole of the study area every two weeks. These counts fulfil objective 4 of the phase IIIA ornithological studies relating to the Mersey Barrage Feasibility Study, in monitoring the low tide distribution of waders and wildfowl on the Mersey, Alt and North Wirral shores. The high tide BoEE counts are carried out every month and are timed to coincide with spring tides,when the waders congregate at discrete traditional roosting sites.

1.2.1 Data collection - low tide counts

The total numbers and distribution of waterfowl using the Mersey and adjacent areas at low tide were assessed by experienced volunteers who carried out low tide counts of the whole area twice a month during the four winters of 1988/89 to 1991/92. Figure 1.2.1 shows the 96 separate, low tide count areas used to divide the study site into convenient units for counting and distributional analysis. These 96 areas were separated by such features as changes in substrate type, river channels, permanent features such as rock outcrops or large man-made features on the horizon. Whenever possible the numbering of the areas in 1991/92 follows that used in previous years. As in 1990/91, some parts of the Mersey that had been counted as several areas in previous winters were counted as one, as a result of individual counters having counted several areas as one.

Seven comparable counts were carried out each winter, with most counts being performed within an hour of low tide and on the official count day (Table 2), although the availability of volunteer counters meant that the low tide counts made of some areas were a few days on either side of the official date. All areas were counted at least twice during the 1991/92 winter.

In 1991/92, as in the previous two winters, specially designed low tide recording forms were used and returned to the British Trust for Ornithology headquarters for computerisation. Birds found feeding and roosting were recorded separately. Weather conditions and any disturbance were noted, in an effort to control count reliability.

Counts made during the winter of 1988/89 were reported to ETSU **(Clark *et al.* 1990c)**. The bird numbers for the winter of 1989/90 were used in a report also to ETSU **(Clark *et al.* 1990b)**, as well as in a document to the Mersey Oil Spill Project Advisory Group (MOSPAG), which assessed the effects on waterfowl of the Mersey oil spill of August 1989 **(Clark *et al.* 1990a)**. The counts for the 1990/91 winter were used in a report to the Mersey Barrage Company **(Rehfisch *et al.* 1991)**.

1.2.2 Data analysis - low tide counts

The low tide count coverage of the whole area was good for the four winters, with on average 86% of all low tide count areas being counted on each count date. Some areas were missed through counters not being available on the required count date, or because of bad weather. The best available measure of low tide usage for each intertidal area is taken to be the average number of birds counted in the area over the count period.

The changes in the bird numbers over the winter are represented graphically (*eg* Figure 1.3.1.1). These numbers were collated from both the low tide counts and also the separately organised BoEE counts. BoEE counts were also carried out by volunteer counters but the counts were made at high tide.

This winter prolonged periods of foggy weather affected three of the low tide counts. Consequently the January 26/27 counts were not plotted (*eg* Figure 1.3.1.1) because most counters reported that the fog made counts impossible. Data from the other two dates affected by fog, (December 14/15 and January 11/12), were plotted as most counters reported reasonable visibility. These two counts may not be very accurate and should be interpreted with caution.

The peak low tide counts of waterfowl on the Mersey Estuary and the Alt and North Wirral Shore are represented in tables 3 and 4. For each species of waterfowl, figures are presented which show the frequency of the birds on the various mudflats at low tide on the Alt, the North Wirral Shore, and the Mersey Estuary (*eg* Figure 1.3.1.2).

A further set of figures show which mudflats have been used by large numbers of birds over the four winters, 1988/89 to 1991/92 (*eg* Figure 1.3.1.3). For a mudflat or an area to have been considered important for a particular year, it must have held on average at least two percent of the total numbers of a species censused on the Mersey Estuary during the low tide counts of that year. If a mudflat reached this 2% limit in all four winters, it was considered to be consistently important. If the mudflat held 2% of the wintering birds in two or three winters, it was taken to be frequently important. If 2% of the low tide population was reached during only one winter out of four, the mudflat was classed as infrequently important. If the 2% level was never reached, a mudflat was not considered to be important.

1.3 RESULTS

1.3.1 Shelduck

The peak BoEE high tide count was of 4,102 birds in late December, slightly later than in the winter of 1990/91 (Figure 1.3.1.1). Although the numbers were lower than in the 1990/91 winter, they still represent the second highest count of the last five winters on the Mersey. The number of Shelduck decreased from late December but showed a slight increase from late January to late February, before declining again. Nonetheless, numbers were more constant than over the previous winter, which was subject to a much colder spell of weather that may have influenced the movement of birds **(Rehfisch *et al.* 1991)**. The Mersey remains nationally important for wintering Shelduck with 5% of the British population and internationally important with 1.5% of the north west European population (Table 1).

The peak low tide count of feeding and roosting Shelduck on the Mersey was 2,874 in 1991/92. This is lower than in any of the previous three winters, with 3,667 individuals counted during the 1990/91 winter, 4,040 during the 1989/90 winter and 4,982 during the 1988/89 winter (Table 3). Although less important, the numbers on the Alt and North Wirral Shore increased over the 1990/91 winter but were lower than in the winters of 1988/89 and 1989/90 (Table 4).

The low tide feeding distribution of Shelduck on the estuary (Figure 1.3.1.2) was very similar to that of 1988/89 and 1990/91 **(Clark *et al.* 1990c; Rehfisch *et al.* 1991)**. The recent decline in feeding numbers on area 58, near Runcorn Bridge (Figure 1.2.1), continued, with no birds being recorded at all in 1991/92. The greatest numbers of birds were found in the inner parts of Stanlow and Oglet Bays and on the mixed mudflat and saltmarsh of Frodsham Score. Some small changes in feeding distribution were noted on the Alt and North Wirral Shore.

The most frequently used areas, during the 1991/92 winter, were very similar to those most commonly used in the last three winters (Figure 1.3.1.3). Shelduck tend to use those mudflats in the upper part of the estuary with the longest exposure time, possibly to allow a maximum feeding time or because of the distribution of a preferred invertebrate prey.

1.3.2 Wigeon

The BoEE peak count of Wigeon this winter was 11,500, the highest of the last four years. The species was just below the 1% threshold for being internationally important, holding an average of 0.9% of the north-west European wintering population (Table 1). During this winter, Wigeon numbers rose from November to reach a peak in the third week of January

(Figure 1.3.2.1), with a rapid decline thereafter. Wigeon normally peak on the Mersey in December **(Kirby *et al.* 1990)**.

As in the 1990/91 winter, the low tide counts were rather erratic, with the peak number of 3745 birds counted in late December. Numbers were lower than in the previous two winters but close to the 1988/89 winter peak count of 3757 individuals (Table 3).

The main low tide feeding concentrations of Wigeon were on the Stanlow Bay mudflats and Ince marshes, whilst the mudflats at Mount Manisty and Eastham were used occasionally (Figure 1.3.2.2). This distribution is different from those of the three previous winters when the majority of duck were concentrated in areas of Frodsham Score.

No Wigeon were seen on the Alt and North Wirral coast during the counts.

1.3.3 Teal

The maximum BoEE count of 13,450 Teal, in December, was the highest of the last six winters **(Kirby *et al.* 1991)**. The Mersey holds 2.9% of the north-west European population (Table 1). The numbers of Teal peaked in mid December and then declined rapidly to mid January. There was a slight increase to mid February followed by a further decline (Figure 1.3.3.1). This is similar to the pattern in the 1990/91 winter, and typical of the previous few years.

The peak count of 6,724 Teal during this winter's low tide count (Table 3) was close to the 7,016 of last winter but lower than the peak count of 14,248 during the 1989/90 winter. However, the 1988/89 count of 5909 was slightly lower. Teal are very rarely recorded on the Alt or North Wirral Shore but occasional individuals were recorded this winter (Table 4).

This winter,the low tide distribution of feeding Teal showed Oglet Bay to have most birds, followed by the mudflats off Speke airfield, and between Eastham to Mount Manisty (Figure 1.3.3.2). The New Ferry, Mount Manisty and Stanlow areas were all less important than in the 1990/91 winter. The areas most commonly used this winter (Figure 1.3.3.3) were generally similar to those used in the previous three winters. The one exception to this were the mudflats between Eastham and Mount Manisty which were used slightly more in 1991/92. Areas 32, 69 and 70 were used by 2% or more of the feeding Teal at low tide each winter between 1988/89-1991/92.

1.3.4 Mallard

The peak BoEE count of 1,016 was recorded in December.

This winter's peak low tide count recorded 1,068 Mallard on the Mersey Estuary (Table 3). This was an increase over the winters of 1988/89 (872 birds) and 1990/91 (738 birds) but lower than in the 1989/90 winter (1,361 birds). 396 Mallard were counted on the Alt and North Wirral shores (Table 4), a higher number than that recorded during the 1990/91 winter (312) but lower than in the previous two winters of 1989/90 (459) and 1988/89 (430).

The most important feeding areas for feeding Mallard were Hale Head and Mount Manisty. In the winter of 1990/91, Oglet Bay, Stanlow Bay and the vicinity of Mount Manisty were the three most important areas for feeding Mallard. Mudflat 58, below Runcorn Bridge (Figure 1.2.1), was used regularly in the winter of 1989/90 but not since.

1.3.5 Pintail

The peak BoEE count was of 6,089 Pintail. The numbers on the Mersey tend to fluctuate markedly from year to year, with 2,746 Pintail in 1990/91, 8,000 in 1989/90, and 4,288 in the 1988/89 winter. Numbers peaked this winter in mid to late December, declining rapidly to mid January, before increasing again to late February (Figure 1.3.5.1). This general pattern is very similar to that of the 1990/91 winter.

The Mersey regularly holds nearly 24% of the British wintering Pintail population and has remained important in a European context with 8.4% of the north-west European population present in winter (Table 1).

The maximum low tide count during the winter of 1991/92 was 1,386 Pintail (Table 3). The numbers have not changed significantly over the past four winters, with maximum low tide counts of 1316 in 1990/91, 1413 in 1989/90 and 1230 in 1988/89. There was only a single record of Pintail on the Alt and North Wirral Shore (Table 4). The low tide counts over the 1991/92 winter showed much less variation than the BoEE counts, with a peak in early January and no second increase in late February or early March (Figure 1.3.5.1).

This winter (Figure 1.3.5.2), most Pintail fed at the southwest end of Stanlow Bay (mudflats 33, 34 and 36), at New Ferry and Hale Head and also in the areas 76, 77 and 84 (Figure 1.2.1). These areas were generally those found to be important over the past three winters (Figure 1.3.5.3). Since the winter of 1989/90, mudflats 42, 43 and 44 in Stanlow Bay have become less important for feeding Pintail (Figure 1.2.1).

1.3.6 Oystercatcher

The BoEE maximum count was of 154 birds in late March 1992. This figure is substantially higher than that of the 1990/91 winter peak of 54 birds, also in March. This winter, the numbers built up steadily from November to March.

The maximum low tide count on the Alt and North Wirral shore was of 3,824 birds, similar to the 4,091 of the previous winter but lower than in the winters of 1989/90 (6,533 birds) and 1988/89 (14,369 birds) (Table 4). The Alt and North Wirral Shore were the most important feeding areas, with few birds noted in the Mersey Estuary (Figure 1.3.6.1), thus following the pattern of the previous three winters.

1.3.7 Ringed Plover

The BoEE maximum count of Ringed Plover was six.

Low tide numbers peaked at 106 on the Mersey (Table 3). Numbers have fluctuated over the last four winters but the 1991/92 winter count was higher than in the previous three winters, when the peaks ranged from 45 in the winter of 1990/91 to 80 in the 1988/89 winter.

On the Alt and North Wirral Shore, the peak low tide count was 87. This winter, numbers were lower than in 1988/89 and 1989/90 when the peak counts were 167 and 188 birds respectively but higher than in the 1990/91 winter when the peak count was of 28 individuals.

The low tide distribution (Figure 1.3.7.1) was very similar to that of the previous winter with the preferred feeding areas found at New Ferry and the central part of the North Wirral Shore. Mudflat 76 (Figure 1.2.1) was also used during the 1991/92 winter.

1.3.8 Golden Plover

The maximum BoEE count of 1,900 Golden Plover during the 1991/92 winter was slightly higher than that of the previous winter. Peak numbers were in February, as opposed to December in 1990/91. The Mersey is not nationally important for this species (Table 1).

In 1991/92, the peak Mersey low tide count of 2,024 birds was higher than in any of the previous three winters (Table 3). On the Alt and North Wirral Shore, the winter 1991/92 count of 570 Golden Plover was higher than that of the 1990/91 and 1988/89 winters but lower than that for the 1989/90 winter, when a maximum count of 710 was recorded (Table 4).

During the 1991/92 winter, the preferred feeding areas for Golden Plover were Frodsham Score and the mudflats between Eastham and Mount Manisty (Figure 1.3.8.1). Mudflat 93, on the Alt (Figure 1.2.1) was also important. Unlike the winter of 1990/91, the Ince marshes were not important as a feeding area, and the mudflats on the northern side of the estuary were not used.

1.3.9 Grey Plover

The peak BoEE high tide count this winter was 902 birds in late February, much lower than the exceptional count of 2,500 Grey Plover made in the 1990/91 winter (**Rehfisch *et al.* 1991**). The average peak count over the last five winters on the Mersey is 854 birds, which makes it nationally important for this species, with 4.1% of the British wintering population (Table 1). The Mersey is continuing to increase in national importance for Grey Plover, from 1.4% of the national population in 1989/90 to 3.4% in 1990/91, to the current 4.1%.

The BoEE peak counts in both 1991/92 and 1990/91 were in February (Figure 1.3.9.1). During the 1990/91 winter, up to 2,000 birds were present in early December, with a decline in numbers to the end of January followed by a steep increase to a peak February count. Over the 1991/92 winter, Grey Plover numbers declined from 500 in late November to 83 in mid January before rapidly increasing in February. This February peak may indicate a passage of birds moving through the estuary in late winter as has been noted from the Wash.

Although the 1991/92 low tide counts were more variable than the BoEE counts, and were affected by fog in December and January, they also showed a February peak (Figure 1.3.9.1).

The maximum low tide count on the Mersey, during the 1991/92 winter, was 475 birds (Table 3), the highest count of the past four winters. On the Alt and North Wirral Shore, the peak count was 443, lower than the counts of the 1989/90 and 1990/91 winters (Table 4). Unlike the previous three winters, higher numbers of Grey Plover fed on the Mersey Estuary during the 1991/92 winter than on the Alt and North Wirral Shore.

The most important areas for feeding on the Mersey Estuary were the Oglet mudflats, mudflats around Frodsham Score and at the western end of Stanlow Bay (Figure 1.3.9.2). Mudflats 76 and 77 were also used (Figure 1.2.1). Outside the estuary, the Alt was the most important area, with smaller numbers along the North Wirral Shore. The overall distribution is fairly similar to that of the previous three winters, although Frodsham Score and mudflats 76 and 77 were used during the 1991/92 winter but not in the 1990/91 winter (Figure 1.3.9.3).

1.3.10 Lapwing

The 1991/92 BoEE maximum count of 12,500 Lapwing in November was the highest count of the last four winters on the Mersey. The maximum count of the 1990/91 winter was 11,700 in December. The Mersey is not nationally important for this species (Table 1).

The maximum low tide count on the Mersey in the 1991/92 winter was 11,153 (Table 3), lower than the previous year but higher than those of the 1988/89 and 1989/90 winters. On the Alt and North Wirral Shore, the peak count of 1,060 birds (Table 4) was higher than in the previous winter but lower than in 1988/89 or 1989/90.

During the 1991/92 winter, the most important areas on the Mersey Estuary for feeding Lapwing at low tide were Oglet Bay and mudflats 76 and 77 (Figures 1.2.1 and 1.3.10.1). The mudflats around Frodsham Score were also used but were less important. The Alt and North Wirral Shore were not important as feeding areas but were used for roosting. During the 1990/91 winter, the Ince Marshes and Frodsham Score were the most important low tide feeding areas. The feeding distribution of Lapwing during the 1991/92 winter most closely resembled that of the 1989/90 winter **(Clark *et al.* 1990b)**.

1.3.11 Knot

The peak BoEE high tide count on the Mersey this winter was of 206 Knot in February, which is well below the peak count of 870 birds in December 1990/91. The Mersey Estuary is not nationally important for this species (Table 1).

During the 1991/92 winter, the peak Mersey low tide count was of 3,160 birds (Table 3). This was higher than in the previous three winters when 1,809 (1990/91), 1,862 (1989/90), and 2,224 (1988/89) birds were counted. On the Alt and North Wirral Shore the peak count of 4,826 (Table 4) was lower than the 11,502 and 11,753 recorded over the previous two winters and considerably lower than the 48,296 of the 1988/89 winter.

The Mersey low tide maximum count for the 1991/92 winter was higher than the corresponding BoEE count as one of the important Knot roosts on the Mersey, at New Ferry, was not counted during high tide.

The Mersey Estuary holds relatively few Knot at low tide. The areas most frequented used during the 1991/92 winter were Oglet Bay, Hale Head and New Ferry (Figure 1.3.11.1). For the first time in four winters the mudflats at Hale Head were used by feeding Knot. The Stanlow Bay mudflats were used less than during the 1990/91 winter. The Alt was more important than the North Wirral Shore, with fewer birds feeding at the latter site during the 1991/92 winter than in the 1990/91 winter.

1.3.12 Sanderling

During the 1991/92 winter, the Mersey Estuary held no Sanderling during either the low tide or BoEE high tide counts. The counts on the Alt and North Wirral Shore peaked at 751 Sanderling, more birds than in the winters of 1990/91 and 1988/89 but fewer than in 1989/90 (Table 4).

The low tide distribution of Sanderling was concentrated around the Alt (Figure 1.3.12.1) which was similar to the pattern of the previous three winters. Slightly more use was made of the North Wirral Shore than in the 1990/91 winter.

1.3.13 Dunlin

The 1991/92 BoEE maximum count of 55,000 birds in January is the largest ever on the Mersey, exceeding the 52,000 Dunlin of the 1990/91 winter. The national and international importance of the Mersey for this species increased to 7.6% of the British wintering population and an estimated 2.4% of the north-west European population (Table 1). Numbers of Dunlin rose steeply from November to peak in January, before declining rapidly to the end of March, when virtually all the birds had left the estuary (Figure 1.3.13.1). During the 1990/91 winter, Dunlin numbers were more constant between December and late January, with a steep decline thereafter. The national BoEE counts, during the 1990/91 winter, showed record counts of Dunlin on two other estuaries in north-west England, namely the Dee and Morecambe Bay. It is unlikely that these increases were related to the cold weather of early 1991 but indicate an actual increase in the regular wintering population (**Kirby *et al.* 1991**).

The peak low tide count during the 1991/92 winter on the Mersey Estuary was 17,621 (Table 3). This was lower than the 33,114 counted in the 1990/91 winter but higher than in the winters of 1988/89 and 1989/90. On the Alt and North Wirral Shore, the 3,297 peak count (Table 4) was similar to those in the winters of 1990/91 and 1988/89 but lower than that of winter 1989/90. Overall, the low tide counts showed a general decline from November to January, with an increase from late January to February (Figure 1.3.13.1).

The large differences between this winter's BoEE and low tide counts on the Mersey might have resulted from a large influx of Dunlin arriving just before the January high tide count and departing before the next low tide count.

During the 1991/92 winter the Dunlin feeding distribution on the Mersey was similar to that in the 1990/91 winter (Figure 1.3.13.2) with the exceptions of Ince Bank, which was not used at all, and Frodsham Score, which was used less frequently. Other important areas were Stanlow Bay, Oglet Bay and New Ferry. Mudflats 76, 77 and 80 (Figure 1.2.1) were used more than in the previous three winters. Most parts of the Alt and North Wirral Shore were also used by feeding Dunlin, with mudflat 16 being the most important (Figure 1.2.1).

The areas on the Mersey Estuary found to be consistently important to feeding Dunlin over the last four winters are Stanlow Bay, Oglet Bay and parts of Frodsham Score (Figure 1.3.13.3). The less important feeding areas tend to be those associated with a higher sand content (Figures 2.2.1.1 and 2.2.1.2).

count of 503 birds (Table 4). Numbers on the Alt and North Wirral Shore had increased continuously between 1988/89 and 1990/91.

Most of the Mersey Estuary was used by feeding Curlew (Figure 1.3.16.2) with few changes noted in the last four winters. The most important areas were Stanlow Bay, Oglet Bay and mudflat 58, near Runcorn Bridge (Figures 1.3.16.3 and 1.2.1). Similarly, most of the Alt and North Wirral Shore was used by feeding Curlew with little change over the last four winters (Figure 1.3.16.3).

1.3.17 Redshank

During the winter of 1991/92, the maximum BoEE count was 4,578 birds, higher than the 1990/91 peak of 4,330 birds. The Mersey holds 5.4% of the national wintering population and 2.7% of the north-west European population (Table 1). Numbers peaked in December and February (Figure 1.3.17.1). Such fluctuations were similar to those noted during the 1990/91 BoEE counts.

The peak Mersey low tide count for this species was 3,421 birds, the lowest since 1988/89, and a large decrease from the 1990/91 winter (Table 3). The low tide numbers declined from the mid November peak to mid December before increasing again to early January. The peak low tide count for the Alt and North Wirral Shore was of 1895 birds, higher than the counts during the 1990/91 winter but slightly lower than those in the 1988/89 and 1989/90 winters.

Feeding Redshank were found over much of the Mersey Estuary (Figure 1.3.17.2) but showed some distributional changes from the 1990/91 winter. Frodsham Score was an important feeding area during the 1990/91 winter but unimportant during the 1991/92, 1988/89 and 1989/90 winters. It is possible that the cold weather of the 1990/91 winter modified the feeding distribution of the Redshank (**Rehfisch *et al.* 1991**). The mudflats at New Ferry and Mount Manisty (mudflat 33) (Figures 1.2.1 and 1.3.17.2) were used more in the winter of 1991/92 than during 1990/91. The feeding distribution on the Alt and North Wirral shore was similar to that of the 1990/91 winter but mudflats 14, 15 and 16 were more important during the 1991/92 winter (Figures 1.2.1 and 1.3.17.2). On the Mersey, during the last four winters, the most consistently important areas for feeding Redshank have been Stanlow Bay, Oglet Bay and New Ferry (Figure 1.3.17.3).

1.3.18 Turnstone

The BoEE high tide counts during the 1991/92 winter recorded only a single bird on the Mersey, in December.

The peak low tide count on the Mersey was 39 Turnstone, slightly more than in 1990/91 (Table 3). Fewer Turnstone were seen on the Alt and North Wirral Shore (487) than during the previous two winters (Table 4).

Very few Turnstone were recorded feeding on the Mersey Estuary but New Ferry and mudflat 80 were used regularly by a few individuals (Figures 1.2.1 and 1.3.18.1). The North Wirral Shore and the Alt were used more frequently. The Egremont area of the North Wirral Shore (Figure 1.2.1) was the most important area, as was the case in the 1990/91 winter.

1.3.14 Bar-tailed Godwit

The BoEE peak count for the Mersey this winter recorded 40 Bar-tailed Godwit in December, higher than the maximum count of 7 made during the 1990/91 winter.

The low tide peak count for the Mersey Estuary was 59, higher than in the previous three winters and in marked contrast to the zero count of the 1990/91 winter (Table 3). The Alt and North Wirral Shore peak count was 4,713 (Table 4) which was lower than in any of the previous three winters. The peak low tide counts on the Alt and North Wirral have shown a continuous decline since 1988/89. This decline may be related to sediment changes that have occurred on the North Wirral.

The Mersey Estuary is unimportant as a low tide feeding area but the majority of the Alt and North Wirral Shore mudflats were used, with mudflats 17 and 18 being the most important (Figure 1.3.14.1).

1.3.15 Black-tailed Godwit

The peak BoEE count of 278 birds in January 1991/92 exceeded the 247 counted in March 1991. The Mersey continues to increase in importance for this species. There were also counts of 245 in December 1991 and 200 in February 1992. The Mersey now regularly holds 2.2% of the national wintering population of this species (Table 1).

The peak BoEE high tide and low tide counts for Black-tailed Godwit roughly coincided (Figure 1.3.15.1). More Black-tailed Godwit were present on the Mersey between December and March during the 1991/92 winter than in the previous winter and it is possible that some of the birds were redistributing from other estuaries (**Kirby *et al.* 1991**).

The 1991/92 low tide maximum count on the Mersey of 411 birds was higher than in any of the previous three winters (Table 3). Like the BoEE counts, the Mersey low tide counts have shown a steady increase since 1988/89. No birds were recorded from the Alt and North Wirral Shore (Table 4). The birds arrived on the estuary in early December with numbers peaking in early to mid January and declining thereafter. The most important feeding areas were at Hale Head and Eastham (Figure 1.3.15.2).

1.3.16 Curlew

The peak BoEE count of 1,365 in March of the 1991/92 winter was lower than the 1,800 of the 1990/91 winter. The Mersey regularly held 1.6% of the national population over the last four winters (Table 1). After periods of severe cold, as experienced during the 1990/91 winter, Curlew numbers are sometimes depressed for several years (**Kirby *et al.* 1991**).

The BoEE counts showed a steady increase in numbers from late December to March (Figure 1.3.16.1), whilst the low tide counts showed a peak in early January, followed by a steady decline to March.

The peak low tide count on the Mersey during the 1991/92 winter was 1,216 (Table 3), higher than in the 1990/91 and 1988/89 winters but slightly lower than in the 1989/90 winter. The Alt and North Wirral shore showed a small decrease from 1990/91, with a maximum

1.3.19 Total birds

The areas of the Mersey Estuary most commonly used for feeding during the 1991/92 winter, by all species of birds, were in Stanlow Bay, Oglet Bay, Frodsham Score, New Ferry and the mudflats by Speke airfield (Figure 1.3.19.1). Sandier areas such as 38 and 56 (Figure 1.2.1) were used hardly at all. Ince Marsh was less important than in the 1990/91 winter. The central areas of the North Wirral shore and the outer mudflats of the Alt were important feeding areas (Figure 1.3.19.1), with greater numbers of birds on the outer mudflats than during the 1990/91 winter.

Over the last four winters, the most important feeding areas for all birds on the Mersey were Stanlow Bay, Oglet Bay and Ince Marsh (Figure 1.3.19.2).

1.4 DISCUSSION

The 1991/92 winter was the fourth consecutive winter of intensive monitoring of wildfowl and waders in Liverpool Bay. After the much colder conditions of the previous winter, 1991/92 was generally mild and similar to the winters of 1988/89 and 1989/90. Prolonged periods of foggy weather affected some of the low tide counts in December and January.

High numbers of Shelduck, Pintail, Wigeon, Teal, Dunlin and Black-tailed Godwit were recorded during the BoEE high tide counts. Conversely, the low tide counts of Dunlin and Redshank were much lower than those of the previous winter (**Rehfisch *et al.* 1991**), whilst those of Grey Plover were much higher. The numbers of birds recorded in the high tide and low tide counts, and their seasonal fluctuations, were different in most species. This can be explained by the behaviour of such species as Teal and Dunlin which feed and roost in creeks during low tide, making them very difficult to count. Dunlin can also be difficult to see at a distance, especially on mudflats when visibility is impaired by mist and poor light as was the case during the 1991/92 winter. It is also possible that a large short-term influx of birds occurred just before the BoEE mid January count.

Many species showed fluctuations in numbers during the 1991/92 BoEE counts similar to those of 1990/91, suggesting that the cold weather of that winter did not affect the birds as much as might have been expected. In both the 1990/91 and 1991/92 winters, Pintail, for example, had two peak counts, in December and in March. The national BoEE counts of Pintail also show erratic fluctuations from month to month (**Kirby *et al.* 1991**). Grey Plover numbers showed similar declines during December and January with steep increases in February over both winters. For such species as Shelduck, Curlew and Redshank, the decline in numbers during December and January was less marked in 1991/92 than in the previous winter, indicating that these species may be more susceptible to the onset of cold weather.

The distribution of birds on the Mersey was influenced by physical conditions in much the same way as previously noted (**Rehfisch *et al.* 1991**). Wigeon used mudflats and occasionally saltmarsh. Once again Shelduck were to be found on mudflats with greater exposure times allowing longer feeding periods. Curlew were found feeding over most of the estuary including the sandier parts. Redshank utilised muddier areas and, to a lesser extent, saltmarshes. Redshank numbers were highest in the middle of the estuary. Dunlin avoided very sandy areas and saltmarshes *eg* areas 38, 45 and 78 (Figure 1.2.1). Area 44 was used much less by Dunlin this winter than in 1990/91, possibly because the mudflat has become sandier over the past two years.

The overall low tide feeding distribution of most species in 1991/92 was very similar to that of the 1990/91 winter. Small scale redistribution occurred for Wigeon, Teal, Grey Plover, Black-tailed Godwit and Redshank. The change in Redshank distribution may be explained by the decrease in numbers found wintering in 1991/92 compared with the previous winter. Conversely, a wider range of mudflats was used by Black-tailed Godwit, matching the continuing increase in numbers on the Mersey. Grey Plover low tide counts were higher than in the previous winter and this was also reflected by their wider feeding distribution on the Mersey. During 1991/92, for the first time in four winters, more Grey Plover used the Mersey for feeding than the Alt and North Wirral shores (Tables 3 and 4). Although Teal numbers were similar to those in 1990/91, Oglet Bay was less important as a feeding area. Some of the changes seen this winter may be explained by changes in the rate and type of sedimentation, with associated changes in prey species and their availability.

The sandier parts of the estuary were generally least used by birds *eg* mudflats 56, 57 and 73 (Figures 1.2.1 and 1.3.19.1). During the 1991/92 winter, the Ince saltmarsh was far less important as a feeding area than during the 1990/91 winter (Figure 1.3.19.1). Mudflats 76 and 77 (Figure 1.2.1) were both important for three winters but unfortunately there were no data for the 1990/91 winter. The most utilized areas were the same as last winter; Stanlow Bay, Oglet and to a lesser degree, Frodsham Score (Figure 1.3.19.2). Ince marshes is classed as frequently important but was used only by four species.

Generally, the areas most important to all species collectively on the Mersey are also those that are most regularly used by all individual species.

The proposed tidal barrage would shorten the immersion period of the Mersey Estuary mudflats by varying amounts (from 35% to 58%), depending on their distance from the barrage and the tidal state (**MBC 1992**). Generally the nearer a mudflat to the barrage, the greater the reduction in immersion time of the mudflat. The immersion period of the mudflats near New Ferry, Garston, Speke airfield, and Eastham would be reduced post-barrage, as would be the immersion periods of the outer mudflats of Oglet Bay and Stanlow Bay. The reduction in immersion time is lessened up the estuary, away from the barrage, towards Runcorn Bridge and beyond.

The effect of the barrage would vary with each bird species and be linked closely to the preferred feeding areas of the birds. Shelduck feed on mudflats with greater exposure times (Figure 1.3.1.3) and would be affected less than most other species. The main loss of Teal feeding areas would occur near Speke airfield and New Ferry (Figure 1.3.2.3). Many of the mudflats used most regularly by feeding Pintail, at New Ferry, Garston, Speke and Eastham (Figure 1.3.5.3), would have greatly reduced immersion times post-barrage. Grey Plover would have reduced feeding times on the Eastham, outer Oglet Bay and outer Stanlow Bay mudflats (Figure 1.3.9.3). Dunlin would lose a few important feeding areas in Stanlow and Oglet Bays (Figure 1.3.13.3). Curlew would lose many important feeding areas (Figure 1.3.16.3), because it is distributed, at low densities, over most mudflats, including the outer sandier mudflats that are most likely to be flooded by a barrage (Figure 1.3.16.3). New Ferry and some of the outer Stanlow Bay mudflats would be the most important areas partially lost to feeding Redshank (Figure 1.3.17.3). When all species are considered, the reduced feeding times at New Ferry, near Speke airfield, and in the outer Stanlow and Oglet

Bay mudflats, would have the most impact in potentially limiting the number of birds that the Mersey Estuary can support.

SECTION 2

DIURNAL AND NOCTURNAL DISTRIBUTION AND FEEDING ACTIVITY OF WATERFOWL ON THE MERSEY

2.1 INTRODUCTION

When day-length is short, waders wintering in north-west Europe feed for most of the daytime low water periods **(Goss-Custard *et al.* 1977a; Baker 1981)**. At high tide,some species may continue feeding in fields **(Goss-Custard 1969; Hepplestone 1971; Townshend 1981; Goss-Custard & Durell 1984)**. In temperate zones daytime feeding periods can be restricted to 8-9 hours in mid-winter increasing to 14 hours by the end of March, so the shortest available times for diurnal feeding are often during cold weather when the birds have higher metabolic requirements.

To make up for any short-fall in food intake birds may have to feed at night. Studying the nocturnal behaviour of waterfowl is thus essential to any understanding of the way birds use an environment, yet little work has been done on the duration of nocturnal feeding. **Wood (1983)** found that Grey Plover could not fulfil their metabolic requirements by feeding only during the day and observed these birds on their feeding areas at night **(Wood 1986)**. In winter Curlew have been seen in similar numbers at night as in the day on the intertidal mudflats of the Dutch Wadden Sea, though in the summer most birds fed only by day **(Zwarts *et al.* 1990)**. Other studies have found similar seasonal variations **(Goss-Custard 1969; Heppleston 1971; Pienkowski 1982)**. Nocturnal feeding of Grey Plover, Dunlin, Knot and Bar-tailed Godwits can increase as the winter progresses, as birds become more likely to feed on dark nights **(Zwarts *et al.* 1990)**. The amount of nocturnal feeding has been related to the state of the moon with increased feeding on moonlit nights **(Zwarts *et al.* 1990)**, as visually hunting predators are helped by a certain amount of light. This increase in feeding according to light conditions has been demonstrated by the large numbers of Bewick Swans at Slimbridge which continue feeding at night under artificial light **(Hill 1990)**.

The energy requirements of birds vary seasonally. For example, in spring birds have increased metabolic requirements as they prepare for migration. In some cases the increased requirements of the birds coincide with increased prey activity, allowing an increased prey uptake and thus necessary pre-migration fattening **(Zwarts 1990)**. Some waders are restricted in their intake rates by the need for digestive pauses when feeding on prey that have a large indigestible component **(Zwarts & Dirksen 1990)**. Generally, the prey are less completely digested as intake rate increases **(Zwarts & Blomert 1990)**, so when food is scarce in winter birds may extract a higher energy yield from the available food.

The strategies employed by waterfowl to fulfil their metabolic requirements are as yet imperfectly understood but a better understanding of the diurnal and nocturnal feeding ecology of the Mersey waterfowl is emerging after several years of study **(Clark *et al.* 1990c; Rehfisch *et al.* 1991)**. The 1991/92 winter has seen a continuation of past work, and the results are presented here.

The 1991/92 winter provided the opportunity for a third winter of night-time monitoring of the feeding behaviour and distribution of waterfowl on the Mersey mudflats. Oglet Bay was chosen as the main site for nocturnal observations, as work carried out during the two previous winters had shown that Stanlow Bay was too large to allow optimal usage of an image intensifier and that Oglet Bay held larger bird populations and was more representative than New Ferry.

From the 1990/91 winter it had become apparent that the western end of Stanlow Bay, the area near Mount Manisty, was important for several bird species, in particular Teal, Pintail and roosting Redshank. Observations were therefore made at Mount Manisty, throughout the tidal cycle, both day and night, to further the understanding of the ecology of these species on the Mersey.

Whenever reference is made to the 1988/89 winter the figures can be found in **Clark *et al.* (1990c)**, figures for the 1989/90 winter can be found in **Clark *et al.* (1990b)**, and figures for the 1990/91 winter in **Rehfisch *et al.* (1991)**.

2.2 DATA COLLECTION, PRESENTATION AND ANALYSIS

The data presented here are for the commoner species: Shelduck, Wigeon, Teal, Pintail, Grey Plover, Dunlin, Knot, Black-tailed Godwit, Curlew and Redshank. This section of the report fulfils objectives 2 and 3 of the phase IIIA ornithological studies relating to the Mersey Barrage. Objective 2 required the continuation of long-term monitoring throughout the tidal cycle at selected sites around the Mersey, and objective 3 the continuation of night-time monitoring at selected sites to assess the between-year variability in night time activity patterns.

2.2.1 Data collection - all-day counts

2.2.1.1 Diurnal

Four Mersey sites were chosen for intensive counting during the hours of daylight. All-day study sites at Stanlow (Figure 2.2.1.1), Oglet (Figure 2.2.1.2), Mount Manisty (Figure 2.2.1.3) and New Ferry (Figure 2.2.1.4) were counted every hour by BTO staff from dawn to dusk. Counts were made at approximately fortnightly intervals at Stanlow and Oglet. From November to February all-day counts were carried out whenever time permitted at Mount Manisty, a new site chosen primarily because of its importance to wildfowl. Four all-day counts were carried out at New Ferry in January and February.

Each of these four all-day study sites was divided into several all-day count areas. These areas were smaller than the low tide count areas. This allowed a more precise analysis of the changes between winters of the numbers and behaviour of feeding and roosting birds. The dates of the counts were chosen to cover as much of the whole tidal cycle each month as possible (Table 5). The counts were made from single vantage points at each site.

2.2.1.2 Nocturnal

All night data were collected at the Oglet (Figure 2.2.1.2) and the Mount Manisty (Figure 2.2.1.3) all-day sites. Night-time counts at Oglet were monthly and took two hours to complete because the observer had to walk most of the length of the bay to cover the area properly at night. Otherwise the methods were like those used for the all-day counts (Section 2.2.1.1). All night data were collected in December, January and February from Mount Manisty for the first time. The counts took an hour to complete and were made from a hide on the saltmarsh to compensate for the lessened magnification of the image-intensifier (Figure 2.2.1.3: Area 5). All the areas counted in daylight could be counted from the hide at night.

Night-time counts were carried out using an image intensifier fitted with a catadiopteric Nikkor 500/f8 lens or a Nikkor 300/f4.5 lens, depending on the light conditions. On dark overcast nights the 300mm lens was used because it has greater light gathering powers. The 500mm lens magnified the object 9.1 times, the 300mm lens 5.5 times. The telescopes used for the daytime counts magnified between 20 and 40 times. It was thus to be expected that the outer mudflats would not be counted as well at night as during the day.

Areas with dark, non-reflective substrata made nocturnal bird counts more difficult. Small, dark, roosting or infrequently moving birds were difficult to pick up at night. Large, white Shelduck were more easily seen than small, grey Dunlin. Moonlit nights improved the quality of image intensifier counts, though night-time counts are still likely to have underestimated the bird population present on the mudflats relative to day-time counts. This is particularly true for birds on the outer mudflats. The large variances observed in the numbers of feeding birds of some species was a reflection of the two-hourly nature of the counts and the potentially large differences in the number of birds seen feeding on different nights (*eg* Figure 2.3.3.1).

2.2.2 Data analysis - all-day counts

2.2.2.1 Diurnal

The average numbers of waterfowl feeding on each of the all-day count mudflats were compared between the years of available data. The averages represent the total number of bird hours spent feeding on each of the intertidal areas and were calculated using:

$$\text{Usage} = \sum_{t=-6}^{t=+5} (A \times B)$$

Where:
t = hours from low tide
A = average number of birds feeding at time t when area is exposed
B = proportion of counts when area is exposed at time t.

Thus an area that was used by large numbers when it was exposed but which was only briefly exposed will have a low score, as will an area that was used by small numbers but which was exposed for long periods.

These average numbers of the commoner birds found in the Mersey estuary and the percentage feeding at the all-day sites were represented graphically in relation to the state of the tide (*eg* Figure 2.3.1.1). Note that in these figures, six hours before low tide is the same as six hours after. The distribution of the birds over the winter in the Stanlow and Oglet all-day sites are also represented graphically (*eg* Figures 2.3.1.2 and 2.3.1.3).

The numbers and feeding frequencies during the day were compared between the winters of 1988/89, 1990/91 and 1991/92; the data from the 1989/90 winter were analysed differently **(Clark *et al.* 1990c)**.

2.2.2.2 Nocturnal

The night-time data were analysed in the same way as the data from the all-day counts (Section 2.2.2.1). Both the total numbers and the percentage feeding of the most common bird species found at night on the Mersey were represented graphically (*eg* Figure 2.3.1.1). The nocturnal distribution of the birds over the all-day mudflats was mapped for Oglet (*eg* Figure 2.3.1.3) and Mount Manisty (*eg* Figure 2.3.3.2).

Comparisons were made of the numbers of birds and the frequency of nocturnal feeding at Oglet between the winters of 1989/90, 1990/91 and 1991/92.

Comparisons were also made between the diurnal and nocturnal distributions of the birds at both Oglet and Mount Manisty. At the latter, this comparison was repeated after dividing the data into that gathered during spring and neap tides.

Only major differences in the day and night distributions of birds were noted, as night-time counts were more likely to underestimate the actual bird population present on the mudflats than day-time counts due to the problems of visibility (Section 2.2.1.2).

2.3 RESULTS

2.3.1 Shelduck

By day, the largest numbers of feeding Shelduck were seen one or two hours before low tide at both Stanlow and Oglet (Figure 2.3.1.1). Over 80% of Shelduck fed from 4 hours before to 1 hour after low tide, with over 90% feeding from 3 to 1 hours before low tide. There was a gradual decline in feeding numbers on the rising tide. Birds sometimes moved away from both areas over high tide, preferring to roost elsewhere. In both areas, numbers of birds began to increase 5 hours before low tide but feeding activity decreased, possibly due to birds arriving from their roosting areas and waiting for the water levels to drop before commencing feeding.

At night in Oglet Bay there was a large variation in the number of feeding Shelduck. Numbers increased from 6 hours before low tide to peak 2 hours before low tide, thereafter showing a gradual decline towards high tide (Figure 2.3.1.1). Most Shelduck fed on the receding tide, with 80% or more of the birds feeding 2 hours either side of low tide.

At Stanlow the diurnal feeding distribution of Shelduck was very similar during the 1991/92 winter to that recorded the previous winter (Figure 2.3.1.2) though channel 21 held fewer Shelduck than the previous year. This channel area was accreting sediments rapidly over the 1990/91 winter and by the 1991/92 winter it had become very similar in character to the surrounding mudflats. Over the four winters of counts, Shelduck at Stanlow have always been present in greater numbers in the inner parts of the bay, in areas 11, 13, 14, 15 and 20.

During the day Oglet held fewer Shelduck than were seen the previous 1990/91 winter (Figure 2.3.1.3). The inner bay areas preferred during the 1990/91 winter were still extensively used but the numbers using the outer mudflats declined. There was an increase in the use made of channel 51 in 1991/92. Over the four winters of counts carried out at Oglet Shelduck have shown a continued preference for the inner parts of the bay.

The day and night distributions of Shelduck at Oglet were very similar (Figure 2.3.1.3), though fewer birds were seen at night, possibly a reflection of the low magnification of the image intensifier. At night, more Shelduck were seen feeding in the 1991/92 winter (Figure 2.3.1.3) than in 1990/91. This increase was most noticeable in areas 54, 63, 65 and 66. This increase in night-feeding may be due to the milder prevailing conditions of the 1991/92 winter making feeding more profitable (***cf.* Rehfisch *et al.* 1991**). Fewer Shelduck were seen feeding during the 1989/90 winter at night.

Summary: Shelduck fed during most of the day, though less on rising tides. Feeding at night was also mainly on the receding tide. During the 1991/92 winter more birds were present at Stanlow by day, while at Oglet fewer birds fed by day and more by night than in the 1990/91 winter. Over the last four winters Shelduck preferred the inner parts of the Stanlow and Oglet bays for feeding.

2.3.2 Wigeon

During the day (Figure 2.3.2.1) the numbers of Wigeon using Stanlow showed a slight decrease over the 1990/91 winter. The majority of the birds used the area for loafing or roosting. Feeding activity peaked just before and during high tide declining rapidly thereafter, unlike the 1990/91 winter when most feeding took place on the receding tide.

A few Wigeon were seen during the day in Oglet Bay but none was seen at night.

The distribution at Stanlow was similar to that of the previous winter, with the majority of Wigeon keeping to the Ince Bank (Figure 2.3.3.2). Only very small numbers used mudflat area 25 compared to the previous winter.

2.3.3 Teal

Large numbers of Teal fed during the day at Stanlow. The highest proportions of feeding birds were found over the high tide period (Figure 2.3.3.1), and the lowest proportions around low tide. Over high tide Teal could be hard to see, moving into channels or up the River Gowy making precise behavioural observations difficult. During the 1991/92 winter fewer Teal were seen during the day at Stanlow than in the previous 1990/91 winter. In 1991/92 Teal numbers declined from 4 hours before to 3 hours after low tide; by comparison, during the previous winter numbers were much more constant throughout the tidal cycle and a greater proportion of the birds fed over low water. The colder weather of the 1990/91 winter may have necessitated longer periods of feeding. The 1988/89 winter was similar to 1991/92, with no sustained cold period but the percentage of feeding Teal remained higher over the entire tidal cycle. Hence there would appear to be a gradual decline in the importance of Stanlow as a feeding area.

Large numbers of Teal fed during the day at Oglet. The highest proportions of feeding birds were found over the high tide period and the lowest proportions around low tide (Figure 2.3.3.1). The numbers of Teal using Oglet by day (Figure 2.3.3.1) were similar to those seen in 1990/91 but higher than the numbers seen in 1988/89. Peak numbers of Teal occurred 2 hours either side of low tide, as in the previous 3 winters, with the majority of birds roosting or loafing. Numbers of Teal using Oglet at night were similar to those of 1989/90 but slightly up on 1990/91. As Teal numbers dropped on the receding tide at Stanlow, an increase was noted at Oglet. There was a similar relationship during the 1990/91 winter but this did not occur during the 1988/89 winter. It is probable that there is an interchange between Stanlow and Oglet, Stanlow being important for roosting birds, especially on higher tides when Oglet is completely covered.

Observations made at night at Oglet revealed fewer Teal than by day (Figure 2.3.3.1). The large numerical fluctuations reflect the less frequent counting at night.

During the day very few Teal were seen over low tide at Mount Manisty, though numbers increased on the rising tide (Figure 2.3.3.2). On spring tides feeding occurred over much of the high tide period as the saltmarsh became partly flooded (Figure 2.3.3.3). On neap tides, after some initial feeding activity towards high tide, the birds tended to roost in channels and became hard to see, or else they flew away. Mount Manisty, similarly to Stanlow, could be more important as a roosting site, with an interchange of Teal with Oglet Bay.

Observations made at night at Mount Manisty revealed fewer birds than during the day (Figures 2.3.3.2 and 2.3.3.3) but, as in the day, the largest Teal numbers were present and fed at or near high tide.

At New Ferry maximum Teal numbers were present from low tide to 2 hours after (Figure 2.3.3.1). Teal tended to roost elsewhere on the estuary over high tide, at such sites as Bromborough and possibly Stanlow (**Rehfisch *et al.* 1991**), possibly to escape disturbance.

Teal distributed themselves very thinly and evenly at Stanlow in the 1991/92 winter (Figure 2.3.3.4), unlike the previous two winters of 1989/90 and 1990/91 when feeding Teal were more common in areas 11, 14, 15 and 20. More Teal used the then more pronounced channel areas 21 and 22, and mudflat 16, during the 1988/89 winter.

At Oglet Teal continued to prefer the inner parts of the bay, including the channel 51 and 61, and mudflat 62, for feeding (Figure 2.3.3.5), as they have done over the four winters of study. Teal distributed themselves sparsely over the outer mudflats. The nocturnal distribution of Teal revealed more birds feeding on mudflats 63, 65 and 66. These are areas that are more prone to disturbance by humans and dogs during the day. This increased use of these areas by night had not been previously recognised.

By day at Mount Manisty most feeding Teal were found in channel 4 (Figure 2.3.3.6). The birds also used this area to roost in large numbers (Figure 2.3.3.7). At night small numbers of Teal fed and roosted in most parts of the Mount Manisty site (Figures 2.3.3.6 and 2.3.3.7).

At New Ferry Teal were mainly found in the southernmost areas 8, 9 and 10 (Figure 2.3.3.8).

Summary: Teal used both Stanlow and Oglet in large numbers. Although some feeding occurred over most of the tidal cycle, feeding activity peaked around high tide. It would appear that Stanlow may be particularly important for roosting Teal and that there may be some interchange between Stanlow, Mount Manisty and Oglet. At Oglet, Teal fed more on some mudflats at night than they did during the day, potentially a reflection of human disturbance. Mount Manisty was particularly important for feeding Teal over high tide. Teal at New Ferry fed more on the rising tide with numbers being highest at low water.

2.3.4 Pintail

In 1991/92 peak numbers were recorded at Stanlow on receding tides (Figure 2.3.4.1). Fewer Pintail were counted than during the previous winter when the feeding distribution was more even across the tidal range. Prior to 1990/91 Stanlow was not important for feeding and was only used by small numbers of roosting and loafing birds.

Although Oglet is not important for the Mersey Pintail population more birds were seen during the day than the previous 1990/91 winter (Figure 2.3.4.1). Peak feeding activity occurred from before low tide to 2 hours before high tide; by comparison, during the colder 1990/91 winter the greatest percentage feeding activity was on the receding tide, with the majority of duck roosting from just before low tide to high tide. Very few Pintail were seen at night at Oglet.

Observations made at Mount Manisty showed that Pintail moved up the shore on the rising tide feeding *en-route* (Figure 2.3.4.2). On spring tides, when the saltmarsh was flooded, they fed over the high tide period, but on neap tides more Pintail roosted on the mudflats at high tide (Figure 2.3.4.3). Once the tide began to recede Pintail gradually left the area. Pintail seemed to arrive and leave Mount Manisty at the same stages of the tidal cycle by night as by day, though fewer birds were seen (Figure 2.3.4.2).

New Ferry is important to Pintail over most of the tidal cycle (Figure 2.3.4.1). Many of the birds disappeared at high tide (especially on spring tides), possibly roosting on the estuary itself or moving onto the Stanlow saltmarshes. It is possible that disturbance over high tide during the day caused the duck to seek alternative roosting areas. Peak feeding activity was around low tide.

There was little significant change in distribution at Stanlow between 1990/91 and 1991/92 although areas 13, 19 and 23 were not used in 1991/92 and conversely mudflat 17 was occasionally used (Figure 2.3.4.4). As in preceding years, few Pintail were found feeding at Oglet (Figure 2.3.4.5).

During the day at Mount Manisty most Pintail fed in areas 2, 3, 4 and especially 1 (Figure 2.3.4.6). The latter area, saltmarsh, was particularly used during high spring tides when it flooded. The other areas would flood on lower tides and were then used by a few feeding birds. Pintail would roost in large numbers in areas 3 and 6 (Figure 2.3.4.7). These roosts would form towards high tide, and be the precursors to intensive feeding in saltmarsh area 1 on spring tides. On neap tides most birds would roost waiting for the estuarine mudflats to become exposed on the receding tide. At night many fewer birds were seen feeding or roosting than during the day (Figures 2.3.4.6 and 2.3.4.7).

Pintail at New Ferry would feed during the day by following the tide, showing a preference for areas 3, 6, 8 and 9 (Figure 2.3.4.8). Pintail were less widely distributed at New Ferry during the 1991/92 winter than in the 1988/89 winter but this may be linked to changes in invertebrate distributions that might have occurred over the period, as a result of an oil spill that occurred in the area in August 1989 **(Clark *et al.* 1990a).**

Summary: New Ferry and Mount Manisty were the two most important all-day sites for Pintail. Pintail fed in especially large numbers at Mount Manisty around high tide, especially on spring tides, when the saltmarsh flooded. At New Ferry Pintail concentrated their feeding around low tide. Stanlow held more Pintail than Oglet by day.

2.3.5 Grey Plover

The number of Grey Plover recorded at Oglet and Stanlow showed little change from the previous winter (Figure 2.3.5.1). The numbers were fairly constant at both sites throughout most of the tidal cycle. At Stanlow numbers were lowest either side of high tide, as birds moved elsewhere or roosted in places where they were hard to see. Over 85% of the birds fed between 5 hours before and 3 hours after low tide. The birds fed for longer on rising tides than during the cold 1990/91 and the milder 1988/89 winters.

At Oglet most Grey Plover were present 4 hours either side of low tide, many roosting elsewhere at high tide (Figure 2.3.5.1). Over 90% of birds present fed throughout the tidal cycle.

A small increase in the numbers of Grey Plover at Oglet at night was noted over the 2 previous winters (Figure 2.3.5.1).

The distribution of Grey Plover at both Stanlow (Figure 2.3.5.2) and Oglet (Figure 2.3.5.3) showed little change from those of previous years.

Summary: Grey Plover fed intensively over most of the tidal cycle at both Stanlow and Oglet, although numbers decreased markedly over the high tide period. The Stanlow birds fed for longer on rising tides than in 1990/91. There was little change in the distribution of Grey Plover at Stanlow and Oglet over the last 4 winters. Very few birds were seen feeding at night at Oglet.

2.3.6 Knot

Most Knot were seen at Stanlow on the receding tide and were always feeding (Figure 2.3.6.1).

Knot were present in very variable numbers at Oglet (Figure 2.3.6.1), with most feeding occurring on the rising tide. Only a few individuals were seen at night.

New Ferry was the all-day site with the greatest Knot populations (Figure 2.3.6.1). Numbers were greatest on the rising tide, with over 80% of the birds feeding through most of the tidal cycle.

The preferred feeding areas of Knot at New Ferry this 1991/92 winter (Figure 2.3.6.2) were similar to those as most used during the 1988/89 winter, though fewer birds were seen in areas 8, 9 and 10.

2.3.7 Dunlin

At Stanlow over 75% of Dunlin fed throughout the tidal cycle (Figure 2.3.7.1). The percentage feeding on the rising tide did not decline, unlike the cold 1990/91 winter when mudflats froze. Dunlin numbers peaked at low water. Thereafter numbers tended to decline, implying that feeding conditions might not be as favourable on the rising tide or were more favourable elsewhere. Very few birds were present over the high tide period, leaving to find suitable roosting areas elsewhere on the Mersey *eg* on the Frodsham Score.

At Oglet over 85% of Dunlin present fed over the entire tidal range (Figure 2.3.7.1), again a slight increase over the 1990/91 winter. The highest numbers of Dunlin were found 4 hours either side of low tide, similarly to Stanlow where most Dunlin left the site near high tide to roost elsewhere.

The numbers of Dunlin recorded at night at Oglet were lower than during the day (Figure 2.3.7.1), with the highest counts on receding tides. At high tide the birds were closer to the observation points and therefore more easily seen. After low tide numbers declined rapidly. This was as the birds left to roost or else moved to outer mudflats, where they were very hard to locate with the image intensifier, to continue feeding.

At Stanlow (Figure 2.3.7.2) Dunlin numbers were similar to those of the 1988/89 and 1989/90 winters, but more birds were present during the colder 1990/91 winter. Less use was made of mudflats 23 and 24 than in the previous 1990/91 winter, this coinciding in a substrate change towards sandier sediments.

At Oglet (Figure 2.3.7.3) there was little change between 1990/91 and 1991/92 in Dunlin distributions; in both of those years more mudflats were used than during the previous two winters. Though fewer Dunlin were recorded at night, the day and night distributions were broadly comparable.

Summary: Dunlin numbers were lower at both Stanlow and Oglet during the 1991/92 winter than in the previous winter. Dunlin fed through most of the tidal cycle. Actual numbers of birds declined markedly at high tide as they left the areas to roost elsewhere on the estuary. At Stanlow some birds departed immediately after low tide, as in the 1990/91 winter, implying that feeding conditions might not be as favourable on the rising tide. Many fewer birds were seen at night than during the day at Oglet, though the day and night distributions at Oglet remained similar.

2.3.8 Black-Tailed Godwit

A few Black-tailed Godwits were seen at Stanlow (Figures 2.3.8.1 and 2.3.8.2).

The increase in numbers noted on the Mersey estuary over the last two winters continued, with Oglet Bay, once again, proving an important area (Figure 2.3.8.1). The numbers of birds increased towards high tide as the godwits arrived from other parts of the estuary. Oglet was used mainly as a high tide roost, though high percentages of birds would sometimes feed either side of high tide. During the previous 1990/91 winter Black-tailed Godwits had been seen feeding in greater numbers on the receding tide. So few birds were recorded at Oglet at night that comparison with daytime data was not possible.

During the day at Oglet Black-Tailed Godwits fed on fewer mudflats during the 1991/92 winter than during the 1990/91 winter (Figure 2.3.8.3). The main channel, areas 51 and 61, running through Oglet was most heavily used. These birds were seen only on one mudflat at night (Figure 2.3.8.3).

Summary: Black-tailed Godwit numbers were relatively high for a second consecutive winter, with the birds concentrating in Oglet Bay, especially at high-tide.

2.3.9 Curlew

At Stanlow Curlew numbers remained fairly constant over the tidal cycle with peak numbers 2 hours after low tide (Figure 2.3.9.1). There was a slight decline in numbers over the high tide period. Almost all Curlew fed from 4 hours before to 3 hours after low tide. The decline in numbers from 4 hours before low tide to high tide noted during the 1990/91 winter was not repeated this winter. A greater proportion of birds fed either side of low tide than in 1990/91, thus resembling the 1989/90 winter. It is possible that the colder weather experienced during 1990/91 may have influenced the feeding efficiency and behaviour of the birds (**Rehfisch *et al.* 1991**). The numbers of birds recorded at Stanlow during the 1991/92 winter were broadly similar to those found during the 1988/89 and 1990/91 winters.

At Oglet numbers of Curlew remained fairly constant during the day (Figure 2.3.9.1), except at high tide, when Curlew moved off to roost or were seen to continue feeding in the fields surrounding Oglet Bay. The greatest percentage of birds fed 4 hours either side of low tide. Fewer Curlew used Oglet than in the 1990/91 winter.

More Curlew fed at night at Oglet (Figure 2.3.9.1) than during the 1990/91 winter, the numbers being closer to those found during the 1989/90 winter, another mild winter. It is probable that the cold weather of 1990/91 made feeding difficult with invertebrates remaining deeper in the mud and the birds choosing to roost rather than feed at night. The greatest feeding activity during the 1991/92 winter was from 3 hours before to 2 hours after low tide with fewer birds feeding over the high tide period.

Since 1989/90 the distribution of birds at Stanlow has changed slightly as the degree of sandiness has altered some of the mudflats (Figure 2.3.9.2). The areas 18, 19 and 25 were used much more extensively than in previous winters. Curlew have been found to be present on most mudflats over the four winters of data collection.

At Oglet the distribution of Curlew has not changed significantly over the last 4 winters (Figure 2.3.9.3). At night more Curlew were seen feeding in areas 65 and 66 this 1991/92 winter than in the 1990/91 winter.

Summary: Curlew numbers at Stanlow and Oglet remained fairly constant over most of the tidal cycle, only declining over the high tide period. A greater proportion of the birds fed from 2 to 4 hours after low tide than in the cold 1990/91 winter. There was little difference in the day and night Curlew distributions at Oglet. Some changes in mudflat usage have occurred at Stanlow since 1989/90, and may reflect changes in mudflat sediments.

2.3.10 Redshank

In 1991/92 the numbers of Redshank at Stanlow and Oglet were half those recorded the previous winter, Stanlow showing the greatest decrease (Figure 2.3.10.1). Numbers remained fairly constant at Stanlow from 1 to 4 hours before low tide, before dropping rapidly on the rising tide as the birds moved into the saltmarsh or left for other areas of the estuary. The percentage of feeding activity remained at over 90% from 5 hours before to 3 hours after low tide. Redshank numbers were more stable from 2 hours after low tide during the 1990/91 winter, though the percentage of feeding birds remained high for longer on the rising tides during the 1991/92 winter.

At Oglet the greatest numbers of Redshank were found 4 hours either side of low tide (Figure 2.3.10.1). Over 80% of the birds fed actively from 4 hours before to 3 hours after low tide. This is broadly comparable to 1990/91, although during that winter more feeding took place on the receding tide. Small numbers of Redshank were present at high tide.

The night counts at Oglet (Figure 2.3.10.1) showed that over 90% of Redshank fed 4 hours either side of low tide and that the numbers of birds seen declined on the rising tide. There was a similar pattern in the change in bird numbers and percentages feeding in the 1989/90 winter. The 1990/91 winter also recorded high percentages of feeding birds around low tide, but very erratic bird numbers. In all 3 winters, similar bird numbers were found during the day and at night.

All-day observations at Mount Manisty (Figure 2.3.10.2) showed that the area is important for feeding from 4 hours before to 1 hour after low tide. Numbers of Redshank were greatest at high tide, partly because of birds seen flying in from the Stanlow mudflats to roost. Manisty is particularly important for roosting Redshank on spring tides when other roosting sites are flooded (Figure 2.3.10.3).

There were few Redshank at night at Mount Manisty and little feeding activity except for 2 hours either side of high tide, when some arrived to roost (Figures 2.3.10.2 and 2.3.10.3). In this respect there was little difference between spring and neap tides.

The daytime distributions of Redshank at Stanlow (Figure 2.3.10.4 MAP) and Oglet (Figure 2.3.10.5) were broadly similar to those of the previous 3 winters, though more birds used the outer mudflats at Oglet during the 1991/92 winter. At both sites the higher mudflats were used by more birds. The nocturnal distribution of Redshank was similar to that found during the day.

During the day most Redshank fed in areas 2, 3 and 7 of Mount Manisty, areas of open mudflats (Figure 2.3.10.6). The roosting Redshank preferred area 4, where they would form dense flocks along the sides of the main channel (Figure 2.3.10.7). At night fewer Redshank were seen and, unlike during the day, the birds present seemed to roost and feed in the same areas, 3, 4 and 6 (Figures 2.3.10.6 and 2.3.10.7).

Summary: Redshank numbers at Stanlow were highest on the receding tide. Fewer Redshank used Oglet during the 1991/92 winter than in the 1988/89 and 1990/91 winters. At Oglet the maximum feeding activity was 4 hours either side of low tide with a decline in numbers at high tide. Numbers at night at Oglet were comparable to 1990/91 with the greatest feeding activity 4 hours either side of low tide. Similar numbers of feeding Redshank were found during the day and at night. There was little change in the daytime distribution at Stanlow or Oglet, but more of the outer mudflats were used at night at Oglet than in previous winters. The inner bay mudflats were used by the greatest numbers of feeding birds. The distribution of Redshank over the Oglet mudflats did not vary between day and night.

During the day Mount Manisty was particularly important as a spring tide roosting area for Redshank, though a some birds fed there, especially on neap tides. At night the area was also used as a roosting site.

2.4 DISCUSSION

The 1991/92 winter saw a continuation of the intensive field surveys started during the 1989/90 winter, which compared the day and night distributions of wildfowl and waders on the Mersey. This was the third mild winter since the start of the Mersey studies, the 1990/91 winter having been much colder.

Most waterfowl species fed through most of the tidal cycle. Teal and Pintail were more selective. During the 1991/92 winter Teal were seen to feed more on the rising tide at New Ferry. There was also evidence of Teal movements from Stanlow and Mount Manisty to Oglet. Teal fed in parts of Stanlow and more especially Mount Manisty at high tide. Teal would be present in particularly large numbers when the saltmarsh around Mount Manisty flooded during spring tides. On neap tides Teal would also feed, by following the water's edge, in saltmarsh channels. The duck would then move to Oglet, and possibly New Ferry, to feed over the low tide period. Many fewer Teal were present at night at Mount Manisty.

Pintail fed actively around low tide at New Ferry and on spring tides at Mount Manisty. On neap tides Pintail roosted at Mount Manisty. Pintail, like Teal, would converge on Mount Manisty at high tide. On spring tides Pintail would feed on the flooded saltmarsh, on neap tides smaller numbers would feed in the channels while waiting to regain estuarine mudflats on the receding tide. At night Pintail numbers were smaller.

Both Teal and Pintail fed mainly on mudflats rather than saltmarsh, confirming that they are mainly feeding on invertebrates as the mudflats hold very few seeds **(A. Jemmett pers. comm.)**.

The previous 1990/91 winter was colder than this winter. Some birds showed behavioural changes that could be linked to this climatic change. During the 1991/92 winter Grey Plover, Dunlin, Curlew and Redshank fed for longer on the rising tide, while Shelduck and Curlew fed for longer at night. As the metabolic requirements of the birds should be higher during a cold winter, the shorter period spent feeding during the day in 1990/91 is probably a result of conditions which did not make made feeding energetically worthwhile. Teal fed more intensively throughout the tidal cycle during the 1990/91 winter. They would appear to be the only species studied on the Mersey that was able to increase their feeding time to compensate for the colder weather conditions of that winter. This difference in behaviour may be due to the prey of Teal being different to that of the other species and less affected by the cold. Many invertebrates bury themselves more deeply in cold conditions and become less available to birds. It is possible that the Teal feed on very small species of invertebrate that do not escape effectively by deeper burrowing.

Redshank were seen feeding in similar numbers by day and by night. Redshank fed and roosted in different sections of Mount Manisty during the day, but at night they roosted where they had fed. This may be due to the lessened risk of predator attack at night. The behaviour of Teal at Oglet also changed at night. Some mudflats that were very commonly used at night were much less frequently used during the day. These mudflats are close to the "Mersey Way", a public footpath, which is regularly used by walkers, joggers and dogs during the day. It is likely that it is this human-related disturbance which stops the Teal feeding on these mudflats during the day. Human activity is known to cause disturbance in birds **(Forshaw 1983; Belanger & Bedard 1989; Rehfisch *et al.* 1991; Kenney & Knight 1992)**.

