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The Impact of the *Sea Empress* Oil Spill on the Abundance and Distribution of Waterbirds within Milford Haven Year 3 Final Report

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Report of work carried out by the British Trust for Ornithology under contract to the Countryside Council for Wales and the Sea Empress Environmental Evaluation Committee

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EXECUTIVE SUMMARY

1. On 15 February 1996, the *Sea Empress* oil tanker, laden with 130,000 tonnes of crude oil, ran aground at the entrance to Milford Haven. Approximately 72,000 tonnes of crude oil and between 480 and 760 tonnes of heavy fuel oil were released from the tanker over the next six days. Much of the local coastline was affected by the oil.

2. This study aimed to assess whether the oil spill adversely affected the waterbird populations found in the Cleddau Estuary complex at Milford Haven. Two polluted sites (Angle Bay and Pembroke River) and two relatively unpolluted 'control' sites (the Carew/Cresswell and Cleddau Rivers) were chosen to be monitored intensively over the three winters after the oil spill. The mudflats of Angle Bay were heavily affected by secondary contamination consisting of heavy sheens of oil derived from the initial strandings of crude and heavy fuel oil high up the shoreline. No physical or chemical clean-up was undertaken of the mudflats, although they sustained some minor damage from straying vehicles. The physical clean-up was concentrated on the upper shore above the mudflats. Saltmarsh and mudflats at Pembroke River were also affected by heavy fuel oil and sheens of crude oil. Contaminated areas of the upper shore were covered with sand to stabilize the oil. No treatment was carried out on the saltmarsh or mudflats. No significant amounts of surface oil reached the other two sites. No chemical dispersants, which are known to impact strongly on the rate of environmental recovery, were used within the estuary.

   The waterbird populations at the four sites were monitored from 1996/97 to 1998/99 using standard British Trust for Ornithology all-day (across the tidal cycle) count methodology to assess the feeding areas most used. In addition, high tide Wetland Bird Survey (WeBS) counts were analysed using data from 1982/83 to 1998/99.

3. The results of the WeBS and all-day counts are summarised for three species of wildfowl: Shelduck *Tadorna tadorna*, Wigeon *Anas penelope*, Teal *Anas crecca*, and four species of wader: Oystercatcher *Haematopus ostralegus*, Dunlin *Calidris alpina*, Curlew *Numenius arquata* and Redshank *Tringa totanus*. Both WeBS and all-day count data were modelled in order to compare the populations of each species at each site between winters and to take into account factors such as month, regional population trend (in the former case) and the state of tide and count sector (in the latter).

   Details of ringed birds recovered in the area of the Cleddau Estuary and those ringed there and recovered elsewhere over the last 22 years are summarised. The proportions of juvenile and adult birds caught at Angle Bay before and after the oil spill are analysed.

4. The oil spill immediately affected birds in the area, causing thousands of mortalities. A significant proportion of the casualties were seabirds outside the estuary. Few birds within the estuary were incapacitated, although daily WeBS counts carried out following the spill revealed that over 1,000 birds had oiled plumage. The majority of these were gulls, but some waders and Shelduck were also affected.

   The loss of food resources and disturbance from the clean-up operations at the time will have affected all birds in addition to those that were oiled.

5. In the two months immediately following the spill, there was evidence that some birds moved away from the oiled embayments. Shelduck, Wigeon, Oystercatcher and Redshank numbers declined at both Angle Bay and Pembroke River, whilst Curlew numbers also declined greatly at the latter site. Birds would normally be moving away from the estuary during this period, but some probably left earlier than usual.

6. In 1996/97, the winter after the spill, Shelduck and Redshank numbers had recovered at Angle Bay. The recovery of Redshank may have been due to the recovery of their invertebrate prey, that of Shelduck due to the high abundance of a small opportunistic polychaete, *Chaetozone gibber,* in the bay. Wigeon, however, declined further, Oystercatcher showed no recovery and Curlew declined to their lowest recorded number. This was probably due to the decline in their main prey species: cockles *Cerastoderma edule* and the large predatory polychaete, *Nephtys hombergii.* In contrast, Teal numbers increased greatly and numbers stayed high until the end of the study. At Pembroke River, Wigeon, Oystercatcher and Curlew numbers recovered, whilst Teal and Dunlin also increased. There was no recovery of Shelduck or Redshank.

7. All-day counts indicated that Oystercatcher and Curlew numbers recovered at both the oiled sites between 1996/97 and 1998/99 as the prey species recovered, whilst those at unoiled sites mostly declined or remained unchanged. Redshank continued to recover and become more widely distributed at Angle Bay, but their numbers only increased at Pembroke River in 1998/99. Wigeon numbers recovered in 1997/98 but fell again the following winter. Shelduck numbers at Angle Bay declined in 1997/98, following their initial recovery the winter before and numbers stayed low in 1998/99, despite the recovery of *Hydrobia ulvae* populations. However, Shelduck recovered at Pembroke River in 1997/98.

8. The study thus indicated that the *Sea Empress* oil spill may have adversely affected the populations of five of the seven waterbird species considered in the parts of the Cleddau Estuary that it reached. The effects were mostly confined to the first two months after the spill, or the following winter and recoveries in all species had been noted by 1997/98. Teal numbers increased greatly at Angle Bay following the spill, possibly due to increases in *Enteromorpha* growth and numbers of meiofaunal invertebrates.

9. Recommendations for further work are listed in Section 6.

1. GENERAL INTRODUCTION

The Cleddau Estuary[1] (Figure 1.1) holds large numbers of waterbirds in winter, with a five-year mean of nearly 18,000 birds (Waters *et al.* 1998). The estuary is nationally important for its Shelduck *Tadorna tadorna*, Wigeon *Anas penelope*, Teal *Anas crecca* and Curlew *Numenius arquata* (Table 1.1).

The Oil Spill

On 15 February 1996, the *Sea Empress*, laden with 130,000 tonnes of crude oil, ran aground on rocks at Mill Bay at the entrance to Milford Haven (see Figure 1.1). Approximately 72,000 tonnes of crude oil and between 480 and 760 tonnes of heavy fuel oil (HFO) were released from the tanker over the following six days. Some of the oil was carried into Milford Haven, affecting a large length of its coastline.

Crude oil first entered Angle Bay (Figure 1.2) on 16 February, heavy fuel oil entered on 22 February. The initial strandings were at high tide, high up on the rock platforms, shingle and gravel shores above the mudflats (Jane Hodges *in litt.*). The mudflats were heavily affected by secondary contamination derived from the initial high tide strandings. Heavy sheens of mostly crude oil were dragged down the shore and deposited on the mudflats by the ebb tide, with ribbons and pats of thicker brown oil embedded in them. The oil on the mudflats was then frequently 'lifted' and worked back up the shore by the flood tide. Apart from some minor trenching at the junction between the upper shingle shore and the mudflats, no physical or chemical clean-up was carried out of the mudflats. The physical clean-up operations were concentrated on the upper shore above the mudflats. Bulk oil was flushed into trenches and then extracted by vacuum tankers. Over 310 tonnes of oil were removed in the first week. During the first phase of the clean-up the upper beaches were disturbed and part of the eel-grass *Zostera angustifolia* bed in the south-east corner of the bay was damaged by vehicles (Jane Hodges *pers. comm.*). More detailed cleaning was carried out between May and August 1996. This second phase of the clean-up removed surface and sub-surface oil in the shore above the mudflats. No heavy vehicles were used. The operation was manual, using shovels, a small dumper truck and a mini-excavator, working on small sections at a time to minimize disturbance. In March, the following year, there was little contamination remaining in the area between Sawdern Point and Kilpaison. On the south side of the bay, however, brown oil and sheens were widespread in the upper edges of the mudflats between the surface of the mud and the silt below and pockets of oil were found in the shingle and mud (Jane Hodges *in litt.*).

Sheens of crude oil entered Pembroke River (Figure 1.3) on 18 February, but the major shoreline impact occurred on 22 February when heavy fuel oil was carried into the embayment (Jane Hodges *in litt.*). Areas of the shoreline between Bentlass and Goldborough Pill were most affected, while the shoreline between Bentlass and Quoits Water was affected to a lesser extent. A much smaller amount of heavy fuel oil was also stranded on the north shore east of Pennar Park. Due to the time of stranding, the impact was mostly restricted to the upper foreshore above the main bird feeding areas. In places, oil was deposited on saltmarsh between mean high water

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1 The Cleddau Estuary as defined by the Wetland Bird Survey (WeBS). This includes Milford Haven Waterway, the Daugleddau, Eastern and Western Cleddau and associated intertidal embayments, tributary rivers and pills.

mark and mid-tide levels. *Zostera* beds and mudflats below were affected by secondary contamination derived from oil stranded on the upper shore, but not to the same extent as at Angle Bay. The main high tide roost at Brownslate was extensively impacted by heavy fuel oil and there was a high probability of contamination of birds using this area. Polluted areas were covered with sand during mid-April to 'soak up' mobile oil, helping to stabilize it and reduce the birds' contact with the oil. The area was considered too sensitive for a major clean-up operation. Again, the mudflats and saltmarsh were not subjected to physical or chemical treatments. The residual heavy fuel oil stranded on the upper shore formed an asphalt pavement during spring and summer of that year, which had a tendency to soften in the sunshine and produce rainbow sheen and globules of free oil. In March 1997, the situation had remained fairly unchanged.

There was comparably little contamination of the estuary upstream of Neyland/Pembroke Dock. No significant amounts of surface oil reached booms that were deployed at Jenkin's Point (Figure 1.1) at the entrance to the Carew and Cresswell Rivers (Figure 1.4) (Jane Hodges *in litt.*). Some oil sheens did enter the rivers, and a small quantity of brown oil (emulsified crude oil) was stranded on the upper shore at Jenkin's Point.

Sheens of oil and oily seaweed were stranded on the foreshore as high up the estuary as Black Tar on the Daugleddau above Llangwm (Figure 1.1). Brown oil was seen on the water in the Eastern Cleddau (Figure 1.5) upstream of Picton Point and some stranding along the high water mark occurred. These are unlikely to have seriously affected the shoreline or mudflats (Jane Hodges *in litt.*). Within a few weeks after the spill, the estuary and tributaries above the Cleddau bridge were considered to be relatively free of oil.

In summary, the main intertidal areas affected by the spill on the Cleddau Estuary were Angle Bay and Pembroke River. No treatments involving the use of chemical dispersants were used within the estuary. Such treatments are known to have a major impact on the rate of recovery of the environment (Smith 1968).

The Study

The *Sea Empress* spill has provided the opportunity to assess the impact of oil deposits on the waterbirds of intertidal areas. Other studies of this spill have aimed to assess the impact of the oil on the waterbirds' invertebrate prey in the intertidal sediments. Changes in the sediment infauna may reveal the underlying reasons for the birds' distribution. In heavily oiled areas, the prey organisms may have been heavily depleted. Birds that used affected mudflats may have remained and, as a result, suffered increased mortality rates or may have been forced into other areas to feed. In either case, the local populations would be expected to have decreased in the immediate aftermath of the incident.

This study monitored the use made by waterbirds of intertidal areas in the Cleddau Estuary over three winter seasons, in relation to oiling levels. Four sites were studied: a heavily oiled site, Angle Bay; a moderately oiled site, Pembroke River; and two effectively non-oiled sites, the Carew/Cresswell rivers and the 'Upper Cleddau', where the Eastern and Western Cleddau meet. The non-oiled sites are similar to Pembroke River in topography and substrate composition. There is no local site similar to Angle Bay that has not been oiled. Within the constraints of the study, Angle Bay and Pembroke River are considered oiled, while the Carew/Cresswell and Upper Cleddau are considered to act as relatively unoiled control sites.

At the oiled sites, waterbird populations were expected to recover with time as did most shoreline faunas after the *Torrey Canyon* spill (Smith 1968) (Figure 1.6). It was expected that the recovery rates, measured by waterbird usage (see methods), would have been more rapid at Pembroke River than at Angle Bay, due to the less comprehensive deposition of oil at the former site. Furthermore, it was expected that the recovery rates would also differ between species according to their feeding preferences and would be dependant upon the mortality and recolonisation rates of their food organisms. The use of the non-oiled sites was expected to reflect the natural population changes, although initially there may have been increases due to possible influxes of birds from oiled areas.

2. A BRIEF REVIEW OF THE EFFECTS OF OIL SPILLS

2.1 Oil Spills and the Environment

Oil can enter the environment from a multitude of sources. These range from natural seepage, through the varied activities of the oil industry, to the industrial and domestic use of petroleum products. Alone, biogenic (animal or plant derived) input of hydrocarbons into the seas of the world is estimated at 26 to 30 million tonnes per year (HMSO 1981). In comparison, global inputs of oil, a hydrocarbon, into the marine environment are thought to amount to 4.5 to six million tonnes per year, of which about one percent are into United Kingdom waters. As crude and other oils are organic substances, which can be largely assimilated by the environment, there is often no detectable accumulation of oil above the natural background levels within the seas.

This situation can change when the input of hydrocarbons, often in the form of oil, occurs on a large scale or is locally concentrated. Accidental oil spills, such as the *Torrey Canyon* (117,000 tonnes), the 1978 *Amoco Cadiz* (223,000 tonnes) and the 1989 *Exxon Valdez* (38,000 tonnes), or vast 'strategic' releases of petroleum such as occurred in the Gulf of Arabia, have focused the attention of the media. The *Amoco Cadiz* spill impacted over 100 miles of coastline, with oil up to a depth of 30 cm, killed over 4,500 sea birds and led to a 25% drop in tourism to Brittany the following year. The *Exxon Valdez* oil spill off Prince William Sound, Alaska, was also seen as an environmental catastrophe. There were strong initial impacts on the marine bird community, but it was found that both habitats and bird populations were resilient to this sort of severe but short-term perturbation (Wiens *et al.* 1996).

Smaller spills, such as the 150 tonnes of Venezuelan Heavy Crude released into the Mersey in August 1989 and the 20 tonnes of Heavy Fuel Oil spilled into the Severn Estuary in February 1991, also received much national public attention. These spills caused localised pollution which had an impact on local amenities and wildlife and was also an economic burden. The Mersey oil spill (150 tonnes) had only a 'moderate' impact mitigated by wind and tide (Taylor *et al.* 1990), with no significant effect on the bird populations that could be attributed directly to the effect of the oil (Clark *et al.* 1990). The Severn spill killed at least 197 birds and, locally, high percentages of oiled waterbird and gulls were recorded, but only a very small proportion of the total population was affected (Rehfisch *et al.* 1992). There was no evidence that the timing of the bird's migration changed or that they used oiled areas less at high tide. The breeding success of the resident Shelduck during the following breeding season did not appear to have been affected.

Such spectacular examples of pollution only account for some 5% of the petroleum hydrocarbons (PCH) that go into the maritime environment. In contrast, urban and coastal runoffs account for over 40% of the PCH discharge into the environment, and much of these will go directly into estuaries (Wilson 1988). When estuaries are already prone to conditions of anoxia these hydrocarbon inputs will only degrade slowly, leading to an accumulation in the sediments with possible long-term effects on the fauna and flora.

2.2 Physical Nature and Effects of Oil

The physical properties of the oil will determine the effect it has on the environment. The properties that most affect the impact of oil on the environment include: i) density, ii) viscosity, iii) pour point, and iv) distillation characteristics.

Oil floats on water if its density is less than that of water and thus it will float more easily on heavier, salty seawater than on less dense freshwater. Low density oils are also on the whole more fluid and rich in volatile components. The density of an oil is normally expressed in terms of specific gravity. Pure water has a specific gravity (s.g.) of 1.0, while most crude oils vary between 0.8-1.0 s.g.

The viscosity of the oil is dependent on temperature and is a measure of its resistance to flow. The more viscous an oil, the less fluid it is.

The pour point is the temperature below which an oil will not flow. This can also be used to describe the oils fluidity characteristics.

Volatility is best described by the distillation characteristics, *i.e.* the proportions of an oil which distil within given temperature ranges. Less volatile oils distil in the higher temperature ranges, and *vice versa*.

The behaviour of the spilled oil will be affected by these properties. Apart from the characteristics of the oil itself, other factors may have much influence on the impact of the oil. The weather, the local hydrography and ambient temperature will all help to determine the spread of the oil and thus its consequences for the environment. Oil will drift and spread with the wind, tides and currents. In estuaries, the latter two factors are of more importance in determining movements of floating oil than the former which is more influential in the open sea. Spreading will be limited by the rate of loss of volatile components to the air. As they disappear, the oil becomes more viscous. Eventually the oil will form emulsions in strong wave conditions or floating 'tar islands' several centimetres thick. Upon spreading, evaporative processes may lead to a rapid loss of the lighter oil fractions. It is estimated that up to a third of the 117,000 tonnes of oil spilt from the *Torrey Canyon* may have been removed by evaporation within three days. Petroleum products which have been refined leading to a loss of volatile fractions, such as fuel or bunker oil, will evaporate less readily. Non-volatile residues are those that normally reach shores as tar balls. In severe weather conditions oil can be adsorbed on, or mixed with, particulate matter and carried to the bottom. There, its biological and chemical degradation will be very slow. Chemical degradation is mainly in the form of various oxidative processes speeded up by ultra-violet radiation. The oxidative products are frequently soluble in water and may be lost to the slick. The processes of degradation continue but are modified once the oil is on shore.

In summary, oils of high density, high viscosity and low volatility tend to be more persistent but less mobile than low density, low viscosity, highly volatile oils.

2.3 Oil and the Fauna and Flora

The biological effects can be generalised as mechanical smothering with attendant thermoregulation and photosynthetic problems, loss of insulation and buoyancy, as well as chronic, acute and sub-lethal poisoning which may cause behavioural changes or result in death.

2.3.1 Flora

Algae and saltmarsh vegetation can be killed by smothering, which stops photosynthesis and leads to increased temperatures under the oil layer. However, seaweed populations can recolonise rapidly from free-floating zoospores, especially as areas that have been severely affected by oil spills often are left with low herbivore populations, leading in some cases to an increase in plant biomass. The death of topshells and periwinkles as a result of the *Sea Empress* oil spill led to extensive growth of mostly green algae (SEEEC 1997). Saltmarsh 'polluted' by oil can be more vigorous after this organic input (Mellanby 1974).

2.3.2 Plankton

Plankton and the zooplankton which feed upon the primary producers of aquatic systems form the base of aquatic food chains. Oil spills affect the plankton by attenuating the light available for photosynthesis and leading to some forms of poisoning. However, some bacterioplankton can benefit from the introduction of organic matter, such as oil, into the water body, increasing in number and thus increasing the speed of breakdown of the oil. The timing of the spill can be very important. For example, significant deaths of plankton can occur if the spill coincides with larval settlement of such species as barnacles *Semibalanus* (Nelson-Smith 1968). Generally, plankton has high regenerative capacities and oil has little demonstrable effect on its numbers (Smith 1968). Even Liverpool Bay, which suffers from chronic hydrocarbon pollution, as defined by concentrations of above 0.1 ppm, has normal levels of primary production (HMSO 1981).

2.3.3 Macrobenthic invertebrates

The effects of oil on invertebrates are best known for the intertidal fauna. These animals can be poisoned or smothered by the oil as the tide recedes, in cases of gross oil pollution; moreover, filter-feeders can ingest oil droplets while feeding. By affecting such filter-feeding species as cockles, oysters and clams, oil pollution can be of considerable economic importance to regions with extensive mariculture. Generally invertebrate deaths are related to the proportion of lighter, toxic fractions. In the absence of these, most molluscs resist oil well.

Chasse & Morvan (1978) reported the survival rates of various species of invertebrates after the *Amoco Cadiz* spill. Molluscan species, such as Thin Tellin *Tellina tenuis*, showed high survival rates and many polychaetes remained largely unaffected. Many other species, however, had very low survival rates, particularly the amphipod *Ampelisca brevicornis*, which could not be found following the spill.

When no detergents are used, Limpets *Patella vulgata* can often survive an oil spill and help to clear the oil by browsing, surviving up to 20-30% oil in their food (Smith 1968). Top-shells can survive a 5-50% oil intake. After the *Chrissi P. Goulandris* incident at Milford Haven in 1967, recolonisation was rapid with a fauna similar to the original nine months after the spill (Nelson-Smith 1968). Most original deaths were of gastropod molluscs.

Crustaceans such as crabs and lobsters show signs of suppressed feeding in 0.9 ppm oil in sea-water, and may suffer high death rates in cases of severe oiling (HMSO 1981). Mussels tainted by oil are refused by crabs that will otherwise feed on mussels grown in clean water (Perkins 1968). Sedentary crustacea are most affected by oil pollution.

Ragworms *Nereis* (*Hediste*) *diversicolor* and lugworms *Arenicola* can be killed in large numbers when oil enters the substratum of sandy or muddy beaches or intertidal flats. Similarly, indicator species of clean waters such as sea-urchins and starfish, can be killed in large numbers by toxic oil. Numbers of the rare Cushion Star *Asterina phylactica* were much reduced by the *Sea*

Empress spill but the species appeared to be recovering in West Angle Bay (SEEEC 1997). Topshells and periwinkles died and up to 90% mortality was recorded of limpets. The Egg-shell Razor *Pharus legumen* is thought to have been affected by the *Sea Empress* spill (Hughes *et al.* 1997). Amphipod mortality was extensive but by 1997, recolonisation was evident in many areas.

2.3.4 Fish

Adult fish are highly mobile and can normally escape an oiling incident by swimming away. The main effect is on the less mobile larval stages which are part of the plankton or else when highly toxic light oils such as gasoline are spilled in restricted inshore localities leading to large adult casualties (HMSO 1981). There has been no observable decline in fish stocks that can be specifically attributable to oil pollution. Following the *Sea Empress* spill, tissue concentrations of oil components increased temporarily in some fish species, but most fish were only affected to a small degree (SEEEC 1997).

2.3.5 Mammals

On the whole, mammals can escape most of the effects of a spill by vacating the area. Cetaceans, being smooth-skinned, are less at risk than furred animals such as otters, especially as these depend on the beach for entry to and exit from the sea. Ingestion of oil can lead to chronic or acute effects. None of the local Grey Seals *Halichoerus grypus*, cetaceans or Otters *Lutra lutra* were obviously affected by the *Sea Empress* spill (SEEEC 1997).

2.3.6 Birds

In the public perception, the welfare of seabirds is a primary concern in the event of an oil spill. A normally free flying animal struggling in a straightjacket of tar can be a highly emotive sight. This has led to much effort being made by various organisations to monitor the numbers of birds killed by oil (*e.g.* the RSPB and the Dutch Beached Bird Surveys) in order to enhance our understanding of the factors that lead to large scale bird deaths.

The first major recorded bird-kill was in the Shetlands in 1907 when over 100,000 Puffins *Fratercula artica* were estimated to have died (*c.f.* total Puffin population of 125,000 pairs in 1982; Harris 1984). Since the two world wars, the frequency of oil-related bird deaths has increased (Bourne 1968).

Birds are affected by oil directly and indirectly. Direct effects include poisoning through preening, preening difficulties, feeding difficulties and loss of body heat and buoyancy. Ingestion of oil can lead to chronic or acute poisoning through the disruption of the nervous system. Sub-lethal exposure to oil can lead to behavioural changes and general weakness, leading to increased susceptibility to such infections as acute enteritis and various pulmonary conditions (Beer 1968), as well as salt-secretion problems. The effect of oil and other pollutants varies with the species of bird, and sometimes with the individual. For example, Guillemots *Uria aalge* with small livers are more vulnerable to poisoning than other individuals with larger livers (Moriarty 1975). Birds are more at risk during periods of hard weather when they are mobilising fat reserves through their livers, which increases the toxin levels in their blood. Furthermore, in winter, oil decomposes more slowly, increasing the duration of the threat.

Camphuysen (1989) records that 30,000 birds are washed ashore every winter in the Netherlands, 68.4% of which are oiled, making oil the major cause of death, followed by food shortage and entanglement in plastic. Oiling seems to have been responsible for a greater proportion of wildfowl deaths, 31.6% of corpses being found to be at least partly oiled (Camphuysen 1989): 27.7% of the swans, and 28.6% of Shelduck *Tadorna tadorna* and dabbling duck corpses were oiled. 43.4% of all gull corpses were found oiled; the proportion of Black-headed Gulls *Larus ridibundus* and Common Gulls *Larus canus* which were oiled being more than average. The birds most prone to death by oiling are the auks, 89% or more of beached corpses of Guillemots and Razorbills having been found oiled (Mead & O'Connor 1980). It is unfortunately not possible to estimate mortality at sea accurately, as the proportion of dead birds recovered may vary widely. Camphuysen (1989) found that between 0.3 and 56% of dead birds released experimentally at sea were subsequently recovered.

In total, some 7,000 oiled birds were washed ashore following the *Sea Empress* spill, but almost certainly many more birds will have been killed and washed out to sea (SEEEC 1997). The *Sea Empress* oil spill killed at least 3,326 Common Scoter *Melanitta nigra*, about 5% of the UK wintering population. Ninety percent of the birds killed were Common Scoter, Guillemots and Razorbills *Alca torda*. A high proportion of the local diver populations were also killed. Locally there were 13% fewer breeding Guillemots and 7% fewer breeding Razorbills in 1996 than in 1995 but by the 1997 breeding season, numbers had recovered significantly. Some 10,000 fewer Common Scoter visited Carmarthen Bay in 1997 than in 1996.

Certain habitats, such as estuaries, are particularly affected by spills and other forms of pollution. Thus, waterbirds associated with estuaries, such as ducks, geese and swans, are frequently affected by spills. Even small discharges in an enclosed area can lead to great bird mortality. Through an unfortunate combination of temperature and wind direction there were unusually high bird concentrations in Skagerrak in January 1981, and two small oil discharges killed an estimated 30,000 birds (Camphuysen 1989).

It is debatable whether chronic or acute oil pollution leads to a greater mortality of birds (Tasker *et al.* 1987, *c.f.* Camphuysen 1989). After the *Amoco Cadiz* spill, acute oil pollution led to the September Isles Puffin colony being decimated and it has not yet recovered. Most beached birds off the Dutch coast in the 1980s died from chronic oil pollution. The decline in wintering numbers of Guillemot that occurred in the British Isles in the 1980s has been partly attributed to deaths caused by both chronic and acute oiling (Lloyd *et al.* 1991), especially in the British Channel, yet overall Guillemot numbers seem to be rising when measured at colonies (Camphuysen 1989). It is important to remember that whereas there is some evidence that oil may have caused localised declines of some bird species, there is no evidence of oil having been the cause of an overall population decline, though this may often be due to the difficulty in collecting the relevant information. It is equally important to remember that some species are more vulnerable than others, and that these include estuarine wildfowl and to a lesser extent waders (Tasker *et al.* 1990), though the effect of oil on waders has not yet been extensively studied (Anon. 1990a).

Apart from moral satisfaction, efforts at rehabilitating oiled birds have proved singularly unsuccessful (Beer 1968), and even with the advent of the new less harmful cleaner 'Teepol' less than 10% of birds are successfully released to the wild (Camphuysen 1989). The study commissioned as a result of the *Sea Empress* oil spill confirmed that survival rates of rehabilitated Guillemots were very low (Wernham *et al.* 1997).

Indirect effects on birds include the temporary loss of feeding grounds when covered by oil, and spills can also lead to a diminution of both plant and invertebrate food numbers and quality, as well as habitat destruction. The geographical position of the oil on the mudflats can determine which birds are affected. Seabirds are most affected by spills out in open water, while waders are affected by oil on the mudflats which are frequently their primary feeding grounds. The Dutch Beached Bird Survey found that 9.6% of all beached birds were waders, of which only 12.3% were oil-fouled; the majority of the rest probably died from severe winter conditions leading to feeding difficulties. The enormous marine oil spills of the Gulf War polluted some 560 km of Saudi Arabian Gulf coastline and may have lead to a decline of 97% in the numbers of waders present during the spring migration and early winter (Evans & Keijl 1993). The 'missing waders' may have been displaced as a result of a lack of prey and due to the noxiousness of the oil. However, it is possible that tens of thousands of waders may have died and at least three-quarters of the few remaining birds were oiled (Evans & Keijl 1993). Waders with over 10% plumage oiling were found to be significantly lighter than unoiled birds. The *Amoco Cadiz* spill of 1978 led to low invertebrate survival rates and birds would thus have been affected by the depleted food resources. The strongest impacts of the coastal *Exxon Valdez* spill were on wintering or resident species feeding on or close to the shore (*e.g.* Dunlin *Calidris alpina*, Whimbrel *Numenius phaeopus* and American Wigeon *Anas americana*). After only one and a half years, however, there was little evidence of a continuing impact on these birds (Wiens *et al.* 1996).

2.3.7 Summary

There is little evidence that oil has been responsible for any long term impact on total animal populations, though this may be partly due to the difficulty in distinguishing natural variability from the effects of oil. It is quite possible that a very large oil spill could lead to the local or regional extinctions of a rare species (HMSO 1981).

The localised depletion of a species can have a knock-on effect on the balance of a system. The temporary demise of a herbivore can lead to a rapid increase in plant densities; sometimes several years are required before a state of relative balance is achieved.

Little is known about the effects of sub-lethal concentrations of oil, but these may be critical to some birds and also to juvenile stages of various organisms, nor is much known about the long-term effects of hydrocarbon accumulation in sediments.

Of the main groups of birds commonly found in estuaries, waders are thought to be the least affected by oil pollution, ducks and swans slightly more prone to it, while oil may be a major cause of gull mortality.

2.4 The Effect of Artificial Cleaners

After the *Torrey Canyon* oil spill, the local authorities used both mechanical and chemical cleaners. In estuaries, plants such as Common Saltmarsh-grass *Puccinellia maritima*, Red Fescue *Festuca rubra*, Common Reed *Phragmites communis* and Long-bracted Sedge *Carex extensa* were particularly affected by the oil (Ranwell 1968), though many plants remained healthy with some showing increased growth as small quantities of oil acted as 'fertilizer' (Mellanby 1974). Invertebrates, such as Ragworms and the amphipods *Corophium volutator* and *Gammarus* spp., were found dead in the Hayle Estuary, but the deaths were associated with gullies. The sandy flats, which had not been treated by detergents, showed no evidence of harm. Even such tide-line scavengers as the Sand-hopper *Orchestia*, which lived by the oil drift-line, appeared unaffected (Smith 1968). The oil that drifted into the Hayle Estuary weathered rapidly even though untreated. The areas most affected by the spill were those that were sprayed by detergents (Smith 1968). For example, spraying at sea killed most Pilchard *Sardina pilchardus* eggs and surface phytoplankton.

Significant environmental degradation is only caused by very large concentrations of oil, the main destructive impact of a spill often being caused by detergents used for cleaning up visual imperfections. One of the problems associated with detergents is that they destroy bacteria and other organisms that can help break down oil naturally, and lead to an unbalanced ecosystem. They may also be toxic to certain organisms. Recent methods for dealing with oil spills include the artificial introduction of bacteria to enhance natural populations (Anon. 1990b). The 10 years that it took the environment to recover after the *Torrey Canyon* incident were mainly due to the loss of herbivore populations killed by the application of detergents.

Even with the more environmentally friendly detergents now available, it is generally wiser to restrict their use to areas where economics require visually pleasing conditions, for example tourist beaches. Most effort should be directed at picking up spilled oil from the water's surface, and preventing it from reaching land. The tendency nowadays is to recommend as little action as possible (Johnston 1984), and to let an often resilient nature run its course. Yet, even after approximately 3,000 tonnes of detergent were used to 'clean up' the oil after the *Torrey Canyon* spill, no species were known to have been lost to the area (Mellanby 1974).

After the locally severe *Tampico Maru* spill in California, very large mortalities were recorded amongst bivalves and crustaceans, but two years later the coast appeared largely normal except for increased numbers of Giant Kelp *Macrocystis* due to the temporarily reduced predation pressure caused by a decline in echinoderm and abalone numbers during and shortly after the spill (Nelson-Smith 1968). This incident is particularly interesting because the oil was left completely untreated and shows how the natural system can recover when left to its own devices.

2.5 Oil Pollution Importance and Spill Impact Assessment

It is important to note that oil is only one source of pollution, and that MAFF considers pollution caused by radioactive wastes, chlorinated hydrocarbons and toxic heavy metals to be of higher priority than that caused by oil (HMSO 1981).

Yet, oil pollution can have substantial local costs when spills occur near holiday amenities or in areas with important inshore fisheries. Oil also slows down the oxidation of sewage and increases the biological oxygen demand (B.O.D.) of water-bodies (Moriarty 1975; Wilson 1988), leading to potentially costly clean-up operations due to new legislative requirements for minimum oxygen levels in rivers.

Even though these costs exist, there is still a relatively small volume of information about long-term effects of oil spills. One fundamental problem is the frequent difficulty in distinguishing the impact of a pollutant from natural variations in the system being observed. Most ecosystems show very large fluctuations from year to year, and it is often difficult to tell whether it is the pollutant or another parameter that leads to a particular variation. Any work on the impact of an oil spill should always consider this problem seriously and it may be considered essential to have long-term data available from before the spill and to continue monitoring long after the spill to assess recovery. Another problem is that it can be very difficult to assess if animals seen in years following a spill are those that had been present at the site or recent colonisers taking advantage of newly available habitat. If it is the latter, mortality brought about by the oil would be less apparent.

Past studies of oil spills have often suffered from a lack of baseline data from the site. This study has the advantage of being able to make use of data from the long-running Wetland Bird Survey scheme.

3. METHODS

3.1 Wetland Bird Survey (WeBS) Counts

3.1.1 Study sites

Monthly WeBS (high tide) counts of waterbirds were analysed for the four main sites: Angle Bay, Pembroke River, Carew/Cresswell and the Upper Cleddau, using data collated from the winters (November to March) of 1982/83 to 1998/99. Counts covered the entire embayments of Angle Bay and Pembroke River and also the entire Carew/Cresswell complex. The Upper Cleddau counts include the entire Eastern and Western Cleddau, Millin Pill, Sprinkle Pill, Landshipping Quay, Llangwm Pill and the Daugleddau as far south as and including Garron Pill (see Figure 1.1).

3.1.2 Data analysis

WeBS data were analysed in relation to the south-west Wales regional trend in numbers for each of the seven main species. A regional index (based on the Ogmore Estuary, Afan Mouth and Port Talbot Harbour, Swansea Bay, Burry Inlet, Carmarthen Bay, Nevern Estuary, Teifi Estuary and Dyfi Estuary) was calculated for each month of each year between 1984/85 and 1997/98 using the method in Underhill & Prŷs-Jones (1994). Months where more than 50% of the index value was estimated due to missing counts were omitted from the modelling analyses (below). Index values for winters 1982/83 and 1983/84 were not calculated for any species as the levels of impution of estimated values were consistently too high.

For each of the four sites on the Cleddau, generalized linear models (GLMs: McCullagh & Nelder 1989) were used to relate the number of birds on each WeBS count to the winter (1984/85 to 1997/98), month (November to March), and regional index, *i.e.*

$$\ln(\text{count}) = \mu + \alpha_i(\text{winter}) + \beta_i(\text{month}) + \gamma(\text{regional index})$$

Models assumed a Poisson error distribution (as is appropriate for data with a high proportion of low or zero values) and specified a log link function (*i.e.* to create a log linear relationship between mean count and the independent variables). Winter and month were treated as class variables and the regional index as a continuous variable. The estimated values of the model parameters α_i indicate the numbers of birds each winter relative to that in 1997/98. These, together with summed WeBS counts (see below), are plotted in a series of graphs, for each species and site considered, to enable bird numbers to be better compared across winters. The estimates for each winter are plotted as a line with standard error bars. A negative estimate indicates that the number of birds present at a site, relative to the south-west Wales regional population, was lower in that winter than in winter 1997/98 and *vice versa*. Differences in estimates between winters, or parts of winters, were tested for by imposing appropriate constraints on the α_i and applying likelihood ratio tests (see Wetherill 1981, pp 350-353). For example, under the assumption that numbers in 1984/85 and 1985/86 were the same, the α coefficients for those winters were set equal. Two model estimates were calculated for winter 1995/96, one for the months before the oil spill (November to January) and one for the months after the oil spill (February and March). Additional counts made daily in the week following the spill, and weekly thereafter are included along with the routine WeBS counts.

Summed WeBS counts for each winter are the sums of the monthly WeBS counts made between November and March at each site in each winter and are represented by the shaded bars in the series of graphs (Figures 4.1.1.1, 4.1.2.1 etc). For the purposes of presentation, sums of WeBS counts for each winter at each site include imputed values where counts were not made for a particular month. These were calculated using all 17 years of WeBS data as follows:

$$A \times B/C$$

where A is the sum of the available monthly counts in the year, B is the sum of the available yearly counts for the month, and C is the total of all the available counts in all years and months. This was run as a bootstrap with five iterations in order to increase the accuracy of the imputed value. The imputed values were not included in the modelling analyses above, as the model takes missing values into account. Summed WeBS counts for each winter are plotted together with model estimation, although the two are not scaled to match each other.

3.2 All-day Counts

3.2.1 Study sites

The all-day counts also focused on the same four sites: Angle Bay, Pembroke River, Carew/Cresswell and Upper Cleddau (Figures 1.2 to 1.5). Each site was divided into several sectors to allow detailed analyses of results. Angle Bay was divided into 10 sectors, all affected by the spill. Sector 4 is an area of rocky shore and Sector 10 is a small harbour. Each of the other three sites were divided into 12 sectors. At Pembroke River, sectors counted at the eastern end of the site (Sectors 7, 8, 10, 11 and 12) which extended as far upriver as Quoits Water Pill, were not affected by oil deposition. The count area at Carew/Cresswell extended to Newshipping Point on the Carew River and nearly to New Park on the Cresswell River. The area covered at the Upper Cleddau site included the entrance to Landshipping Quay, the mouth of Millin Pill, the mouth of Sprinkle Pill and the intertidal areas at the confluence of the Eastern and Western Cleddau Rivers. Saltmarsh is found at the fringes of all sites, except Angle Bay, but was not surveyed. Where possible, the boundaries of the sectors followed those laid down by Hellawell & Phillips (1987) and Prŷs-Jones (1989). For the purposes of this study however, some count areas used by those studies have been divided into smaller units.

The species recorded include divers, grebes, cormorants, herons, wildfowl, waders and auks. In order to monitor all species comprehensively, an area of open water (Sector 88, Figures 1.2 to 1.5) was also counted at each site.

3.2.2 Count methodology

In order to gain a full picture of the use of the four intertidal areas by waterbirds and other birds, counts were carried out across the tidal cycle (an 'all-day' count - see Clark 1990). This choice of methodology allows the most important feeding areas to be identified. Each site was counted once every hour from six hours before to five hours after low tide. Counts were made throughout the hours of daylight. Feeding and roosting birds were counted separately and factors such as disturbance to a sector or impaired visibility were noted. All birds present on the exposed sectors were counted. Wildfowl in the shallow water offshore, which were feeding on invertebrates or plants on or in the substrate were included in the counts for the respective sector. Those species such as divers, grebes, cormorants and diving ducks which use open water were counted as feeding or roosting over the appropriate sector or on the open water count area. Birds roosting in areas of saltmarsh were not counted, as accurate counts are very difficult in this habitat.

Counts took place between November and March as the estuary is most important for birds during the winter period. The migration and early autumn periods have been excluded because numbers of birds can fluctuate widely from year to year, for reasons not associated with the state of the estuary. Each site was counted twice a month with one count on a spring tide and one on a neap tide where possible, with the exception of November when each site was counted once.

