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THE IMPACT OF THE SEVERN OIL SPILL OF FEBRUARY 1991 ON THE POPULATIONS AND DISTRIBUTIONS OF WATERFOWL

by

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EXECUTIVE SUMMARY

This report is submitted to the Impact Assessment Steering Group, on behalf of British Steel who commissioned the study. The aim of this work was to assess the effects of the Severn oil spill of 11 February 1991 on waterfowl.

This study had the following three main objectives:-

1. to determine the proportion of the bird population present judged to have died as a result of oiling acquired from the spill.

2. to monitor changes that might have occurred in feeding distribution, numbers and timing of migration of oiled and unoiled birds.

3. to assess any possible changes in Shelduck breeding success on the estuary that might be related to the oiling.

The first two objectives were met by work carried out by the British Trust for Ornithology, the third by the Wetlands Advisory Service of the Wildfowl and Wetlands Trust. The study period ranged from the end of the 1990/91 winter to the Shelduck breeding season in 1991.

The first objective was met by collating data from agencies that dealt with the retrieval of oiled and dying birds, such as the RSPCA and the Avon Naturalists Trust, as well as information on the number of oiled birds found during the RSPB beached bird survey of the Welsh coastline. Estuary-wide numbers of oiled birds were obtained from volunteers carrying out low-tide counts on behalf of the BTO. These results are reported in Section 3. In total 197 birds were handed in oiled or dead to the RSPCA or the Avon Naturalists Trust (Table 3.1). A few more birds were found oiled or dead during the beached bird survey (Table 3.2). Locally high percentages of oiled Shelduck, Dunlin, Redshank and gulls (Figures 3.3.1 to 3.3.4) were recorded from the low-tide counts, but again few dead birds were seen. It would seem that several hundred birds were oiled but that only a very small proportion of the wintering population on the Severn died as an immediate result of the spill.

The second objective is dealt with in Sections 4 and 5 of this report. Section 4 uses information on feeding bird distributions, gathered during extensive low tide counts, to analyse the numbers using selected oiled and unoiled sections of the Severn. Had the effect of the oil been severe, the birds would have had limited feeding opportunities in the oiled sections and fewer would have

been expected in those sections. No significant differences were found in the proportion of Shelduck, Dunlin, Curlew and Redshank using oiled and unoiled sections before and after the spill. This implies that the oiling that occurred on the flats did not stop birds feeding. Section 5 compares the change in bird numbers in 1991 to changes that occurred during the four past years 1987 to 1990. There was no evidence that Shelduck, Dunlin, Curlew or Redshank left the estuary early or that they used oiled sections less at high tide. Thus it did not appear that their timing of migration was changed.

The third objective, to assess any possible changes in Shelduck breeding success on the estuary, was sub-contracted to the Wetlands Advisory Service of the Wildfowl and Wetlands Trust and their report forms section 6 of this report. The numbers distribution and breeding success of Shelduck within the Severn were monitored using similar techniques to those employed in the previous two years. The pattern of counts in 1991 was similar to those found in previous years suggesting that there was no detectable effect on the breeding population of Shelduck within the Severn.

The lack of significant effects of the oil spill on bird populations was thought to be the result of the following factors:

1. The total amount of oil released was not very large compared to the size of the estuary, and much of it may have dispersed to the sea, although some was recovered out in the estuary, and some probably sank and would have affected only the subtidal benthos.

2. The released heavy fuel oil had a relatively low proportion of the light volatile fractions which are more harmful to life than the heavier, less volatile, fractions. Heavier oils smear but are less poisonous.

3. The oil did not concentrate in large enough quantities to cause the smothering of mudflats and sediments, which would have led to widespread plant and invertebrate deaths. Oiling was localised and patchy.

4. Unoiled sections of the estuary were present at all times including some, such as Bridgwater Bay, which are particularly important to feeding birds.

5. No detergents were used to clean up the residue of the oil spill on the south shore of the estuary; the more environmentally friendly methods of burial and removal of oil-stained material were preferred. Detergents are often the cause of more deaths to living organisms than the spilled oil.