Shelduck, Teal and Redshank concentrated on the open mudflats closest to land, often mudflats with a lesser immersion time. This could be related to invertebrate distributions as Teal are known to select preferred habitats immediately upon post-migration arrival **(Evans & Dugan 1984)** and many birds distribute themselves according to the density of their prey **(Goss-Custard *et al.* 1977b)**. This could also be related to predator avoidance, though this seems unlikely as these mudflats closer to land are more open to a surprise attack by aerial predators, though this may be counter-balanced by the nearness of cover.

Shelduck, Dunlin and Curlew distributions showed changes that could be attributable to sediment movements. Sediment type and bird distributions have been found to be closely linked **(Prater 1972; Tjallingii 1972; Rands & Barkham 1981; Clark 1983; Kelsey & Hassall 1989)**. Dunlin are known to select areas with a higher proportion of silt and clay and also prefer estuaries with softer muds **(McCulloch & Clark 1992)**, the physical structure of sediments can determine their suitability as habitats for prey organisms, and it is the prey and the ease with which they can be harvested which determines the value of particular sediments to birds **(Wolff 1969; Evans 1976; Goss-Custard *et al.* 1988)**. Substrate penetrability can be important, as very solid, densely packed sediments make it difficult for the foraging bird to insert its bill **(McCulloch & Clark 1992)**.

Curlew and Redshank were the most widespread species in the estuary, being found in small numbers on most of the all-day mudflats. This may be due to inter- and intra-specific competition or to disturbance **(Goss-Custard 1977)**.

SECTION 3

PINTAIL AND TEAL MOVEMENTS WITHIN THE MERSEY

3.1 INTRODUCTION

After two years of intensive monitoring of the Mersey waterfowl, it had become clear that the estuary held large numbers of both Pintail and Teal during the day **(Clark *et al.* 1990b, 1990c)**. How the ducks used the estuary at night was not known, as only some Teal and very few Pintail had been observed by night. In the context of the proposed tidal barrage it was necessary to know, for both Teal and Pintail, if the Mersey Estuary was just used as a safe day-time roost, or whether the intertidal areas of the estuary were essential to the feeding of these ducks.

During the 1990/91 winter, a sample of Teal was radio-tagged and their movements analysed **(Rehfisch *et al.* 1991)**. These tagged birds used the estuary differently at high and low tides, during cold and warm periods, and at night and during the day. In 1990/91 Pintail proved to be very difficult to catch. The five birds caught and tagged managed to pull off their radio tags before any useful data were collected.

Objective 1 of the phase IIIA ornithological studies (Mersey Barrage Feasibility Study) was to monitor the day and night distribution patterns of Pintail using radio telemetry. This was to further our understanding of why these birds occur in such internationally important numbers on the Mersey and how they use the estuary and surrounding habitats. A small sample of eight Teal was also to be caught and tagged to allow between-year comparisons.

Radio-tagging has drawbacks in that it can interfere with the behaviour of birds, though the method of attachment and the weight of the radio pack will determine the amount of disruption to the bird's normal behaviour. Harnesses often lead to behavioural changes **(Kenward 1987)**. Fewer problems have been associated with tail-mounted tags **(Kenward 1987; Giroux *et al.* 1990; Wanless 1992)**. A correlation has been found between radio weight and weight loss in Teal, **(Greenwood & Sargeant 1973)**. This effect and other types of behavioural changes are lessened by lighter packs **(White & Garrott 1990; Schroth 1991)**.

3.2 DATA COLLECTION, PRESENTATION AND ANALYSIS

3.2.1 Data collection

Duck were caught using standard cannon-netting techniques. A thorough knowledge of the area, of bird behaviour, of tides, and of weather conditions is required to optimise the probability of catching ducks safely. To allow a catch, the ducks have to be directly in front of the cannon-net in an area 27m by 13m. In total 13 man days were spent observing duck behaviour and a further 57 man days trying to catch the birds.

The Mount Manisty area (Figure 2.2.2.3), which held the majority of Pintail seen this winter, is tidal and the birds were patchily distributed. Only areas 3, 4 and 6 of Mount Manisty were potential Pintail catching sites, for the substrate had to be solid enough to allow the use of a cannon-net and the birds had to feed or roost in the areas. As the gradients in these areas were very shallow, a 10cm tidal difference could be crucial to the position of the birds from one day to the next. A day of high pressure was enough for the tide not to rise as far as expected and for the ducks to be out of range of the catching equipment. 49 man-days were spent at Mount Manisty catching only two Pintail, both tagged (Table 8), and 25 Teal, eight of which were tagged (Tables 6 & 7). Few Pintail were caught because their behaviour was unpredictable, leading to their roosting and feeding in different positions from one day to another.

Pintail were caught more successfully at New Ferry (Figure 2.2.2.4), with 28 ducks caught in 21 man-days, of which 10 were tagged (Tables 8 & 9).

To lessen any interference to the behaviour of the Teal and Pintail the radio-tags were largely tail-mounted and chosen to be as light as possible. 10g two stage transmitters were used as they were not too heavy for the birds, while at the same time emitting a powerful enough signal to be picked up in an environment prone to radio-static interference from industry **(Rehfisch *et al.* 1991)**. Powerful transmitters are also invaluable in poor conditions where the transmission range is much reduced by obstacles in the line of detection or poor climatic conditions **(Kenward 1987)**.

Six Teal were fitted with the same type of 10g back-mounted radio-transmitter (Biotrack, Wareham, Dorset BH20 5AJ), with a theoretical 5km range, as used the previous winter **(Rehfisch *et al.* 1991)**. Two Teal were fitted with similar devices, but in the tail-mounted form. These tags were attached by tying two cable clips around the four central tail feathers (rectrices) of each bird.

All of the Pintail were tagged with 10g tail-mounted radio-transmitters, to lessen the likelihood of the birds pulling them off. The previous 1990/91 winter had shown that Pintail could pull off back-mounted radio-transmitters.

Tracking was carried out at least weekly from 26 November 1991 to 10 March 1992. Birds were tracked continuously for two tidal cycles over twenty-five hours. This allowed a comparison to be made of the distributional changes in relation to both tidal state and daylight. Whenever possible, readings were taken from elevated sites with uninterrupted views of the Mersey to give the best reception. The sites were situated in such a way that birds anywhere on the estuary would be within reception range (Figure 3.2.1). To drive around the Mersey, with stops for radio-tracking, took about three hours. Thus measurements taken at 'high tide' were within one and a half hours of high tide. 'Low tide' measurements were made within one and a half hours of low tide.

On several occasions through the winter, both at night and during the day, attempts at finding radio-tagged birds were made further afield. The coverage was from the Dee Estuary to the south, as far east as Woolston Eyes, and up to the Wyre Estuary to the north.

3.2.2 Data analysis

For analytical purposes, the estuary was divided into 12 sections lettered from A to L (Figure 3.2.1). These sections could be related to the low and high tide count areas. Sometimes it was difficult to place a bird accurately in the Stanlow Bay area because of signal interference from the Stanlow industrial complex and because Mount Manisty acted as a partial shield to bearings taken from Eastham Ferry. Any such bird was placed in the arbitrary section "(F+G)", considered the "Stanlow area".

The positions of each of the birds were mapped (Figures 3.3.1 to 3.3.6 for Teal; Figures 3.3.7 to 3.3.16 for Pintail) and a record was kept of how frequently they used the various sections of the estuary.

Radio-tracking data were analysed in a similar way to that used for the 1990/91 winter to try and elucidate whether the birds:

i) only used the Mersey as a safe day-time roost or whether they required the Mersey, both day and night, throughout the winter;

ii) distributed themselves differently according to high or low tides, in the whole estuary or in certain habitats only;

iii) distributed themselves differently with respect to day and night, and whether certain habitats had a particular influence in determining their distribution;

iv) mixed within the estuary or were in separate populations.

Of all the sections, F, G and I were considered less prone to human disturbance through their status as undisturbed nature reserves or as Country Parks with low levels of human activity.

The analysis was carried out using χ^2 "goodness of fit" tests with no more than 20% of the expected frequencies under 5 **(Fowler & Cohen 1987; Sokal & Rohlf 1981)**. The Yates' correction was applied to all 2 by 2 contingency tables.

There may be problems associated with the use of the χ^2 test on pooled data as it is normally used for completely independent observations, though it is justified when a few observations are made of several animals **(Neu *et al.* 1974; White & Garrott 1990)**. Using χ^2 for habitat analysis is more tenable when comparisons are made of a limited number of habitat types **(Alldredge & Ratti 1986)**.

To maintain comparability between reports, sections were pooled in a similar way to the 1990/91 report for the analysis of the Teal locations.

3.3 RESULTS

No radio-tagged Pintail or Teal were located outside the immediate vicinity of the inner Mersey Estuary, by day or by night. No birds were tracked to the east of Runcorn Bridge nor to the west of New Ferry (Figures 3.2.1; 3.3.1 - 3.3.16).

3.3.1 Teal

3.3.1.1 Comparison of the distribution of Teal during the 1990/91 and 1991/92 winters

In 1990/91, Teal were caught at the Hale duck decoy (inland of section A) and at the Bromborough pool (section J) (Figure 3.2.1), whilst in 1991/92 they were caught only at Mount Manisty. The estuary usage made by Teal, caught near Mount Manisty during the 1991/92 winter, was different to that of the birds caught in 1990/91 (χ^2 = 217.92, d.f. =

2, $p < 0.001$) (Table 10). The distribution of Teal caught at Bromborough was also significantly different to the distribution of Teal caught at Mount Manisty ($\chi^2 = 5.33$, d.f. = 1, $p > 0.025$) (Table 11), yet both sets of birds made relatively more use of the lower estuary (sections A to E) than the birds caught at Hale which were found mainly in the upper estuary.

3.3.1.2 Comparison of day and night Teal distributions

Teal showed no statistically significant evidence of changing estuary usage between day and night ($\chi^2 = 0.19$, d.f. = 1, $p > 0.05$) (Table 12).

3.3.1.3 Comparison of Teal distribution in relation to high or low tides

There was no statistically significant evidence of changing estuary usage by Teal between high and low tide ($\chi^2 = 2.59$, d.f. = 4, $p > 0.05$) (Table 13).

3.3.2 Pintail

3.3.2.1 Comparison of day and night Pintail distributions

When the sections were lumped into the smallest possible units (see Section 3.2.2) there was no evidence of different day and night estuary usage ($\chi^2 = 9.49$, d.f. = 6, $p > 0.05$) (Table 14). When the data were pooled according to sections with high and low disturbance levels (Section 3.2.2), Pintail were found in high disturbance areas less during the day than at night ($\chi^2 = 7.39$, d.f. = 1, $p < 0.01$) (Table 15). The Stanlow area, an undisturbed nature reserve, is used more by Pintail during the day than at night ($\chi^2 = 5.65$, d.f. = 1, $p < 0.02$) (Table 16).

3.3.2.2 Comparison of Pintail distribution in relation to high or low tides

Pintail distribution varied with high and low tide ($\chi^2 = 29.98$, d.f. = 5, $p < 0.001$) (Table 17). Pintail were tracked more commonly in the Stanlow area saltmarshes at high tide than at low tide ($\chi^2 = 16.22$, d.f. = 1, $p < 0.001$) (Table 18). Pintail were also found more frequently at high tide than at low tide on the Bromborough Pool, in the Stanlow area and in the Oglet saltmarshes ($\chi^2 = 19.06$, d.f. = 1, $p < 0.001$) (Table 19).

3.4 DISCUSSION

3.4.1 Teal

3.4.1.1 Teal distributions in the 1990/91 and 1991/92 winters

The distribution of Teal caught during the 1991/92 winter, at Mount Manisty, was significantly different from that of Teal caught in the previous winter, at the Hale duck decoy and the Bromborough pool. In 1990/91, Teal caught at the Hale duck decoy stayed predominantly in the upper estuary, while Teal caught at Bromborough stayed in the lower estuary **(Rehfisch *et al.* 1991)**.

The birds caught at Mount Manisty in 1991/92 were tracked twice as frequently in the lower estuary as in the upper estuary. During the 1990/91 winter, it was shown that Teal caught at Bromborough used the Mount Manisty/Stanlow saltmarshes towards high tide, especially during the day. One Teal caught at Mount Manisty in 1991/92 (Figure 3.3.3) was subsequently located at New Ferry. It is likely that some of the Teal caught at Mount Manisty at high tide in 1991/92 would be part of the so-called 1990/91 Bromborough "population" which stayed in the lower estuary. None of the Teal caught at Mount Manisty were tracked to the Hale duck decoy.

3.4.1.2 Day and night Teal distributions

Although the all-day counts carried out from Mount Manisty in 1991/92 recorded fewer birds at night than during the day (Section 2.3.3), Teal did not show a significant change in their distribution from day to night. The sample of radio-tagged Teal was too small to show a significant difference in day and night locations of tagged birds, unless that difference was large. During the 1990/91 winter Teal had clearly different day and night distributions. This was due to large numbers of Teal feeding at night in the Manchester Ship Canal Company (MSCC) sludge pool until it froze over **(Rehfisch *et al.* 1991)**. The sludge pool was not flooded during the 1991/92 winter and was thus not available to feeding ducks.

3.4.1.3 Teal distribution in relation to high or low tides

There was no significant evidence that the use of the estuary by Teal differed between high and low tides during the 1991/92 winter. This result agrees with findings in the 1990/91 winter when all sections of the estuary were considered separately **(Rehfisch *et al.* 1991)**. Unlike the 1990/91 winter, Teal did not show a significantly increased usage of saltmarsh areas at high tide. All-day counts showed that more Teal used the marshes and channels in the vicinity of Mount Manisty at high tide than at low tide. The small sample of radio-tagged Teal in 1991/92 was possibly the reason for finding no statistically significant increase in high-tide usage of the saltmarsh areas.

3.4.1.4 Teal estuary usage

No Teal were tracked outside the Mersey Estuary, as in the 1990/91 winter. The Mersey Estuary was probably essential to the feeding of the Teal population present. Mudflats were used more by Teal than any other habitat type (tracked 47 times on mudflats *cf.* 20 times on other habitats). This confirmed, as suspected in 1990/91, that invertebrates must form an important component of the diet of Teal, as has been found by other authors **(*eg* Olney 1963; 1965)** since very few seeds or other vegetative parts were found on the mudflats **(A. Jemmett pers. comm.)**. There has also been recent evidence of Teal feeding on the meiobenthos **(Gaston 1992)**. Meiobenthos has been ignored in most previous studies of the intertidal parts of estuaries, as it is very time consuming to study and, until now, was thought to be unavailable to birds.

There may be several discrete populations of Teal on the estuary (Section 3.4.1.1). Similarly, Greenland Barnacle Geese are known to have preferred sites both within a single winter and between winters, and to form associated family groups **(Percival 1991)**. Such winter site fidelity is also found in Greenland White-fronted Geese **(Wilson *et al.* 1991)** and central European Greylag Geese wintering in Tunisia. Teal can be highly mobile **(Ogilvie 1981)**, though most evidence points to their being in small functional feeding and roosting units **(Tamisier 1974; 1985)**. It is possible that Teal on the Mersey also have preferred feeding and roosting areas and that birds sampled (by cannon-netting) from one area are more likely to be from a population with a limited distribution over the estuary.

Further ringing might help to demonstrate whether these Teal populations migrate to common breeding sites. Of the Teal caught and ringed during the 1990/91 winter, two were shot in Finland and one was controlled (caught and released alive) breeding in Denmark. If segregation of the breeding population does occur on the Mersey, then it would be expected that Teal caught together might have an increased level of genetic similarity. This could be tested for by collecting blood samples from Teal for genetic analysis.

3.4.2 Pintail

3.4.2.1 Day and night Pintail distributions

Pintail used highly disturbed sections less during the day than at night. Disturbance was suggested as a reason for the lesser use of the MSCC sludge pool by Teal during the 1990/91 winter **(Rehfisch *et al.* 1991)**, and is known to affect geese **(Owen 1972; Forshaw 1983; Madsen 1985; Prins & Ydenberg 1985; Keller 1991)** as well as other waterfowl **(van der Zande *et al.* 1980; Prater 1981; Belanger & Bedard 1989)**. The areas considered to be more disturbed on the Mersey are mainly affected by day-time movements of humans and dogs, especially out on mudflats where dogs are allowed to run and humans are more prone to carry out such activities as boat maintenance and bait-digging. It is probable that these activities make Pintail choose alternative feeding sites during the day. Birds that may be disturbed by small scale human movements may tolerate large-scale engineering activity **(Johnson *et al.* 1987)**, such as occurs in the Stanlow industrial complex, or else habituate to it if, for example, noise is occurring regularly **(Hockin *et al.* in press)**. Birds disturbed by human activities will return after these activities cease if the feeding conditions are good **(Burger 1988)**. Birds are generally more tolerant of disturbance if they are finding it difficult to maintain their calorific intake **(Poysa 1987; Hill 1990)**.

The Stanlow area, a nature reserve largely free of human disturbance, was used by more Pintail during the day than at night. This tallies with the human disturbance hypothesis.

All-day observations carried out at Mount Manisty confirmed that there were many fewer feeding and roosting Pintail in the area at night than in the day (Section 2.3.4).

3.4.2.2 Comparison of Pintail distribution in relation to high or low tides

The Pintail distribution varied with high and low tide. The duck were found in greater numbers in the Stanlow area at high tide than at low tide. Similarly, all-day counts showed that the area around Mount Manisty was used extensively at high tide by both feeding and, especially, roosting Pintail (Section 2.3.4). Pintail only fed on the saltmarsh in large numbers when it flooded. Pintail thus fed mainly on high spring tides, but would still form roosts on neap tides.

Pintail used Bromborough, the Stanlow area and the Oglet saltmarshes more frequently at high tide than at low tide. These areas are either non-tidal, or contain saltmarshes that are covered only by the highest tides. Bromborough and the Stanlow area are used mainly as high tide roosts.

3.4.2.3 Pintail estuary usage

No Pintail were tracked outside the Mersey Estuary. The Mersey Estuary was essential to the feeding of the Pintail population. Pintail were tracked more frequently on mudflats than any other habitat type (163 *cf.* 55 locations). This indicates that invertebrates must form an important component of the diet of Pintail on the Mersey, as has been noted in other places **(Olney 1965; Cramp & Simmons 1977; Euliss *et al.* 1991)**. As for Teal (Section 3.4.1.4), the meiobenthos may be important.

Pintail fed on the Mount Manisty and Stanlow saltmarsh only when it was flooded. For the saltmarsh to flood the tide had to reach 9.3m O.D. or more. This only occurred in 58 out of 294 (19.7%) high tides from 1 November 1991 to 31 March 1992, with intervals of up to 29 days between high tides of at least 9.3m. It is thus unlikely that saltmarsh feeding is not essential for the survival of these ducks. This type of opportunistic use of a habitat was also noted during the 1990/91 winter when Teal and Pintail were recorded flying into the MSCC sludge pool in large numbers until it froze over **(Rehfisch *et al.* 1991)**. Pintail are known to have seasonal changes in their diet **(Euliss *et al.* 1991)**.

Pintail fed on the Mersey mudflats until these were covered. On neap tides, the birds tended to stay *in situ* if they were not dislodged by human disturbance during the day; if the Pintail were disturbed they would fly to the less disturbed saltmarsh areas around Mount Manisty at high tide. On spring tides, Pintail were frequently forced to fly to Mount Manisty as all of the mudflats would be covered, and there they would feed on the flooding saltmarsh on tides of over 9.3m O.D. Many fewer Pintail would use the Mount Manisty saltmarsh at night due to lessened human disturbance in such areas as New Ferry and Garston, and also possibly because of the potential threat of mammalian predators (*eg* **Miller *et al.* 1992**). The fox (*Vulpes*) is common on the saltmarsh, but difficult to see at night.

Pintail were dependent on the Mersey Estuary for both feeding and roosting. Any loss of intertidal mudflats could well lead to a decline in the internationally important Pintail populations on the Mersey. Increased levels of disturbance on the estuary, by recreational water sports for example, could also lead to reduced Pintail populations, especially if the disturbance was throughout the tidal cycle and occurred extensively throughout the estuary.

SECTION 4

THE DISTRIBUTION OF WATERFOWL IN RELATION TO INVERTEBRATES

4.1 INTRODUCTION

The proposed tidal barrage on the Mersey Estuary will have an impact on the estuarine environment and is thus likely to affect the number of waterfowl that can feed on the intertidal mudflats **(Ebrahimi & Elliott 1991; Gray 1992; Mersey Barrage Company 1992)**. Behind a barrage, the tidal range is reduced. This lessens the area of mudflats exposed at low tide and also reduces the time that they are uncovered for feeding. A decline in feeding area can lead to a fall in waterfowl populations **(Goss-Custard & Moser 1988)**. This effect may be counteracted by the reduction in tidal range which can lead to an increase in the biological productivity through the more regulated nature of the post-barrage estuary **(Kirby 1987)**.

Estuaries are habitats rich in birds because of their generally high productivities **(Prater 1981; McLusky 1981; Wilson 1988)**. In the context of the proposed Mersey barrage, it is important to know what prey are utilized by the Mersey Estuary waterfowl populations, and to what extent the potential prey resources are being exploited pre-barrage. As a result of the construction of the proposed barrage, there will be changes to the productivity of the estuary and, hence, the level of exploitation of the available invertebrates and plant matter could be modified considerably, with potentially serious implications for the birds.

To further the understanding of the way that the Mersey waterfowl utilize the estuary, an invertebrate sampling program, started during the 1990/91 winter by Environmental Resources Limited, was continued for the second 1991/92 winter. It was then necessary to examine the association of waterfowl distributions with the numbers or biomass of the various invertebrate species. This is the subject of this section.

4.2 DATA COLLECTION, PRESENTATION AND ANALYSIS

4.2.1 Data collection

The program of invertebrate and seed sampling started by Environmental Resources Limited (ERL) during the 1990/91 winter was continued throughout the 1991/92 winter **(McGill *et al.* 1992; Mersey Barrage Company 1992)**. Analysis of the 1990/91 winter's data had shown no significant relationships between invertebrate densities and bird densities **(Rehfisch *et al.* 1991)**. A change in the siting of the invertebrate sampling stations was required to increase the probability of detecting any relationships that might exist between waterfowl and invertebrates. After consultation between ERL and the BTO, it became apparent that a few extra sampling stations could be established, within the constraints of the available man-power resources. These new stations were sited on mudflats known to hold high densities of feeding birds, intertidal areas 39, 40, 66, 75 and 78 (Figure 1.2.1).

Most types of inner Mersey habitats were covered by the sampling sites, including areas used by both high and low densities of birds. The sampling sites included sandbanks, saltmarshes and their creeks, as well as estuarine mudflats. The complete list of sampling sites and methodologies can be found in **McGill *et al.* (1992)**.

Invertebrate sampling was carried out by ERL. The BTO received monthly means of invertebrate numbers and biomass per square metre for each sampling site. Most sites were sampled monthly from November to March, in both the 1990/91 and 1991/92 winters. Some sites, often those with lower invertebrate densities, were sampled less regularly, but at least once every three months.

4.2.2 Data analysis

Three species of small oligochaete worms, *Tubifex costatus*, *Tubificoides benedeni* and *Clittelio arenius*, were lumped into one category, Oligochaeta, for the purposes of the analysis, as it is improbable that birds would distinguish between the species. Five other invertebrate categories were used in the analysis: *Nereis diversicolor*, *Macoma balthica*, *Corophium volutator*, *Hydrobia ulvae* and total invertebrates. Species that were found in either very low densities or that were very localised, were not included in the analysis as their biomass values were unavailable. It is unlikely that the distribution of birds would be determined by rare invertebrate species. Unfortunately no density or biomass data were available for *Arenicola marina*, a large oligochaete worm that is eaten by some waders but which is difficult to sample as it can burrow more rapidly than man can dig. Seeds found in core samples were not included in the analysis as their densities were very low and, when recorded, they were from parts of the estuary for which no specific low tide counts were available (*eg* individual creeks).

At each sampling station, for each of the two winters, mean density and biomass values were calculated for each invertebrate category. When several ERL sampling stations were on one BTO intertidal area the overall mean density and biomass values were calculated by taking the mean of the winter mean value of each station.

Regression analysis was used in order to detect any associations between feeding bird populations and the densities and biomass of invertebrates. The bird densities (*nos* ha^{-2}) were always treated as the dependent variables. The invertebrate densities (*nos* m^{-2}) and biomass (gm^{-2}) were used as the explanatory independent variables. The densities of feeding birds used were those recorded during low tide counts carried out during the 1990/91 and 1991/92 winters on the BTO intertidal areas (Section 1.2.1). The low tide bird counts were chosen as these were representative of feeding bird distributions and covered the whole of the Mersey Estuary. Only the most widespread and common species, Shelduck, Teal, Pintail, Grey Plover, Dunlin, Curlew and Redshank, were used in the analysis.

The analysis was repeated on untransformed and on $\log_e(x + 1)$ transformed invertebrate data, being appropriate because the invertebrate, and to a lesser extent the bird, data were highly skewed, with a few very large values **(Sokal & Rohlf 1981)**.

The regression of the between-winter changes in bird densities (on the BTO intertidal areas) on the between-winter changes in invertebrate densities and biomass was also examined.

Regressions were considered significant only if they were significant at the conventional 5% level and there was no evidence of a single outlying value which would have contributed overly to the significance of the correlation.

The proportion of the variance in the distribution of the birds explained by invertebrate densities or biomass can be indicated by the coefficient of determination (r^2).

4.3 RESULTS

4.3.1 Shelduck

Regression analysis showed no statistically significant links between Shelduck densities and invertebrate densities, invertebrate biomass and $\log_e$-transformed densities (Tables 28-30) but Shelduck distribution could be partly explained by the $\log_e$-transformed biomass of the Oligochaeta (r^2 = 0.283, n = 28, P = 0.0036), and the $\log_e$-transformed total biomass of the invertebrates (r^2 = 0.203, n = 28, P = 0.0162) (Tables 31 & 32).

Between-year changes in total invertebrate biomass partly explained between-year changes in Shelduck numbers (r^2 = 0.309, n = 13, P = 0.0486) (Tables 33 & 34).

4.3.2 Teal

Regression analysis showed no statistically significant links between Teal densities and invertebrate densities, $\log_e$-transformed densities and biomass (Tables 28-30) but Teal distribution could be partly explained by the $\log_e$-transformed biomass of the Oligochaeta (r^2 = 0.361, n = 28, P = 0.0036) (Tables 31 & 32).

Between-year changes in invertebrate biomass did not help explain between-year changes in Teal numbers (Table 33).

4.3.3 Pintail

Regression analysis showed no statistically significant links between Pintail densities and invertebrate densities, $\log_e$-transformed densities, biomass or $\log_e$-transformed biomass that were not due to the effect of single outliers value (Tables 28-31).

Between-year changes in invertebrate biomass did not help explain between-year changes in Pintail numbers (Table 33).

4.3.4 Grey Plover

Regression analysis showed no statistically significant links between Grey Plover densities, invertebrate densities, $\log_e$-transformed densities, biomass and $\log_e$-transformed biomass, that were not due to the effect of one outlying value (Tables 28-31).

Between-year changes in invertebrate biomass did not help explain between-year changes in Grey Plover numbers (Table 33).

4.3.5 Dunlin

Regression analysis showed no statistically significant links between Dunlin densities and invertebrate densities, $\log_e$-transformed densities and biomass (Tables 28-30) but Dunlin distribution could be partly explained by the $\log_e$-transformed biomass of the Oligochaeta (r^2 = 0.212, n = 26, P = 0.0180), the $\log_e$-transformed biomass of *Macoma balthica* (r^2= 0.196, n = 26, P = 0.0234), and the $\log_e$-transformed total biomass of the invertebrates (r^2= 0.400, n = 26, P = 0.0005) (Tables 31 & 32).

Between-year changes in invertebrate biomass did not help explain between-year changes in Dunlin numbers (Table 33).

4.3.6 Curlew

Regression analysis showed no statistically significant links between Curlew densities and invertebrate densities, $\log_e$-transformed densities, biomass or $\log_e$-transformed biomass that were not due to the effect of single outliers value (Tables 28-31).

Between-year changes in invertebrate biomass did not help explain between-year changes in Curlew numbers (Table 33).

4.3.7 Redshank

Regression analysis showed no statistically significant links between Redshank densities and invertebrate densities, $\log_e$-transformed densities, biomass or $\log_e$-transformed biomass that were not due to the effect of single outliers (Tables 28-31).

Between-year changes in invertebrate biomass did not help explain between-year changes in Redshank numbers (Table 33).

4.3.8 Total birds

Regression analysis showed no statistically significant links between total bird densities and invertebrate densities, $\log_e$-transformed densities and biomass (Tables 28-30) but total bird distribution could be partly explained by the $\log_e$-transformed biomass of the Oligochaeta ($r^2 = 0.412$, $n = 32$, $P < 0.0001$) and the $\log_e$-transformed total biomass of the invertebrates ($r^2 = 0.395$, $n = 32$, $P < 0.0001$) (Tables 31 & 32).

Between-year changes in invertebrate biomass did not help explain between-year changes in total bird numbers (Table 33).

4.4 DISCUSSION

Regression analysis had been used to compare one winter's bird densities on the Mersey Estuary with invertebrate numbers (**Rehfisch *et al.* 1991**). This first approach did not give rise to any significant correlations. Repeating this approach using invertebrate biomass data, after two winters of data-gathering, was more successful.

The densities of Shelduck, Teal, Dunlin and total birds were significantly correlated with the $\log_e$-transformed Oligochaeta biomass (Table 31). Dunlin densities were correlated with *Macoma balthica* densities. The densities of Shelduck, Dunlin and total birds were correlated with total invertebrate biomass (Table 31). Correlations between the above bird species and total invertebrate biomass are largely a result of the Oligochaeta, which provide a large proportion of the total invertebrate biomass. A greater proportion of the variance in Dunlin densities is explained by total invertebrate biomass than oligochaete biomass alone.

Dunlin and Shelduck have been found to feed on oligochaetes, or be significantly correlated to oligochaete densities, in previous studies **(Goss-Custard *et al.* 1988; Cramp & Simmons 1983)**. Dunlin are also known to feed on *Macoma balthica* **(Cramp & Simmons 1983)**.

Teal have been found to feed extensively on nematodes in certain intertidal habitats **(Gaston 1992)** as have other teal species *eg* Chilean Teal (*Anas flavirostris*) **(Marchant & Higgins 1990:1264)**, but generally not on oligochaetes (***eg* Cramp & Simmons 1977)**. In fact, they feed on a very wide variety of invertebrates. The fact that they have not been recorded feeding on oligochaetes is probably due only to the limited number of hard parts found in these worms, which makes it difficult to detect them in gut or faecal samples. to aid post-ingestion identification. Teal have bills that allow the selection of seeds 1mm or less in diameter **(Marchant & Higgins 1990)**, so they should also be able to separate oligochaetes from their substrate.

The lack of any other significant correlations for the other bird species may have been because of:

i) the relatively limited period of data gathering;

ii) the relatively limited number of sampling sites (a problem with most invertebrate-bird studies, due to the labour-intensive nature of invertebrate sample sorting);

iii) the lack of data on such species as *Arenicola marina*, which are a major prey of Curlew **(Cramp & Simmons 1983)**;

iv) the species not being limited by available food, in both years, but by, for example, predator avoidance **(Whitfield 1988)** or intra-specific interactions.

The between-year changes in total invertebrate biomass helped predict between-year changes in Shelduck densities, but in no other waterfowl species (Table 33). It is possible that this species is closer to carrying-capacity than the other waterfowl and that changes in invertebrate biomass will effectively limit the numbers of this duck. This could be tested for by comparing changes in Shelduck numbers with the gradually declining invertebrate prey through the winter, *ie* looking at how the monthly changes in Shelduck numbers vary with the monthly changes in invertebrate biomass.

The fact that the invertebrate biomass and bird densities had to be logged before significant correlations became apparent is a reflection of the relationship between the predictor and the predicant. Natural logarithm transformations of both predictor and predicant straighten asymptotic curves (a line that continually approaches a curve but never meets it) **(Fowler & Cohen 1987:115)**.

Studies of how bird distributions relate to prey densities **(Meire & Kuyken 1984:66; van Eerden 1984:92; Krebs 1978:39)** suggest that birds should not be found at very low densities (or biomass) of prey, as it should not be profitable for them to forage under such conditions. Bird densities should start increasing rapidly from a certain minimum level of prey, before levelling off as intra-specific bird interactions start to be limiting (Figure 4.4.1). An asymptotic curve approximates such a relationship without the initial tail. Data fitting a distribution such as that represented by Figure 4.4.1 would be likely to show a good straight line fit after a predictor/predicant natural logarithm transformation.

It would thus appear that Shelduck, Teal, Dunlin and the total birds on the inner Mersey Estuary could well be distributed in a way approximating that represented in Figure 4.4.1 when feeding on Oligochaeta. This type of relationship could also model Dunlin densities from *Macoma balthica* biomass, and Shelduck, Dunlin and total bird densities from total invertebrate biomass. The past studies that have correlated numbers or densities of potential prey species to bird numbers (***eg*** **Goss-Custard** ***et al.*** **1988**) have rarely arrived at such a relationship. This is probably due to the approach being inherently flawed in that invertebrate numbers are not representative of the amount of available nutrition, as there are large variations in the size, and even greater variations in the weight, of individual organisms within one invertebrate species. Invertebrate biomass is a much better indicator of the potential 'value' of an area to feeding birds than is density, because the relationship between biomass and calories (energy available to birds) will be fairly constant within an invertebrate species, and even between species, as there is little variation in the calorific value of biomass units between species (**McLusky 1981:31**). The results of this analysis confirm that invertebrate biomass is a better predictor of waterfowl densities than are invertebrate densities. The ideal analysis would also include dividing the invertebrate data into biomass size-classes, as birds are known to select prey according to size (**Krebs 1974:26&32**).

Small invertebrates, such as Oligochaeta and Nematoda, have often been largely ignored in the past due to difficulties involved in their identification and sampling (**Wolff & Smit 1990; Zwarts** ***et al.*** **1990**). Many authors conveniently assume that birds will not feed on such small prey "*... nematodes ... were not identified because they are unlikely prey ...*" (**Goss-Custard** ***et al.*** **1988**), though recent studies either prove that these small invertebrates can be a major part of the diet of some waterfowl (**Gaston 1992**) or else imply strongly that small invertebrates must be important (**Zwarts** ***et al.*** **1990**). Such *a priori* errors in bird diet studies are not uncommon (**Bielefeldt** ***et al.*** **1992**).

The results of this study demonstrate that such small invertebrates as oligochaetes can be the best predictors of waterfowl densities. There is a limited difference in the shape and size of nematodes and such oligochaetes as *Tubificoides benedeni*, and it is unlikely that birds will differentiate between them when feeding. The invertebrate sampling on the Mersey did include a quantitative survey of nematode numbers, but this did not include biomass calculations. Nematodes were thus not included in the analysis, though they might have helped improve bird density prediction.

The major component of the small Oligochaeta was *Tubificoides benedeni*, a species that can withstand grossly polluted estuaries (**Gray 1976**). The proposed tidal barrage may increase the retention time of the upstream waters. This may lead to the increased retention of pollutants (**Mersey Barrage Company 1992:142**). *Tubificoides benedeni* is a species (or species complex) that should be able to tolerate any such increase in pollution.

The barrage will also affect the amount of intertidal feeding time available to birds by retaining waters beyond high tide to increase power generation. This will lead to intertidal areas remaining covered for longer periods of the tidal-cycle. This could limit the availability of prey to the waterfowl and could lessen the bird densities accommodated on the post-barrage Mersey Estuary. This effect would only become apparent if the bird populations were already at carrying-capacity on the Mersey Estuary. The lack of significant correlations between some of the bird species and invertebrate biomass would tend to imply that this is probably unlikely, though the relationship may be complicated by fish and shrimps that can have a large impact on invertebrate populations **(Summers 1974)**. The possible exception to this is Shelduck, the densities of which varied with between-year changes in invertebrate densities.

Summary: the best predictions of bird densities could be made from small oligochaete biomass. Invertebrate densities were not found to be of use in predicting bird densities. The birds may have distributed themselves in the way predicted by a simple intuitive model (Figure 4.4.1). The barrage will impact on bird populations by limiting the intertidal areas that the birds feed on, but may not affect a major prey species of Shelduck, Teal and Dunlin, the pollution resistant oligochaete, *Tubificoides benedeni*.

RECOMMENDATIONS FOR FURTHER WORK

1 Winter movements of waterfowl

Conservation groups are interested in knowing what the impact of the proposed tidal barrage will be on the waterfowl populations of the Mersey Estuary. After a preliminary analysis of ringing recoveries **(Clark *et al.* 1990c)** it is still uncertain whether the estuary has stable populations of waterfowl during the winter or whether there is a considerable turnover of birds. To determine which of these hypotheses is correct, the movements of dye-marked samples of each of the key waterfowl species on the Mersey should be followed through the winter, both within the Mersey Estuary and in the rest of Britain, using the network of BTO volunteers and professional scientists. This would enable an assessment to be made of how critical the Mersey Estuary is for waterfowl.

2 Time budgets and feeding distribution analysis

In tandem with the above project, time budgets (the amount of time spent feeding and prey intake rates), with simultaneous between-bird distance measurements, should be carried out using a dye-marked indicator species such as Redshank. This would enable an assessment of prey intake rates to be made in relation to the distances between feeding birds and habitat. This information is important in the context of the changing post-barrage environment which may force birds to feed in smaller areas and less suitable habitats, leading to increased competition for space (and food), a situation which may be particularly detrimental to younger birds.

3 Assessment of mitigation measures

One of the Frodsham lagoons was used by very large numbers of Pintail and Teal during the 1990/91 winter. Similar lagoons in various parts of Britain are very attractive to waterfowl. In the context of post-barrage mitigation measures it is important to assess the potential of the Frodsham lagoons as substitutes for any loss of intertidal areas that may occur. This requires the monitoring of the present physical and chemical characteristics of the lagoons, their present and invading plant and animal faunas, and their present usage by waterfowl. Artificial manipulations of the chemistry and water-levels of the lagoon could increase their plant and animal productivity, making them much more attractive to birds.

4 The proportion of available food taken by birds

Several small areas of Oglet and Stanlow should be studied intensively throughout the winter in parallel with a simultaneous invertebrate sampling program. Regular counts of the birds using the area would enable an estimate to be made of the proportion of invertebrates taken by birds. Comparing this to the actual change in invertebrate biomass would help evaluate the predatory pressure exerted by birds. Repeating the procedure in several habitats should allow the effect of sediment type, nearness of land, and other parameters to be taken into account.

5 Waterfowl disturbance

The levels of human disturbance would be expected to increase dramatically in some parts of the Mersey Estuary during construction of the barrage *eg* at New Ferry. Furthermore birds could be subjected to more disturbance post-barrage if there were an increase in recreational use of the waters upstream of the barrage. Evidence of human disturbance to waterfowl should be collated from the four winters of work on the Mersey. For example, Pintail were seen to be affected by human disturbance this winter, especially at high tide. Detailed field experiments should then be carried out. The level at which human activity becomes disturbing to waterfowl should be measured by observations in both disturbed and non-disturbed parts of the Mersey. This would allow habituation (the facility birds have to get used to repeated disturbance) to be taken into account.

6 Barrage construction and birds

Construction of the barrage will lead to increased disturbance. Human activity, traffic, noise, dust and light levels will increase. The works will lead to sediment changes and a reduction in tidal amplitude which will lead to higher saltmarshes remaining uncovered for a year or two towards the end of the construction phase. Saltmarsh communities are known to recover slowly after periods of drying. After barrage closure there will be a transition phase, which may last 5 to 20 years, before a more stable system is attained. This period of transition is very imperfectly understood, but may lead to great changes in the habitats and invertebrates available to birds. Some of these new habitats will be beneficial to birds, others will not. A review of the scenarios and attendant physical and biological changes that are likely to occur during the construction and transitional phases should be undertaken to reduce the uncertainties manifest in this area.

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TABLES

	Av. peak winter count (Nov.- Mar.)	% of British population	% of European population*
SHELDUCK *Tadorna tadorna*	3745	5.0	1.5
WIGEON *Anas penelope*	6616	2.6	0.9
TEAL *Anas crecca*	11705	11.7	2.9
MALLARD *Anas platyrhynchos*	1195	0.2	<0.1
PINTAIL *Anas acuta*	5925	23.7	8.4
RINGED PLOVER *Pluvialis hiaticula*	26	0.1	0.1
GOLDEN PLOVER *Pluvialis apricaria*	1106	0.6	0.1
GREY PLOVER *Pluvialis squatarola*	854	4.1	0.6
LAPWING *Vanellus vanellus*	7012	0.7	0.4
KNOT *Calidris canutus*	357	0.2	0.1
DUNLIN *Calidris alpina*	32528	7.6	2.3
BLACK-TAILED GODWIT *Limosa limosa*	112	2.2	0.2
CURLEW *Numenius arquata*	1434	1.6	0.4
REDSHANK *Tringa totanus*	4080	5.4	2.7

* For wildfowl, percentages are of the north-west European population **(Pirot *et al.* 1989)**, for waders percentages are of the east Atlantic flyway population **(Smit & Piersma 1989)**.

Table 1 The National and International Importance of the Mersey for waterfowl, 1987/88-1991/92.

Count	Earliest Date	Official Date	Latest Date
1	14/11/91	17/11/91	19/11/91
2	28/11/91	1/12/91	3/12/91
3	12/12/91	15/12/91	17/12/91
4	26/12/92	29/12/92	30/12/92
5	9/ 1/92	12/ 1/92	15/ 1/92
6	23/ 1/92	26/ 1/92	29/ 1/92
7	12/ 2/92	16/ 2/92	18/ 2/92

Table 2 Dates of low tide counts, winter 1991/92.

	1991/1992		1990/1991		1989/1990		1988/1989	
	Feeding	Roosting	Feeding	Roosting	Feeding	Roosting	Feeding	Roosting
SHELDUCK	2237	637	3013	654	3500	540	4517	465
WIGEON	670	3075	3254	1721	22	2912	567	3190
TEAL	665	6059	2592	4424	5079	9169	3992	1917
MALLARD	470	598	407	331	548	813	260	612
PINTAIL	380	1006	111	1205	555	858	380	850
RINGED PLOVER	106	0	38	7	59	5	77	3
GOLDEN PLOVER	2000	24	1100	649	27	1405	23	468
GREY PLOVER	48	427	74	84	138	52	131	13
LAPWING	1306	9847	7029	8364	1021	5624	1446	227
KNOT	2760	400	1789	20	1541	321	2110	124
DUNLIN	11680	5941	32656	458	8563	4357	12886	1333
BLACK-TAILED GODWIT	226	185	32	173	22	40	0	6
BAR-TAILED GODWIT	6	53	0	0	7	0	0	0
CURLEW	958	258	938	28	972	328	813	66
REDSHANK	3066	355	6400	61	3907	580	3259	100
TURNSTONE	39	0	24	0	30	0	12	0

Table 3 Peak winter low tide counts on the Mersey Estuary, winters 1988/89 to 1991/92.

	1991/1992		1990/1991		1989/1990		1988/1989	
	Feeding	Roosting	Feeding	Roosting	Feeding	Roosting	Feeding	Roosting
SHELDUCK	51	81	55	12	158	148	175	55
WIGEON	0	0	0	19	0	0	0	0
TEAL	3	0	0	0	0	0	0	2
MALLARD	72	324	15	297	53	406	210	220
PINTAIL	0	1	0	7	0	0	0	2
OYSTERCATCHER	3466	358	3409	682	4175	2358	12713	1656
RINGED PLOVER	87	0	28	0	166	22	56	111
GOLDEN PLOVER	250	320	6	275	10	700	3	85
GREY PLOVER	443	0	650	0	534	0	362	0
LAPWING	0	1060	0	666	220	1350	300	750
KNOT	1616	3210	3502	9000	5494	6259	27234	21062
SANDERLING	751	0	295	0	851	0	465	0
DUNLIN	3212	85	3427	0	6744	45	3320	30
BLACK-TAILED GODWIT	0	0	3	0	0	0	21	0
BAR-TAILED GODWIT	4553	160	6138	0	6193	520	7592	250
CURLEW	273	230	174	498	336	128	289	30
REDSHANK	1895	0	1617	0	1920	150	1915	165
TURNSTONE	487	0	551	0	745	53	403	0

Table 4 Peak winter low tide counts on the Alt and North Wirral Shore, winters 1988/89 to 1991/92.

Count	Date			
	New Ferry	Stanlow	Oglet	Mount Manisty
1	10/ 1/92	18/11/91	14/11/91	11/11/91
2	20/ 1/92	2/12/91	26/11/91*	20/11/91
3	5/ 2/92	17/12/91	28/11/91	21/11/91
4	14/ 2/92	9/ 1/91	12/12/91	4/12/91*
5		23/ 1/92	23/12/91	5/12/91
6		18/ 2/92	23/12/91*	7/ 1/92
7		28/ 2/92	15/ 1/92	7/ 1/92*
8		6/ 3/92	16/ 1/92*	29/ 1/92
9			24/ 1/92	30/ 1/92
10			12 /2/92	2/ 2/92
11			19/ 2/92*	3/ 2/92
12			4/ 3/92*	25/ 2/92*
13			5/ 3/92	

* Count carried out at night

Table 5 Dates of all-day counts, winter 1991/92. Asterisks indicate counts carried out at night, other counts were carried out in daylight.

Date	Ring number	Age & sex	Wing length (*mm*)	Weight (*g*)	Transmitter no., type and anticipated range
20.11.91	ER62951	Ad.♀	173	300	246 2 Stage 5km
	ER62952	Juv.♂	181	330	335 2 Stage 5km
	ER62953	Juv.♂	177	355	234 2 Stage 5km
	ER62954	Juv.♂	179	325	220 2 Stage 5km
21.11.91	ER62955	Ad.♀	180	325	
	ER62956	Ad.♂	197	390	
	ER62957	Ad.♂	189	355	
	ER62958	Ad.♀	186	420	
	ER62959	Juv.♀	175	225	
	ER62960	Ad.♂	192	390	
	ER62961	Ad.♂	197	405	
	ER62962	Juv.♀	189	415	

Ad. = adult (Bird older more than 1 year old) Juv. = juvenile (bird less than 1 year old)

Table 6 Teal caught at Mount Manisty in November 1991 for the purposes of radio-tracking.

Date	Ring number	Age & sex	Wing length (*mm*)	Weight (*g*)	Transmitter no., type and anticipated range
6.12.91	ER62963	Ad.♂	190	415	210 2 Stage 5km
	ER62964	Ad.♂	185	405	
	ER62965	Juv.♂	186	385	240 2 Stage 5km
	ER62966	Juv.♂	185	345	255 2 Stage 5km
	ER62967	Ad.♀	181	375	266 2 Stage 5km
	ER62968	Juv.♀	184	325	
10.12.92	ER62969	Ad.♂	186	345	
	ER62970	Ad.♂	188	350	
	ER62971	Ad.♂	191	350	
	ER62972	Juv.♂	187	315	
	ER62973	Ad.♀	182	335	
	ER62974	*♀	183	330	
	ER62975	*♀	176	305	

Ad. = adult (bird more than 1 year old) Juv. = juvenile (bird less than 1 year old) * = age unknown

Table 7 Teal caught at Mount Manisty in December 1991 for the purposes of radio-tracking.

Place	Date	Ring number	Age & sex	Wing length (*mm*)	Weight (*g*)	Transmitter no., type and anticipated range
Mount Manisty	21.11.91	FA04511	Juv.♂	265	>950	295 2 Stage 5km
	9.12.91	FA04512	*♀	254	715	302 2 Stage 5km
New Ferry	11.12.91	FA04513	*♂	280	1150	345 2 Stage 5km
		FA04514	*♀	268	1050	287 2 Stage 5km
		FA04515	*♂	276	1080	324 2 Stage 5km
		FA04516	*♀	259	1040	278 2 Stage 5km
		FA04517	*♂	283	1200	
		FA04518	*♂	277	>1250	
	21. 1.92	FA04520	*♀	269	1130	320 2 Stage 5km
		FA04521	Ad.♂	279	1110	230 2 Stage 5km
		FA04522	Ad.♂	287	1010	238 2 Stage 5km
		FA04523	Ad.♂	284	1150	
		FA04524	Juv.♂	268	950	249 2 Stage 5km
		FA04525	*♀	256	920	297 2 Stage 5km
		FA04526	Ad.♂	276	1040	308 2 Stage 5km

Ad. = adult (bird more than 1 year old) Juv. = juvenile (bird less than 1 year old) * = age unknown

Table 8 Pintail caught at Mount Manisty and at New Ferry for the purposes of radio-tracking.

Date	Ring number	Age & sex	Wing length (*mm*)	Weight (*g*)	Transmitter no., type and anticipated range
21. 1.92	FA04527	*♀	260	760	
	FA04528	*♀	254	950	
	FA04529	*♀	258	740	
	FA04530	Ad.♂	292	1170	
	FA04531	Ad.♂	282	1120	
	FA04532	*♀	254	920	
	FA04533	*♀	254	920	
	FA04534	*♀	260	860	
	FA04535	*♀	254	790	
	FA04536	Ad.♂	288	1185	
	FA04537	*♀	267	1020	
	FA04538	Ad.♂	281	1175	
	FA04539	Ad.♂	276	990	
	FA04540	*♀	254	990	
	FA04541	*♀	259	710	

Ad. = adult (bird more than 1 year old) Juv. = juvenile (bird less than 1 year old) * = age unknown

Table 9 Pintail caught at New Ferry for the purposes of radio-tracking.

Sections	Hale 1990/91	Bromborough 1990/91	Manisty 1991/92
Upper Estuary (Sections A-E)	156	33	22
Lower Estuary (Sections F-L)	7	149	45

$\chi^2 = 217.92$, d.f. $= 2$, $p < 0.001$

Table 10 Frequency of subsequent observation in the upper and lower estuary of Teal caught at Hale, Mount Manisty and Bromborough.

Sections	Bromborough 1990/91	Manisty 1991/92
Upper Estuary (Sections A-E)	33	22
Lower Estuary (Sections F-L)	149	45

$\chi^2 = 5.33$, d.f. $= 1$, $p < 0.025$

Table 11 Frequency of subsequent observation in the upper and lower estuary of Teal caught at Mount Manisty and Bromborough.

Sections	Day	Night
E+G+(F+G)	12	8
C+D+F+H+I+K	21	26

$\chi^2 = 0.96$, d.f. $= 1$, $p > 0.05$

Table 12 Comparison of day- and night-time distribution of radio-tagged Teal in the Mersey Estuary in 1991/92.

Sections	High tide	Low tide
C	6	7
D+F	10	9
E+G	6	4
(F+G)	7	3
H+I+K	6	9

$\chi^2 = 2.59$, d.f. $= 4$, $p > 0.05$

Table 13 Comparison of high and low tide distribution of radio-tagged Teal in the Mersey Estuary in 1991/92.

Sections	Day	Night
D+F	8	13
G	7	2
(F+G)	22	11
H	4	7
I	10	7
J+K	49	56
L	12	10

$\chi^2 = 9.48$, d.f. $= 6$, $p > 0.05$

Table 14 Comparison of day- and night-time distribution of radio-tagged Pintail in the Mersey Estuary.

Sections	Day	Night
F+G+I+(F+G) low disturbance	44	28
D+H+J+K+L high disturbance	68	98

$\chi^2 = 7.39$, d.f. $= 1$, $p < 0.01$

Table 15 Comparison of day- and night-time distribution of radio-tagged Pintail in the Mersey Estuary between areas of low and high disturbance.

Sections	Day	Night
G+(F+G) Stanlow saltmarsh	29	13
D+F+H+I+J+K+L the rest	83	93

$\chi^2 = 5.65$, d.f. = 1, $p < 0.025$

Table 16 Comparison of day- and night-time distribution of radio-tagged Pintail in the Mersey Estuary, comparing Stanlow saltmarsh with the rest of the estuary.

Sections	High tide	Low tide
D+(F+G)	33	8
F	2	11
G	5	4
H+L	9	24
I	6	11
J+K	54	51

$\chi^2 = 29.98$, d.f. = 5, $p < 0.001$

Table 17 Comparison of high and low tide distribution of radio-tagged Pintail in the Mersey Estuary.

Sections	High tide	Low tide
G+(F+G) Stanlow marsh	33	8
D+F+H+I+J+K+L the rest	76	101

$\chi^2 = 17.30$, d.f. $= 1$, $p < 0.001$

Table 18 Comparison of high and low tide distribution of radio-tagged Pintail in the Mersey Estuary, comparing Stanlow saltmarsh with the rest.

Sections	High tide	Low tide
D+G+J+(F+G) roosts	42	13
F+H+I+K+L the rest	67	96

$\chi^2 = 19.06$, d.f. $= 1$, $p < 0.001$

Table 19 Comparison of high and low tide distribution of radio-tagged Pintail in the Mersey Estuary, comparing roost areas with the rest.

Section (LT)	Bird densities (*nos/ha*)							
	All	SU	T	PT	GV	DN	CU	RK
New Ferry 25-28	17.55	0.75	0.07	0.39	0.00	6.96	0.24	3.03
33	11.31	1.42	2.77	0.23	0.00	0.81	0.04	5.19
35	18.55	2.69	0.88	0.11	0.00	11.14	0.12	3.51
36	19.58	0.28	0.19	0.35	0.01	14.99	0.10	3.21
39	8.53	0.78	0.16	0.00	0.20	6.49	0.16	0.36
40	4.68	0.08	0.00	0.00	0.02	3.96	0.18	0.39
47	2.89	0.58	0.32	0.00	0.00	0.63	0.41	0.09
49	0.14	0.00	0.00	0.00	0.00	0.00	0.14	0.00
55	0.43	0.29	0.00	0.00	0.00	0.07	0.02	0.02
58	0.30	0.02	0.03	0.00	0.00	0.02	0.21	0.02
60	0.29	0.07	0.10	0.00	0.00	0.04	0.07	0.00
66	5.23	0.33	0.02	0.00	0.03	4.48	0.09	0.26
68	35.41	4.04	4.15	0.00	0.09	22.78	0.41	3.43
69	8.13	1.55	2.97	0.02	0.00	1.67	0.02	1.52
70	11.96	1.41	1.92	0.10	0.06	5.22	0.16	2.14
71	11.51	0.84	0.35	0.00	0.00	8.92	0.32	0.62
75	0.58	0.12	0.13	0.04	0.00	0.00	0.04	0.22
76	-	-	-	-	-	-	-	-
78	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00

SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species
- = missing value.

N.B. New Ferry is mean of four sections corrected for area.

Table 20 Mean bird densities - winter 1990/91 Mersey low tide counts.

Section (LT)	Bird densities (nos/ha)							
	All	SU	T	PT	GV	DN	CU	RK
New Ferry 25-28	30.58	0.43	1.00	1.33	0.00	9.69	0.52	7.39
33	24.43	1.62	2.88	0.92	0.00	2.12	0.23	14.08
35	11.67	3.64	0.12	0.00	0.00	7.06	0.24	0.61
36	10.04	0.53	0.07	0.10	0.02	8.34	0.31	0.49
39	10.65	0.33	0.00	0.00	0.27	8.80	0.18	0.89
40	3.24	0.09	0.00	0.00	0.00	2.51	0.05	0.58
47	2.81	0.05	0.00	0.00	0.00	2.37	0.21	0.03
49	0.19	0.01	0.00	0.00	0.00	0.00	0.17	0.00
55	2.38	0.84	0.00	0.00	0.00	0.00	0.18	0.17
58	0.23	0.00	0.00	0.00	0.00	0.00	0.21	0.02
60	0.87	0.11	0.09	0.00	0.00	0.44	0.14	0.02
66	2.12	0.09	0.00	0.00	0.12	1.54	0.10	0.06
68	22.79	3.59	5.67	0.00	0.00	12.89	0.11	0.50
69	4.18	0.92	1.67	0.00	0.00	0.05	0.07	1.30
70	14.06	1.24	2.24	0.20	0.00	5.63	0.14	1.04
71	1.84	0.32	0.00	0.00	0.03	1.27	0.14	0.05
75	0.22	0.00	0.10	0.00	0.00	0.00	0.01	0.10
76	2.46	0.25	0.22	0.13	0.06	0.80	0.12	0.22
78	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00

SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species

N.B. New Ferry is mean of four sections corrected for area.

Table 21 Mean bird densities - winter 1991/92 Mersey low tide counts.

Section (LT)	Bird densities (*nos/ha*)							
	All	SU	T	PT	GV	DN	CU	RK
New Ferry 25-28	13.03	-0.32	0.93	0.94	0.00	2.73	0.28	4.36
33	13.12	0.20	0.11	0.69	0.00	1.31	0.19	8.89
35	-6.88	0.95	-0.76	-0.11	0.00	-4.08	0.12	-2.90
36	-9.54	0.25	-0.12	-0.25	0.01	-6.65	0.21	-2.72
39	2.12	-0.45	-0.16	0.00	0.07	2.31	0.02	0.53
40	-1.44	0.01	0.00	0.00	-0.02	1.45	-0.13	0.19
47	-0.08	-0.53	-0.32	0.00	0.00	1.74	-0.20	-0.06
49	0.05	0.01	0.00	0.00	0.00	0.00	0.03	0.00
55	1.95	0.55	0.00	0.00	0.00	-0.07	0.16	0.15
58	-0.07	-0.02	-0.03	0.00	0.00	-0.02	0.00	0.00
60	0.58	0.04	-0.01	0.00	0.00	0.40	0.07	0.02
66	-3.11	-0.24	-0.02	0.00	-0.09	-2.94	0.01	-0.20
68	-12.62	-0.45	1.52	0.00	-0.09	-9.89	-0.30	-2.93
69	-3.95	-0.63	-1.30	-0.02	0.00	-1.62	0.05	-0.22
70	2.10	-0.17	0.32	0.10	-0.06	0.41	-0.02	-1.10
71	-9.67	-0.52	-0.35	0.00	0.03	-7.65	-0.18	-0.57
75	-0.36	-0.12	-0.03	-0.04	0.00	0.00	-0.03	-0.12
76	-	-	-	-	-	-	-	-
78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species
- = missing value.

N.B. New Ferry is mean of four sections corrected for area.

Table 22 Change in bird densities on low tide counting areas between the winters of 1990/91 and 1991/1992. Positive values indicate an increase, negative a decrease.

Section ERL name and LT number	Invertebrate densities (m^{-2})					
	TU	MA	NE	CO	HY	TOTAL
New Ferry 25-28	16443	539	116	365	375	18549
Manisty (top - bottom) 33	6057	55	95	247	28	6498
Stanlow (and mid and bottom) 35	18515	243	649	2449	210	22152
Stanlow 1 36	3194	85	178	294	101	3875
Stanlow 3# 39	-	-	-	-	-	-
Stanlow 2# 40	-	-	-	-	-	-
Ince Creek (top - bottom) 47	953	15	116	239	0	1351
49@	0	0	0	0	0	0
Weaver (consolidated + fluid) 55	8091	29	243	135	0	8498
58@	0	0	0	0	0	0
60@	0	0	0	0	0	0
BTO outer# 66	-	-	-	-	-	-
Oglet consolidated + BTO inner# 68	25927	0	201	0	0	26159
Oglet fluid 69	41570	308	154	0	0	42086
Oglet (top - bottom + *Spartina#*) 70	13860	0	39	0	0	13898
Oglet Creek 71	11941	232	332	70	0	12621
Sandbank between Oglet and Stanlow# 75	-	-	-	-	-	-
Gantry 76	412	0	39	0	0	451
(Sandbank Stanlow/Gantry + Eastham Sands and Dynamic)# 78	-	-	-	-	-	-

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
# = not sampled - = missing value

Table 23 Mean density of invertebrates (November to March) - winter 1990/91.

Section ERL name and LT number	Invertebrate densities (m^{-2})					
	TU	MA	NE	CO	HY	TOTAL
New Ferry 25-28	29967	785	240	1772	3238	36144
Manisty (top - bottom) 33	20661	157	98	129	8	21062
Stanlow (and mid and bottom) 35	26502	57	1832	496	18	28949
Stanlow 1 36	25933	1044	153	2339	575	30136
Stanlow 3 39	5759	186	305	13519	86	19929
Stanlow 2 40	13828	301	612	5990	264	21213
Ince Creek (top - bottom) 47	1110	12	8	23	0	1153
49@	0	0	0	0	0	0
Weaver (consolidated + fluid) 55	885	0	6	21	240	1151
58@	0	0	0	0	0	0
60@	0	0	0	0	0	0
BTO outer 66	51829	248	634	77	54	53051
Oglet consolidated + BTO inner 68	41796	184	170	137	19	42347
Oglet fluid 69	5139	41	52	42	0	5297
Oglet (top - bottom + *Spartina*) 70	72994	11	556	416	335	74348
Oglet Creek 71	6044	238	46	76	64	6474
Sandbank between Oglet and Stanlow 75	217	2281	15	147	39	3588
Gantry 76	93	0	0	8	0	101
Sandbank Stanlow/Gantry + Eastham Sands and Dynamic 78	52	0	0	77	130	297

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*

Table 24 Mean density of invertebrates (November to March) - winter 1991/92.

Section ERL name and LT number	Invertebrate biomass (AFDW gm^{-2})					
	TU	MA	NE	CO	HY	TOTAL
New Ferry 25-28	2.144	1.302	0.970	0.194	0.169	4.975
Manisty (top - bottom) 33	0.988	0.082	0.165	0.120	0.000	1.354
Stanlow (and mid and bottom) 35	0.564	0.276	1.594	0.418	0.003	2.854
Stanlow 1 36	0.399	0.172	0.455	0.172	0.040	1.238
Stanlow 3# 39	-	-	-	-	-	-
Stanlow 2# 40	-	-	-	-	-	-
Ince Creek (top - bottom) 47	0.134	0.069	0.176	0.072	0.000	0.470
49@	0.000	0.000	0.000	0.000	0.000	0.000
Weaver (consolidated + fluid) 55	3.373	0.029	0.157	0.083	0.000	3.642
58@	0.000	0.000	0.000	0.000	0.000	0.000
60@	0.000	0.000	0.000	0.000	0.000	0.000
BTO outer# 66	-	-	-	-	-	-
Oglet consolidated + BTO inner# 68	5.125	0.321	0.538	0.000	0.000	5.984
Oglet fluid 69	3.267	0.000	0.222	0.000	0.000	3.489
Oglet (top - bottom + *Spartina#*)	4.537	0.032	0.036	0.002	0.000	4.604
Oglet Creek 71	0.915	0.329	1.071	0.026	0.000	2.341
Sandbank between Oglet and Stanlow# 75	-	-	-	-	-	-
Gantry 76	0.052	0.000	0.039	0.000	0.000	0.091
(Sandbank Stanlow/Gantry + Eastham Sands and Dynamic)# 78	-	-	-	-	-	-

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
# = not sampled - = missing value

Table 25 Mean biomass of invertebrates (November to March) - winter 1990/91.

Section ERL name and LT number	Invertebrate biomass (AFDW gm^{-2})					
	TU	MA	NE	CO	HY	TOTAL
New Ferry 25-28	3.821	1.301	0.676	0.761	1.261	7.819
Manisty (top - bottom) 33	2.602	0.207	0.043	0.034	0.000	2.885
Stanlow (and mid and bottom) 35	5.078	1.169	9.741	1.628	0.083	17.699
Stanlow 1 36	3.270	2.861	0.958	4.838	0.227	12.154
Stanlow 3 39	0.726	1.569	0.468	8.793	0.043	11.625
Stanlow 2 40	1.742	2.023	1.365	2.856	0.105	8.091
Ince Creek (top - bottom) 47	0.135	0.014	0.000	0.005	0.000	0.154
49@	0.000	0.000	0.000	0.000	0.000	0.000
Weaver (consolidated + fluid) 55	0.111	0.000	0.014	0.005	0.000	0.129
58@	0.000	0.000	0.000	0.000	0.000	0.000
60@	0.000	0.000	0.000	0.000	0.000	0.000
BTO outer 66	6.530	0.206	1.888	0.025	0.000	8.649
Oglet consolidated + BTO inner 68	5.264	0.138	1.231	0.088	0.003	6.724
Oglet fluid 69	0.516	0.038	0.060	0.011	0.000	0.625
Oglet (top - bottom + *Spartina*) 70	9.146	0.054	1.352	0.180	0.120	10.851
Oglet Creek 71	0.762	0.836	0.032	0.026	0.000	1.656
Sandbank between Oglet and Stanlow 75	0.036	4.000	0.000	0.172	0.000	5.000
Gantry 76	0.033	0.000	0.000	0.002	0.000	0.035
Sandbank Stanlow/Gantry + Eastham Sands and Dynamic 78	0.004	0.000	0.000	0.070	0.000	0.122

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*

Table 26 Mean biomass of invertebrates (November to March) - winter 1991/92.