3.2.3 Data analysis

Analysis of results for presentation follows Evans *et al.* (1990). All-day counts were used to calculate the following:

1. the average exposure time per tidal cycle of each sector;

2. the average number of feeding bird hours per tidal cycle for each species for each count sector;

3. the average number of birds of each species present on each of the four sites at each hour of the tidal cycle and the proportion feeding.

For each species of wader and heron, all-day usage was calculated for each count sector as:

$$\sum_{A=+5}^{A=-6} (BxC)$$

where A is the hours from low tide (0 hours being low tide and +5/-6 high tide, B is the average number of birds feeding at time A on the exposed area, and C is the proportion of counts when the area was exposed at time A.

For wildfowl and other species that may feed on or under the water, all-day usage was calculated as:

$$\sum_{A=+5}^{A=-6} B$$

where the area is considered available from $A = -6$ to $A = +5$.

GLMs were used to analyse data from the all-day counts. For each site, models were created to relate the number of feeding birds counted to the winter (1996/97, 1997/98 or 1998/99), month (November to March), state of tide (hour relative to low water at which the count was undertaken) and the sector (to take into account differences in area and substrate), *i.e.*

$$\ln(\text{count}) = \mu + \alpha_i(\text{winter}) + \beta_i(\text{month}) + \gamma_i(\text{state of tide}) + \delta_i(\text{sector})$$

Models assumed a Poisson error distribution, specified a log link function and treated all four variables as classes. The estimated values of the model parameters α_i indicate the numbers of birds each winter relative to that in 1998/99. A negative estimate value indicates a winter in which fewer birds were recorded than in 1998/99. A positive estimate value indicates a winter in which the number of birds recorded was higher than in 1998/99. Differences in the estimated values of the numbers of feeding birds between winters were tested for by imposing appropriate constraints on the α_i and applying likelihood ratio tests (see Wetherill 1981, pp 350-353).

3.3 Presentation of Results

The order of the species accounts follows Voous (1973). All species observed at the three sites during the period of study are reported, but most emphasis is given to the most numerous species: Shelduck, Wigeon, Teal, Oystercatcher *Haematopus ostralegus*, Dunlin, Curlew and Redshank *Tringa totanus*. The summed WeBS counts of each species over the last 17 years are discussed. These are displayed with the model estimate for each year (Section 3.1.2). Detailed accounts of their numbers and distribution over the three year intensive fieldwork study at each site are given. These are supported by dot maps displaying the number of bird-feeding-hours per tidal cycle and graphs showing the average number of birds and the proportion feeding at each hour through the tidal cycle.

For other species, the main feeding areas are described and the peak numbers present during the winter are given. Those species recorded in the estuary on few occasions during each winter are listed.

3.4 Ringing Analyses

Birds are ringed in order to gain knowledge of their movements and survival rates. Individually numbered metal rings are attached to the leg of the bird when caught as a juvenile or adult, or at the nest as a pullus. The date and location, age and sex of the bird, the ring number, and details of the bird's size are recorded and subsequently logged in the national ringing scheme's database. In the United Kingdom, this is at the BTO. When a ringed bird is caught again or found dead (a recovery), the same details are recorded and logged.

Details of birds recovered in the area of the Cleddau Estuary (Figure 1.1) and those ringed there and subsequently recovered elsewhere were extracted from the BTO database to provide some indication of the birds' breeding origins. This analysis was carried out for the seven main species, using data for birds caught since 1978.

In addition, data from catches at Angle Bay were analysed to determine whether the proportion of juveniles and adults caught in each trapping session differed before and after the oil spill. Many of the birds that used the bay would have moved elsewhere following the spill to seek better feeding conditions. It is hypothesized that there would have been a higher proportion of juveniles left in the bay as they would have been excluded from the other better areas by the more dominant adults. Juvenile Oystercatchers, for example, have previously been shown to be excluded from preferred mussel beds on the Exe Estuary by interference from adults (Goss-Custard *et al.* 1982). Similarly, in a study in south-east Scotland, juvenile Redshank were found to be excluded from feeding areas where the risk of predation was lowest (Cresswell 1994). This analysis was carried out only for Oystercatcher, as too few data were available for Dunlin, Curlew and Redshank, either before or after the oil spill, to allow a comparison to be made, whilst no Shelduck, Wigeon or Teal were ever caught at the site. The following GLM was used to investigate whether the proportion (p) of juveniles caught differed between the periods before and after the spill:

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

A binomial error distribution was assumed, with the logit link function used to ensure valid probability estimates in the range (0,1). Period was treated as a class variable. A likelihood ratio test was used to determine the significance of the α_i and thus the difference between the two periods.

4. RESULTS

4.1 Main Species

The initial results section focuses on the seven main species: Shelduck, Wigeon, Teal, Oystercatcher, Dunlin, Curlew and Redshank, and the results from the modelling of WeBS and all-day count data. Models were created for each site independently. In some cases in the analysis of WeBS data, the regional index was not significant in explaining the number of birds counted, but was nevertheless retained in the model to allow for regional population trends. Winter and month were significant in every model. In the analysis of all-day count data, models related each count of a species to winter, month, the state of tide (*i.e.* hour either side of low water) and the sector. Although the above species were widely distributed across the sites, some were never recorded on certain sectors, in certain months or at certain states of tide on particular sites. In these cases, listed below, data were excluded from the models.

- Shelduck at Sector 11 at the Upper Cleddau
- Wigeon in March and at Sectors 1, 8, 10, 11 and 12 at Pembroke River
- Wigeon at Sector 8 at the Upper Cleddau
- Teal at Sectors 1, 7, 8 and 9 at Angle Bay
- Teal in November and March and at Sectors 1, 2, 3, 6, 7 and 8 at Pembroke River
- Teal at Sectors 3, 6 and 8 at the Upper Cleddau
- Dunlin at Sector 10 at Carew/Cresswell
- Dunlin at Sector 11 and at six hours before low water at the Upper Cleddau
- Redshank at Sector 7 at the Upper Cleddau

Counts affected by poor visibility were also excluded. The variables considered were highly significant in every model.

4.1.1 Shelduck *Tadorna tadorna*

About 10,600 pairs of Shelduck breed in Great Britain, mostly at coastal locations, but increasingly at inland sites (Gibbons *et al.* 1993). Following breeding, most adult Shelduck, both from the UK and continental Europe, move to moulting grounds in the German Wadden Sea and only return to their wintering areas from September onwards. The 1996/97 index value for the British wintering population was typical of those for the last 10 years, although the peak count of over 79,000 birds in January 1997 was the highest since the early 1990s (Waters *et al.* 1998). Shelduck bred very successfully on the Cleddau Estuary in the summer following the *Sea Empress* oil spill, with 25 broods and a total of 217 ducklings reported. There was no evidence that they had been impacted by the incident (Hodges 1997). A similar number of broods was reported in each of the following two breeding seasons, although average brood size was significantly smaller than in 1996, probably due to different weather conditions, disturbance and predation pressures (Hodges 1998). During the winter, the Cleddau Estuary hosts nationally important Shelduck numbers (Table 1.1).

Angle Bay

Summed monthly winter WeBS counts of Shelduck ranged from 54 in 1982 to 501 in 1986. A value of 401 in the year of the spill was the second highest recorded in the last 17 years (Figure

4.1.1.1). This was much higher than in the previous five years and more typical of counts recorded in the mid 1980s. One year after the spill, the summed monthly count was lower, but a more notable decrease occurred in the second winter after the spill, with a sum of less than 100 birds recorded, the lowest since 1982. This decline continued with a slight decrease in the third winter. The model relating WeBS count to year, month and regional population index showed that the number of Shelduck declined in winter 1995/96 between the months prior to and after the spill ($\chi^2_1 = 258.4$, $P < 0.001$). This was the first significant decline in the model estimate. The following winter, the model estimate increased ($\chi^2_1 = 112.3$, $P < 0.001$), followed by a decrease to its lowest value in 1997/98 ($\chi^2_1 = 99.7$, $P < 0.001$) (Table 4.1.1a).

All-day count data showed that feeding Shelduck were concentrated mostly on Mudflats 2 and 3, on the west side of the bay, in all three years (Figure 4.1.1.2). In the first year following the spill, however, small numbers occurred on all sectors at the east end of the bay. In the next two winters, feeding birds occurred on Sectors 5, 6 and 8, but made little or no use of Sectors 7 and 9. The graphs show that most birds fed for the four hours either side of low tide and the pattern was similar in all three years (Figure 4.1.1.2). The average number of Shelduck during each hour of the tidal cycle decreased considerably between the first and second years following the spill from approximately 50-80 birds to 25-40 birds and also decreased slightly between the second and third winters. The model relating number of feeding birds to year, month, mudflat and state of tide showed that the number of feeding Shelduck decreased between 1996/97 and 1997/98 ($\chi^2_1 = 446.8$, $P < 0.001$) and 1997/98 and 1998/99 ($\chi^2_1 = 35.6$, $P < 0.001$) (Table 4.1.1.1).

Pembroke River

Summed monthly winter WeBS counts of Shelduck at Pembroke River ranged from a low of 751 in winter 1998/99 to 2,800 in 1986. There appeared to have been a declining trend since the mid-1980s at this site (Figure 4.1.1.1). The model relating WeBS count to year, month and regional population index showed that the number of Shelduck present in the year of the spill decreased between the months before and after the incident ($\chi^2_1 = 22.1$, $P < 0.001$). No change in the model estimate occurred the following winter ($\chi^2_1 = 0.4$, ns), but an increase occurred between that winter and winter 1997/98 ($\chi^2_1 = 51.1$, $P < 0.001$). However, many other significant fluctuations had occurred in the years prior to the oil spill (Table 4.1.1a).

Figure 4.1.1.3 shows that feeding Shelduck were similarly distributed over the three winters. They were found on all sectors, the most important being the extensive mudflats on the south side of the river between Sectors 3 and 9, together with Sectors 7 and 11 to the east. In the third winter, proportionally fewer birds were recorded on average during the ebb tide than in the previous winters (Figure 4.1.1.3). This was probably because many birds moved upstream of the count sectors at high tide and would only move onto the count sectors as the tide went out. Of those birds that were present at the high tide, a higher proportion were feeding than in either the first or second winter of the study. Between 130 and 170 birds were present on average during each hour of the tidal cycle in the first winter, between 140 and 170 in the second winter and between 100 and 170 in the final winter. The number of feeding Shelduck increased between winters 1996/97 and 1997/98 ($\chi^2_1 = 52.2$, $P < 0.001$), decreased between 1997/98 and the final winter ($\chi^2_1 = 9.3$, $P < 0.01$) (Table 4.1.1.1).

Carew/Cresswell

As at Pembroke River, the summed monthly WeBS counts of Shelduck at Carew/Cresswell have shown a declining trend since the mid-1980s (Figure 4.1.1.1). The sums ranged from 344 in winter 1991/92 to 1,283 in winter 1983/84. Since the *Sea Empress* incident, summed counts have decreased. The model relating WeBS count to year, month and regional population index showed that in 1995/96 there was no change in numbers between the winter months prior to and after the spill ($\chi^2_1 = 1.4$, ns). A decrease occurred the following winter ($\chi^2_1 = 22.5$, $P < 0.001$), but there was no change between 1996/97 and 1997/98 ($\chi^2_1 = 0.1$, ns) (Table 4.1.1a).

Shelduck were observed feeding on all sectors at Carew/Cresswell in the first winter after the spill, although few were noted on Sectors 3, 6 and 10 (Figure 4.1.1.4). In the second winter, feeding birds were concentrated on Sector 2 at the confluence of the two rivers and Sectors 8, 9 and 12 further upstream on the River Carew. In the third winter, Sectors 2, 11 and 12 were the most important feeding areas. The graphs (Figure 4.1.1.4) show that birds fed throughout the tidal cycle in all three winters with the majority feeding five hours either side of low tide. There was a slight increase in the average number of birds present during each hour of the tidal cycle between the first and second winters after the spill and a more notable increase between the second and third winters of the study. Feeding Shelduck numbers increased between 1996/97 and 1997/98 ($\chi^2_1 = 9.8$, $P < 0.01$) and 1997/98 and 1998/99 ($\chi^2_1 = 518.4$, $P < 0.001$) (Table 4.1.1.1).

Upper Cleddau

In contrast to the summed WeBS counts at the three other sites, the number of Shelduck at the Upper Cleddau showed no declining trend, instead showing a revival since a low of 612 in 1992/93 (Figure 4.1.1.1). Numbers in 1995/96 were at their highest since a peak of 1,349 in 1986/87. A slight decrease occurred in the subsequent two years followed by a further increase in 1998/99, numbers reaching the second highest value in 17 years. The model relating WeBS count to year, month and regional population index showed that following three years of significant increases in the model estimates (Table 4.1.1a), there were decreases in the estimates between the months before and after the spill in 1995/96 ($\chi^2_1 = 16.2$, $P < 0.001$) and between the latter months of 1995/96 and winter 1996/97 ($\chi^2_1 = 12.5$, $P < 0.001$), but that there was no change between 1996/97 an 1997/98 ($\chi^2_1 = 0.0$, ns).

Favoured feeding areas in all three winters were at the entrances to Sprinkle Pill (Sectors 1 and 2) and Millin Pill (Sector 10). In the second and third winters, the numbers of birds on Sectors 5 and 12 increased (Figure 4.1.1.5). The graphs show a successive increase from an average 50-60 birds present during each hour of the tidal cycle in 1996/97 to an average 60-140 birds in 1998/99. The number of feeding birds increased between 1996/97 and 1997/98 ($\chi^2_1 = 163.7$, $P < 0.001$) and 1997/98 and 1998/99 ($\chi^2_1 = 683.6$, $P < 0.001$) (Table 4.1.1.1).

4.1.2 Wigeon *Anas penelope*

Wigeon breed amongst upland lakes and peat bogs. There is a small population in Great Britain of about 300-500 pairs (Gibbons *et al.* 1993). In winter, many thousands of birds from Siberia, Scandinavia and Iceland arrive on British estuaries. The highest ever peak count of 405,502 Wigeon was recorded in Great Britain in January 1997 and the British population index has shown an increase since a low point in 1989/90 (Waters *et al.* 1998). Nationally important numbers of Wigeon were present on the Cleddau Estuary prior to the oil spill (Cranswick *et al.* 1997; Table 1.1).

Angle Bay

Summed monthly winter WeBS counts of Wigeon at Angle Bay fluctuated considerably over the last 17 years between 175 in 1989/90 and 3,424 birds in 1986/87 (Figure 4.1.2.1). Numbers in the winter of the spill were relatively high and decreased the following winter. In 1996/97, the summed count reached the second highest value in 17 years. Numbers then decreased considerably between 1997/98 and 1998/99. The model relating WeBS count to year, month and regional population index showed that the Angle Bay population decreased between the months before and after the spill ($\chi^2_1 = 10.3$, $P < 0.01$). A further larger decrease occurred between 1995/96 (February and March) and winter 1996/97 ($\chi^2_1 = 213.4$, $P < 0.001$). Numbers then increased between winters 1996/97 and 1998/99 ($\chi^2_1 = 1495.7$, $P < 0.001$) (Table 4.1.1a).

Wigeon were seen feeding on all count sectors at Angle Bay (Figure 4.1.2.2). In all three winters, the highest numbers were on Sectors 2, 3, 5 and 6. Birds fed throughout the tidal cycle and on high spring tides they were also observed feeding in adjacent fields. In the first year, average numbers during each hour of the tidal cycle varied between about 60 and 100, their lowest during the study. Number peaked in the second year, averaging between 140 and 220 birds. Numbers were lower in the final year, averaging between 120 and 160 birds. These changes are reflected by the increase in the number of feeding birds between 1996/97 and 1997/98 ($\chi^2_1 = 5439.3$, $P < 0.001$) and 1997/98 and 1998/99 ($\chi^2_1 = 209.2$, $P < 0.001$) (Table 4.1.2.1).

Pembroke River

This is the most important site on the Cleddau Estuary for Wigeon with large numbers present between November and January. The summed monthly winter WeBS count was at its lowest of 2,945 in 1997/98, two years after the spill, and at its highest value of 6,073 the following year (Figure 4.1.2.1). The second highest summed count of 5,715 was recorded in 1996/97, one year after the spill, a big increase on the previous year. The model relating WeBS count to year, month and regional population index showed that in the year of the *Sea Empress* incident, numbers declined between the months before and after the spill ($\chi^2_1 = 2149.6$, $P < 0.001$). Numbers then increased between the latter part of winter 1995/96 and winter 1996/97 ($\chi^2_1 = 3072.0$, $P < 0.001$) and decreased the following winter ($\chi^2_1 = 618.9$, $P < 0.001$) (Table 4.1.1a).

Figure 4.1.2.3 shows that the distribution of feeding birds was similar in the three years of the study. They favoured the extensive mudflats on the south side of the embayment, particularly Sector 5. Feeding activity peaked during the middle of the ebb and flow tides and few birds fed an hour either side of low tide. The average number of birds during each hour of the tidal cycle increased slightly between 1996/97 and 1997/98 and decreased between 1997/98 and 1998/99. The number of feeding birds, however, increased between winter 1996/97 and 1997/98 ($\chi^2_1 = 383.2$, $P < 0.001$) and winter 1997/98 and 1998/99 ($\chi^2_1 = 57.5$, $P < 0.001$) (Table 4.1.2.1). This is due to the higher proportion of birds observed feeding in the final year than in the previous two years.

Carew/Cresswell

The summed monthly WeBS counts of Wigeon also fluctuated considerably at Carew/Cresswell, ranging from 152 in 1983/84 to 2,141 in 1986/87 (Figure 4.1.2.1). Values were relatively high in the last four winters, but showed significant between-year fluctuations (Table 4.1.1a).

Wigeon fed on all count sectors at Carew/Cresswell (Figure 4.1.2.4). They were fairly evenly distributed in winter 1996/97, but in the subsequent years, Sectors 5, 7 and 8 hosted an increased number of feeding birds. Peaks of feeding activity occurred during the middle of the ebb and flow tides. The average number of birds present increased between the first and second years and the second and third years of the study. The number of feeding birds increased between 1996/7 and 1997/8 ($\chi^2_1 = 972.8$, $P < 0.001$) and 1997/98 and 1998/99 ($\chi^2_1 = 936.2$, $P < 0.001$) (Table 4.1.2.1).

Upper Cleddau

Summed monthly WeBS counts of Wigeon at Upper Cleddau ranged between 1,763 in 1987/88 and 3,773 in the year of the *Sea Empress* oil spill. Numbers fluctuated significantly between years and showed no obvious overall trend (Figure 4.1.2.1). The summed WeBS counts show a decreasing trend since the spill, but whereas the model relating WeBS count to year, month and regional population index showed that there was a significant decrease in the model estimate between the months prior to and after the spill in 1995/96 ($\chi^2_1 = 158.5$, $P < 0.001$), there was no change between the latter months of winter 1995/96 and winter 1996/97 ($\chi^2_1 = 0.0$, ns), and an increase between 1996/97 and 1997/98 ($\chi^2_1 = 5.2$, $P < 0.05$) (Table 4.1.1a).

Wigeon fed on most count sectors, but in low numbers on Sectors 7, 11 and 12 and not at all on Sector 8 (Figure 4.1.2.5). The most important area appeared to be around the mouth of Sprinkle Pill and Fowborough Point, particularly in the final year of study. As at Pembroke River and Carew/Cresswell, peaks of feeding activity occurred during the ebb and flow tides with few birds feeding for an hour either side of low tide. The average number of birds present increased between the first and second years and even more so between the second and third years of study (Figure 4.1.2.5). The number of feeding birds increased between 1996/7 vs 1997/8 ($\chi^2_1 = 34.6$, $P < 0.001$) and 1997/98 and 1998/99 ($\chi^2_1 = 186.2$, $P < 0.001$) (Table 4.1.2.1).

4.1.3 Teal *Anas crecca*

The British breeding population of Teal is thinly distributed in areas throughout England, Scotland and Wales and there has been a marked contraction in its range over the last twenty years (Gibbons *et al.* 1993). The wintering population, in contrast, has been relatively stable in recent years after a previous increase. The peak count in Great Britain of nearly 120,000 in 1996/97 was slightly lower than that in the previous winter (Waters *et al.* 1998). The Cleddau Estuary regularly holds nationally important numbers (Table 1.1).

Angle Bay

Teal were only recorded by WeBS at Angle Bay before the *Sea Empress* oil spill in 1982/83, 1991/92 and 1993/94, with no more than 30 birds in any winter (Figure 4.1.3.1). One year after the spill, however, there was a summed count of 353 birds over the winter. In both subsequent winters, just below 250 birds were counted in total. There was no difference in the number of

Teal counted by WeBS in the months just before and just after the incident in 1995/96 ($\chi^2_1 = 3.2$, NS). Since then, Teal numbers have increased each year (Feb/Mar 1996 vs 1996/97: $\chi^2_1 = 140.7$, $P < 0.001$; 1996/97 vs 1997/98: $\chi^2_1 = 24.1$, $P < 0.001$) (Table 4.1.1a).

The main feeding area at Angle Bay was on Sector 3 (Figure 4.1.3.2). The appearance of Teal at the site was erratic, with flocks of over a hundred birds on some days, but none on others within the same month. The number of feeding birds increased between the first and second years, but decreased between the second and third years (1996/97 vs 1997/98: $\chi^2_1 = 169.1$, $P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 255.2$, $P < 0.001$) (Table 4.1.3.1).

Pembroke River

Figure 4.1.3.1 shows that Teal were much more numerous at Pembroke River in the mid-1980s than in recent years. Summed monthly winter WeBS counts ranged from 58 in 1993/94 to 546 in 1988/89. The highest numbers in the 1990s were recorded in winters 1995/96 and 1996/97. There was no change in numbers counted by WeBS in the months before and after the spill in 1995/96 ($\chi^2_1 = 0.1$, ns), but an increase occurred the following year ($\chi^2_1 = 7.6$, $P < 0.01$). This was followed, however, by a decrease between 1996/97 and 1997/98 ($\chi^2_1 = 91.2$, $P < 0.001$) (Table 4.1.1a).

On the all-day counts, feeding birds were occasionally observed at Goldborough Pill and at the eastern end of the site each year (Figure 4.1.3.3). Feeding numbers declined between 1996/97 and 1997/98 ($\chi^2_1 = 57.6$, $P < 0.001$) and increased the following year ($\chi^2_1 = 222.9$, $P < 0.001$) (Table 4.1.3.1).

Carew/Cresswell

As at Pembroke River, Teal numbers at Carew/Cresswell were much lower in the 1990s than in the 1980s (Figure 4.1.3.1). Summed WeBS counts often exceeded 2,000 birds in the former period, but afterwards rarely reached 1,000 birds. Figure 4.1.3.1 shows an overall decline through time in the model estimate, although there were year to year increases and decreases (Table 4.1.1a).

In the first and second winters after the spill, Teal fed mostly on Sectors 1, 2 and 3 near Lawrenny (Figure 4.1.3.4). In the final winter, however, more birds were observed feeding on Sectors 8 and 12 on the River Carew. This is possibly due to one incident in winter 1998/99 when shooting disturbance further upriver forced many birds out of the smaller channels onto the count sectors. Peaks of feeding activity occurred during the ebb and flow tides, with few birds feeding at low tide. The numbers of birds observed fluctuated over the tidal cycle, probably as a result of movement between the mudflats and unsurveyed saltmarsh and small creeks. On average, up to 40 Teal were recorded in the first winter, 15 in the second winter and 25 in the third winter. A decrease in feeding birds occurred between the first and second winters ($\chi^2_1 = 183.1$, $P < 0.001$), followed by an increase between the second and third winters ($\chi^2_1 = 339.0$, $P < 0.001$) (Table 4.1.3.1)

Upper Cleddau

This is the most important site on the Cleddau Estuary for Teal. Summed WeBS counts varied between 3,672 in 1994/5 and 7,743 in 1988/89. Numbers recorded in the 1990s have generally been lower than in the latter half of the 1980s (Figure 4.1.3.1). Following a series of decreases, numbers increased between 1994/95 and the months before the spill in 1995/96 ($\chi^2_1 = 447.9$, $P < 0.001$) before decreasing in the latter months of winter 1995/96 ($\chi^2_1 = 245.4$, $P < 0.001$). The following winter, however, numbers increased again ($\chi^2_1 = 61.1$, $P < 0.001$) but numbers were stable between 1996/97 and 1997/98 ($\chi^2_1 = 0.6$, NS) (Table 4.1.1a).

The main feeding areas at Upper Cleddau were on Sectors 1 and 2 at Sprinkle Pill, Sector 4 at Landshipping Quay and Sector 10 at Millin Pill (Figure 4.1.3.5). More were recorded at Sprinkle Pill in the latter years of the study than in winter 1996/97. The peak average number of birds recorded four hours after low tide increased from about 200 birds in 1996/97 to 280 in 1997/98 and 300 the following year (Figure 4.1.3.5). Peaks of feeding activity occurred during the ebb and flow tides and few birds were seen at low water for they were hidden along tidal creeks and banks. There was a significant increase in feeding birds between each winter (1996/97 vs 1997/98: $\chi^2_1 = 1994.2$, $P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 106.6$, $P < 0.001$) (Table 4.1.3.1).

4.1.4 Oystercatcher *Haematopus ostralegus*

A population of 33,000-43,000 pairs of Oystercatcher breed in Great Britain, occupying both inland and coastal sites (Piersma 1986; Gibbons *et al.* 1993). In autumn and winter, the number of birds increases with an influx of migrants from northern Europe. A peak of nearly 266,000 was recorded on the estuaries and coasts of Great Britain in 1996/97, the population index showing an increase of 28% on the previous year (Waters *et al.* 1998). The Cleddau Estuary usually holds between 300-500 Oystercatchers in winter and is not nationally important for the species (Table 1.1).

Angle Bay

The summed WeBS counts of Oystercatcher at Angle Bay ranged from 206 in 1990/91 to 521 in 1987/88 and has fluctuated irregularly over the last 17 years (Figure 4.1.4.1). Since the oil spill, the summed count decreased for two years then recovered in 1998/99. Oystercatcher numbers recorded by WeBS counts decreased between the months before and after the spill in winter 1995/96 ($\chi^2_1 = 28.8$, $P < 0.001$), did not change between the latter months of winter 1995/96 and 1996/7 ($\chi^2_1 = 1.1$, ns), but decreased further the following year ($\chi^2_1 = 10.6$, $P < 0.01$). However, similar declines had occurred in some years prior to the oil spill (Figure 4.1.4.1 and Table 4.1.1b).

Birds fed on all count sectors at Angle Bay, with Sectors 2, 3, 6, 7, 8 and 9 being most important (Figure 4.1.4.2). Birds fed throughout the exposure period, and roosted or fed on the upper rocky shore or in nearby fields at high tide. The average number of feeding birds present each year increased through the three-winter study. (1996/97 vs 1997/98 ($\chi^2_1 = 141.8$, $P < 0.001$ 1997/98 vs 1998/99 $\chi^2_1 = 5.8$, $P < 0.05$) (Table 4.1.4.1).

Pembroke River

Summed WeBS counts of Oystercatcher at Pembroke River ranged from 115 birds in winter 1991/92 to 503 in winter 1988/89 (Figure 4.1.4.1). Numbers fluctuated throughout the last 17 winters, but two notable decreases occurred, one in 1991/92, the other in the year of the *Sea Empress* oil spill ($\chi^2_1 = 60.5$, $P < 0.001$) (Table 4.1.1b). Numbers then recovered between the latter months of 1995/96 and 1996/97, ($\chi^2_1 = 171.8$, $P < 0.001$), before decreasing again in 1997/98 ($\chi^2_1 = 18.8$, $P < 0.001$).

Oystercatchers fed on all mudflats, with the exception of Sectors 2 and 3. Sectors 4, 5, 6 and 9 were the most important areas (Figure 4.1.4.3). Sector 7 held more birds in the latter years than in 1996/97 and many birds also roosted on the stony spit between Sectors 7 and 8. Feeding occurred throughout the exposure period, although there were fewer birds present during the low tide period, when they may have moved out of the embayment to feed on exposed areas in the main waterway. In contrast to the WeBS counts, the number of feeding Oystercatchers recorded by the all-day counts increased between the first and second years of the study ($\chi^2_1 = 38.3$, $P < 0.001$) and to a lesser extent between the last two years ($\chi^2_1 = 7.9$, $P < 0.01$) (Table 4.1.4.1).

Carew/Cresswell

Small numbers of Oystercatcher used the Carew/Cresswell complex. The summed monthly winter WeBS counts varied between 20 in 1994/95 and 84 in 1989/90 (Figure 4.1.4.1). The summed count fell after 1989/90 until the year of the oil spill, when there was a sharp increase. The count then decreased each year after the spill. The model relating WeBS count to year, month and regional population index showed that there was no significant change in numbers between each successive year between 1989/90 and the *Sea Empress* incident with the exception of a decrease between 1993/94 and 1994/95 (Table 4.1.1b). There was, however, a highly significant increase in the model estimate between the months just prior to and just after the oil spill in 1995/96 ($\chi^2_1 = 20.1$, $P < 0.001$), possibly due to the displacement of birds from the oiled sites. There was no change between late winter 1995/96 and 1996/97 ($\chi^2_1 = 0.0$, NS), but numbers decreased the following year ($\chi^2_1 = 7.6$, $P < 0.01$).

The main feeding areas at Carew/Cresswell were Sectors 6, 7, 8 and 11 and birds fed throughout the exposure period. Less use was made of Sector 12 in each successive year (Figure 4.1.4.4). The number of feeding birds using the site declined between 1996/97 and 1997/98 ($\chi^2_1 = 62.5$, $P < 0.001$), before stabilising out the following winter ($\chi^2_1 = 0.5$, NS) (Table 4.1.4.1).

Upper Cleddau

Summed WeBS counts ranged from 86 birds in 1984/85 to 441 birds in winter 1985/86 and numbers fluctuated between years (Figure 4.1.4.1). The lowest value of the model estimate was recorded between the months prior to and after the spill in 1995/96 ($\chi^2_1 = 22.0$, $P < 0.001$) but it increased to its highest value the following year ($\chi^2_1 = 125.5$, $P < 0.001$). Between 1996/97 and 1997/98, however, the estimate decreased to its second lowest value ($\chi^2_1 = 70.5$, $P < 0.001$). These between-winter changes were larger than those recorded in years prior to the oil spill (Table 4.1.1b).

Birds fed on the exposed substrate on all count sectors during the first winter of the three year study, the most important being Sectors 3, 5, 9 and 12. These areas remained the most important in the next two winters (Figure 4.1.4.5). In 1998/99, Sector 3 held more birds than any other. Feeding bird numbers did not change between 1996/97 and 1997/98 (χ^2_1 = 0.3, NS), but decreased significantly between 1997/98 and 1998/99 ($\chi^2_1 = 9.3$, $P < 0.01$) (Table 4.1.4.1).

4.1.5 Dunlin *Calidris alpina*

Almost 10,000 pairs of Dunlin breed in Great Britain (Reed 1985; Stone *et al.* 1997), mainly in the flows of northern Scotland and on peaty bogs in the English and Scottish uplands (Stroud *et al.* 1987). The wintering population is boosted by the arrival of large numbers of migrant birds from northern Scandinavia and the former USSR (Lack 1986). Over 540,000 birds were counted around the estuaries and shores of Great Britain in January 1996/97 - the highest for 20 years (Waters *et al.* 1998). The Cleddau Estuary usually holds between 3,000 and 5,000 Dunlin in winter, but in recent years higher numbers have used the estuary (Table 1.1).

Angle Bay

Summed WeBS counts of Dunlin ranged from 280 in 1989/90 to 3,635 in 1993/94 (Figure 4.1.5.1). The summed counts showed a decline in the latter part of the 1980s, but increased during the early 1990s until a peak in 1993/94. There was a subsequent decrease in numbers over the next two years. Numbers of Dunlin increased between the months just before and just after the spill in 1995/96 ($\chi^2_1 = 4.2$, $P < 0.05$), an increase that continued in 1996/97 ($\chi^2_1 = 88.3$, $P < 0.001$), before a slight fall ($\chi^2_1 = 4.6$, $P < 0.05$). Summed WeBS counts also decreased from 1997/98 to 1998/99 (Table 4.1.1b).

Feeding Dunlin were present on all count sectors in 1996/97, but were absent from Sector 9 in the following two years (Figure 4.1.5.2). Sectors 2, 3, 5 and 6 held the most birds. The average number of Dunlin present decreased between 1996/97 and 1997/98. A maximum average of about 200 birds occurred in both years, but fewer birds were present during the ebb and flow tides in the second year (Figure 4.1.5.2). In winter 1998/99, many more Dunlin were present with a maximum average of nearly 600 birds. Peak bird numbers, each year, occurred in the two hours after low tide. For feeding birds, these changes were highly significant (1996/97 vs 1997/98: $\chi^2_1 = 1{,}543.6$, $P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 18{,}196.9$, $P < 0.001$) (Table 4.1.5.1).

Pembroke River

Summed WeBS counts varied between 1,167 in 1993/94 and 10,980 in 1996/97. In contrast to the trend at Angle Bay, numbers of Dunlin at Pembroke River decreased consistently between 1989/90 and 1993/94 and increased the following two years (Figure 4.1.5.1). The oil spill had no immediate impact on numbers in 1995/96 (χ^2_1 = 0.0, NS). However, between the latter months of winter 1995/96 and winter 1996/97, numbers increased ($\chi^2_1 = 1326.0$, $P < 0.001$) before decreasing between 1996/97 and 1997/98 ($\chi^2_1 = 279.5$, $P < 0.001$) (Table 4.1.1b).

In the first two years of the three year study, Dunlin fed mostly on Sectors 5, 6 and 9, with smaller numbers feeding on mudflats at the eastern end of the embayment. In the final year, birds made more use of the eastern sectors (Figure 4.1.5.3). The average number of birds present during different hours of the tidal cycle fluctuated as birds moved between count sectors and uncounted areas, but increased in successive years from a maximum of just under 600 in 1996/97 to over 600 in 1997/98 and 700 in 1998/99 (Figure 4.1.5.3). Feeding Dunlin numbers increased between each year (1996/97 vs 1997/98: $\chi^2_1 = 1{,}176.4$, $P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 236.7$, $P < 0.001$) (Table 4.1.5.1).

Carew/Cresswell

Summed WeBS counts at Carew/Cresswell varied considerably between years, ranging from 94 in 1987/88 to 4,795 in 1996/97 (Figure 4.1.5.1). Numbers increased after the winter of 1993/94 to a peak in 1996/97. Numbers increased between the months before and after the oil spill in 1995/96 ($\chi^2_1 = 176.8, P < 0.001$), numbers stabilised between the latter months of winter 1995/96 and winter 1996/97 ($\chi^2_1 = 3.0$, NS), before decreasing between 1996/97 and 1997/98 ($\chi^2_1 = 674.3, P < 0.001$) (Table 4.1.1b).

Dunlin fed on all sectors at Carew/Cresswell, except for Sector 10 (Figure 4.1.5.4). There was some variation in distribution between the three years of the study, although Sectors 5 and 6 were consistently important. Most birds were present from three hours before to three hours after low tide (to four hours after low tide in the third year). Within this period, the average number of birds during each hour of the tidal cycle changed from nearly 600 in 1996/97 to between 400 and 500 in 1997/98, and between 600 and 800 in 1998/99. Similar changes in feeding numbers were recorded (1996/97 vs 1997/98: $\chi^2_1 = 1{,}770.8, P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 10{,}026.1, P < 0.001$) (Table 4.1.5.1).

Upper Cleddau

The summed WeBS counts of Dunlin at Upper Cleddau ranged from 554 in 1989/90 to 6,039 in 1995/96 (Figure 4.1.5.1). Numbers increased between the months before and after the spill in 1995/96 ($\chi^2_1 = 981.0, P < 0.001$) (Table 4.1.1b), but decreased significantly between the late winter of 1995/96 and winter 1996/97 ($\chi^2_1 = 1814.6, P < 0.001$). Numbers increased between 1996/97 and 1997/98 ($\chi^2_1 = 748.0, P < 0.001$). With the exception of the substantial decrease and recovery over the winters 1988/89 to 1990/91, these fluctuations were very large in comparison to previous years.

Dunlin were seen feeding on all sectors at Upper Cleddau, except for Sector 11 (Figure 4.1.5.5). The average number of birds present increased between successive years of the study from between 100 and 250 in 1996/97, to about 300 in 1997/98, to between 300 and 420 in 1998/99. The number of feeding birds increased throughout this period (1996/97 vs 1997/98: $\chi^2_1 = 2{,}250.4, P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 744.2, P < 0.001$) (Table 4.1.5.1).

4.1.6 Curlew *Numenius arquata*

The Curlew characteristically breeds on damp upland moorlands, but this century has colonised many lowland regions, including agricultural habitats (Gibbons *et al.* 1993). The breeding population of Great Britain has been estimated at 33,000-38,000 pairs (Reed 1985; Stone *et al.* 1997). Some of this population winters in France, but many other Curlew from continental Europe, notably Scandinavia, migrate to Great Britain to winter (Prater 1981). A peak of 70,000 wintered on the estuaries and shores of Great Britain in 1996/97 (Waters *et al.* 1998), an increase on the previous year (Cranswick *et al.* 1997). The Cleddau Estuary holds nationally important numbers of Curlew during the winter (Table 1.1).

Angle Bay

Summed WeBS counts of Curlew at Angle Bay ranged from 182 in 1996/97 to 1,178 in 1991/92 (Figure 4.1.6.1). The summed count in the winter following the oil spill was the lowest recorded in 17 years and this figure increased only slightly over the next two years. Numbers increased between the months before and after the spill in 1995/96 ($\chi^2_1 = 26.0$, $P < 0.001$), but decreased between the latter months of winter 1995/96 and winter 1996/97 ($\chi^2_1 = 84.6$, $P < 0.001$). Between winter 1996/97 and winter 1997/98, numbers recovered after the low in the winter after the spill ($\chi^2_1 = 130.4$, $P < 0.001$) (Table 4.1.1b).

Curlew used all parts of the bay, but favoured Sectors 2 and 3 in all three years of the study (Figure 4.1.6.2). Feeding activity and numbers present both peaked at or near the time of low tide. Many of those that left the bay around high tide fed in the surrounding fields. The average number present during each hour of the tidal cycle increased in each successive year, an increase reflected in the number of feeding birds (1996/97 vs 1997/98: $\chi^2_1 = 200.2$, $P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 103.0$, $P < 0.001$) (Table 4.1.6.1).

Pembroke River

The summed WeBS counts of Curlew at Pembroke River varied between 276 in 1991/92 and 1,167 in 1989/90 (Figure 4.1.6.1). The summed count in 1996/97 was the highest since large numbers were recorded in the late 1980s. After a drop in 1997/8, the summed count increased further the following year. There was a large decrease in numbers between the months before and after the spill in 1995/96 ($\chi^2_1 = 532.8$, $P < 0.001$), but numbers then increased in winter 1996/97 ($\chi^2_1 = 505.0$, $P < 0.001$) before decreasing between 1996/97 and 1997/98 ($\chi^2_1 = 37.4$, $P < 0.001$) (Table 4.1.1b). A similar decrease to that seen immediately after the oil spill also occurred in winter 1991/92.

Curlew were observed feeding on all count sectors at Pembroke River (Figure 4.1.6.3). The most important areas were Sectors 4, 5, 6 and 9. The majority of birds fed from four hours before until three hours after low tide. The maximum average number of birds present increased each year from about 80 in 1996/97 to 90 in 1997/98 to over 95 in 1998/99, an increase reflected in the number of feeding birds (1996/97 vs 1997/98: $\chi^2_1 = 22.0$, $P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 27.8$, $P < 0.001$) (Table 4.1.6.1).