No further work is recommended with respect to this particular incident. This report highlights the importance of intensive monitoring of estuaries which are exposed to the possibility of oil or any other point source of pollution. This study was able to demonstrate with some certainty that the oil had little effect on the Severn bird population as a whole only because of many years of accumulated data. Without these data no informed assessment of the environmental damage would have been possible.

GENERAL INTRODUCTION

The Severn Estuary qualifies as a Wetland of International Importance, in accordance with the criteria specified in the Ramsar Convention (Iran 1971, Regina 1990), and as a Special Protection Area (SPA), under the EC Directive on the Conservation of Wild Birds, for its populations of wintering and passage waterfowl. The UK government has already designated the Upper Severn as a Ramsar/SPA site. The Severn has a large tidal range which affects the physical environment and thus the attendant biological communities present in the estuary. This leads to unusual estuarine communities of reduced species diversity and low productivity characteristic of liquid mud and tide-swept sand and rock. The Severn is also particularly important for such migratory fish as Salmon *Salmo salar*, Sea Trout *Salmo trutta*, Sea Lamprey *Lampetra fluviatilis*, Allis Shad *Alosa alosa*, Twaite Shad *Alosa fallax*, and Eel *Anguilla anguilla*. The Twaite Shad and Sea Lamprey populations are the largest found in any United Kingdom estuary.

The estuary is frequented by thousands of wintering birds, as demonstrated by the British Trust for Ornithology's national Birds of Estuaries Enquiry (BoEE). The Severn qualifies as a Ramsar site because it regularly supports over 20,000 waterfowl. Additionally, it meets the Ramsar criteria of regularly holding 1% or more of the populations of a species or subspecies of wildfowl in NW Europe (Pirot *et al.*, 1989) or wader from the east Atlantic flyway (Smit & Piersma, 1989). Thus the populations of Shelduck, Dunlin, Curlew and Redshank present on the Severn are of international importance. A British wetland is considered to be nationally important if it regularly holds 1% or more the estimated British population of one species or subspecies of waterfowl. The Severn's populations of Ringed Plover, Grey Plover, Knot and Turnstone are of national importance (Table 1). In 1990, the Severn was the ninth most important United Kingdom estuary with respect to the numbers of waders present (Kirby *et al.,* 1991).

Most of the waterfowl only winter on the Severn, many breeding across northern Europe and the High Arctic, although Shelduck do breed and moult on the Severn. The large numbers of wintering birds use the mudflats and salt marshes of the Severn for feeding. They are dependent for their survival on the limited, but rich, invertebrate communities which inhabit the intertidal mudflats and sandflats. Some ducks, in particular, will also utilise such vegetal resources as seeds and certain saltmarsh plants.

Approximately 20 tonnes of Heavy Fuel Oil from the British Steel Llanwern works were spilled into the Severn Estuary on 11 February 1991. Although the oil spill occurred fairly late in winter, the majority of wintering waterfowl were still on the Severn and thus at risk from oiling. The purpose of this study was to assess what effect, if any, the accidental spillage had on the numbers and distribution of waterfowl using the area for the remains of the 1990/91 winter and into the Shelduck breeding season. The oil could have affected the birds directly by physical contamination or indirectly by acting on, and reducing, the numbers of invertebrates on the mudflats and plants in the saltmarshes.

An accurate independent assessment of any effects of the oil spill was possible because of the existence of data sets giving the numbers and distributions of waterfowl during the 1990/91 winter as well as in previous winters. Data are available from both monthly Birds of Estuaries Enquiry (BoEE) high tide counts, collected by the BTO and co-sponsored by the JNCC and RSPB, and twice monthly low tide counts carried out by both volunteer counters and professionals, as part of the contract to the Department of Energy (ETSU TID) ETSU TID 4074 and 4076. These data were augmented by *ad hoc* fieldwork and observations, from both staff and volunteers, which covered most of the estuary.