Section ERL name and LT number	Invertebrate biomass (AFDW gm^{-2})					
	TU	MA	NE	CO	HY	TOTAL
New Ferry 25-28	1.677	-0.001	-0.294	0.567	1.092	2.844
Manisty (top - bottom) 33	1.614	0.125	-0.122	-0.086	0.000	1.531
Stanlow (and mid and bottom) 35	4.514	0.893	8.147	1.210	0.080	14.845
Stanlow 1 36	2.871	2.689	0.503	4.666	0.187	10.916
Stanlow 3 39	-	-	-	-	-	-
Stanlow 2 40	-	-	-	-	-	-
Ince Creek (top - bottom) 47	0.001	-0.055	-0.176	-0.067	0.000	0.316
49	0.000	0.000	0.000	0.000	0.000	0.000
Weaver (consolidated + fluid) 55	-3.262	-0.029	-0.143	-0.078	0.000	-3.513
58	0.000	0.000	0.000	0.000	0.000	0.000
60	0.000	0.000	0.000	0.000	0.000	0.000
BTO outer 66	-	-	-	-	-	-
Oglet consolidated + BTO inner 68	0.139	-0.183	0.693	0.088	0.003	0.740
Oglet fluid 69	2.751	0.038	-0.162	0.011	0.000	-2.864
Oglet (top - bottom + *Spartina*) 70	4.609	0.022	1.316	0.178	0.120	6.247
Oglet Creek 71	-0.153	0.507	-1.039	0.000	0.000	-0.685
Sandbank between Oglet and Stanlow 75	-	-	-	-	-	-
Gantry 76	-0.019	0.000	-0.039	0.002	0.000	-0.056
Sandbank Stanlow/Gantry + Eastham Sands and Dynamic 78	-	-	-	-	-	-

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
- = missing value

Table 27 Change in invertebrate biomass (November to March) over the winters of 1990/91 and 1991/92. Positive values indicate an increase, negative a decrease.

Birds	Invertebrates					
	TU	MA	NE	CO	HY	Total
SU	0.042	0.117	0.233	0.082	0.058	0.022
T	0.166	0.162	0.052	0.126	0.026	0.128
PT	0.000	0.045	0.097	0.008	0.537# *	0.000
GV	0.000	0.098	0.215	0.773# *	0.127	0.073
DN	0.001	0.023	0.000	0.012	0.044	0.000
CU	0.035	0.004	0.004	0.001	0.647# ***	0.054
RK	0.017	0.027	0.062	0.030	0.084	0.019
Total	0.033	0.079	0.010	0.016	0.268# *	0.029

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species

* = P>0.05 ** = P>0.01 *** = P>0.001
# = significance of correlation based largely on one outlier

Table 28 Coefficients of determination for waterfowl-invertebrate relationships (densities).

Birds	Invertebrates					
	TU	MA	NE	CO	HY	Total
SU	0.103	0.127	0.052	0.037	0.208	0.050
T	0.162	0.192	0.001	0.154	0.127	0.127
PT	0.012	0.079	0.078	0.032	0.011	0.013
GV	0.001	0.025	0.300	0.326	0.124	0.189
DN	0.006	0.019	0.066	0.159	0.125	0.029
CU	0.208	0.039	0.036	0.076	0.287# *	0.189
RK	0.017	0.018	0.002	0.003	0.007	0.002
Total	0.293# *	0.126	0.116	0.053	0.037	0.136

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species

* = P>0.05 ** = P>0.01 *** = P>0.001
# = significance of correlation based largely on one outlier

Table 29 Coefficients of determination for waterfowl-invertebrate relationships (densities logged).

Birds	Invertebrates					
	TU	MA	NE	CO	HY	Total
SU	0.122	0.209	0.399	0.136	0.098	0.053
T	0.211	0.245	0.039	0.134	0.022	0.007
PT	0.001	0.004	0.267	0.054	0.903# **	0.000
GV	0.141	0.003	0.203	0.738	0.210	0.242
DN	0.082	0.252	0.048	0.051	0.000	0.268
CU	0.018	0.140	0.002	0.002	0.769# ***	0.072
RK	0.047	0.030	0.076	0.137	0.631# **	0.216
Total	0.008	0.244	0.049	0.278	0.356	0.187

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species

* = P>0.05 ** = P>0.01 *** = P>0.001
# = significance of correlation based largely on one outlier

Table 30 Coefficients of determination for waterfowl-invertebrate relationships (biomasses).

Birds	Invertebrates					
	TU	MA	NE	CO	HY	Total
SU	0.283 **	0.000	0.217# *	0.003	0.006	0.203 *
T	0.361 **	0.129	0.003	0.087	0.006	0.085
PT	0.020	0.075	0.003	0.001	0.488# *	0.024
GV	0.001	0.033	0.044	0.287	0.041	0.241
DN	0.212 *	0.196 *	0.254# **	0.118	0.097	0.400 ***
CU	0.033	0.023	0.037	0.023	0.273# **	0.027
RK	0.104	0.000	0.004	0.000	0.143# *	0.065
Total	0.412 ***	0.041	0.227# **	0.066	0.137# *	0.395 ***

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species

* = P>0.05 ** = P>0.01 *** = P>0.001
# = significance of correlation based largely on one outlier

Table 31 Coefficients of determination for waterfowl-invertebrate relationships (biomasses logged).

Bird species ($\log_e$densities)	Invertebrate species ($\log_e$biomass)	Regression coefficients	Intercept coefficients
Shelduck	Oligochaetes Total invertebrates	0.3484 0.2314	0.2553 0.2720
Teal	Oligochaetes	0.4801	0.2134
Dunlin	Oligochaetes *Macoma balthica* Total invertebrates	0.6109 1.0738 0.6695	0.8277 1.0710 0.5019
All bird species	Oligochaetes Total invertebrates	0.9876 0.7586	0.9463 0.8319

Table 32 Invertebrate correlates of waterfowl densities using natural logarithm-transformed data.

Birds	Invertebrates					
	TU	MA	NE	CO	HY	Total
SU	0.010	0.132	0.438# *	0.106	0.011	0.309 *
T	0.045	0.052	0.053	0.005	0.152	0.004
PT	0.002	0.131	0.055	0.083	0.488# **	0.022
GV	0.029	0.099	0.012	0.029	0.004	0.002
DN	0.004	0.198	0.034	0.146	0.082	0.061
CU	0.046	0.115	0.019	0.147	0.241	0.085
RK	0.012	0.103	0.131	0.107	0.095	0.092
Total	0.002	0.161	0.060	0.113	0.225	0.045

TU = Oligochaetes: *Tubifex/Tubificoides/Clitellio* MA = *Macoma baltica* NE = *Nereis diversicolor*
CO = *Corophium volutator* HY = *Hydrobia ulvae*
SU = Shelduck T = Teal PT = Pintail GV = Grey Plover DN = Dunlin
CU = Curlew RK = Redshank All = Total of birds of all species

* = P>0.05 ** = P>0.01 *** = P>0.001
# = significance of correlation based largely on one outlier

Table 33 Coefficients of determination of between-year changes in waterfowl densities and invertebrate biomasses.

Bird species (change between years)	Invertebrate species (change between years)	Regression coefficient	Intercept coefficient
Shelduck	Total invertebrates	0.0483	-0.1620

Table 34 Correlate of between-year changes in Shelduck densities and invertebrate biomass.

FIGURES

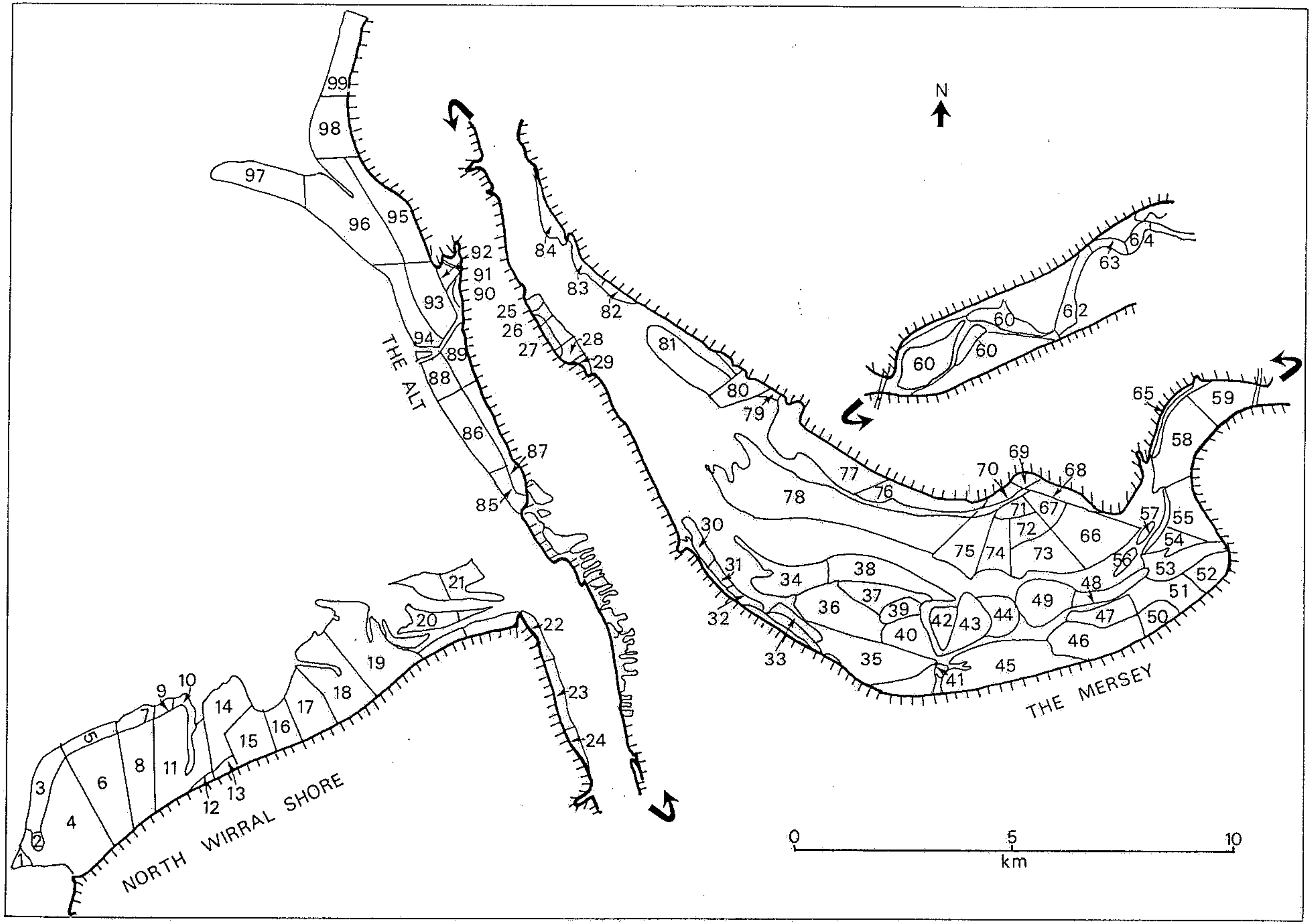


Figure 1.2.1 The locations of the 96 intertidal areas which were surveyed regularly during the 1988/89 to 1991/92 winters.

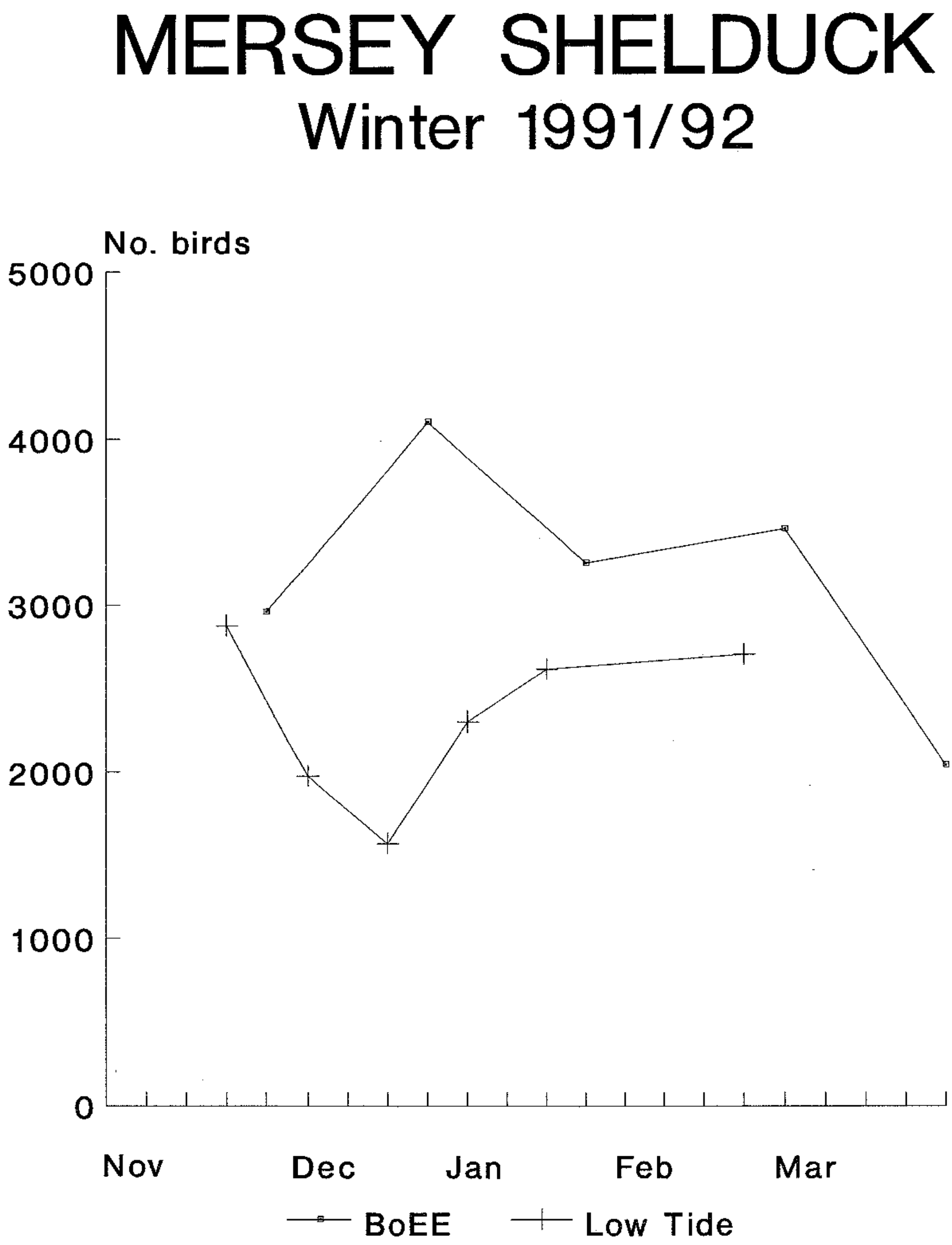


Figure 1.3.1.1 High tide (BoEE) and low tide counts of Shelduck during the 1991/92 winter.

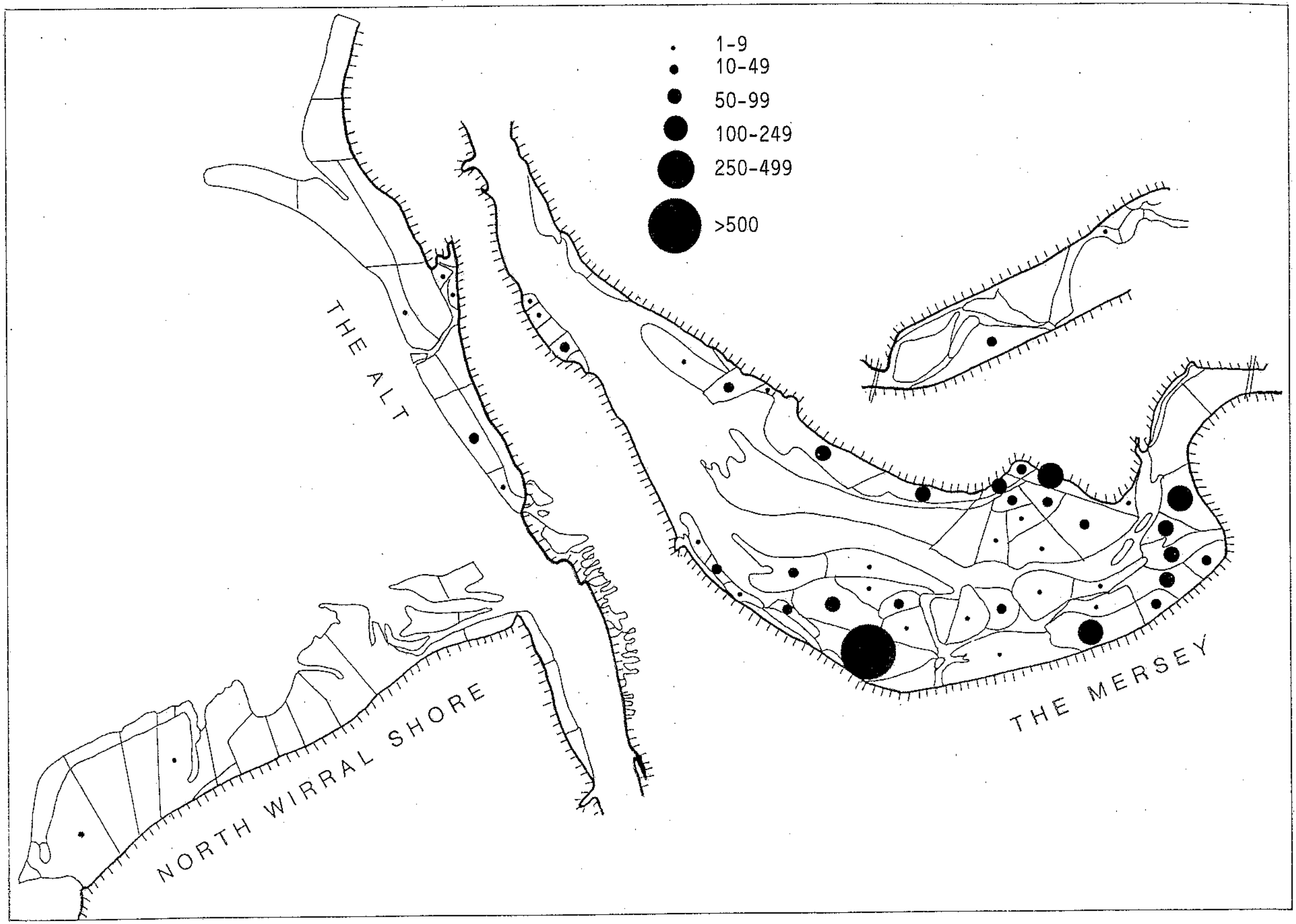


Figure 1.3.1.2 The average number of Shelduck feeding at low tide on each intertidal area during the 1991/92 winter.

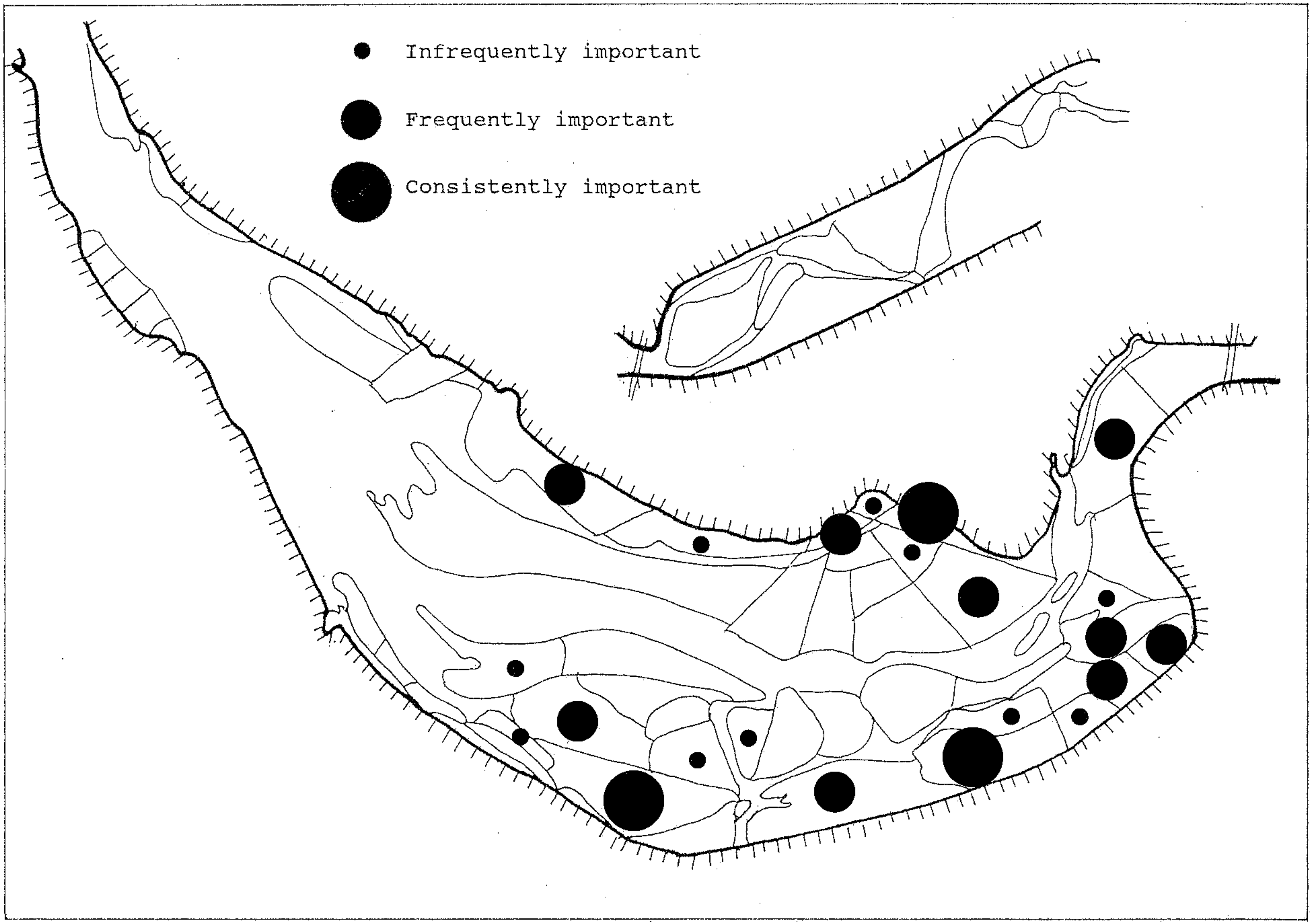


Figure 1.3.1.3 The relative importance of intertidal areas for feeding Shelduck in the winters 1988/89 to 1991/92 (for definition of importance classes, see Section 1.2.2).

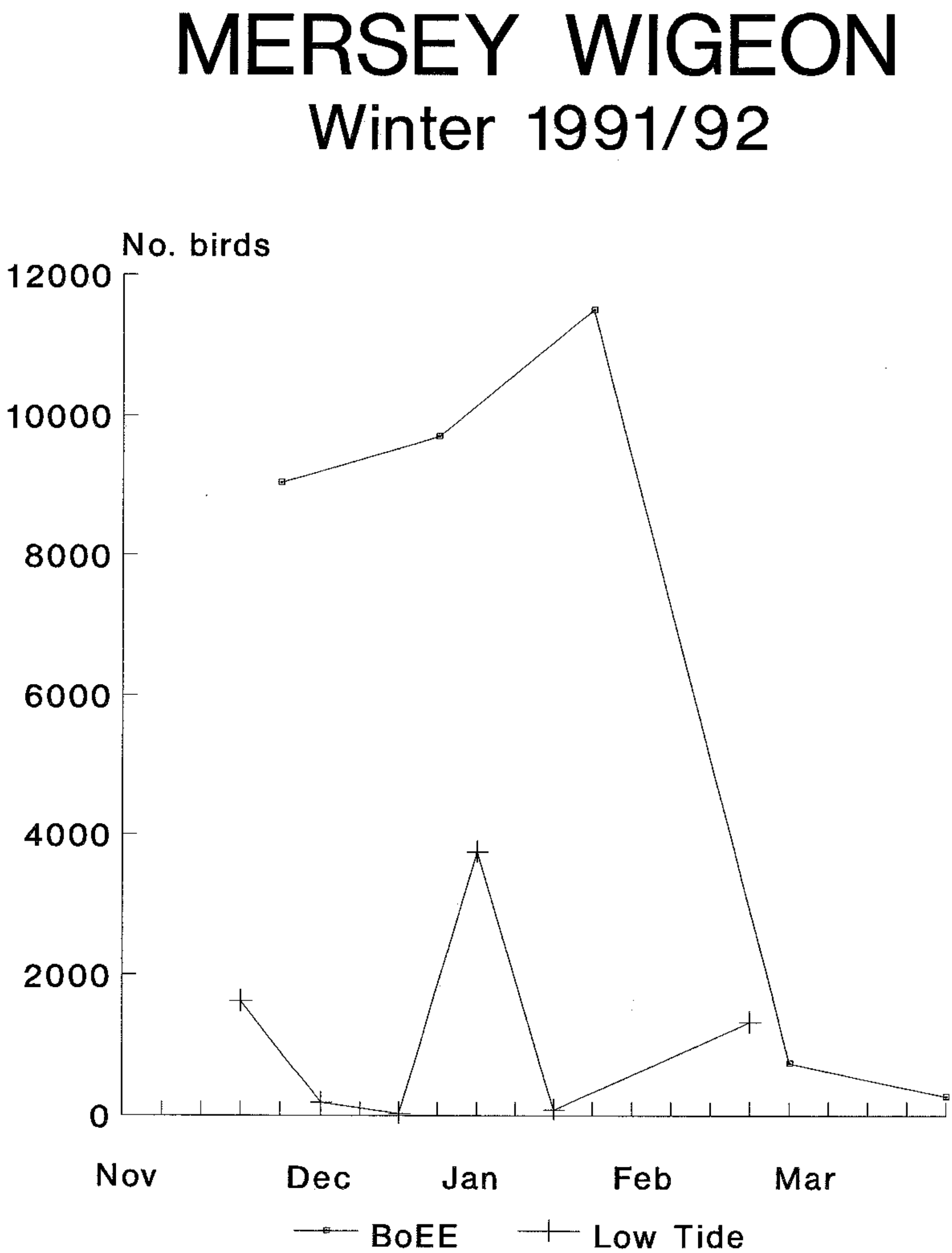


Figure 1.3.2.1 High tide (BoEE) and low tide counts of Wigeon during the 1991/92 winter.

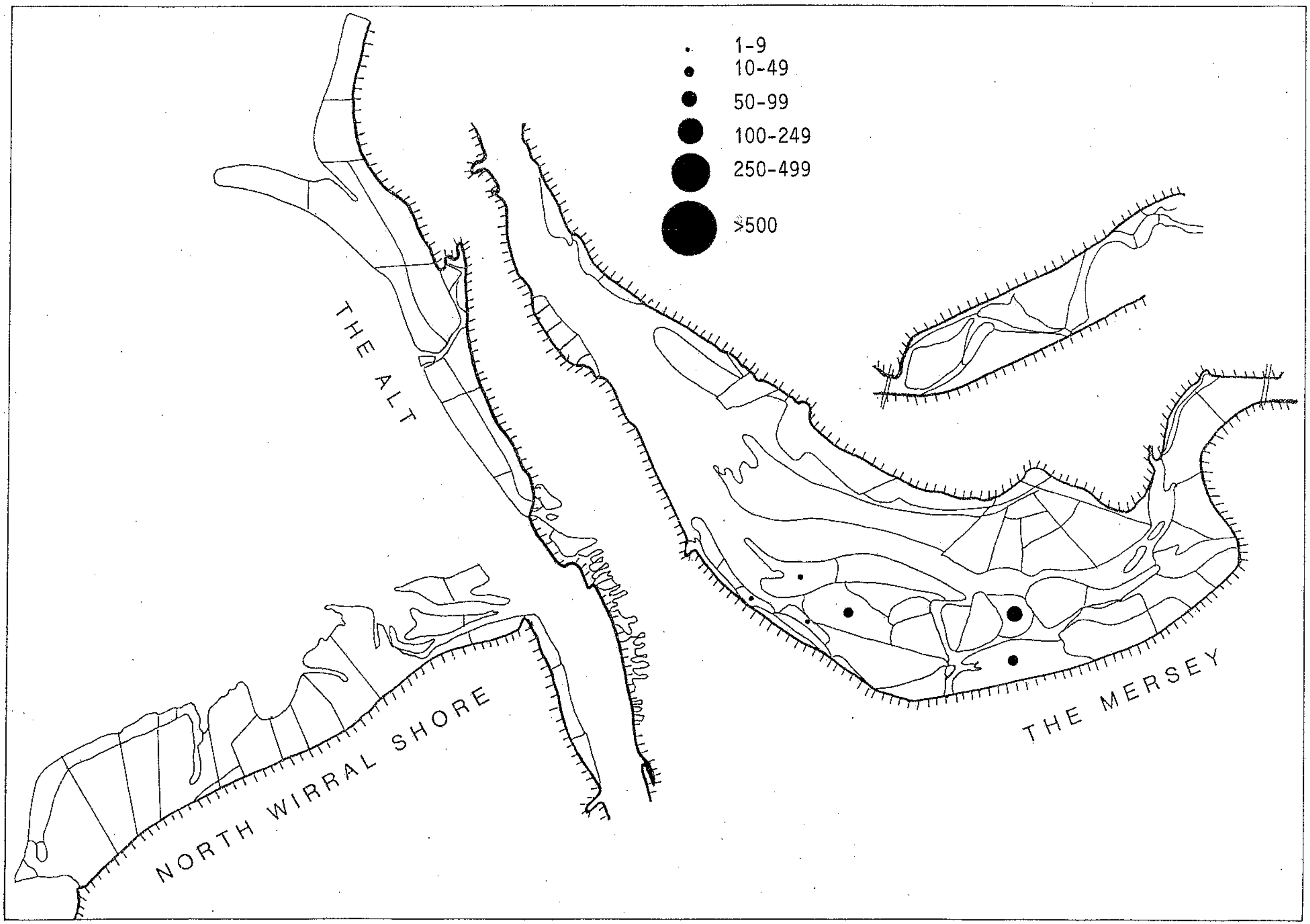


Figure 1.3.2.2 The average number of Wigeon feeding at low tide on each intertidal area during the 1991/92 winter.

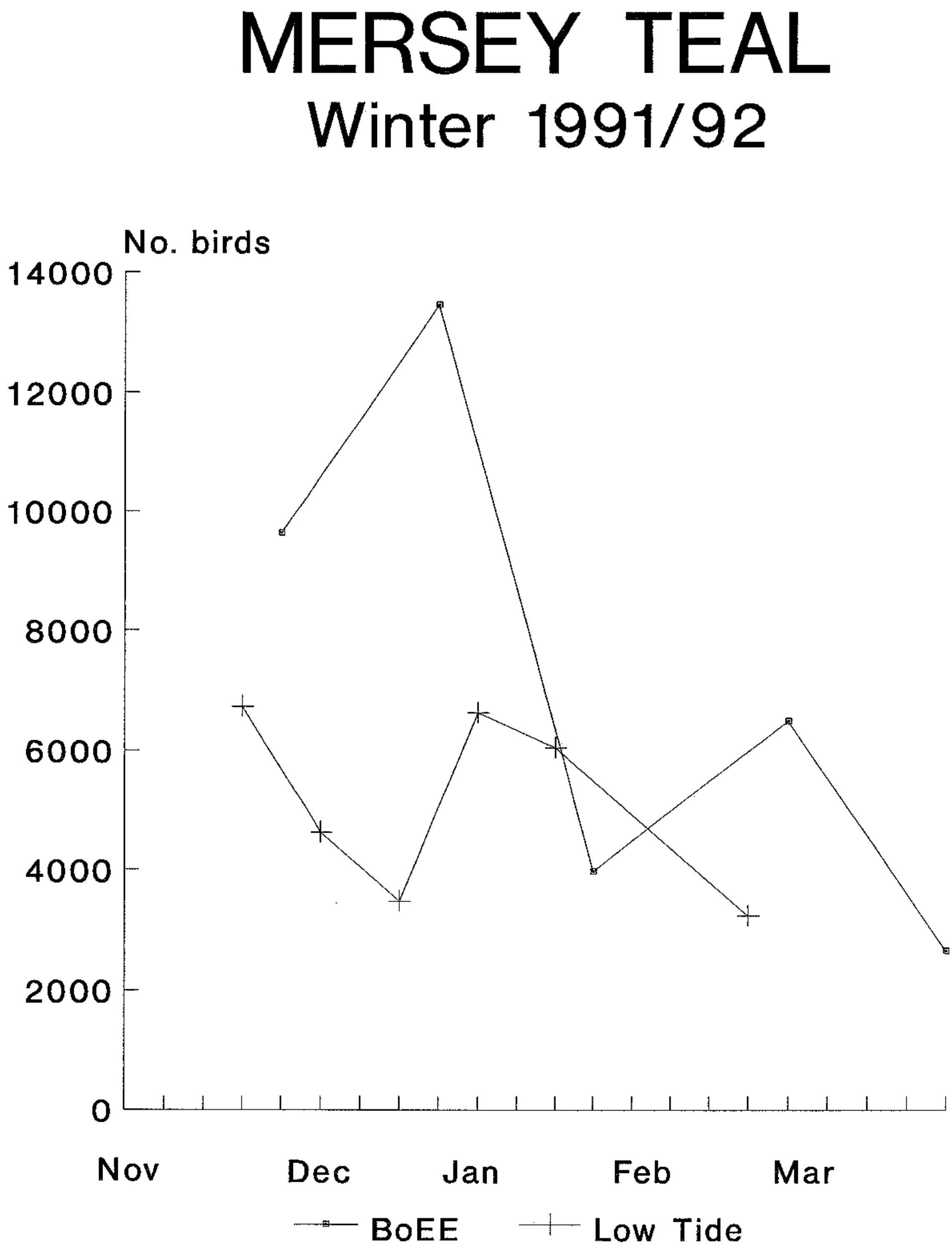


Figure 1.3.3.1 High tide (BoEE) and low tide counts of Teal during the 1991/92 winter.

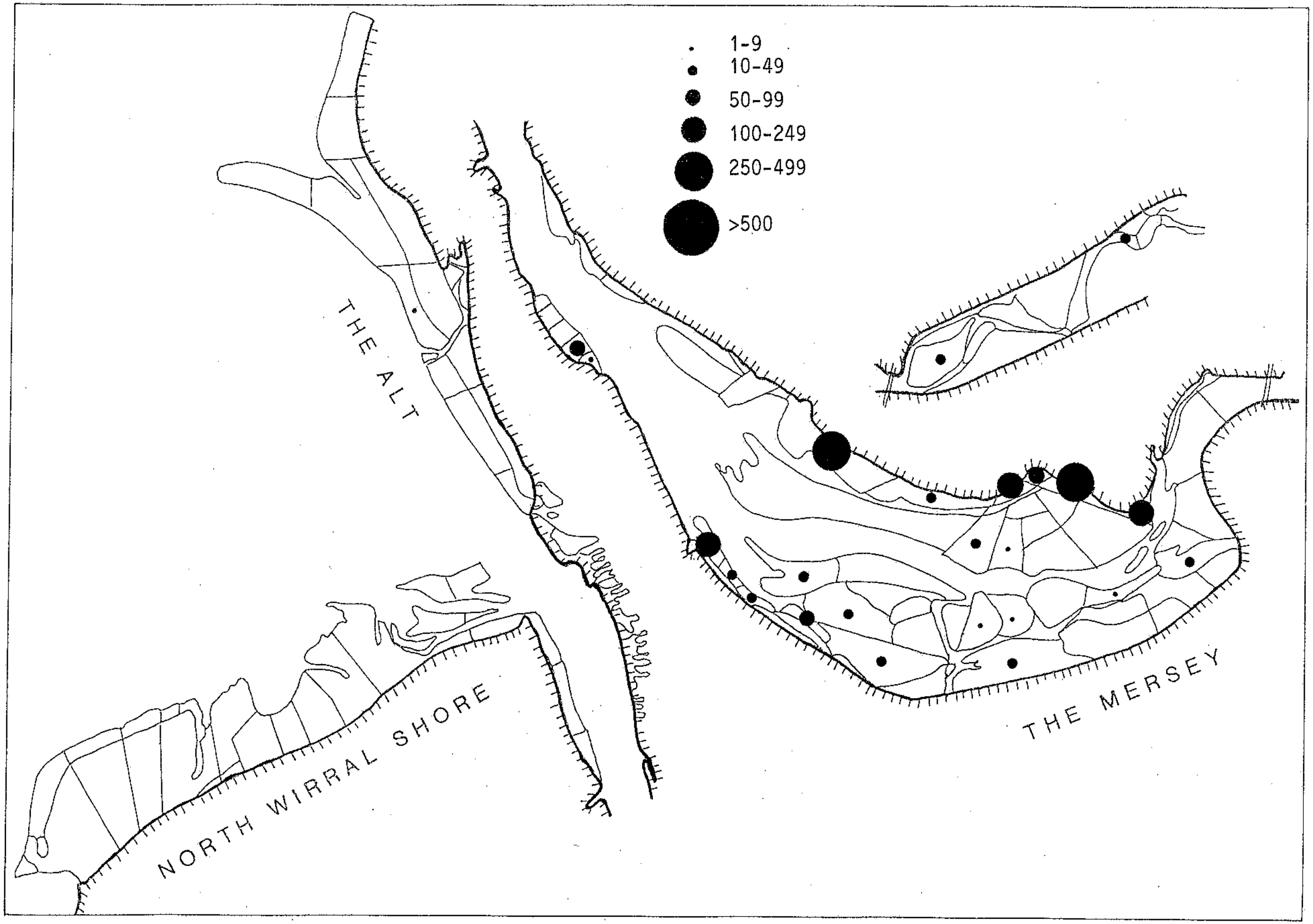


Figure 1.3.3.2 The average number of Teal feeding at low tide on each intertidal area during the 1991/92 winter.

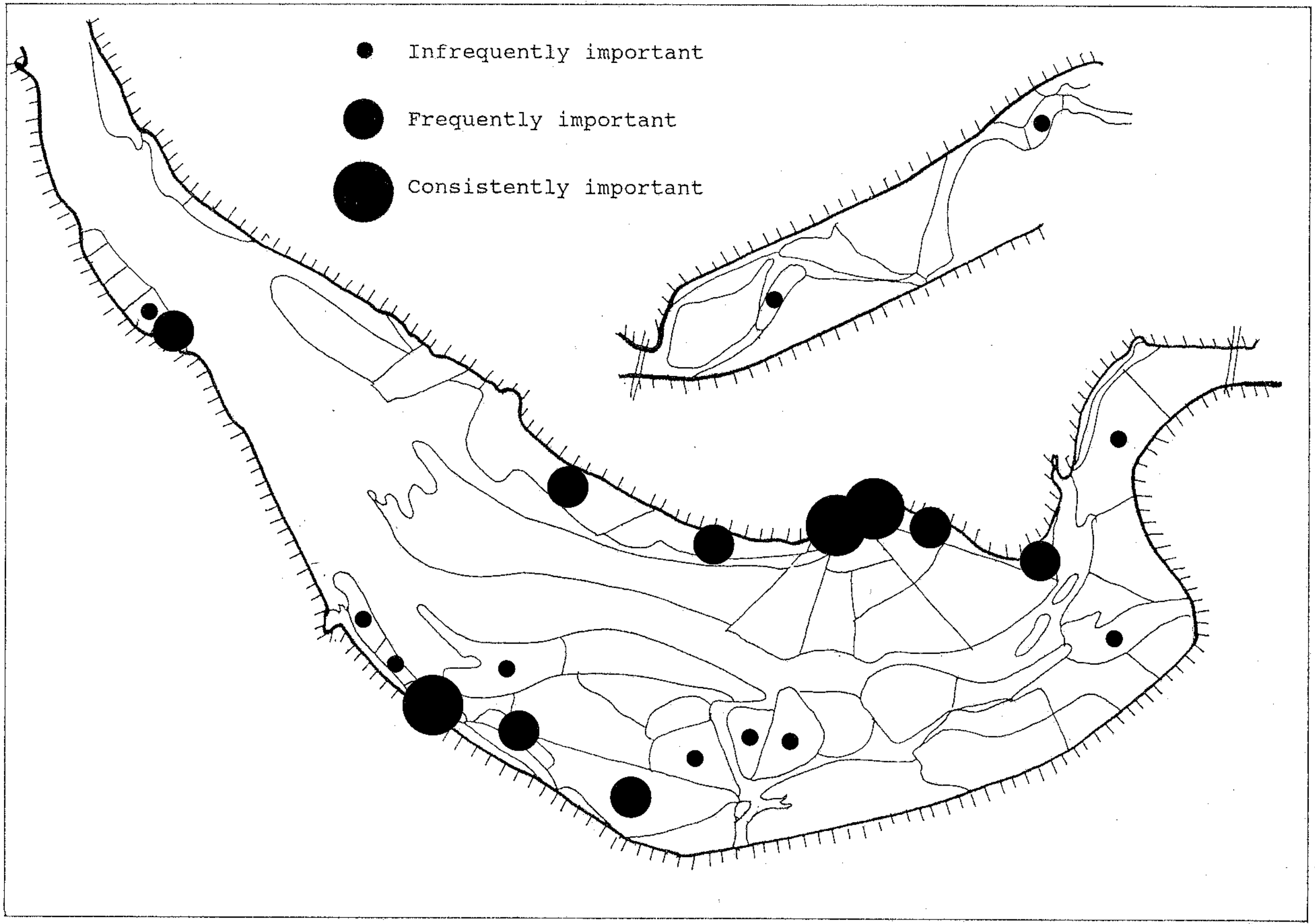


Figure 1.3.3.3 The relative importance of intertidal areas for feeding Teal in the winters 1988/89 to 1991/92. (for definition of importance classes, see Section 1.2.2).

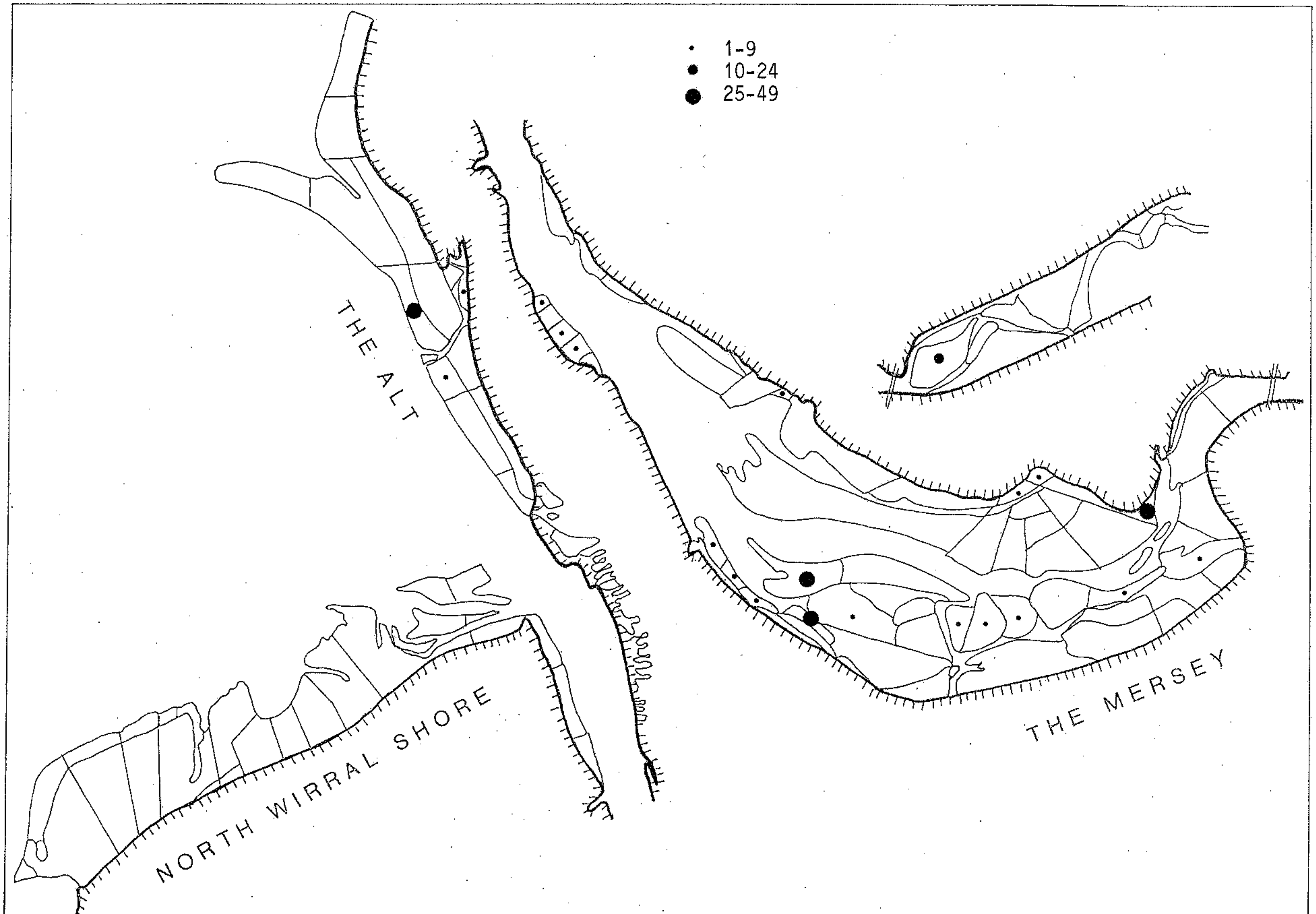


Figure 1.3.4.1 The average number of Mallard feeding at low tide on each intertidal area during the 1991/92 winter.

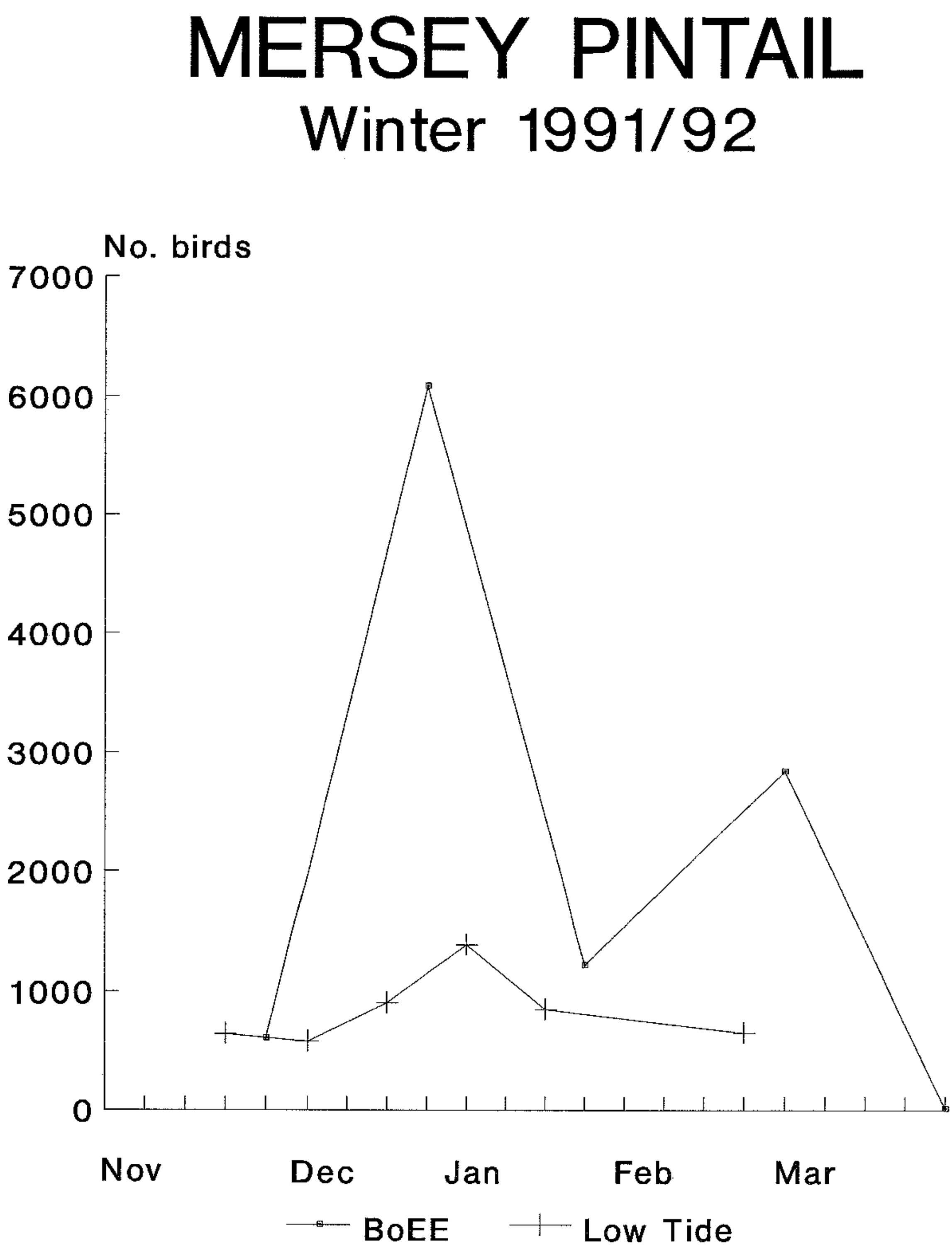


Figure 1.3.5.1 High tide (BoEE) and low tide counts of Pintail during the 1991/92 winter.

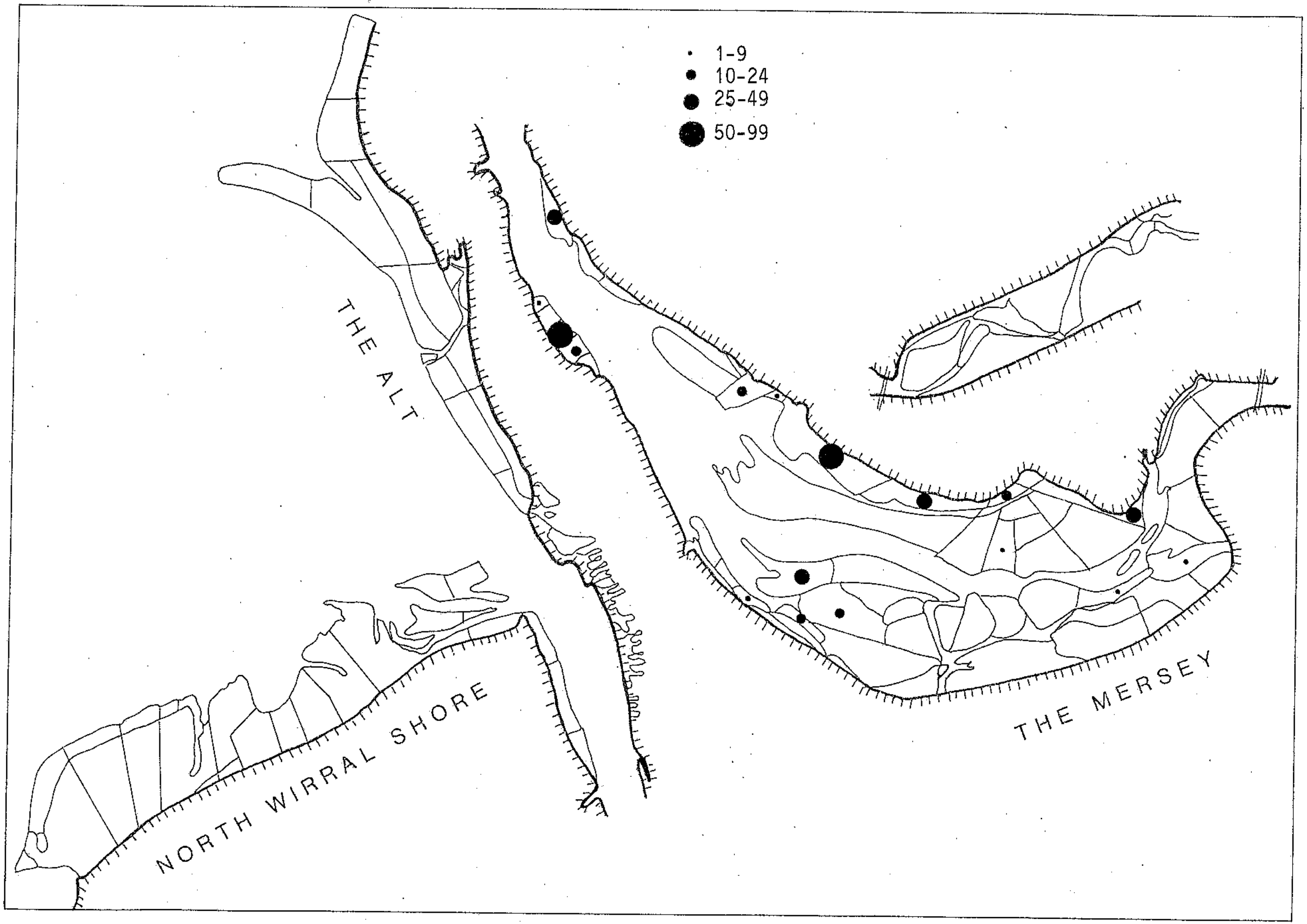


Figure 1.3.5.2 The average number of Pintail feeding at low tide on each intertidal area during the 1991/92 winter.

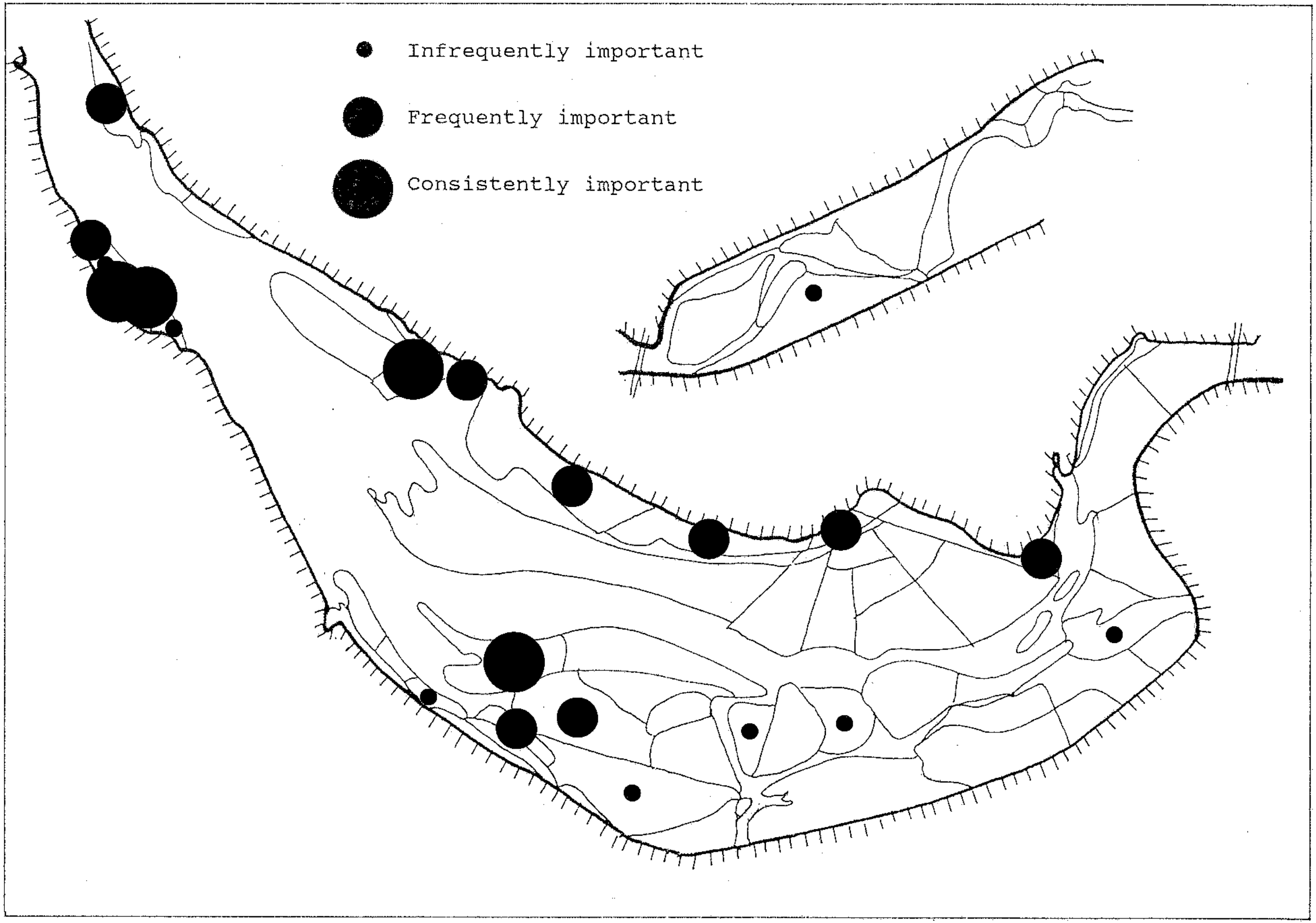


Figure 1.3.5.3 The relative importance of intertidal areas for feeding Pintail in the winters 1988/89 to 1991/92 (for definition of importance classes, see Section 1.2.2).

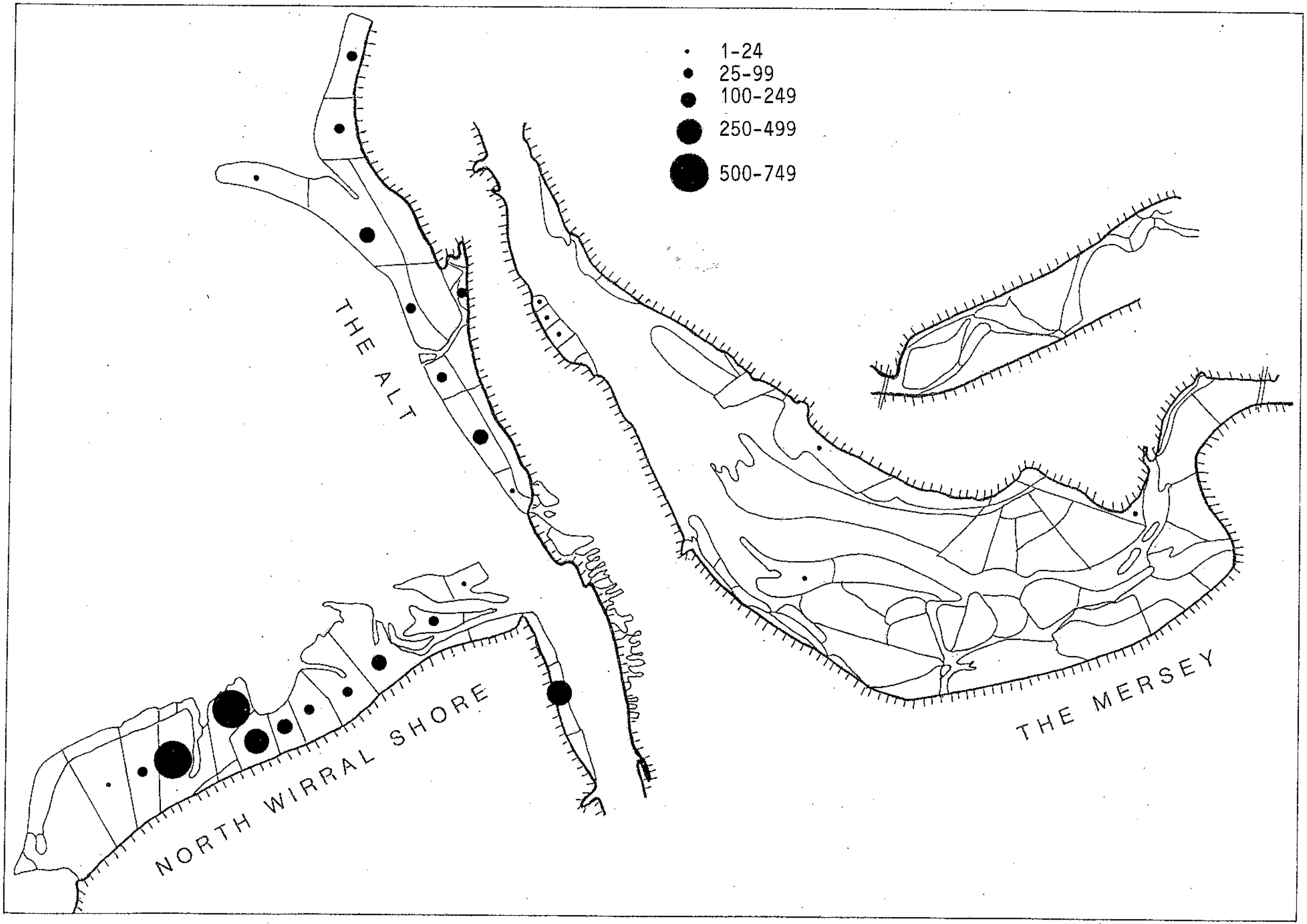


Figure 1.3.6.1 The average number of Oystercatcher feeding at low tide on each intertidal area during the 1991/92 winter.

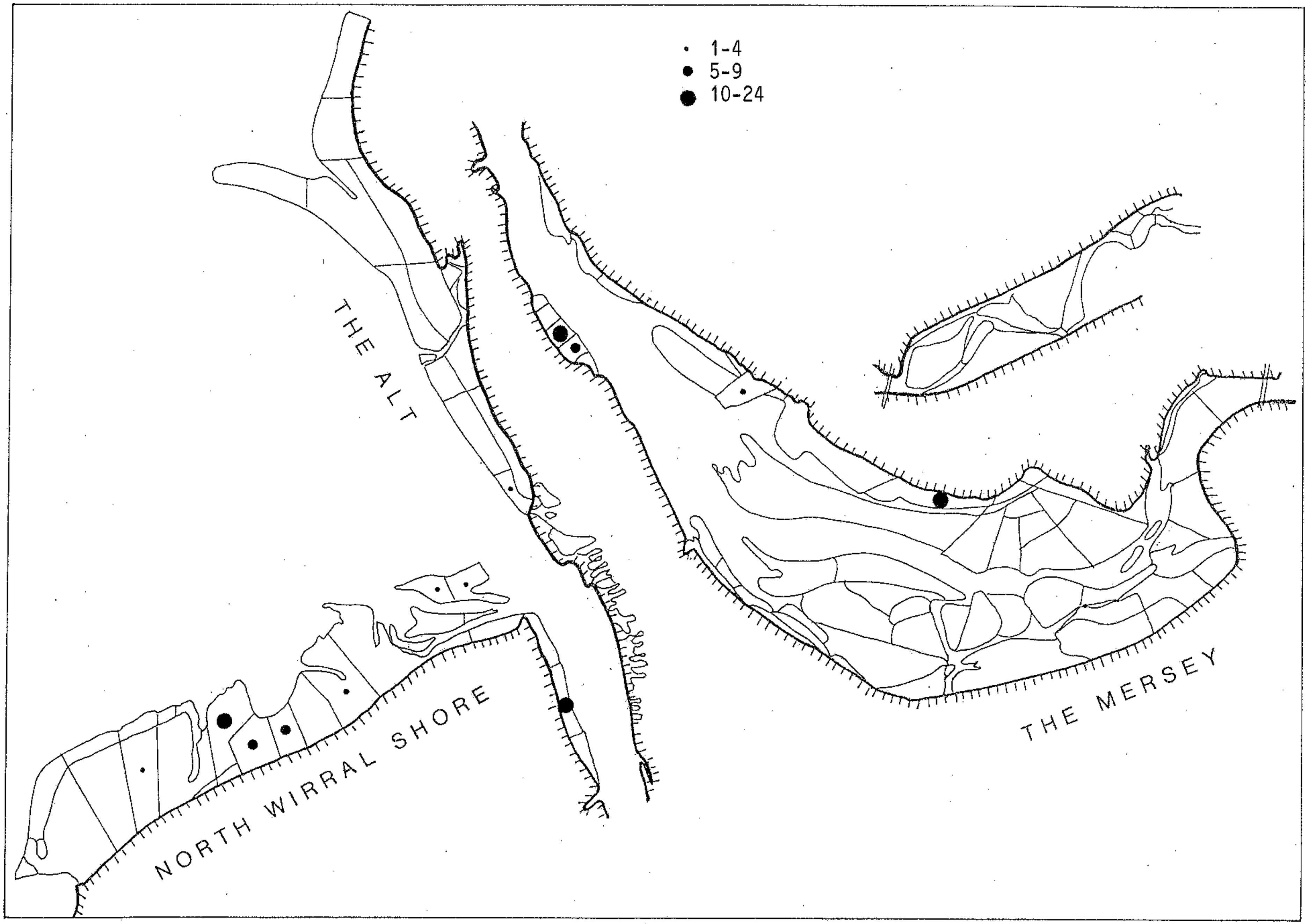


Figure 1.3.7.1 The average number of Ringed Plover feeding at low tide on each intertidal area during the 1991/92 winter.