Carew/Cresswell

The highest summed WeBS counts occurred in the latter half of the 1980s, with a peak of 1,385 in 1986/87. The lowest total of 308 was recorded in winter 1991/92 (Figure 4.1.6.1). Since a recovery of numbers in 1992/93, the summed counts have shown a slightly decreasing trend. Curlew numbers decreased between the months before and after the spill in 1995/96 ($\chi^2_1 = 78.7$, $P < 0.001$), then increased in 1996/97 ($\chi^2_1 = 58.7$, $P < 0.001$) before decreasing in 1997/98 ($\chi^2_1 = 7.2$, $P < 0.001$) (Table 4.1.1b).

Curlew fed on all sectors at Carew/Cresswell, although few used Sector 10 (Figure 4.1.6.4). The distribution of feeding birds was similar during each of the three winters and the majority of birds fed from four hours before to four hours after low tide. The average number of birds present during each hour of this part of the tidal cycle varied between 40 and 45 in winter 1996/97, between 35 and 50 in winter 1997/98 and between 35 and 45 in winter 1997/98. The number of feeding birds did not change significantly between the first and second years ($\chi^2_1 = 0.9$, NS), but increased highly significantly between 1997/98 and 1998/99 ($\chi^2_1 = 18.5$, $P < 0.001$) (Table 4.1.6.1).

Upper Cleddau

The summed WeBS count of Curlew at Upper Cleddau ranged from 1,375 in winter 1983/84 to 2,718 in 1989/90 (Figure 4.1.6.1). As at Carew/Cresswell, there was a decrease in numbers between the months before and after the oil spill in 1995/96 ($\chi^2_1 = 93.2$, $P < 0.001$), followed by an increase in winter 1996/97 ($\chi^2_1 = 145.8$, $P < 0.001$), and a decrease the following winter ($\chi^2_1 = 109.7$, $P < 0.001$) (Table 4.1.1b).

Curlew fed on all sectors at Upper Cleddau and the distribution was similar in each of the three years, Sectors 2, 5 and 10 having the most usage (Figure 4.1.6.5). A lower proportion of the birds present were feeding than at the other three sites. From three hours before to three hours after low tide, the average number of birds present during each hour of the tidal cycle varied between 55 and 80 in 1996/97, between 45 and 85 in 1997/98 and between 40 and 60 in 1998/99. Feeding numbers did not vary significantly between each successive year (1996/97 vs 1997/98: $\chi^2_1 = 0.0$, NS; 1997/98 vs 1998/99: $\chi^2_1 = 3.2$, NS) (Table 4.1.6.1).

4.1.7 Redshank *Tringa totanus*

An estimated 30,000-34,000 pairs of Redshank breed in Great Britain, mainly on wet grasslands and on coastal saltmarshes (Reed 1985; Gibbons *et al.* 1993; Stone *et al.* 1997). The British wintering population is formed of birds from both Great Britain and Ireland, and Iceland (Prater 1981). A peak of 70,000 wintered on Great Britain's estuaries and shores in 1996/97 (Waters *et al.* 1998). Numbers of Redshank on the Cleddau Estuary have declined and have not been at a level of national importance since the 1980s (Table 1.1). Redshank numbers in the whole of Wales have decreased, relative to the rest of Britain (Austin & Rehfisch 1998).

Angle Bay

Summed WeBS counts of Redshank at Angle Bay ranged from 40 birds in 1990/91 to 289 in 1989/90 (Figure 4.1.7.1). Summed counts in the 1980s were consistently over 150 birds, but in the 1990s, were never over 100. Redshank numbers decreased between the months before and after the spill in 1995/96 ($\chi^2_1 = 42.0$, $P < 0.001$), but had increased by the following winter ($\chi^2_1 = 16.7$, $P < 0.001$). However, a similar decrease and recovery had occurred between 1989/90 and 1991/92 (Figure 4.1.7.1 and Table 4.1.1b). Numbers did not change between 1996/97 and 1997/98 ($\chi^2_1 = 0.3$, NS).

The all-day distribution of feeding Redshank was similar in all three years of the study (Figure 4.1.7.2). Sector 10 was by far the most important area. Some birds fed on sectors at the eastern side of the bay in the second and third winters, but not in the first winter. The average number of birds present during each hour of the tidal cycle increased each year from 10-15 birds in 1996/97 to 13-20 birds in 1997/98 to 15-25 birds in 1998/99. The number of feeding birds increased between each successive winter (1996/97 vs 1997/98: $\chi^2_1 = 62.0$, $P < 0.001$; 1997/98 vs 1998/99: $\chi^2_1 = 59.9$, $P < 0.001$) (Table 4.1.7.1).

Pembroke River

As at Angle Bay, summed WeBS counts of Redshank in the 1990s were much lower than in the 1980s, ranging from 260 in 1991/92 to 985 in 1989/90 (Figure 4.1.7.1). Following a decrease in numbers in the winter after the spill, the summed counts rose slightly in the next two years.

The model described a decrease in numbers between the months before and after the oil spill in 1995/96 ($\chi^2_1 = 4.5$, $P < 0.05$), but no significant change since then (February & March 1996 vs 1996/97: $\chi^2_1 = 3.4$, NS; 1996/97 vs 1997/98: $\chi^2_1 = 0.7$, NS). Much larger decreases had occurred in years prior to the oil spill (Figure 4.1.7.1 and Table 4.1.1b).

Redshank fed on all parts of Pembroke River, except for Sector 1 (Figure 4.1.7.3). Sector 5 was the most important area in each of the three years. The majority of birds were feeding from five hours before to four hours after low tide. The average number of birds present during each hour of the tidal cycle within this period was similar in the first two winters at 15-35 birds, and increased in the third winter to 25-45 birds. The number of feeding birds did not change between the first and second winters ($\chi^2_1 = 1.6$, NS), but increased significantly between the second and third winters ($\chi^2_1 = 208.3$, $P < 0.001$) (Table 4.1.7.1).

Carew/Cresswell

Summed WeBS counts of Redshank at Carew/Cresswell ranged from 313 in 1991/92 to 1,213 in 1986/87 (Figure 4.1.7.1). After increasing in the latter part of the 1980s, numbers dropped dramatically in 1991/92. There was a slight recovery the following year, but generally numbers were lower in the 1990s. Numbers of feeding Redshank decreased between the months before and after the oil spill in 1995/96 ($\chi^2_1 = 92.0$, $P < 0.001$), but increased significantly between the latter months of winter 1995/96 and winter 1996/97 ($\chi^2_1 = 56.5$, $P < 0.001$), before decreasing the following winter ($\chi^2_1 = 34.9$, $P < 0.001$) (Table 4.1.1b).

Redshank used all areas at Carew/Cresswell for feeding, although few were recorded on Sectors 6 and 10 (Figure 4.1.7.4). In the first year, Sectors 1 and 8 held most birds, but in the second and third winters of study, Sector 12 was most important. The average number of birds present during each hour of the tidal cycle increased from between 20 and 33 birds in the first year to between 28 and 40 birds in the second year, followed by a decrease to between 24 and 33 birds in the third year (Figure 4.1.7.4). The number of feeding birds increased between 1996/97 and 1997/98 ($\chi^2_1 = 158.7$, $P < 0.001$) and decreased the following winter ($\chi^2_1 = 15.2$, $P < 0.001$) (Table 4.1.7.1).

Upper Cleddau

As recorded at the other three sites, summed WeBS counts in the 1990s were generally lower than in the 1980s, ranging from 926 in 1997/98 to 2,527 in 1990/91 (Figure 4.1.7.1). The WeBS counts decreased between the months before and after the spill in 1995/96 ($\chi^2_1 = 11.7$, $P < 0.001$), did not change between the latter months of winter 1995/96 and winter 1996/97 ($\chi^2_1 = 0.6$, NS), but decreased the following year ($\chi^2_1 = 41.0$, $P < 0.001$). There were, however, several significant increases and decreases in the model estimates between successive years prior to the oil spill (Figure 4.1.7.1 and Table 4.1.1b).

Only small numbers of Redshank were observed at Upper Cleddau. Birds fed mostly on Sector 4, but Sectors 1, 5, 6 and 10 were also used (Figure 4.1.7.5). Peaks in the number of birds present occurred three to four hours before and after low tide. At low tide, birds may have been feeding out of sight along the banks of channels. The average number of birds present during those peaks increased from 10-11 birds in 1996/97 to 17-21 birds in 1997/98 and decreased to 10-12 birds in the final winter (Figure 4.1.7.5). Feeding numbers increased between 1996/97 and 1997/98 ($\chi^2_1 = 114.8$, $P < 0.001$) and decreased the following winter ($\chi^2_1 = 58.0$, $P < 0.001$) (Table 4.1.7.1).

4.2 Other Species

4.2.1 Great Crested Grebe *Podiceps cristatus*

Great Crested Grebes were most numerous at Angle Bay where the majority of birds present were observed roosting. Peaks of 24, 26 and 22 birds were recorded in the first, second and third winters respectively. It is possible that birds that fed out to sea or in the main Milford Haven Waterway used the shelter of the bay in which to roost.

One to four birds were regularly recorded in 1996/97 at Pembroke River with a maximum of six in February. Only one or two birds were recorded in 1997/98. In the final winter, one to two birds were regularly recorded between November and February and three to four birds in March.

Great Crested Grebes were infrequent at Carew/Cresswell. One bird was occasionally recorded in the first two winters. In the final winter, one or two birds were observed, with a maximum of three on one count in March.

Between one and five birds were often recorded at the Upper Cleddau in 1996/97, with a peak of seven in February. A maximum of four birds was recorded in the following two winters.

4.2.2 Little Grebe *Tachybaptus ruficollis*

Little Grebes were regularly observed throughout all three winters at Pembroke River, Carew/Cresswell and the Upper Cleddau. None were recorded at Angle Bay in 1996/97 or 1998/99, but one bird was present on four occasions in early winter 1997/98.

At Pembroke River, maxima of 11, 10 and eight were recorded in the respective winters.

Peak numbers at Carew/Cresswell were 11, 10 and 13 in the respective winters.

Peaks of nine, six and six were observed at the Upper Cleddau in the respective winters.

4.2.3 Cormorant *Phalacrocorax carbo*

One to two Cormorants were recorded on most days throughout each winter at Angle Bay. A maximum of three were seen on one count in February of the second winter.

At Pembroke River, one or two birds often fed at the western end of the site near the mouth of the embayment in each winter. Birds also roosted on Sector 2 and on buoys in the channel. A peak of five birds was recorded in the first winter and peaks of four birds in the latter winters of the study.

One to two Cormorants also fed at Carew/Cresswell on occasions throughout each winter. In the second and third winters of the study, roosting birds were also observed on the mudflats and particularly on Black Mixen rock. Peaks of five and six were recorded in 1997/98 and 1998/99 respectively.

Cormorants were most numerous at the Upper Cleddau. Birds fed on the open water throughout the site in each winter and roosted mainly on Sectors 3 and 5. Maxima of seven, 16 and 17 were observed in successive winters.

4.2.4 Little Egret *Egretta garzetta*

At Angle Bay, a Little Egret was recorded on one occasion in the first winter. Throughout the second and third winters, one bird was recorded feeding on numerous occasions on Sector 10.

Up to three Little Egrets were recorded at Pembroke River in 1996/97. The maximum count increased to five birds in 1997/98 and to six birds in 1998/99. One to two birds were more regularly recorded feeding on most sectors.

At Carew/Cresswell, one or two birds regularly fed on most sectors in all three winters. A maximum of five was recorded in March 1997 and a maximum of six in March 1999. However, no more than two birds were recorded in the second winter.

Single Little Egrets were observed on one or two days each winter at the Upper Cleddau. Two were recorded in March 1997.

4.2.5 Grey Heron *Ardea cinerea*

Grey Herons were most numerous at Angle Bay and Pembroke River, with one to three birds regularly present. Peaks of five birds were observed at both sites in the first winter.

At Carew/Cresswell, single birds were commonly seen in each winter, although a peak of six birds was observed in December 1998.

Single birds were also common at the Upper Cleddau. Two birds were occasionally present in 1996/97, up to four in 1997/98 and up to three in 1998/99.

4.2.6 Mallard *Anas platyrhynchos*

The number of Mallards at Angle Bay peaked each winter in December, with 57 in 1996/97, 45 in 1997/98 and 126 in 1998/99. Between 10 and 20 birds were usually present in the first two winters and between 30 and 40 in the final winter. Feeding activity was concentrated on Sector 2 in all three winters, but birds also used other sectors.

Up to 16 Mallards were recorded at Pembroke River in the first winter. In the second and third winters, however, peaks of only four and five birds respectively were observed and rarely more than two birds were seen. Most feeding activity occurred in shallow water covering Sectors 1 and 2.

Small numbers of Mallard were regularly recorded at Carew/Cresswell, feeding mainly on Sector 10, but also on Sectors 1, 2, 3 and 11. The peak numbers observed each winter were 45 in December 1996, 40 in December 1997 and 65 in January 1999 were observed.

Mallard were also regularly recorded feeding on most areas at the Upper Cleddau, Sector 1 especially. Peaks of over 90 birds were observed in 1996/97 and 1997/98, although less than 20 was a more usual figure. In 1998/99, a peak of only 32 birds was recorded, and less birds were present in general than in the first two winters.

4.2.7 Goldeneye *Bucephala clangula*

Goldeneye were very occasional at Angle Bay. Two birds were recorded on one count in 1996/97, one or two birds were recorded on three days in 1997/98 and none were seen in 1998/99.

Between one and 10 Goldeneye were regularly observed at Pembroke River in all three winters. Thirteen were recorded on one count in 1998/99.

At Carew/Cresswell, up to five birds were regularly observed in 1996/97, with a peak of 10 in January. Only one to four birds were recorded in the following two winters.

Goldeneye were also more numerous in the first winter at the Upper Cleddau. One to three birds were frequently observed, with a peak of eight in January. Up to three birds were only occasionally seen in 1997/98 and up to four birds were seen regularly the following winter.

4.2.8 Red-breasted Merganser *Mergus serrator*

Red-breasted Mergansers were seen only in winter 1996/97 at Angle Bay, when one or two birds were recorded on three occasions.

At Pembroke River, one to three birds were observed throughout the first winter. In 1997/98, singles were seen on three occasions and none were seen the following winter.

Following a peak of five Red-breasted Mergansers in November of the first winter at Carew/Cresswell, one or two birds were recorded until January. No birds were seen at the site in the following two winters.

Red-breasted Mergansers were most commonly seen at the Upper Cleddau. Birds were recorded throughout each winter, with peaks of five in 1996/97 and four in both 1997/98 and 1998/99.

4.2.9 Ringed Plover *Charadrius hiaticula*

Ringed Plover were most numerous at Angle Bay. In the first winter, up to four birds were occasionally recorded, with a peak of 25 in February. They were more frequent in the second winter when 15 to 25 were often recorded and a maximum of 30 birds was present in February. Numbers increased further in 1998/99, with 20 to 40 frequently observed and a peak of 45 occurred in November. Birds were most often seen on Sector 6, although Sectors 1, 2, 8 and 10 were also used.

Ringed Plover were infrequent at Pembroke River. Up to 14 were recorded in December of the first winter. A maximum of 12 was recorded in the second winter and up to 23 were observed in the final winter. Birds were most often located on Sectors 7 and 8.

No Ringed Plover were recorded at Carew/Cresswell.

Ringed Plover were also infrequently observed throughout each winter at the Upper Cleddau. Up to 15 were recorded in the first two winters, but only up to seven in 1998/99.

4.2.10 Golden Plover *Pluvialis apricaria*

Flocks of mainly roosting birds were occasionally present at Angle Bay in all three winters. Maxima of 410, 800 and 65 were recorded in 1996/97, 1997/98 and 1998/99, respectively.

Golden Plover were recorded only once at Pembroke River, when 52 were seen in March of winter 1997/98.

In the first two winters small groups of 20 to 50 Golden Plover were frequently observed at Carew/Cresswell, although 300 were recorded in December 1996. In winter 1998/99, much larger roosting flocks were observed, with a peak of 1,270 in February.

Golden Plover were only occasionally recorded at the Upper Cleddau in each winter. Peaks of 18, 12 and 60 birds were noted in successive winters.

4.2.11 Grey Plover *Pluvialis squatarola*

Grey Plover were recorded throughout each winter at Angle Bay, although numbers were low in winter 1997/98. Peaks of 86, 25 and 104 were seen in 1996/97, 1997/98 and 1998/99 respectively. Feeding birds were most often on Sectors 5, 6 and 8.

At Pembroke River, Grey Plover were recorded regularly each winter. Numbers were highest during the first winter of the study. Peaks of 94, 30 and 43 were recorded in successive years. Feeding activity was concentrated on Sectors 5, 6 and 9, although birds also used other areas.

At Carew/Cresswell, up to 10 birds were frequently seen each winter. Peak counts occurred in January of each winter, numbering 35, 15 and 17 in successive years. Feeding birds favoured Sectors 5, 6 and 7 at the confluence of the two rivers.

At the Upper Cleddau, Grey Plover were also frequently recorded during each winter. Peaks of 30 birds were recorded in 1996/97 and 1997/98, whilst a peak of only 11 was recorded 1998/99. Feeding birds were most often on Sectors 1, 2 and 12.

4.2.12 Lapwing *Vanellus vanellus*

Lapwing were infrequently observed at Angle Bay each winter. A flock of 540 birds was recorded in 1996/97, but much smaller numbers were observed in the following two winters.

Very few Lapwing were seen at Pembroke River. None were recorded in the first winter, three were recorded on one occasion in the second winter and 18 on one occasion in the third winter.

Large flocks of Lapwing, the majority of which were roosting, were present at Carew/Cresswell throughout all three winters. Peaks of 775, 1,039 and 803 were recorded in successive winters. Birds were usually associated with sectors on the River Cresswell.

Similarly, large flocks of mainly roosting birds were occasionally present between November and January at the Upper Cleddau. Peaks of 1,013, 377 and 331 were recorded in the first, second and third winters respectively.

4.2.13 Knot *Calidris canutus*

Knot were most numerous in winter 1996/97. Up to 43 were recorded at Angle Bay, mainly on Sectors 5 and 6. Only two and four birds were observed in the following two winters.

A peak of 56 Knot was recorded at Pembroke River in 1996/97, birds mostly using Sectors 6 and 9. Up to 14 were seen in 1997/98 and birds were recorded in all months. A peak of 16 birds was recorded the following winter.

No Knot were recorded at Carew/Cresswell.

Up to three were seen feeding at the Upper Cleddau on two days in winter 1996/97, but none were recorded in the following two winters.

4.2.14 Bar-tailed Godwit *Limosa lapponica*

Bar-tailed Godwit were commonly recorded at Angle Bay in all three winters, although numbers were low in the second winter, when a maximum of nine birds was seen in November. Peaks of 32 and 34 birds were recorded in 1996/97 and 1998/99, respectively. Feeding birds favoured Sectors 5, 6, 7 and 8 on the eastern side of the bay.

Bar-tailed Godwit were also frequently recorded at Pembroke River. Peaks of 20, 27 and 16 were recorded in successive winters. Birds most often fed on Sector 7 during the first winter and on Sector 11 during the second and third winters, but also fed on other areas.

No Bar-tailed Godwits were seen at Carew/Cresswell.

At the Upper Cleddau, Bar-tailed Godwits were recorded only occasionally. One was present in November and December of the first winter, two in January of the second winter, but no birds were seen during the third winter.

4.2.15 Greenshank *Tringa nebularia*

One to three Greenshank were present at Angle Bay throughout winter 1996/97. In the following two years, one bird was recorded in January only. Feeding occurred mostly on Sector 10.

One or two Greenshank were recorded at Pembroke River on several occasions in 1996/97, but none were seen during the following two winters.

One or two Greenshank were present at Carew/Cresswell on several days during 1996/97. However, none were seen in 1997/98 and only one was seen in December 1998/99.

At the Upper Cleddau, one or two Greenshank were occasionally recorded in the first winter of the study. Up to three were seen throughout the second winter, but only single birds were recorded in winter 1998/99.

4.2.16 Turnstone *Arenaria interpres*

Turnstone were seen regularly at Angle Bay in all three winters, most often on the west side of the bay. Peaks of 16, 23 and 36 were recorded in 1996/97, 1997/98 and 1998/99, respectively.

At Pembroke River, birds were less frequent than at Angle Bay, but were recorded in all three winters, usually on Sectors 7 and 8. Peaks of 12, 22 and 19 were recorded in successive winters.

No Turnstone were recorded at Carew/Cresswell or the Upper Cleddau.

4.3 Occasional Species

The following species were also recorded during all-day counts, but in numbers too small to be included in separate species accounts:

Red-throated Diver *Gavia stellata*
Black-throated Diver *Gavia arctica*
Great Northern Diver *Gavia immer*
Red-necked Grebe *Podiceps grisegena*
Slavonian Grebe *Podiceps auritus*
Black-necked Grebe *Podiceps nigricollis*
Shag *Phalacrocorax aristotelis*
Mute Swan *Cygnus olor*
Pink-footed Goose *Anser brachyrhynchus*
Canada Goose *Branta canadensis*
Brent Goose *Branta bernicla*
Gadwall *Anas strepera*
Pintail *Anas acuta*
Shoveler *Anas clypeata*
Pochard *Aythya ferina*
Tufted Duck *Aythya fuligula*
Scaup *Aythya marila*
Eider *Somateria mollissima*
Common Scoter *Melanitta nigra*
Goosander *Mergus merganser*
Coot *Fulica atra*
Sanderling *Calidris alba*
Snipe *Gallinago gallinago*
Black-tailed Godwit *Limosa limosa*
Spotted Redshank *Tringa erythropus*
Guillemot *Uria aalge*

4.4 Ringing Analyses

4.4.1 Movements of ringed birds

Details of all Wigeon, Teal, Oystercatcher, Dunlin, Curlew and Redshank recovered in the area of the Cleddau Estuary and those ringed there and subsequently recovered elsewhere since 1978 are shown in Tables 4.4.1.1 to 4.4.1.6. The two Wigeon recovered in the area had been ringed in England and Scotland. Three of the five Teal were ringed in England, the other two in The Netherlands, over 600 km away. No Shelduck were recovered in this period. Three Oystercatcher recoveries indicate that some of the wintering population of south-west Wales may originate from Scotland (Table 4.4.1.3). Apart from one recovery in Norfolk, the remainder came from less than 200 km away. In contrast, Table 4.4.1.4 indicates that much of the Dunlin population that winters in south-west Wales probably originates from Scandinavia and the former USSR. Eight Dunlin were ringed or recovered in Germany, one in Russia, three in Finland, three in Sweden, one in Norway and two in The Netherlands. The three Curlew recoveries came from England and Wales and one of the three Redshank from the Orkneys, the other two from the west coast of England.

4.4.2 Juvenile: adult ratios

The number of juvenile and adult Oystercatcher, Dunlin and Curlew caught in each sample are shown in Tables 4.4.2.1 to 4.4.2.3 . Even though a considerable ringing effort has been made in the Cleddau, data sets for each species, when split into different age groups, were small and this made it unlikely that differences would be detectable between the pre- and post-spill age-ratios. For Oystercatchers, the GLM indicated that there was no significant difference between the proportion of juveniles caught in samples before and after the oil spill ($\chi^2 = 0.08$, ns). This may have been partly due to the lack of data: the comparison only used data from seven catches before the spill (from over a decade earlier) and from three catches afterwards. In addition, due to the small quantity of data, the analysis took no account of the possible biases between mist- and cannon-netted samples in the proportions of different age classes caught (Pienkowski & Dick 1976).

5. DISCUSSION

The *Sea Empress* oil spill had strong initial impacts on the marine bird community, causing at least seven thousand mortalities, most notably Guillemots, Razorbills and Common Scoter between St. Brides Bay and Carmarthen Bay. Within the Cleddau Estuary, little mortality was reported, although 8% of the 11,400 birds counted on 22 February 1996 were found to have oiled plumage (Poole 1996; Parr *et al.* 1997).

Winter 1995/96

During the first two weeks after the spill, there was pronounced movement of birds away from the oiled embayments (Poole 1996; Jane Hodges *pers. comm.*). Shelduck, Wigeon, Oystercatcher and Redshank showed significant declines at Angle Bay and Pembroke River between the periods before and after the spill in winter 1995/96. Curlew also declined significantly at Pembroke River. Invertebrate surveys in the months immediately after the spill revealed a decline in the species numbers at Angle Bay. Moribund cockles *Cerastoderma edule* and large polychaetes such as *Notomastus latericeus* were noticed on the sediment surface and the amphipod *Ampelisca brevicornis* had disappeared from the site and also at Pembroke River. The loss of food resources as mudflats were covered with oil, and disturbance from oil monitoring and clean-up operations would have forced birds away from the polluted areas in search of clean feeding areas. Surprisingly, however, Dunlin and Curlew both showed significant increases at Angle Bay, the increase in the latter species being coincident with declines at all other study sites. These may have been migrant birds from other areas stopping off at this site during March.

If birds remained within the Cleddau Estuary complex in the immediate aftermath of the oil spill, numbers at the less affected embayments would be expected to have increased due to the influx of birds displaced from the polluted lower embayments. Of the species which did decline at the polluted sites, Wigeon and Oystercatcher showed increases at Carew/Cresswell. Redshank, however, also declined at Carew/Cresswell and at the Upper Cleddau, where all but Dunlin declined. Poole (1996) suggested that birds at the upper sites may also have been temporarily displaced and moved to freshwater sites or further afield. This would have been the time when birds began moving away on migration and declining numbers might represent birds migrating earlier than usual.

Winter 1996/97

In the following winter, there was an indication that Shelduck and Redshank numbers had recovered at Angle Bay. Wigeon, however, declined further, and Oystercatcher did not recover. Curlew numbers also declined to their lowest recorded number, but very large numbers of Teal were observed at Angle Bay for the first time. The abundance and distribution of waterbirds is closely linked to their food resources (Wolff 1969, Goss-Custard *et al.* 1991). In the winter, following the spill, a number of invertebrate species had declined in abundance, although others showed no change and some increased dramatically. The mollusc *Hydrobia ulvae*, an important constituent in the diet of Shelduck, fluctuated at Angle Bay, but showed no overall decline (Rostron 1998). However, the recovery of Shelduck may be attributable to the dramatic increase in numbers of the small polychaete *Chaetozone gibber*. This is an opportunistic species which, like the better known *Capitella capitata* complex, takes advantage of conditions subject to environmental stress which forces out normally occurring species. Small oligochaete and polychaete worms can form a significant part of the diet of Shelduck (Cramp & Simmonds 1977; Lack 1986). This may also be a causal factor in the abundance of Teal at the site, which are known to feed on organisms of the epibenthic meiofauna (Gaston 1994). Teal probably also made use of the increased growth of algae *Enteromorpha*. The shrimps *Crangon crangon*, which are favoured prey items of Redshank, were reported to be recruiting well in August 1996 (Rostron 1998). This may have aided the recovery of Redshank in winter 1996/97. However, most Redshank at Angle Bay feed in the small harbour (Sector 10) at Angle village, where no invertebrate survey was carried out. The reasons for the decline in numbers of Wigeon and Curlew are unclear. Wigeon are often associated with *Zostera* beds and the *Zostera* population at Angle Bay was robust and extensive, despite exposure to emulsified crude oil (Hodges & Howe 1997). It is also surprising that Oystercatcher did not recover, as numbers of cockles, a principal food item, recovered quickly from initial mortalities after the oil spill. However, Oystercatcher prefer to take larger individuals, as foraging profitability increases with increased size of prey (Zwarts *et al.* 1996). Rostron (1998) reported that juvenile cockles were present in September 1996 and adults were "quickly re-established". The cockle population at Angle Bay may, therefore, have consisted of individuals that were too small for efficient foraging by Oystercatchers.

At Pembroke River, Wigeon, Oystercatcher and Curlew numbers recovered, while Teal and Dunlin numbers also increased. There was no recovery of Shelduck or Redshank. Unfortunately, no sediment infauna surveys were carried out in winter 1996/97, so it is not possible to relate the changes in bird numbers to their prey organisms.

At Carew/Cresswell, Teal, Curlew and Redshank recovered from the initial declines following the oil spill and Oystercatcher and Dunlin numbers remained high. However, Shelduck and Wigeon numbers declined slightly, perhaps because of birds returning to the lower embayments.

At the Upper Cleddau, Teal, Oystercatcher and Curlew all recovered after the initial declines following the oil spill. Wigeon and Redshank showed no recovery. Shelduck continued to decline, while Dunlin numbers decreased considerably.

Population changes over the study period

Shelduck showed a large decline at Angle Bay in winter 1997/98 after the high numbers present the previous winter. At the end of summer 1997, invertebrate surveys carried out on the east side of the bay and on Sectors 2 and 3 on the south-west side of the bay (Figure 1.2) showed that on the mid- and lower shores, there was a significant reduction in the number of species and individuals (Rostron 1998, 1999). *C. gibber* was no longer in such abundance as it had been the previous winter, and the number of *H. ulvae* was still low, possibly accounting for the decline in Shelduck. In the following winter, Shelduck numbers declined even further, despite good recruitment of juvenile *H. ulvae* and *C. gibber* in all areas of the bay. At Pembroke River, Shelduck numbers increased in winter 1997/98 and decreased the following winter. This contrasts with the abundance of *H. ulvae*. No great change occurred in the invertebrate populations on the lower and mid-shores between November 1994 and August 1997, but the number of *H. ulvae* declined on the upper shore (Rostron 1998). By November 1998, however, numbers had increased on all parts of the shore (Rostron 1999). The all-day counts indicated that Shelduck numbers at both the unoiled sites increased in successive winters after the oil spill. The additional birds may have been those normally found on the lower embayments. However, the analysis of the WeBS counts, which takes into account the regional population index, showed that the only significant increase at the unoiled sites occurred between 1997/98 and 1998/99 at the Upper Cleddau. Therefore the increased number of birds at the unoiled sites may reflect regional population increases rather than birds displaced from sites within the Milford Haven complex with poorer feeding conditions.

Wigeon at Angle Bay recovered in 1997/98 after the decline in 1996/97, but numbers fell again in 1998/99. In the early part of winter, eel-grass *Zostera* is an important food source, with algae such as *Enteromorpha*, more important later in winter. At Angle Bay, the *Zostera angustifolia* populations did not change significantly in 1996 (Hodges & Howe 1997), and remained healthy in 1997 and 1998 (Rostron 1998, 1999). Algae may grow vigorously on substrates in the event of a die-off of grazing invertebrates resulting from an oil spill. The extent of algal growth on the mudflats in 1997 is not known, but in August 1998, there was a thick cover of *Enteromorpha* on Sectors 2 and 3, the area most used by Wigeon and also Teal (Figure 1.2). It would seem, therefore, that some other factor affected the abundance of Wigeon at Angle Bay in 1998/99. Numbers of Wigeon at the Upper Cleddau showed similar fluctuations. Pembroke River is the most important site at the Cleddau Estuary for Wigeon. Between one and two thousand birds are present in the early part of winter, but numbers decline rapidly from January onwards. Their distribution at Pembroke River is closely tied to the large sward of *Z. angustifolia* (covering Sectors 3, 4, 5, 6 and 9) (Figure 1.3). In 1996 and 1997 the sward was very dense and growth was lush (Hodges & Howe 1997; Rostron *pers. comm.*). In 1998, however, growth was much reduced (Rostron 1999). Increased numbers of Wigeon at Pembroke River in the two winters following the spill were probably attracted by this abundant food resource. Despite the reduced growth of *Zostera* in 1998, however, Wigeon numbers increased again in winter 1998/99. A greater proportion of the birds present were observed feeding in 1998/99 than in previous winters. Increased feeding activity may have been necessary if the *Zostera* was in poorer condition and this would account for the increase in use of the mudflats between 1997/98 and 1998/99. However, at Carew/Cresswell, where *Zostera* is not found, numbers also increased in successive years (Figure 4.1.2.4).

Teal were present at Angle Bay in large numbers for the first time in winter 1996/97 and declined only slightly thereafter. Whether this was as a result of the oil spill is uncertain. Teal feed mainly on seeds and invertebrates (Cramp & Simmonds 1977), but Gaston (1994) found that they feed on minute invertebrates such as meiofaunal nematodes. Birds may have taken advantage of the abundance of the small polychaete *C. gibber* and also the increased growth of *Enteromorpha*. At Pembroke River, Teal decreased to very low numbers in 1997/98 after the relatively high numbers in 1996/97, and increased only slightly in 1998/99. Birds are usually found upstream of the oiled part of the embayment, although some are found at Goldborough Pill. Numbers in years before the spill had been as low as in 1997/98, so it is difficult to distinguish between the effects of the oil spill and normal population fluctuations. Very similar fluctuations were also seen at Carew/Cresswell.

Oystercatcher and **Curlew** numbers recovered at the oiled sites following the spill, while numbers at the unoiled sites generally declined or remained unchanged in successive years. The main food items of Curlew include various large polychaetes, the bivalve molluscs *Scrobicularia* and *Macoma*, and *Carcinus* (Crustacea). At Angle Bay, numbers of *Nephtys hombergii*, the main predatory polychaete at the site, fell by August 1996 (Rostron 1998). Populations of *Nephtys* had recovered in 1997 and further increased in 1998. This may account for the low numbers of

Curlew recorded at Angle Bay in winter 1996/97 and the subsequent recovery in the following two winters. At Angle Bay, the shore is poor in bivalves other than cockles. As mentioned above, these organisms quickly re-established themselves in the bay after initial mortalities following the spill. There was no report of a further increase in subsequent years, only that cockle numbers fluctuated on the topmost part of the shore in 1997 and 1998 (Rostron 1999). However, they were presumably of larger size than in the previous winter, possibly accounting for the recovery of Oystercatcher. At Pembroke River, use of the mudflats by both Oystercatcher and Curlew increased between the first and second winters after the spill, despite the decline in numbers with respect to the regional population and the overall decline in the diversity and number of invertebrates at all sampling stations. In the following winter, the number of birds increased as expected with the increased abundance of most invertebrates at the site.

Dunlin numbers at Angle Bay dropped in 1997/98, but increased substantially in 1998/99. This may be due to the decrease in invertebrate abundance in 1997 and subsequent recovery in 1998. The main food items of Dunlin are *Hydrobia* and other small molluscs, and polychaetes such as *Nephtys*, which did show these fluctuations. At Pembroke River, the number of feeding Dunlin increased in successive years. In 1997/98 the increase appeared to be on Sector 5 (Figure 1.3), an area below the main stranding of oil, despite the overall decrease in invertebrate abundance. The following year, when invertebrates recovered in this area, the use made of the area by Dunlin decreased overall, but there was an increased usage of the eastern end of the embayment. Fluctuations also occurred at the unoiled sites. Dunlin are a very mobile species both within and between estuaries. Factors such as cold weather can cause large short-term changes in numbers, so the effects of the oil spill may be obscured.

Redshank numbers at Angle Bay increased over the study period following their initial post-spill decline. As already stated, most Redshank fed in the small harbour at Angle village, which was much less affected by oiling. However, in successive years, they made more use of Sector 6 on the south-east side of the bay (Figure 1.2), where numbers of principal food items such as *N. hombergii* and *H. ulvae* also increased. At Pembroke River, Redshank did not significantly recover from the decline following the spill until winter 1998/99. This corresponds with the recovery in the abundance of invertebrates at the site. At the unoiled sites, there were conflicting results from the WeBS and all-day count analyses. This may have been because Redshank at these sites may have spent much of the time unseen along the banks of creeks and channels and in the saltmarsh. However, in contrast to the oiled sites, numbers have apparently declined at Carew/Cresswell and the Upper Cleddau.

In summary, the *Sea Empress* oil spill may have adversely affected five of the seven waterbird species (which were Shelduck, Wigeon, Oystercatcher, Curlew and Redshank) in the parts of the Cleddau Estuary complex that it reached (Tables 4.1.1a and 4.1.1b). These effects were short-lived, however. Declines occurred either in the two months immediately following the spill or in the following winter, but were followed by quick recoveries. Similar findings have been reported in studies of other oil spills. Murphy *et al.* (1997), for example, found that only three of 12 coastal bird species declined in number in the area of the *Exxon Valdez* oil spill and Day *et al.* (1997) correspondingly found that only 12 (35%) of 34 coastal or marine species reduced their use of oil-affected habitats. Impacts of the *Exxon Valdez* were most evident in 1989, the year of the spill, but much reduced thereafter. Only 19% of species were still negatively affected by 1991 (Day *et al.* 1997) and at the community level recovery was well underway, with most of the habitat apparently returned to normal (Wiens *et al.* 1996). It is interesting to note too that on the Cleddau Estuary, three species (Oystercatcher, Curlew and Redshank) declined at Pembroke River and four (Shelduck, Teal, Curlew and Redshank) declined at Carew/Cresswell in winter 1991/92, possibly due to another oil spill. These declines were of similar scale to those seen after the *Sea Empress* spill, although in some cases, they were no greater than others that had previously been recorded by the WeBS counts. The causes of those fluctuations cannot be speculated upon without more information about water quality through time.

6. RECOMMENDATIONS FOR FURTHER WORK

It is critical that the response to oil spills be rapid as much of the impact occurs within the first few days and weeks of the oil being released. A frequent problem with attempting to assess the impact of oil spills is the lack of baseline data.

We make a series of recommendations that are both general to all aspects of assessing the impacts of oil spills and more focused on assessing the impact of oil spills on birds and especially waterbirds.

Co-ordinated rapid response

- A rapid response team made up of statutory agencies should be on permanent standby with a contingency plan in place for future oil spills. Such a team should have a list of interested organisations for immediate monitoring of affected sites. The most critical days are those that immediately follow the spill.

Continued monitoring

- The Cleddau Estuary should continue to be monitored as part of the Wetland Bird Survey (WeBS). After a further three years of data have been collected by 2002, it is recommended that the new data be analysed to assess if there has been a complete recovery of all species on the site. The larger number of years of data will help put the changes observed immediately after the spill in context.

- The present analysis did not incorporate any past oiling incidents, such as occurred in 1991, in the assessment of the effect of the *Sea Empress* spill on the local waterbird populations. If oil spills are important in determining waterbird presence, past waterbird population fluctuations will have been influenced by past spills and therefore the analyses would be more complete if these incidents were included in the overall assessment. The Environment Agency collect water quality data from the UK's coastal areas. Such water quality parameters as BOD, ammoniacal nitrogen and percentage dissolved oxygen have been found to help explain waterfowl densities on estuaries (Austin & Rehfisch 1998). Water quality data gathered for the Cleddau through time would indicate when oil spills have occurred and could be linked to the observed Cleddau waterbird population changes through time. It is therefore recommended that the EA be approached to assess the feasibility of such an assessment.

- As part of the impact assessment of future oil spills it is recommended that the behaviour of waterbirds be considered. In particular every effort should be made to assess what invertebrates and plants the waterbirds are feeding on (from observations or faecal analysis) so that their distributions can be linked to invertebrate distributions. To interpret waterbird distributions it is important that invertebrate biomass data be collected from sampling stations positioned in the bird count areas. The invertebrate data could be collected at a cruder level with polychaetes, oligochaetes, molluscs and crustaceans divided into small, medium and large size categories for biomass assessment. Prey size is a major factor in helping determine its use by waterbirds.

- Selected areas of coast most often affected by oil spills ought to be intensively monitoring to provide the high quality baseline data which will allow the impact of future oil spills to be assessed. As part of the standard WeBS programme of site monitoring, WeBS Low Tide Counts could be encouraged at such sites.