The BTO has long been involved with estuarine bird studies and coordinates and acts as a repository for the BoEE data. This annual survey, based on monthly high tide counts, has been running since 1969 and records the numbers of waterfowl wintering on British estuaries. The BTO has also conducted detailed studies of several British estuaries, including the Severn, the Mersey and the Humber. These studies include the impact assessment of a spill of Venezuelan crude oil that occurred on the Mersey in August 1989 (Clark *et al.*, 1990).

The Wildfowl and Wetlands Trust has been studying wildfowl populations in Britain for many years and has been carrying out a detailed breeding study of the Shelduck on the Severn since 1988.

The Severn oil spill is the second, the Mersey being the first, pollution incident in a British estuary for which such detailed data are available from both before and after the incident.

Section 1

Oil spills and the environment:

a brief review

1.1 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 user 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 6 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 *Amoco Cadiz* (223,000 tonnes) and more recently the Exxon Valdex, or vast `strategic' releases of petroleum such as occurred in the Gulf of Arabia, have focused the attention of the media. Smaller spills, such as the 150 tonnes of Venezuelan heavy crude released into the Mersey in August 1989, also received much national public attention. This spill caused localised pollution which had an impact on local amenities and wildlife and was also an economic burden. The *Amoco Cadiz* spill killed over 4,500 sea birds and also led to a 25% drop in tourism to Brittany the following year. On the other hand, the Mersey oil spill (150 tonnes) only had a `moderate' impact mitigated by wind and tide (Taylor *et al.*, 1990), with no significant effect on the bird populations (Clark *et al.*, 1990).

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.

1.2 Physical nature and effects of oil

The physical properties of the oil will directly affect its effects on the environment. The properties are mainly dependent on: i) density, ii) viscosity, iii) pour point, and iv) distillation characteristics.

Oil will float on water if its density is less than that of water. Oil will thus 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 oil's 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 with the wind, the tides and the 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. The speed and possible extent of spreading of the oil, and thus the extent of its effect, will also be affected by wind, weather and tides as well as physical characteristics such as viscosity. 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 either emulsions in strong wave conditions or else 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 *Torrey Canyon* spill of 117,000 tonnes 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.

1.3 Oil and the fauna and flora

The biological effects can be generalised as mechanical smothering with the attendant thermoregulation and photosynthetic problems, loss of insulation and buoyancy, as well as chronic, acute or sub-lethal poisoning whose effects range from behavioural changes to death.

1.3.1 Flora

Algae and saltmarsh vegetation can be killed by smothering which stops photosynthesis and leads to increased temperatures under the oil layer. 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. Saltmarsh `polluted' by oil can be more vigorous after this organic input (Mellanby, 1974).

1.3.2 Plankton

Plankton and the zooplankton which feed upon the more primary producers of aquatic systems and 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, in the form of oil, into the water body. This leads to an increase in the numbers of bacteria and thus to an increased breakdown speed of the oil spill. The timing of the spill can be very important as locally significant deaths of plankton can occur if the spill coincides with the settling of larvae of such species as *Balanus* (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 0.1ppm, has normal levels of primary production (HMSO, 1981).

1.3.3 Macrobenthic invertebrates

The effects of oil on invertebrates are best known for intertidal animals. 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 toxic fractions, most molluscs resist oil well.

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 *Monodonta* 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, though most original deaths were of gastropod molluscs (Nelson-Smith, 1968).

Crustaceans such as crabs and lobsters show signs of suppressed feeding in 0.9ppm 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.

Worms such as the polychaete *Nereis (Hediste) diversicolor* and the oligochaete *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.

1.3.4 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.

1.3.5 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.

1.3.6 Birds

In the public perception, oil pollution and birds are often synonymous. A normally free flying animal struggling in a straightjacket of tar can be a highly emotive vision. 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) and 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 were estimated to have died (*c.f.* total Puffin population of 21,000 on Unst in 1969/70 (Nicolson, 1975)). Since the two world wars, the frequency of oil-related bird deaths has increased (Bourne, 1968).