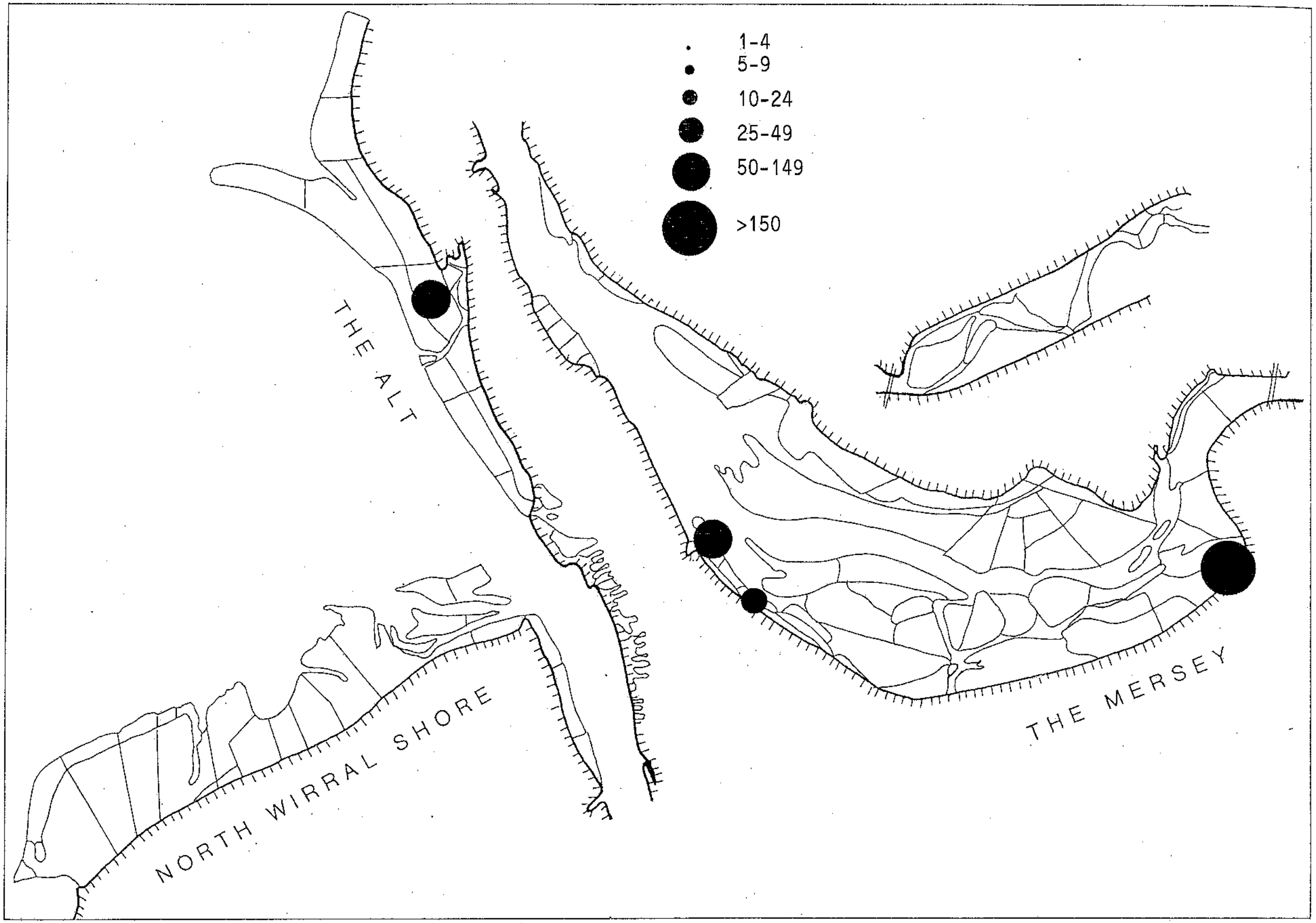


Figure 1.3.8.1 The average number of Golden Plover feeding at low tide on each intertidal area during the 1991/92 winter.

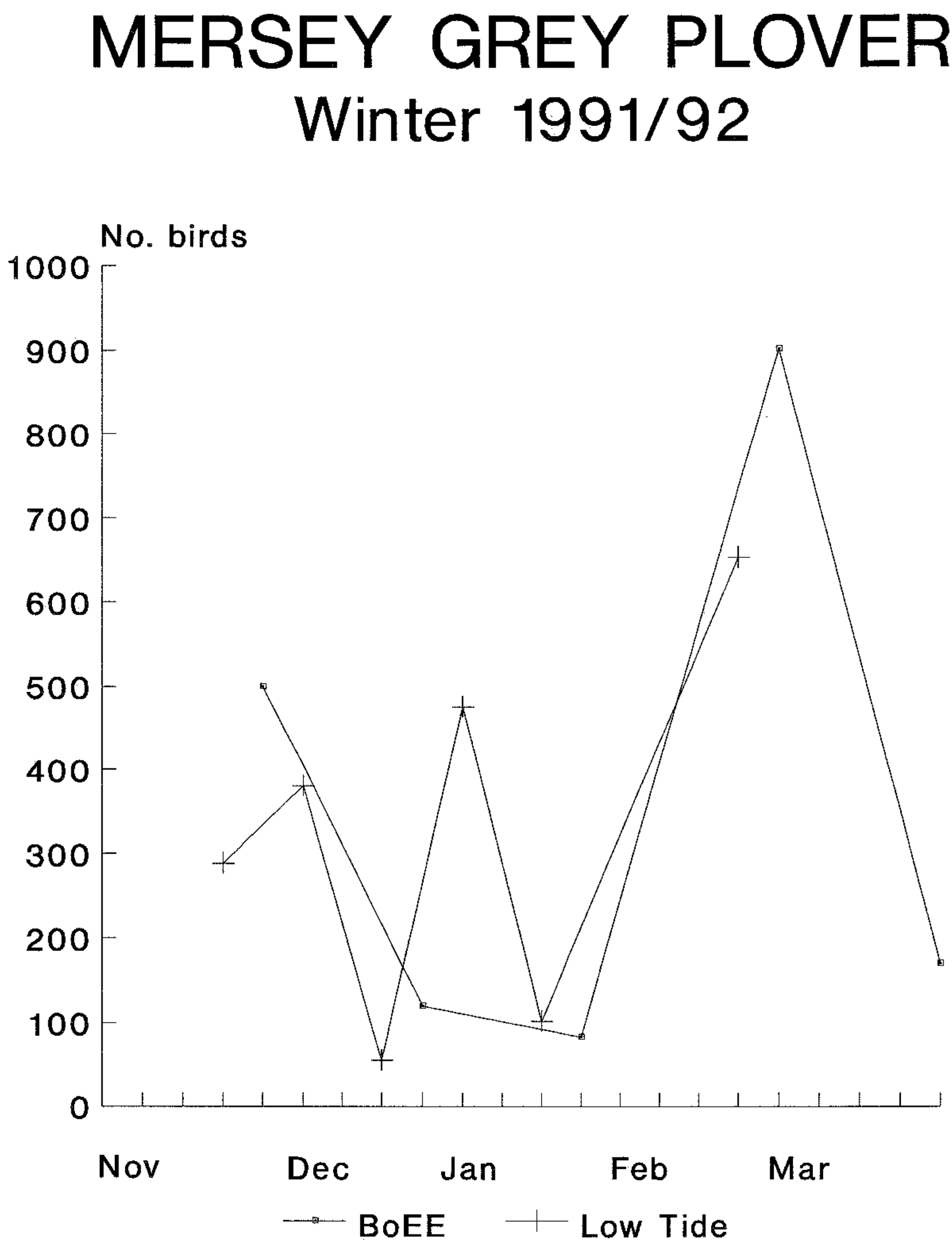


Figure 1.3.9.1 High tide (BoEE) and low tide counts of Grey Plover during the 1991/92 winter.

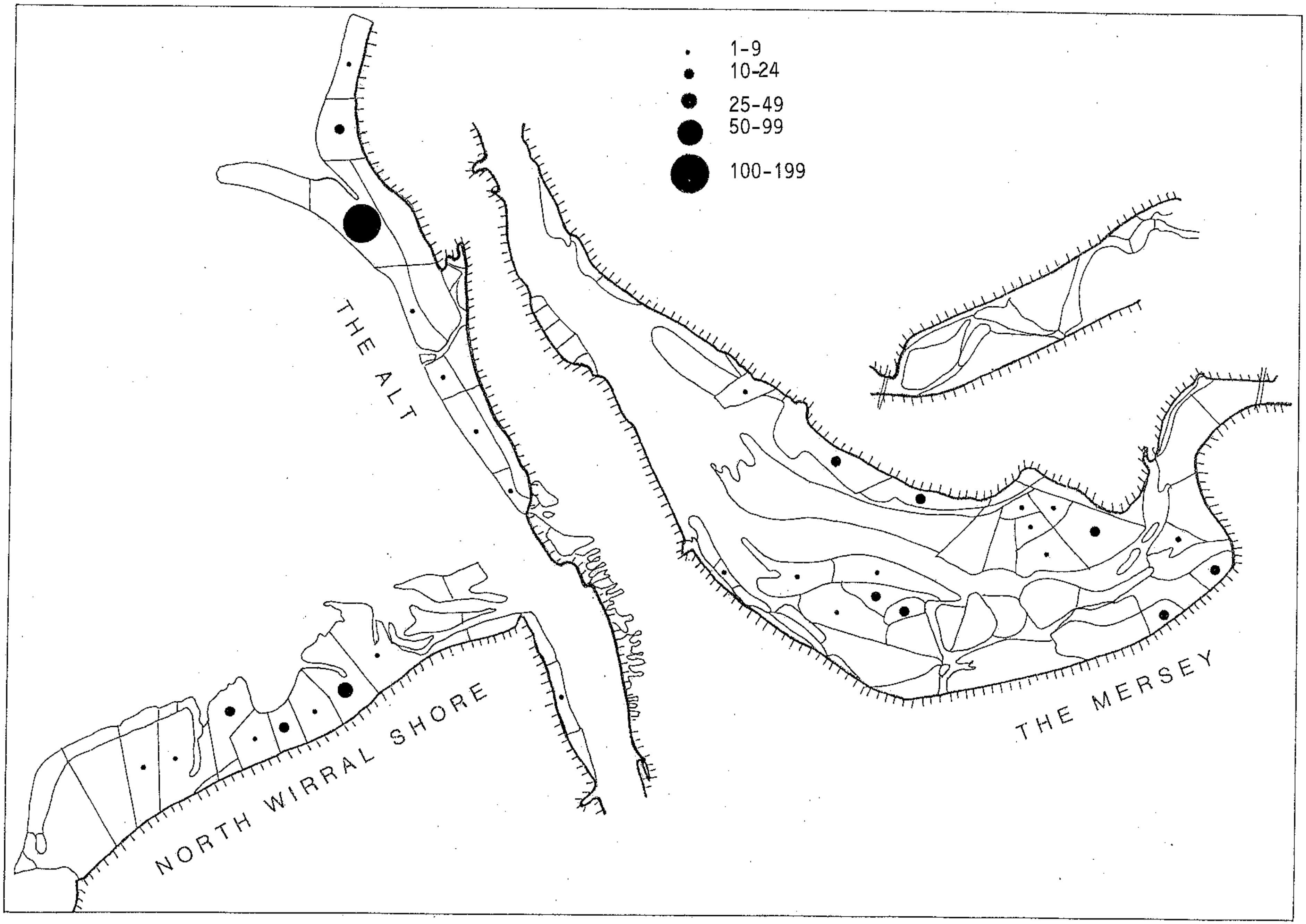


Figure 1.3.9.2 The average number of Grey Plover feeding at low tide on each intertidal area during the 1991/92 winter.

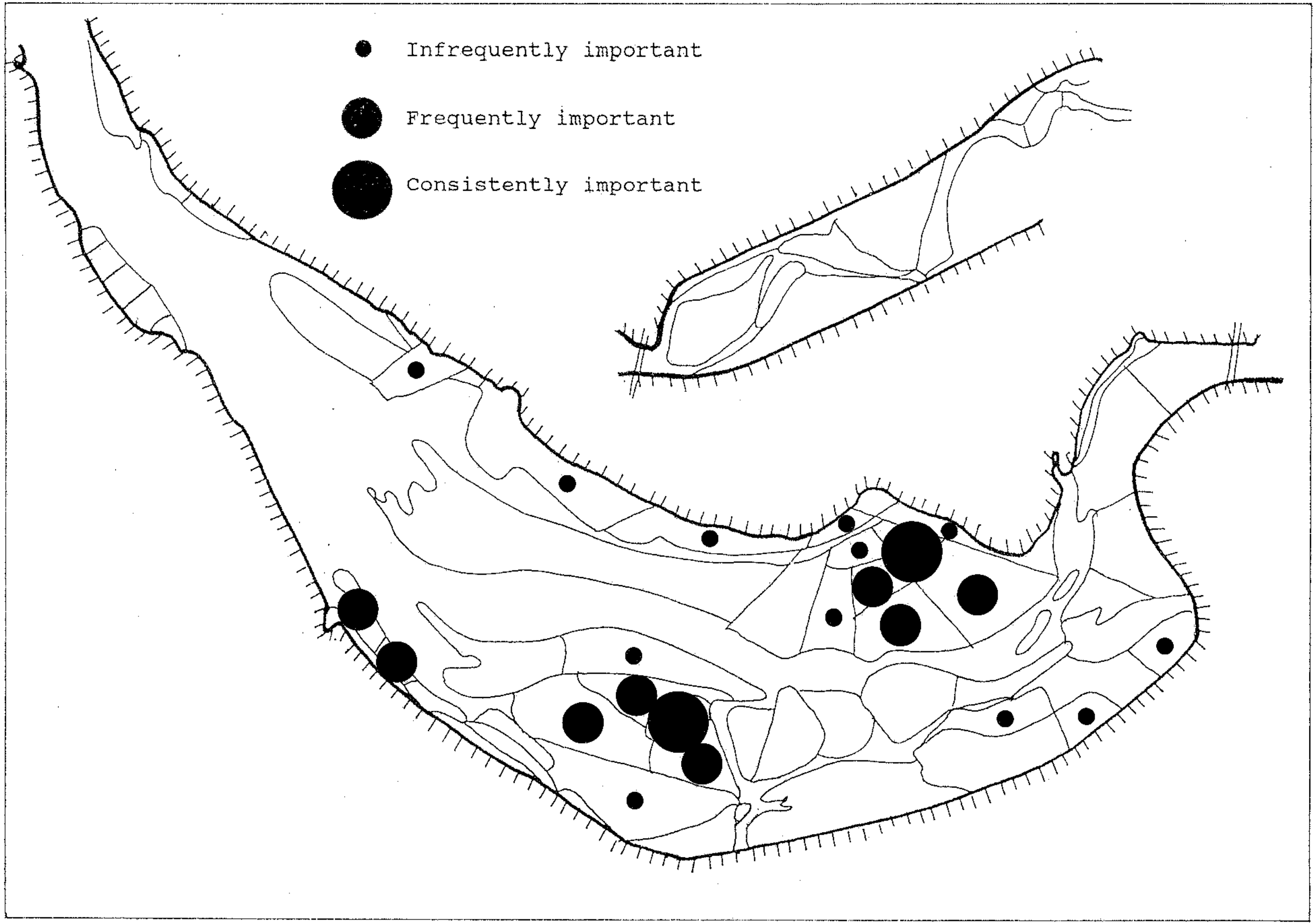


Figure 1.3.9.3 The relative importance of intertidal areas for feeding Grey Plover in the winters 1988/89 to 1991/92 (for definition of importance classes, see Section 1.2.2).

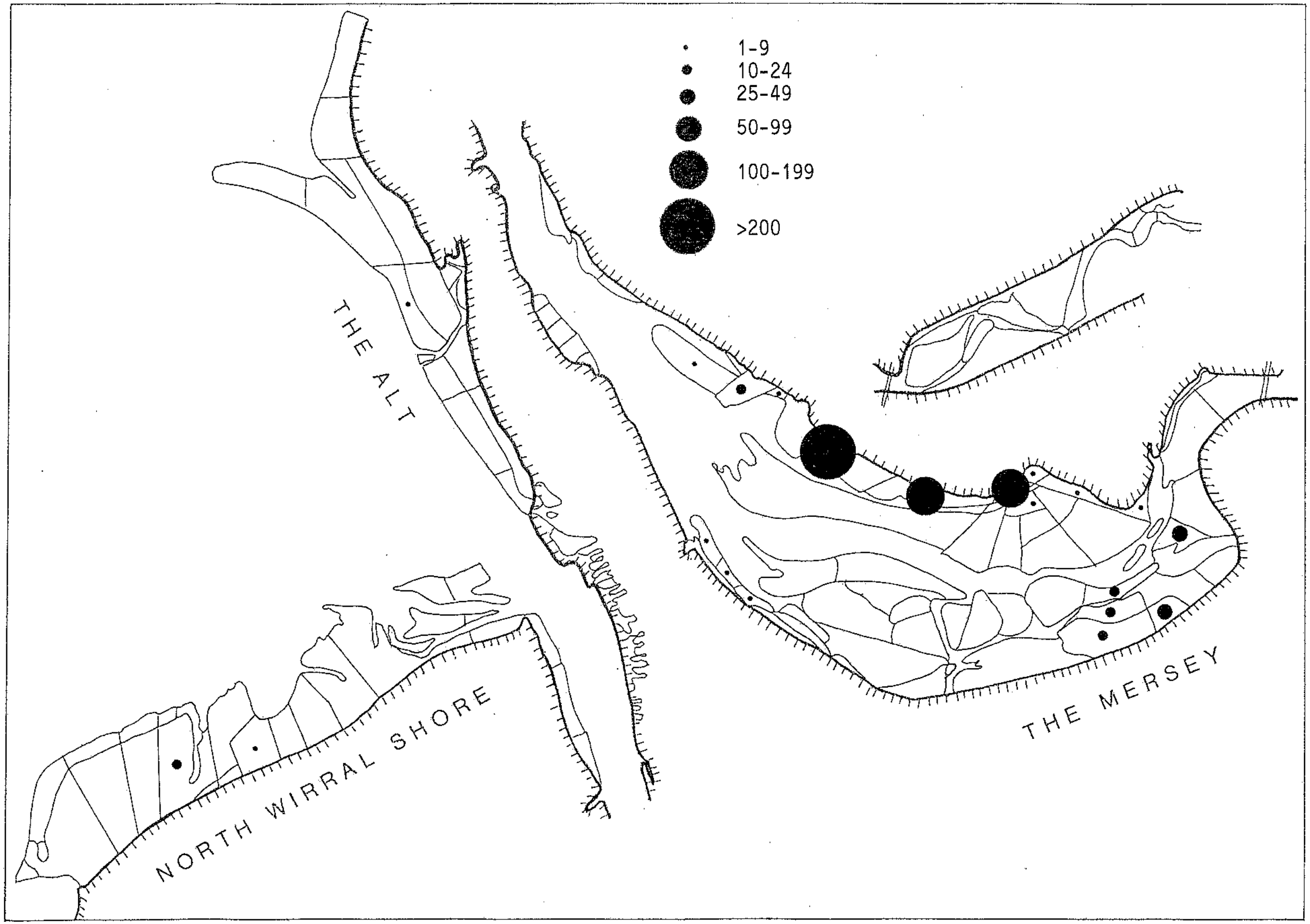


Figure 1.3.10.1 The average number of Lapwing feeding at low tide on each intertidal area during the 1991/92 winter.

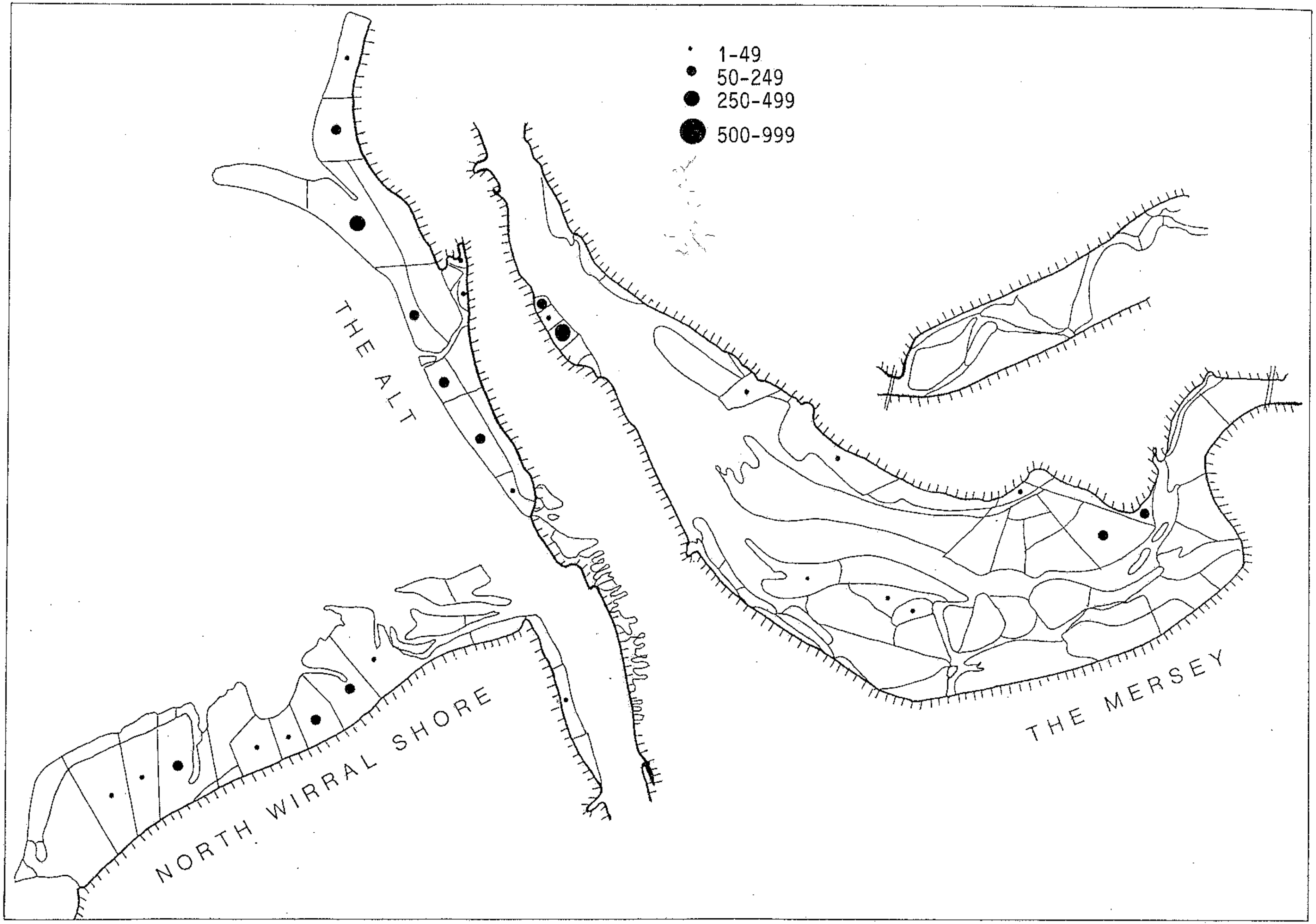


Figure 1.3.11.1 The average number of Knot feeding at low tide on each intertidal area during the 1991/92 winter.

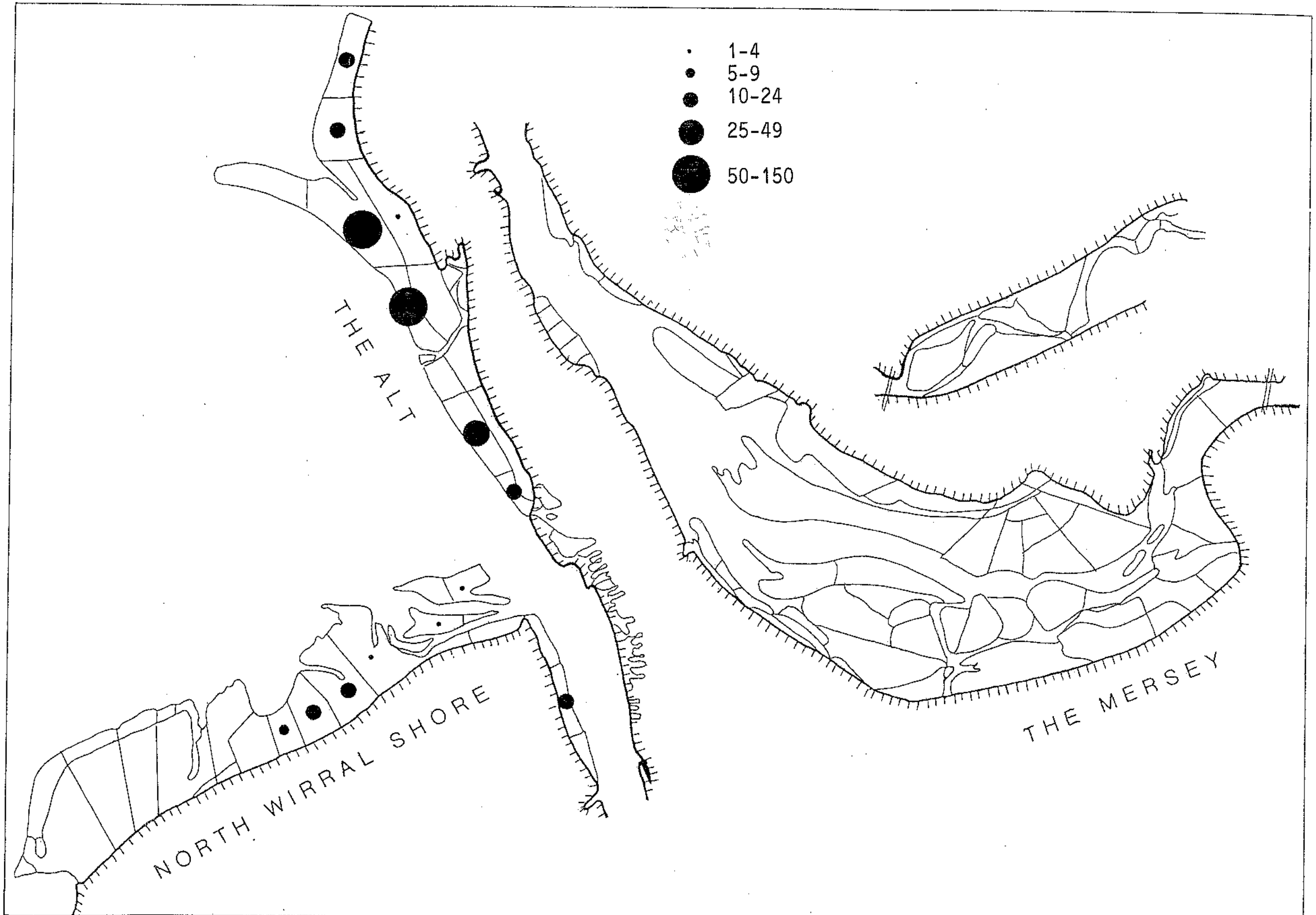


Figure 1.3.12.1 The average number of Sanderling feeding at low tide on each intertidal area during the 1991/92 winter.

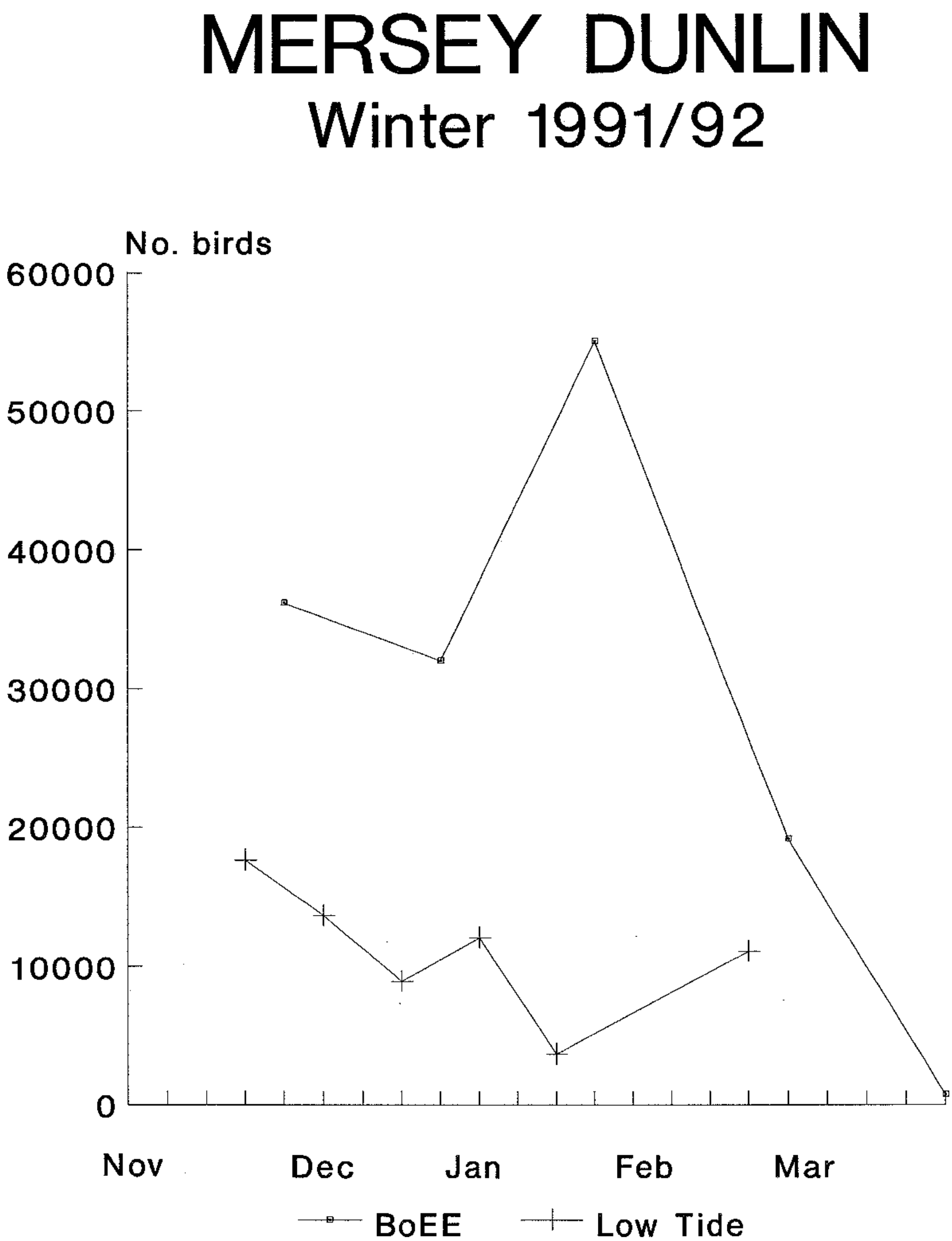


Figure 1.3.13.1 High tide (BoEE) and low tide counts of Dunlin during the 1991/92 winter.

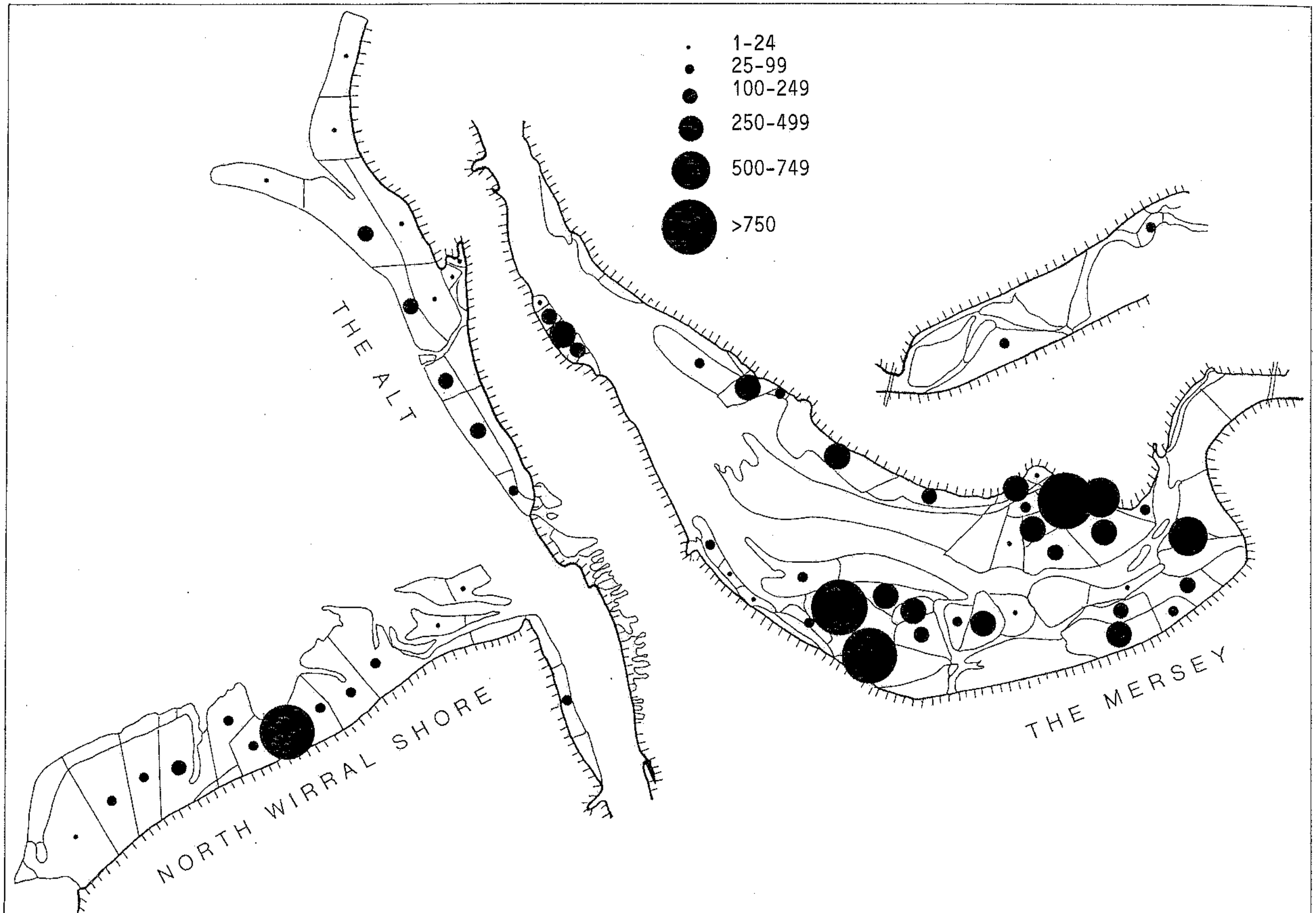


Figure 1.3.13.2 The average number of Dunlin feeding at low tide on each intertidal area during the 1991/92 winter.

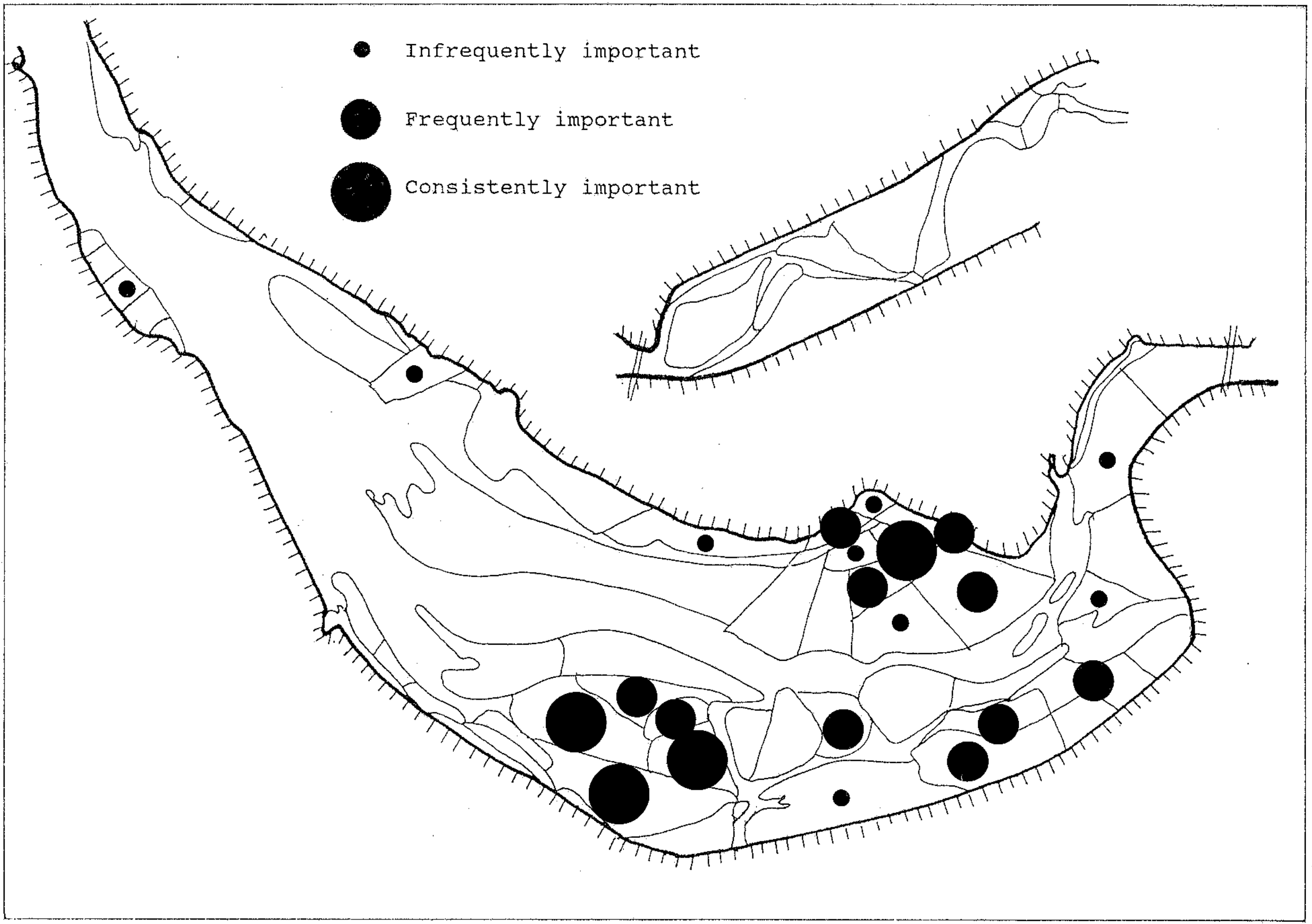


Figure 1.3.13.3 The relative importance of intertidal areas for feeding Dunlin in the winters 1988/89 to 1991/92 (for definition of importance classes, see Section 1.2.2).

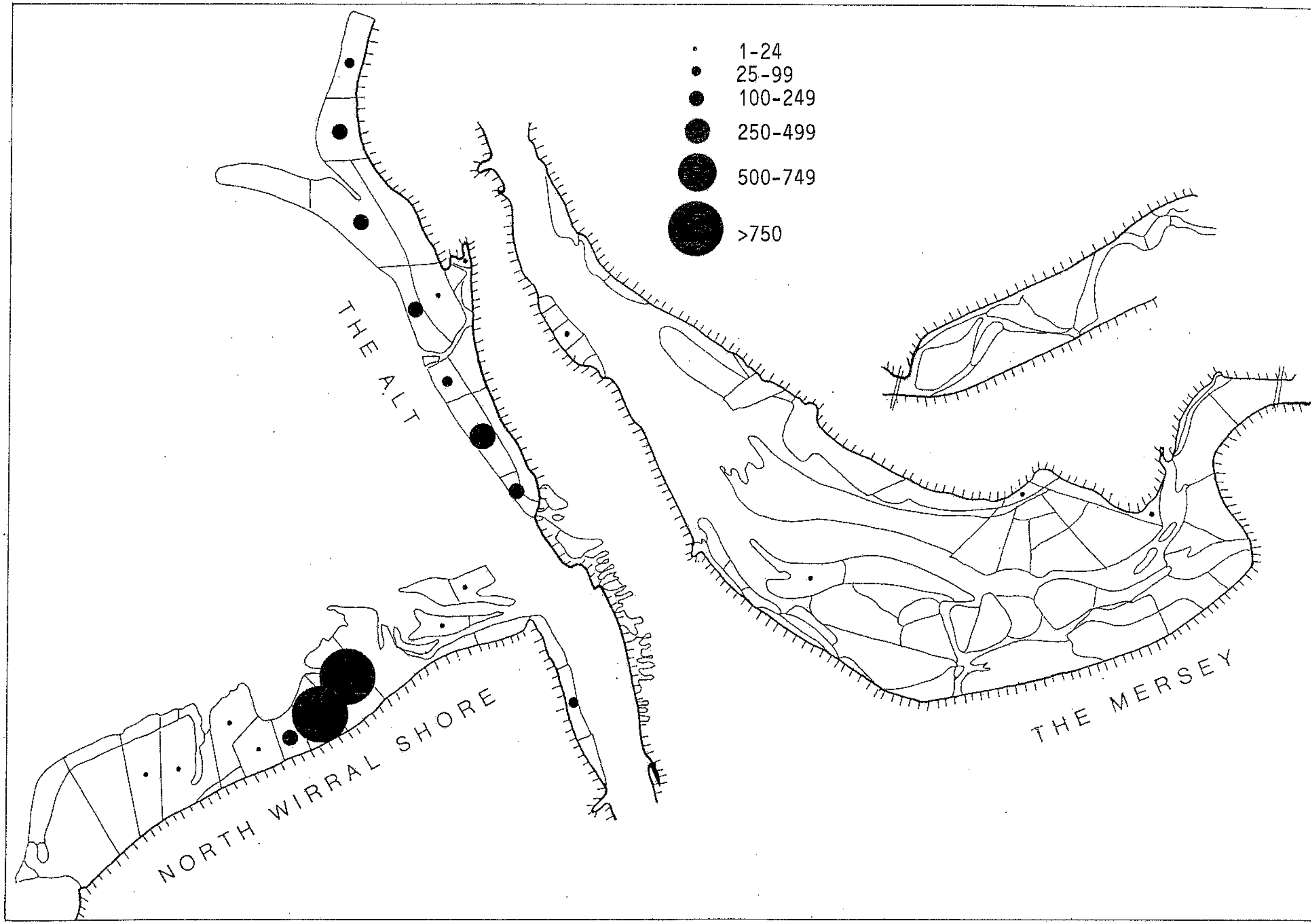


Figure 1.3.14.1 The average number of Bar-tailed Godwit feeding at low tide on each intertidal area during the 1991/92 winter.

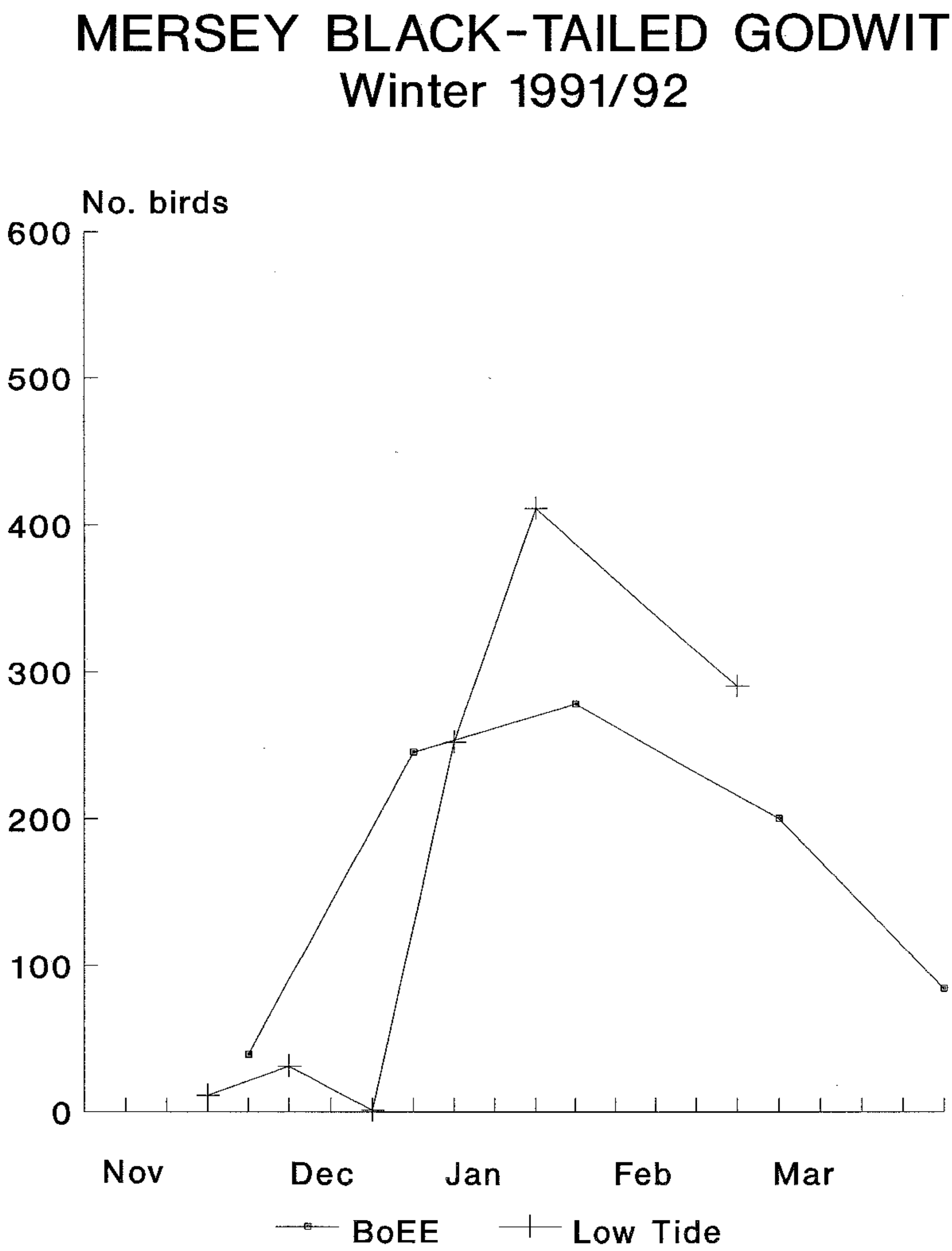


Figure 1.3.15.1 High tide (BoEE) and low tide counts of Black-tailed Godwit during the 1991/92 winter.

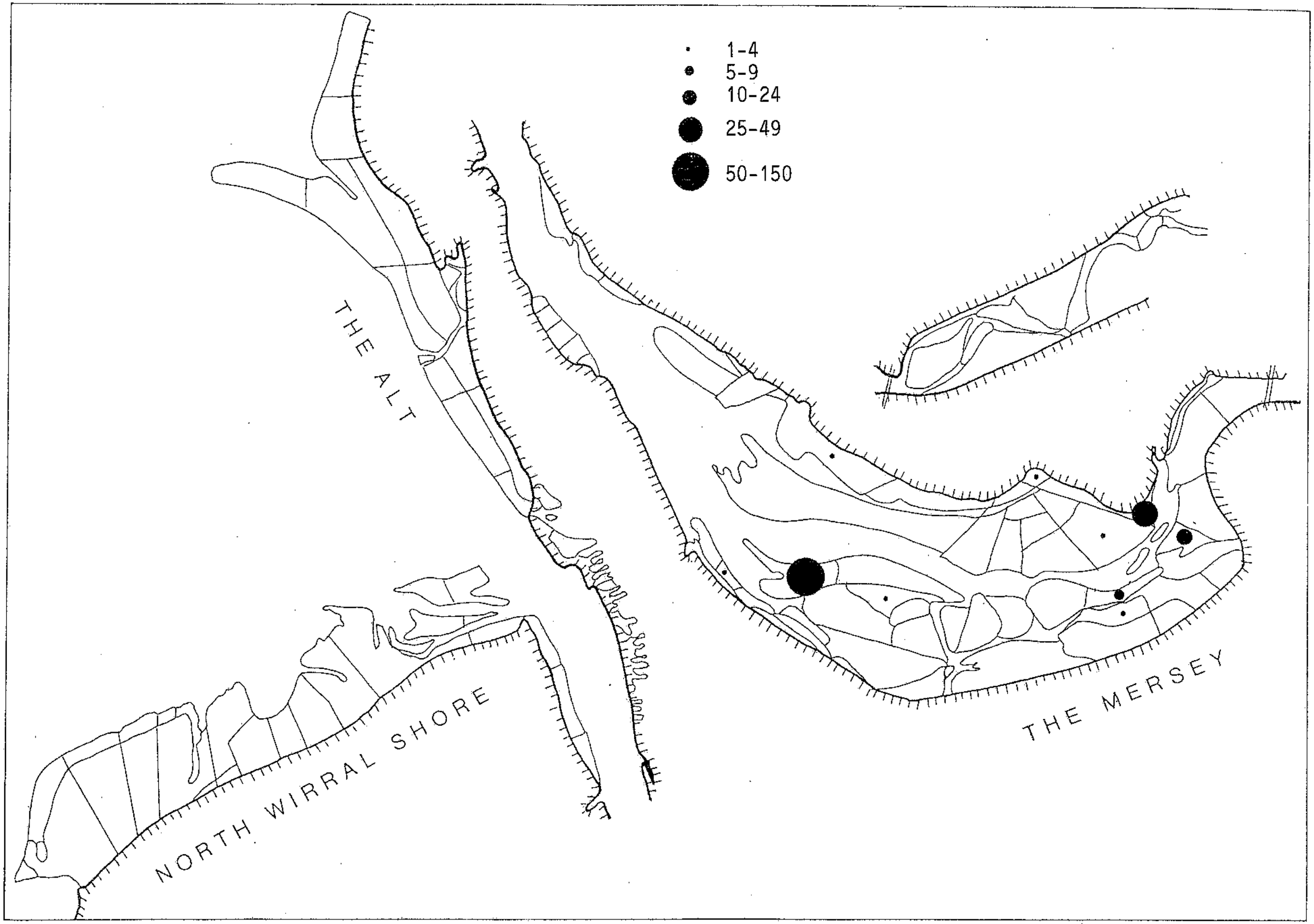


Figure 1.3.15.2 The average number of Black-tailed Godwit feeding at low tide on each intertidal area during the 1991/92 winter.

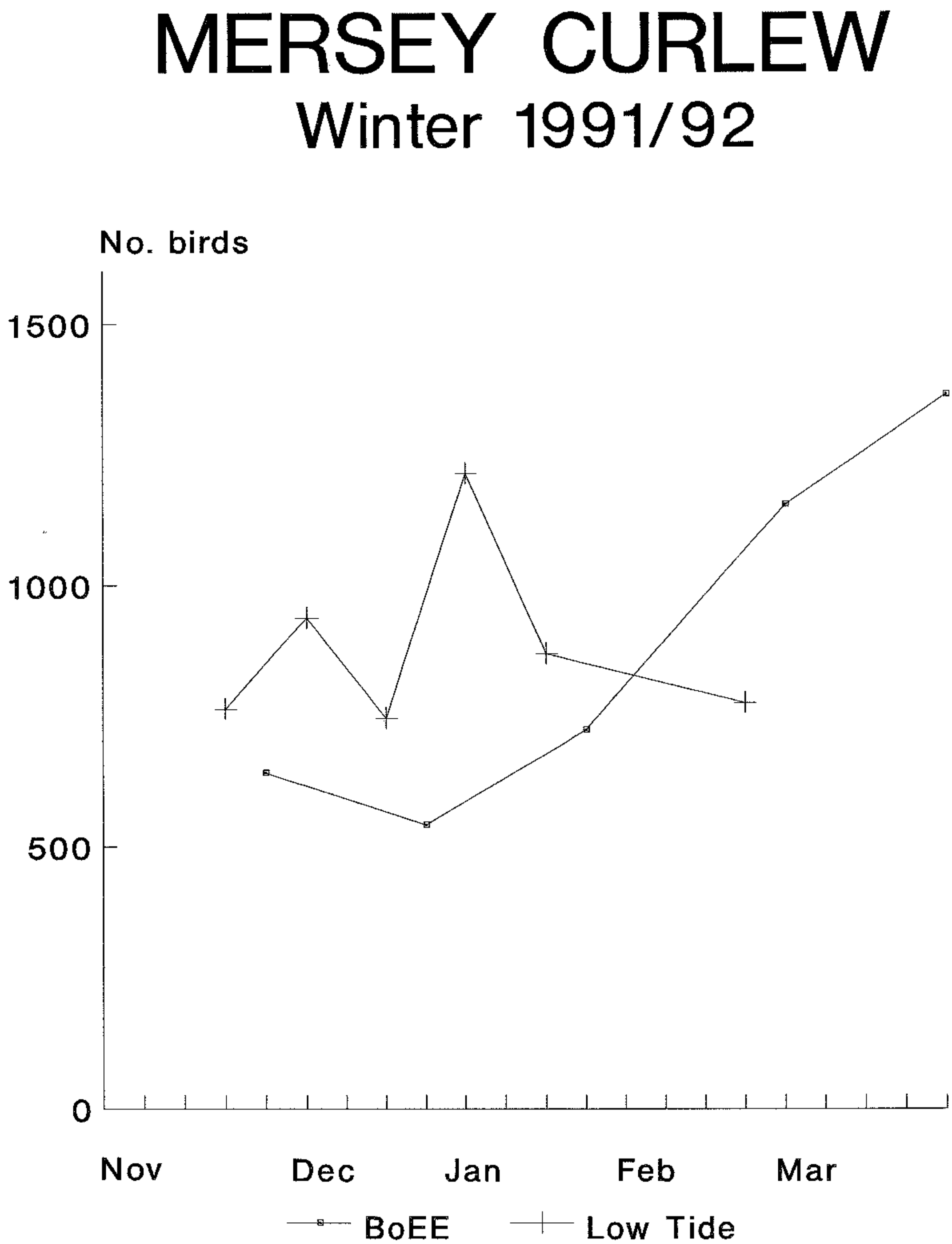


Figure 1.3.16.1 High tide (BoEE) and low tide counts of Curlew during the 1991/92 winter.

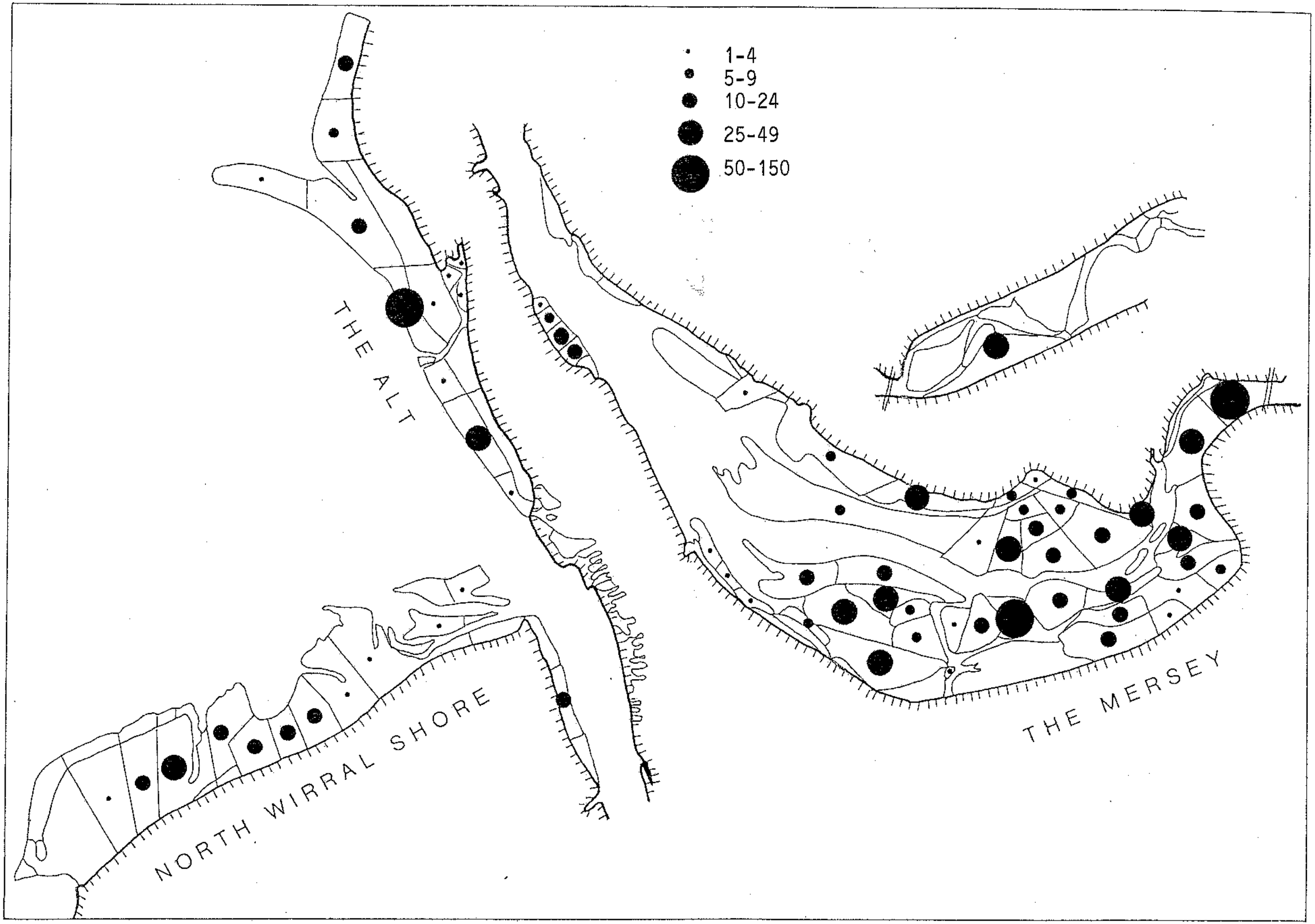


Figure 1.3.16.2 The average number of Curlew feeding at low tide on each intertidal area during the 1991/92 winter.

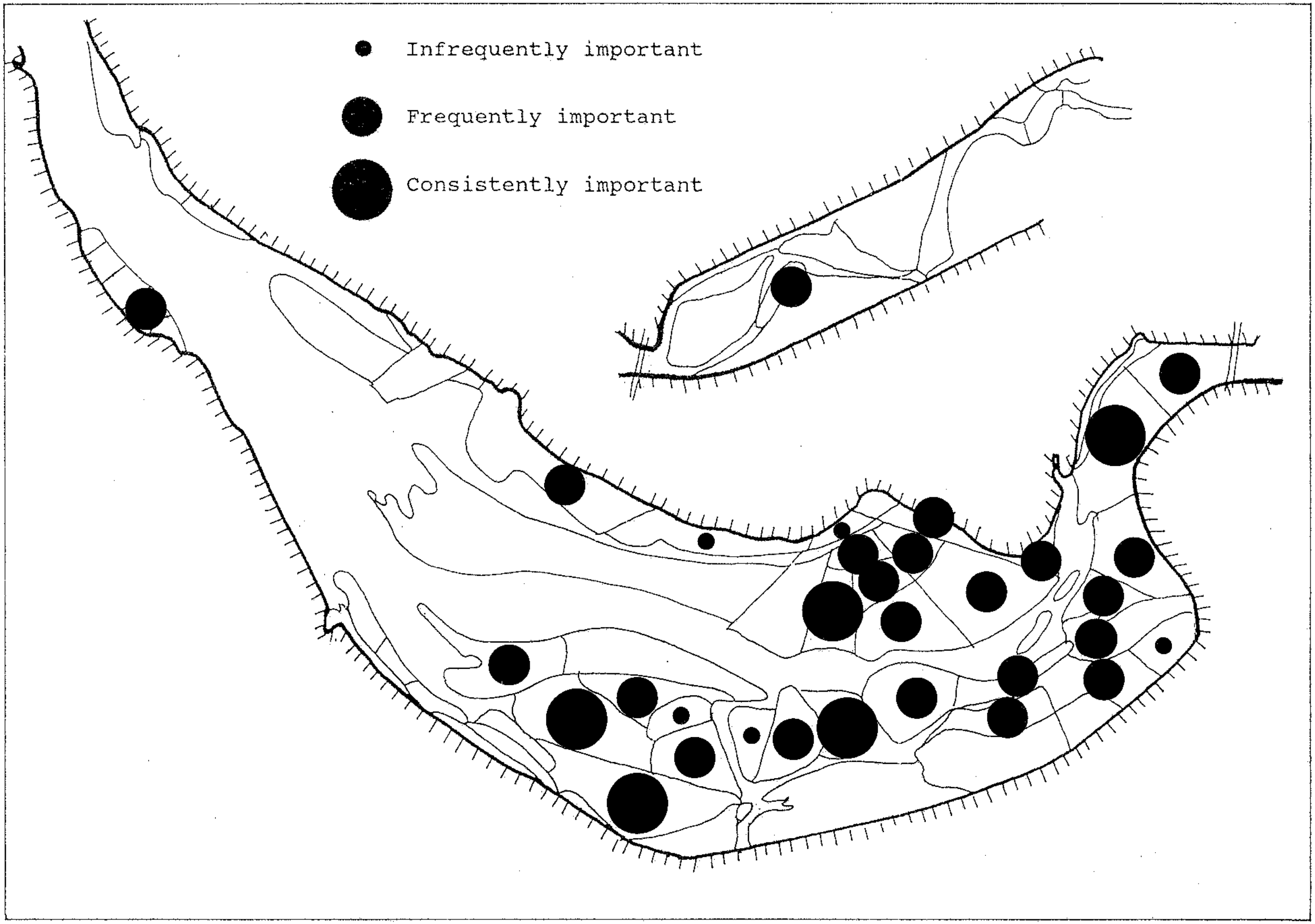


Figure 1.3.16.3 The relative importance of intertidal areas for feeding Curlew in the winters 1988/89 to 1991/92 (for definition of importance classes, see Section 1.2.2).

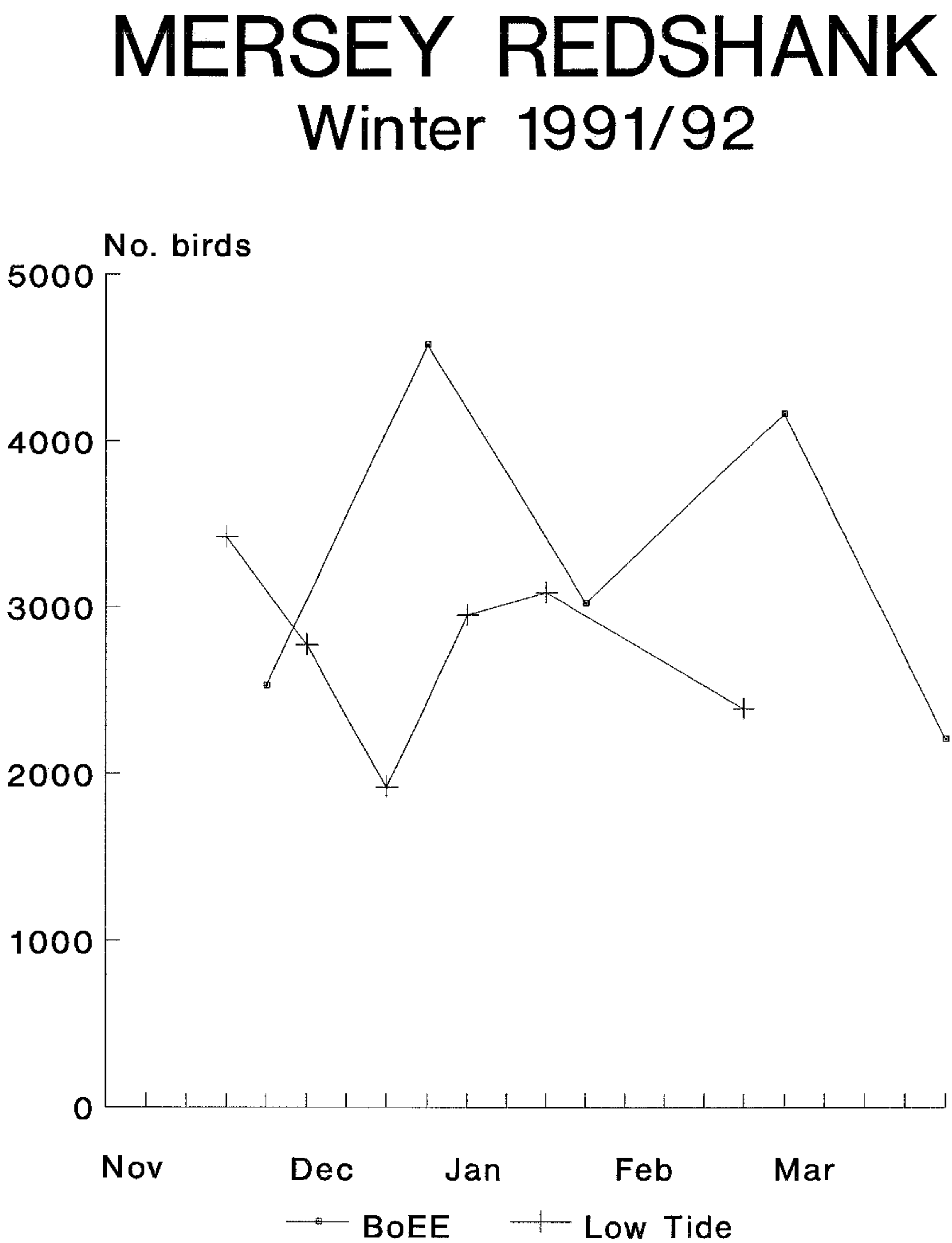


Figure 1.3.17.1 High tide (BoEE) and low tide counts of Redshank during the 1991/92 winter.