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APPENDIX 1

TABLES

Species	Five-year mean winter peak WeBS count (1991/92-1995/96) (and % national importance)	Winter 1996/7 peak WeBS count	Winter 1997/8 peak WeBS count	Threshold level for national (GB) importance
Shelduck *Tadorna tadorna*	919 (1.2%)	1,023	939	750
Wigeon *Anas penelope*	2,885 (1.0%)	3,351	3,058	2,800
Teal *Anas crecca*	1,959 (1.4%)	2,220	2,637	1,400
Oystercatcher *Haematopus ostralegus*	345 (0.1%)	526	413	3,600
Dunlin *Calidris alpina*	3,449 (0.7%)	8,561	5,318	5,300
Curlew *Numenius arquata*	1,322 (1.1%)	1,283	1,330	1,200
Redshank *Tringa totanus*	685 (0.6%)	647	553	1,100

Table 1.1 The five-year mean peak WeBS counts prior to the *Sea Empress* oil spill, the peak WeBS count in winter 1996/97 and 1997/98 and the qualifying level of national importance for a site. A wetland is considered important in a national context if it regularly holds at least 1% of one species, sub-species or population of waterbird in Great Britain.

	Shelduck				Wigeon				Teal			
	AB	PR	CC	UC	AB	PR	CC	UC	AB	PR	CC	UC
84/85 v 85/96	+++	+++			---	---	---	+++			-	---
85/86 v 86/87	+++	+	---	+++	+++	+++	+++				---	+++
86/87 v 87/88		---		---	---	+++	---	---			+	+
87/88 v 88/89		++	+++		+++	++	+++	+++			++	+++
88/89 v 89/90		+++	---	+	---	+++	---	+++		---	---	---
89/90 v 90/91					+++	---	+++			---	+++	---
90/91 v 91/92					+++	+++	---	+++	+		---	+++
91/92 v 92/93		+++	+++	--	+++	+++	++	---	--		+++	---
92/93 v 93/94		---	---	+	+++	---	+++	---	+++	--	-	---
93/94 v 94/95	+		+++	+++	---	+++	---		---	+++	---	---
94/95 v N-J 95/96	+++		+	+++		+++	+++	+++		+++	+++	+++
N-J 95/96 v F, M 96	---	---		---	--	---	++	---			---	---
F, M 96 v 96/97	+++		---	---	---	+++	---		+++	++	+++	+++
96/97 v 97/98	---	+++			+++	---	+++	+	+++	---	---	

Table 4.1.1a The significance of the difference between estimates for one winter and the next in models relating WeBS counts of wildfowl to year, month and regional index. AB = Angle Bay; PR = Pembroke River; CC = Carew/Cresswell; UC = Upper Cleddau. A plus sign indicates an increase in numbers from one year to the next, a minus sign, a decrease. +/- $P < 0.05$; ++/-- $P < 0.01$; +++/--- $P < 0.001$. No notation indicates no significant change from one year to the next and shaded areas indicate that data were unavailable.

	Oystercatcher				Dunlin				Curlew				Redshank			
	AB	PR	CC	UC	AB	PR	CC	UC	AB	PR	CC	UC	AB	PR	CC	UC
84/85 v 85/96		--	--		+++	+++	---		---		+++			+		
85/86 v 86/87	+++		++	-	---	---	---	---	+++	+++	-	+++	++	+++		++
86/87 v 87/88	+++	+++		--	---		---	---	++			---		+++		---
87/88 v 88/89	---		--	+++		+++	+++	---	+++		++	+++	++		++	+++
88/89 v 89/90	-	--	+++		---	+++	---	---	---	+	---			++		---
89/90 v 90/91	---			+	+++	---	+++	+++	---	---		---	---	---	+	+++
90/91 v 91/92	+++	---			+++	---	---	+++	+++	---	---	---	+	---	---	---
91/92 v 92/93	+	+++		--	++	---	+++	+++		+++	+++	+++			+++	+++
92/93 v 93/94	---				+++	---	---		---	---	--	---	--	+++		---
93/94 v 94/95	+++	+++	-	--	---	+++	+++	---	+++	+	---	+++			--	---
94/95 v N-J 95/96		---		++	---	+++	+++	++	---	+++	+++	---	+++	--		+++
N-J 95/96 v F, M 96	---	---	+++	---	+		+++	+++	+++	---	---	---	---	-	---	---
F, M 96 v 96/97		+++		+++	+++	+++		---	---	+++	+++	+++	+++		+++	
96/97 v 97/98	--	---	--	---	-	---	---	+++	+++	---	++	---			---	---

Table 4.1.1b The significance of the difference between estimates for one winter and the next in models relating WeBS counts of waders to year, month and regional index. AB = Angle Bay; PR = Pembroke River; CC = Carew/Cresswell; UC = Upper Cleddau. A plus sign indicates an increase in numbers from one year to the next, a minus sign, a decrease. +/- $P < 0.05$; ++/-- $P < 0.01$; +++/--- $P < 0.001$. No notation indicates no significant change from one year to the next and shaded areas indicate that data were unavailable.

	Angle Bay		Pembroke River		Carew/Cresswell		Upper Cleddau	
	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2
1996/97	0.768 (0.029)		-0.058 (0.014)		-0.556 (0.022)		-0.786 (0.021)	
		446.8***		52.2***		9.8**		163.7***
1997/98	0.193 (0.032)		0.041 (0.013)		-0.480 (0.021)		-0.494 (0.019)	
		35.6***		9.3**		518.4***		683.6***
1998/99	0		0		0		0	

Table 4.1.1.1 Estimates (with standard errors in parentheses) for each of three winters in models relating all-day count data for Shelduck at each of the four study sites to winter, month, state of tide (hours either side of low water) and sector. The significance of the difference between successive estimates is indicated by a χ^2 value (each with 1 degree of freedom). * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = not significant.

	Angle Bay		Pembroke River		Carew/Cresswell		Upper Cleddau	
	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2
1996/97	-1.198 (0.022)		-0.339 (0.013)		-1.023 (0.018)		-0.478 (0.025)	
		5439.3***		383.2***		972.8***		34.6***
1997/98	0.201 (0.014)		-0.087 (0.011)		-0.446 (0.015)		-0.323 (0.024)	
		209.2***		57.5***		936.2***		186.2***
1998/99	0		0		0		0	

Table 4.1.2.1 Estimates (with standard errors in parentheses) for each of three winters in models relating all-day count data for Wigeon at each of the four study sites to winter, month, state of tide (hours either side of low water) and sector. The significance of the difference between successive estimates is indicated by a χ^2 value (each with 1 degree of freedom). * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = not significant.

	Angle Bay		Pembroke River		Carew/Cresswell		Upper Cleddau	
	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2
1996/97	0.145 (0.067)		-0.839 (0.117)		-0.235 (0.047)		-0.905 (0.017)	
		169.1***		57.6***		183.1***		1994.2***
1997/98	0.880 (0.057)		-2.361 (0.214)		-1.031 (0.060)		-0.143 (0.014)	
		255.2***		222.9***		339.0***		106.6***
1998/99	0		0		0		0	

Table 4.1.3.1 Estimates (with standard errors in parentheses) for each of three winters in models relating all-day count data for Teal at each of the four study sites to winter, month, state of tide (hours either side of low water) and sector. The significance of the difference between successive estimates is indicated by a χ^2 value (each with 1 degree of freedom). * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = not significant.

	Angle Bay		Pembroke River		Carew/Cresswell		Upper Cleddau	
	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2
1996/97	-0.307 (0.022)		-0.205 (0.023)		0.413 (0.050)		0.127 (0.035)	
		141.8***		38.3***		62.5***		0.3 ns
1997/98	-0.048 (0.020)		-0.062 (0.022)		0.035 (0.053)		0.108 (0.035)	
		5.8*		7.9**		0.4 ns		9.3**
1998/99	0		0		0		0	

Table 4.1.4.1 Estimates (with standard errors in parentheses) for each of three winters in models relating all-day count data for Oystercatcher at each of the four study sites to winter, month, state of tide (hours either side of low water) and sector. The significance of the difference between successive estimates is indicated by a χ^2 value (each with 1 degree of freedom). * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = not significant.

	Angle Bay		Pembroke River		Carew/Cresswell		Upper Cleddau	
	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2
1996/97	-0.927 (0.010)		-0.377 (0.008)		-0.369 (0.006)		-0.736 (0.010)	
		1543.6***		1176.4***		1770.8***		2250.4***
1997/98	-1.478 (0.012)		-0.109 (0.007)		-0.684 (0.007)		-0.240 (0.009)	
		18196.9***		236.7***		10026.1***		744.2***
1998/99	0		0		0		0	

Table 4.1.5.1 Estimates (with standard errors in parentheses) for each of three winters in models relating all-day count data for Dunlin at each of the four study sites to winter, month, state of tide (hours either side of low water) and sector. The significance of the difference between successive estimates is indicated by a χ^2 value (each with 1 degree of freedom). * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = not significant.

	Angle Bay		Pembroke River		Carew/Cresswell		Upper Cleddau	
	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2
1996/97	-0.562 (0.024)		-0.215 (0.022)		-0.095 (0.029)		0.048 (0.027)	
		200.2***		22.0***		0.9 ns		0.0 ns
1997/98	-0.214 (0.021)		-0.111 (0.021)		-0.122 (0.028)		0.048 (0.027)	
		103.0***		27.8***		18.5***		3.2 ns
1998/99	0		0		0		0	

Table 4.1.6.1 Estimates (with standard errors in parentheses) for each of three winters in models relating all-day count data for Curlew at each of the four study sites to winter, month, state of tide (hours either side of low water) and sector. The significance of the difference between successive estimates is indicated by a χ^2 value (each with 1 degree of freedom). * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = not significant.

	Angle Bay		Pembroke River		Carew/Cresswell		Upper Cleddau	
	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2	Model estimate	χ^2
1996/97	-0.592 (0.039)		-0.363 (0.028)		-0.248 (0.030)		-0.162 (0.056)	
		62.0***		1.6 ns		158.7***		114.8***
1997/98	-0.271 (0.035)		-0.401 (0.028)		0.105 (0.027)		0.371 (0.049)	
		59.9***		208.3***		15.2***		58.0***
1998/99	0		0		0		0	

Table 4.1.7.1 Estimates (with standard errors in parentheses) for each of three winters in models relating all-day count data for Redshank at each of the four study sites to winter, month, state of tide (hours either side of low water) and sector. The significance of the difference between successive estimates is indicated by a χ^2 value (each with 1 degree of freedom). * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = not significant.

Ring Number	Ringing Site	Ringing Date	Age	Finding Site	Finding Date	Distance Moved (km)
FA58992	Highland Region	6.11.94	A	Dyfed	29.12.94	678
FA76900	Hereford & Worcester	3.3.96	J	Dyfed	11.12.96	191

Table 4.4.1.1 Details of Wigeon recovered in the Cleddau Estuary area. A = Adult, J = Juvenile.

Ring Number	Ringing Site	Ringing Date	Age	Finding Site	Finding Date	Distance Moved (km)
3307917	Texel, NETHERLANDS	10.10.83	J	Dyfed	17.1.84	677
3338673	Texel, NETHERLANDS	26.10.83	J	Dyfed	4.11.85	676
EH42585	Leicester & Rutland	14.2.89	U	Dyfed	20.1.90	299
ES55690	Gloucester	15.10.94	A	Dyfed	8.1.97	170
ES77979	Gloucester	1.11.95	J	Dyfed	24.11.95	169

Table 4.4.1.2 Details of Teal recovered in the Cleddau Estuary area. A = Adult, J = Juvenile, U = Unaged.

Ring Number	Ringing Site	Ringing Date	Age	Finding Site	Finding Date	Distance Moved (km)
FS65188	Dyfed	22.6.78	P	Dyfed	16.5.81	5
FV49813	Dyfed	22.9.79	A	Dyfed	25.2.83	0
FV49815	Dyfed	22.9.79	A	Dyfed	27.7.81	0
FV49816	Dyfed	22.9.79	A	Dyfed	19.8.92	0
FV54098	Dyfed	22.9.79	A	Norfolk	10.2.90	396
FV98751	Dyfed	22.9.79	A	Dyfed	12.8.81	0
FV98752	Dyfed	22.9.79	A	Shetland	16.8.81	1006
FV98534	Dyfed	25.6.86	P	Dyfed	9.3.91	8
FA19477	Highland Region	26.3.89	A	Dyfed	19.8.92	653
FA37021	Dyfed	1.1.90	J	Dyfed	8.3.92	77
FC12635	Dyfed	23.6.91	P	Devon	23.9.91	174
FC66067	Dyfed	19.8.92	A	Grampian Region	14.5.96	612
FC66084	Dyfed	19.8.92	A	Dyfed	25.4.94	18
FC60239	Glamorgan	5.12.93	A	Dyfed	7.5.94	70
FC66397	Dyfed	1.3.96	U	Dyfed	8.3.96	2

Table 4.4.1.3 Details of Oystercatcher ringed or recovered in the Cleddau Estuary area. A = Adult, J = Juvenile, U = Unaged, P = Pullus.

Ring Number	Ringing Site	Ringing Date	Age	Finding Site	Finding Date	Distance Moved (km)
BX01655	Dyfed	11.3.78	A	Schleswig-Holstein, GERMANY	13.9.81	991
BX71415	Pembroke	11.3.78	A	Schleswig-Holstein, GERMANY	29.4.78	971
3328839	Oland, SWEDEN	17.7.79	A	Dyfed	7.2.81	1487
3328839	Oland, SWEDEN	17.7.79	A	Dyfed	30.1.82	1487
323292	Murmansk, RUSSIA	12.8.80	J	Dyfed	7.2.81	2786
81120312	Schleswig-Holstein, GERMANY	18.8.80	A	Dyfed	25.1.87	972
BX71780	Dyfed	7.2.81	A	Weser-Ems, GERMANY	8.9.91	909
BX72696	Dyfed	7.2.81	A	Lincolnshire	11.4.82	375
NS23381	Dyfed	7.2.81	J	Anglesey	6.2.82	189
PT21690	Turku-Pori, FINLAND	21.7.81	A	Dyfed	25.1.87	1938
3341665	Halland, SWEDEN	21.8.81	J	Dyfed	30.1.82	1256
BX54561	Dyfed	30.1.82	A	Friesland, NETHERLANDS	26.11.83	735
H100589	Noord-Holland, NETHERLANDS	21.10.82	U	Dyfed	9.2.85	683
BX54574	Dyfed	4.2.84	A	Jutland, DENMARK	29.8.84	990
80760080	Helgoland, GERMANY	27.9.84	U	Dyfed	9.2.85	910
80630868	Rostock, GERMANY	13.10.84	J	Dyfed	11.1.86	1134
NB53801	Dyfed	10.3.85	J	Lincolnshire	15.9.85	390
80680198	Rostock, GERMANY	27.9.85	J	Dyfed	25.1.87	1139
80703069	Rostock, GERMANY	24.9.86	J	Dyfed	25.1.87	1139
NB53812	Dyfed	25.1.87	A	Turku-Pori, FINLAND	21.7.88	1938
8381613	Finnmark, NORWAY	23.6.91	P	Dyfed	25.1.92	2747
KT30642	Vaasa, FINLAND	20.7.92	A	Dyfed	12.2.93	2128

Table 4.4.1.4 Details of Dunlin ringed or recovered in the Cleddau Estuary area. A = Adult, J = Juvenile, U = Unaged, P = Pullus.

Ring Number	Ringing Site	Ringing Date	Age	Finding Site	Finding Date	Distance Moved (km)
FR43661	Anglesey	7.10.82	A	Dyfed	8.4.86	180
FC66051	Dyfed	19.8.92	A	Durham	23.5.95	375
FR90982	Dyfed	14.9.96	A	Dyfed	7.10.97	5

Table 4.4.1.5 Details of Curlew ringed or recovered in the Cleddau Estuary area. A = Adult.

Ring Number	Ringing Site	Ringing Date	Age	Finding Site	Finding Date	Distance Moved (km)
DR11705	Dyfed	12.3.78	A	Lancashire	20.12.80	289
DR35223	Dyfed	28.10.78	A	Orkney	4.4.85	830
DR35226	Dyfed	18.11.84	A	Cumbria	23.8.86	290

Table 4.4.1.6 Details of Redshank ringed or recovered in the Cleddau Estuary area. A = Adult.

Date	Number of Juveniles	Number of Adults
11 March 1978	0	2
8 October 1978	0	14
22 September 1979	0	41
27 February 1980	0	1
31January 1982	0	3
5 February 1983	7	3
14 December 1985	1	4
14 September 1996	4	38
7 September 1997	2	18
23 August 1998	0	4

Table 4.4.2.1 The number of juvenile and adult Oystercatcher in each catch at Angle Bay. The oil spill occurred in February 1996.

Date	Number of Juveniles	Number of Adults
11 March 1978	68	106
3 September 1978	72	0
22 September 1979	6	0
7 February 1981	59	233
31 January 1982	38	70
5 February 1983	7	47
4 February 1984	3	59
18 November 1984	6	23
9 February 1985	20	41
10 February 1985	3	12
10 March 1985	53	14
14 December 1985	11	4
25 January 1987	25	141
20 January 1991	20	14
17 February 1991	12	9
25 January 1992	19	30
23 February 1992	1	6
14 September 1996	50	0

Table 4.4.2.2 The number of juvenile and adult Dunlin in each catch at Angle Bay. The oil spill occurred in February 1996.

Date	Number of Juveniles	Number of Adults
8 October 1978	0	2
22 September 1979	0	1
9 March 1985	0	6
14 September 1996	1	23
7 September 1997	0	38
23 August 1998	0	14

Table 4.4.2.3 The number of juvenile and adult Curlew in each catch at Angle Bay. The oil spill occurred in February 1996.

APPENDIX 2

FIGURES

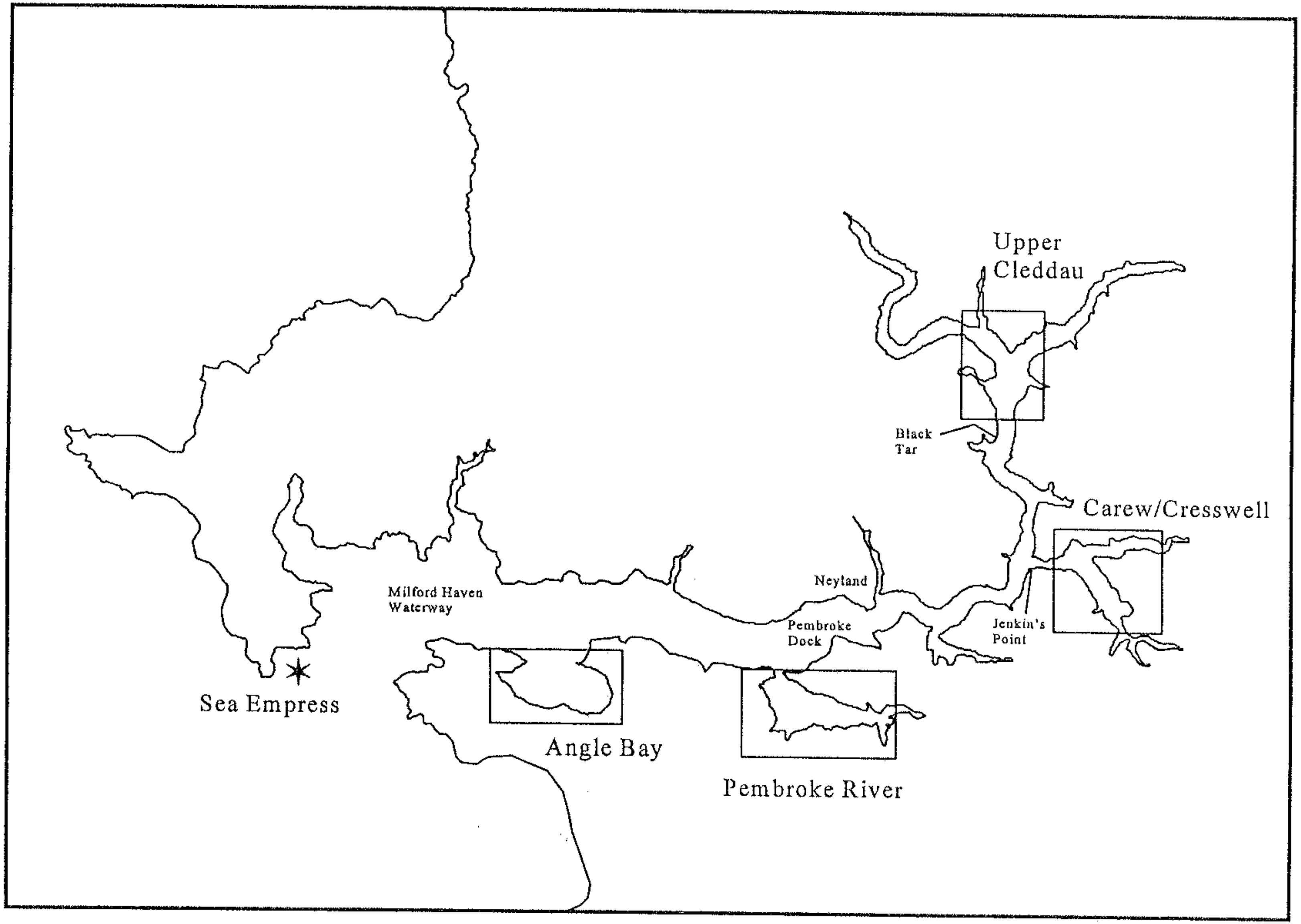


Figure 1.1 Map of the Cleddau estuary highlighting the four study sites.

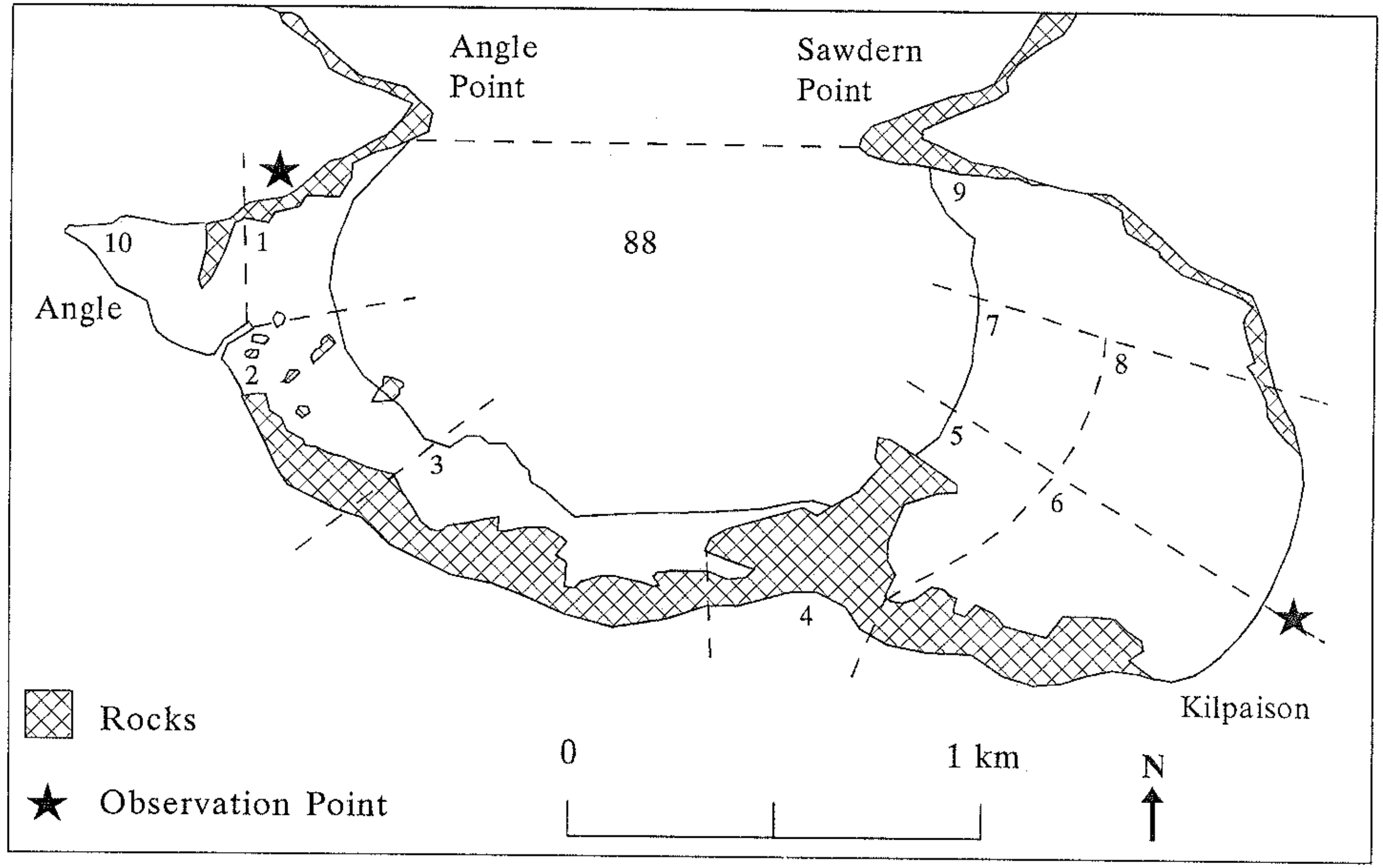


Figure 1.2 The Angle Bay study site, showing numbered sectors. Observation points are marked with an asterisk.

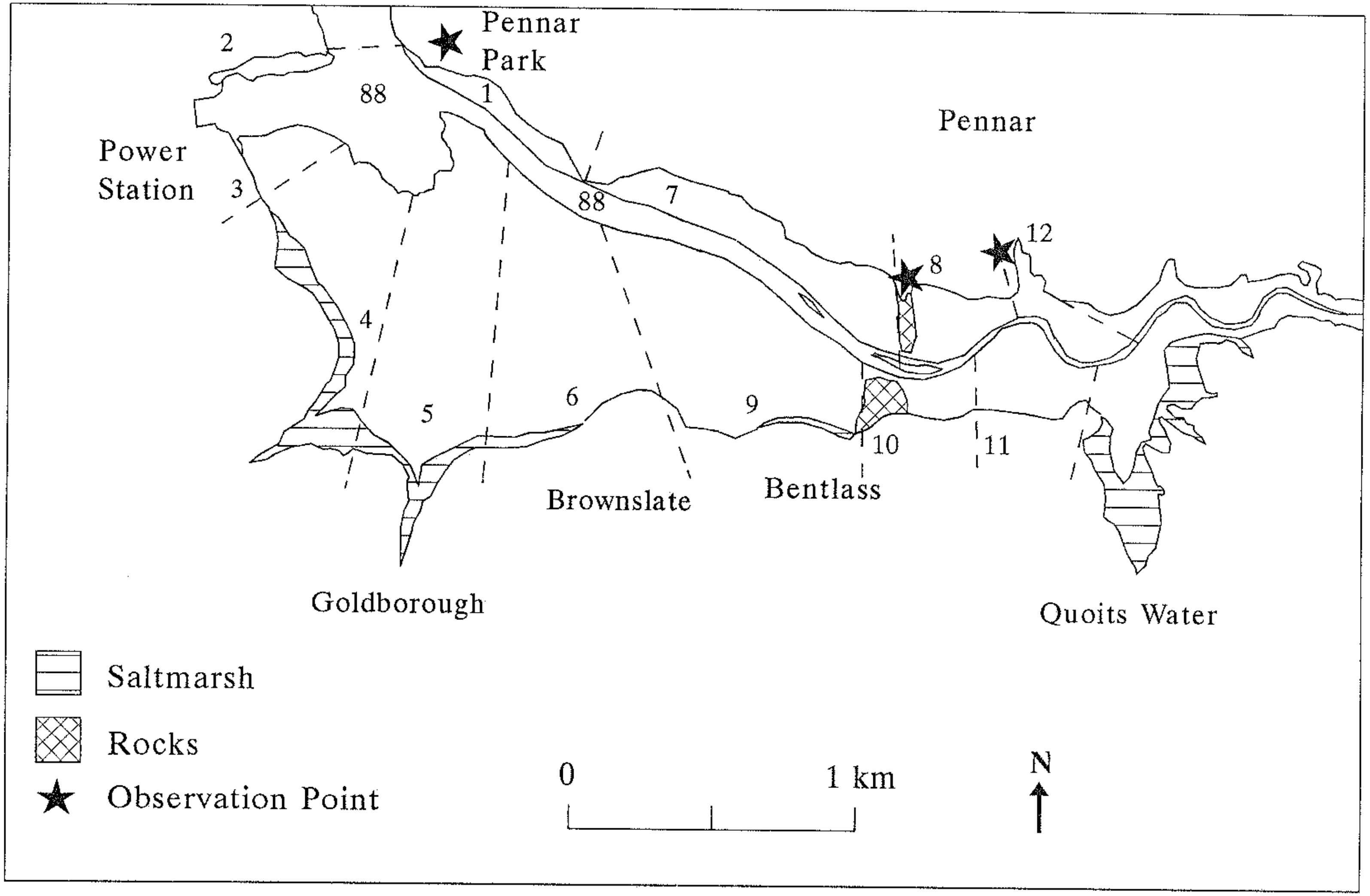


Figure 1.3 The Pembroke River study site, showing numbered sectors. Observation points are marked with an asterisk.

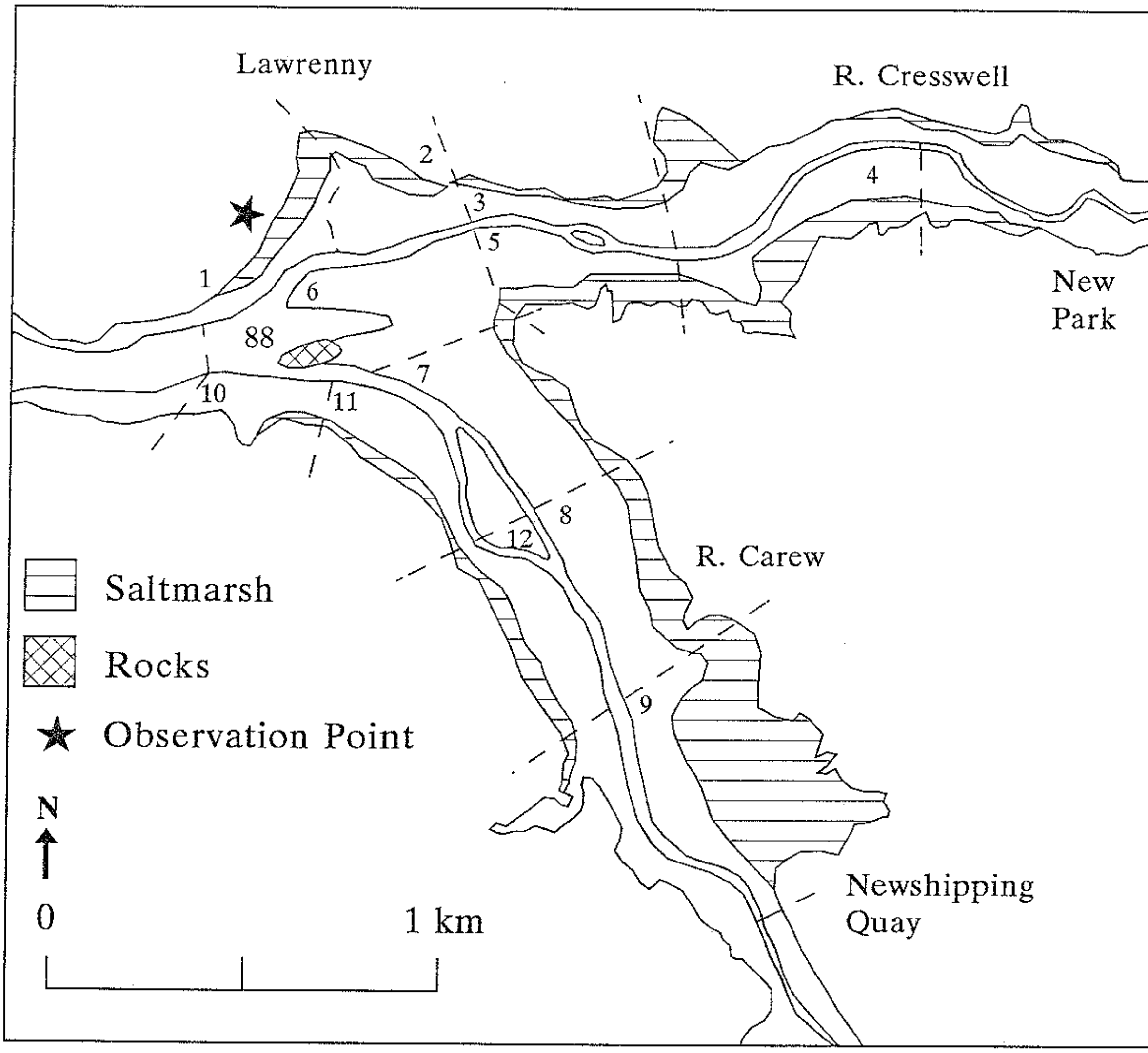


Figure 1.4 The Carew/Cresswell study site, showing numbered sectors. The one observation point is marked with an asterisk.

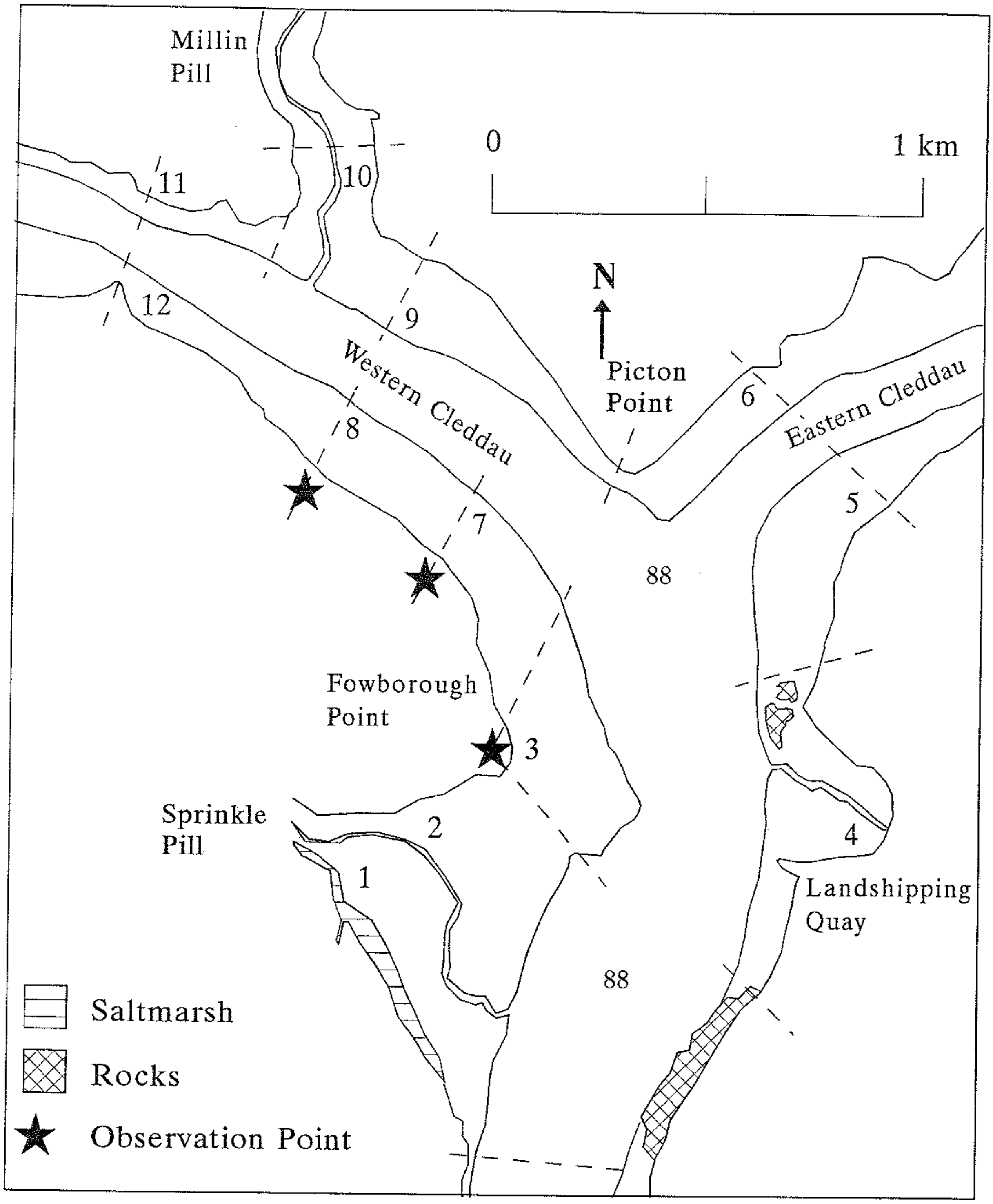


Figure 1.5 The Upper Cleddau study site, showing numbered sectors. Observation points are marked with an asterisk.

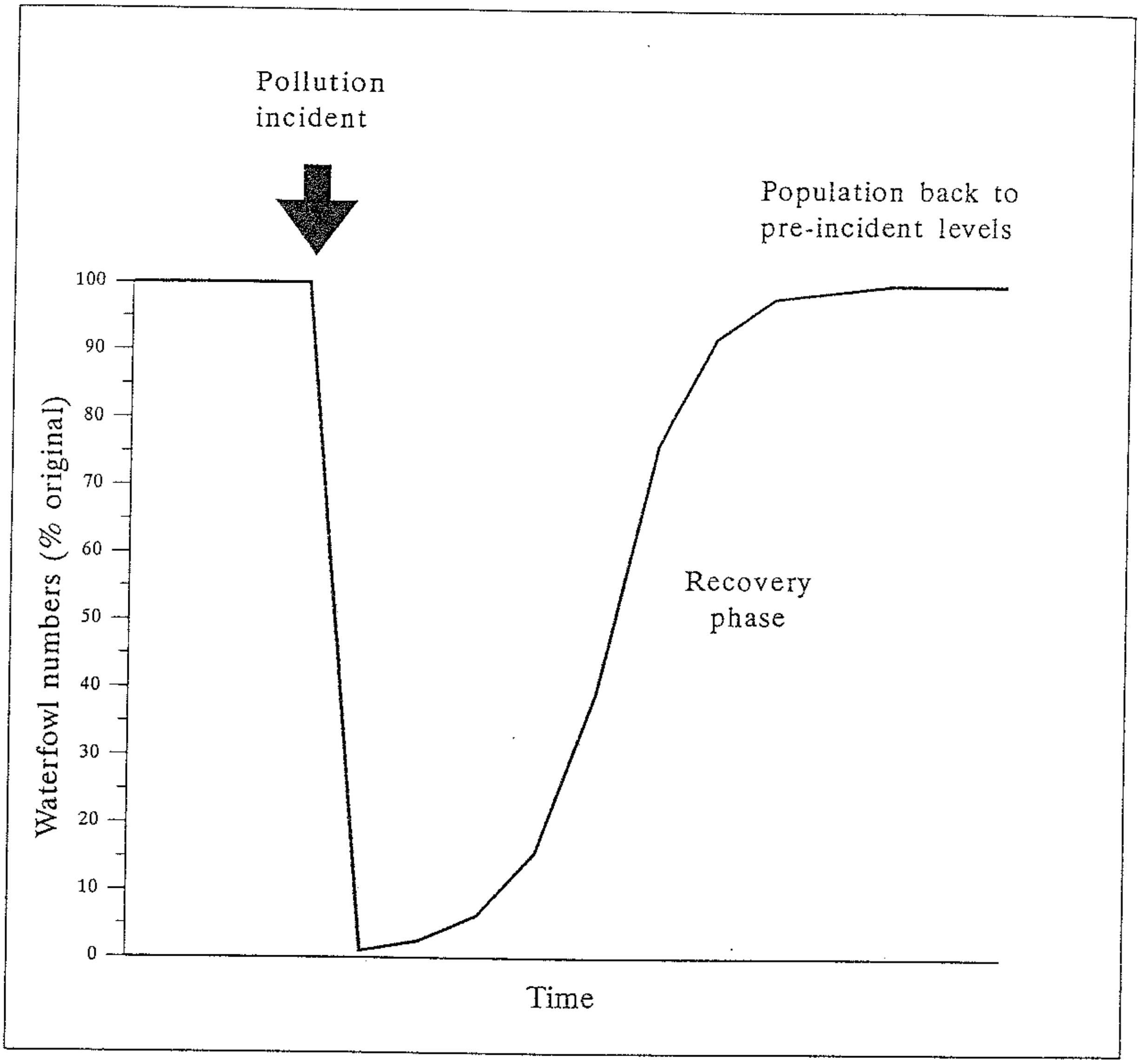


Figure 1.6 The expected pattern of population recovery.