Birds are affected by oil directly or indirectly. Direct effects include poisoning through preening, preening difficulties, feeding difficulties, 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, a 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. Guillemots 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 30,000 birds 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 plastic entanglement.

Certain habitats such as estuaries are particularly affected by spills and other forms of pollution. Thus waterfowl associated with estuaries, such as ducks, geese and swans, are more 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).

Birds can also be indirectly affected by oil spills. Feeding grounds can be temporarily lost 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. 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 and dabbling duck corpses were oiled. 43.4% of all gull corpses were found oiled; the proportion of Black-headed and Common Gulls 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, quite apart from the total number of deaths caused by oiling, due to the wide range of beached bird recovery values (0.3-56%) obtained when birds are experimentally released overboard (Camphuysen, 1989).

It is debatable whether chronic or acute oil pollution leads to a greater mortality of birds (Tasker *et al.*, 1987, cf. Camphuysen, 1989). After the *Amoco Cadiz* spill, acute oil pollution led to the Sept Isles Puffin colony being decimated and it has not yet recovered. Most beached birds off the Dutch coast in the 1980's died from chronic oil pollution. The decline in Guillemot numbers that occurred in the British Isles in the 1980's has been partly attributed to deaths caused by both chronic and acute oiling (Clare *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, although this may change when the effects of the Gulf War become clearer. 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).

1.3.7 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 genetic plasticity of many marine organisms means that laboratory experiments on toxicity are not representative of natural environments. Many species may rapidly be selected for tolerant individuals, thus lessening the spill impact.

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.

1.4 Nature and its toll, or artificial cleaners?

After the locally severe *Tampico Maru* spill in California, very large mortalities were recorded amongst bivalves and crustaceans, but two years later the shore appeared largely normal except for increased numbers of Giant Kelp due to the reduced predation pressure caused by a decline in echinoderm and abalone numbers during and 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.

After the *Torrey Canyon* oil spill, the local authorities used both mechanical and chemical cleaners. In estuaries, saltmarsh plants such as *Puccinellia maritima, Festuca rubra, Phragmites communis* and *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). *Nereis diversicolor, 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 amphipod *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 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. Part of the problem with detergents is that they destroy bacteria and other organisms that can help break down oil naturally, and lead to an unbalanced ecosystem. Recent methods for dealing with oil spills include the artificial introduction of bacteria to enhance natural populations (Anon., 1990b). The ten 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 a massive $3 \times 10^6 dm^3$ of detergent were used to `clean' up the oil after the *Torrey Canyon* spill, no species were lost to the area (Mellanby, 1974).

1.5 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.

A study such as this, which considers most particularly the impact of an oil spill on the bird-life of an estuary, has specific problems: for example, it is difficult to estimate total deaths from beached birds, past experiments having shown that the number of corpses recovered is frequently not closely linked to actual deaths. Furthermore birds found dead are probably not only linked to one incident, as there is always a background level of birds dead from natural causes or chronic long-term pollution.

Section 2

Description of 11 February 1991

Severn oil spill

2.1 Background

On 11 February 1991 15-20 tonnes of heavy fuel oil from the Llanwern British Steel Corporation Plant, South Wales, escaped from a fractured pipeline (at ST396829) and spilled into the waters of the Severn Estuary between Redwick and Whitson (Fig. 2.1). The ensuing slick was first sighted off Denny Island, near Portishead, moving towards the Wessex coast. Monitoring the slick and coordinating the cleaning efforts involved such agencies as the Welsh, the Wessex and Severn Trent National Rivers Authorities as well as local councils.

2.2 Type of oil

The formal sample taken from Llanwern on 11 February 1991 and subsequently analysed by the NRA showed the oil to be a Heavy Fuel Oil containing homologous series of aliphatic hydrocarbons ranging from nC9 $\Rightarrow$ nC30+ with nC17/Pristane ratios of 2.3 and nC18/Phytane ratios of 2.1 (Table 2.1); also present were Polycyclic Aromatic Hydrocarbons (PAH's) and Alkyl substituted PAH's.