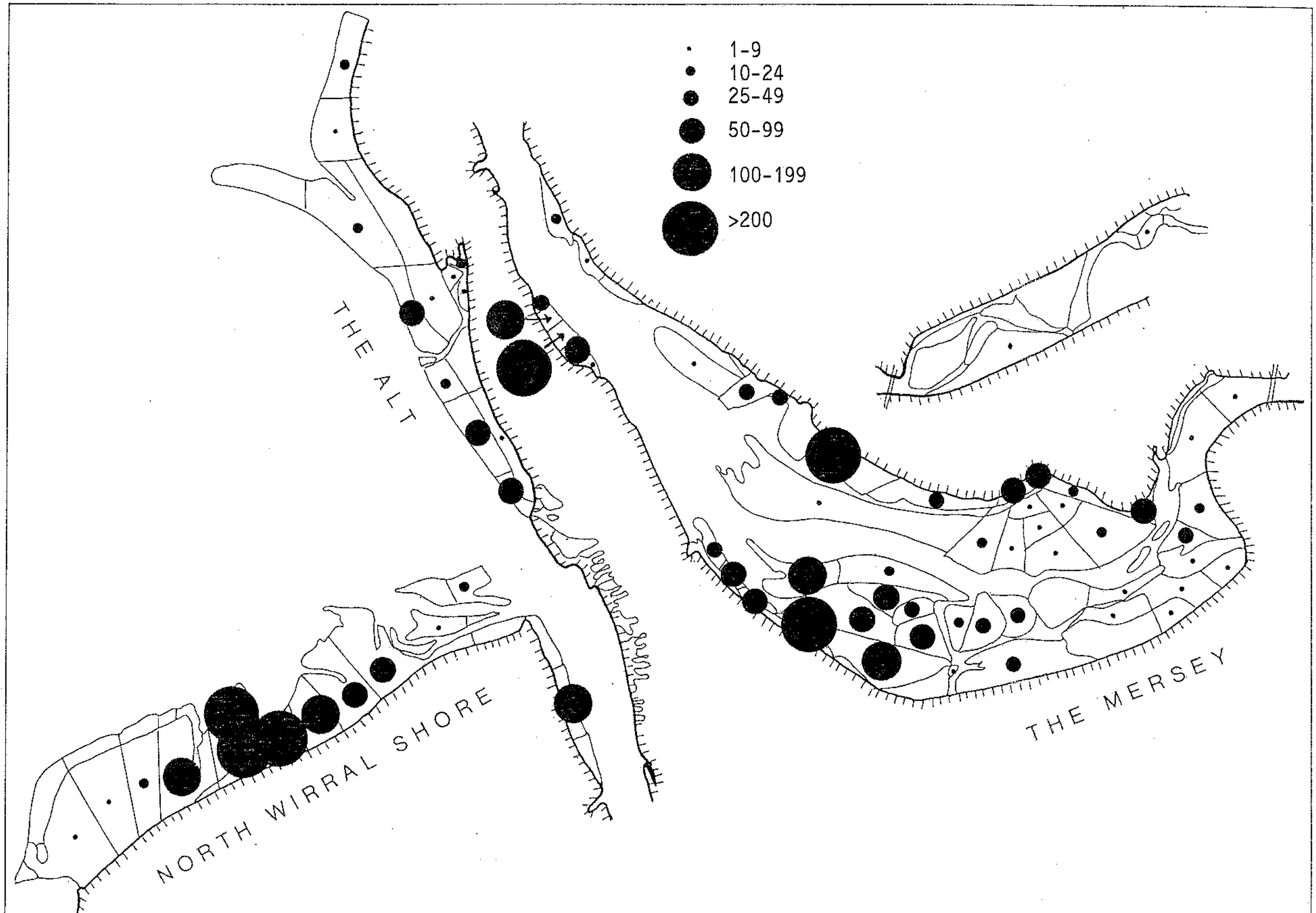


Figure 1.3.17.2 The average number of Redshank feeding at low tide on each intertidal area during the 1991/92 winter.

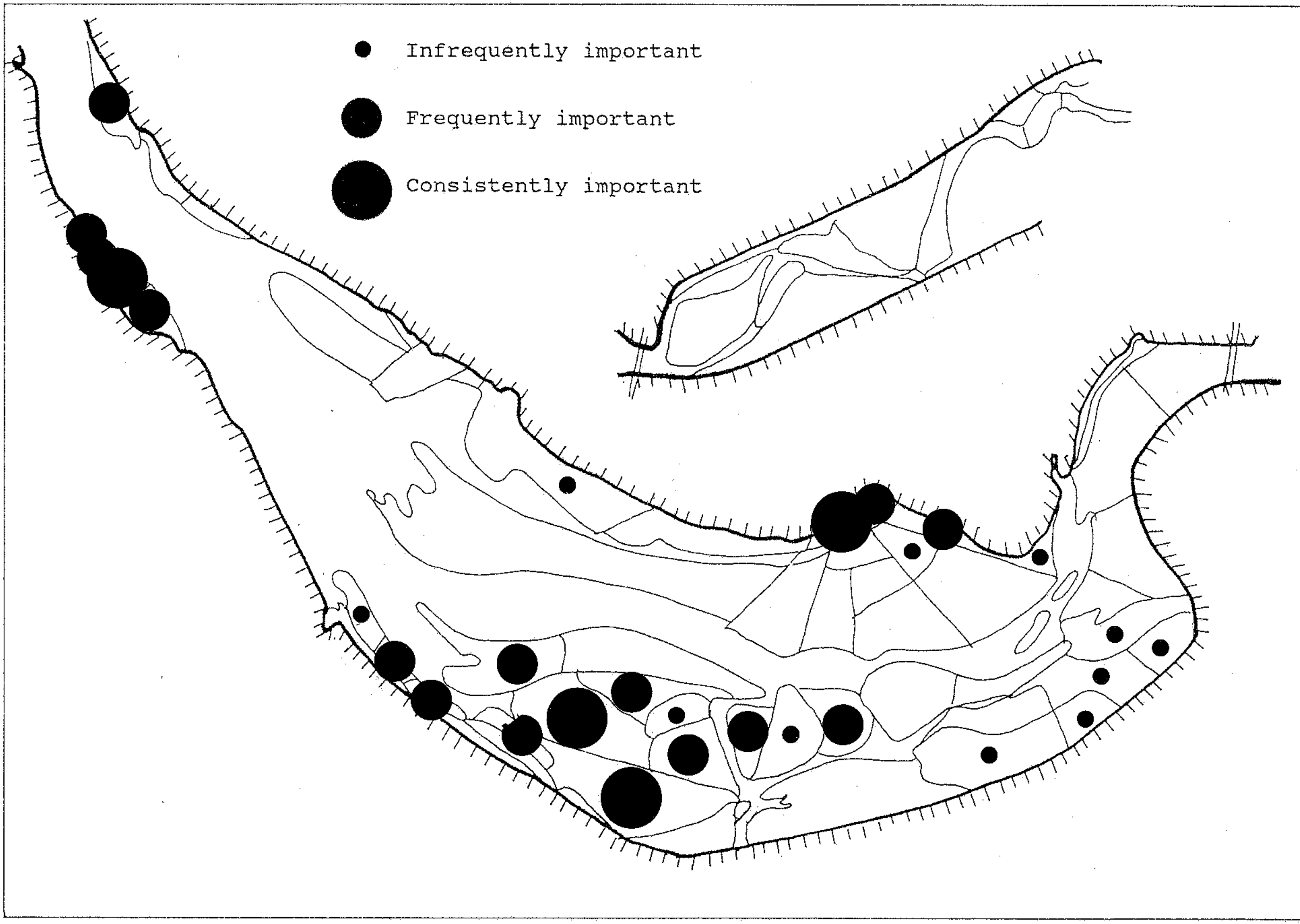


Figure 1.3.17.3 The relative importance of intertidal areas for feeding Redshank in the winters 1988/89 to 1991/92 (for definition of importance classes, see Section 1.2.2).

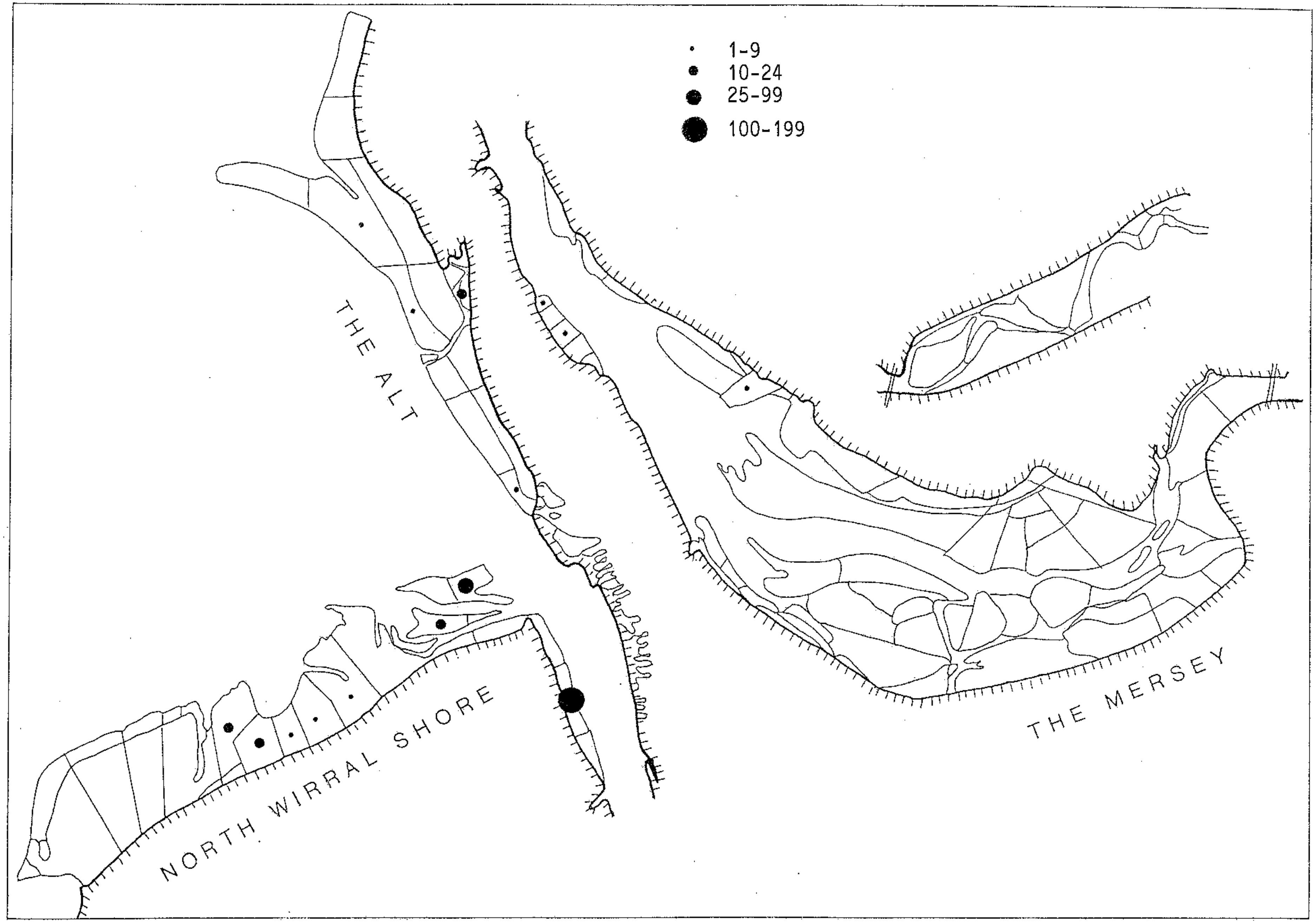


Figure 1.3.18.1 The average number of Turnstone feeding at low tide on each intertidal area during the 1991/92 winter.

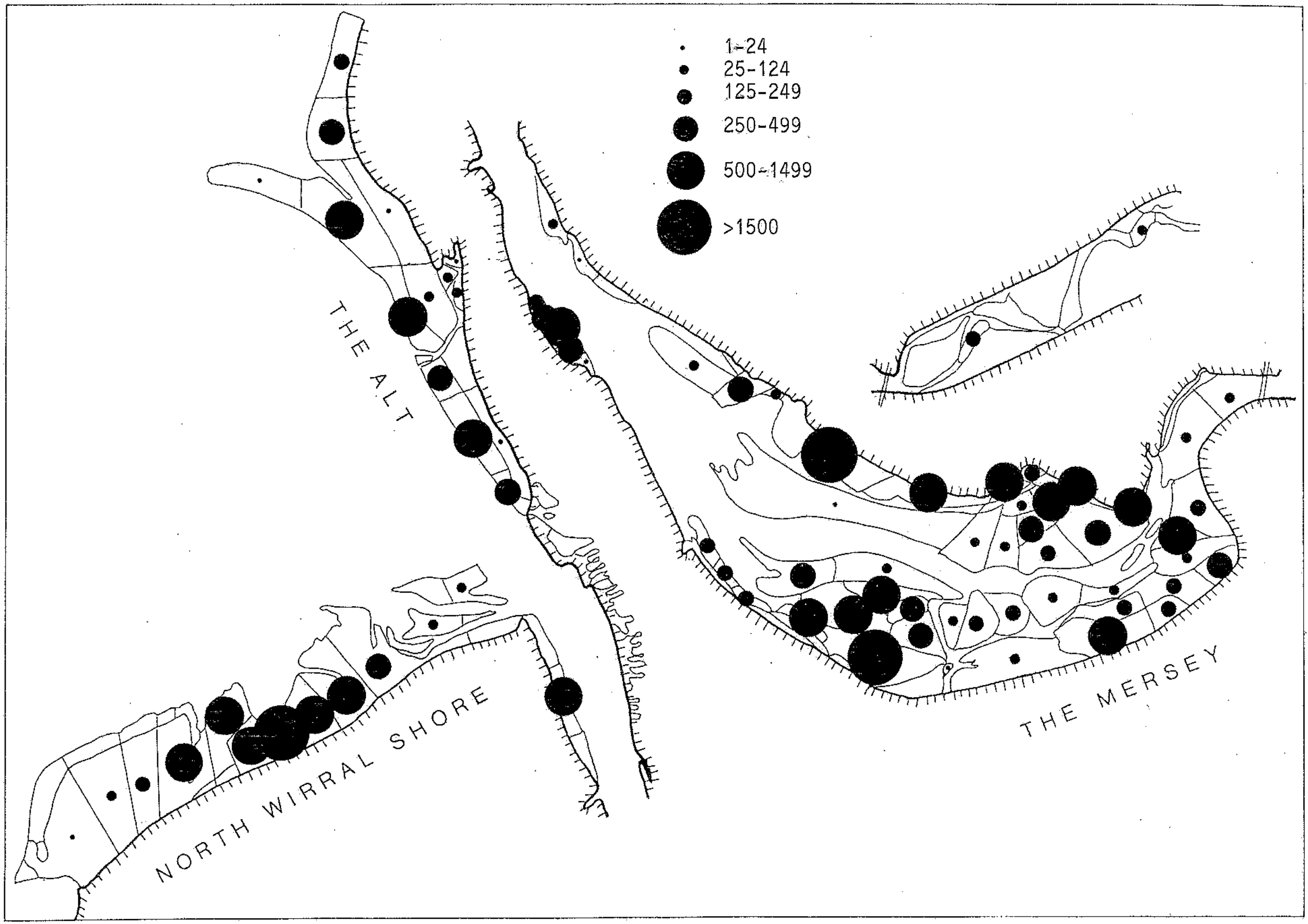


Figure 1.3.19.1 The average number of feeding birds of all species at low tide on each intertidal area during the 1991/92 winter.

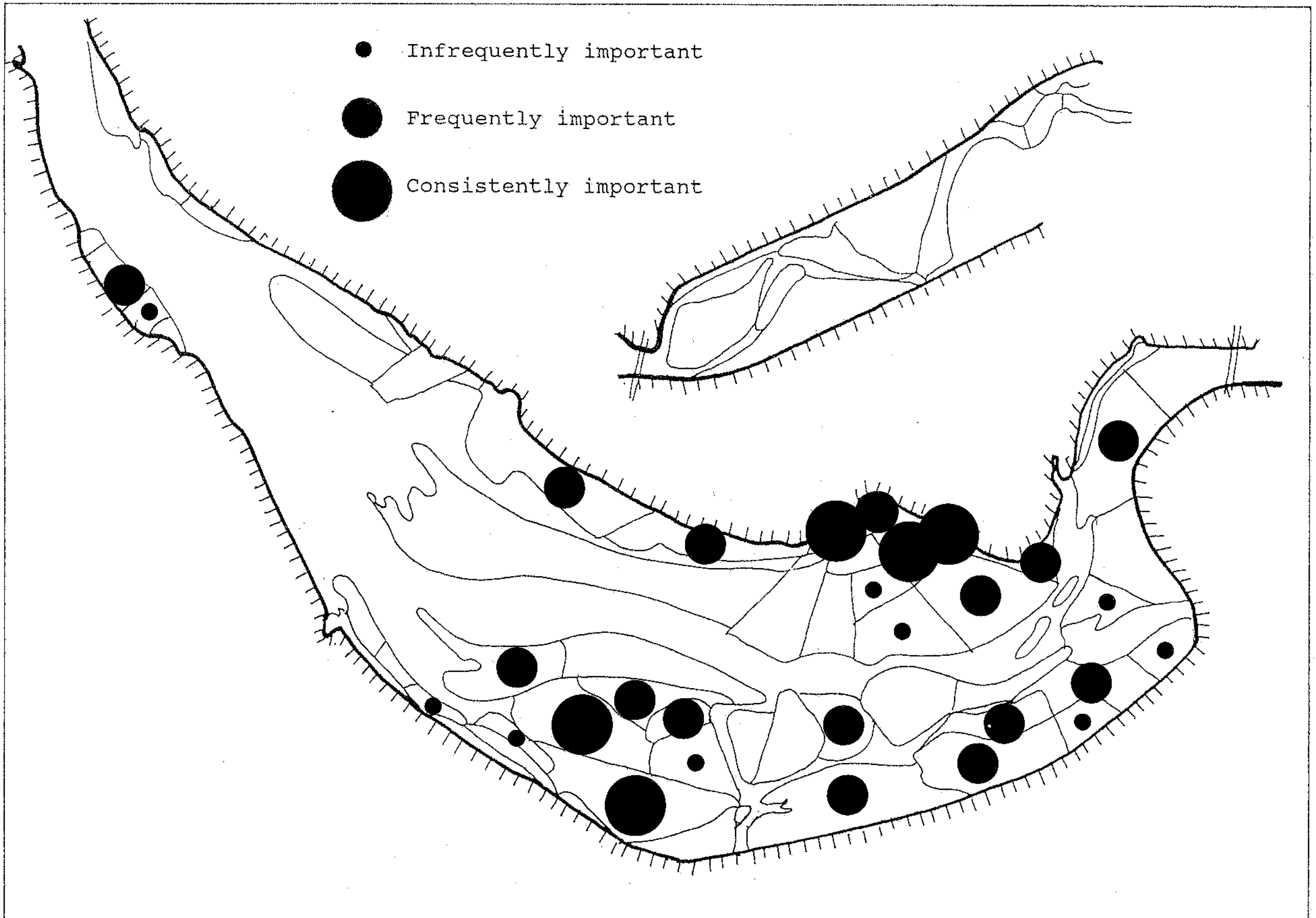


Figure 1.3.19.2 The relative importance of intertidal areas for feeding birds of all species in the winters of 1988/89 to 1991/92 (for definition of importance classes, see Section 1.2.2).

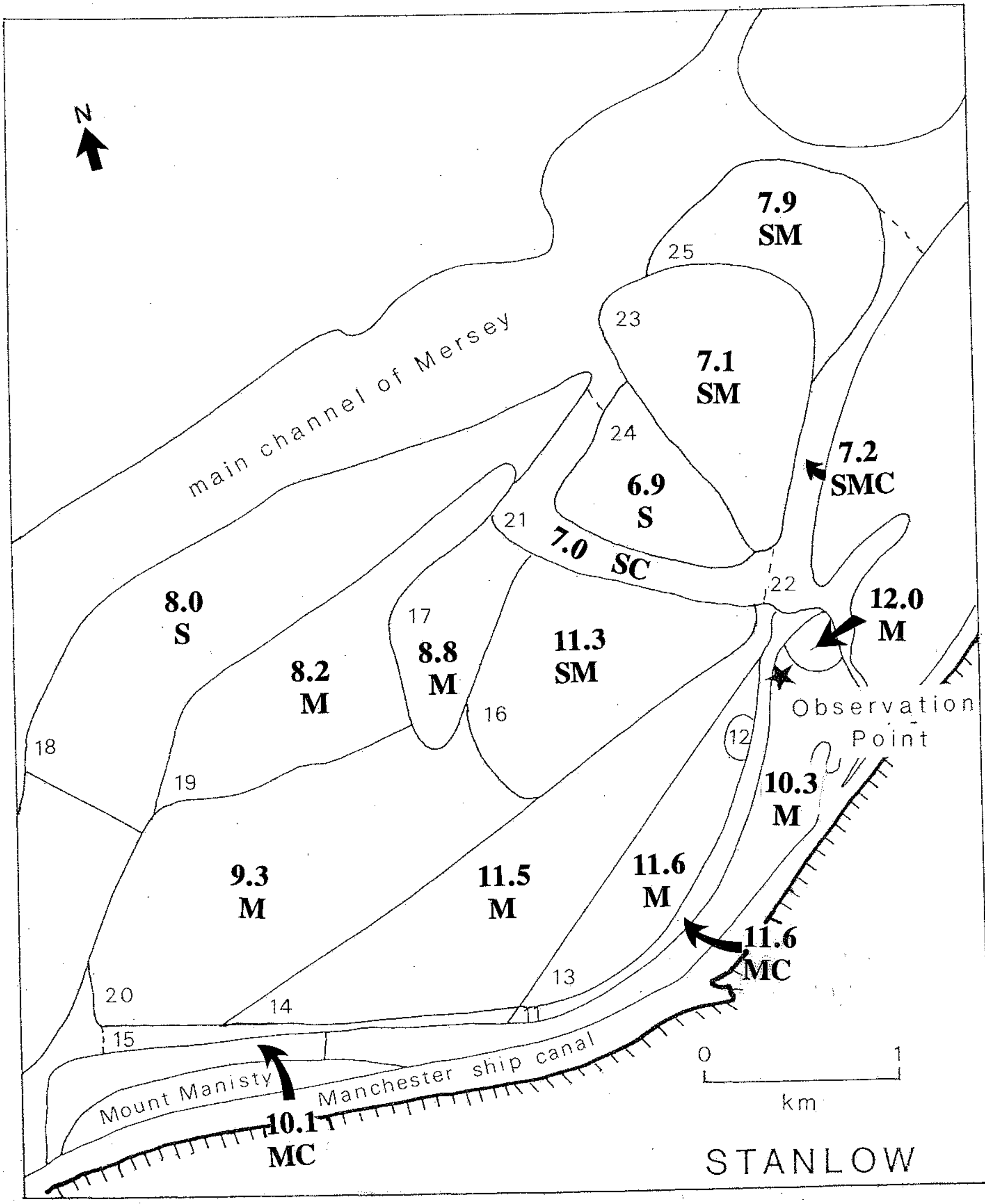


Figure 2.2.1.1 The Stanlow all day study site. The average exposure time (hours) in winter and the main substrate type are given for each intertidal area.
(C = channel, M = mud, S = sand, SM = mixed sand/mud).

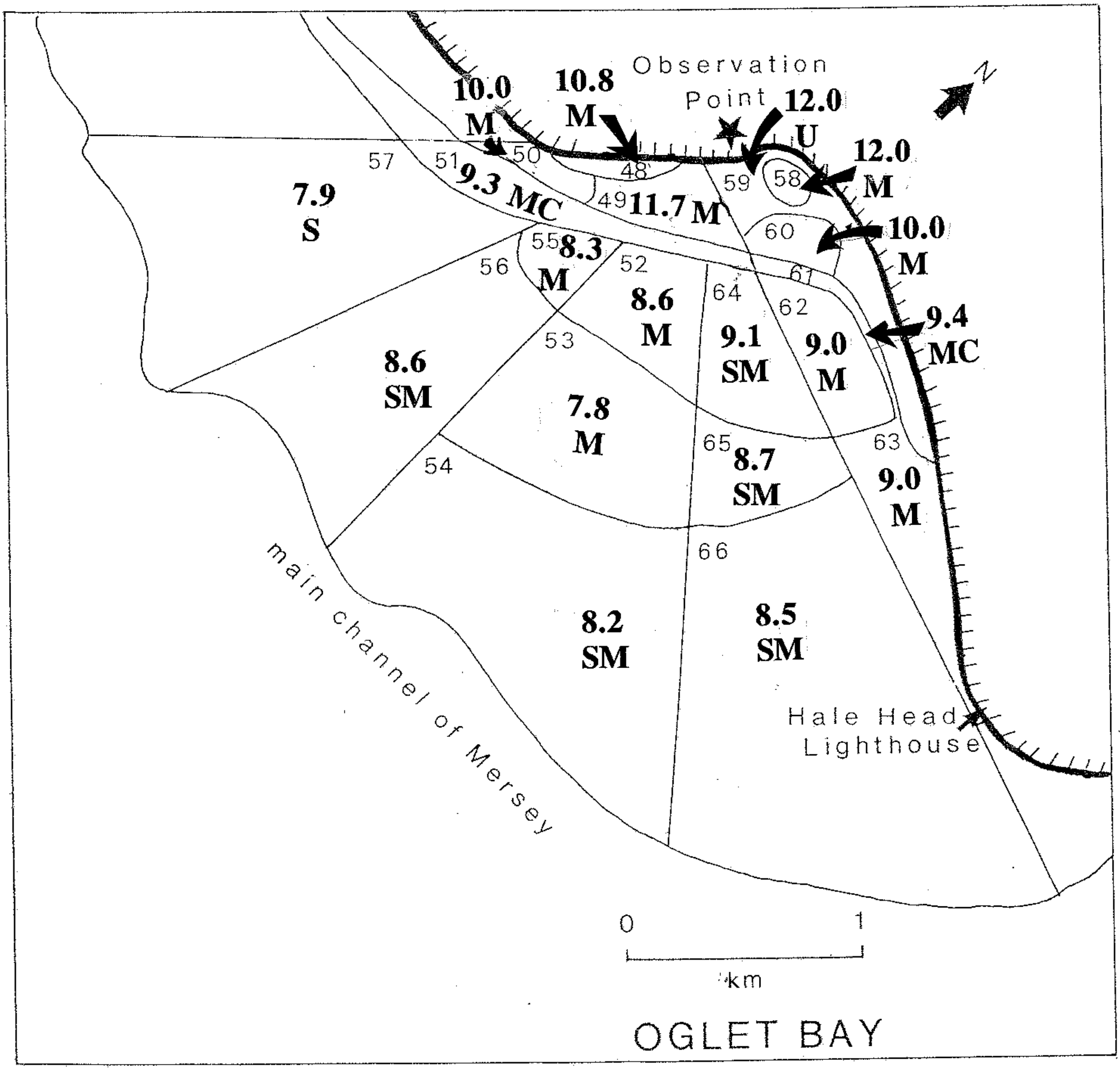


Figure 2.2.1.2 The Oglet Bay all day study site. The average exposure time (hours) in winter and the main substrate type are given for each intertidal area.
(C = channel, M = mud, S = sand, SM = mixed sand/mud, U = ungrazed saltmarsh).

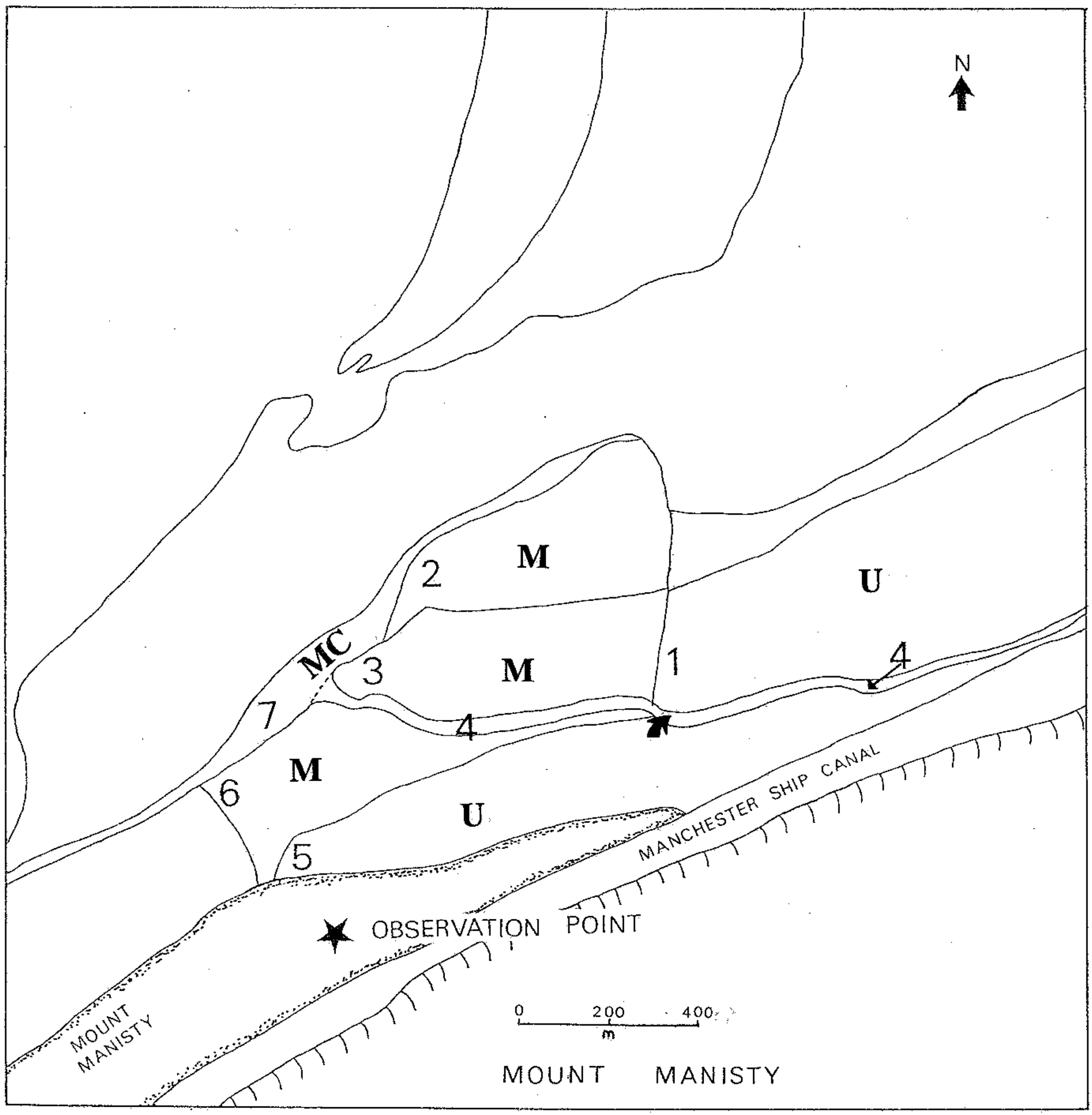


Figure 2.2.1.3 The Mount Manisty all day study site. The main substrate type is given for each intertidal area. (C = channel, M = mud, U = ungrazed saltmarsh).

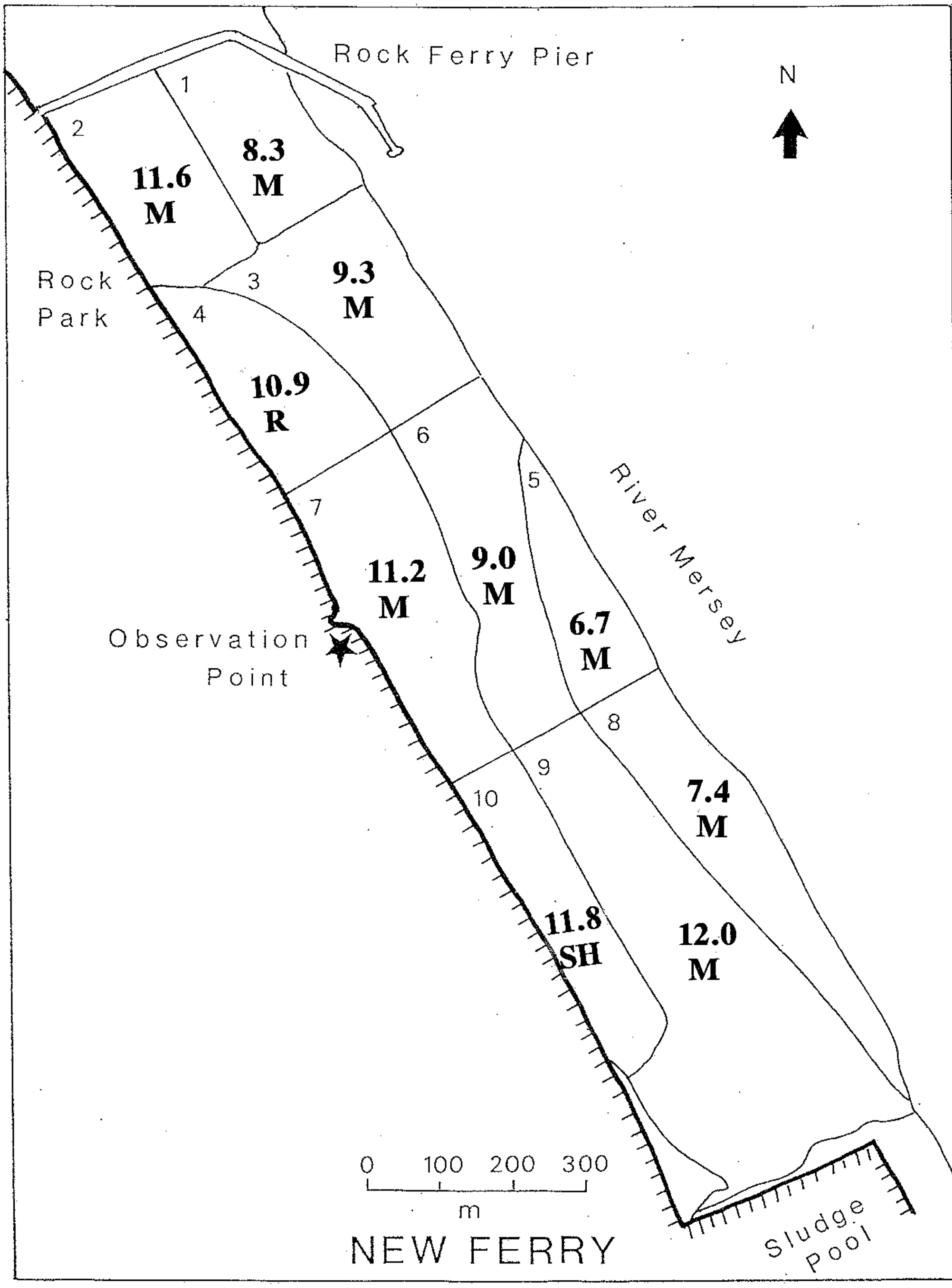


Figure 2.2.1.4 The New Ferry all day study site. The average exposure time (hours) in winter and the main substrate type are given for each intertidal area.
(M = mud, R = rock, SH = shingle).

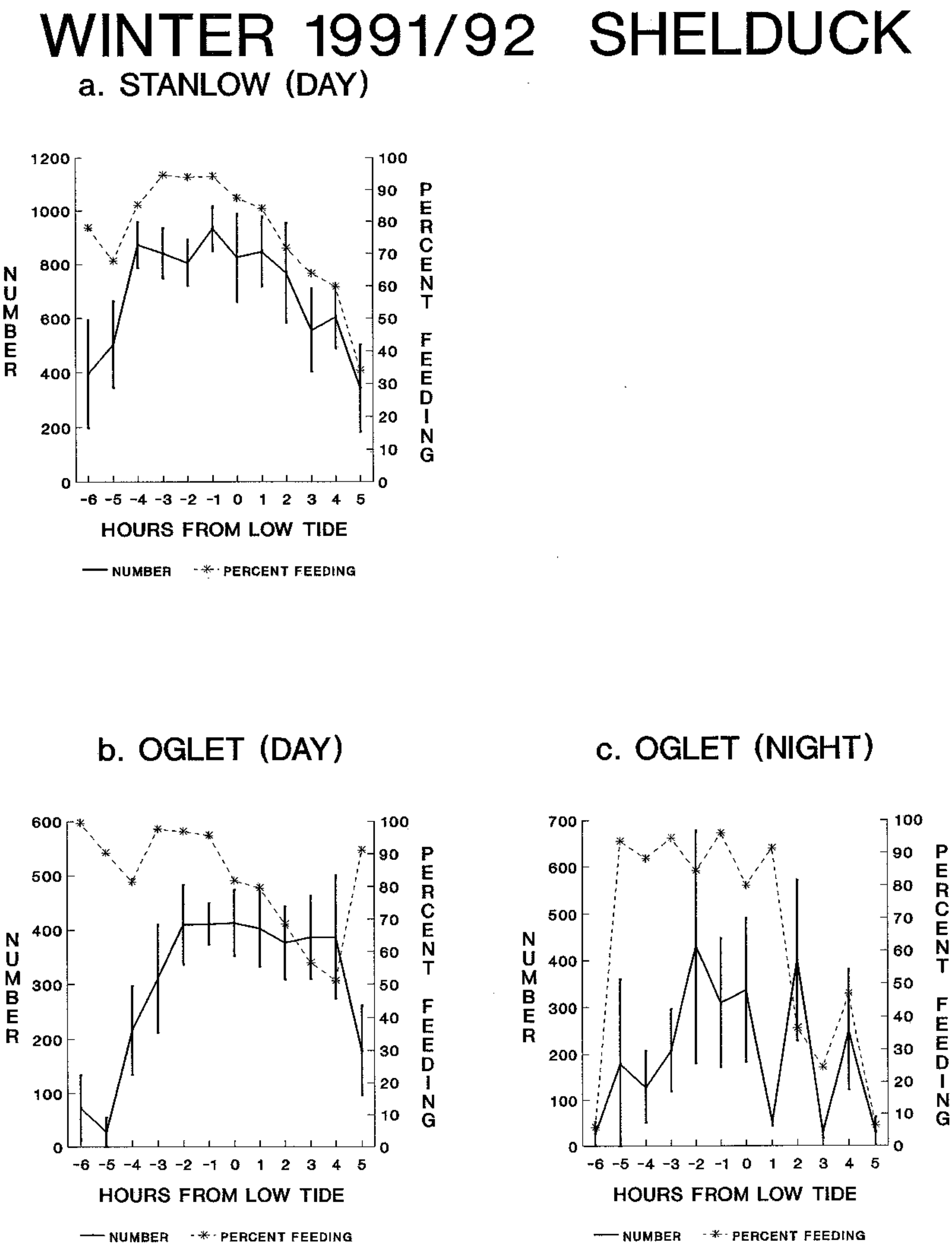


Figure 2.3.1.1 The number of Shelduck present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

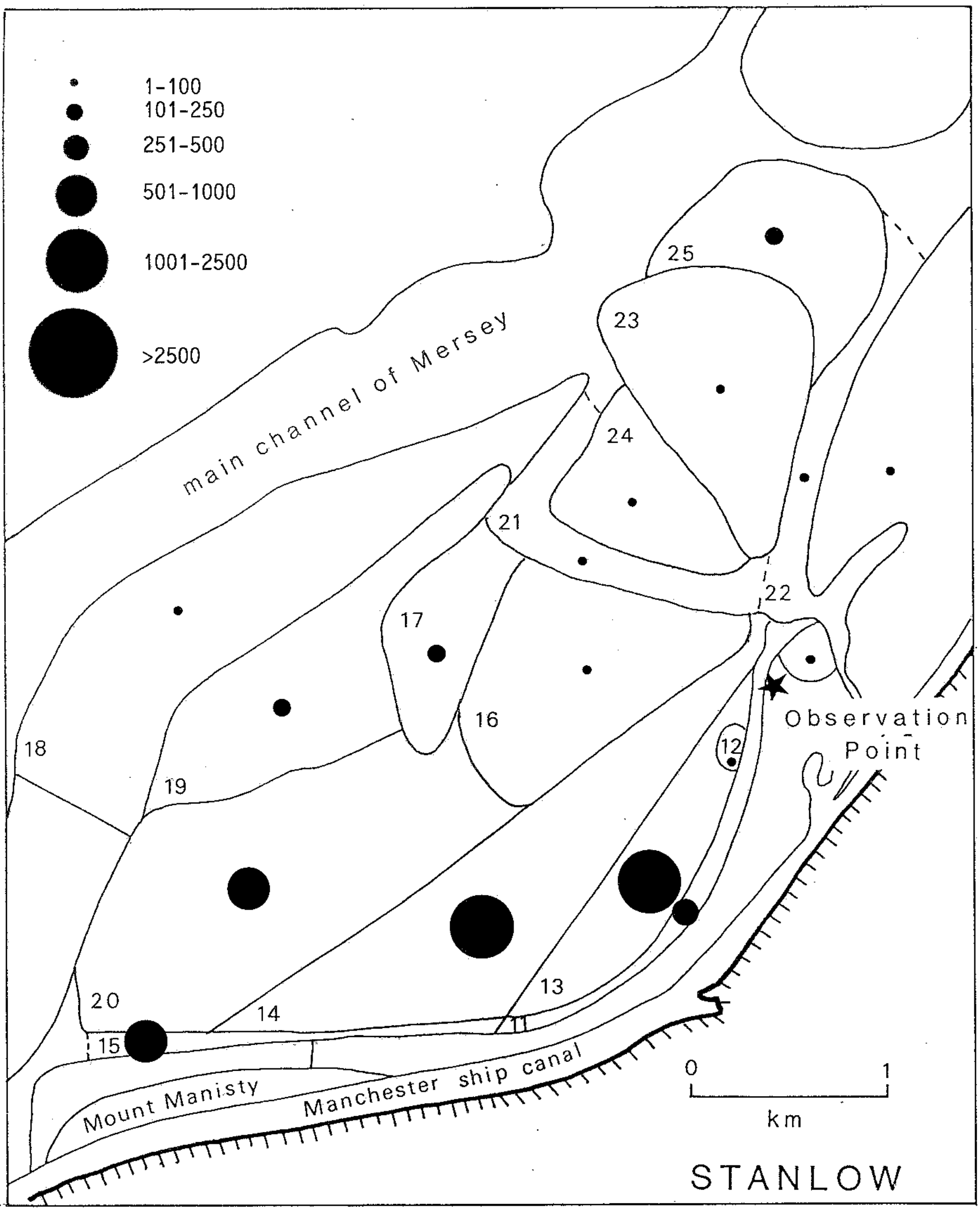
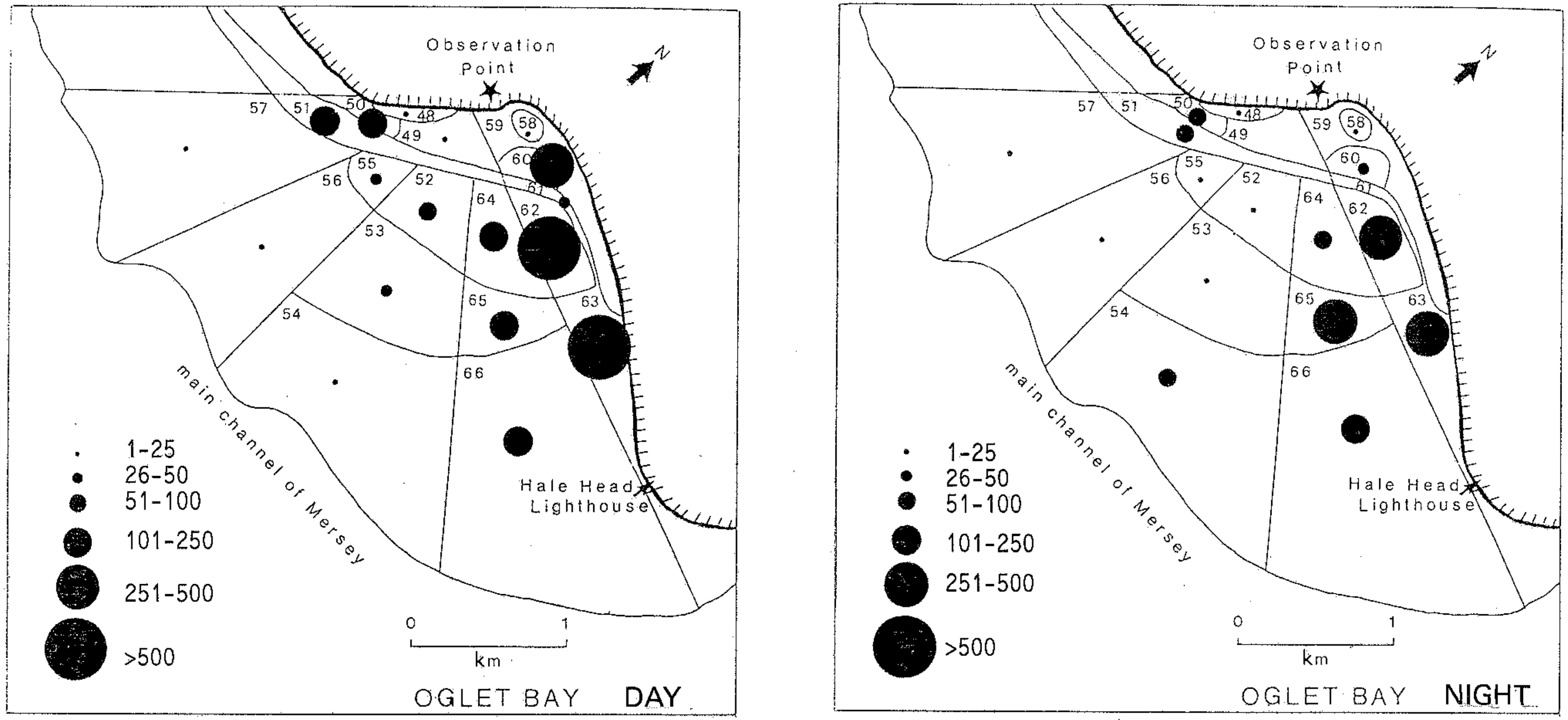


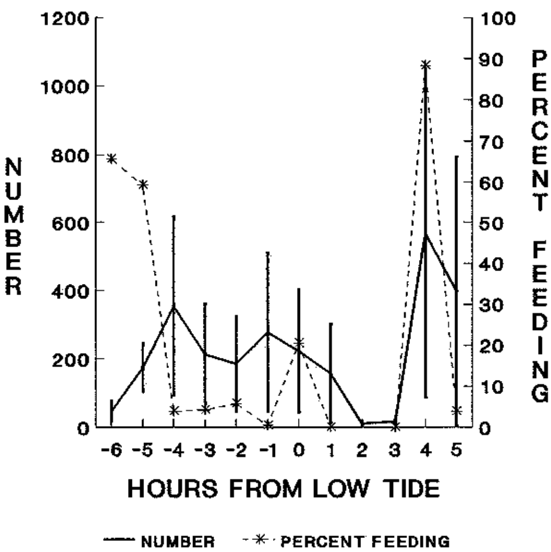
Figure 2.3.1.2 The number of bird hours per tidal cycle of feeding Shelduck on each intertidal area at Stanlow during the day, winter 1991/92.



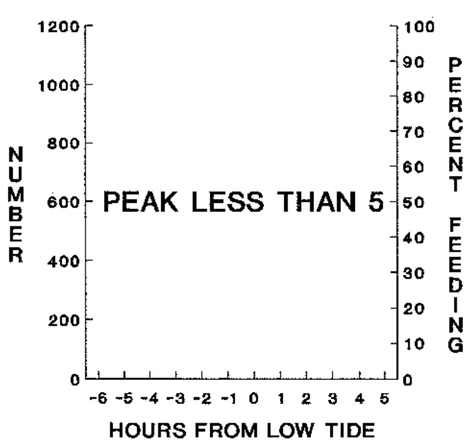
Fiugre 2.3.1.3 The number of bird hours per tidal cycle of feeding Shelduck on each intertidal area at Oglet Bay during the day and night, winter 1991/92.

WINTER 1991/92 WIGEON

a. STANLOW (DAY)



b. OGLET (DAY)



c. OGLET (NIGHT)

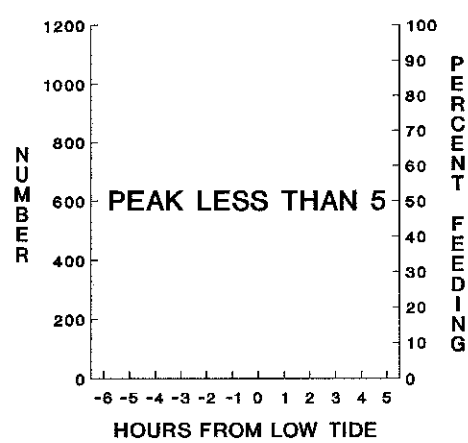


Figure 2.3.2.1 The number of Wigeon present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

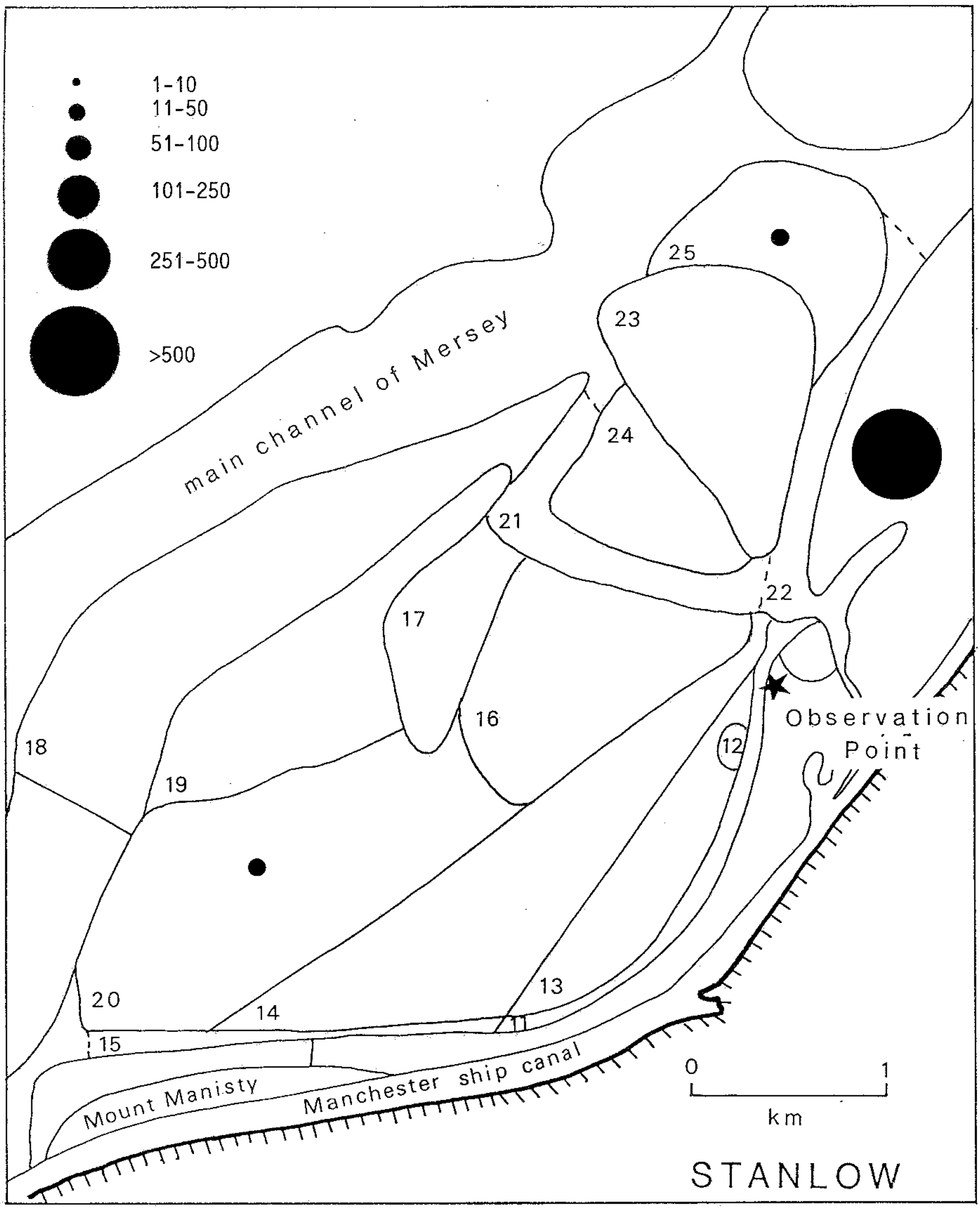


Figure 2.3.2.2 The number of bird hours per tidal cycle of feeding Wigeon on each intertidal area at Stanlow during the day, winter 1991/92.

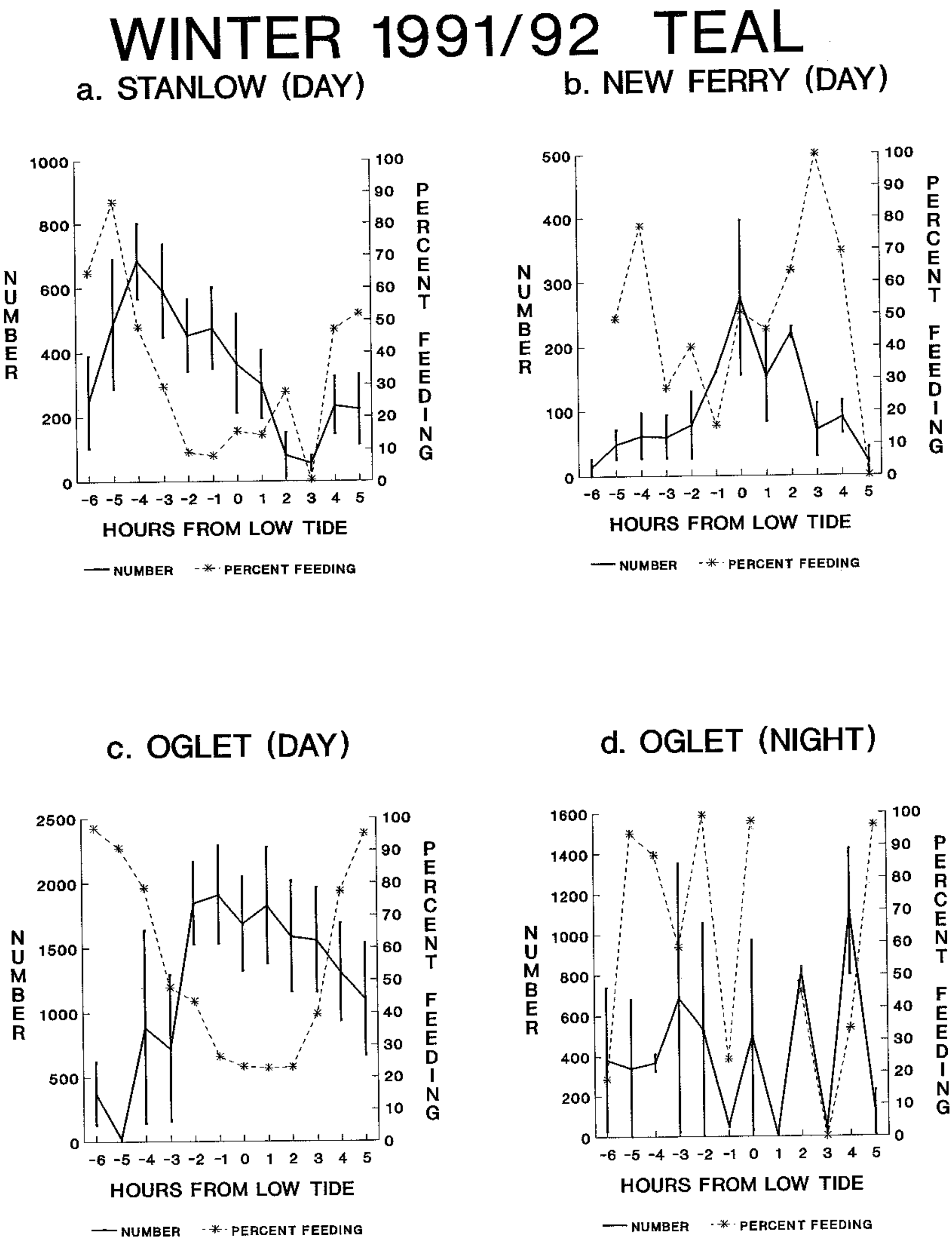
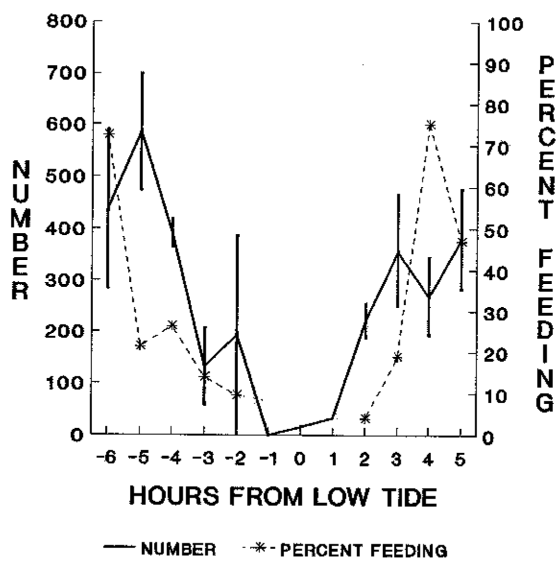


Figure 2.3.3.1 The number of Teal present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

WINTER 1991/92 TEAL

a. MANISTY (DAY)



b. MANISTY (NIGHT)

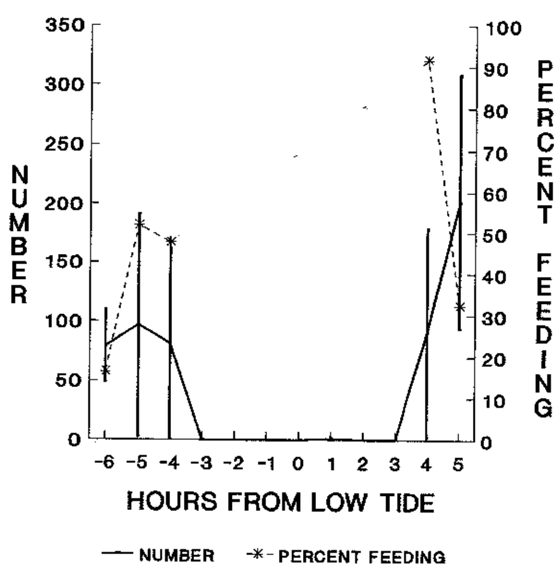


Figure 2.3.3.2 The number of Teal present and the percentage feeding on the Mount Manisty study site, both during the day and at night, during the 1991/92 winter.

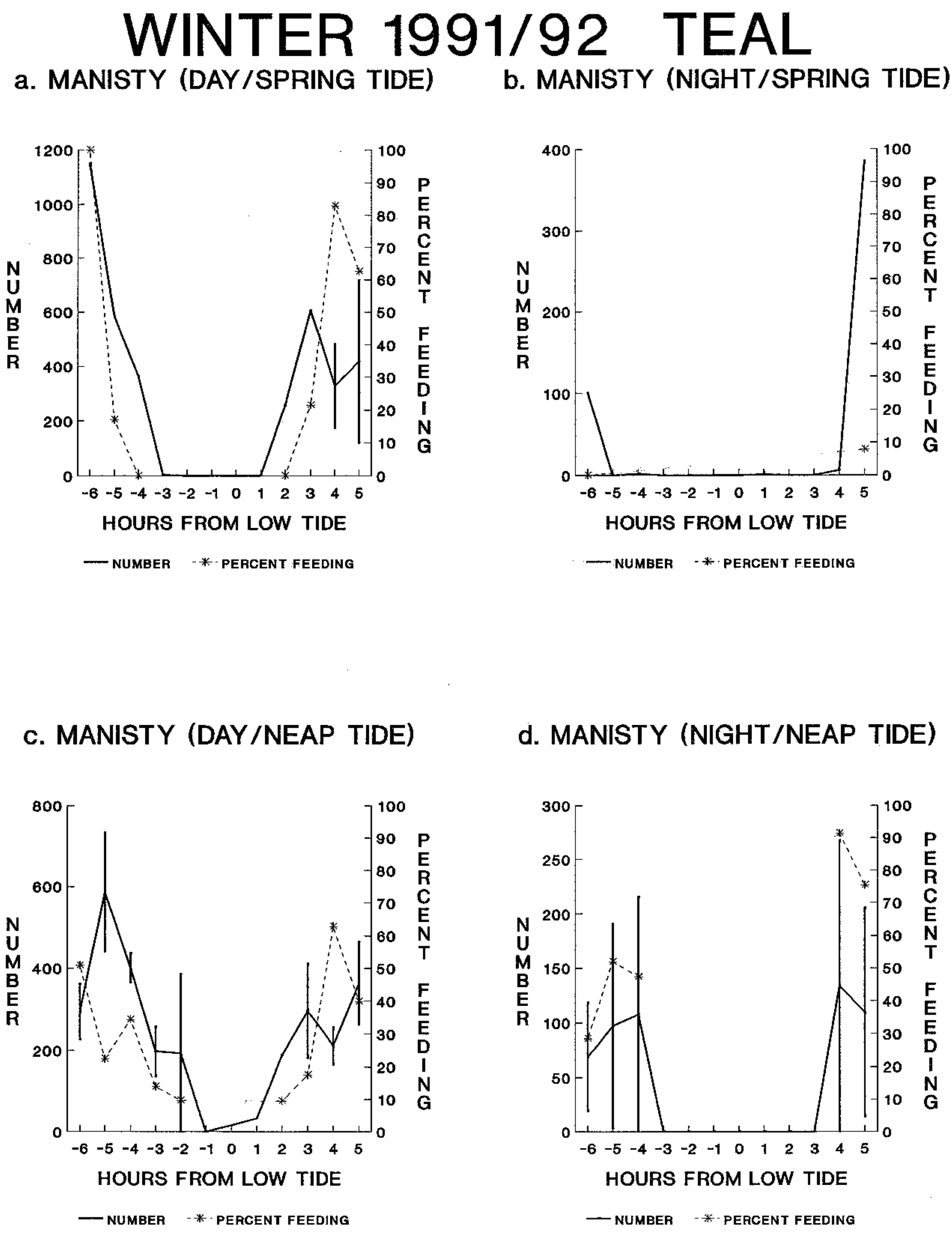


Figure 2.3.3.3 The number of Teal present and the percentage feeding on the Mount Manisty study site, both during the day and at night, on both spring and neap tides, during the 1991/92 winter.