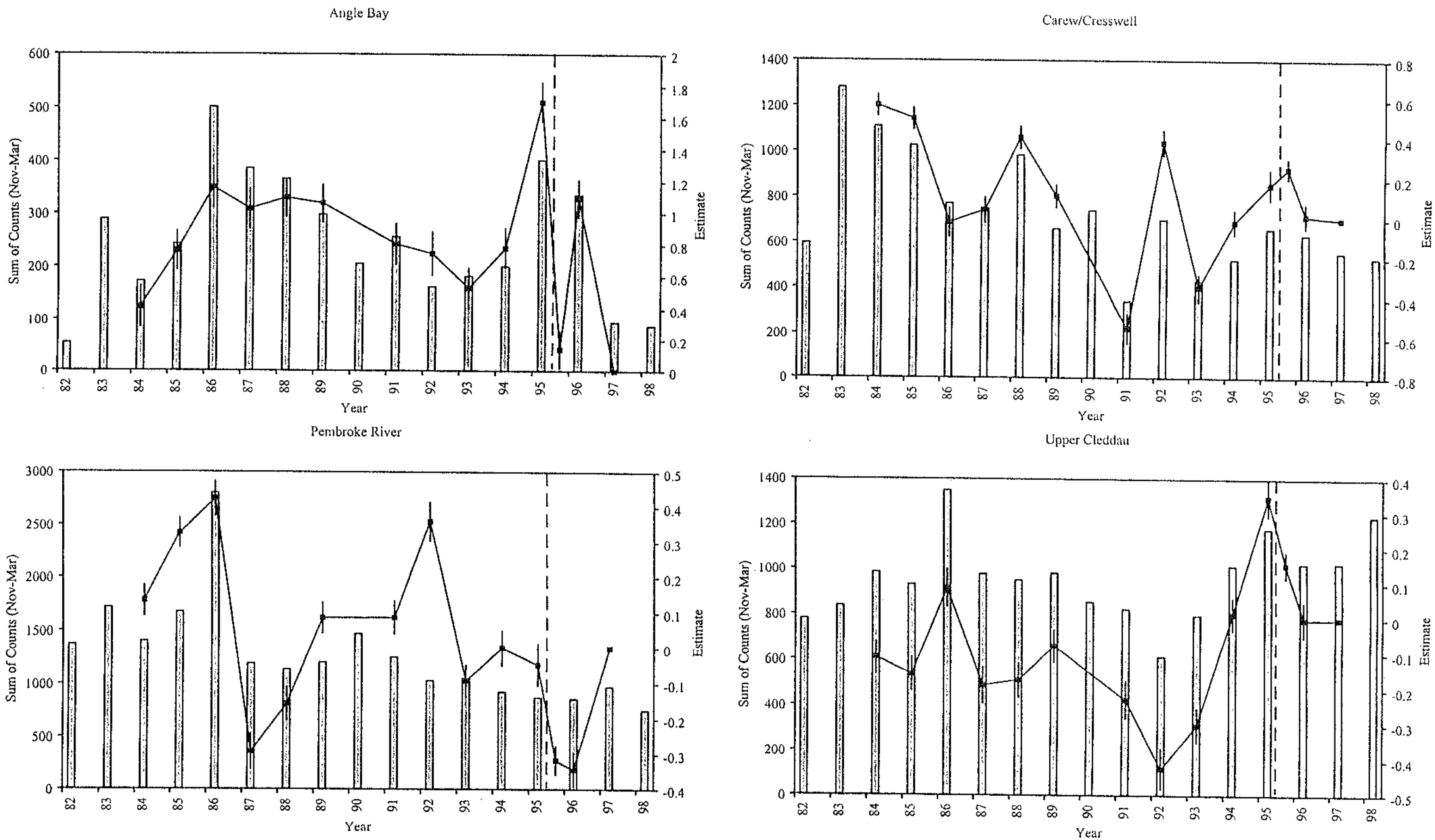
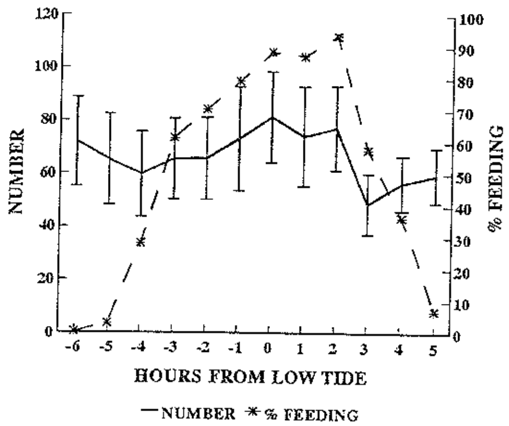
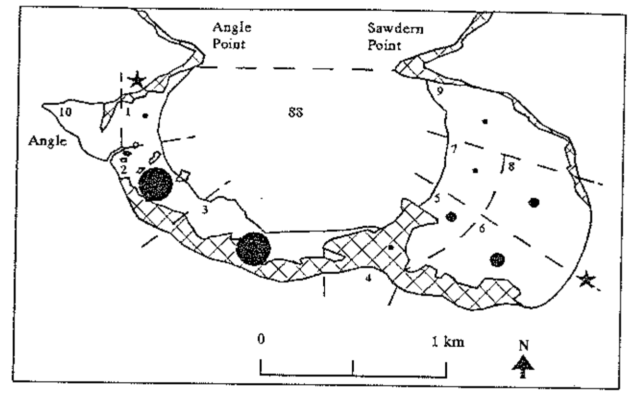


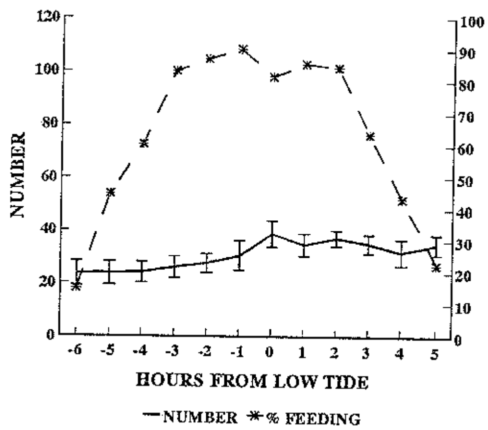
Figure 4.1.1.1 Summed WeBS count data (bars) for Shelduck for the winters (November to March) of 1982/83 to 1998/99 and estimates (line, with standard errors) for models relating count to year, month and regional index. 82 = 1982/83, etc. The dotted line indicates the date of the spill; points immediately before and after are the estimates for November 1995 to January 1996 and February to March 1996 respectively.

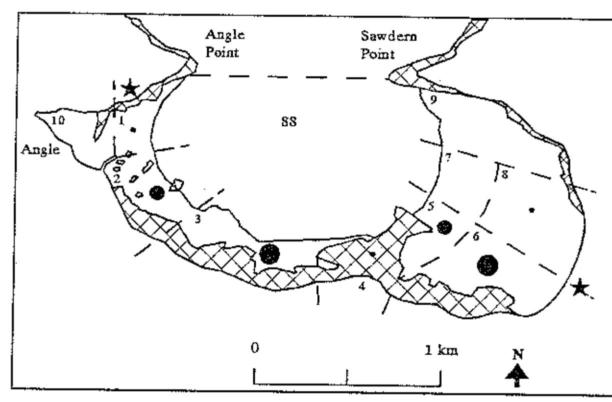
1996/97



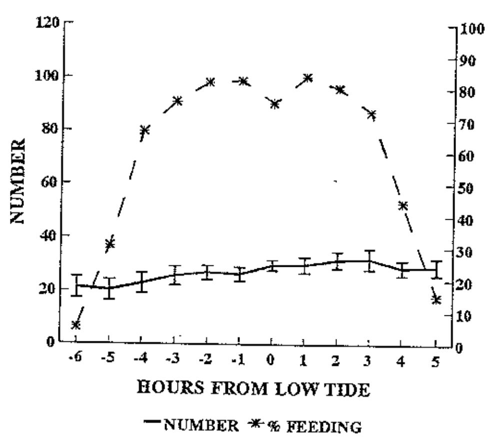


1997/98





1998/99



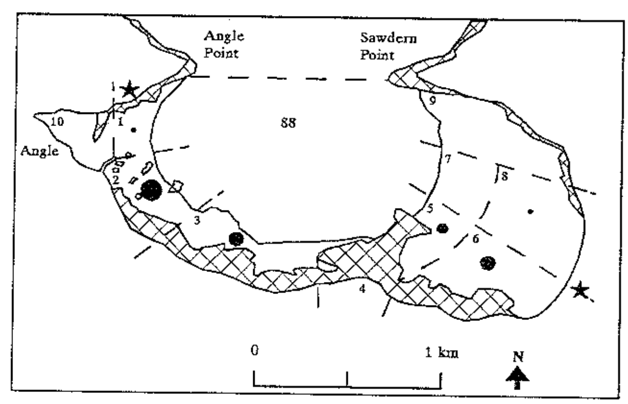
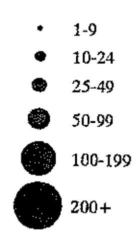
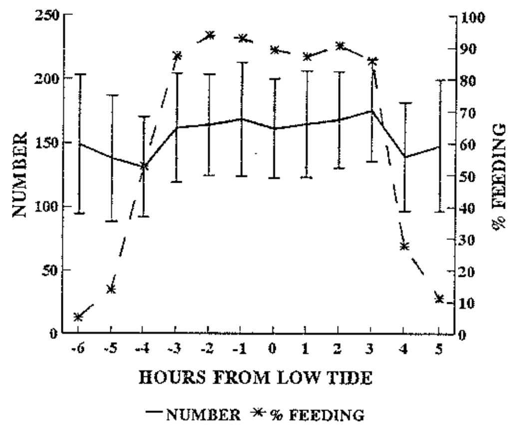
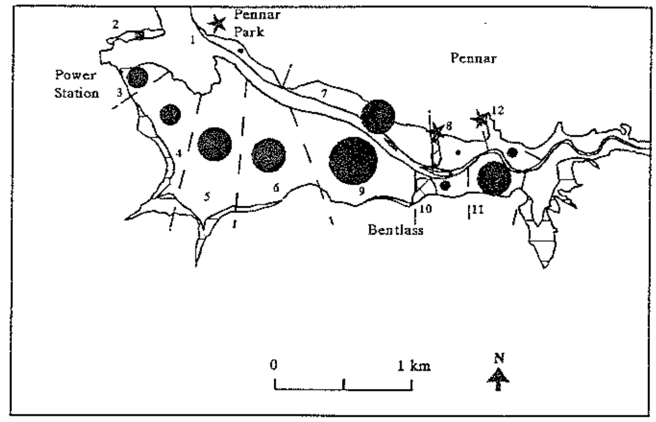


Figure 4.1.1.2 The number of Shelduck present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Shelduck (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Angle Bay.

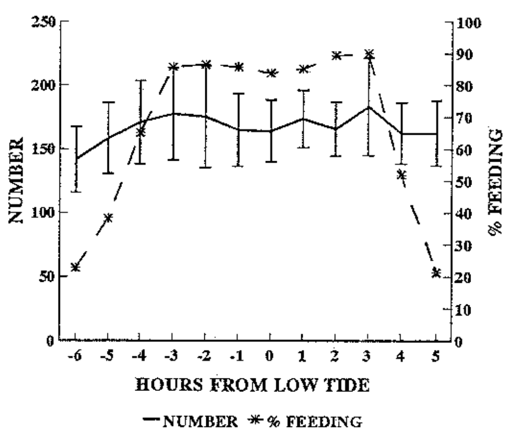


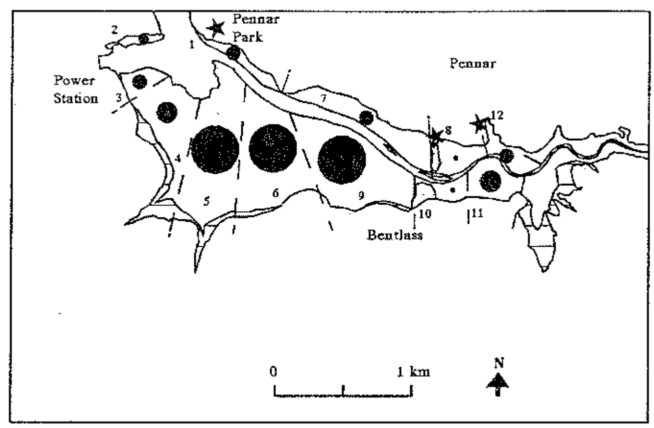
1996/97



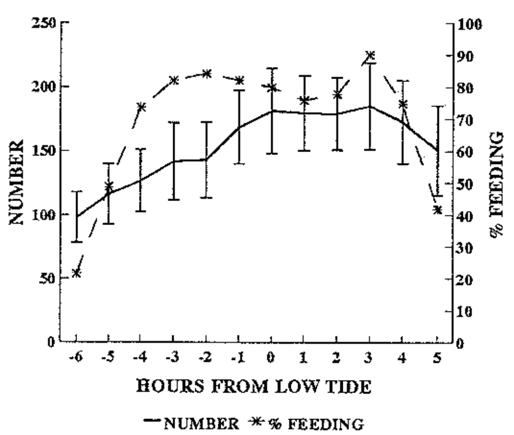


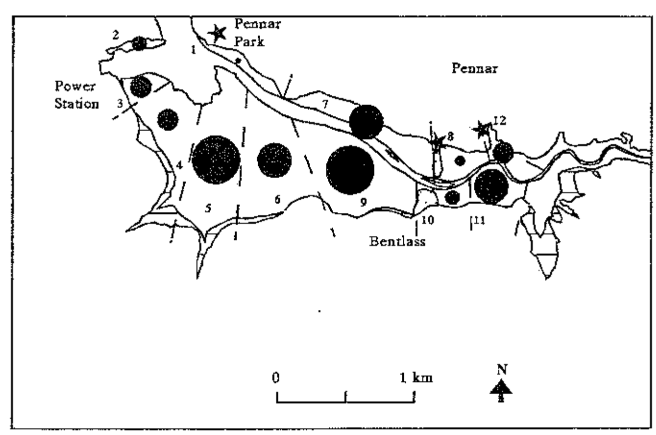
1997/98





1998/99





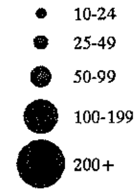


Figure 4.1.1.3 The number of Shelduck present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Shelduck (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Pembroke River.

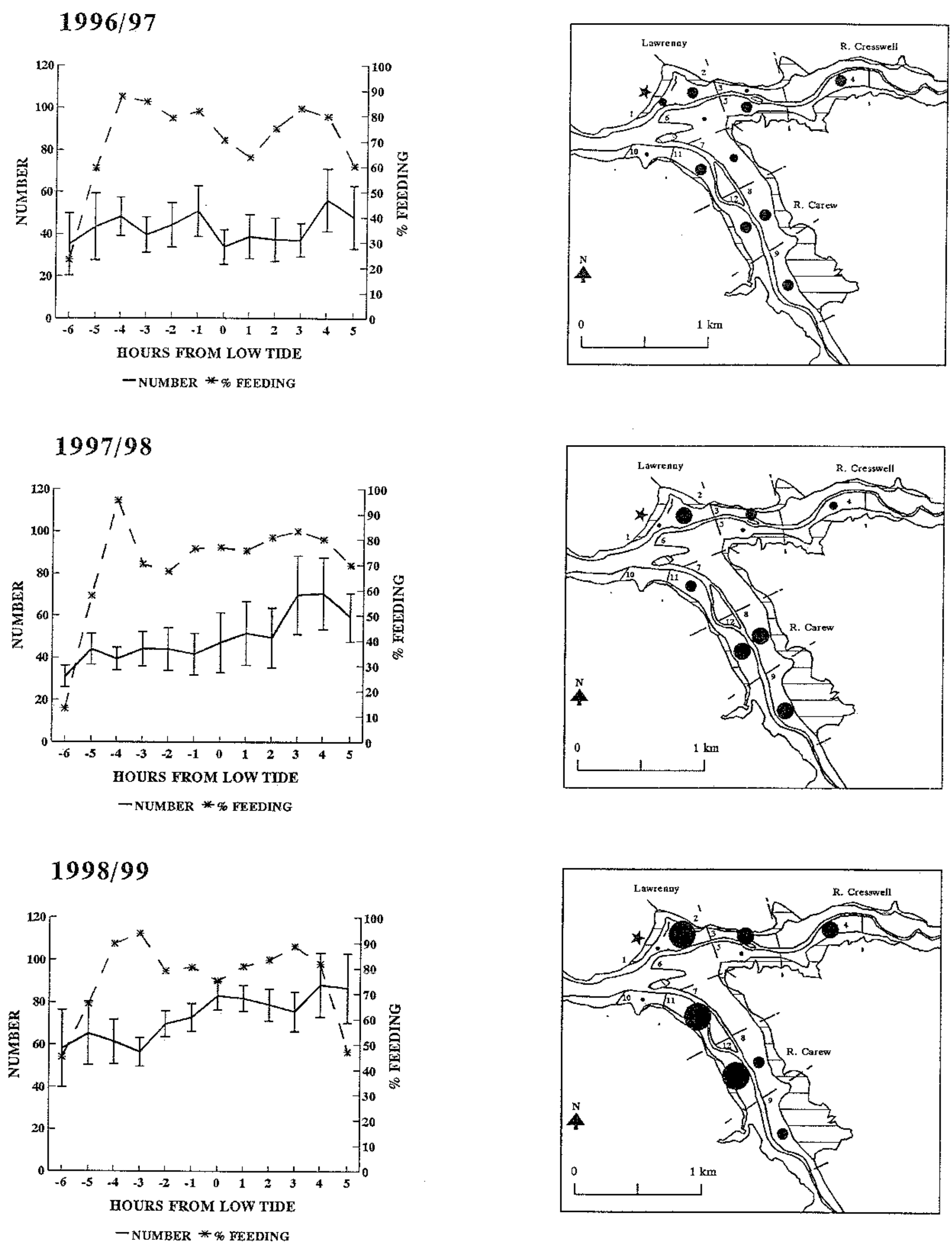
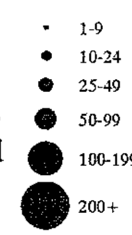
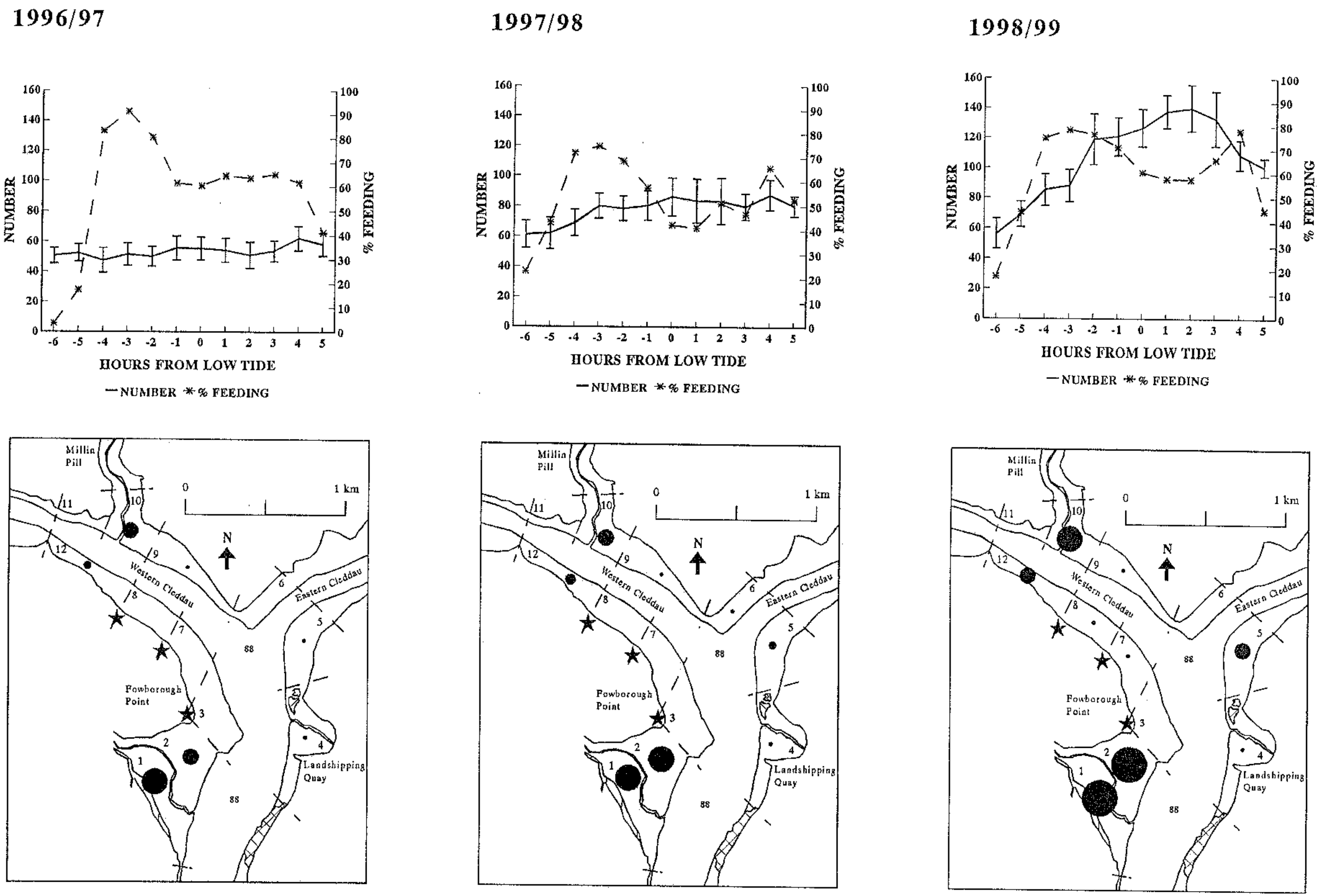


Figure 4.1.1.4 The number of Shelduck present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Shelduck (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Carew/Cresswell.





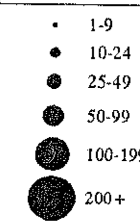


Figure 4.1.1.5 The number of Shelduck present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Shelduck (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Upper Cleddau.

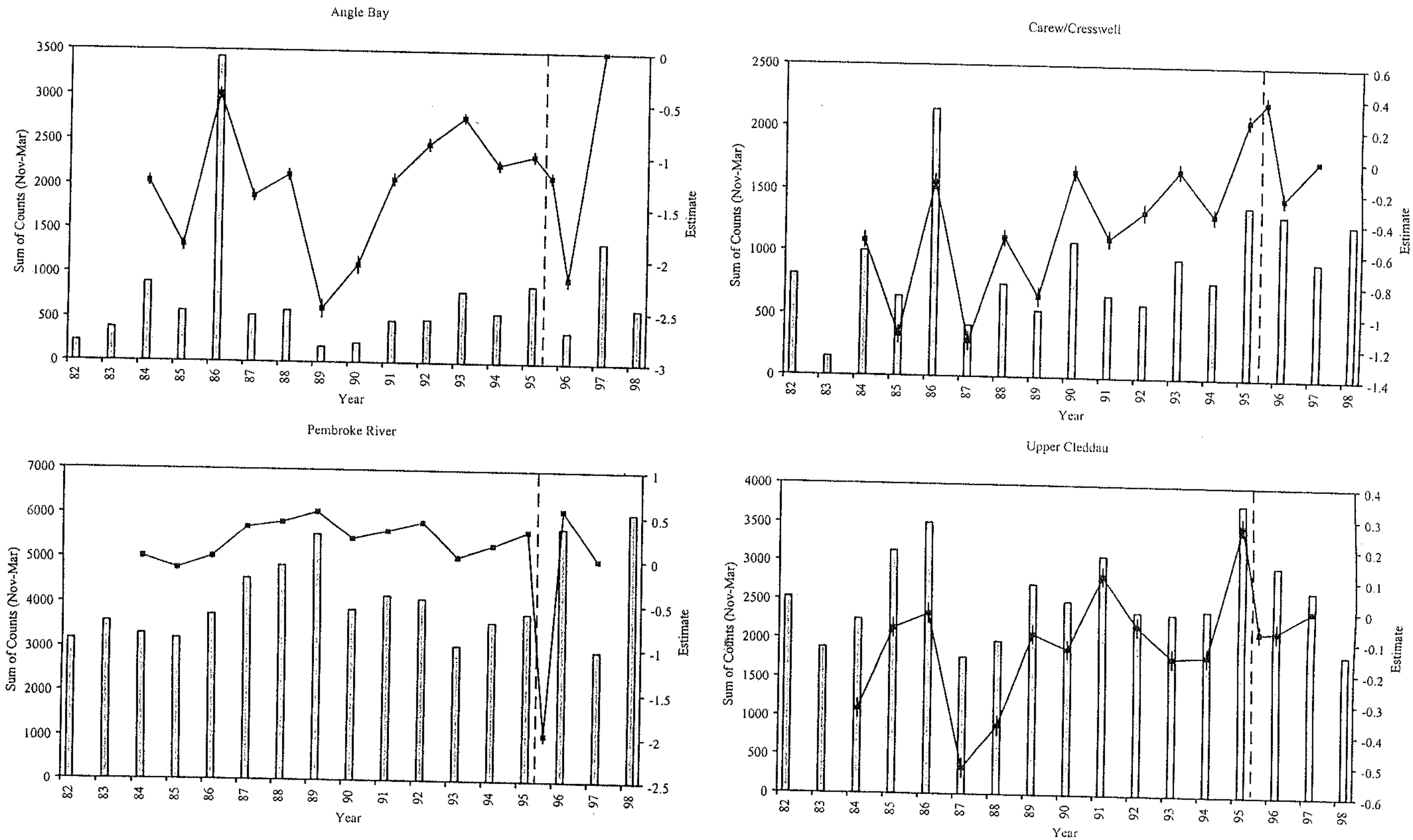
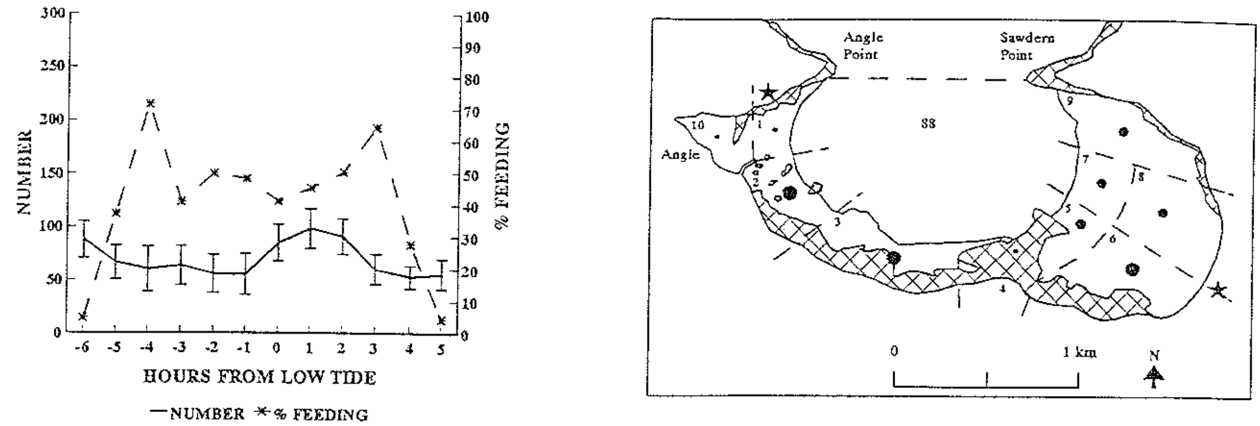
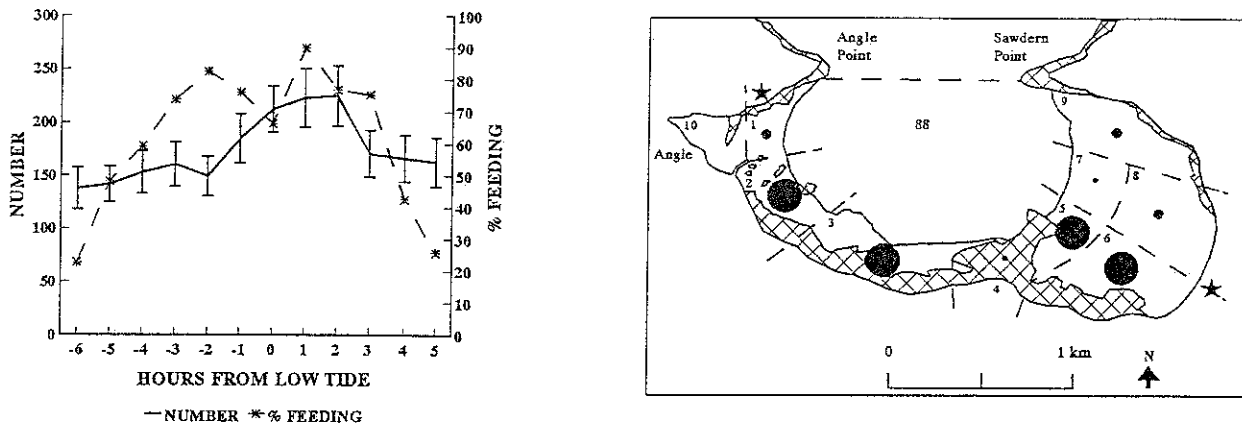


Figure 4.1.2.1 Summed WeBS count data (bars) for Wigeon for the winters (November to March) of 1982/83 to 1998/99 and estimates (line, with standard errors) for models relating count to year, month and regional index. 82 = 1982/83, etc. The dotted line indicates the date of the spill; points immediately before and after are the estimates for November 1995 to January 1996 and February to March 1996 respectively.

1996/97



1997/98



1998/99

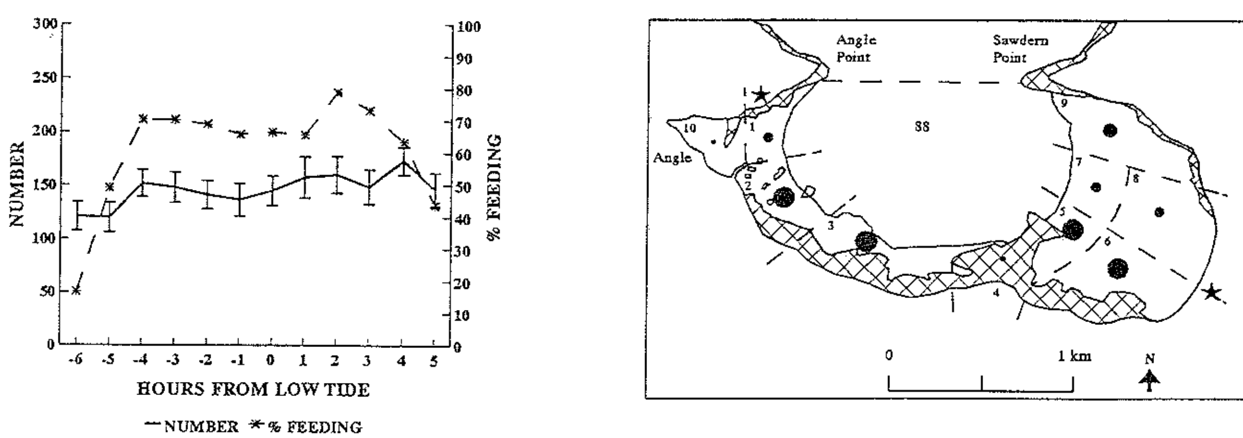
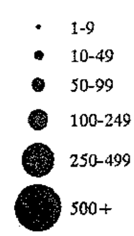
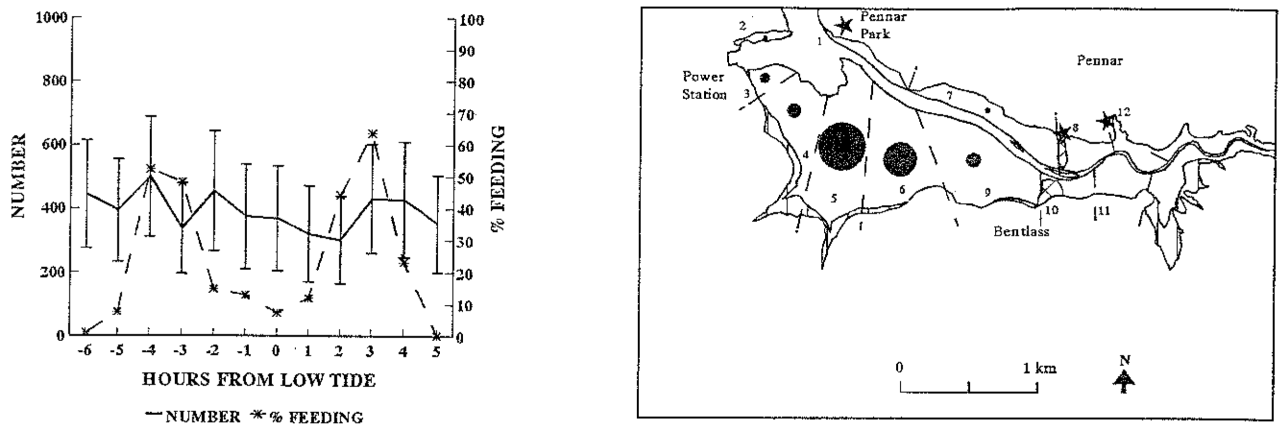


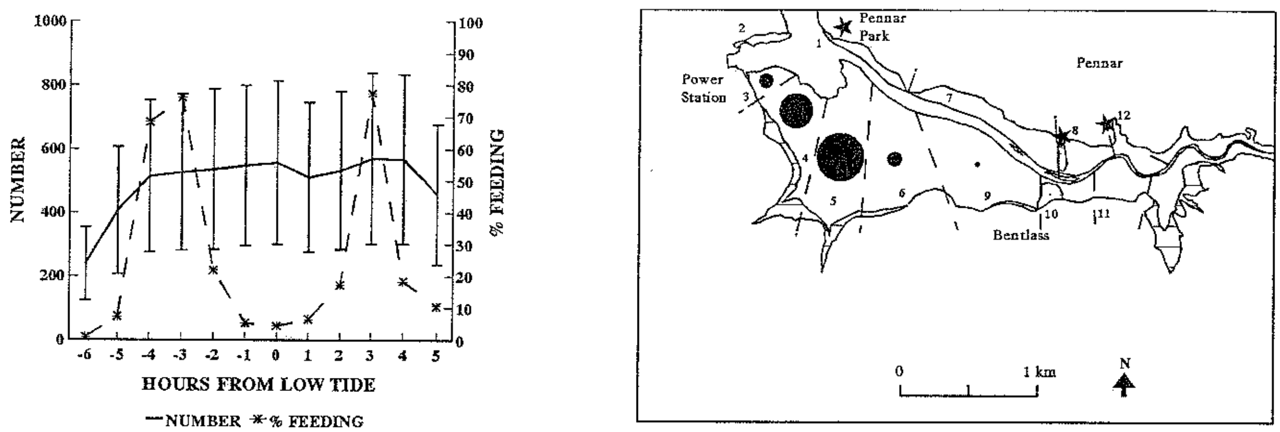
Figure 4.1.2.2 The number of Wigeon present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Wigeon (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Angle Bay.



1996/97



1997/98



1998/99

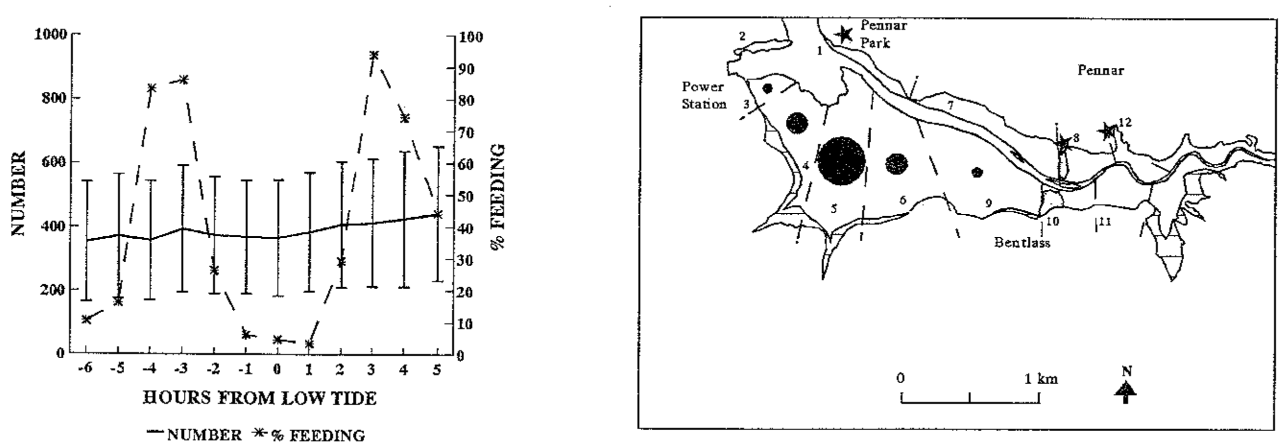
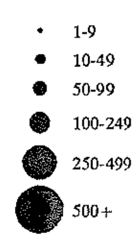
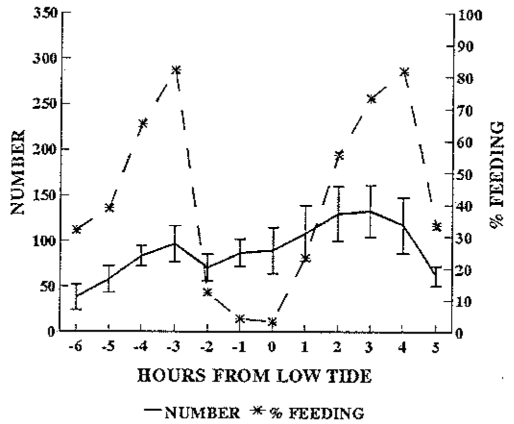
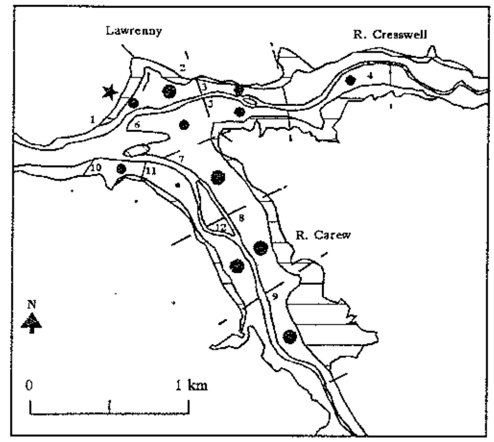


Figure 4.1.2.3 The number of Wigeon present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Wigeon (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Pembroke River.