Oil samples were taken for analysis from different parts of the estuary, both on the English and the Welsh sides. The samples taken at the British Steel outlet, the foreshore near the outlet, Porton House and from a slick near Black Nore Point (Table 2.1) matched the formal sample. The other samples taken from the shore or floating out in the estuary and subsequently analysed showed consistent nC17/Pristane and nC18/Phytane ratios of 2.2-2.3 and 2.0-2.3 respectively (Tables 2.1 and 2.2). The oil was always thought to be of a heavy fuel oil type.

This identification of the oil was important as an oil spill occurred in spring 1991 in Milford Haven so it was necessary to be able to distinguish the origins of spilled oil.

2.3 Extent of spill

Even though the source of the oil was Wales, the southern or English, side of the Severn Estuary was most affected by the beached oil (Figure 2.1). Most of the oil was deposited ashore with the spring tides which started on 12 February, although little was washed up until the 13th February.

On the afternoon of 11 February a slick, triangular in shape, of 15km^2 area and estimated at 16 metric tonnes was seen from the air off Denny Island. Oil was also seen concentrated inland near the British Steel works.

On 12 February oil was sighted in the River Avon, on the Clevedon foreshore, off Portishead near Battery Point, and between the Flatholm and Steepholm islands. The majority of the slick was still in mid-channel.

Aerial reconnaissance on 13 February showed that the width of the slick varied between 50m and 300m and extended from the mouth of the docks at Bristol to Weston-Super-Mare. This was the day on which quantities of oil started arriving on the Wessex coast. There were small oil blobs the size of a 50p piece at the Wick St. Lawrence sea-defences (Woodspring Bay) and near Clevedon Pier, oil films at Portishead, and offshore from Ladye Bay. Oil was also found ashore near the Severn Bridge and at Brean Down. The main slick was between Sand Point, Flatholm and Steepholm (McGillivray in NRA, 1991). There were no more signs of oil off the Welsh coast near the point of oil release.

On 14 February, oil was sighted from Portishead to Clevedon and in the River Banwell Estuary. At sea, thin oil slicks were visible from Clevedon down to Weston-Super-Mare. These were the remnants of the main oil slicks which largely dispersed between the 13 and 14 February.

More oil came ashore on 15 February, leading to extensive oiling at Portishead, and to a lesser extent at Clevedon and on the Portbury Wharf saltmarsh.

On 16 February oil was recorded from the shores of Brean Down, Portbury Wharf, Kilkenny Bay and Woodspring Bay. Little oil was seen on either Flatholm or Steepholm. Out to sea, occasional films of oil and the remains of a broken oil slick, comprising lumps of `tarry' weathered oil from 2cm to 5m wide, were seen between the two islands. The Burnham mud banks had occasional lumps of black oil (Womack in NRA, 1991). Oil sheens were still visible out at sea near Battery Point (Holden in NRA, 1991).

By 17 February, oil had mostly stopped coming ashore. Oil carried in the estuary waters was very scattered and only small quantities were present. Oil at Portishead was seen to have lifted off and re-deposited during successive tides.

Overall the majority of the beached oil was concentrated at Portishead (Marsh in NRA, 1991) and in the surrounding sections of Portbury and Clevedon. Apart from in the previously mentioned areas, low tide counts carried out by BTO volunteers and staff found signs of oiling in the Brean section. The March low tide count carried out in the Peterstone section also found small quantities of oil on the beach and on the saltmarsh, but it is not certain whether this was due to the Llanwern incident, and generally the area seemed fairly clean.

2.4 Cleaning operations

Heavy fuel oil is not very amenable to spraying with detergents (Taylor in NRA, 1991). The possibility of using a large boom was discussed for the River Avon, but was not considered feasible due to the high tidal velocities encountered on the Severn. Similarly, the use of booms to protect the coast was considered and rejected due to the extent of the affected area.

Some oil was retrieved in mid-channel on to absorbent booms trailed between pairs of boats. An attempt was made to pump the oil, so retained, into containers. In all, six barrels of oil stained booms and gear were collected.