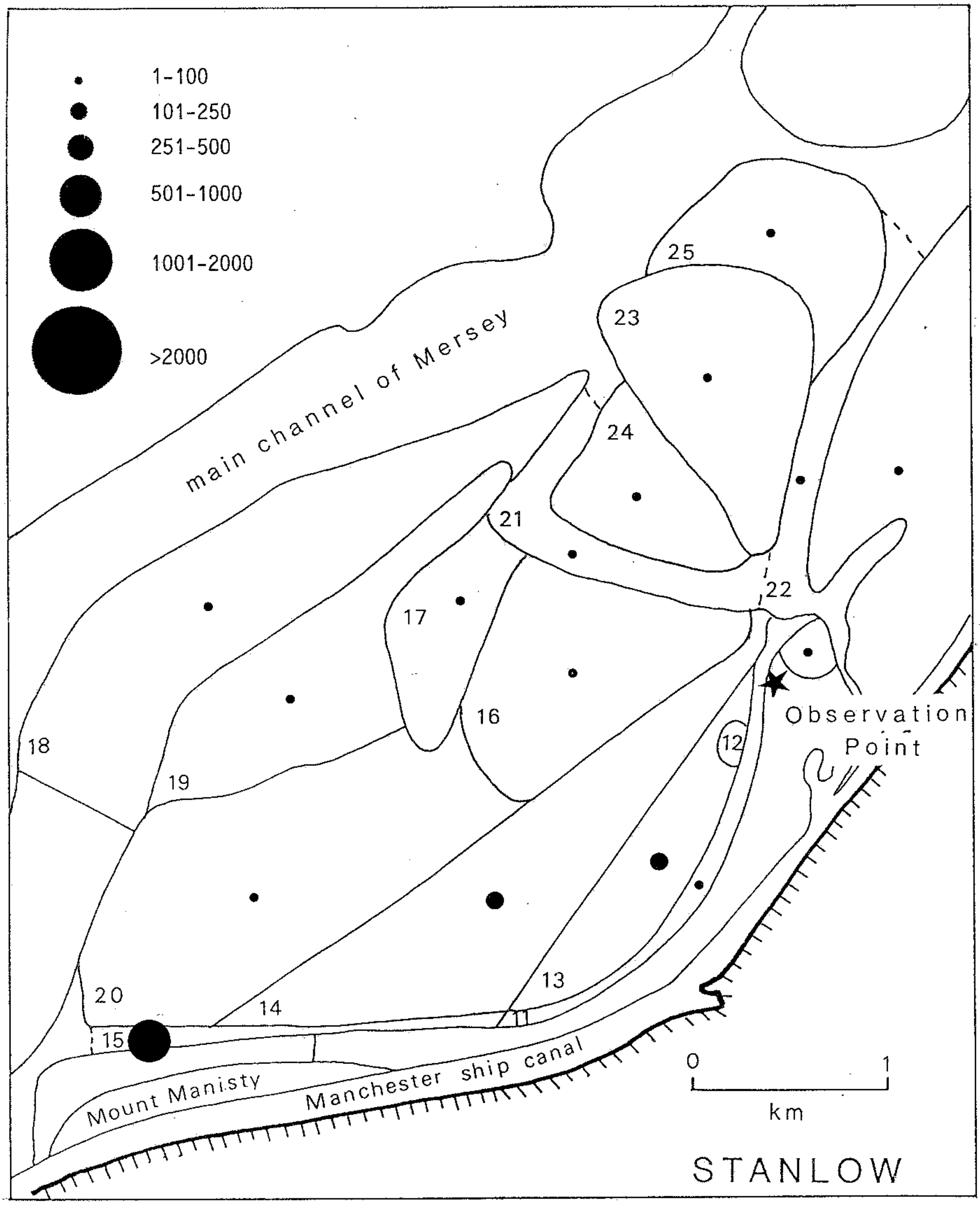
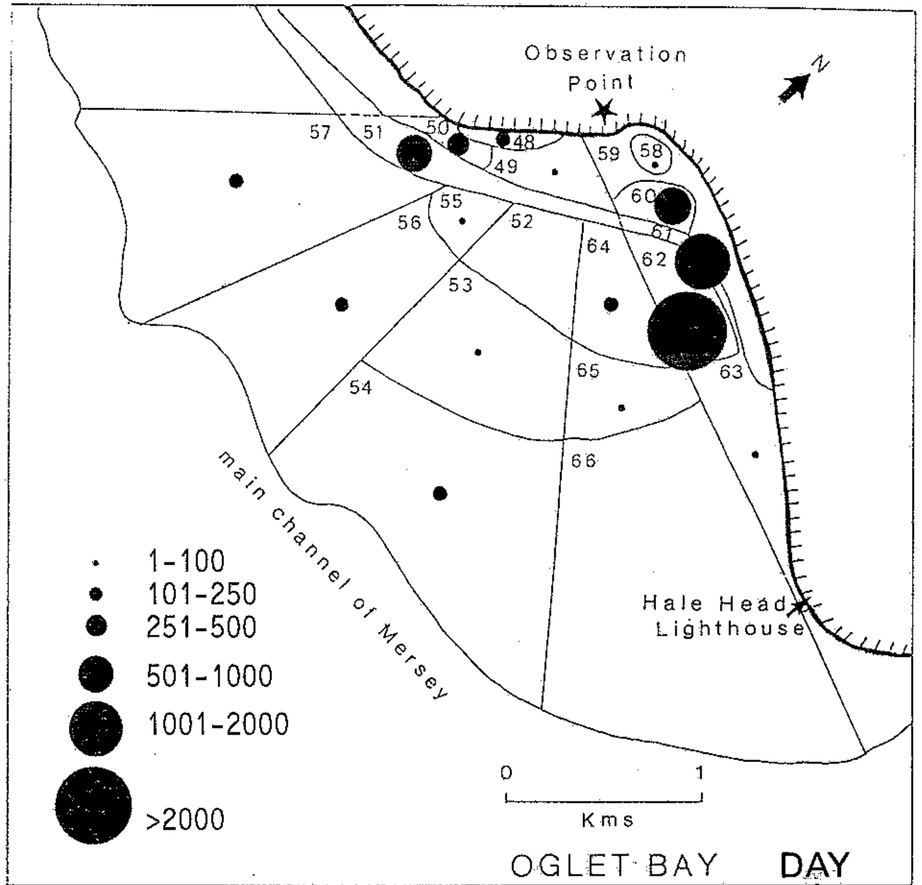


Figure 2.3.3.4 The number of bird hours per tidal cycle of feeding Teal on each intertidal area at Stanlow during the day, winter 1991/92.



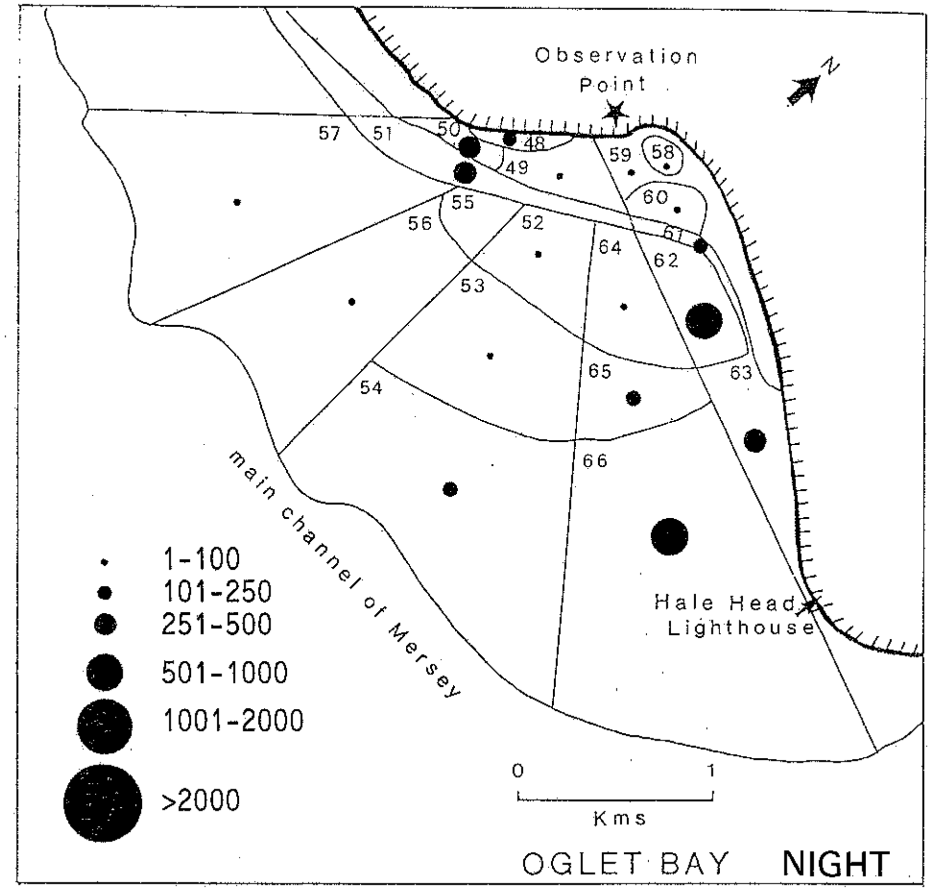


Figure 2.3.3.5 The number of bird hours per tidal cycle of feeding Teal on each intertidal area at Oglet Bay during the day **and at** night, winter 1991/92.

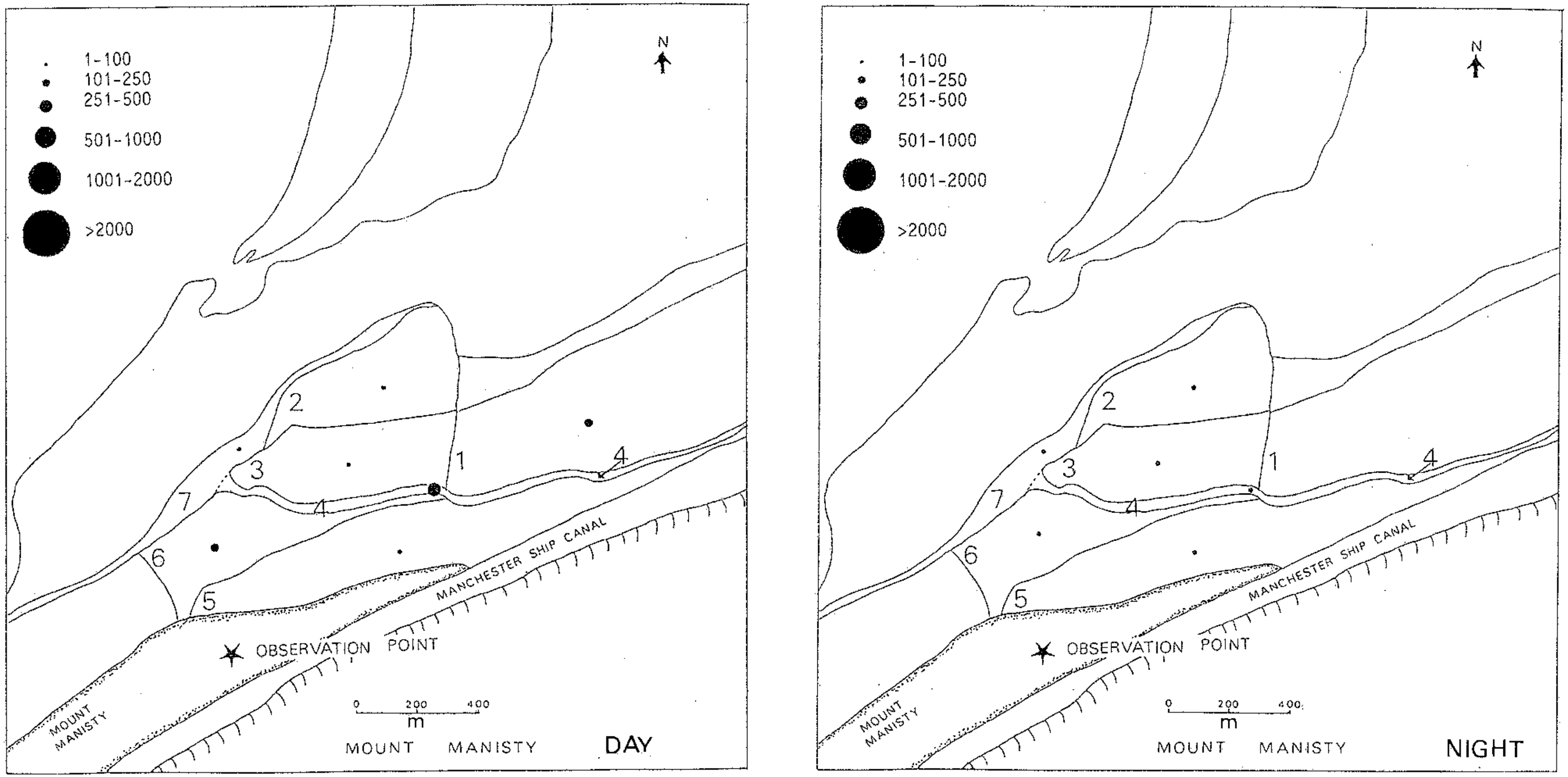


Figure 2.3.3.6 The number of bird hours per tidal cycle of feeding Teal on each intertidal area at Mount Manisty during the day and at night, winter 1991/92.

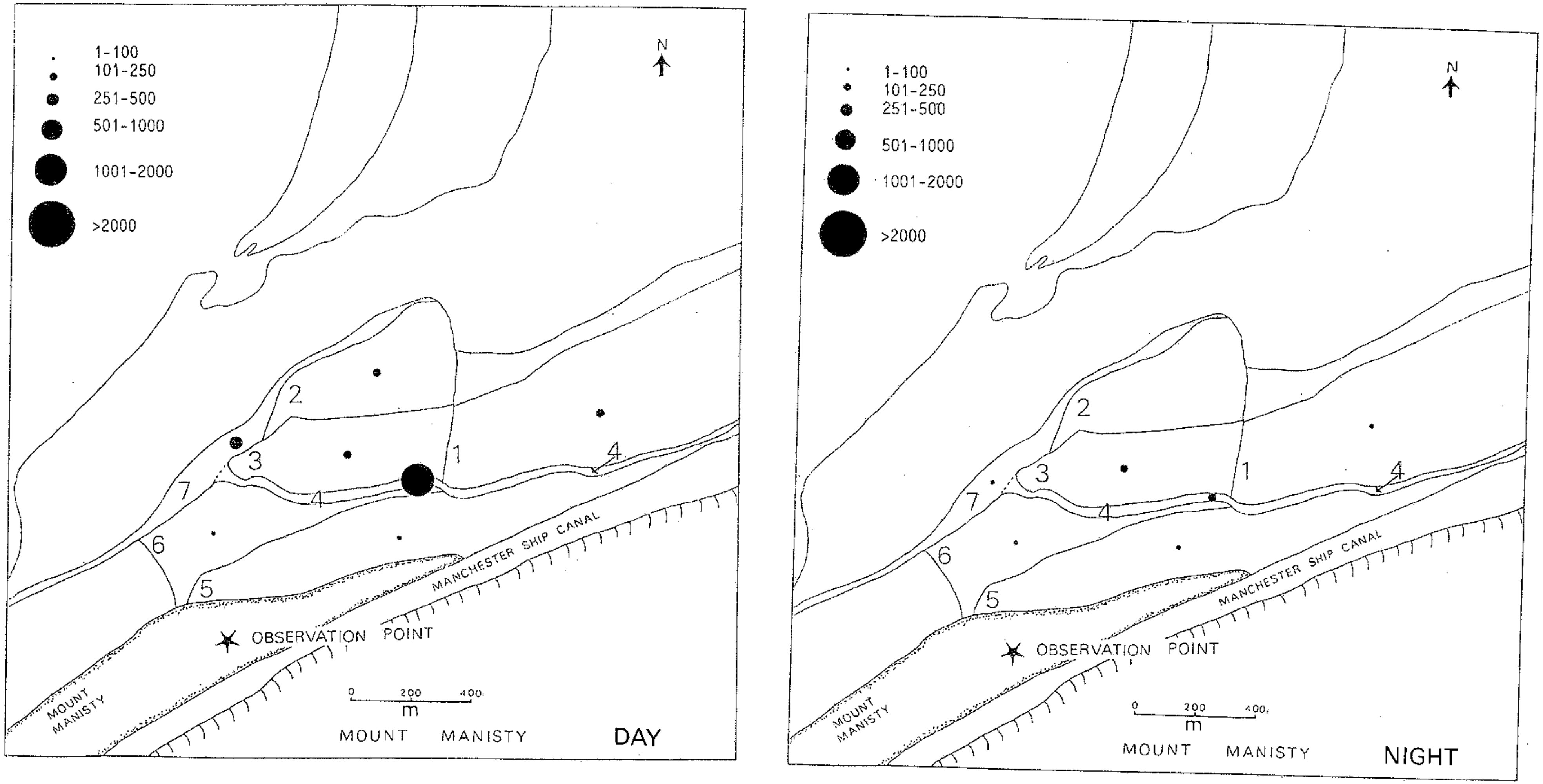


Figure 2.3.3.7 The number of bird hours per tidal cycle of roosting Teal on each intertidal area at Mount Manisty during the day and at night, winter 1991/92.

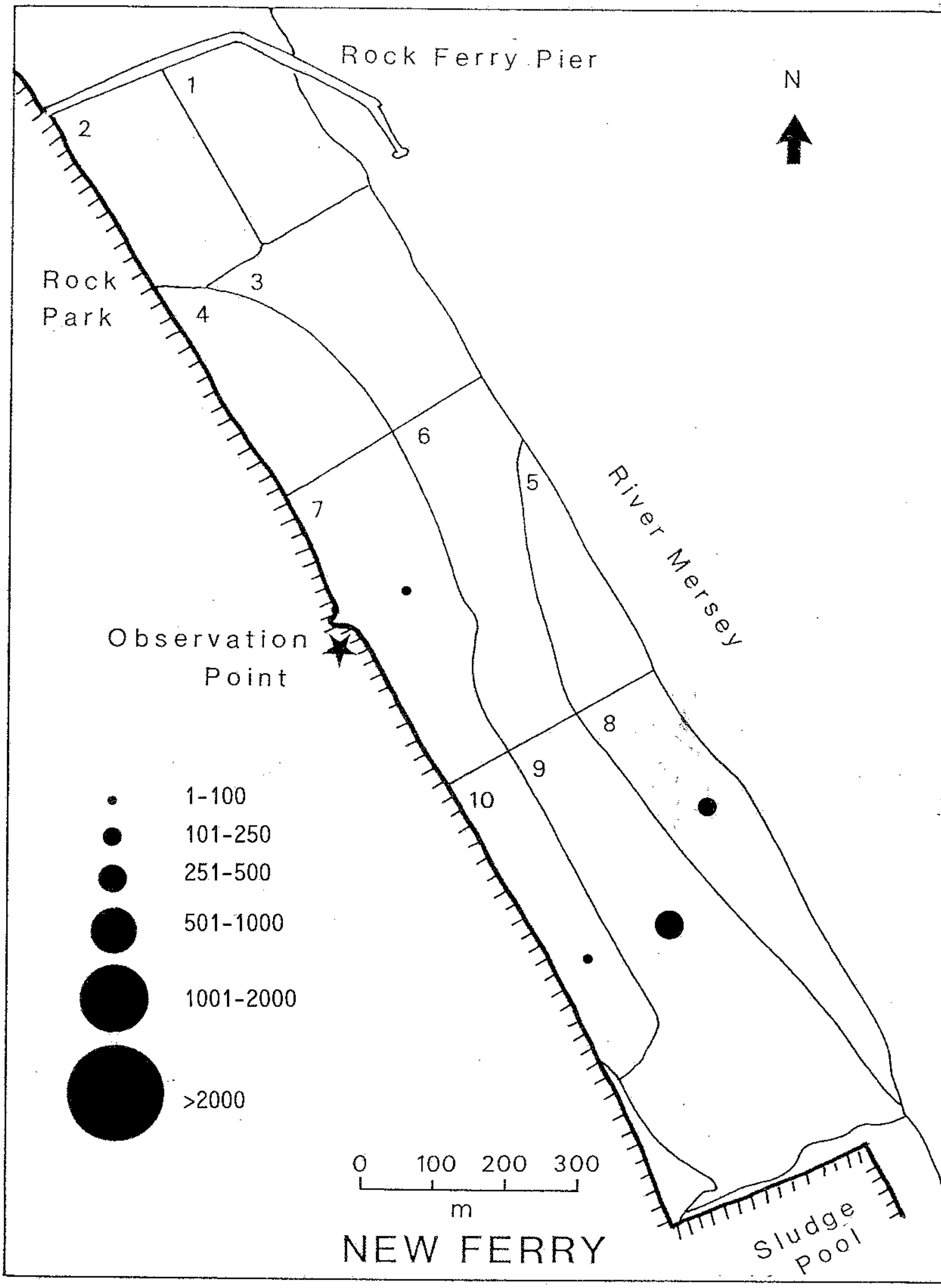


Figure 2.3.3.8 The number of bird hours per tidal cycle of feeding Teal on each intertidal area at New Ferry during the day, winter 1991/92.

WINTER 1991/92 PINTAIL

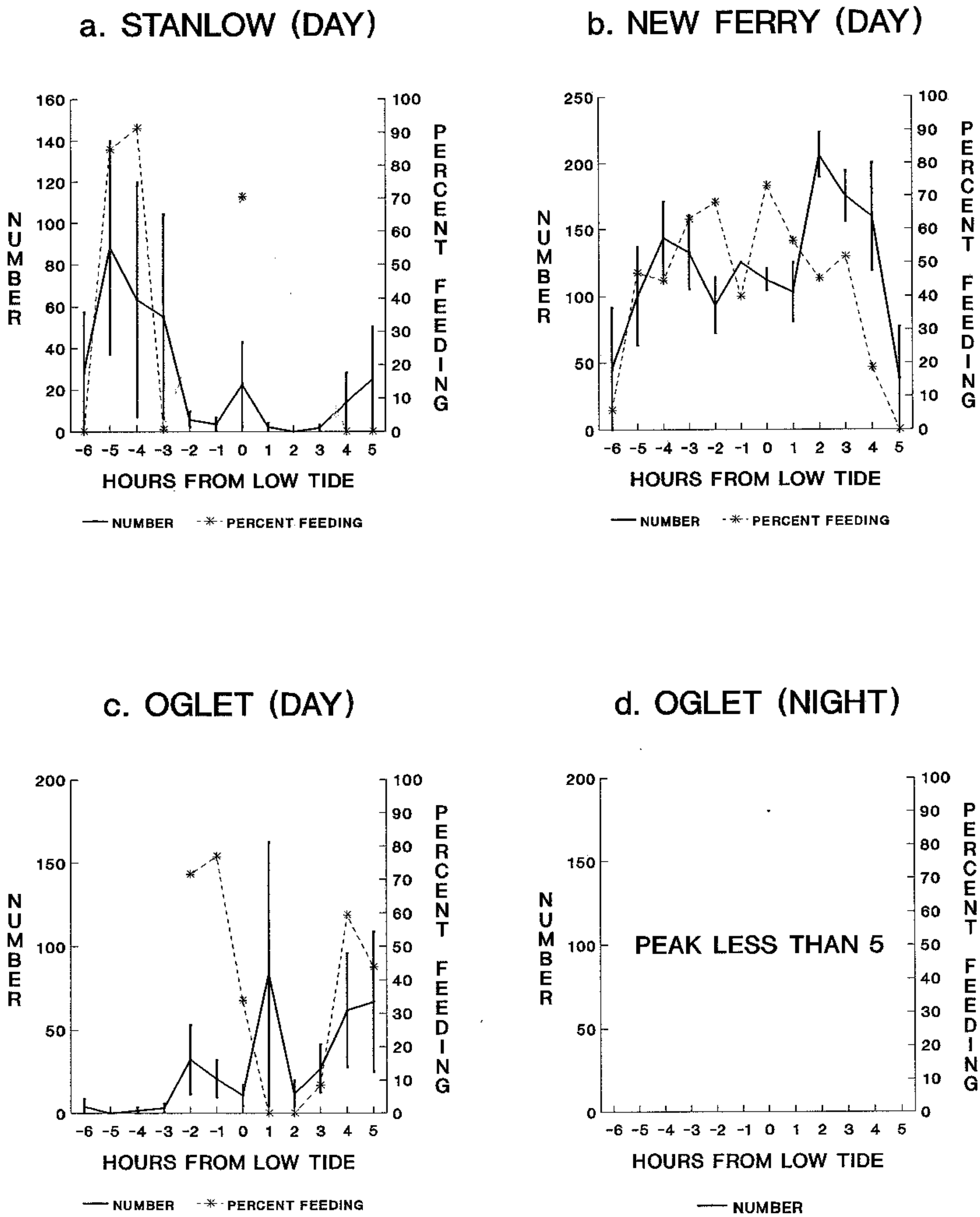
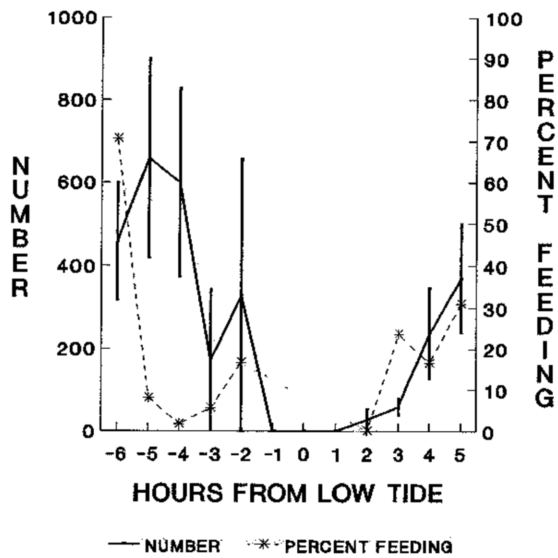


Figure 2.3.4.1 The number of Pintail present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

WINTER 1991/92 PINTAIL

a. MANISTY (DAY)



b. MANISTY (NIGHT)

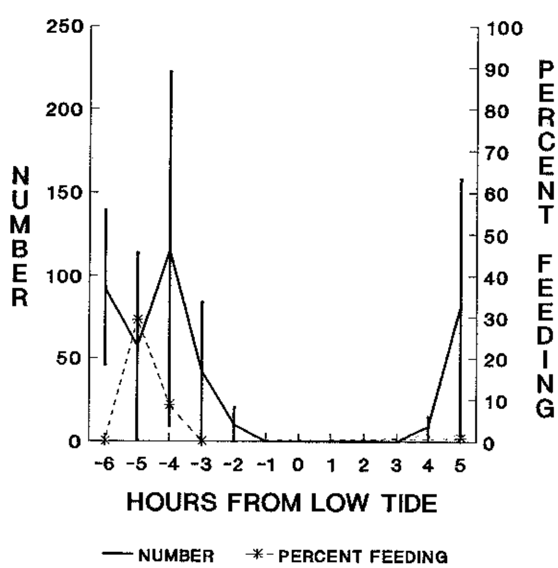


Figure 2.3.4.2 The number of Pintail present and the percentage feeding on the Mount Manisty study site, both during the day and at night, during the 1991/92 winter.

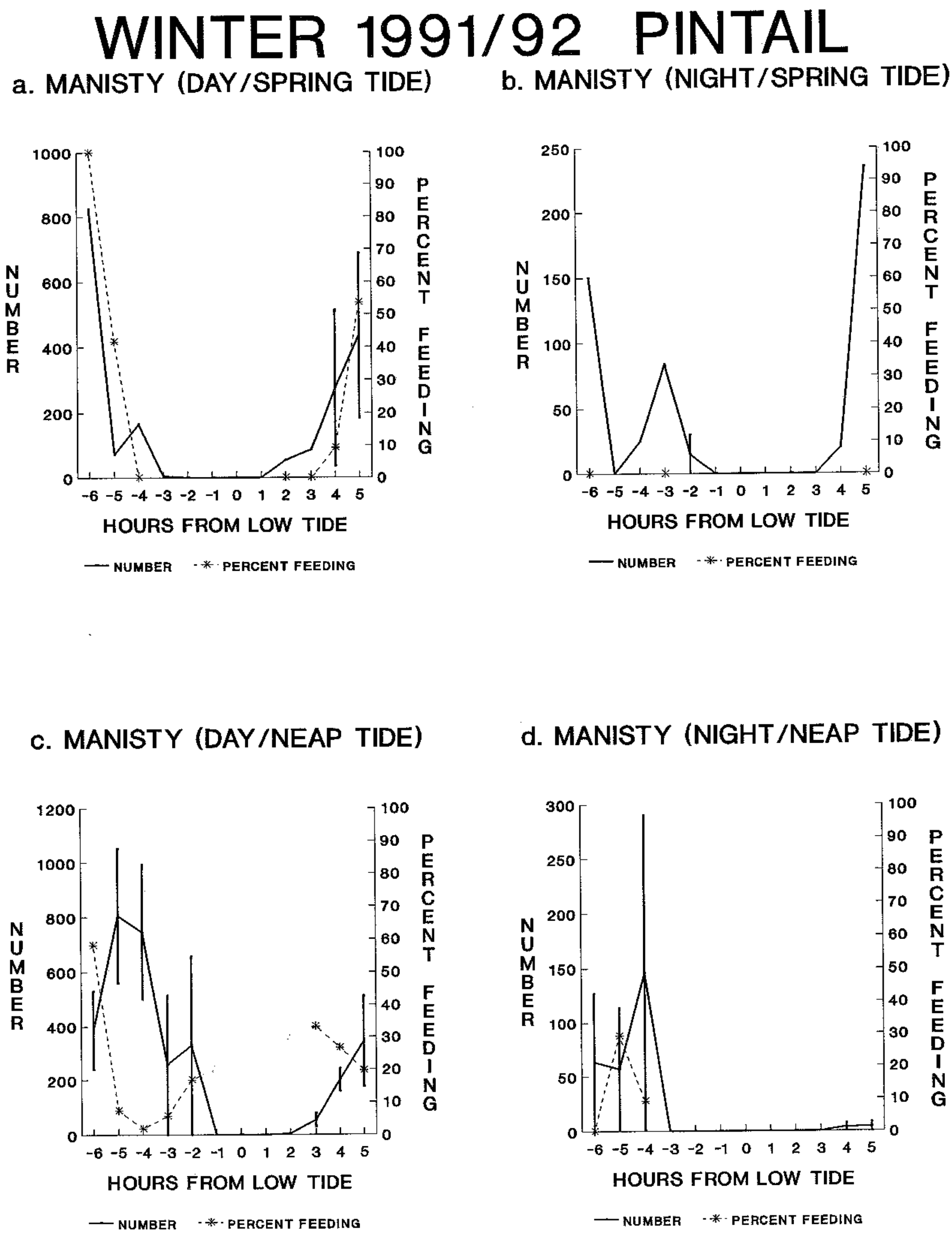


Figure 2.3.4.3 The number of Pintail present and the percentage feeding on the Mount Manisty study site, both during the day and at night, on both spring and neap tides, during the 1991/92 winter.

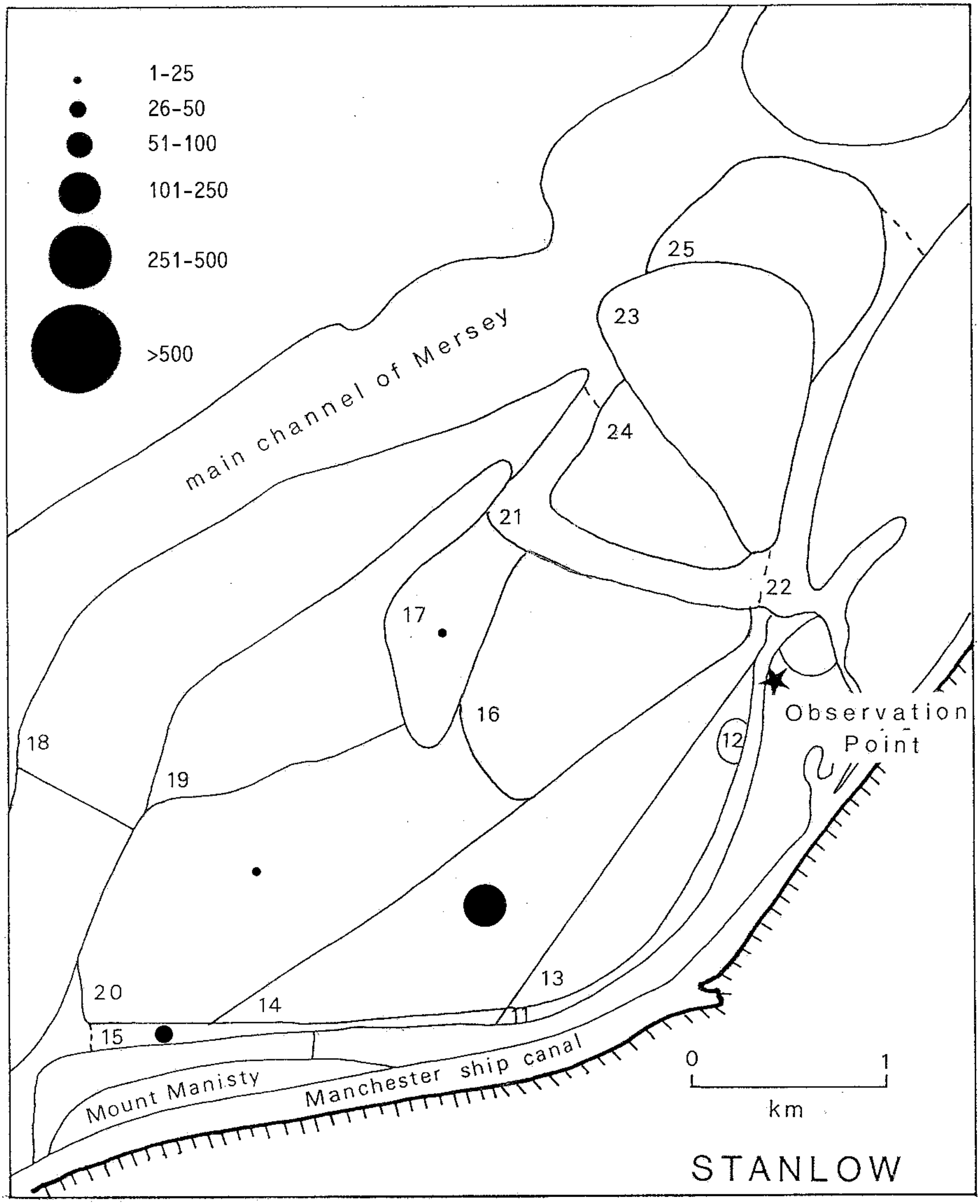


Figure 2.3.4.4 The number of bird hours per tidal cycle of feeding Pintail on each intertidal area at Stanlow during the day, winter 1991/92.

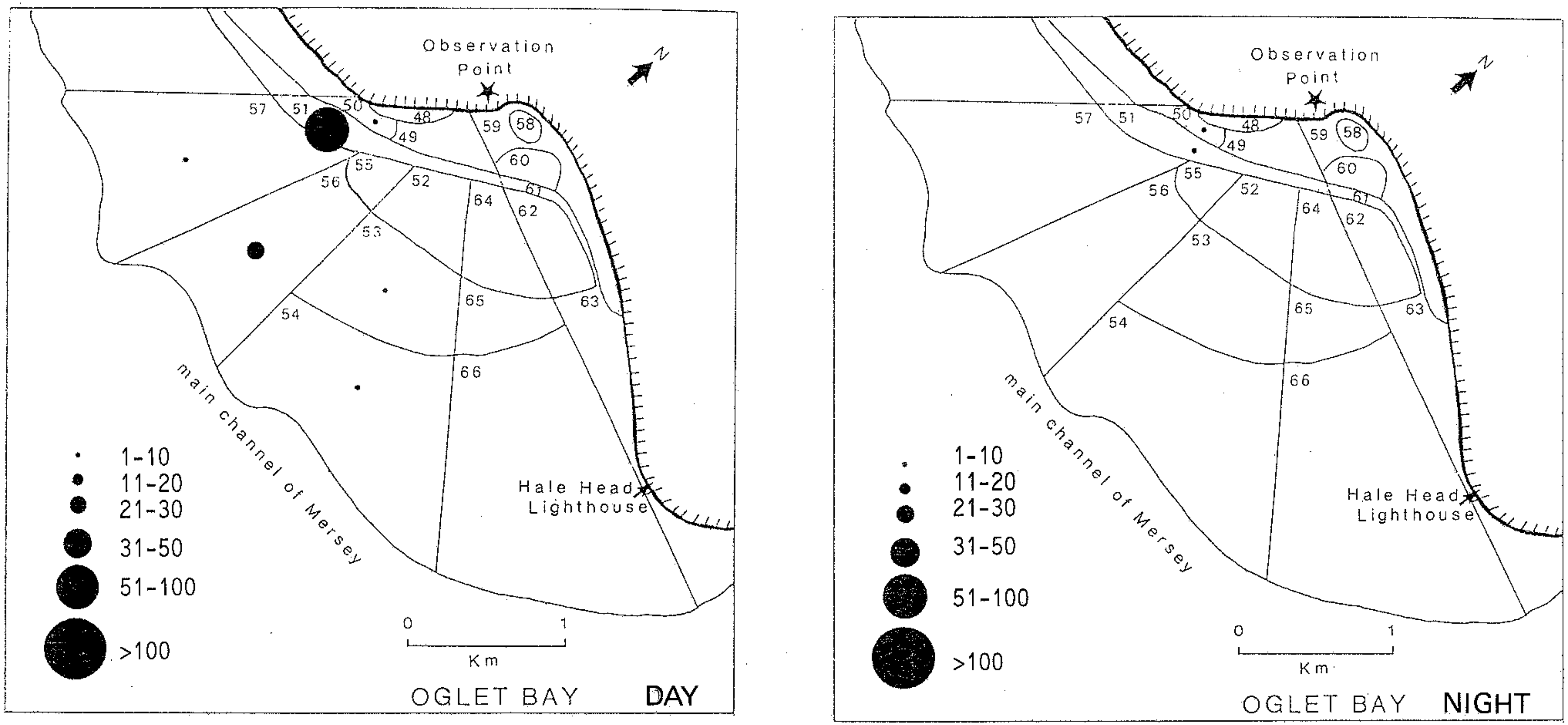


Figure 2.3.4.5 The number of bird hours per tidal cycle of feeding Pintail on each intertidal area at Oglet Bay during the day and at night, winter 1991/92.

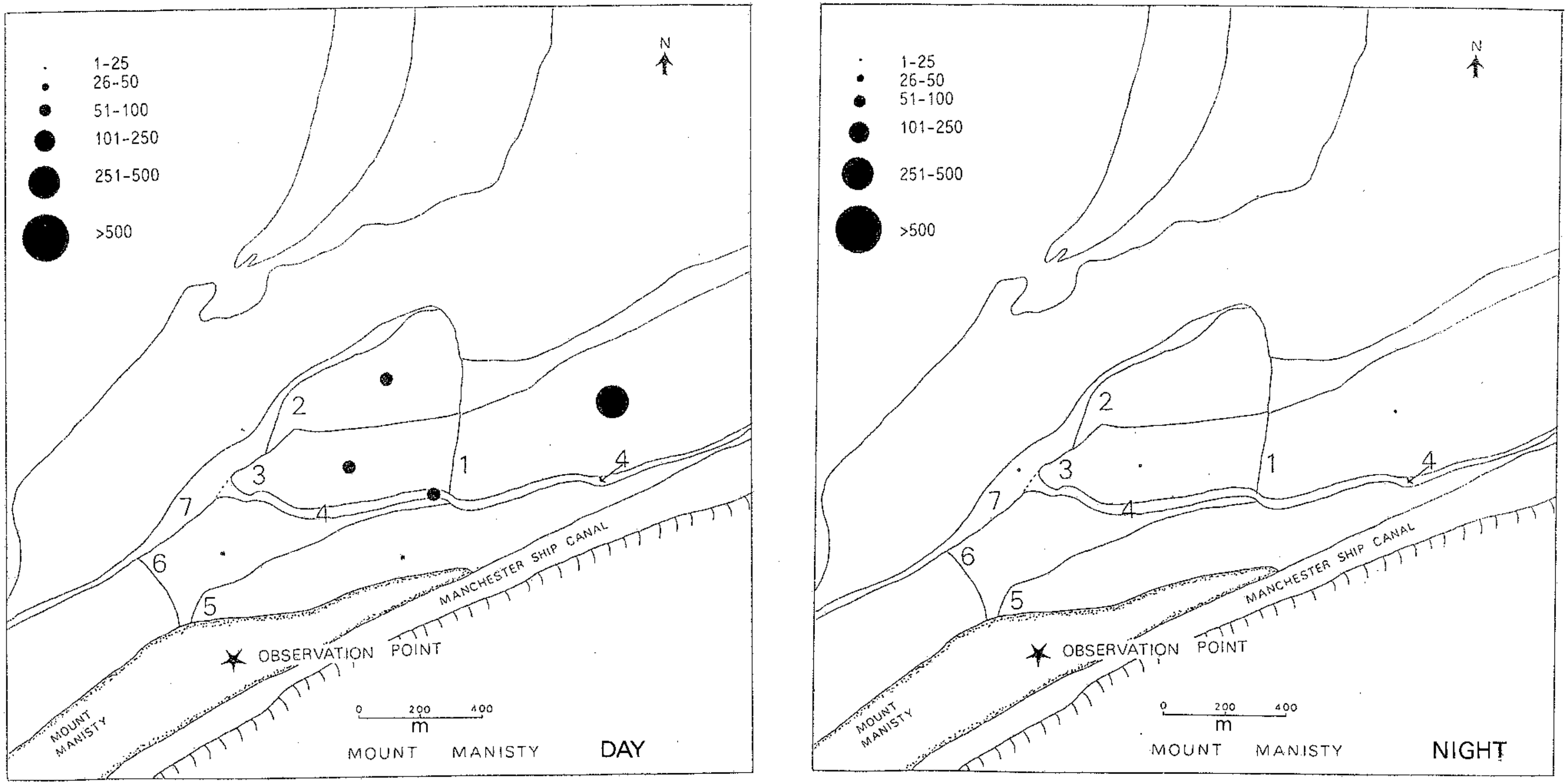


Figure 2.3.4.6 The number of bird hours per tidal cycle of feeding Pintail on each intertidal area at Mount Manisty during the day and at night, winter 1991/92.

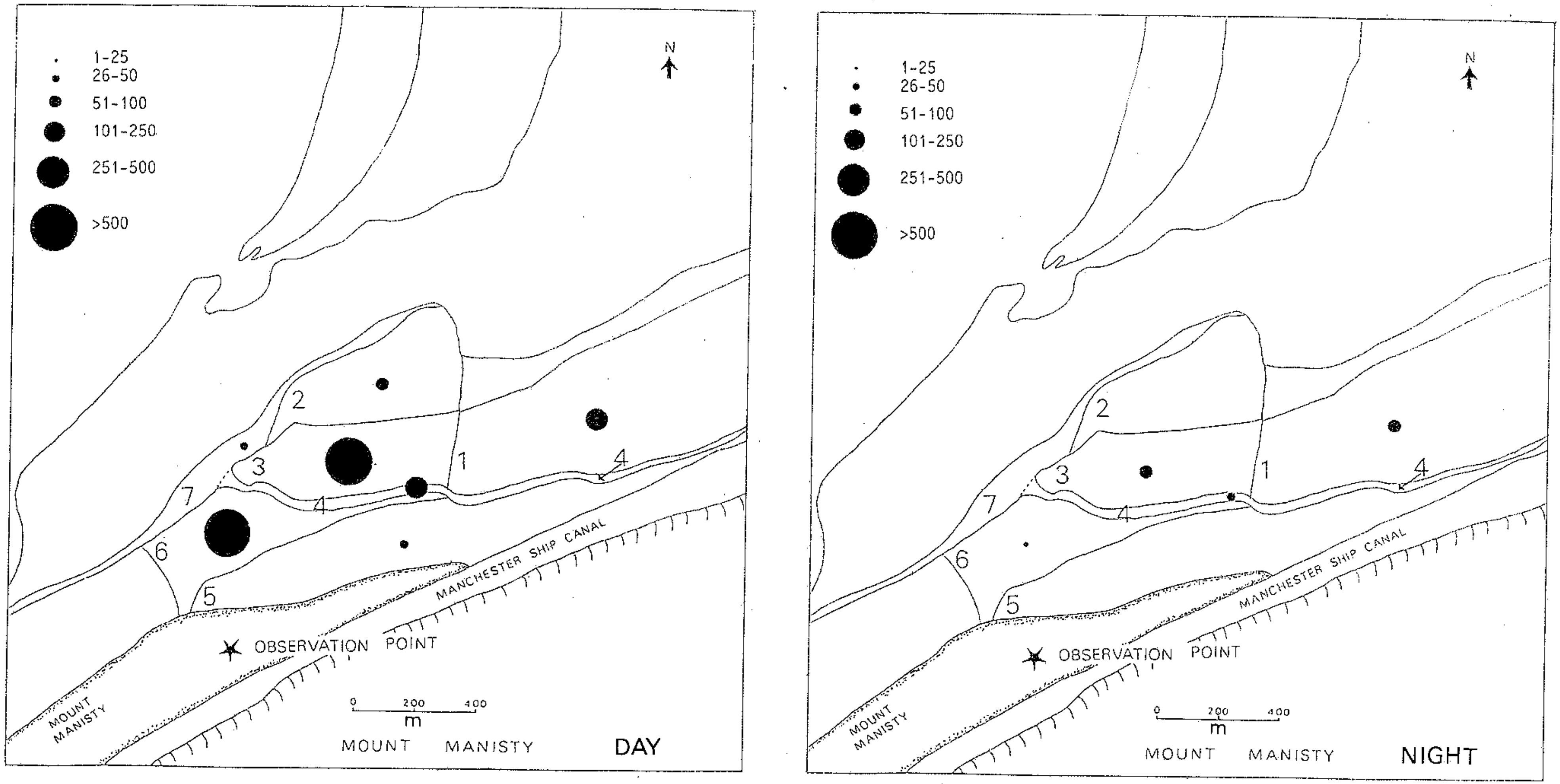


Figure 2.3.4.7 The number of bird hours per tidal cycle of roosting Pintail on each intertidal area at Mount Manisty during the day and at night, winter 1991/92.

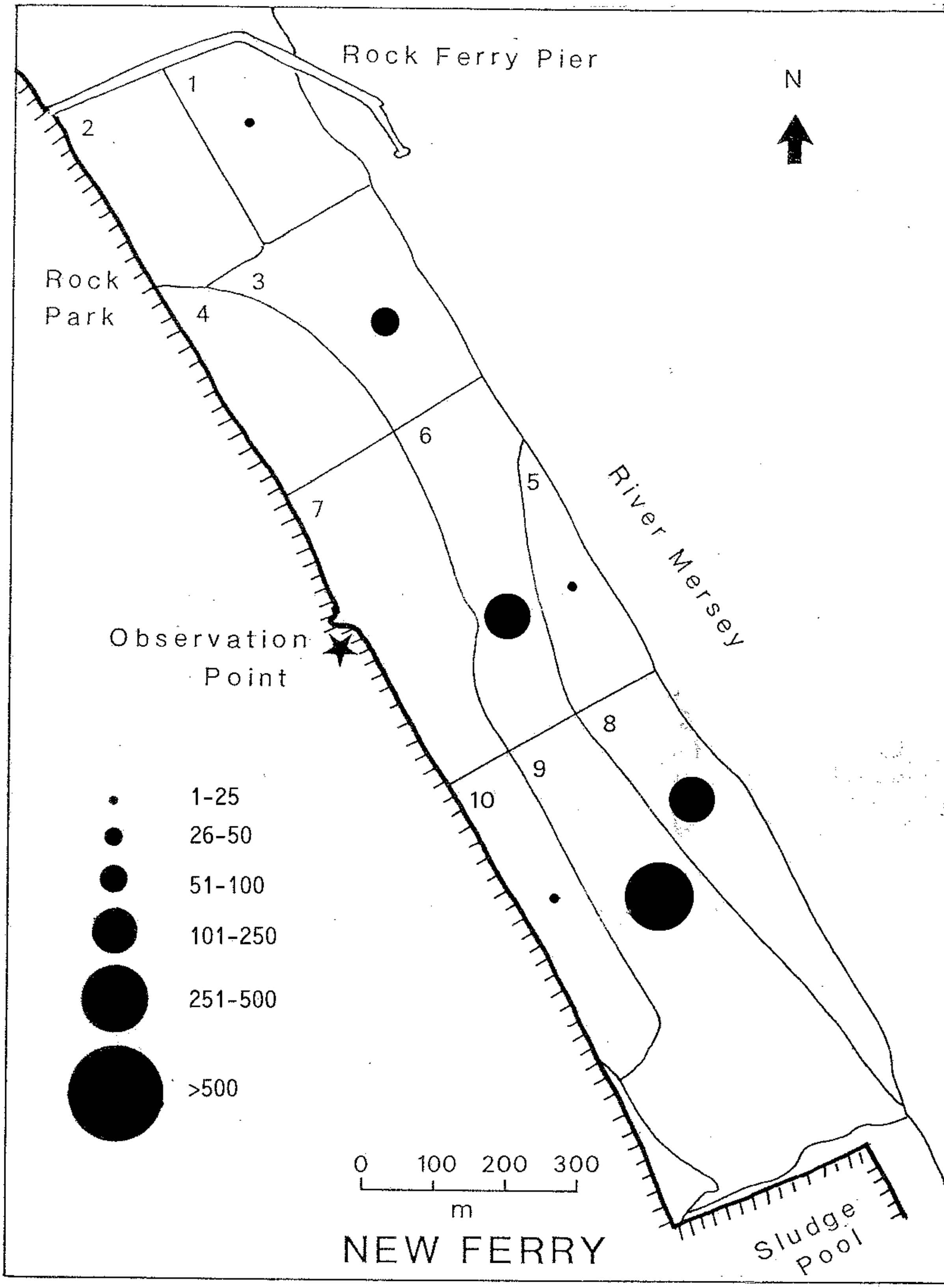
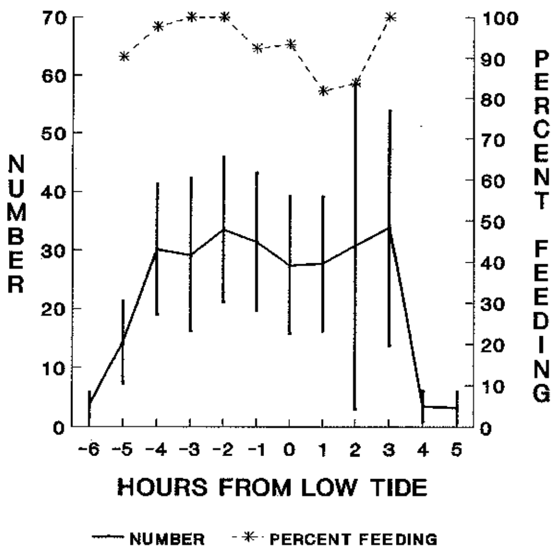


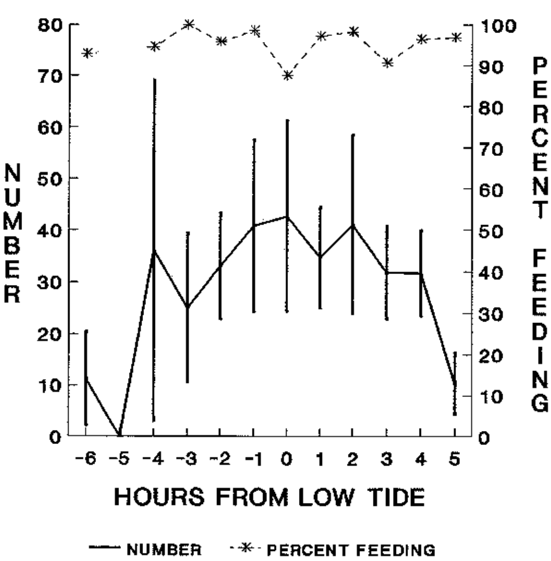
Figure 2.3.4.8 The number of bird hours per tidal cycle of feeding Pintail on each intertidal area at New Ferry during the day, winter 1991/92.

WINTER 1991/92 GREY PLOVER

a. STANLOW (DAY)



b. OGLET (DAY)



c. OGLET (NIGHT)

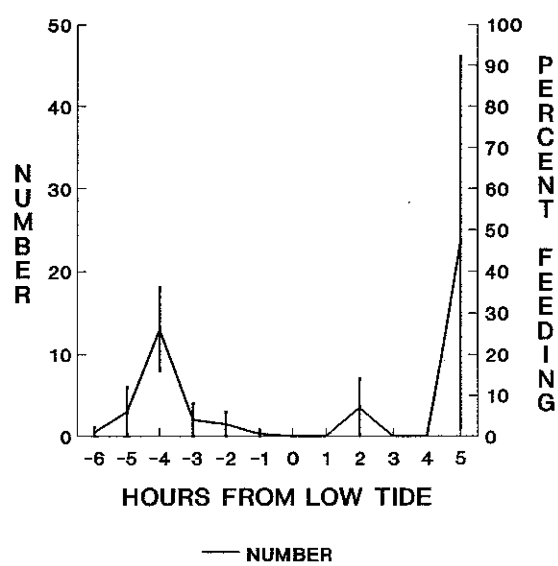


Figure 2.3.5.1 The number of Grey Plover present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

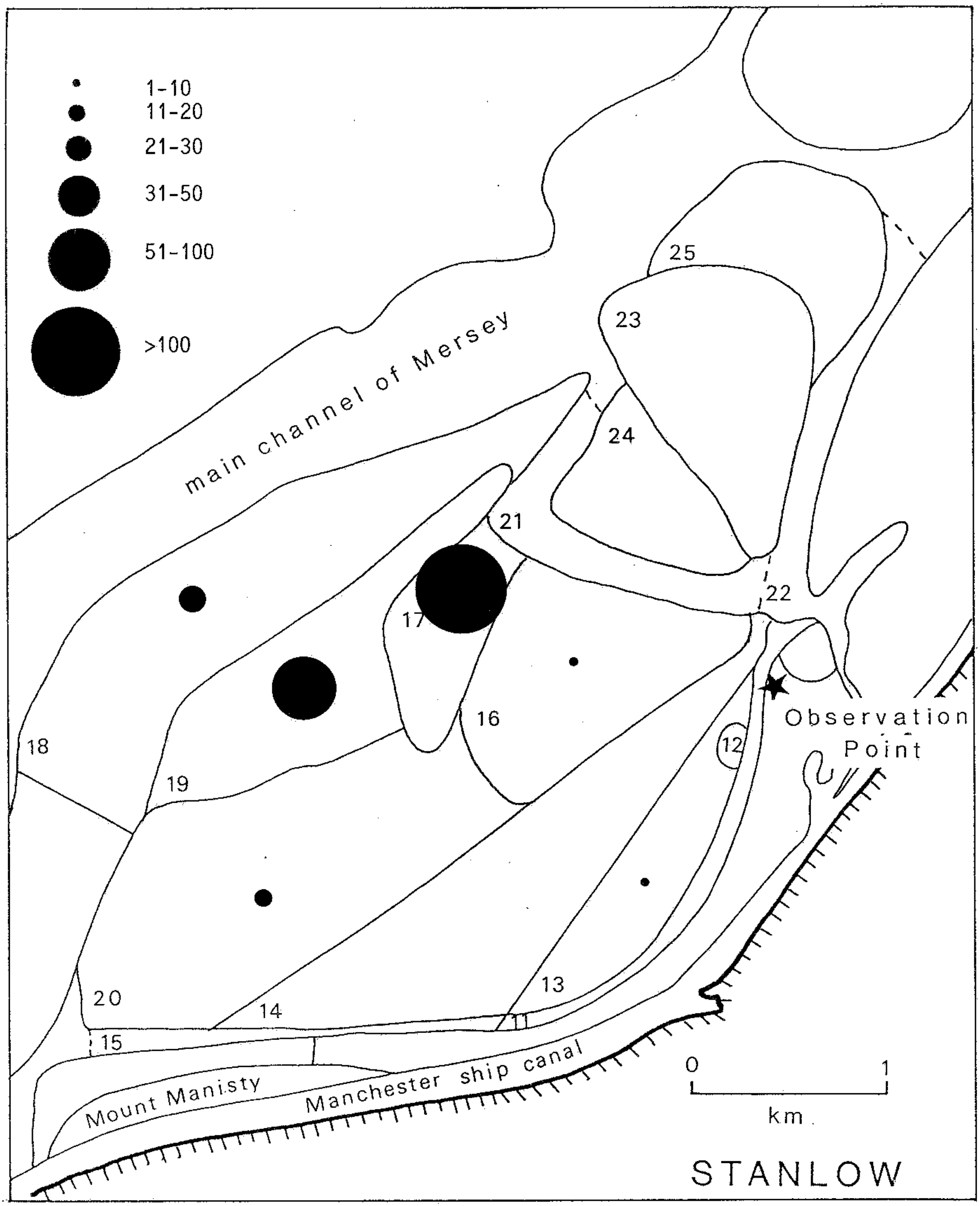


Figure 2.3.5.2 The number of bird hours per tidal cycle of feeding Grey Plover on each intertidal area at Stanlow during the day, winter 1991/92.

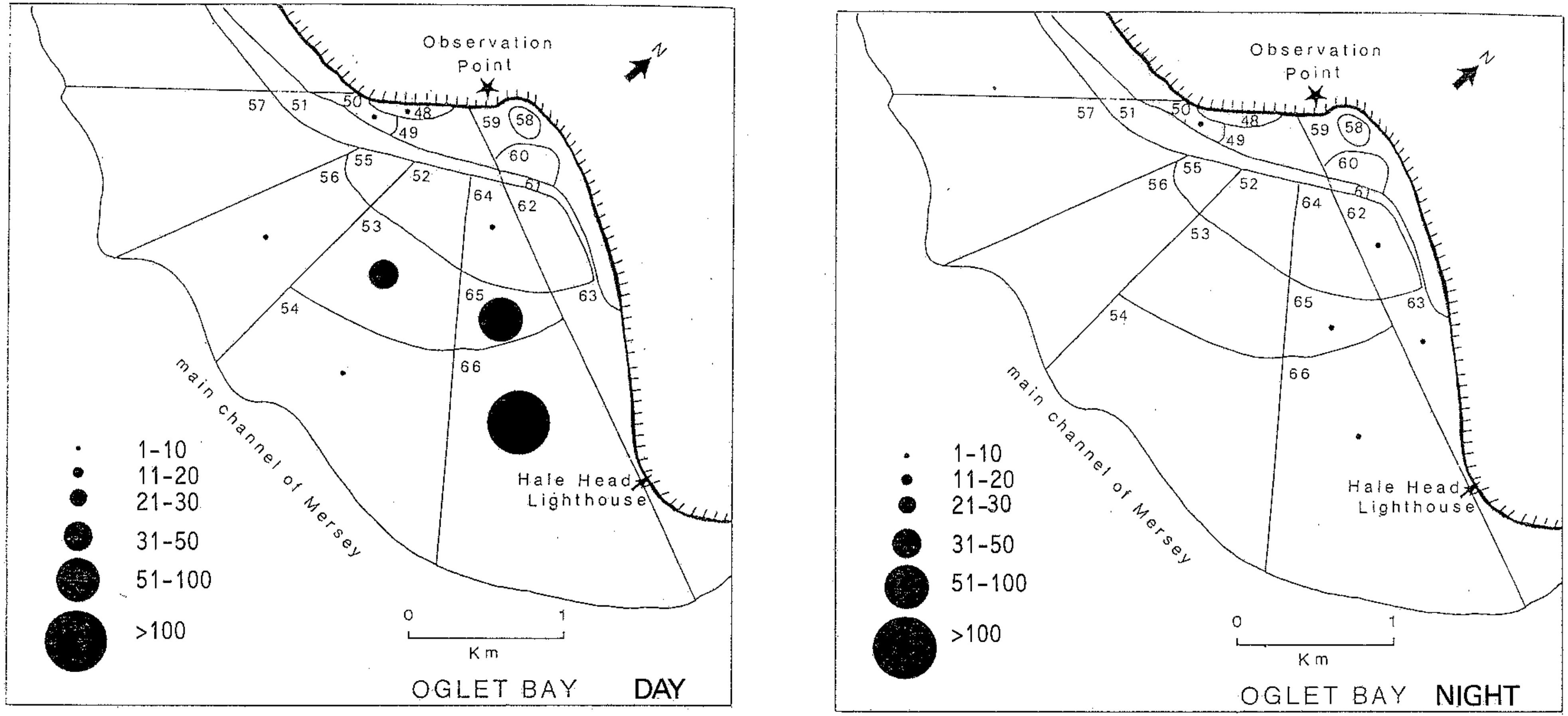


Figure 2.3.5.3 The number of bird hours per tidal cycle of feeding Grey Plover on each intertidal area at Oglet Bay during the day and at night, winter 1991/92.

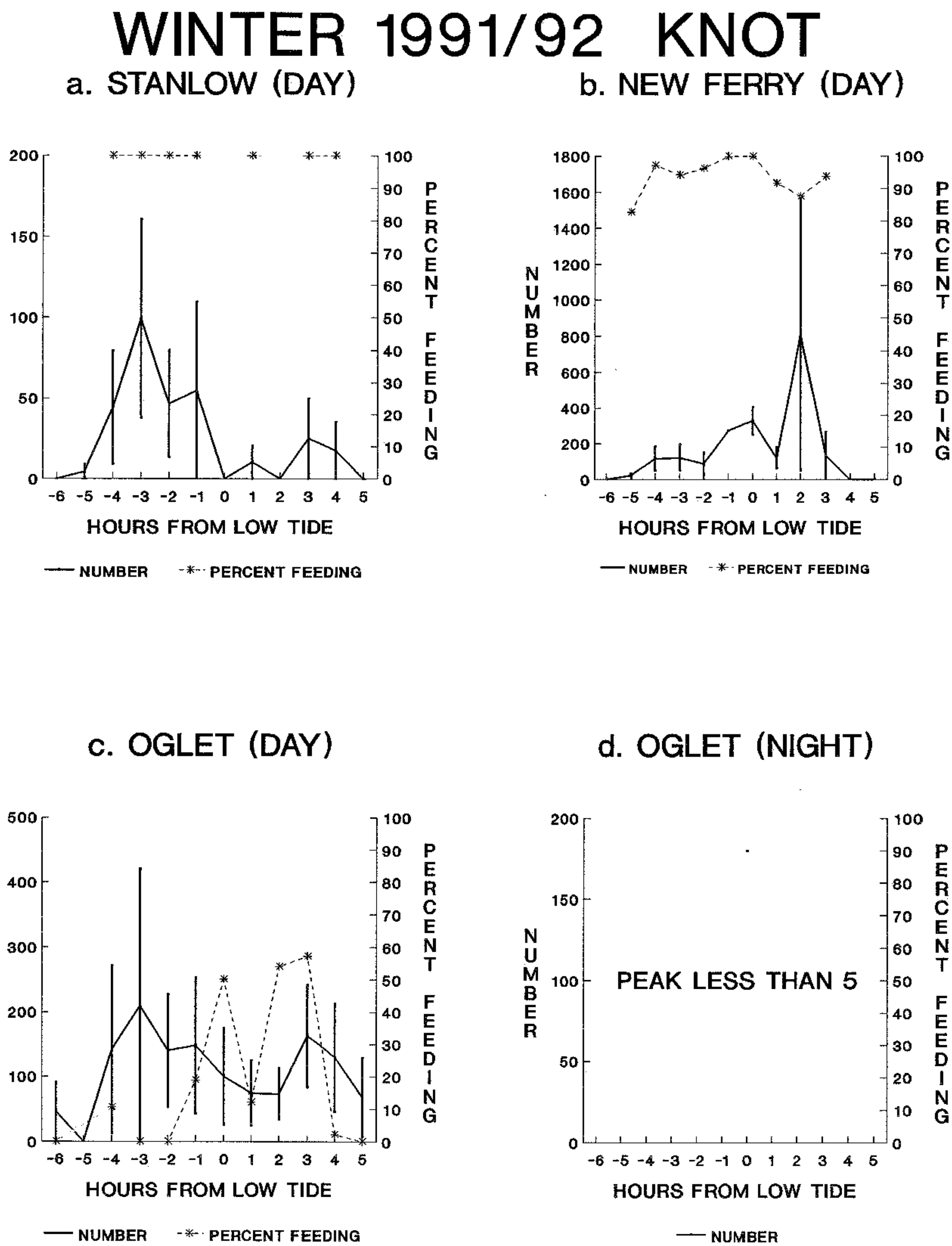


Figure 2.3.6.1 The number of Knot present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

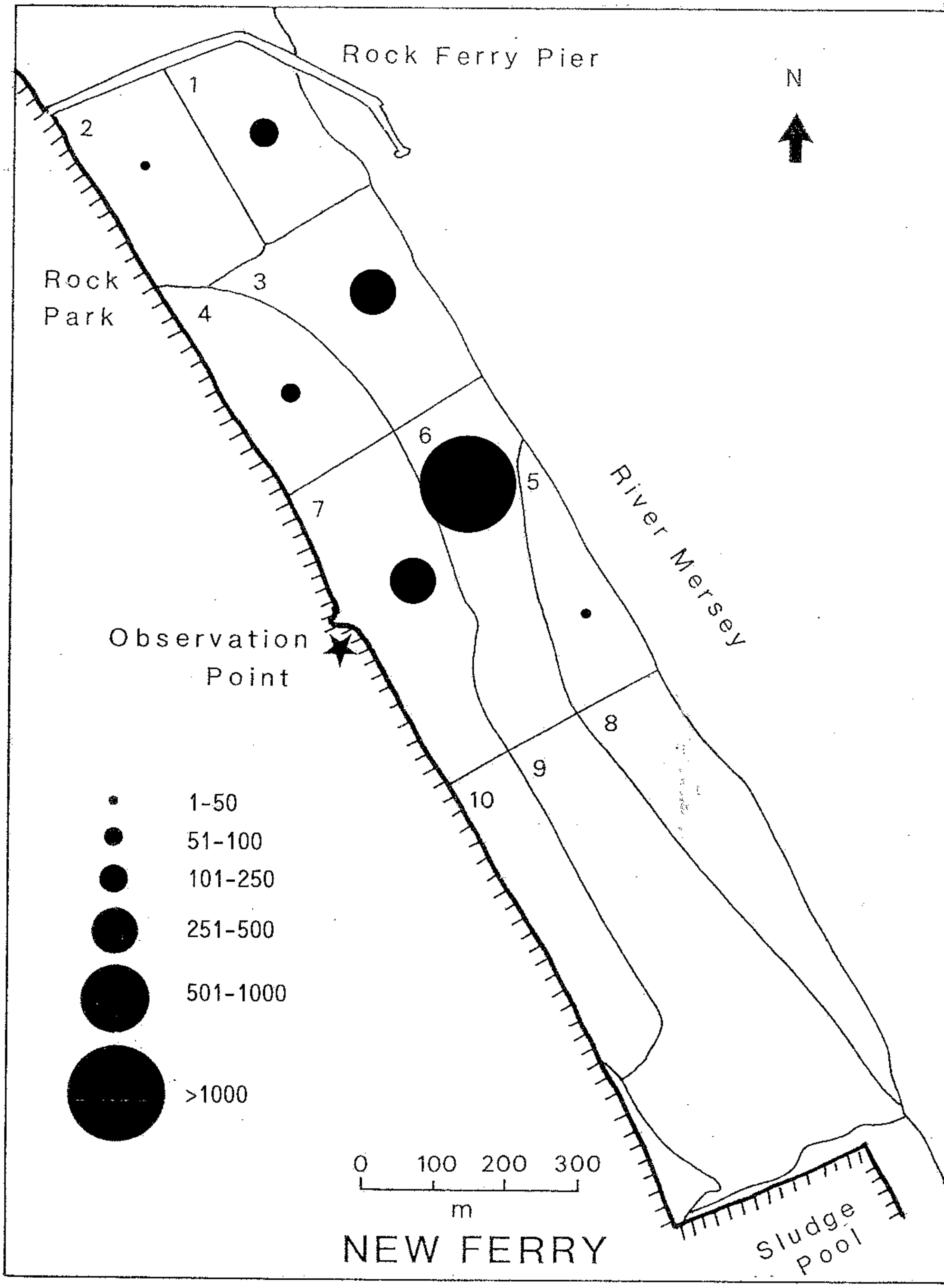
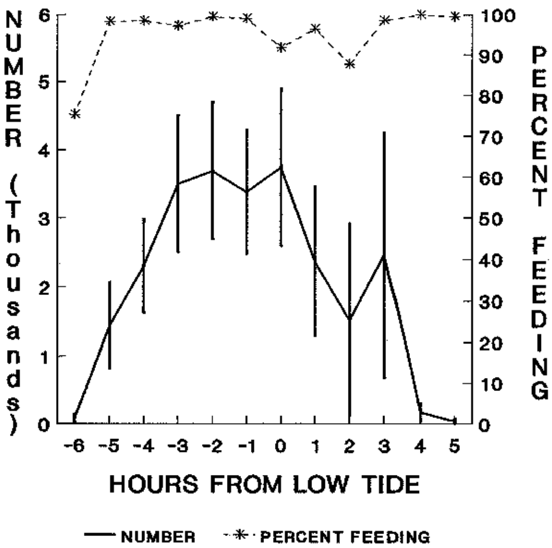


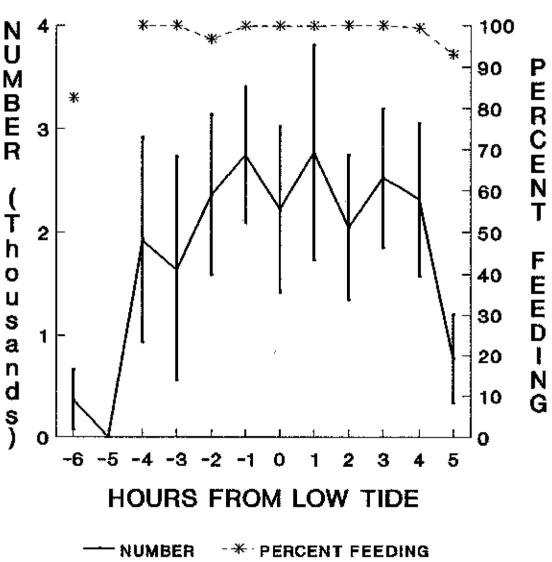
Figure 2.3.6.2 The number of bird hours per tidal cycle of feeding Knot on each intertidal area at New Ferry during the day and at night, winter 1991/92.