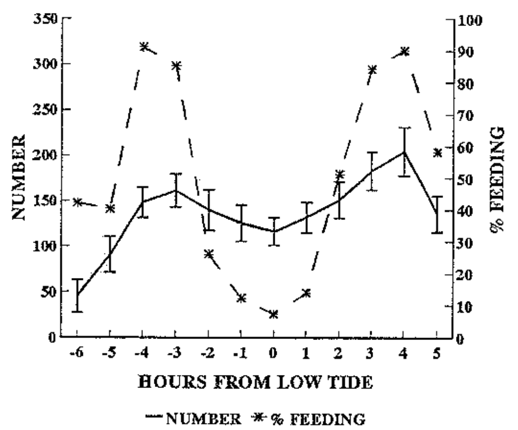


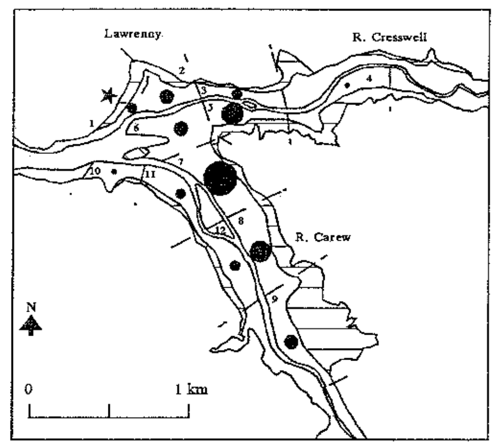
1996/97



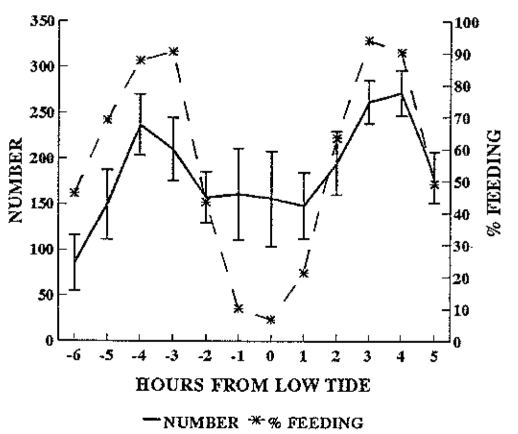


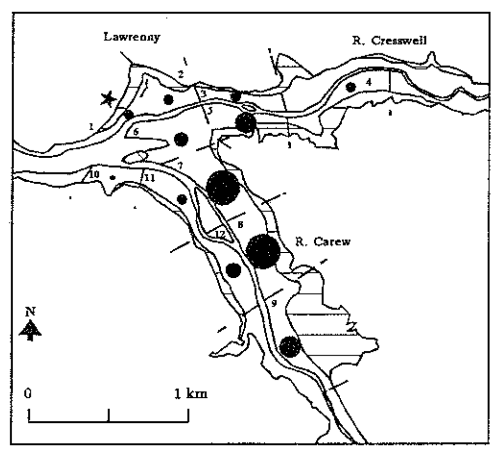
1997/98





1998/99





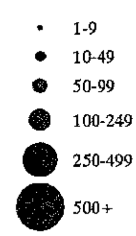
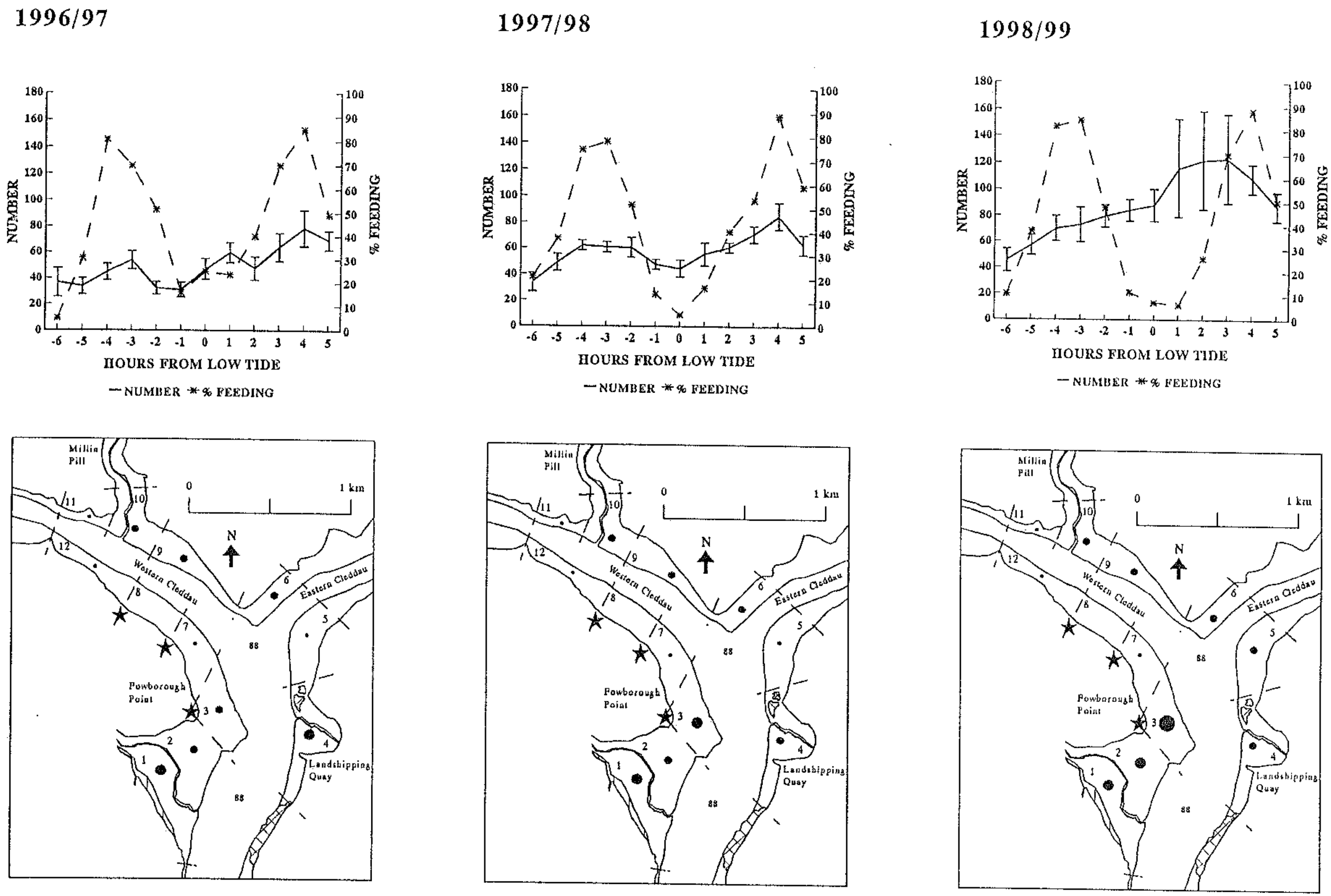


Figure 4.1.2.4 The number of Wigeon present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Wigeon (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Carew/Cresswell.



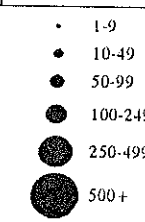


Figure 4.1.2.5 The number of Wigeon present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Wigeon (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Upper Cleddau.

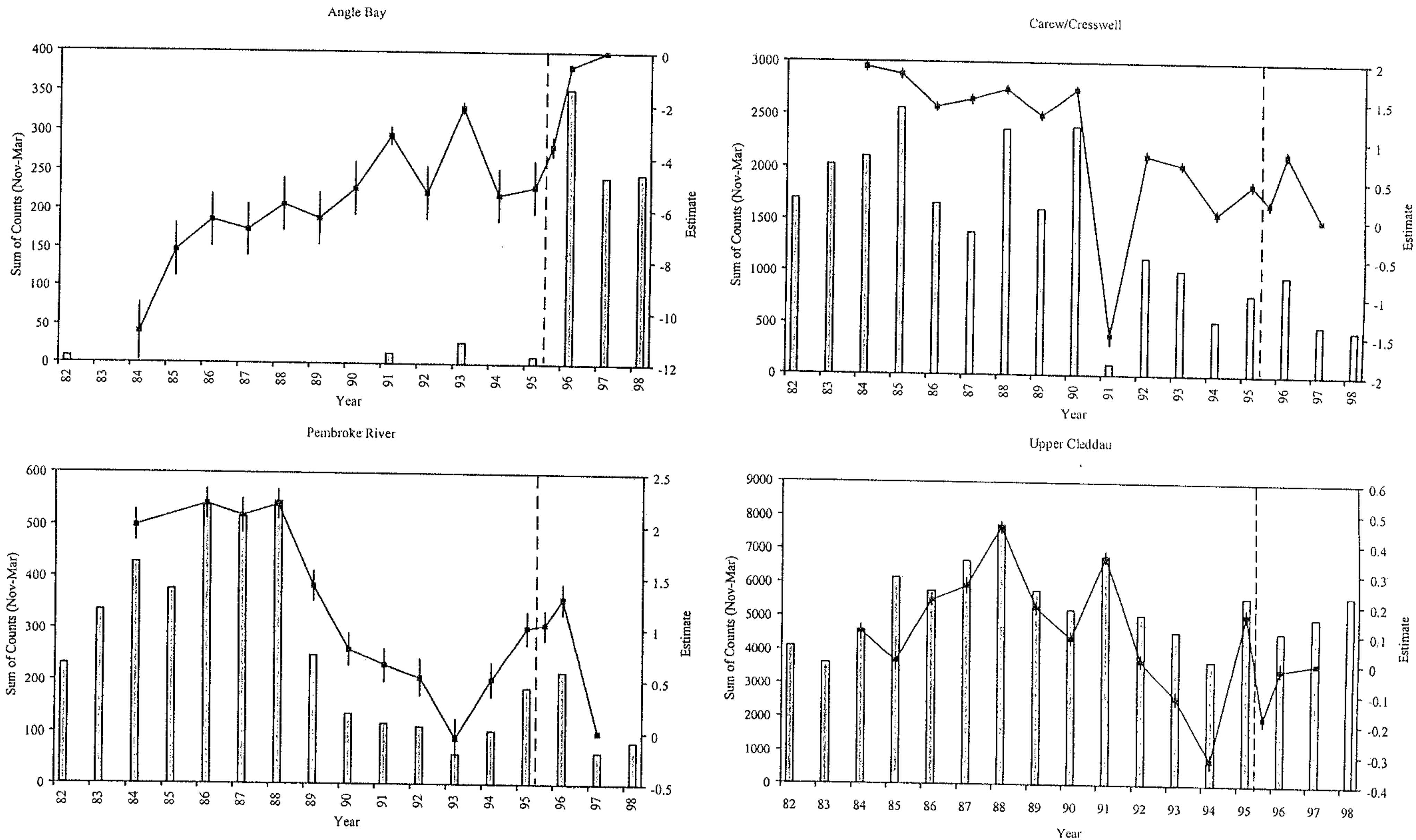
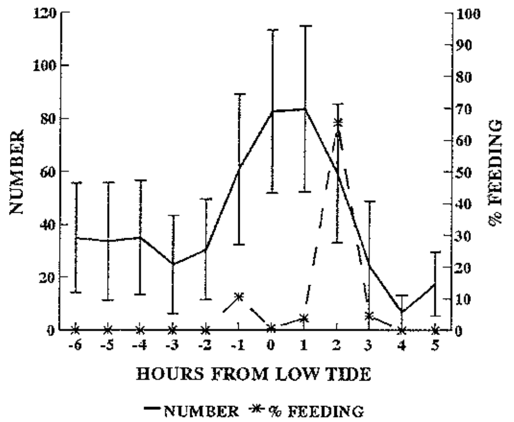
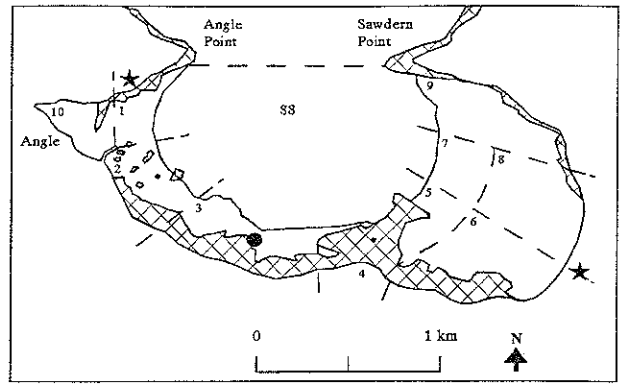


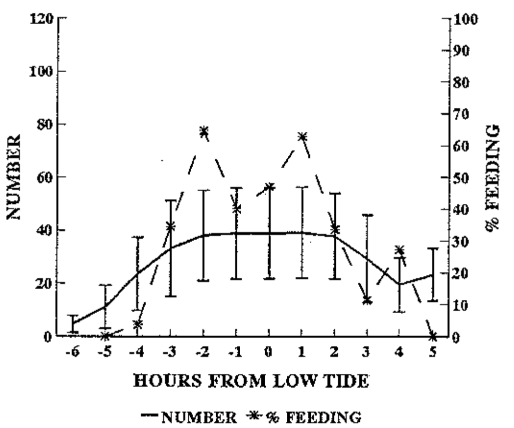
Figure 4.1.3.1 Summed WeBS count data (bars) for Teal for the winters (November to March) of 1982/83 to 1998/99 and estimates (line, with standard errors) for models relating count to year, month and regional index. 82 = 1982/83, etc. The dotted line indicates the date of the spill; points immediately before and after are the estimates for November 1995 to January 1996 and February to March 1996 respectively.

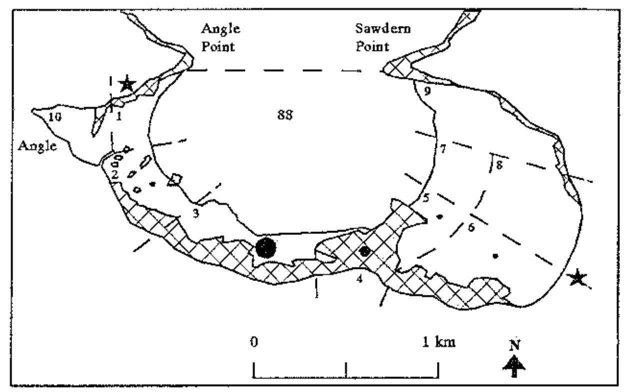
1996/97



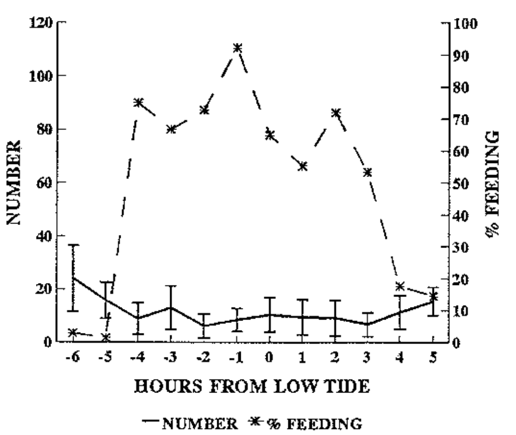


1997/98





1998/99



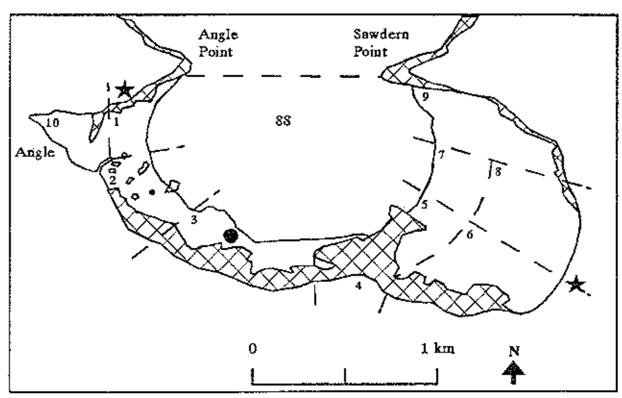
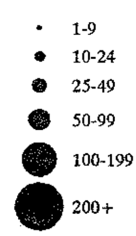
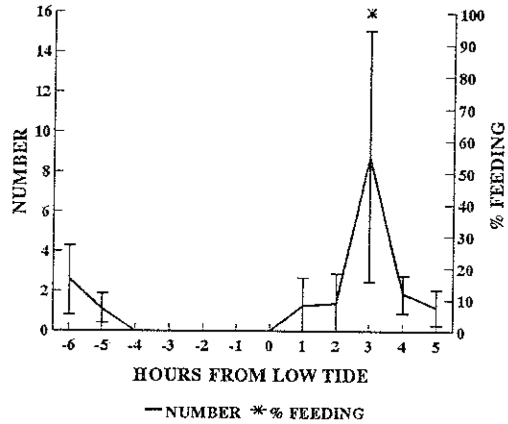
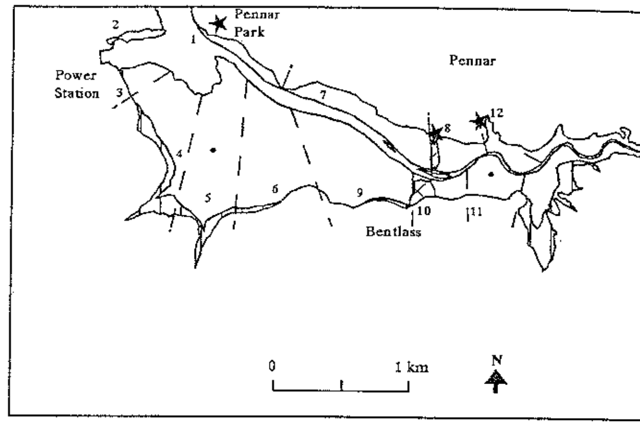


Figure 4.1.3.2 The number of Teal present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Teal (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Angle Bay.

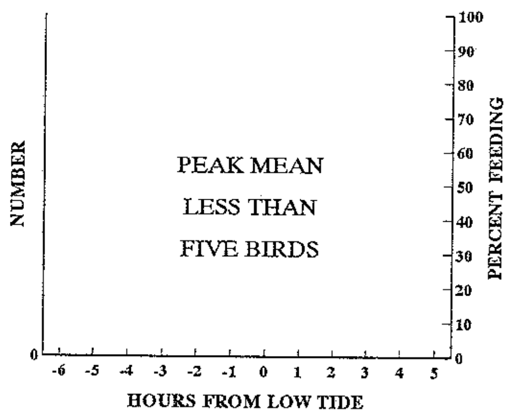


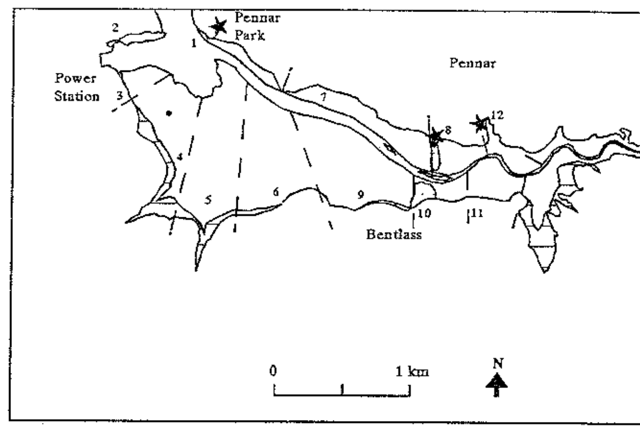
1996/97



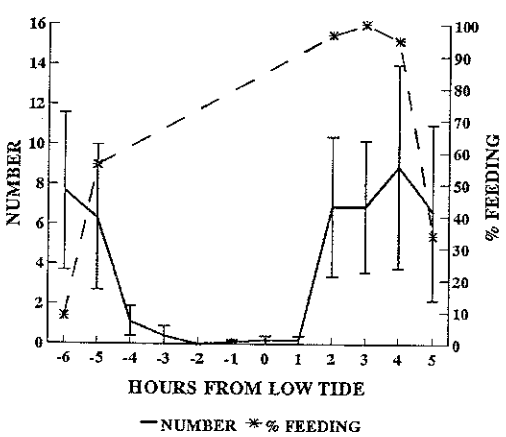


1997/98





1998/99



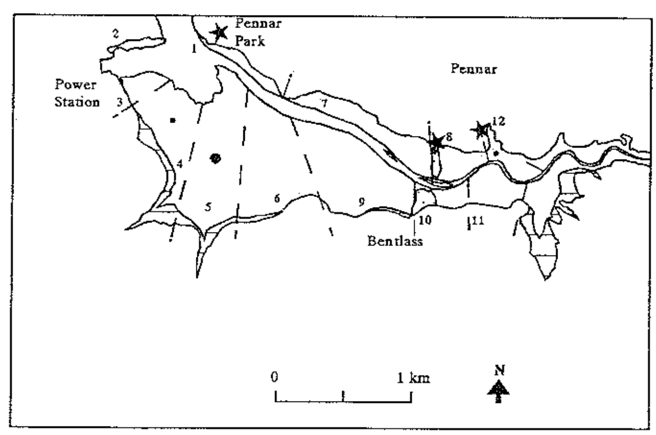
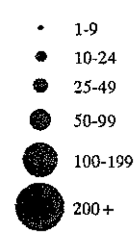


Figure 4.1.3.3 The number of Teal present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Teal (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Pembroke River.



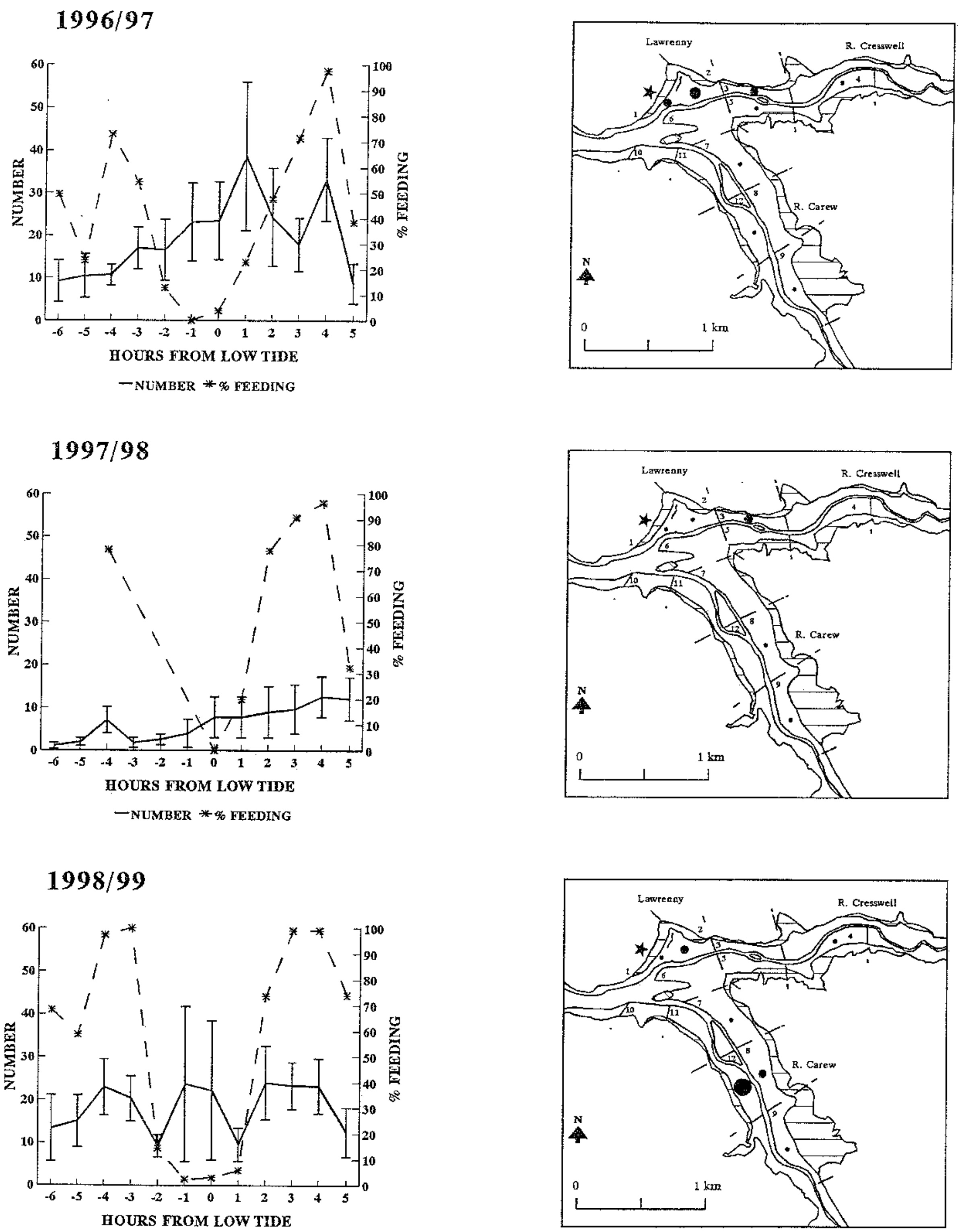
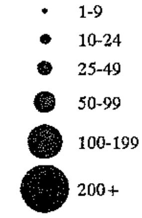


Figure 4.1.3.4 The number of Teal present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Teal (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Carew/Cresswell.



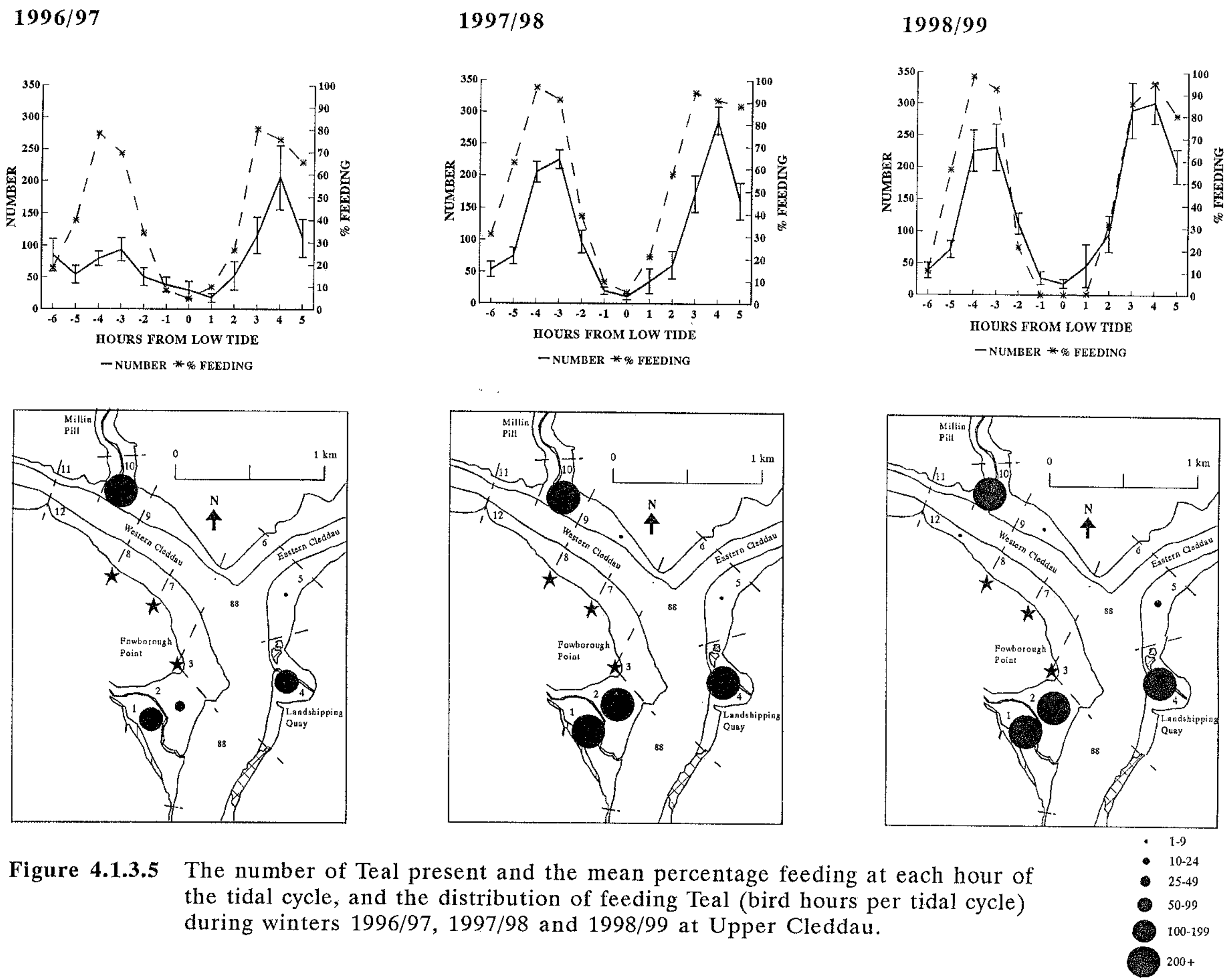


Figure 4.1.3.5 The number of Teal present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Teal (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Upper Cleddau.

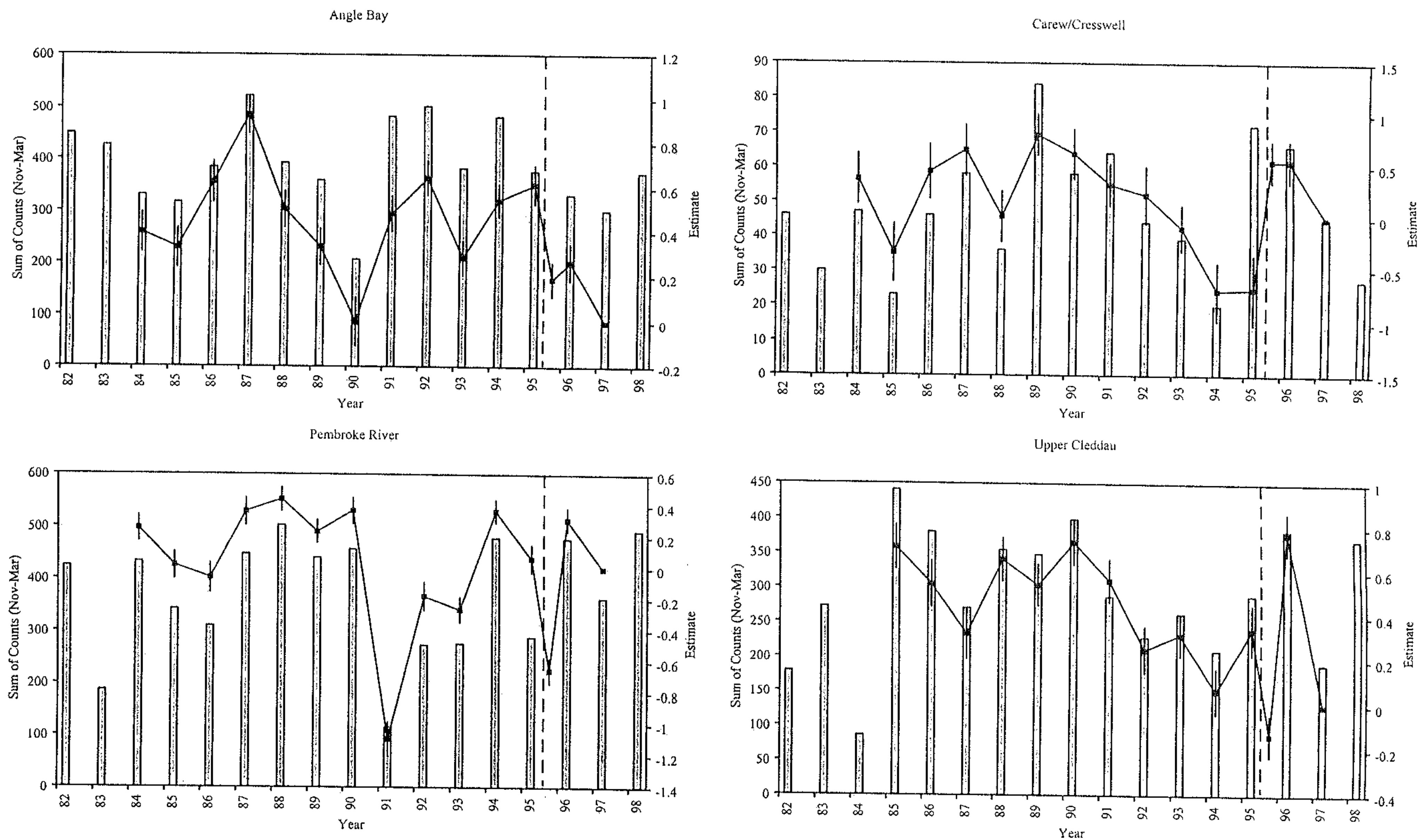


Figure 4.1.4.1 Summed WeBS count data (bars) for Oystercatcher for the winters (November to March) of 1982/83 to 1998/99 and estimates (line, with standard errors) for models relating count to year, month and regional index. 82 = 1982/83, etc. The dotted line indicates the date of the spill; points immediately before and after are the estimates for November 1995 to January 1996 and February to March 1996 respectively.

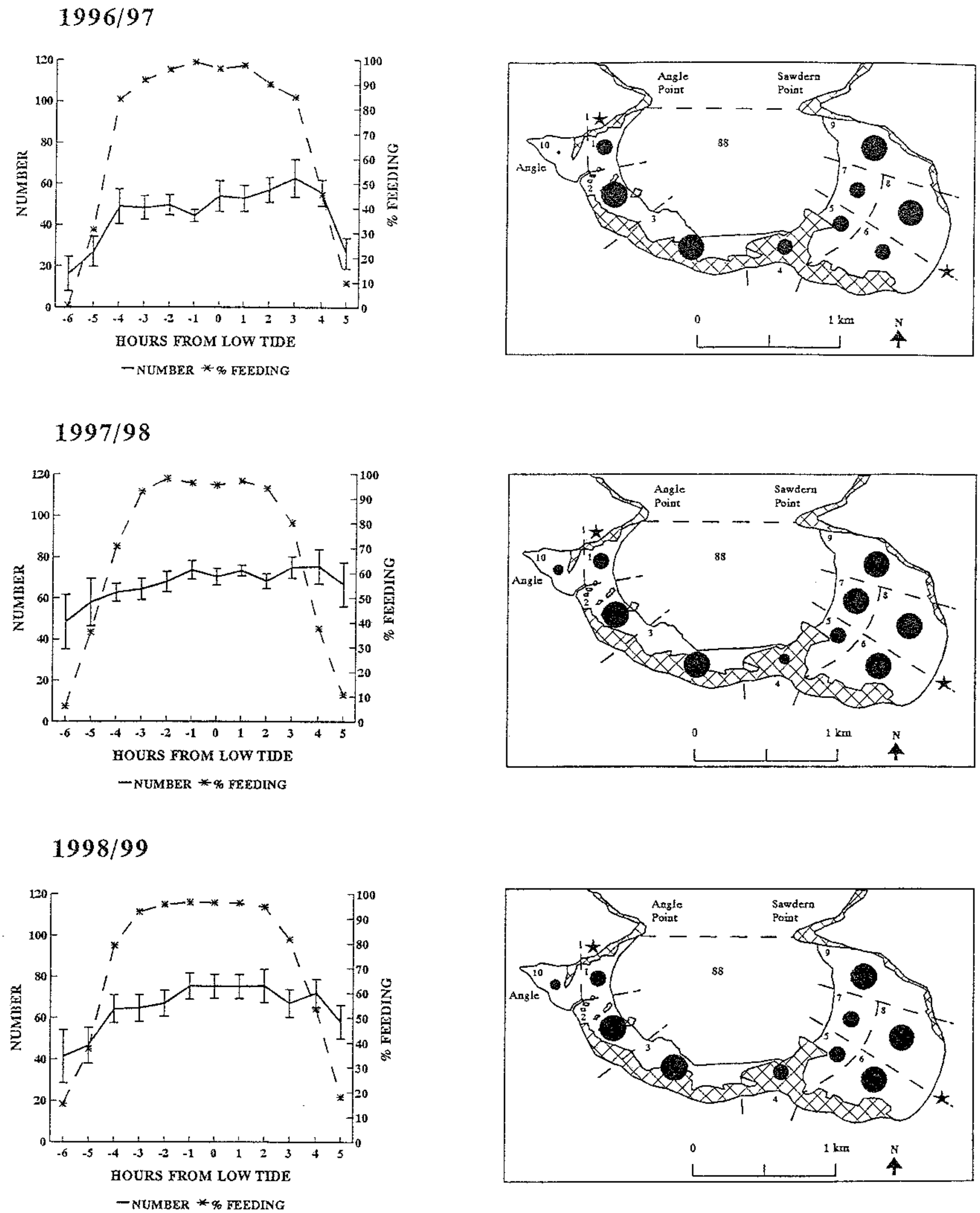
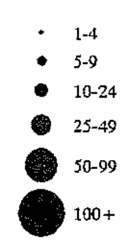
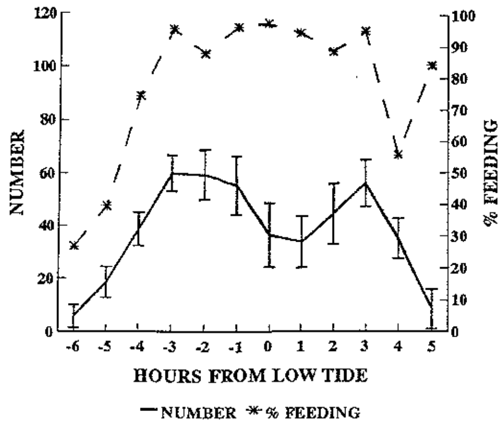
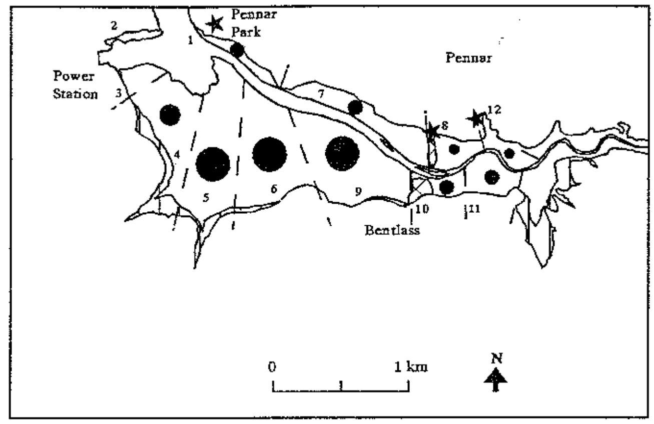


Figure 4.1.4.2 The number of Oystercatcher present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Oystercatcher (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Angle Bay.