The majority of the shore clean-up was carried out between 18 and 21 February 1991, following the highest tides to maximise its effectiveness; responsibility was on a geographical basis. The cleaning process concentrated on such areas as the beaches between Burnham-on-Sea and Sand Bay which are of high amenity value. On the foreshore of Woodspring Bay, Clevedon, and between Clevedon and Portishead, oiled material was collected but no attempt was made to clean up the saltmarsh for biological reasons. Contractors cleaned the heavily oiled Portishead foreshore. The oiled shingle was buried and the heavily oiled seaweed removed for disposal. By 25 February the clean-up operations were largely finished.

No detergents were used on the south shore of the estuary. The emphasis was placed on retrieval, burial if an eye-sore, or else allowing natural break-down of the oil to take place. As mentioned in Section 1.4, detergents and dispersants can have a greater detrimental impact on fauna and flora than the actual oil, and thus the strategy that led to their minimal use has to be welcomed.

Section 3

The immediate impact of the oil spill on the birds

3.1 Introduction

As was seen in the previous section of this report, the heavy fuel oil spread rapidly from the Llanwern works to other sections of the estuary. The Severn is important for the extent of its intertidal zone of mudflats, sand banks, rocky platforms and 993ha of saltmarsh, as well as various bird species. The importance of different sections of the Severn for waterfowl and waders varies quite widely, *c.f.* Shelduck (Figure 3.1.1), Dunlin (Figures 3.1.2), Curlew (Figure 3.1.3) and Redshank (Figure 3.1.4). The areas most favoured by waterfowl on the Severn (as defined: Clark *et al.*, 1989; Warbrick *et al.*, 1991) are to be found from Peterstone to Nash on the northern side of the estuary and Bridgwater Bay to Weston Bay on the southern side of the estuary (Figures 3.1.5).

The first objective of this study was to determine the proportion of the bird population judged to have died as a result of oiling acquired from the spill. This objective will be dealt with in this section by collating all of the estuary-wide observations made of live and dead oiled birds found after the Llanwern heavy fuel oil spill. The species most affected will be noted and this will be linked to both the incidence of oil on different sections and to the behaviour patterns of birds, if these can explain why and which birds were oiled.

3.2 Data collection and analysis

Data on the numbers of live or dead oiled birds were collected from as many organisations as possible. The first objective reports covering the whole estuary came from NRA staff sent out to cover the extent of the spill (NRA, 1991).

The Avon Naturalists Trust and the Royal Society for the Prevention of Cruelty to Animals (RSPCA) acted as a focal point for the clean-up and rehabilitation of oiled and injured birds, and the individuals handed in gave some idea of the most commonly oiled species.

The Royal Society for the Protection of Birds (RSPB) ran a beached bird survey on 23 and 24 February 1991. This covered the northern or Welsh side of the Severn. Volunteers were asked to follow the tideline to record any dead or injured birds that they might find, making a note of any clearly defined cause of death or injury. Unfortunately, there was no equivalent search on the southern shore of the estuary.

The British Trust for Ornithology (BTO) organised twice monthly low tide counts of the Severn Estuary carried out by staff and many volunteers. These low tide counts covered most of the estuary from Bridgwater Bay to Rodley (Figure 3.2). During the two counts carried out immediately after the spill, on 16/17 February and 2/3 March, counters were asked to make a special note of oiled and unoiled birds of all species. Only data from birds that were close enough to be well seen were used in the subsequent analyses. Areas that were not included, either through counter unavailability or because no special note of oiled birds was made, included Sand Bay, Portbury, River Avon, Nash and Rhymney (Figure 2.1). Beachley and Guscar were largely counted from Oldbury and Berkeley. The proportion of oiled to unoiled birds was calculated and represented as a percentage. Figures are presented for Shelduck, Dunlin and Redshank as well as Black-headed Gulls. No figures are presented for the common species, Curlew, which is considered more fully in subsequent analyses, as no oiled birds were seen by the observers.