WINTER 1991/92 DUNLIN

a. STANLOW (DAY)



b. OGLET (DAY)



c. OGLET (NIGHT)

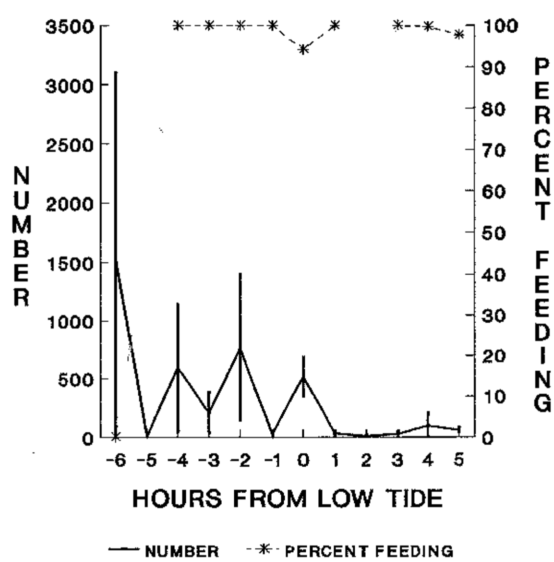


Figure 2.3.7.1 The number of Dunlin present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

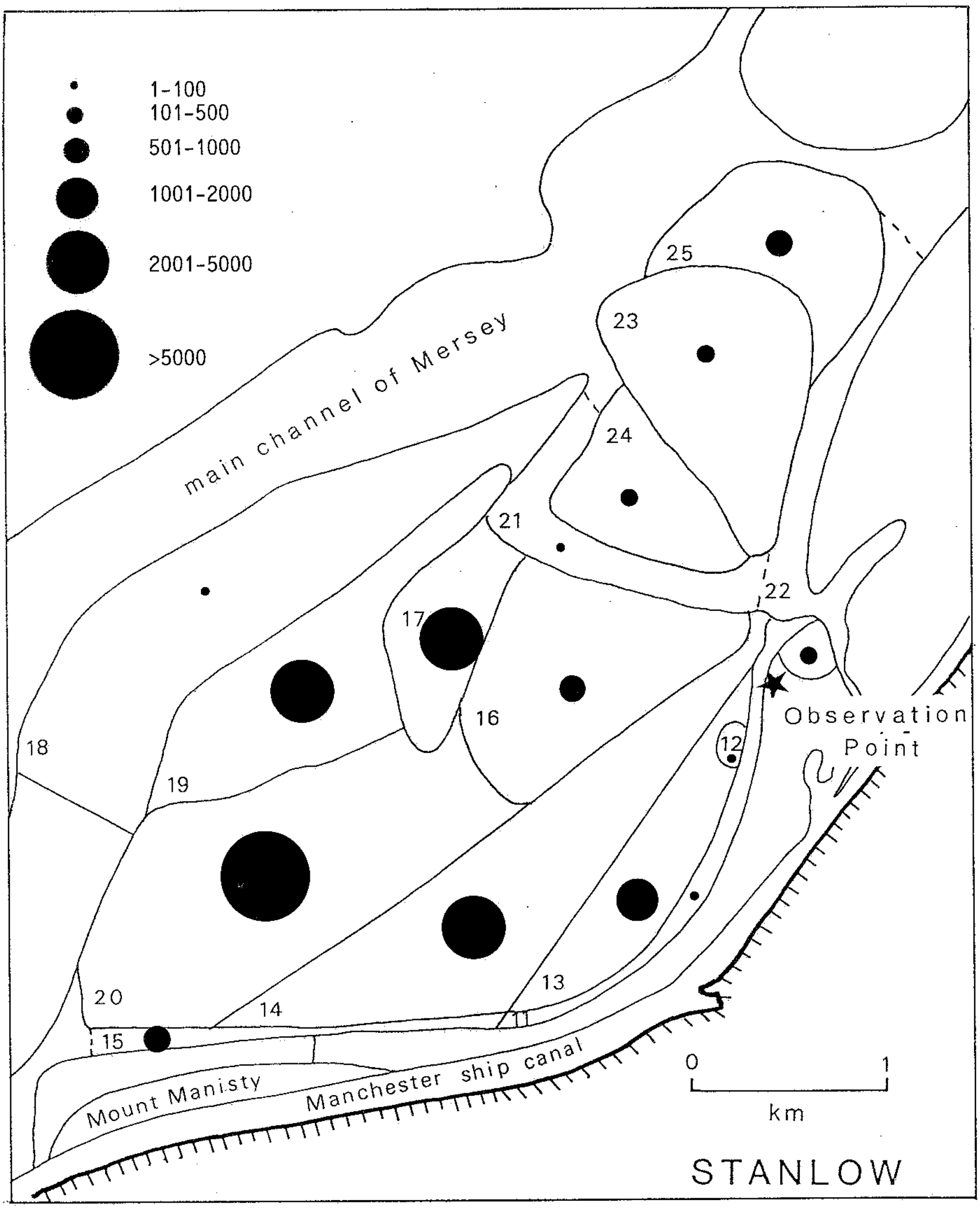


Figure 2.3.7.2 The number of bird hours per tidal cycle of feeding Dunlin on each intertidal area at Stanlow during the day, winter 1991/92.

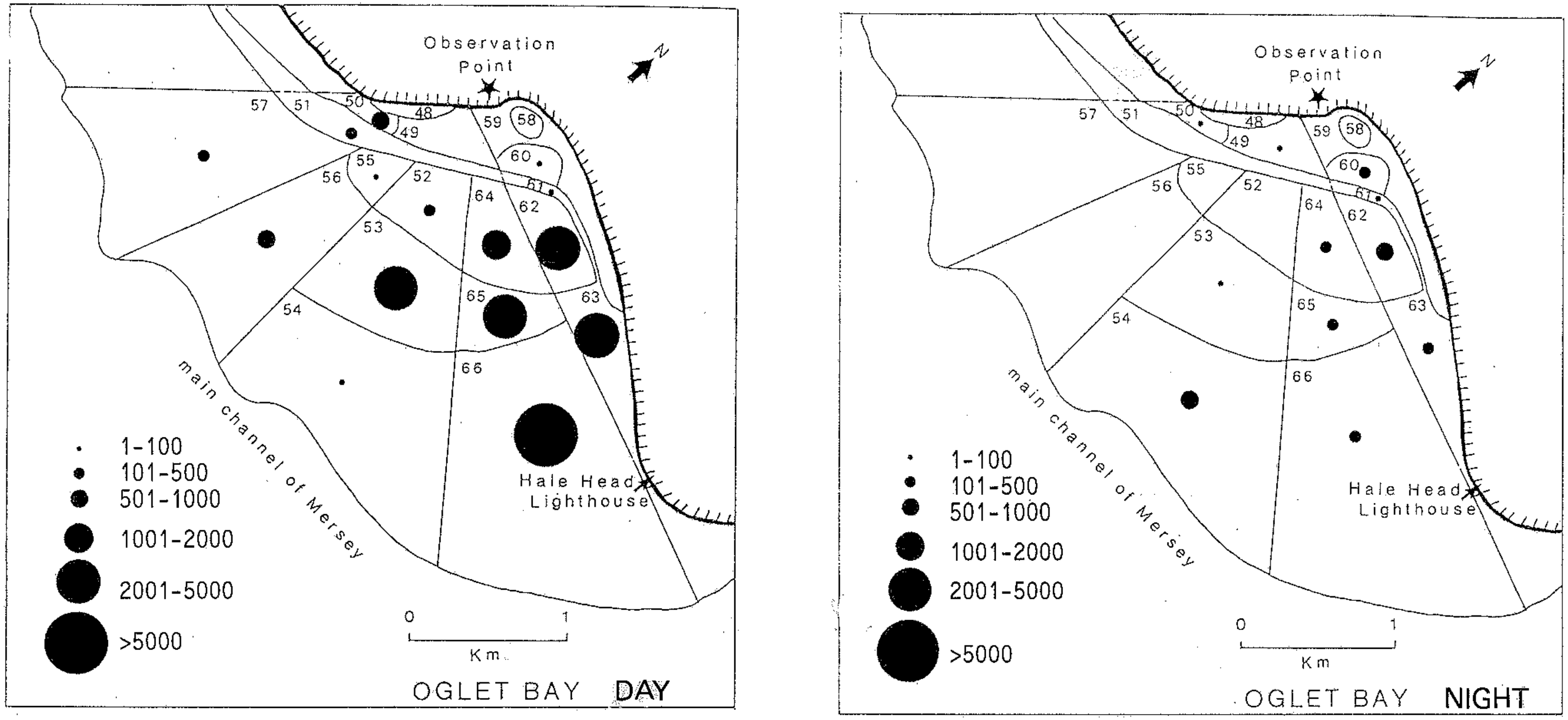


Figure 2.3.7.3 The number of bird hours per tidal cycle of feeding Dunlin on each intertidal area at Oglet Bay during the day and at night, winter 1991/92.

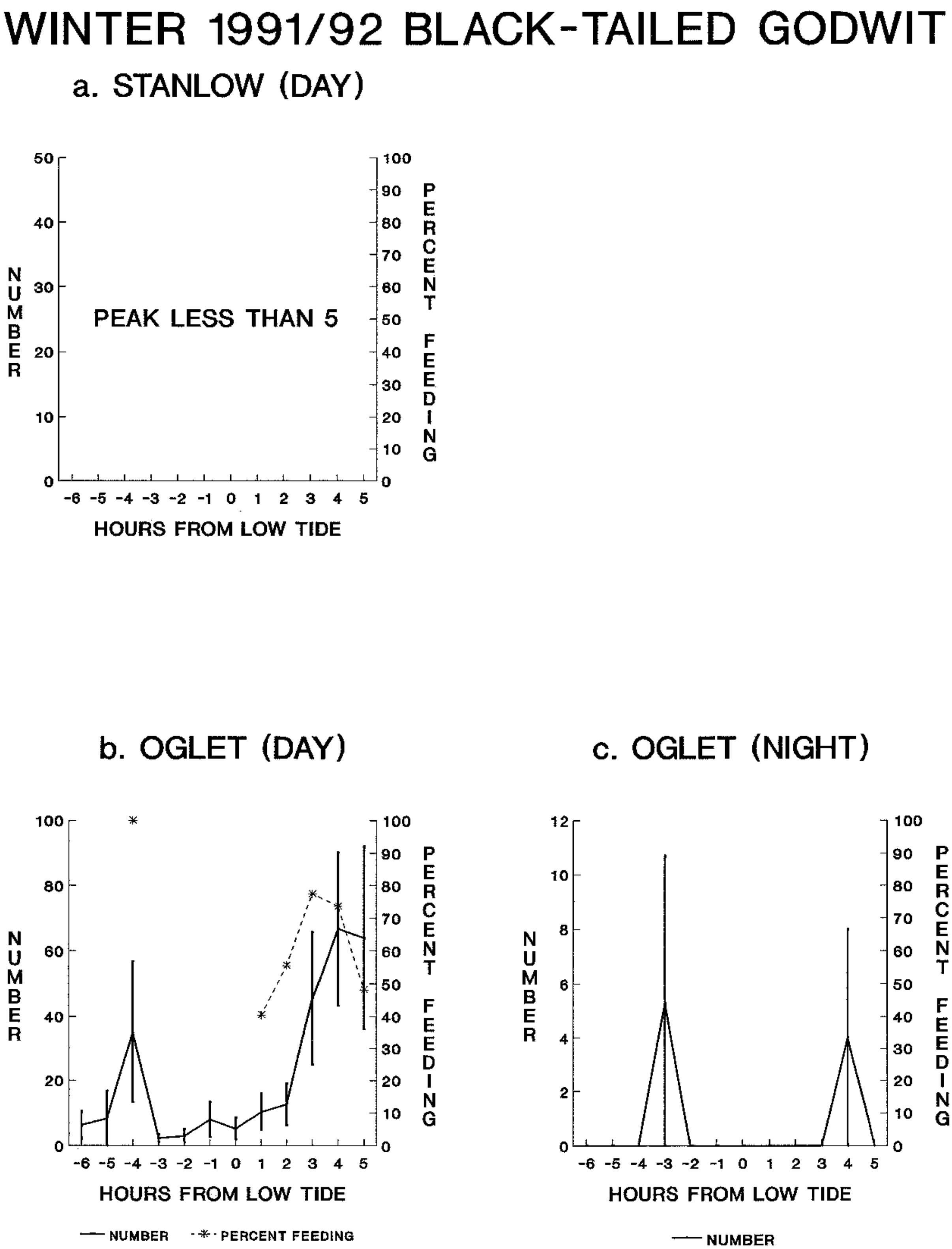


Figure 2.3.8.1 The number of Black-tailed Godwit present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

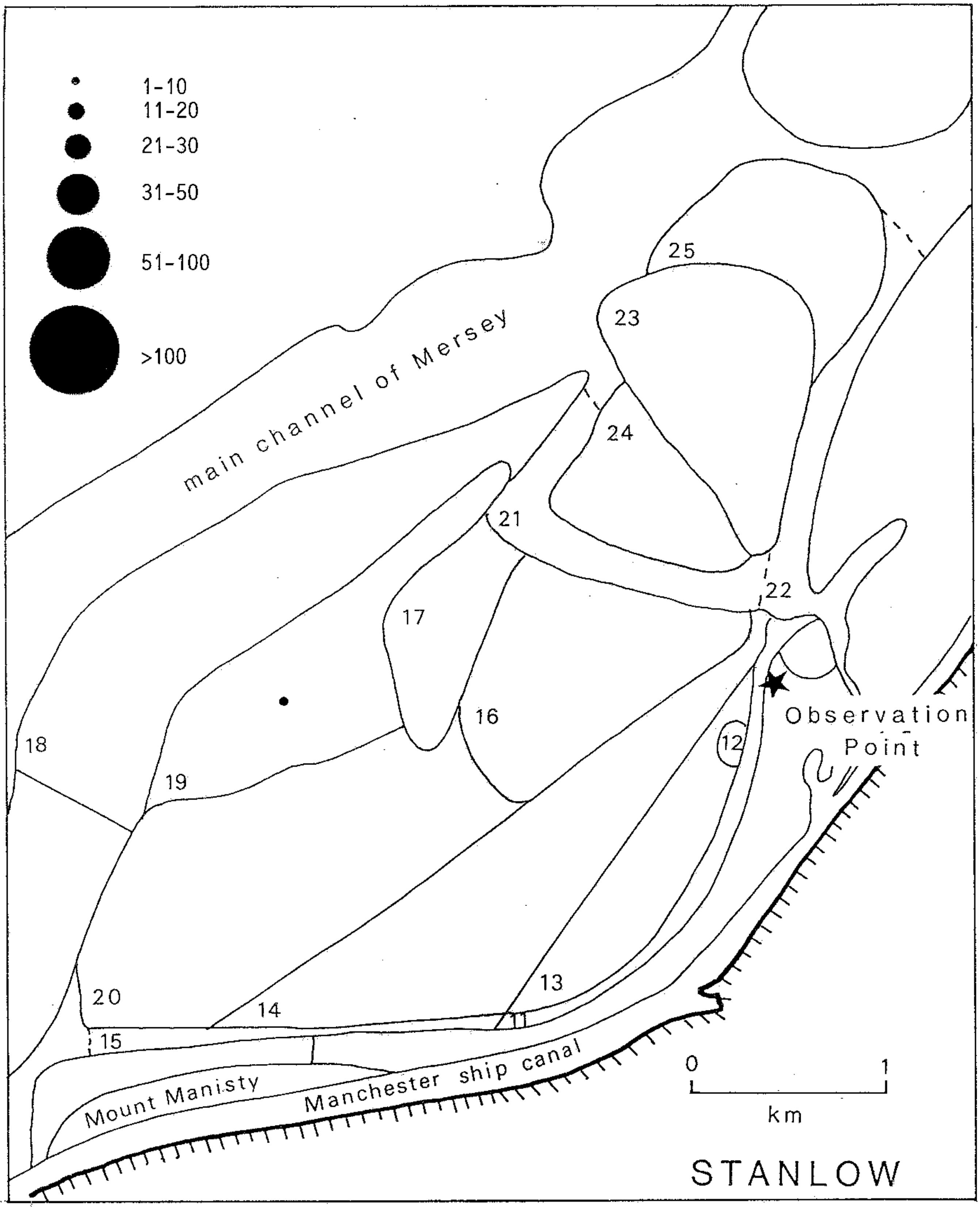


Figure 2.3.8.2 The number of bird hours per tidal cycle of feeding Bar-tailed Godwit on each intertidal area at Stanlow during the day, winter 1991/92.

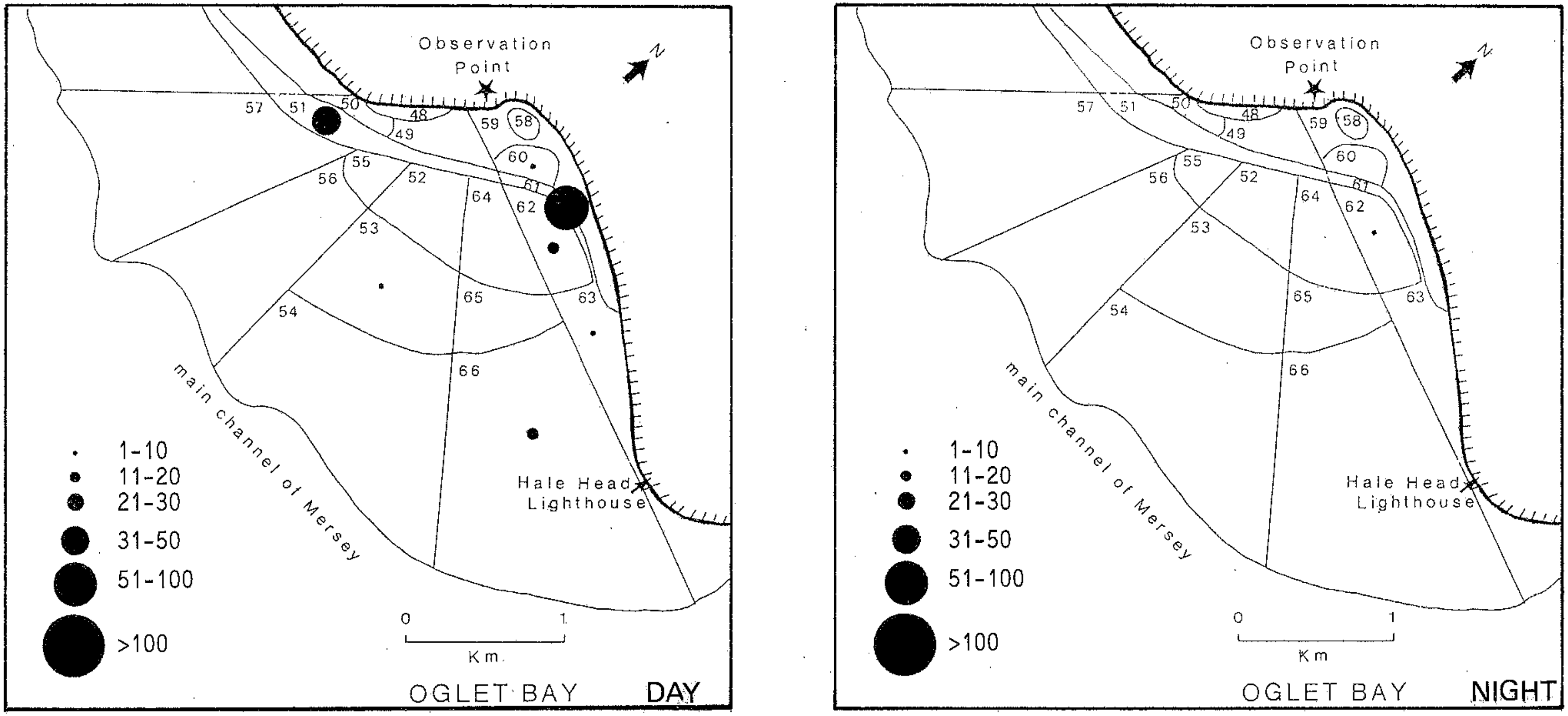
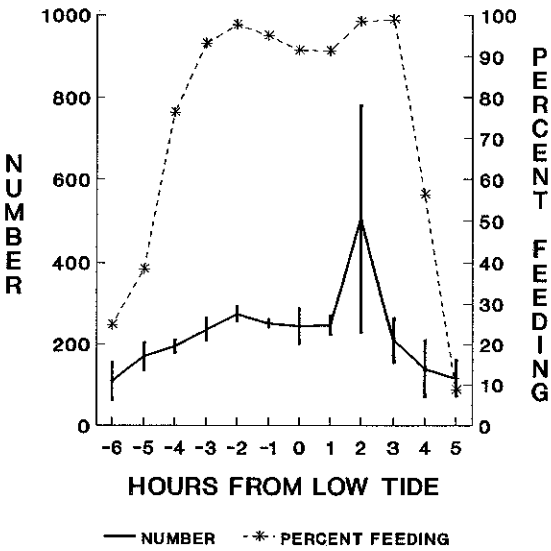


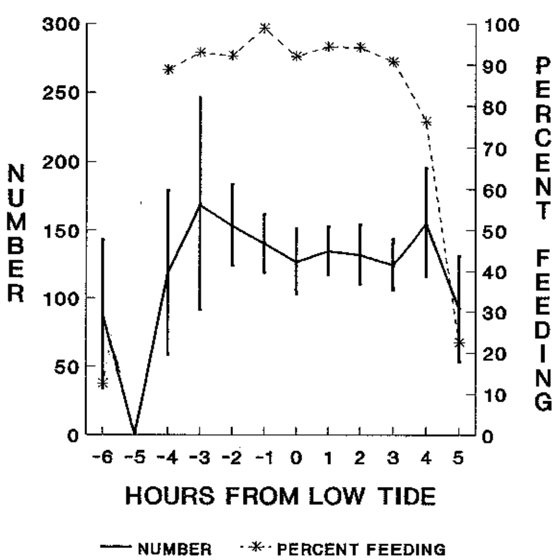
Figure 2.3.8.3 The number of bird hours per tidal cycle of feeding Black-tailed Godwit on each intertidal area at Oglet Bay during the day and at night, winter 1991/92.

WINTER 1991/92 CURLEW

a. STANLOW (DAY)



b. OGLET (DAY)



c. OGLET (NIGHT)

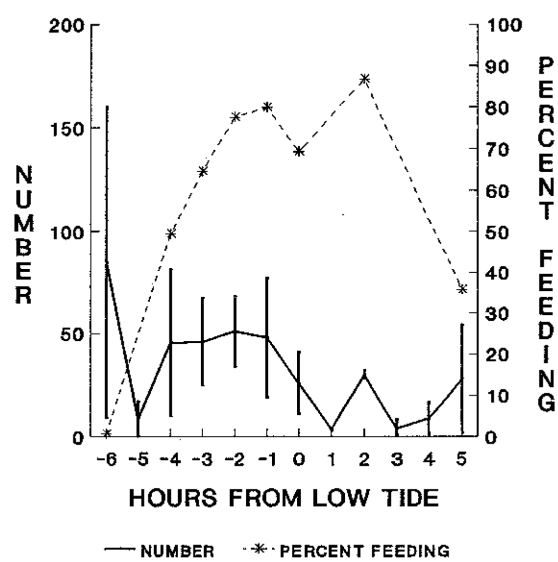


Figure 2.3.9.1 The number of Curlew present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

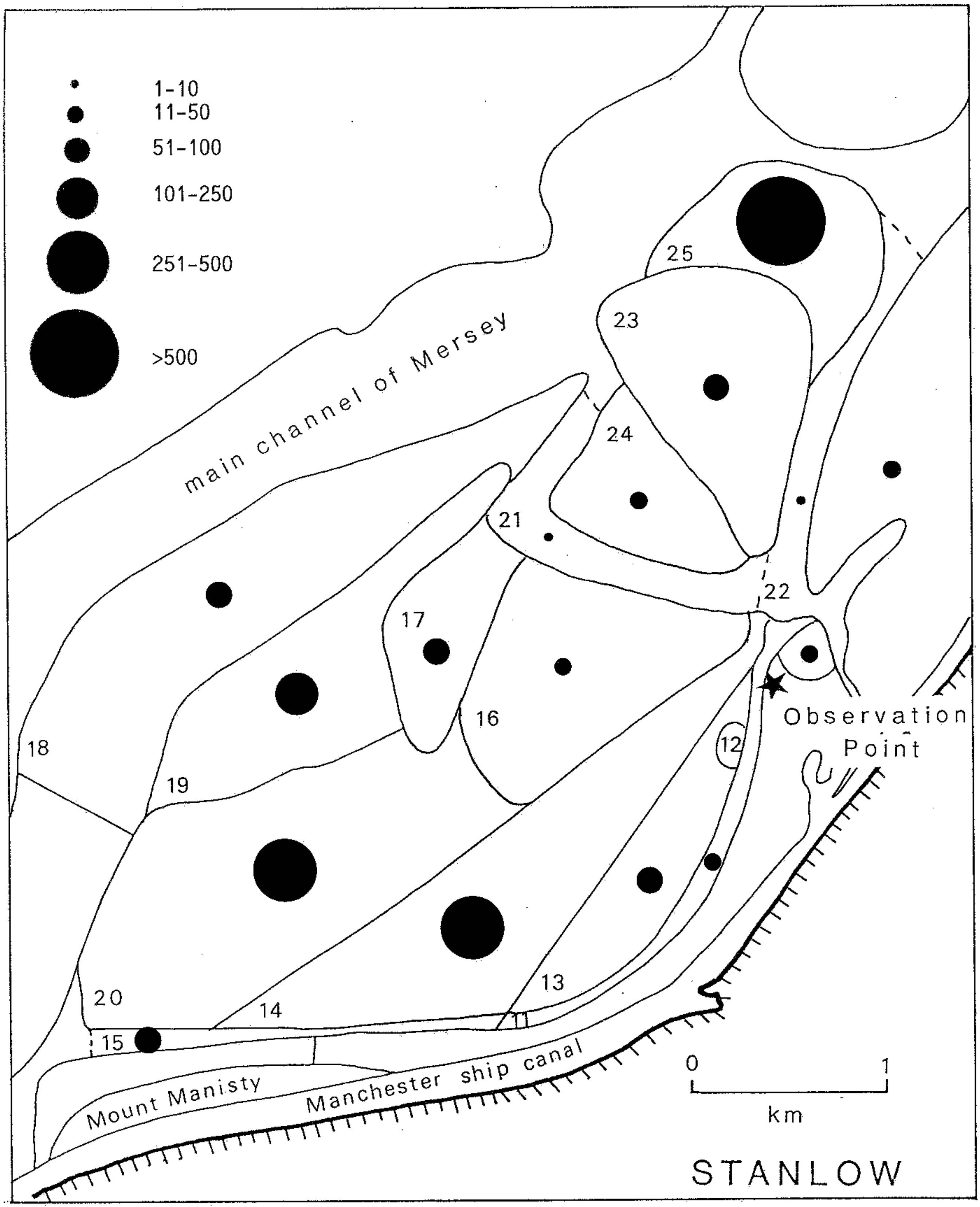


Figure 2.3.9.2 The number of bird hours per tidal cycle of feeding Curlew on each intertidal area at Stanlow during the day, winter 1991/92.

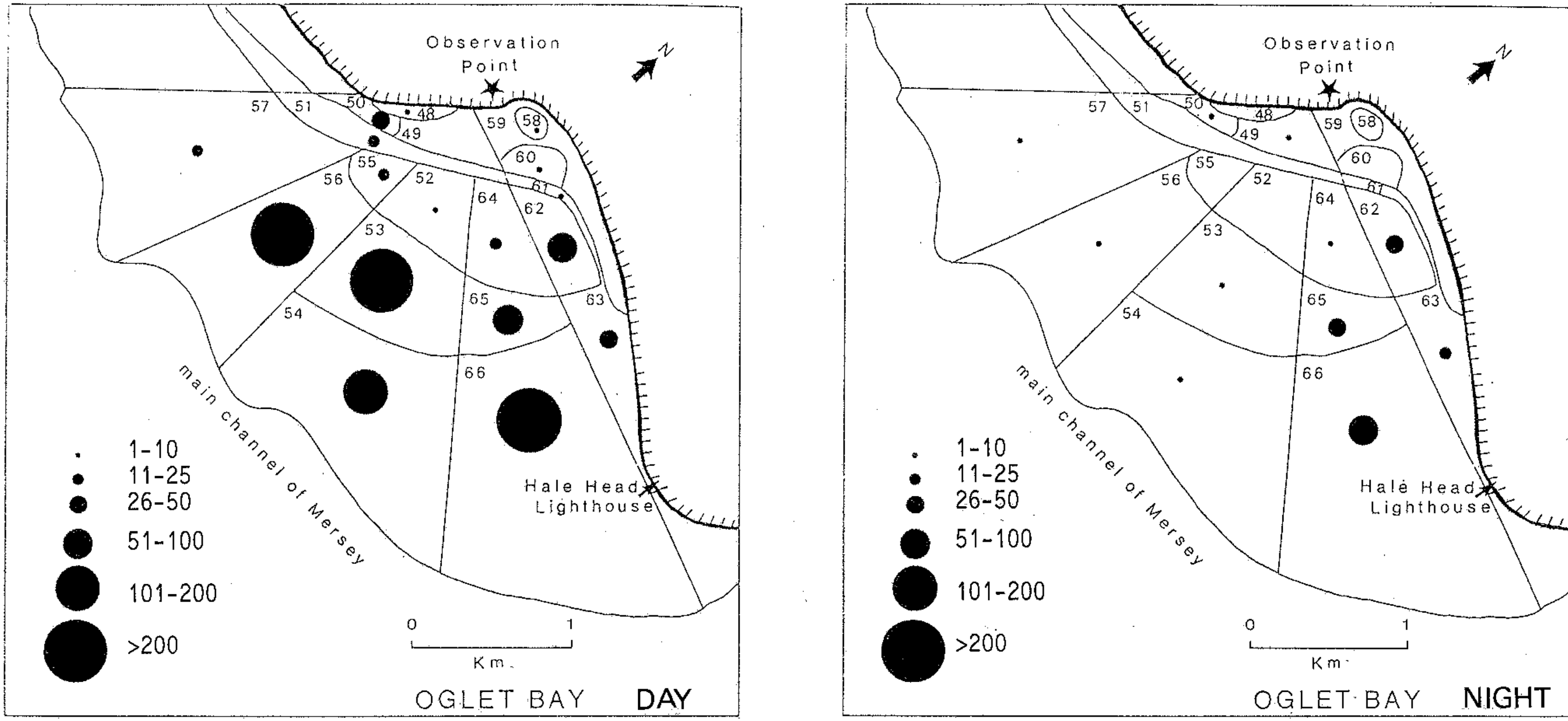
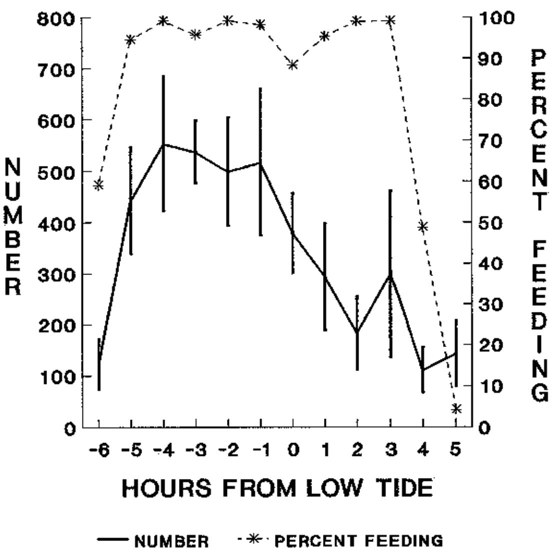


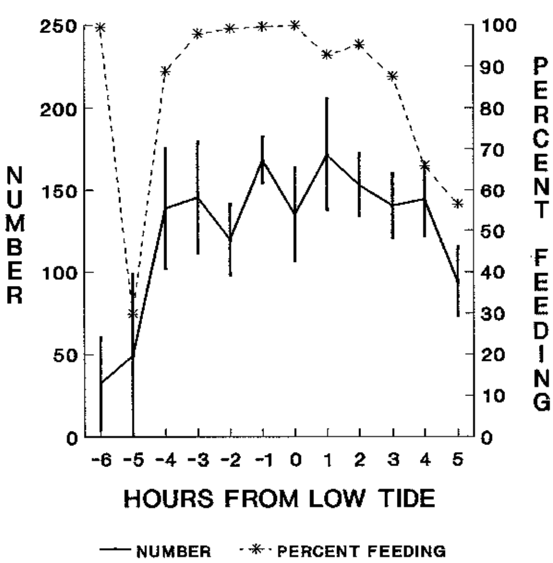
Figure 2.3.9.3 The number of bird hours per tidal cycle of feeding Curlew on each intertidal area at Oglet Bay during the day and at night, winter 1991/92.

WINTER 1991/92 REDSHANK

a. STANLOW (DAY)



b. OGLET (DAY)



c. OGLET (NIGHT)

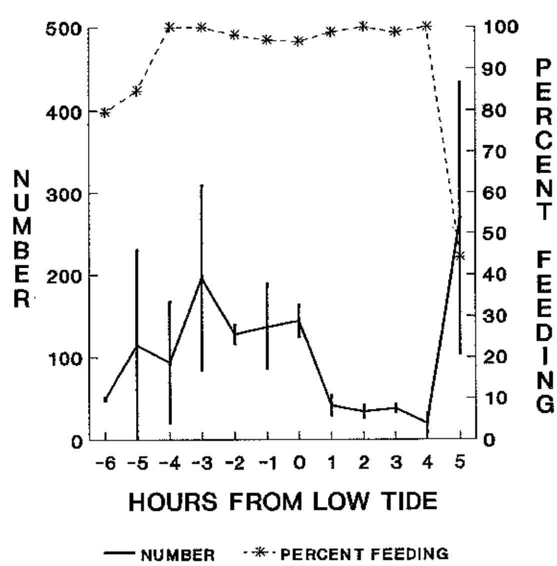
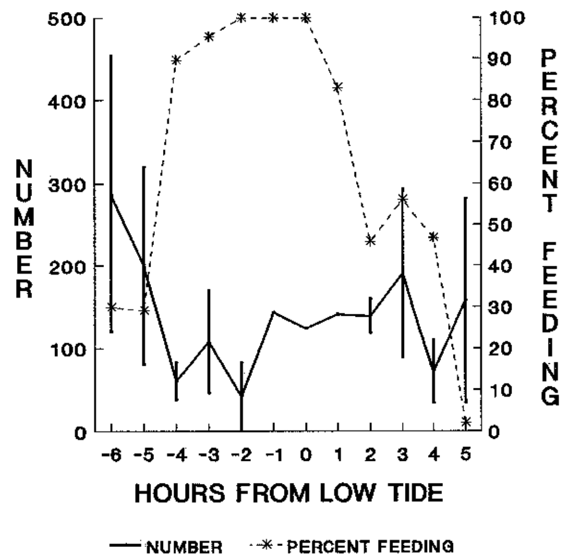


Figure 2.3.10.1 The number of Redshank present and the percentage feeding on the all day study sites, both during the day and at night, during the 1991/92 winter.

WINTER 1991/92 REDSHANK

a. MANISTY (DAY)



b. MANISTY (NIGHT)

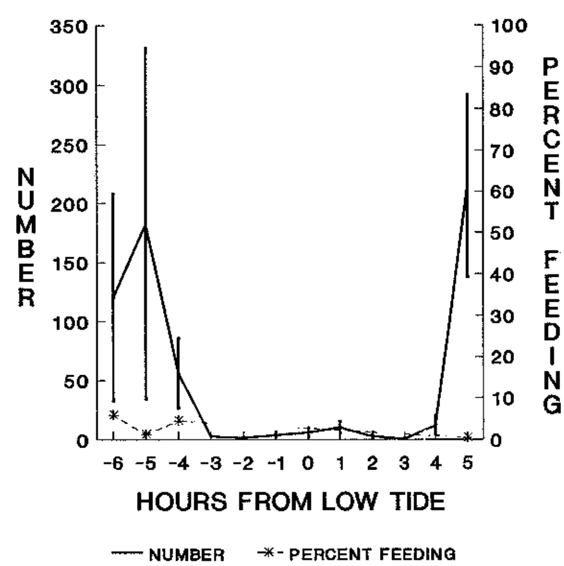


Figure 2.3.10.2 The number of Redshank present and the percentage feeding on the Mount Manisty study site, both during the day and at night, during the 1991/92 winter.

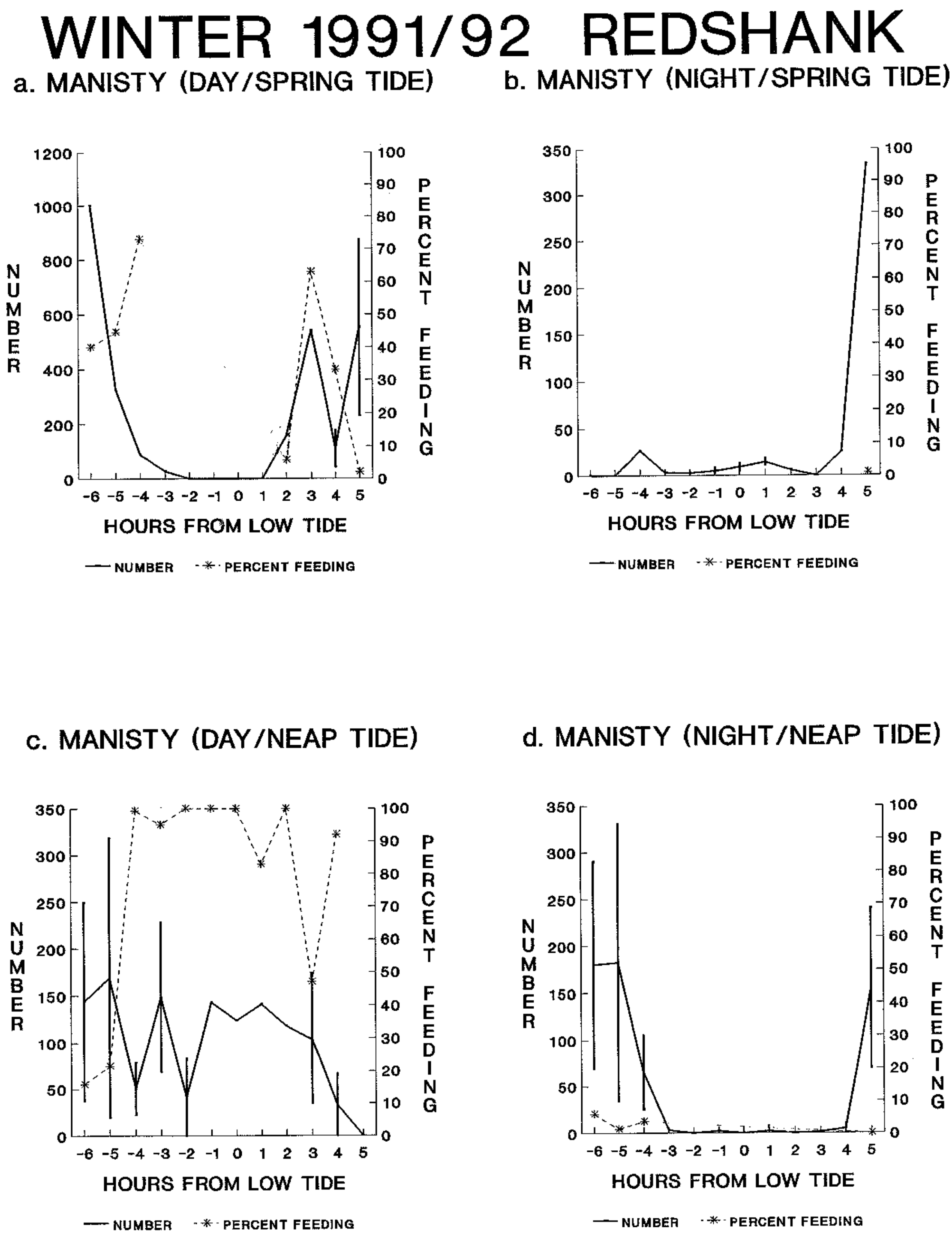


Figure 2.3.10.3 The number of Redshank present and the percentage feeding on the Mount Manisty study site, both during the day and at night, on both spring and neap tides, during the 1991/92 winter.

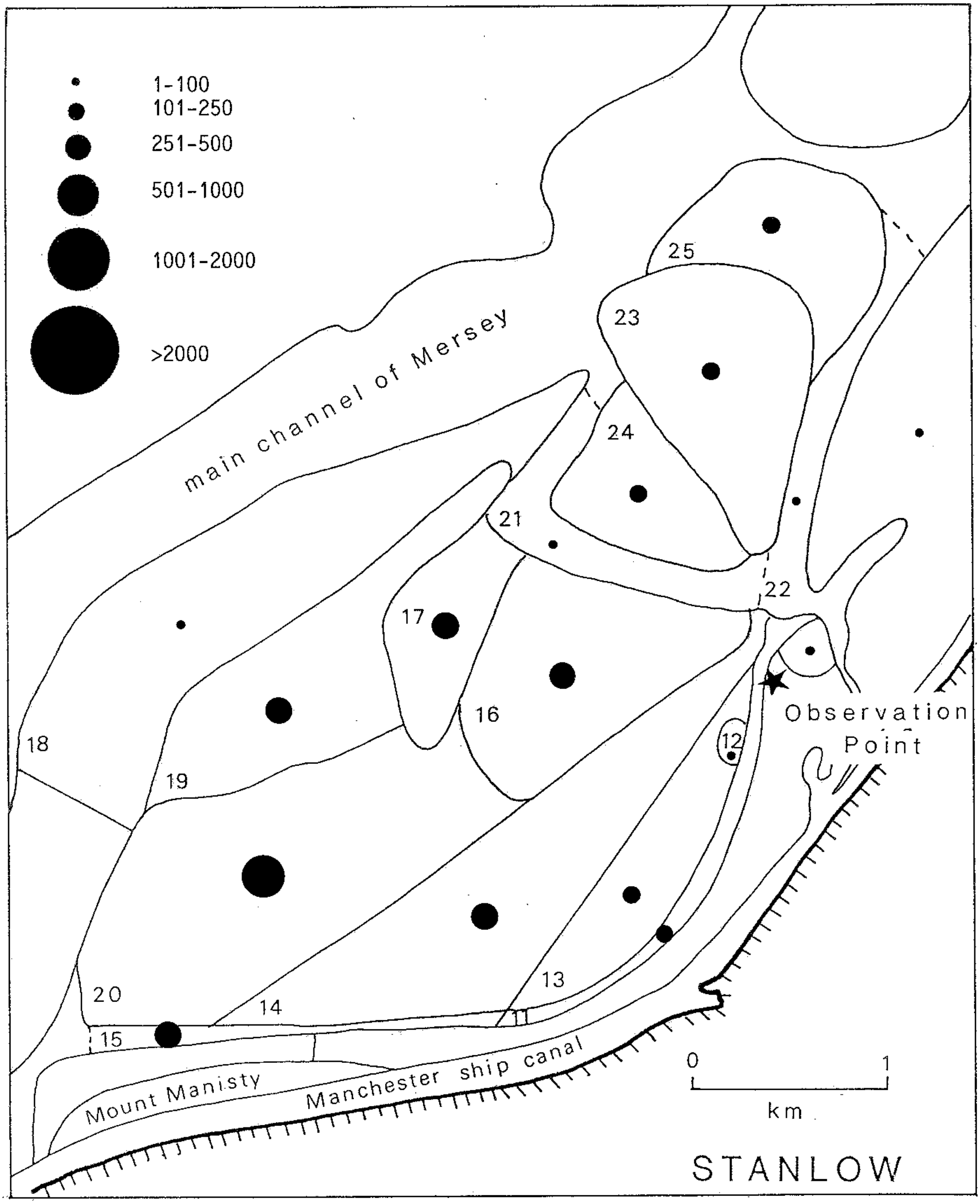


Figure 2.3.10.4 The number of bird hours per tidal cycle of feeding Redshank on each intertidal area at Stanlow during the day, winter 1991/92.

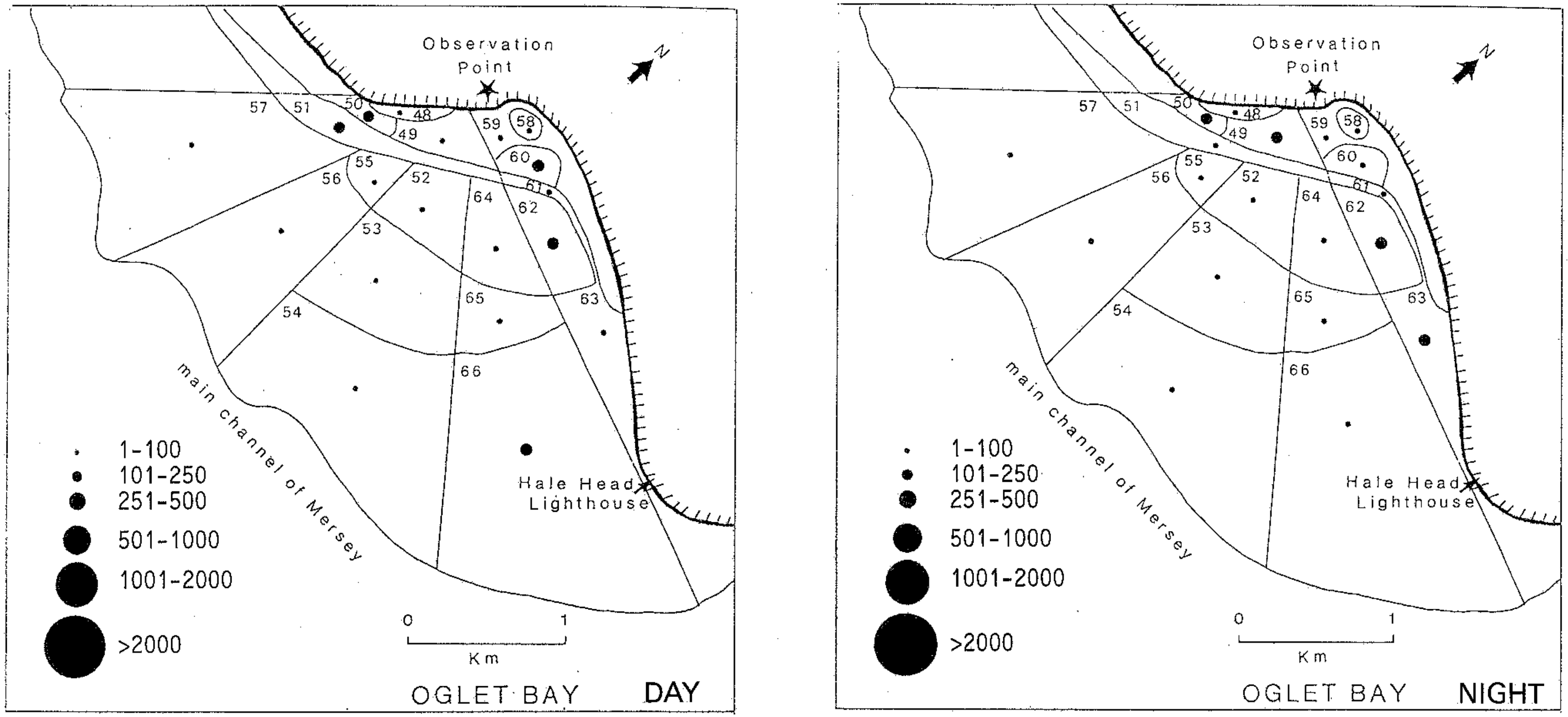
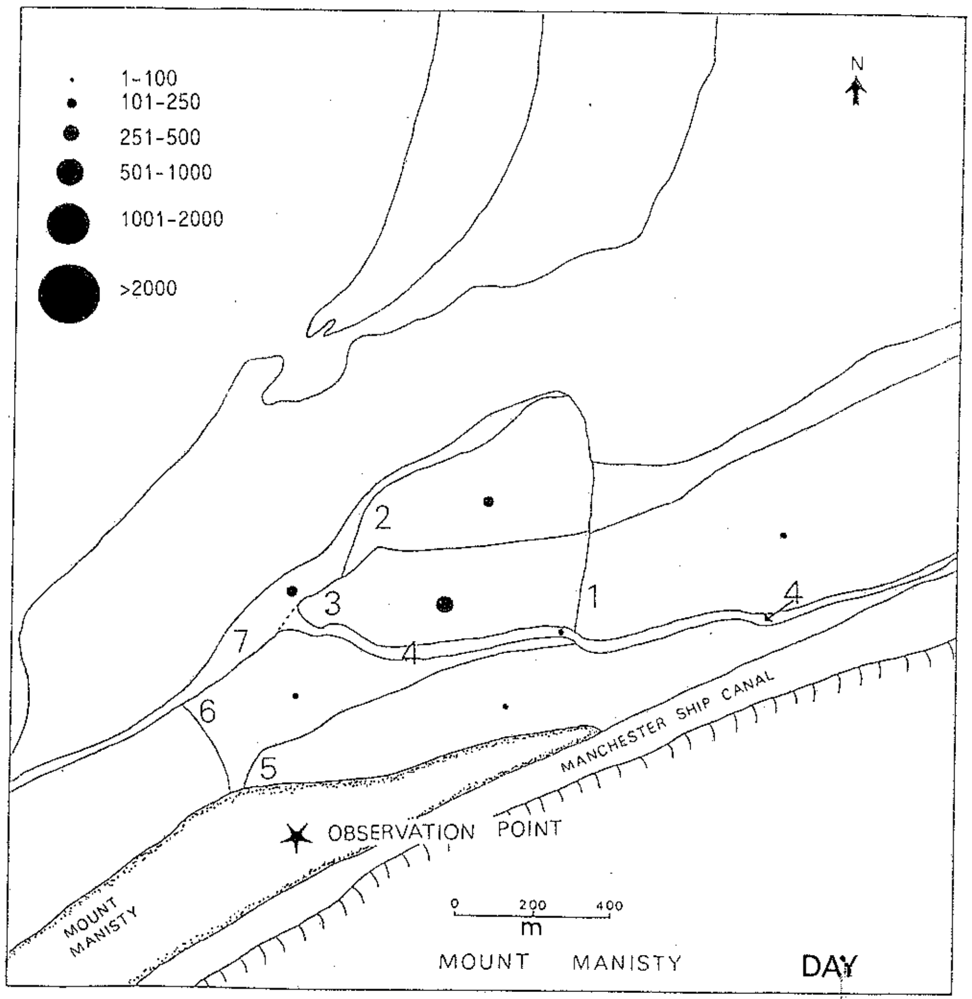


Figure 2.3.10.5 The number of bird hours per tidal cycle of feeding Redshank on each intertidal area at Oglet Bay during the day and at night, winter 1991/92.



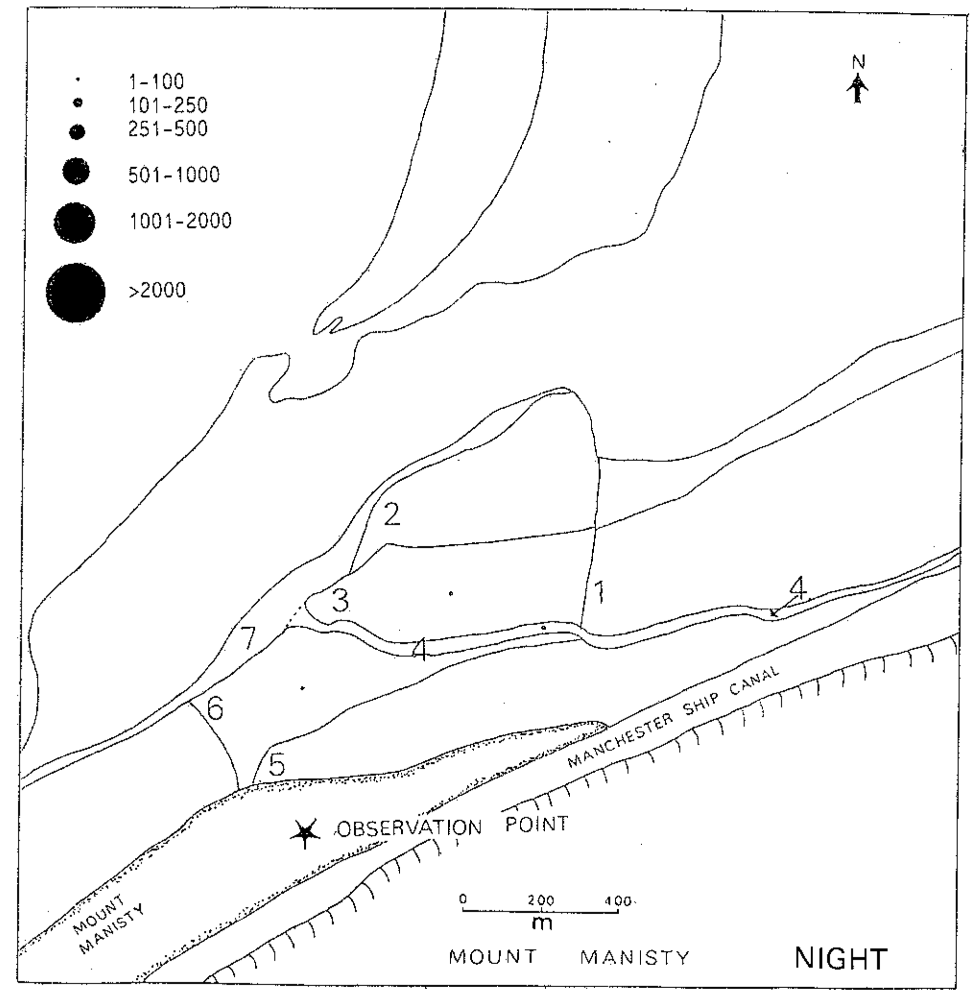


Figure 2.3.10.6 The number of bird hours per tidal cycle of feeding Redshank on each intertidal area at Mount Manisty during the day and at night, winter 1991/92.

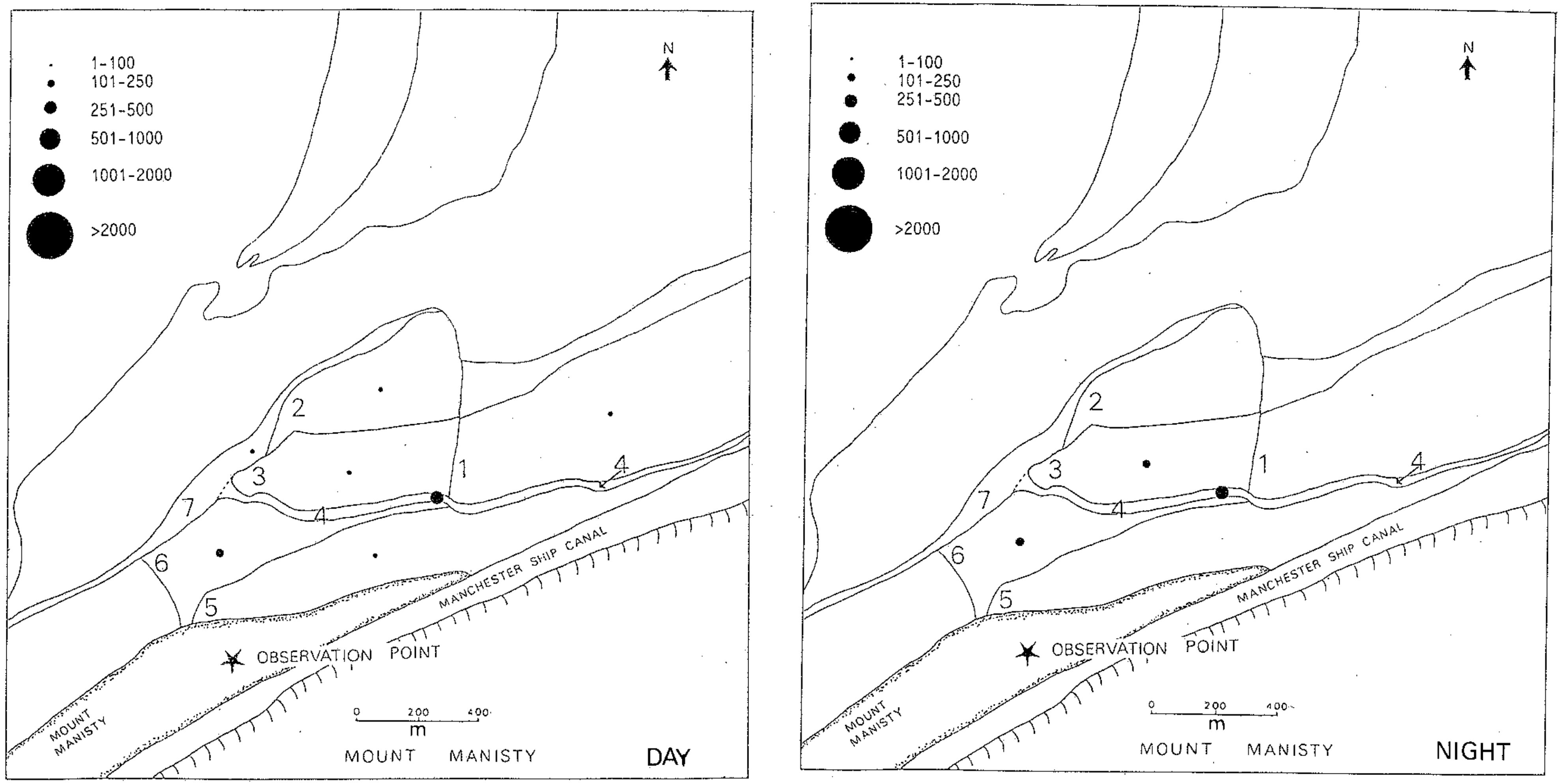


Figure 2.3.10.7 The number of bird hours per tidal cycle of roosting Redshank on each intertidal area at Mount Manisty during the day and at night, winter 1991/92.

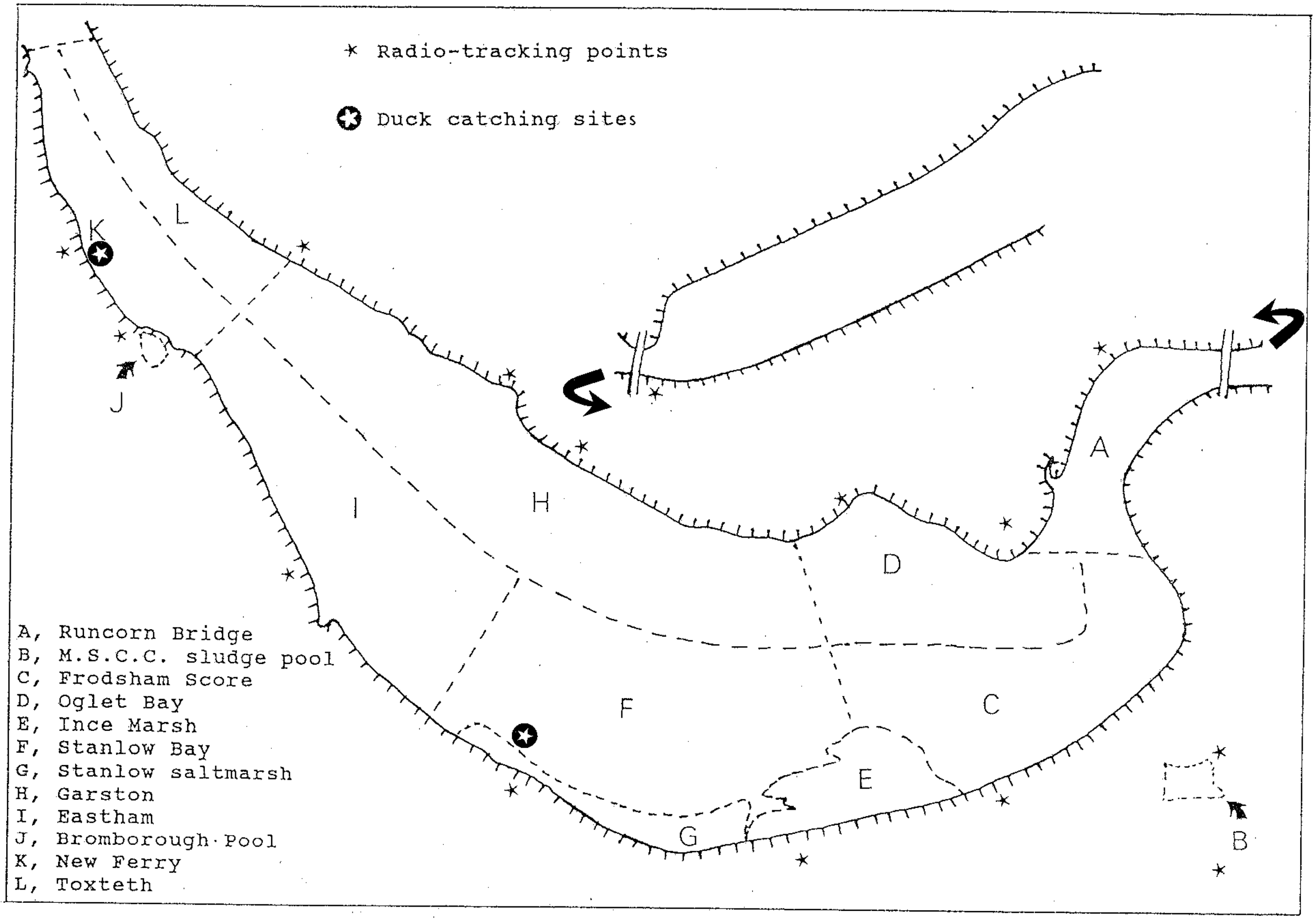


Figure 3.2.1 The location of the duck catching sites, the radio-tracking points, and the estuary divisions used in the analysis of duck movements.