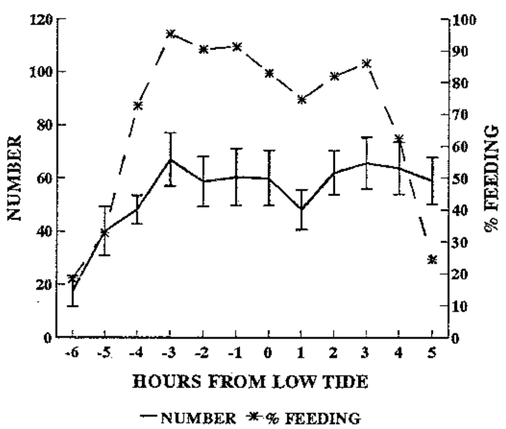


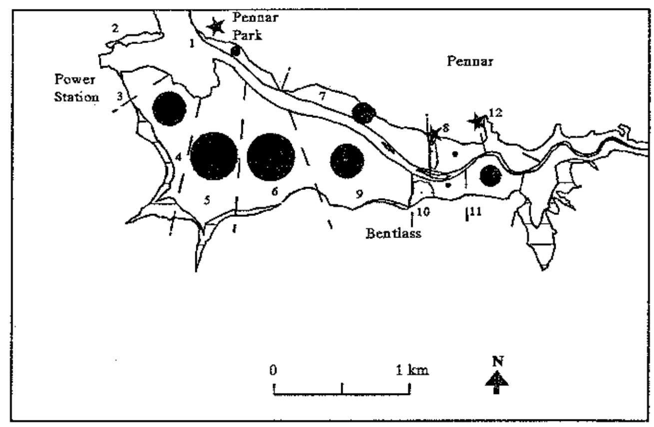
1996/97



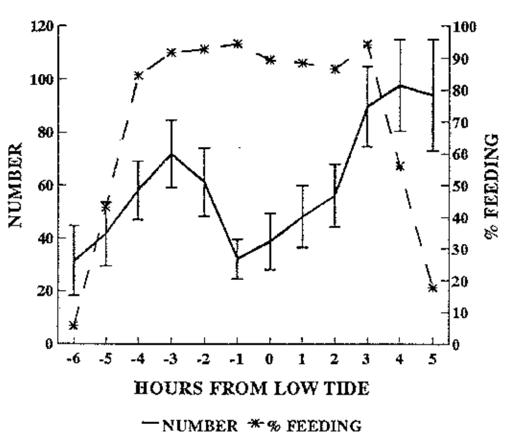


1997/98





1998/99



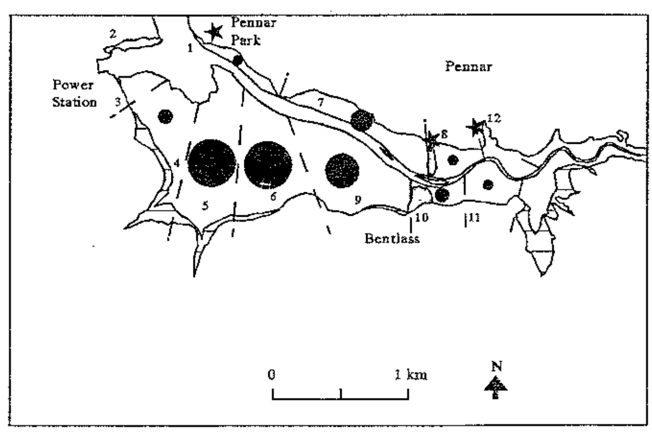
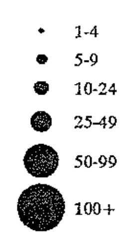


Figure 4.1.4.3 The number of Oystercatcher present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Oystercatcher (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Pembroke River.



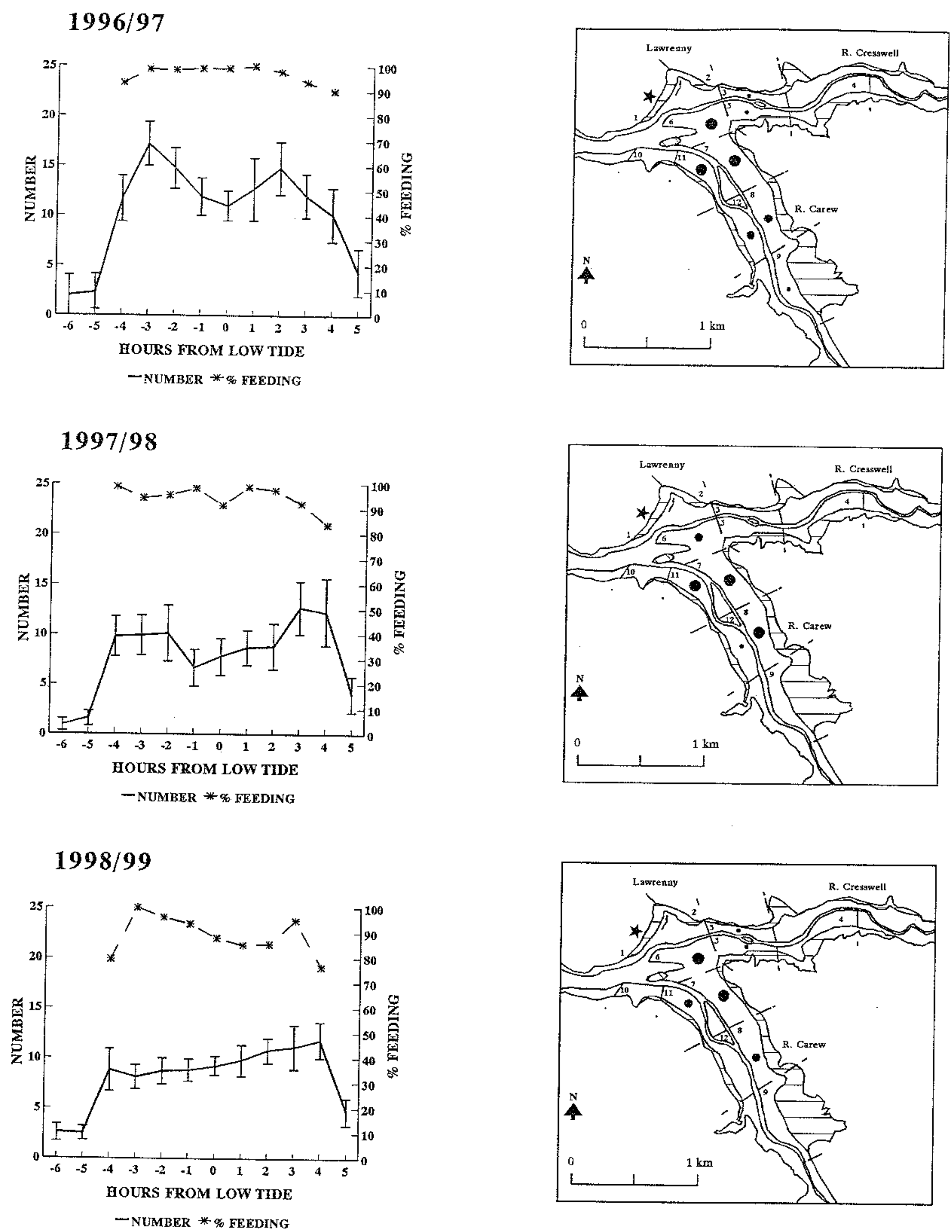
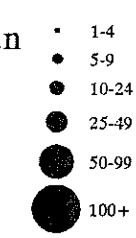


Figure 4.1.4.4 The number of Oystercatcher present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Oystercatcher (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Carew/Cresswell.



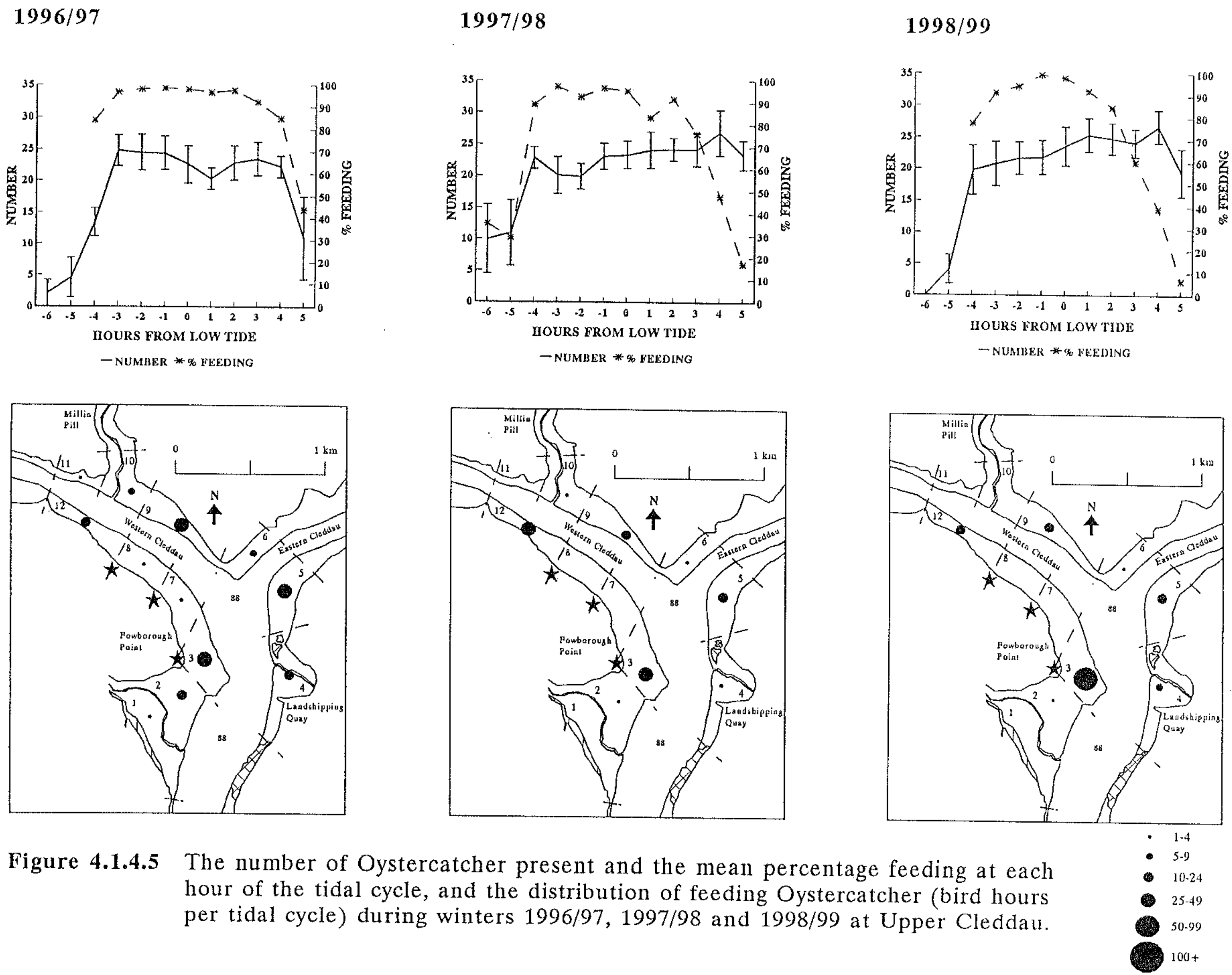


Figure 4.1.4.5 The number of Oystercatcher present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Oystercatcher (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Upper Cleddau.

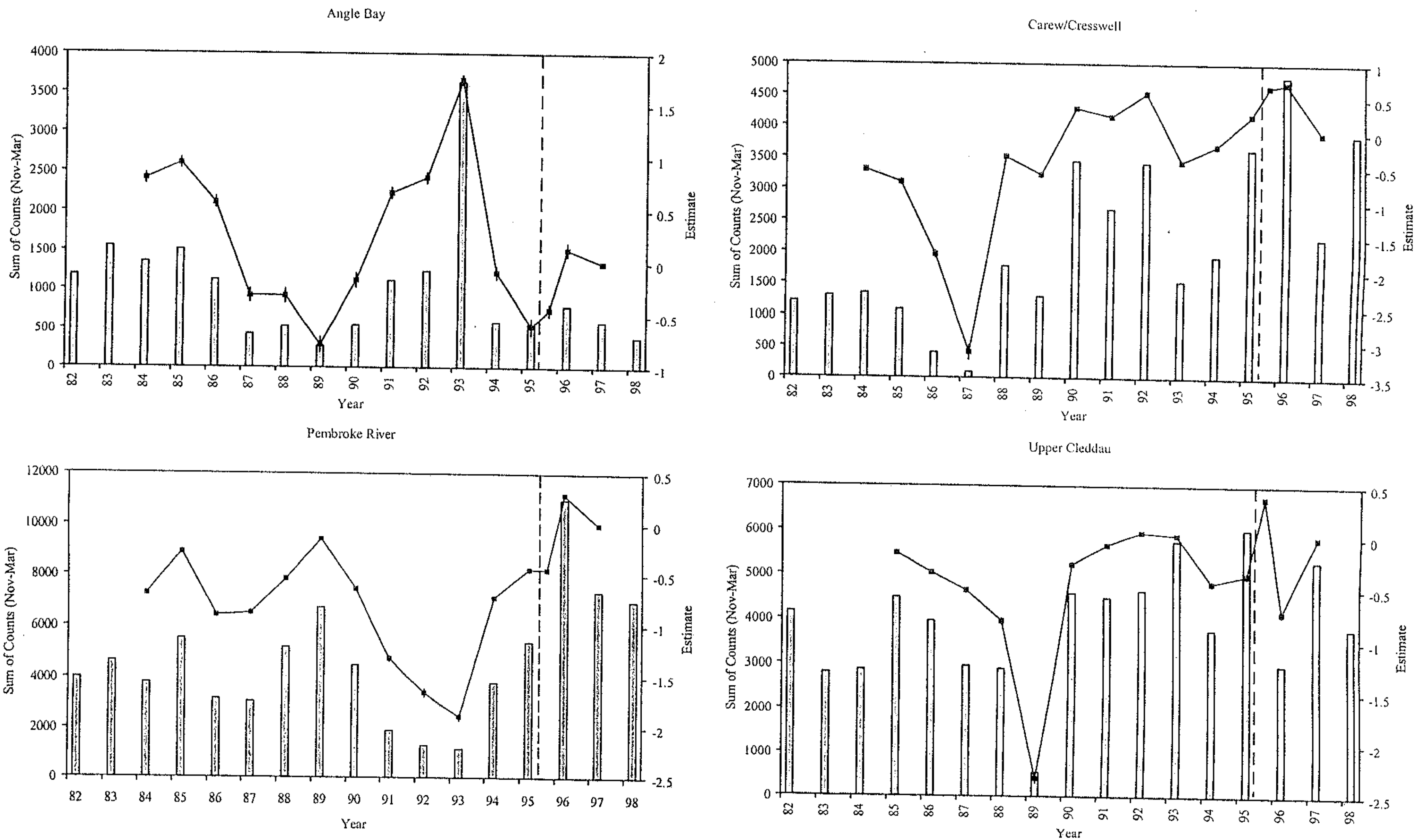
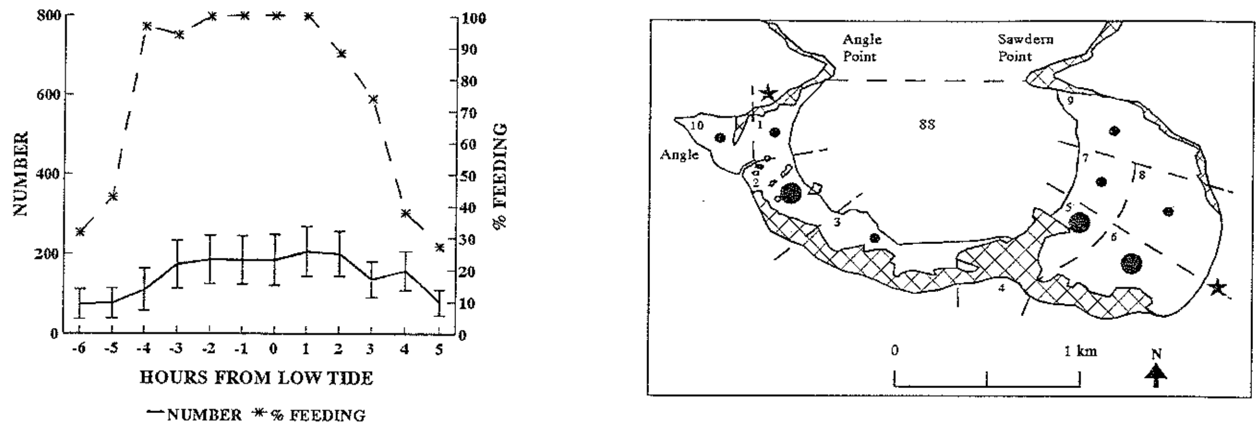
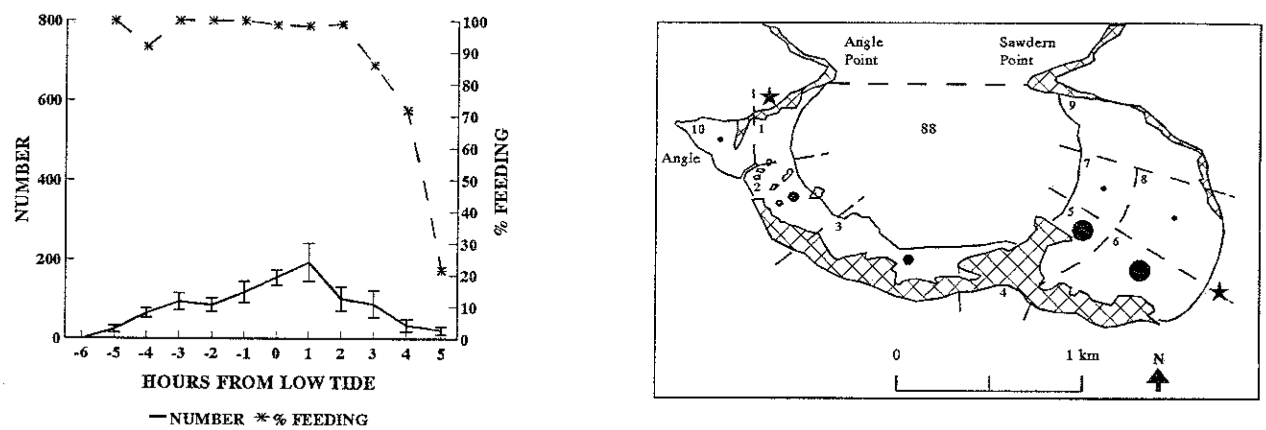


Figure 4.1.5.1 Summed WeBS count data (bars) for Dunlin for the winters (November to March) of 1982/83 to 1998/99 and estimates (line, with standard errors) for models relating count to year, month and regional index. 82 = 1982/83, etc. The dotted line indicates the date of the spill; points immediately before and after are the estimates for November 1995 to January 1996 and February to March 1996 respectively.

1996/97



1997/98



1998/99

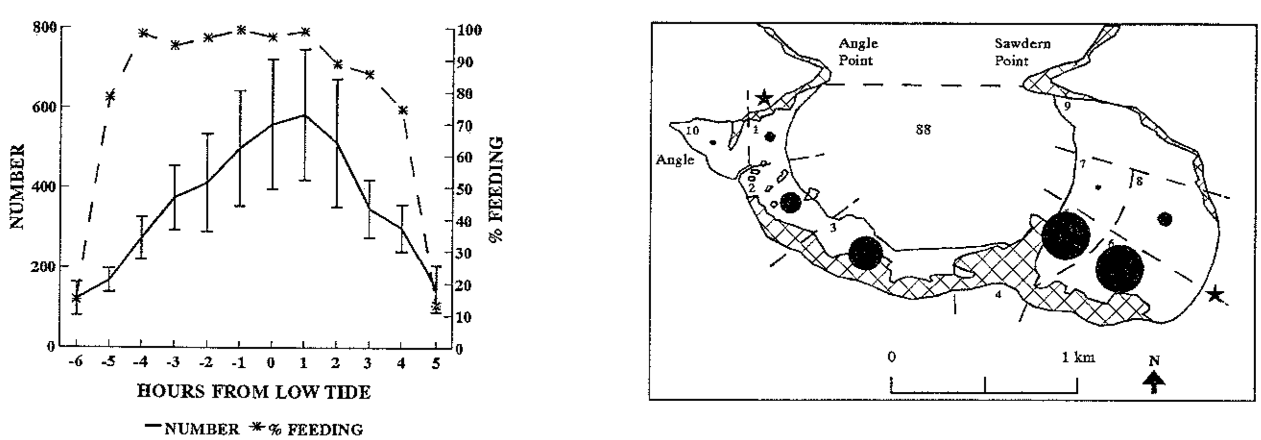
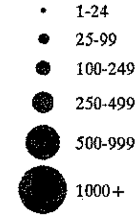
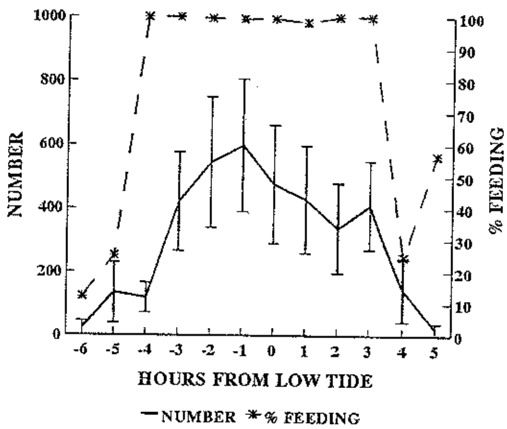
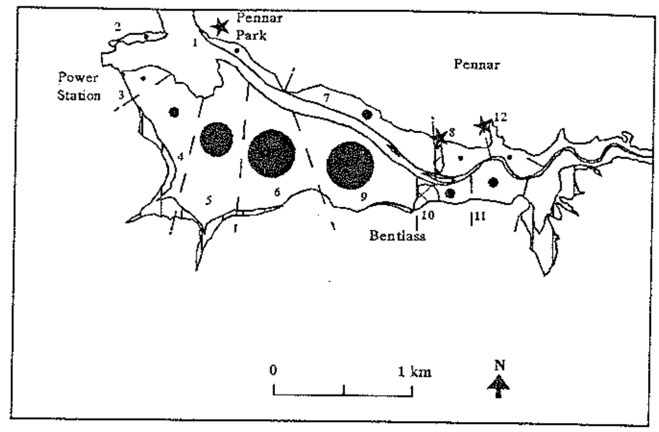


Figure 4.1.5.2 The number of Dunlin present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Dunlin (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Angle Bay.

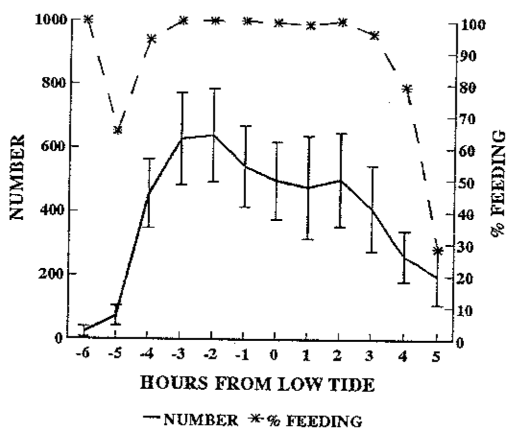


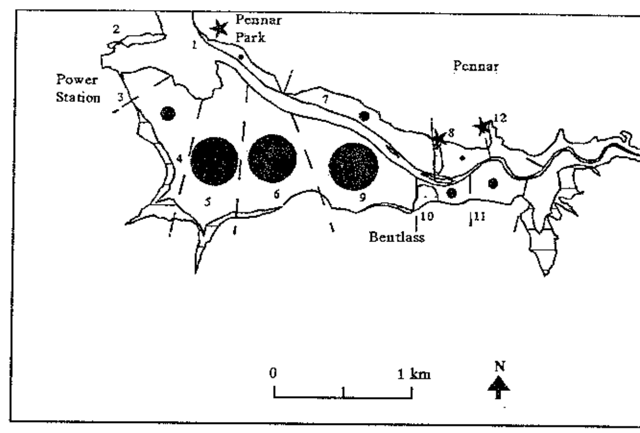
1996/97



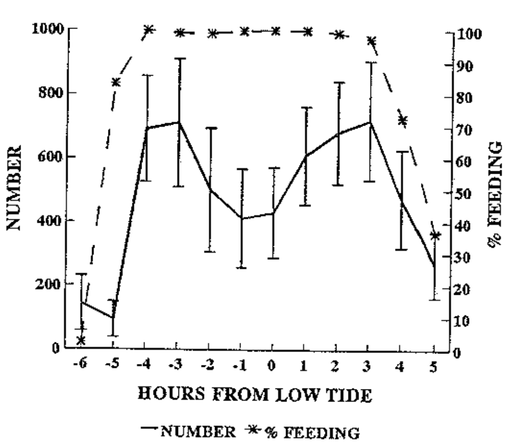


1997/98





1998/99



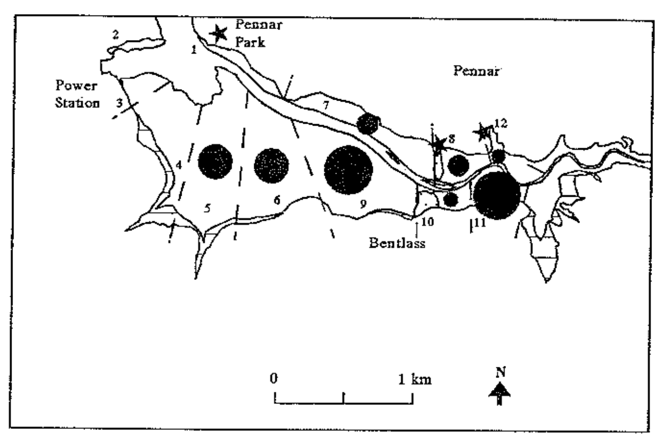
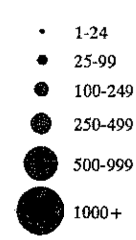
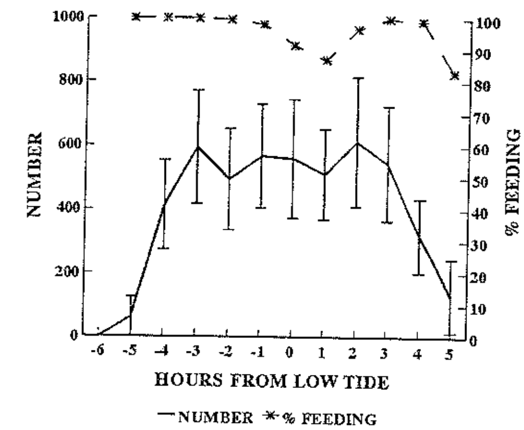
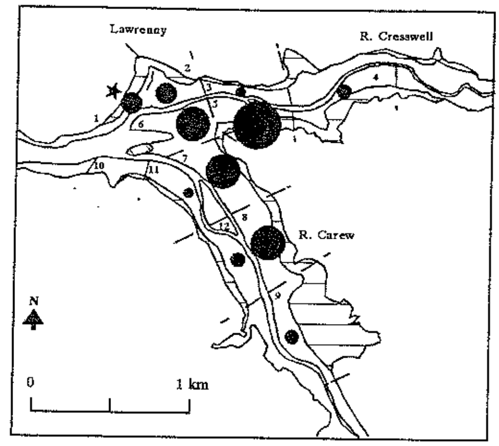


Figure 4.1.5.3 The number of Dunlin present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Dunlin (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Pembroke River.

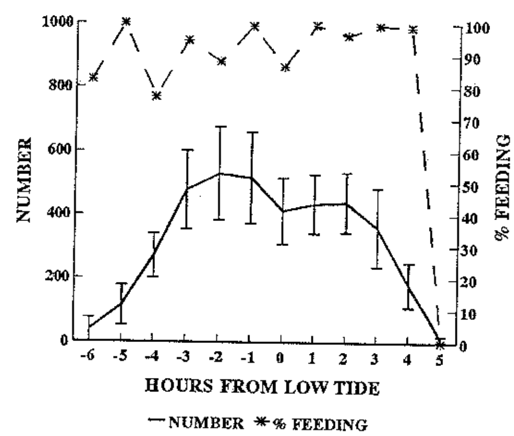


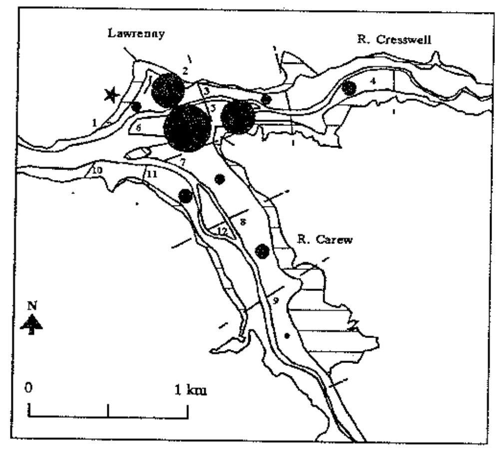
1996/97



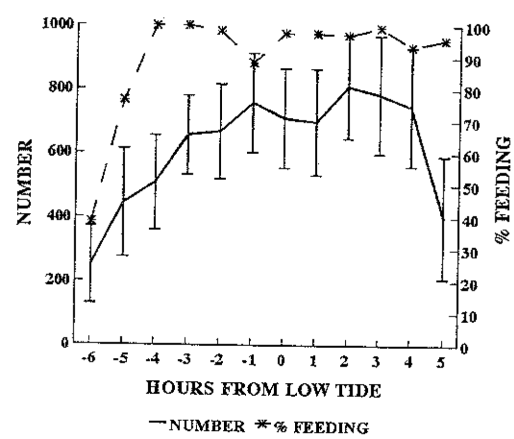


1997/98





1998/99



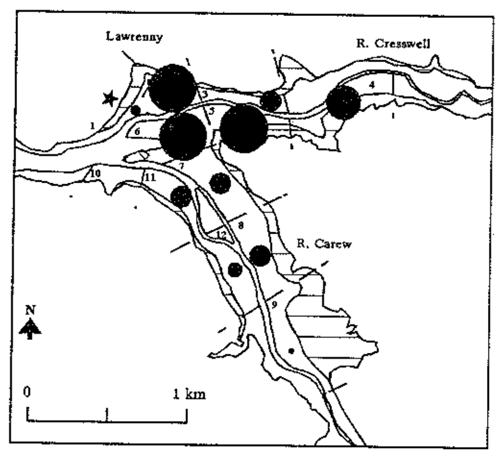
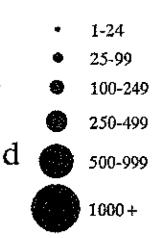
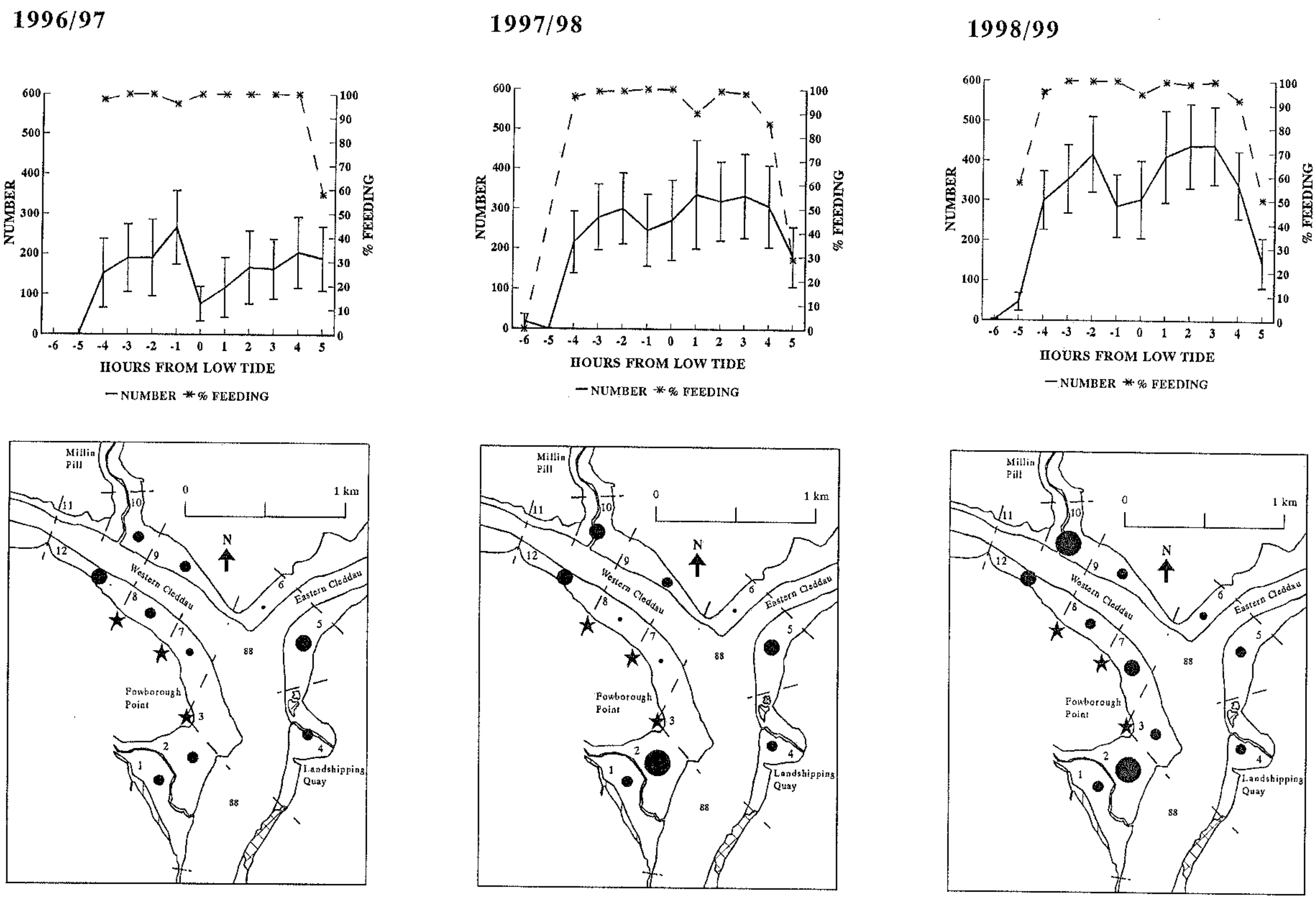


Figure 4.1.5.4 The number of Dunlin present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Dunlin (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Carew/Cresswell.





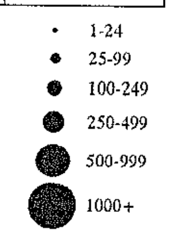


Figure 4.1.5.5 The number of Dunlin present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Dunlin (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Upper Cleddau.

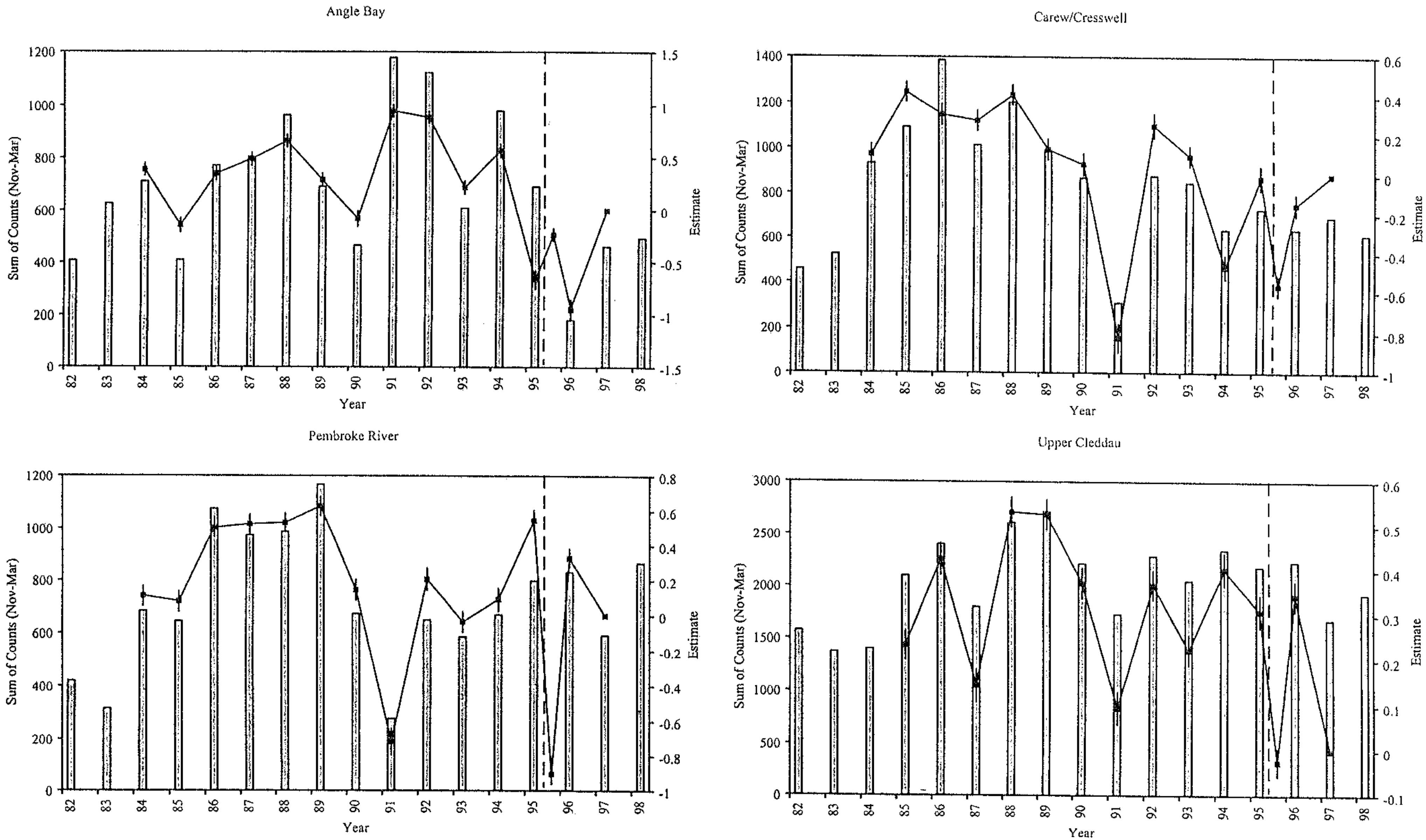
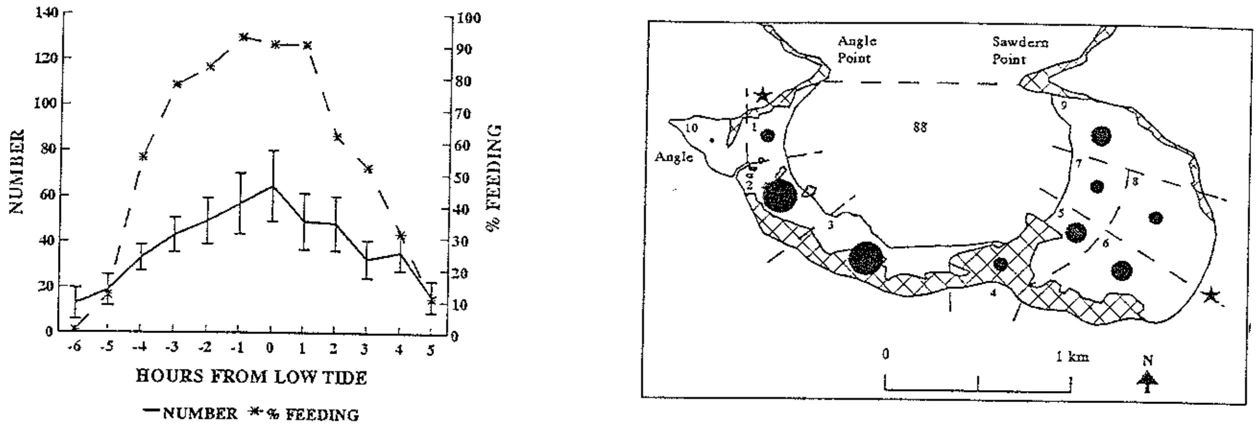
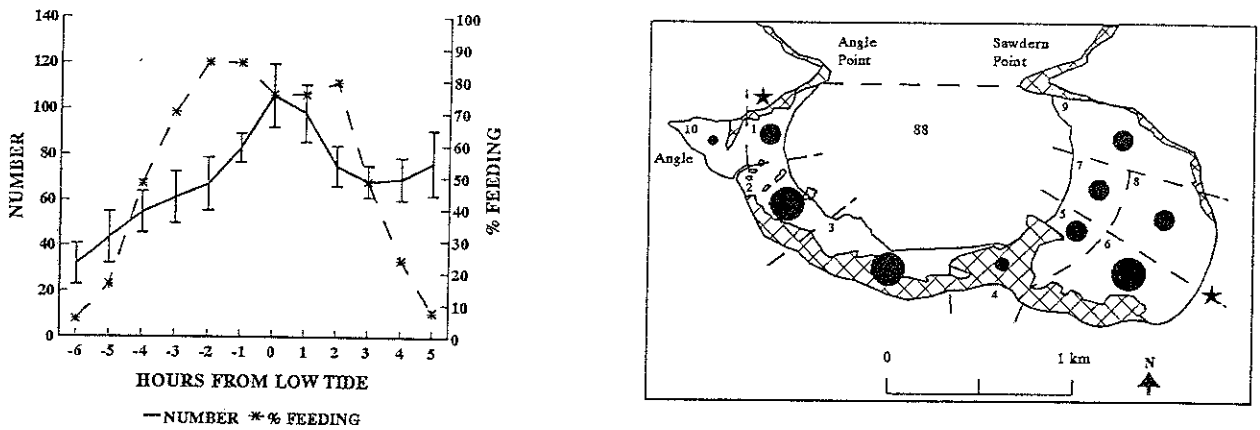


Figure 4.1.6.1 Summed WeBS count data (bars) for Curlew for the winters (November to March) of 1982/83 to 1998/99 and estimates (line, with standard errors) for models relating count to year, month and regional index. 82 = 1982/83, etc. The dotted line indicates the date of the spill; points immediately before and after are the estimates for November 1995 to January 1996 and February to March 1996 respectively.