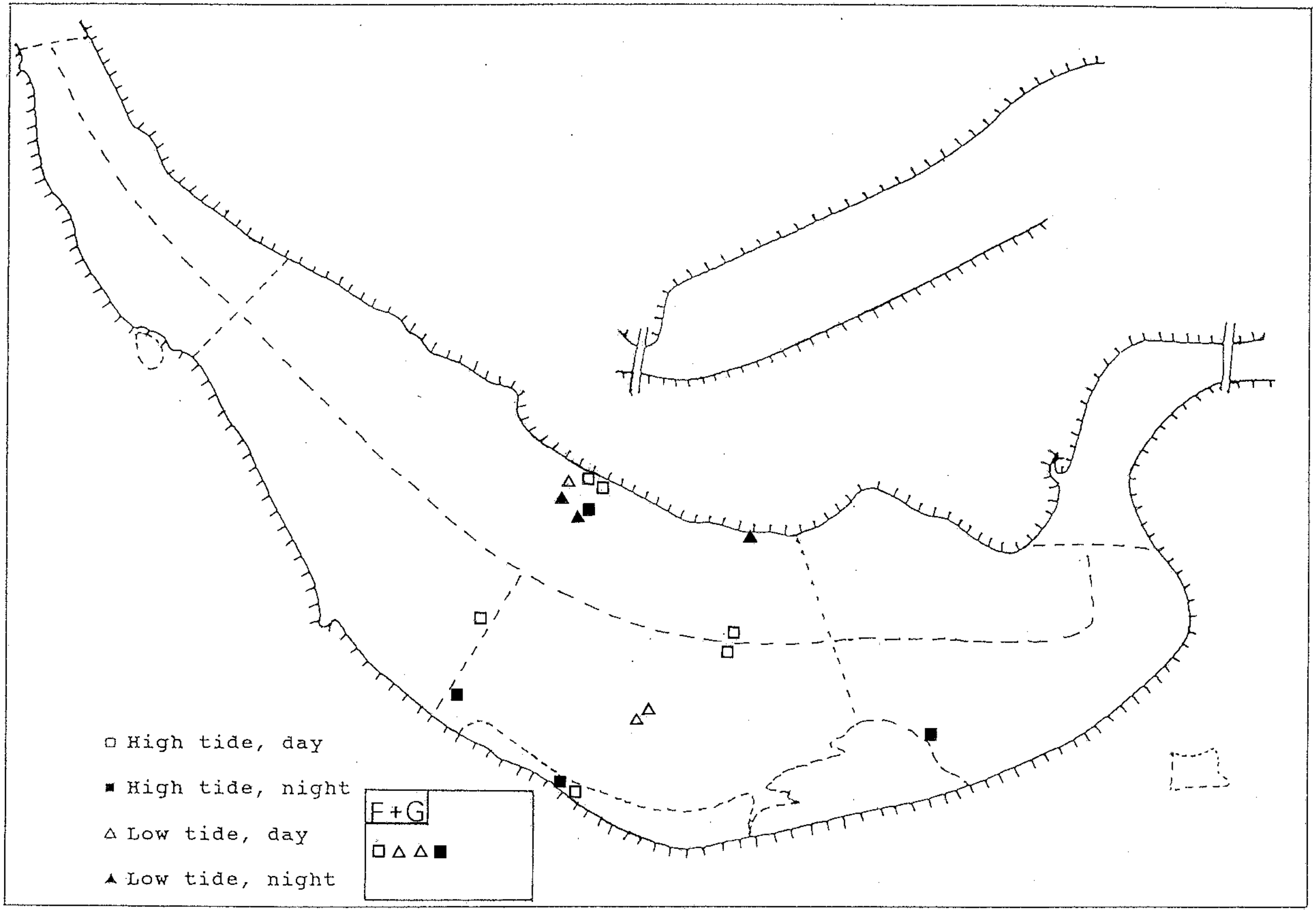


Figure 3.3.1 Locations of a juvenile male Teal, caught at Mount Manisty, from 20 November to 20 December 1991.

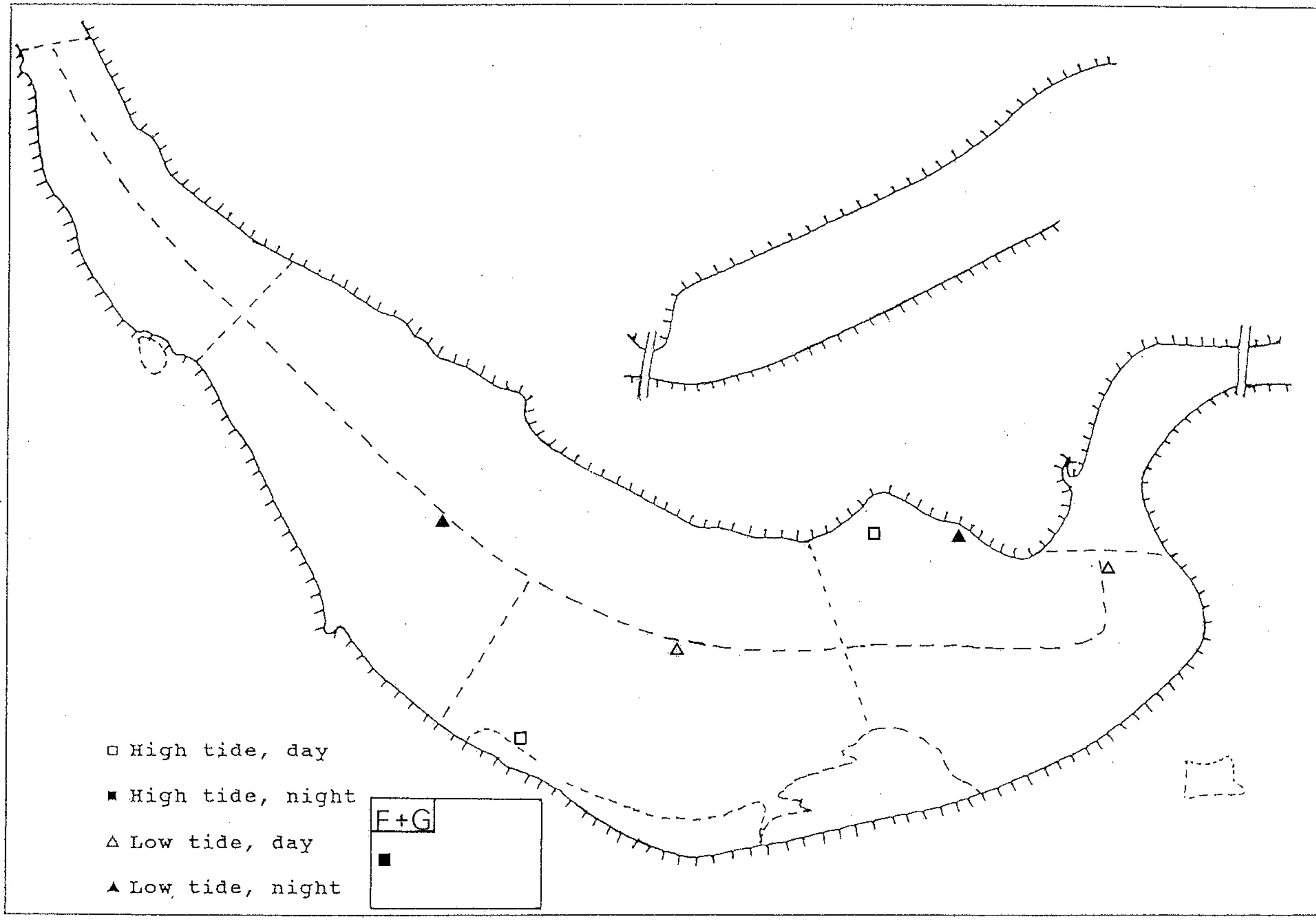


Figure 3.3.2 Locations of a juvenile male Teal, caught at Mount Manisty, from 20 November to 16 December 1991.

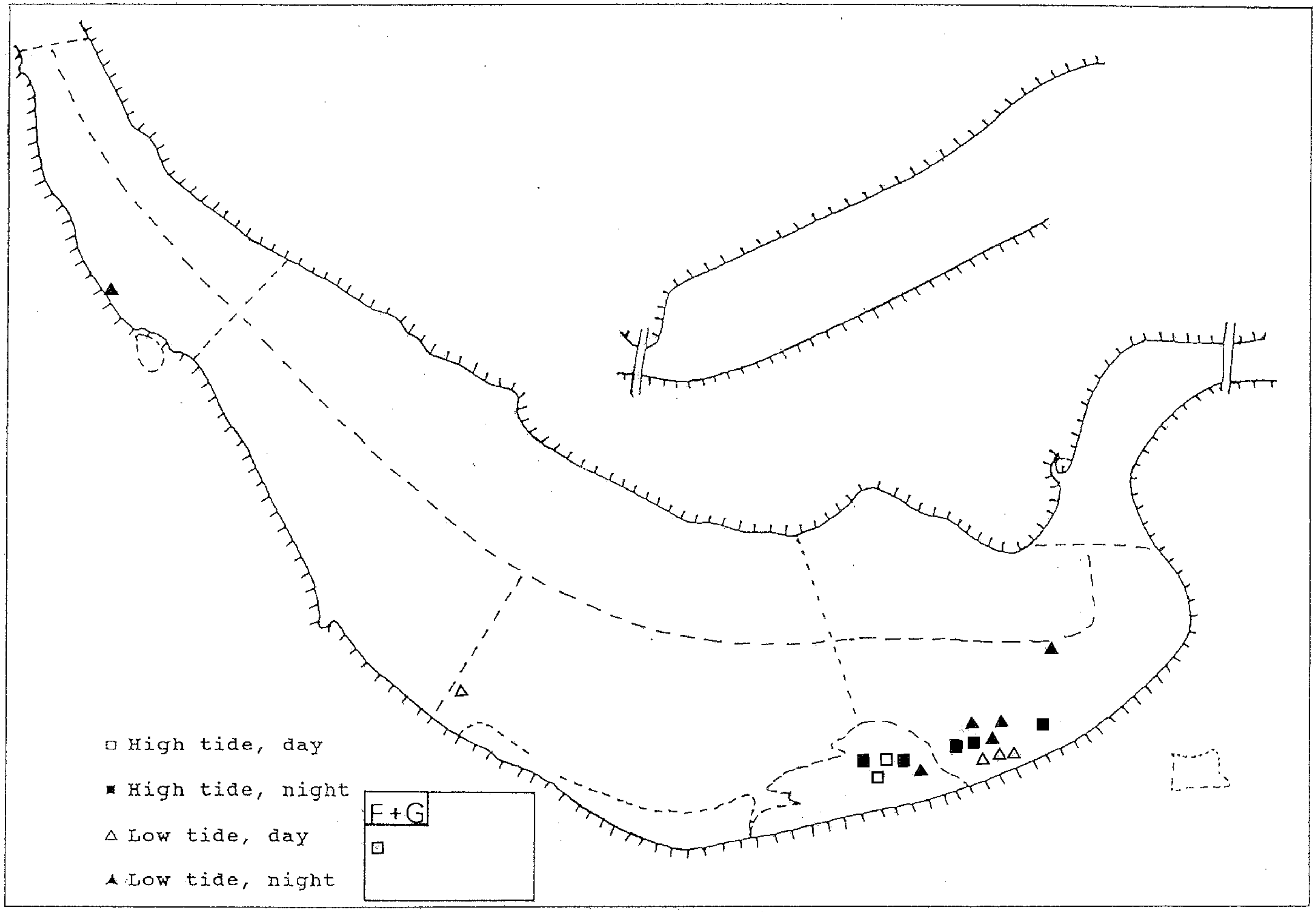


Figure 3.3.3 Locations of an adult female Teal, caught at Mount Manisty, from 20 November 1991 to 5 February 1992.

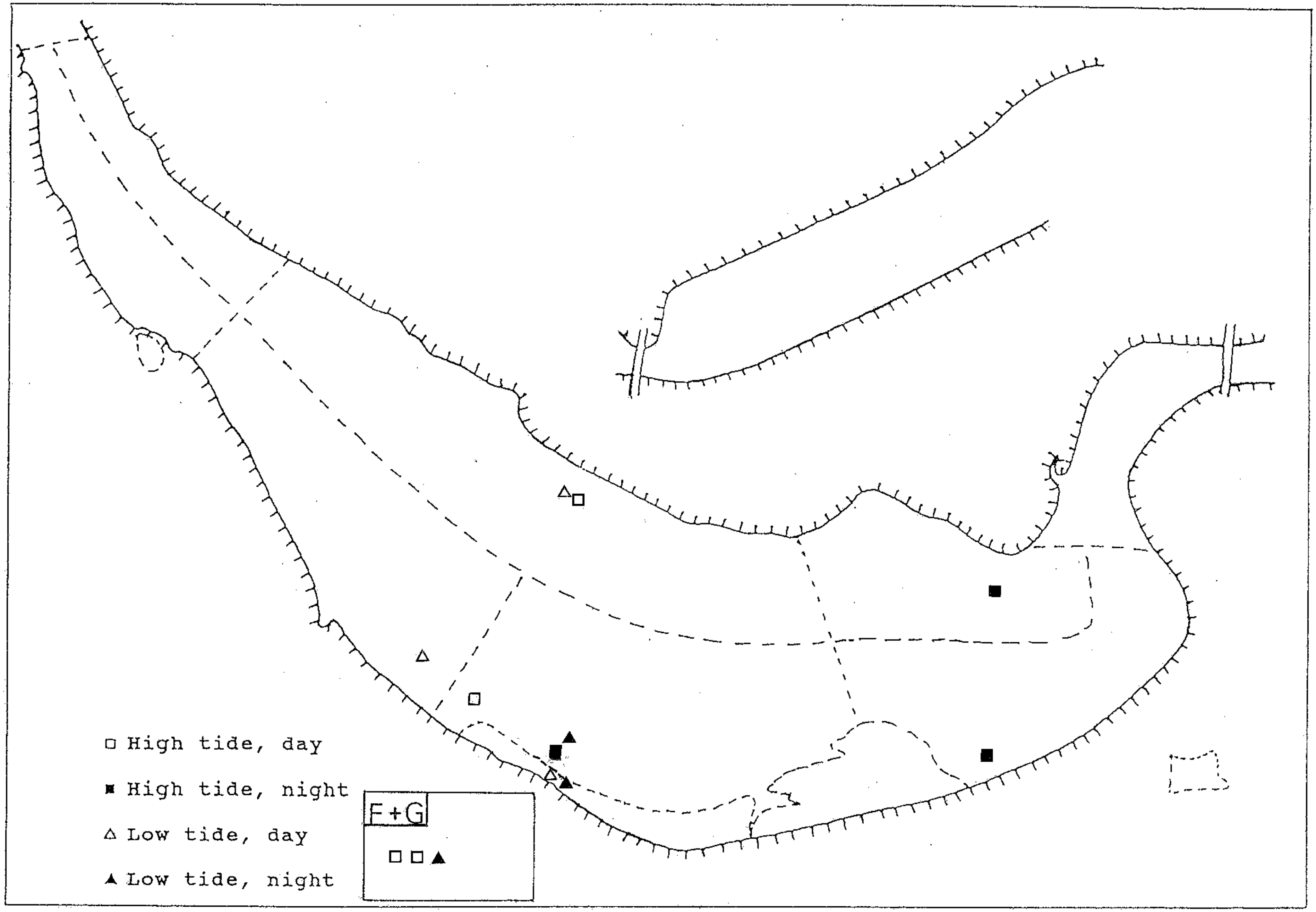


Figure 3.3.4 Locations of an adult male Teal, caught at Mount Manisty, from 6 December to 26 December 1991.

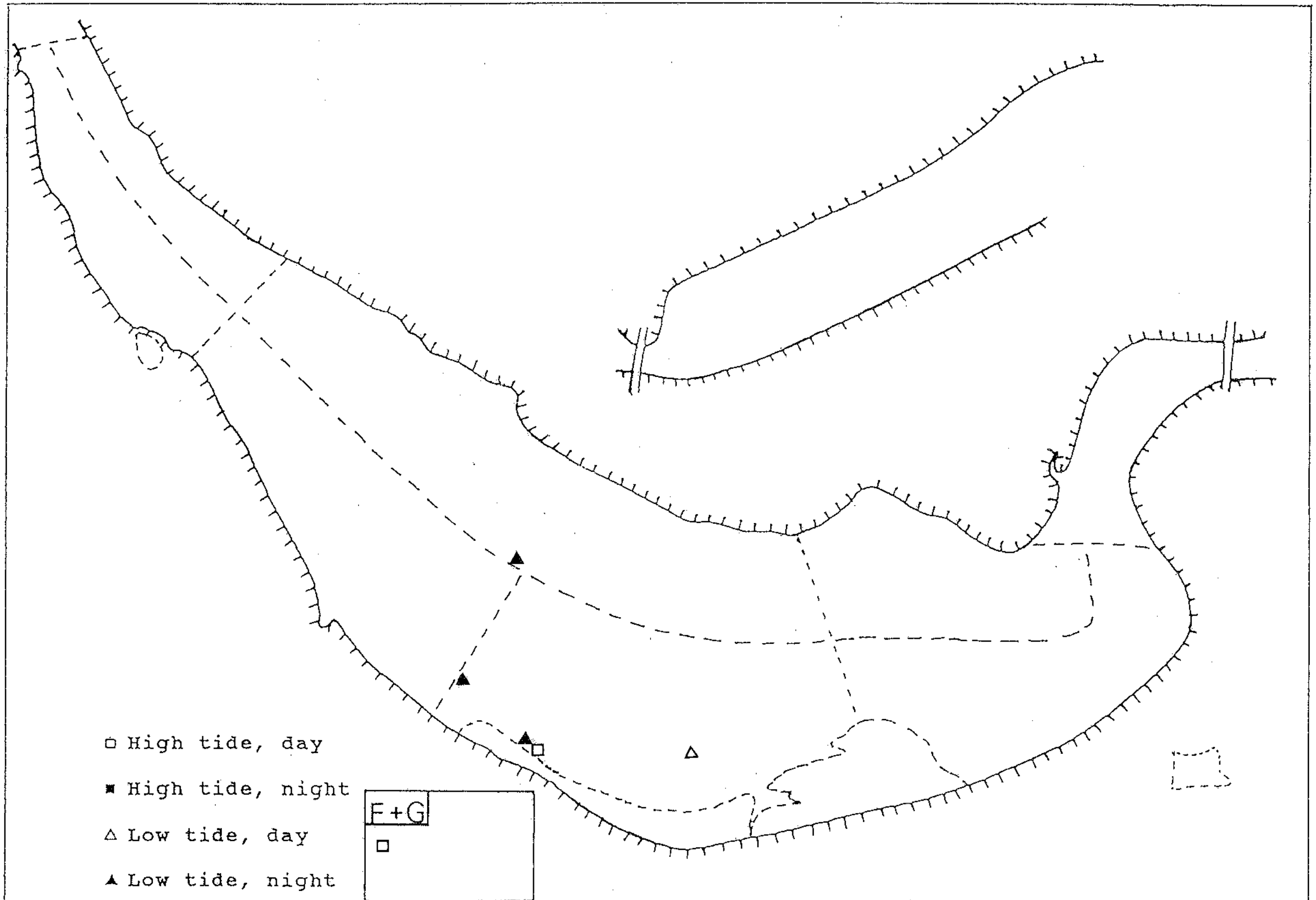


Figure 3.3.5 Locations of a juvenile male Teal, caught at Mount Manisty, from 6 December to 24 December 1991.

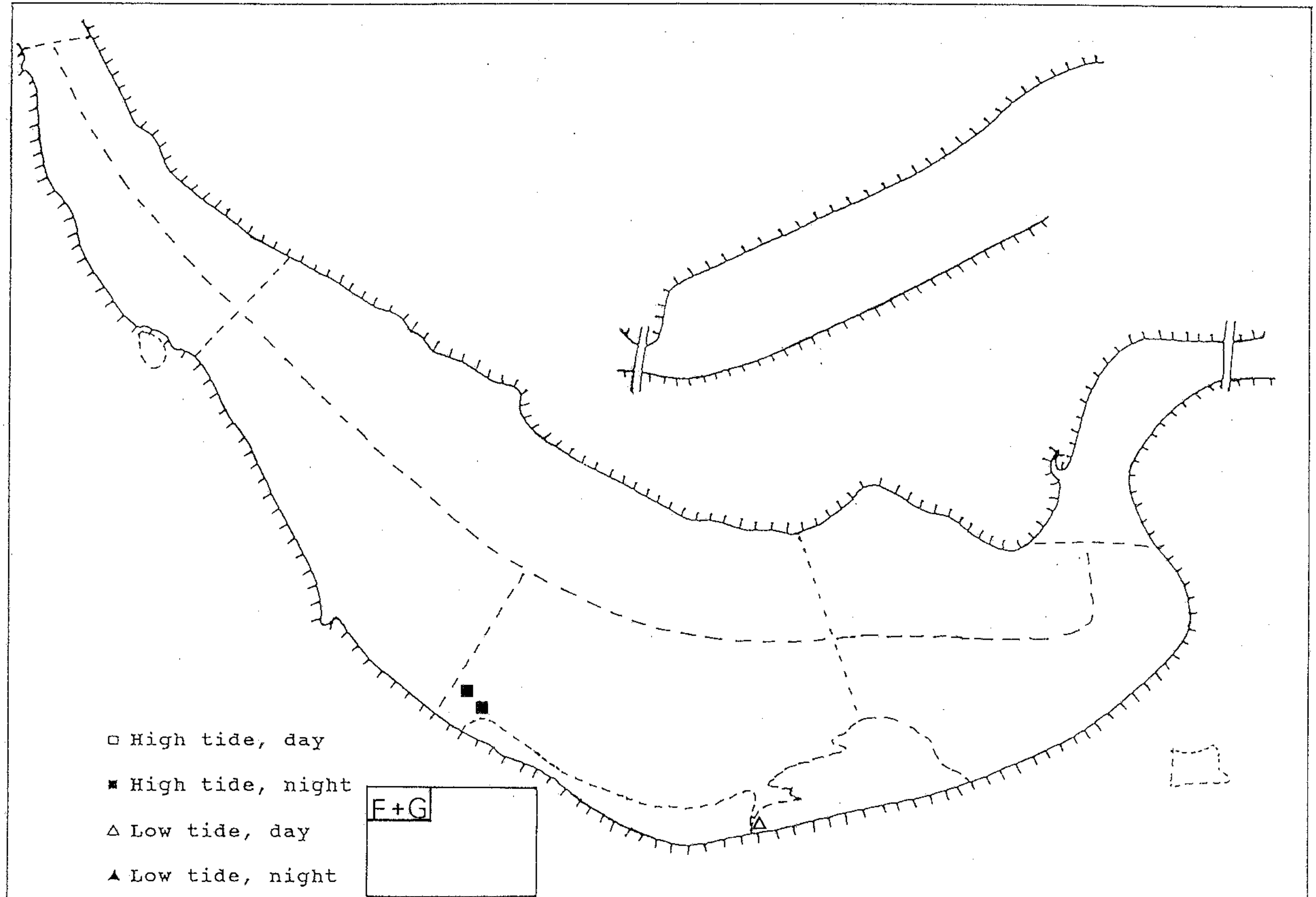


Figure 3.3.6 Locations of an adult female Teal, caught at Mount Manisty, from 6 December 1991 to 27 January 1992.

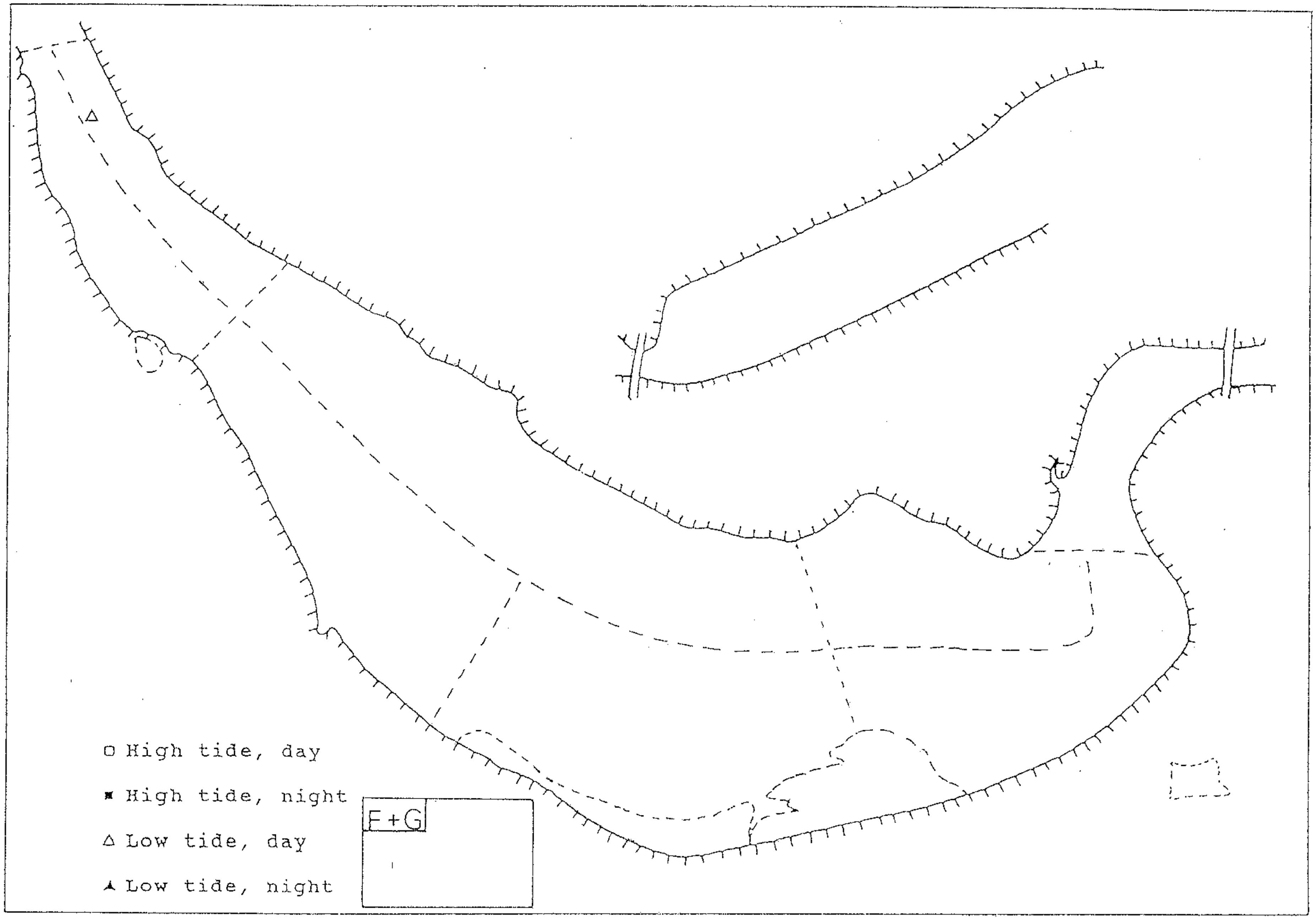


Figure 3.3.7 Locations of a juvenile male Pintail, caught at Mount Manisty, from 21 November 1991 to 6 January 1992.

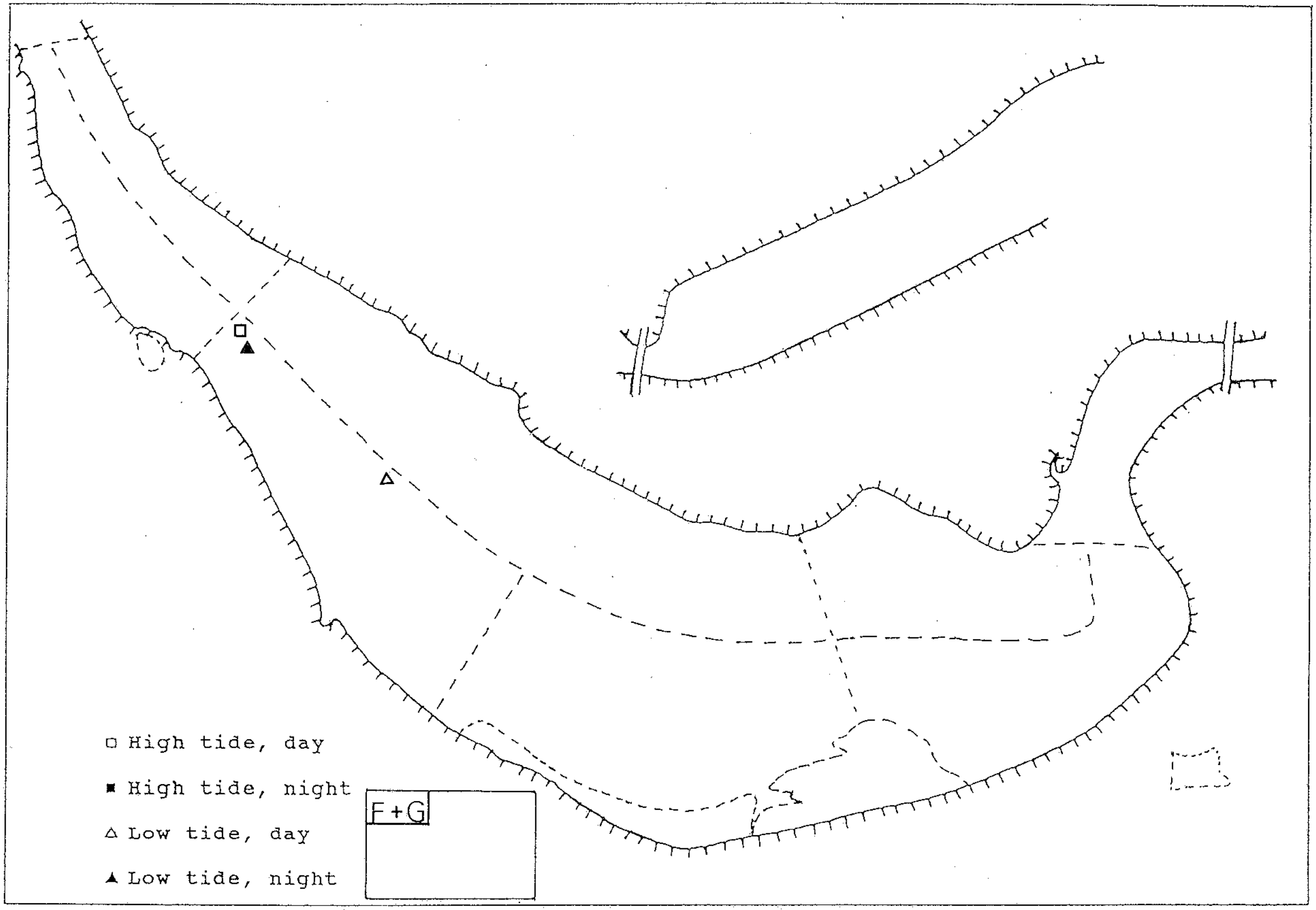


Figure 3.3.8 Locations of an adult female Pintail, caught at Mount Manisty, from 9 December to 16 December 1991.

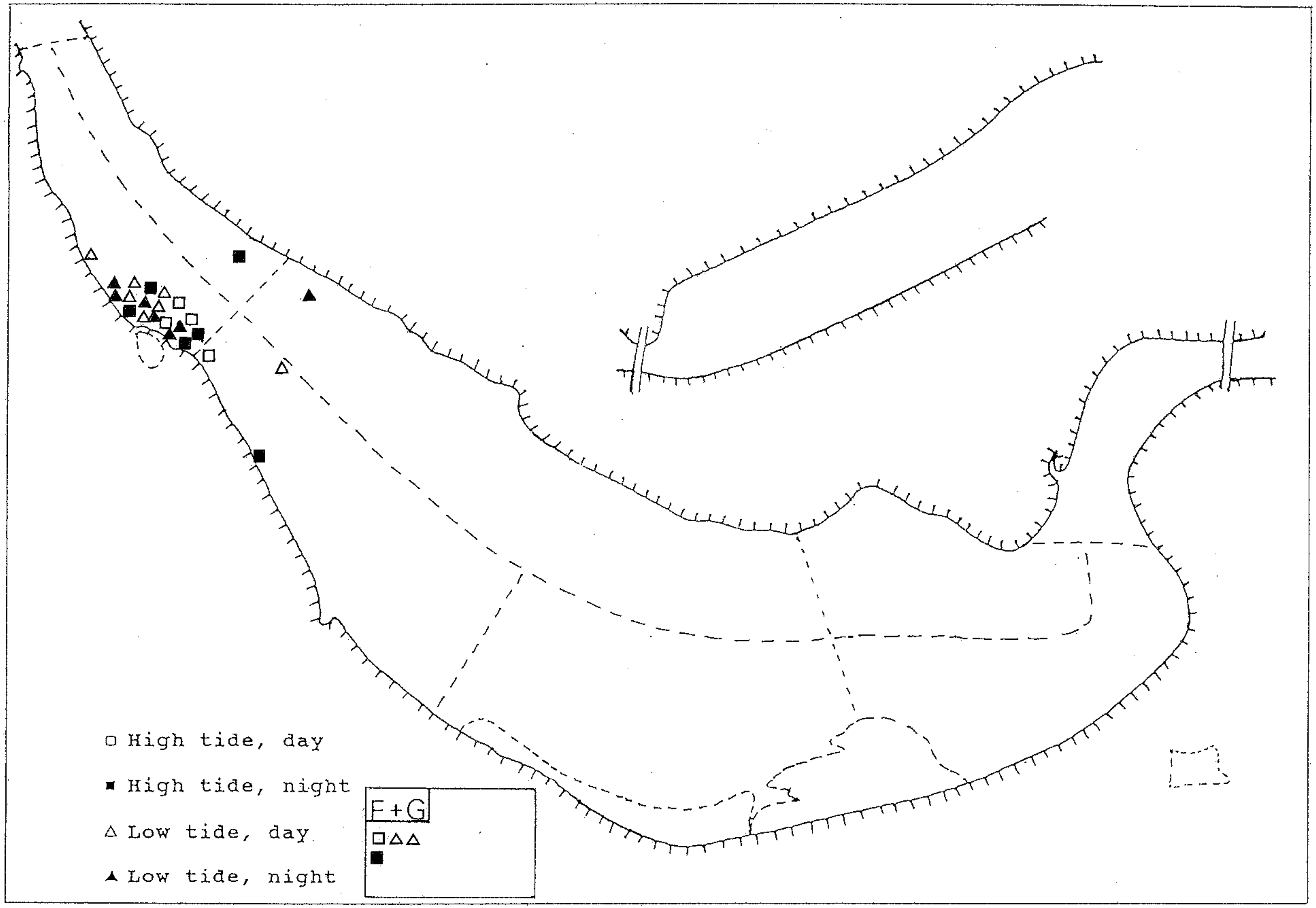


Figure 3.3.9 Locations of an adult female Pintail, caught at New Ferry, from 11 December 1991 to 28 January 1992.

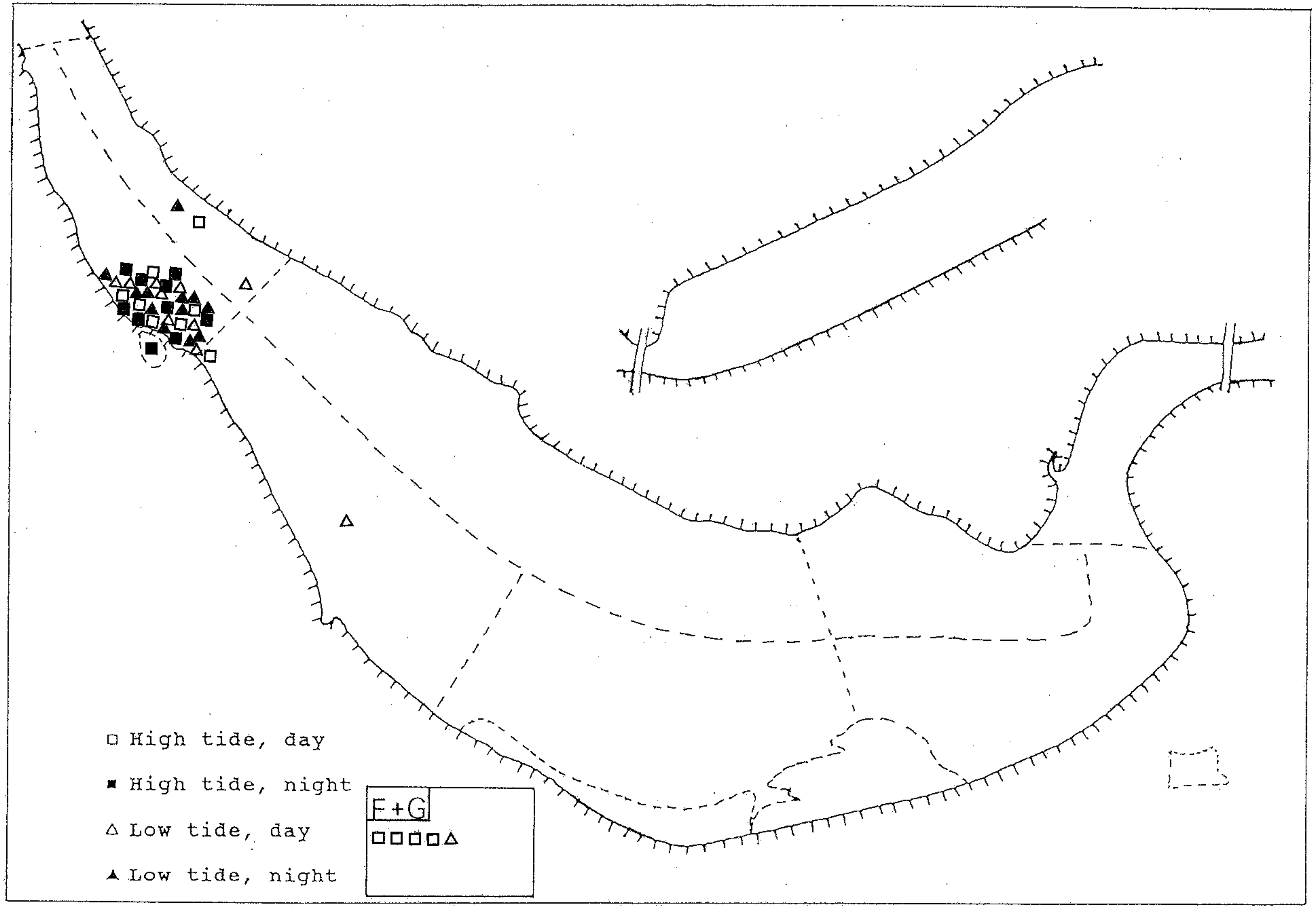


Figure 3.3.10 Locations of an adult male Pintail, caught at New Ferry, from 11 December 1991 to 12 February 1992.

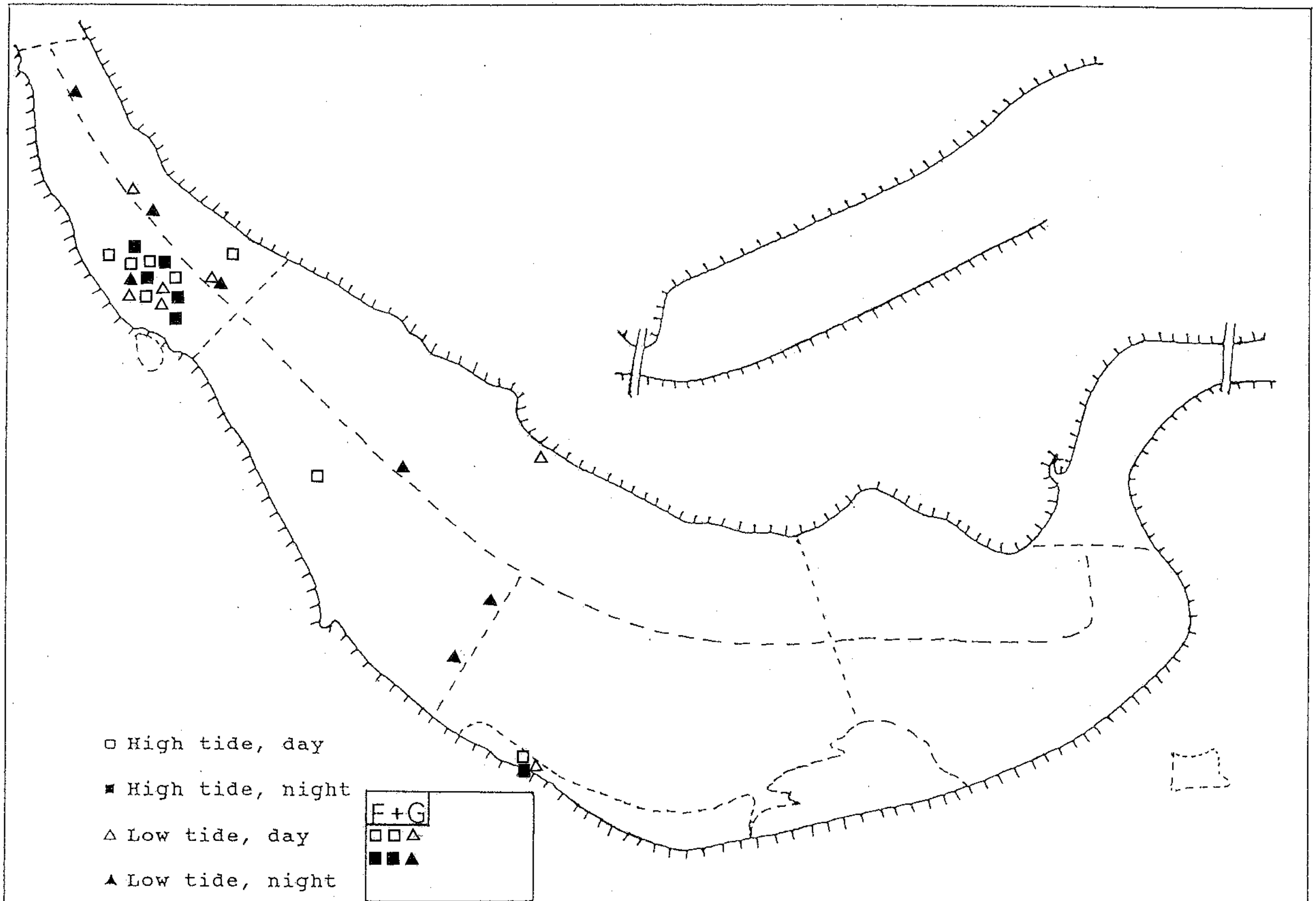


Figure 3.3.11 Locations of an adult male Pintail, caught at New Ferry, from 21 January to 3 March 1992.

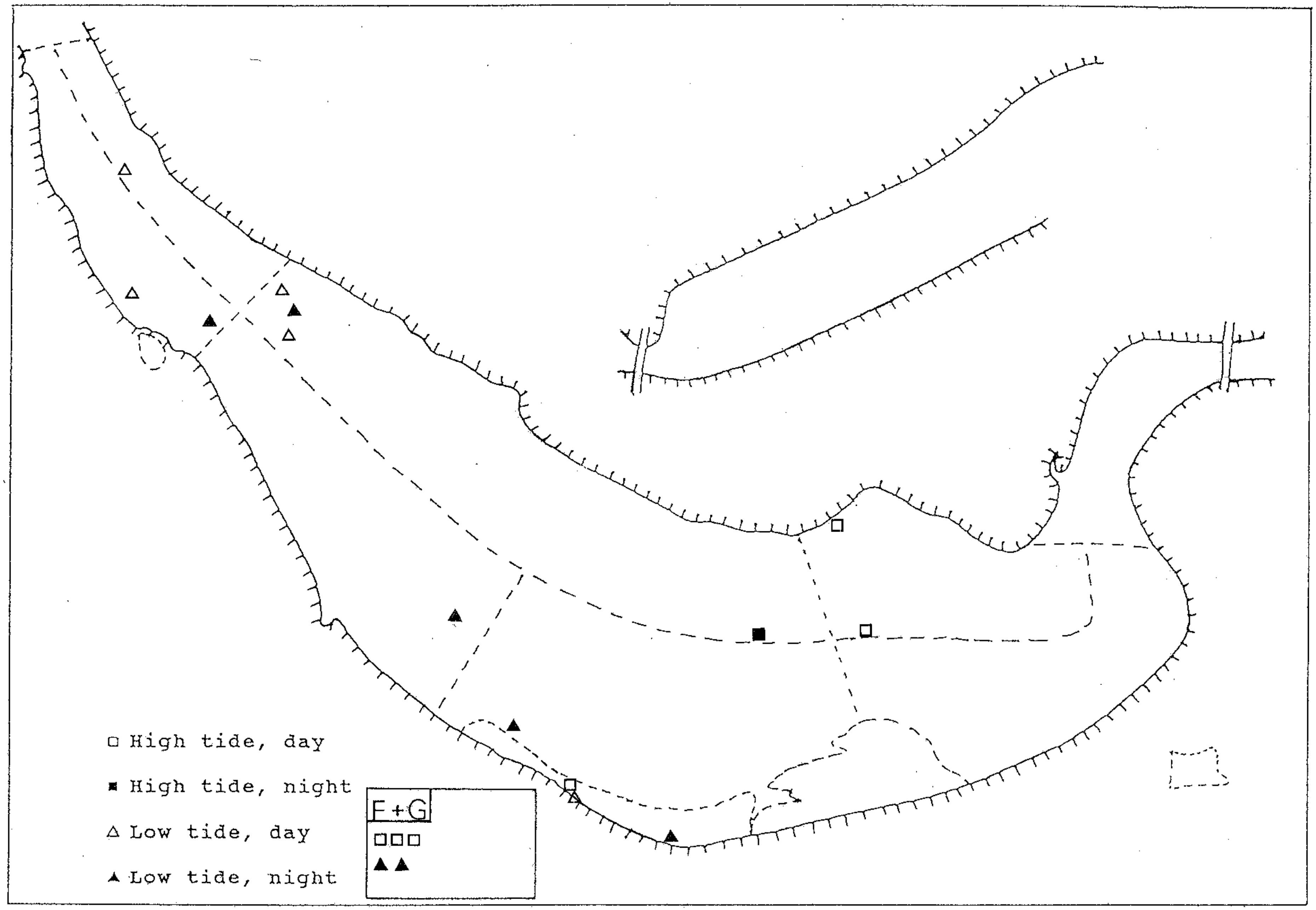


Figure 3.3.12 Locations of an adult male Pintail, caught at New Ferry, from 21 January to 3 March 1992.

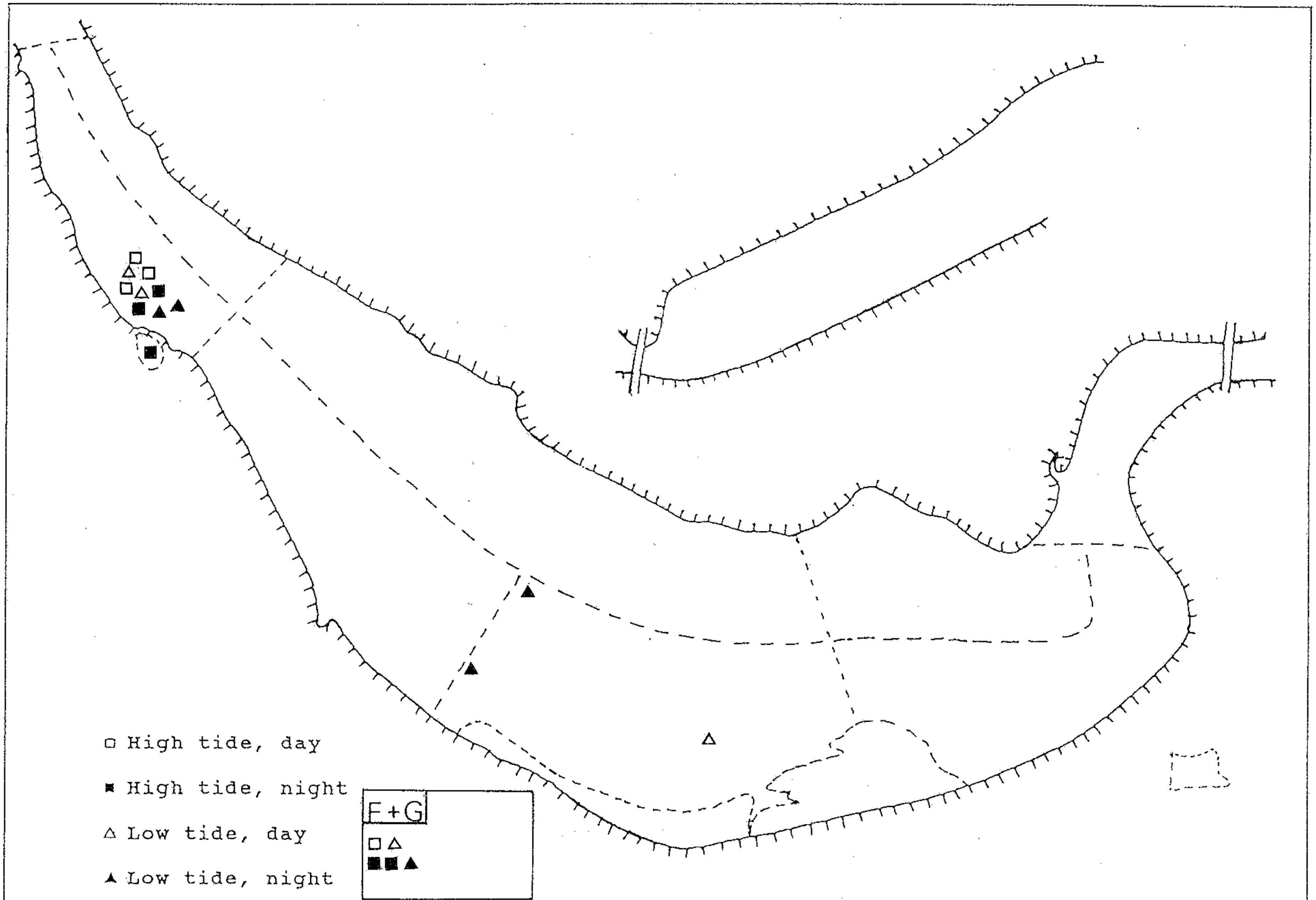


Figure 3.3.13 Locations of a 1st year male Pintail, caught at New Ferry, from 21 January to 12 February 1992.

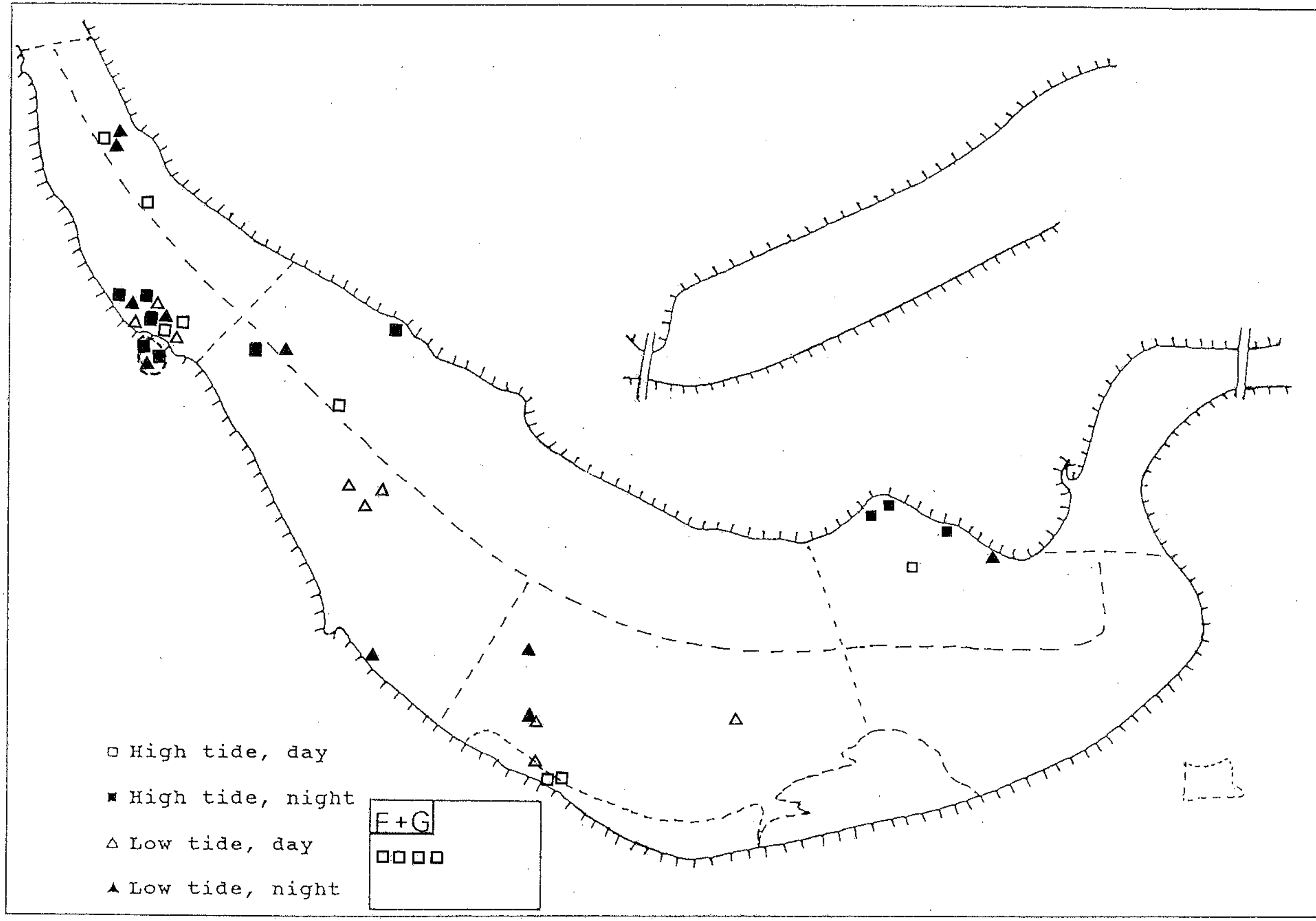


Figure 3.3.14 Locations of an adult female Pintail, caught at New Ferry, from 21 January to 9 March 1992.

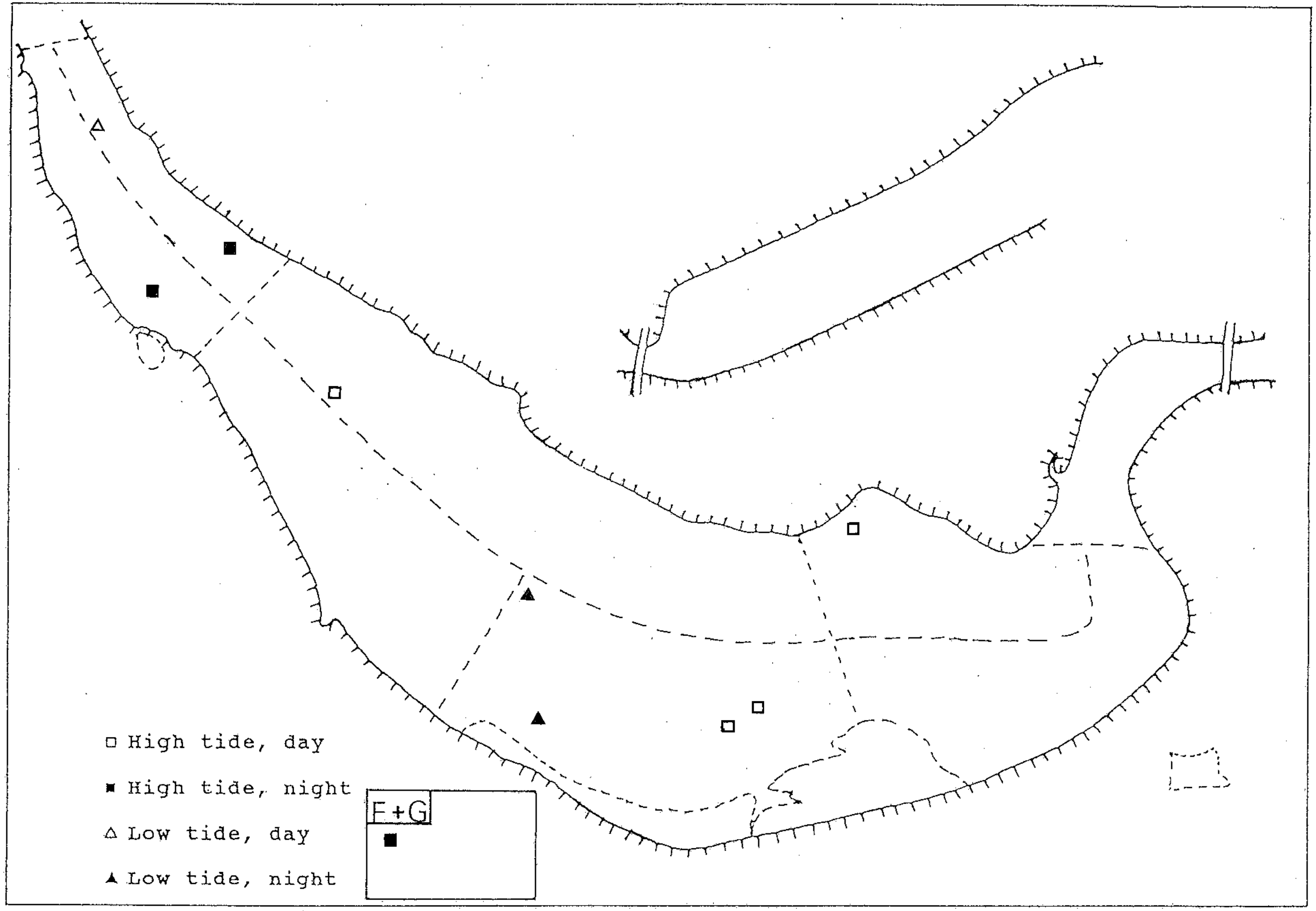


Figure 3.3.15 Locations of an adult male Pintail, caught at New Ferry, from 21 January to 5 February 1992.

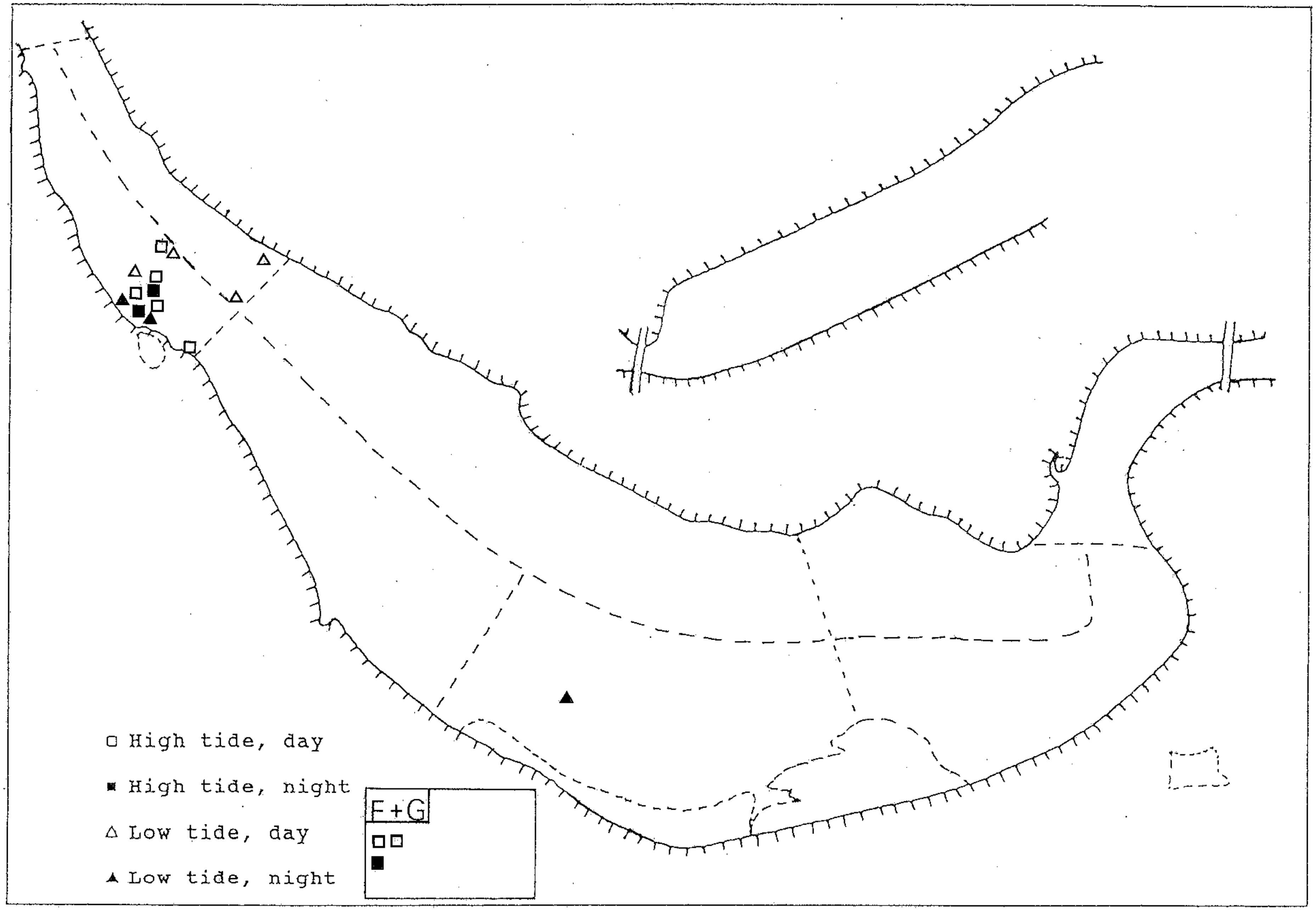


Figure 3.3.16 Locations of an adult female Pintail, caught at New Ferry, from 21 January to 10 February 1992.

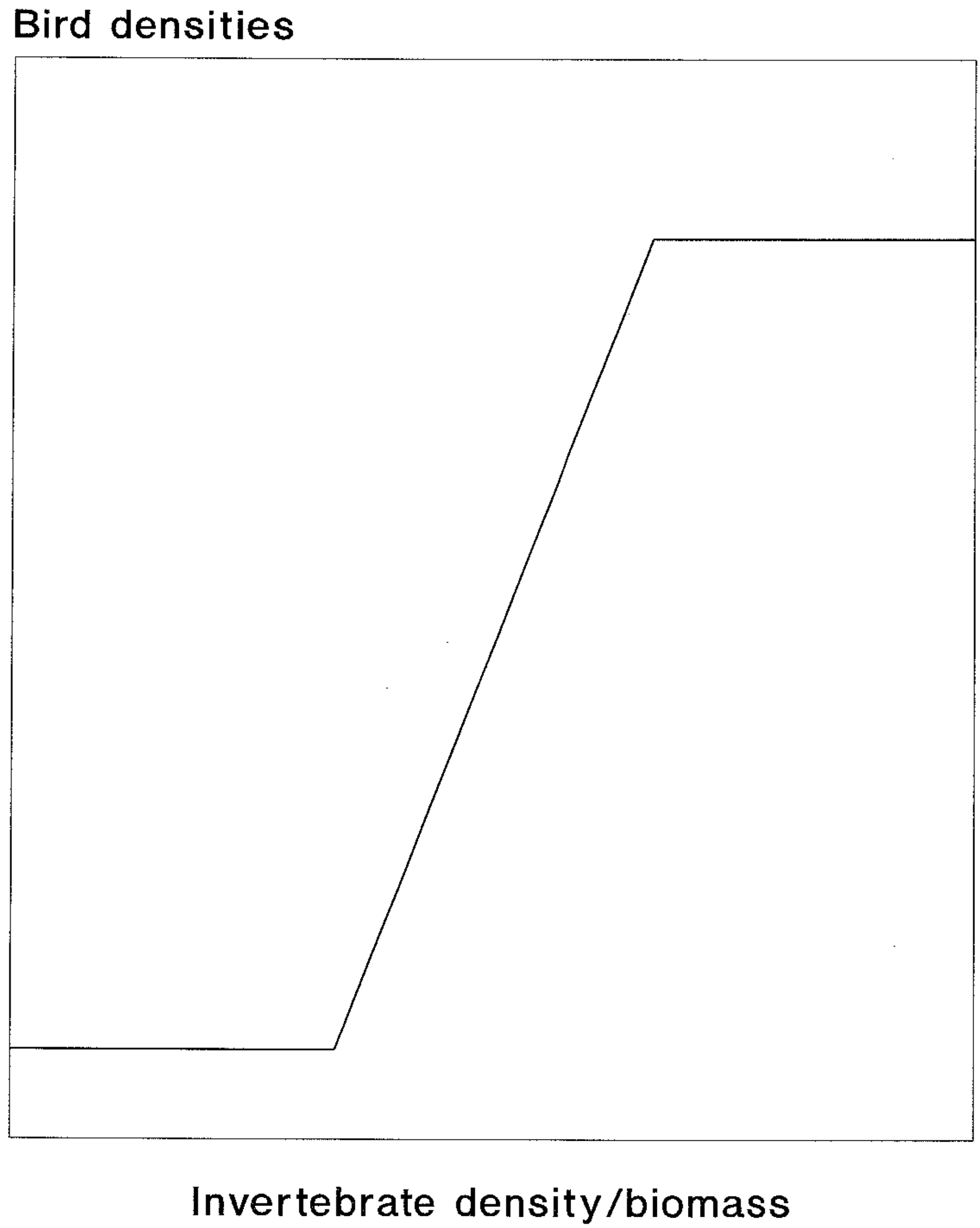


Figure 4.4.1 Model of the variation in bird numbers according to invertebrate densities or biomass.