1996/97



1997/98



1998/99

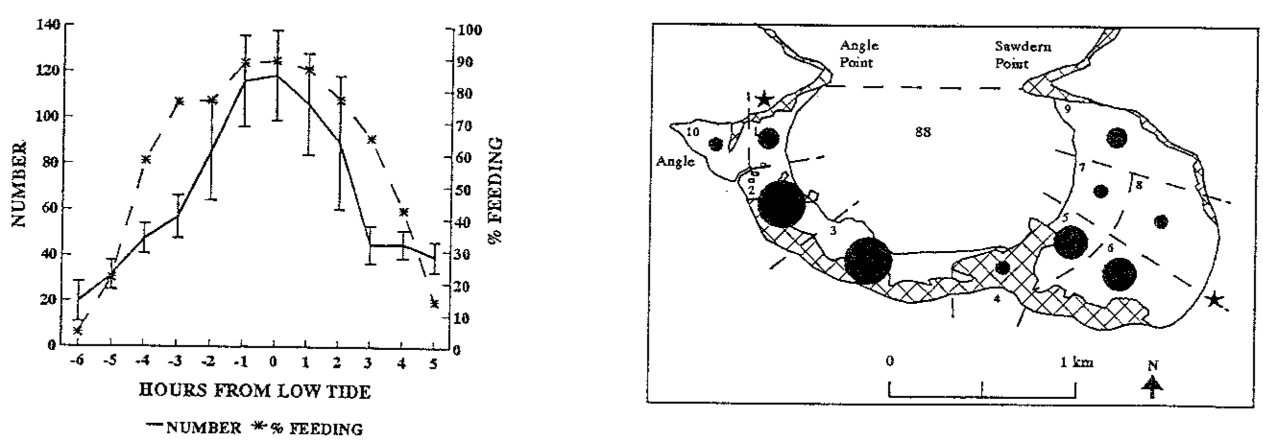
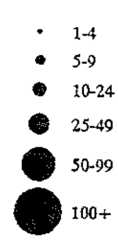
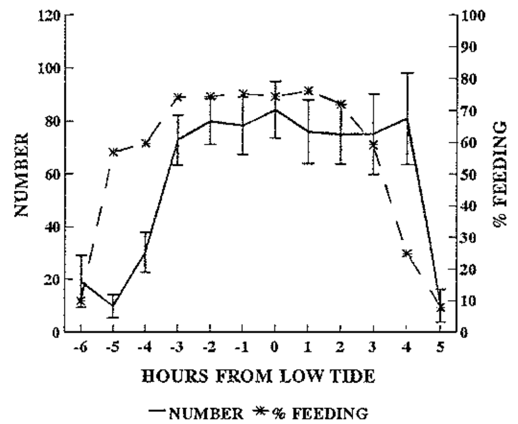
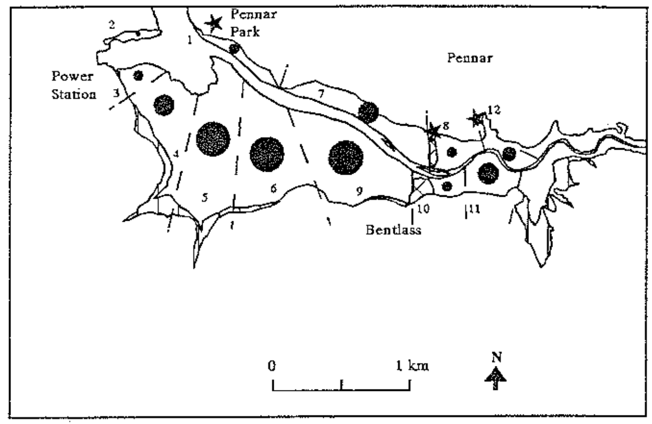


Figure 4.1.6.2 The number of Curlew present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Curlew (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Angle Bay.

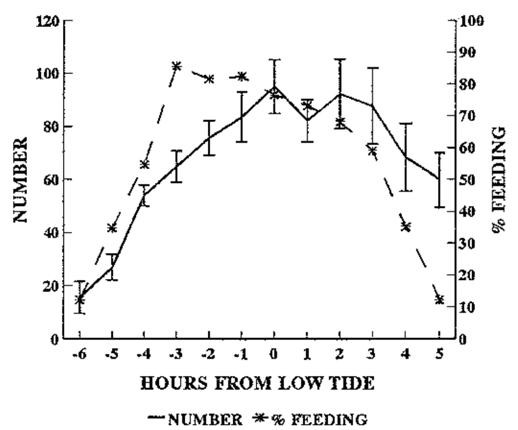


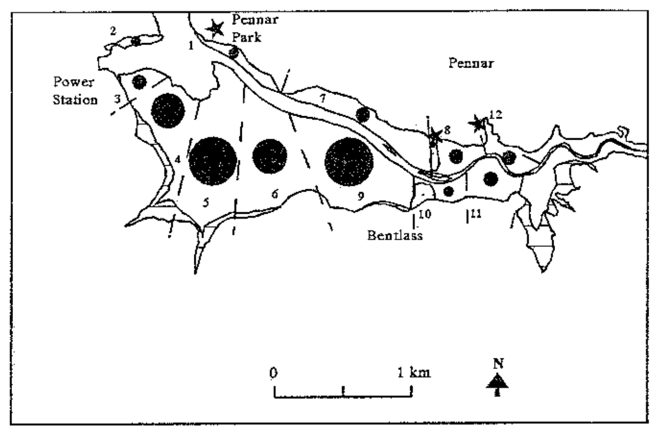
1996/97



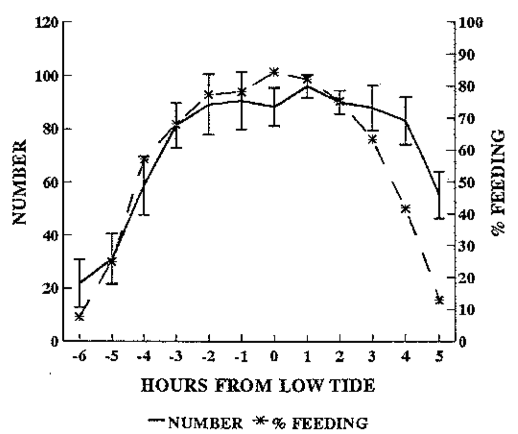


1997/98





1998/99



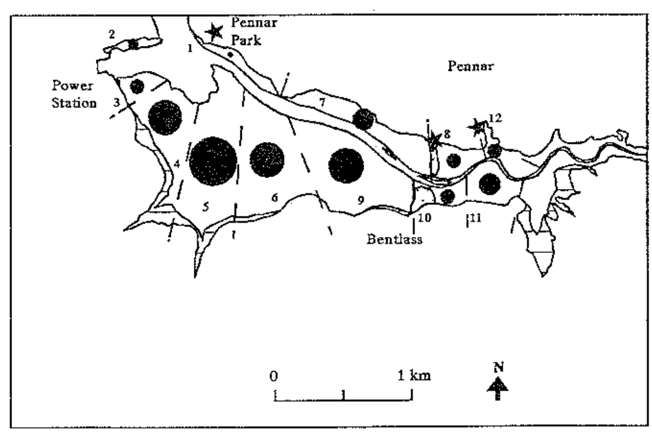
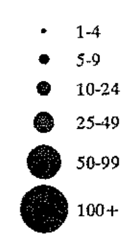


Figure 4.1.6.3 The number of Curlew present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Curlew (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Pembroke River.



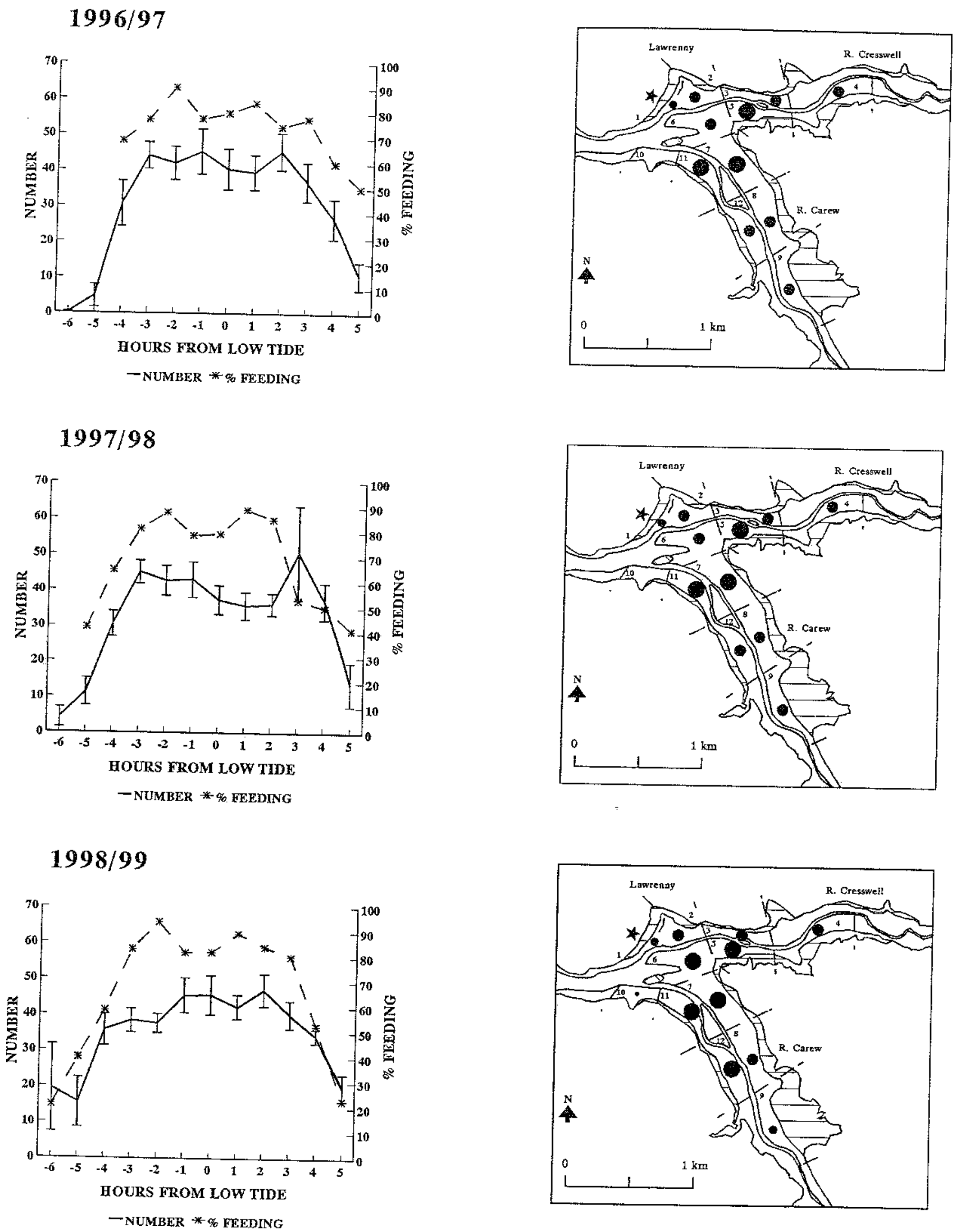
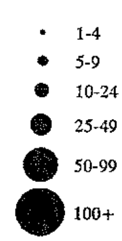


Figure 4.1.6.4 The number of Curlew present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Curlew (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Carew/Cresswell.



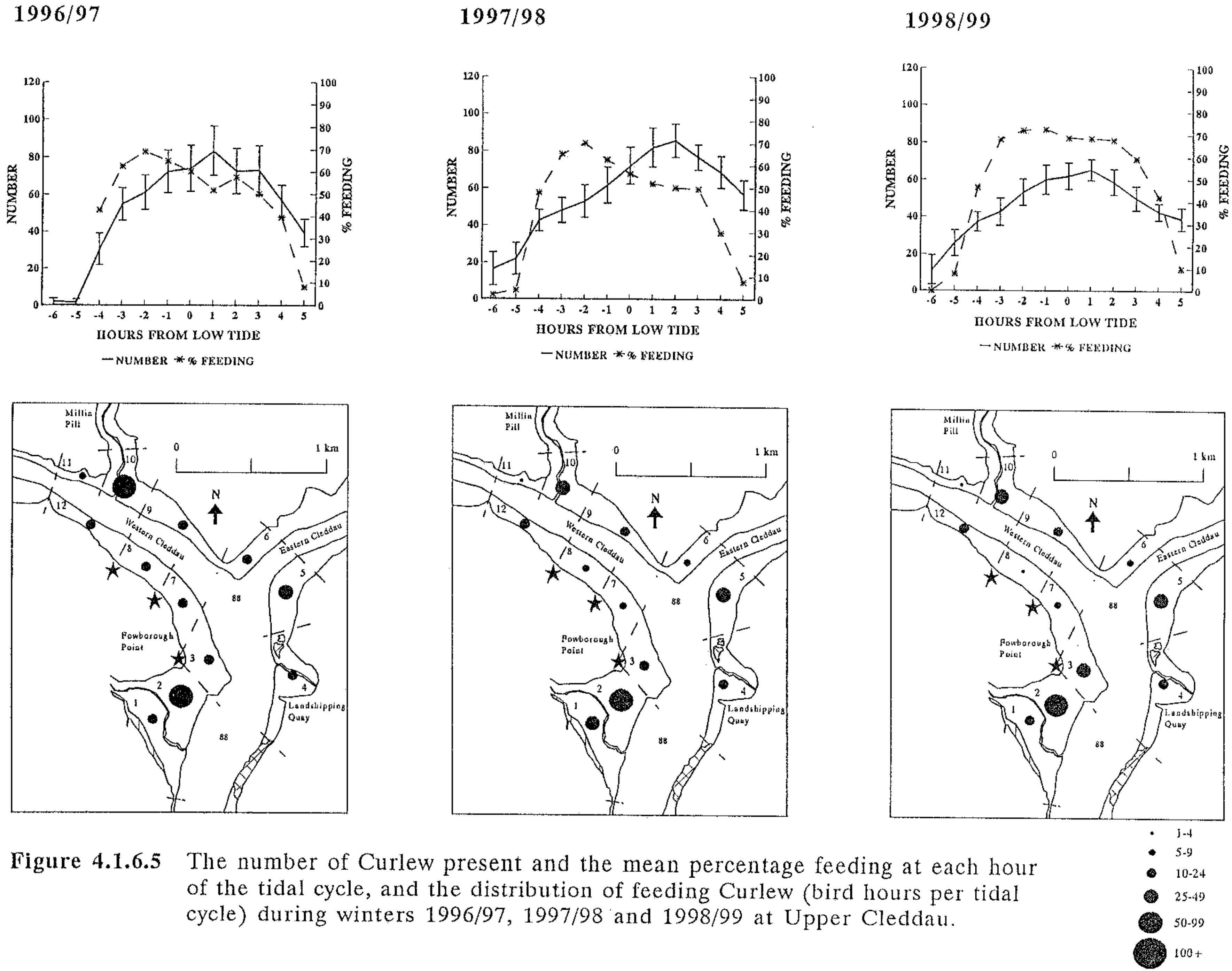


Figure 4.1.6.5 The number of Curlew present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Curlew (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Upper Cleddau.

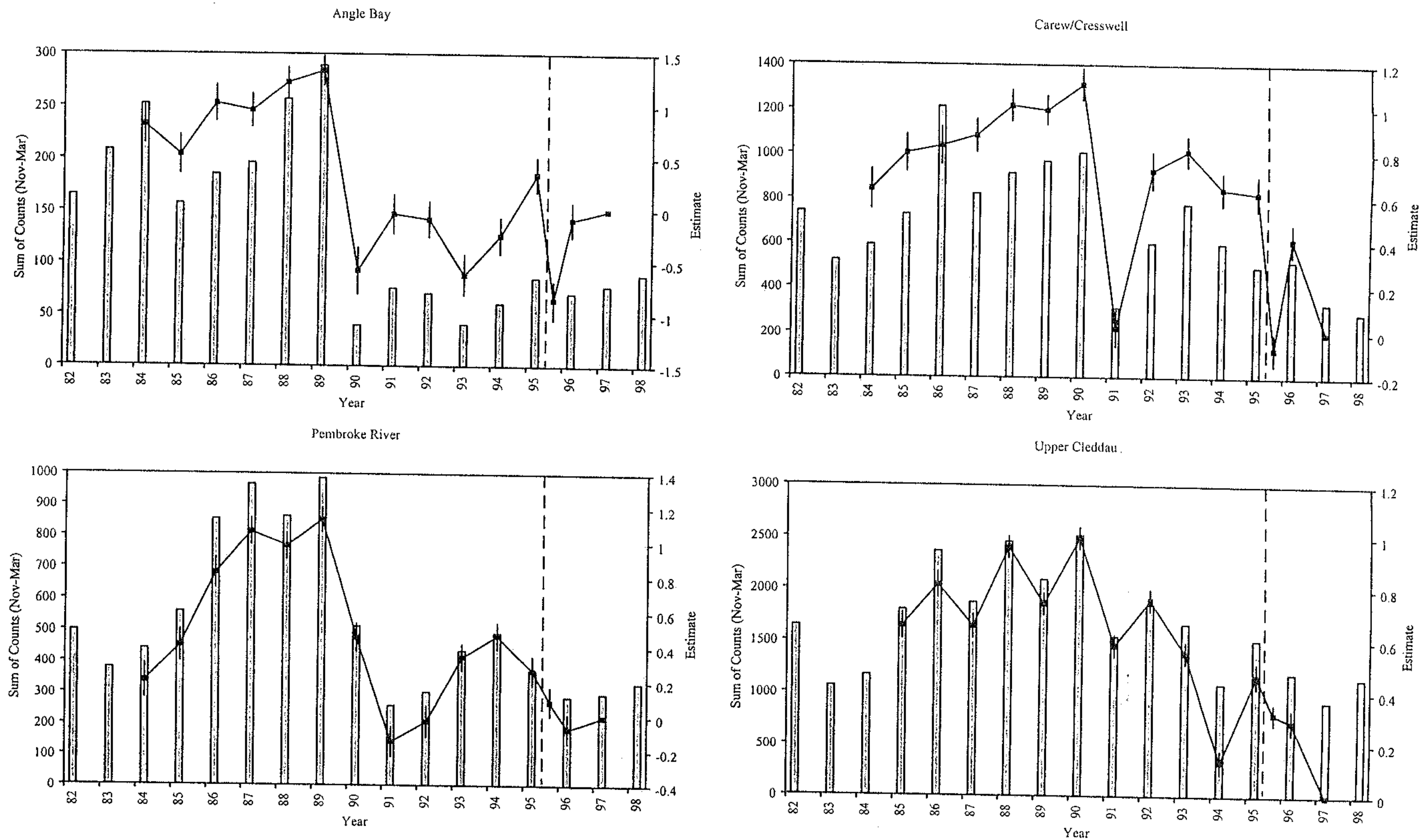
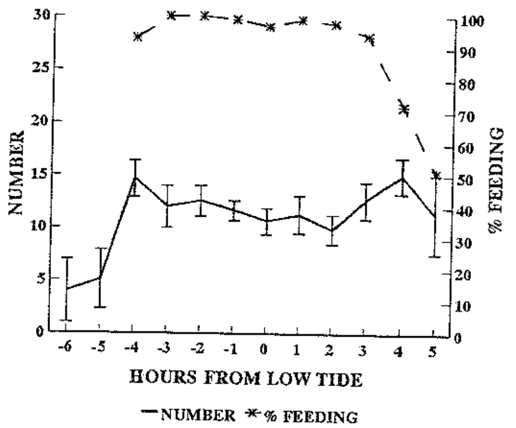
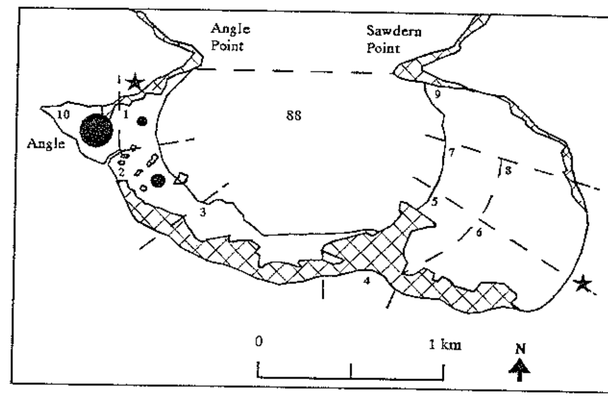


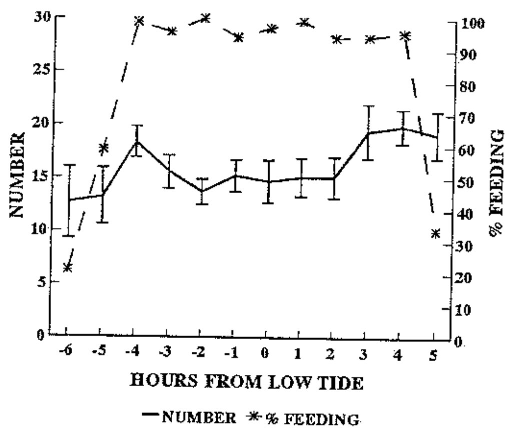
Figure 4.1.7.1 Summed WeBS count data (bars) for Redshank for the winters (November to March) of 1982/83 to 1998/99 and estimates (line, with standard errors) for models relating count to year, month and regional index. 82 = 1982/83, etc. The dotted line indicates the date of the spill; points immediately before and after are the estimates for November 1995 to January 1996 and February to March 1996 respectively.

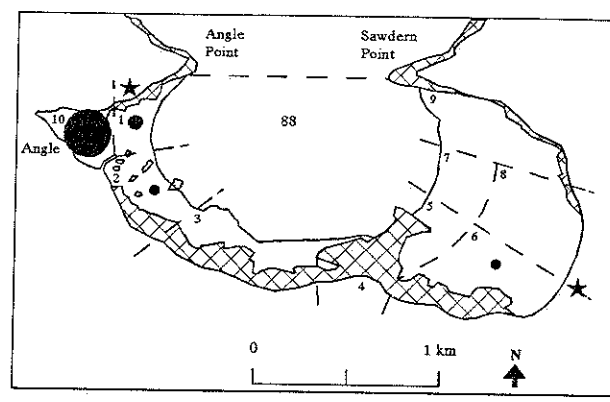
1996/97



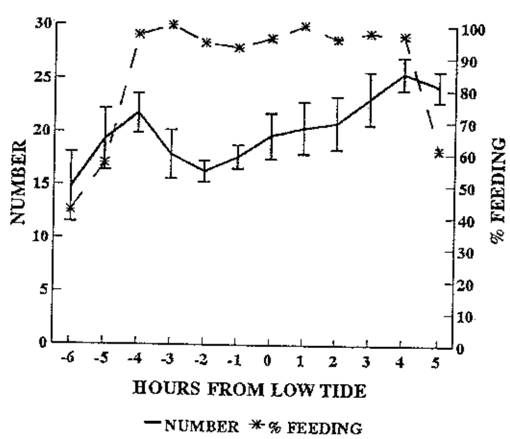


1997/98





1998/99



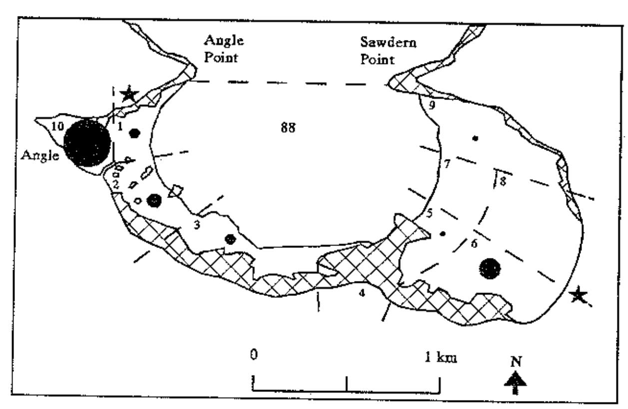
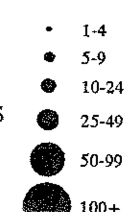
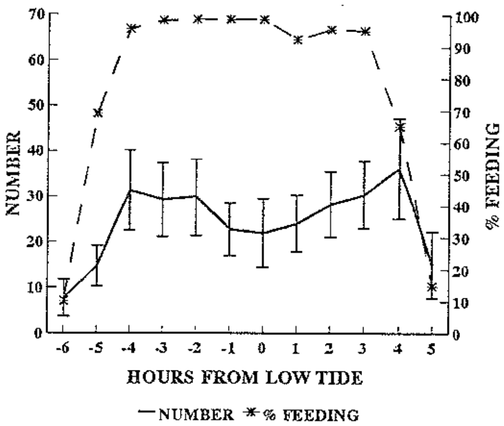
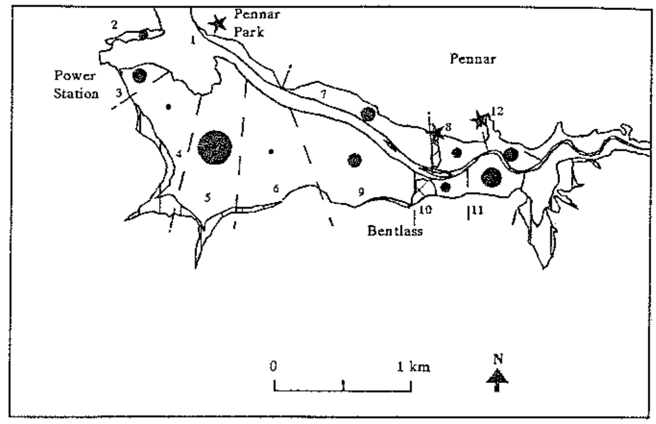


Figure 4.1.7.2 The number of Redshank present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Redshank (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Angle Bay.

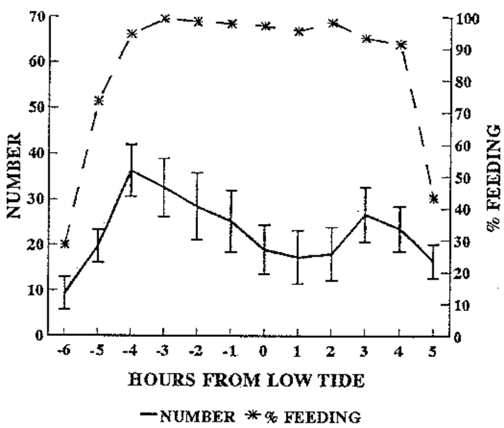


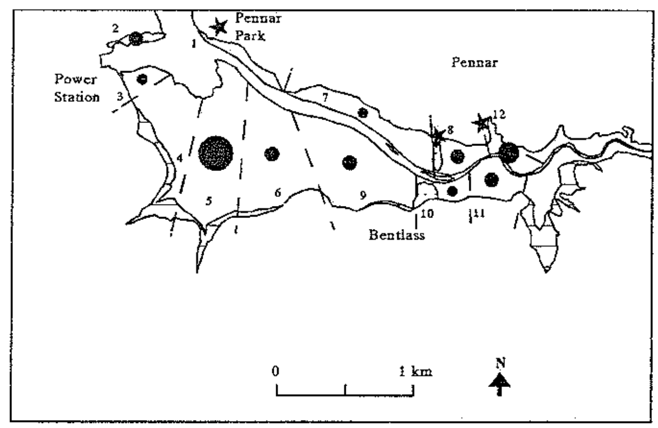
1996/97



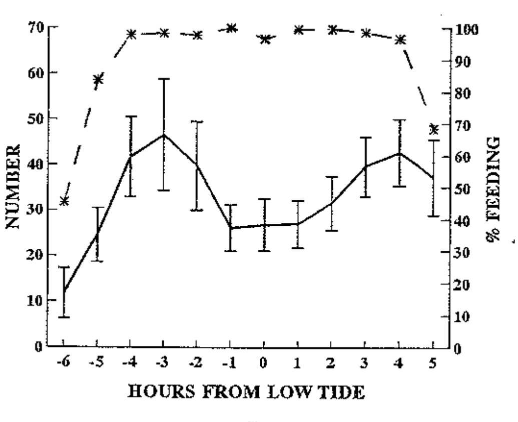


1997/98





1998/99



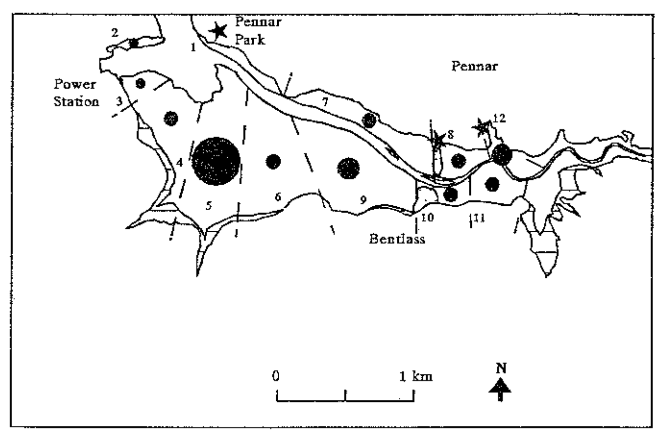
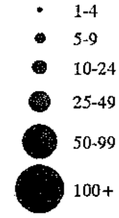
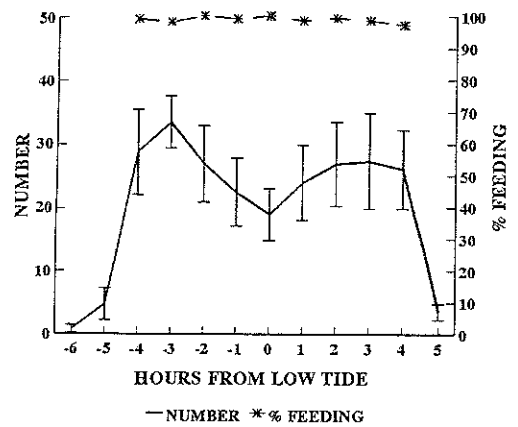
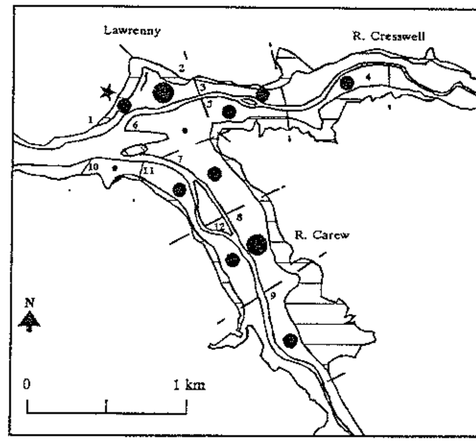


Figure 4.1.7.3 The number of Redshank present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Redshank (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Pembroke River.

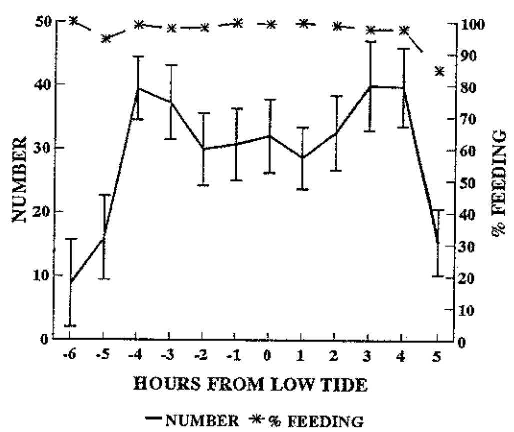


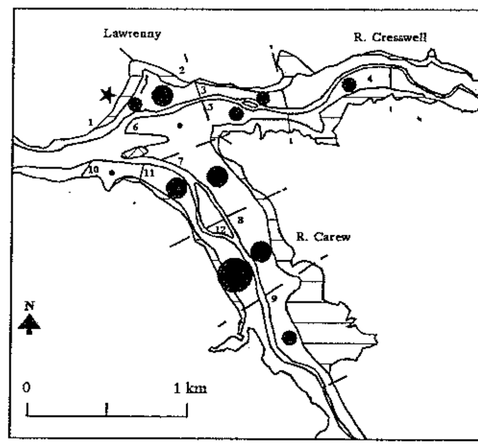
1996/97



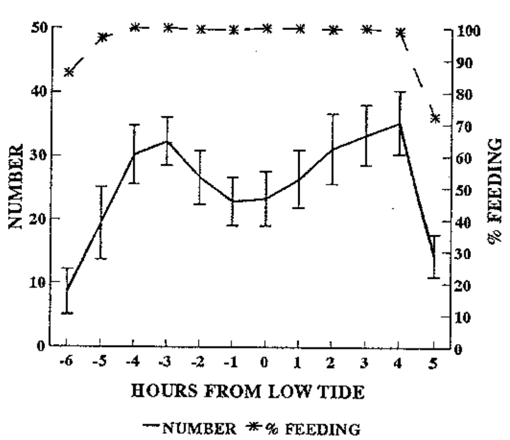


1997/98





1998/99



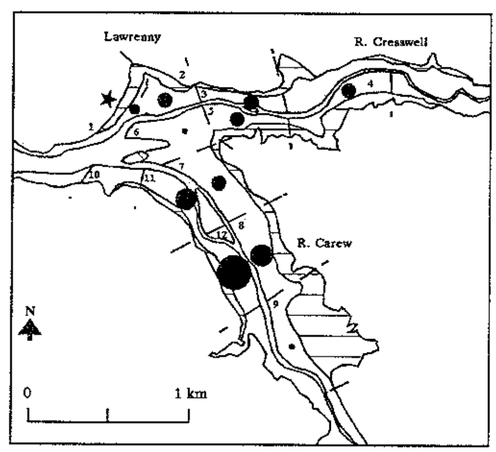
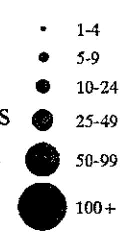
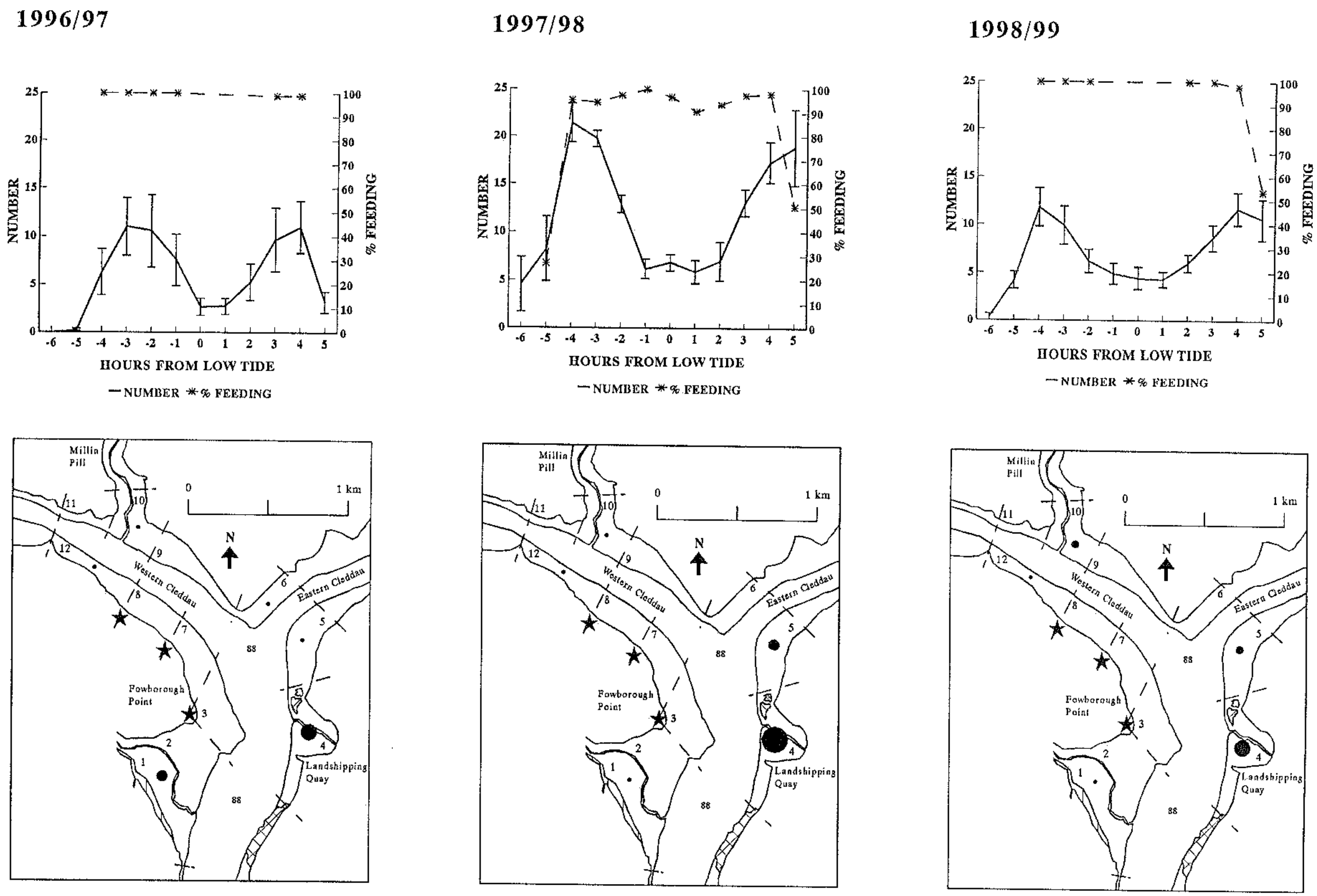


Figure 4.1.7.4 The number of Redshank present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Redshank (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Carew/Cresswell.





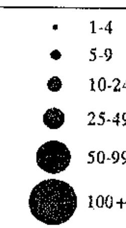


Figure 4.1.7.5 The number of Redshank present and the mean percentage feeding at each hour of the tidal cycle, and the distribution of feeding Redshank (bird hours per tidal cycle) during winters 1996/97, 1997/98 and 1998/99 at Upper Cleddau.