3.3 Results

The first oiled swans, gulls and Shelduck were reported on 12 February (Taylor in NRA, 1991). On 13 February oil came ashore at Clevedon and `hundreds of oiled birds' were noted by the Swansea Coastguard (Taylor in NRA, 1991). Distressed birds were seen near the Congresbury Yeo Outfall (south of Clevedon) on 14 February and on 16 February 20 to 30 oiled seabirds were flying near Steepholm (Womack in NRA, 1991).

In the days immediately following the spill, a total of 96 live and 63 dead birds were recovered by the Avon Naturalists' Trust and the West Hatch RSPCA. A further 38 birds, of which 21 were alive, were handed in to the Avon Naturalists Trust in late February. A final 12 live and 3 dead birds were recovered in March. Of the first 39 birds to be handed in to the RSPCA, eight died (Table 3.1), while the rest were released, a good rehabilitation rate. Mallard was the species most commonly handed in with 18 individuals. In total there were 26 ducks, Mute Swans and Shelduck, six gulls, five waders and two grebes.

The RSPB beached bird survey found most oiled and dead birds to be in Mid and South Glamorgan (Table 3.2). There were only three Shelduck casualties on the Gwent coast following the spill (Tyler, pers. comm.), one of which was found during the beached bird survey. Birds whose indisposition was due to oil included several species of gull, a Dunlin, two Pochard, a Shelduck and a Woodpigeon. Gannets, Razorbills and a Little Auk were also recorded, but were not oiled. Many oiled gulls were also reported to the RSPB from the Gwent and South Glamorgan reservoirs.

The numbers and proportions of oiled birds seen during the low tide counts of February and March 1991 are represented in Tables 3.3.3a-3.3.3c. Oiled Shelduck, Mallard, Dunlin, Redshank, Black-headed, Herring, Lesser Black-backed, Great Black-backed and Common Gulls were seen. Of these, the most commonly oiled species were Shelduck, Dunlin, Redshank and Black-headed Gull. Only two Common Gulls and one Black-headed Gull were seen to be oiled in the early March count and thus no figures from this count were produced for these species.

Oiled Shelduck were found from Magor to Mathern on the northern side of the outer estuary and from Severn Beach to Bridgwater Bay on the southern side of the outer estuary; four oiled Shelduck were also found at Oldbury in the inner estuary (Figure 3.3.1). Most oiled individuals were concentrated in the oiled sections of the estuary from Clevedon to Magor. The thirteen oiled Dunlin seen were in two sections of the estuary, Caldicot and Clevedon (Figure 3.3.2). The four oiled Redshank seen during the low-tide count of February were in the Clevedon section

(Figure 3.3.3). Oiled Black-headed Gulls were found very extensively in the outer and inner Severn Estuary, from Bridgwater Bay and Redwick to Framilode (Fig 3.3.4). The highest percentages of oiled gulls were to be found in Magor and Caldicot on the Welsh side of the Severn and in the sections of Severn Beach, Portishead and Clevedon on the English side of the estuary.

3.4 Discussion

A total of 212 oiled birds were recovered by the Avon Naturalists Trust and the RSPCA. The species breakdown of the first 39 birds only is known as the data on the others were lost as a result of computer failure (Sperring, pers. comm.). The 26 species recovered (ducks, swans, gulls, waders and grebes) are fairly representative of oiling incidents in estuaries (Camphuysen, 1989). The ratio of birds recovered and handed in to the RSPCA will probably have been affected by the habits and comparative visibility of certain species. Waders, which frequently roost in saltmarsh and are cryptically coloured, are less likely to be found than predominantly white species such as swans, Shelduck and gulls which stand out on dark mudflats.

The above caveat will also hold true for the birds recorded by the RSPB beached bird survey. Generally, the oiled birds found by this survey were further west in the estuary than the oiled birds recorded by the estuary-wide BTO low tide counts. This is not necessarily contradictory as the BTO low tide counts recorded mainly live birds, whereas most of the birds found on the RSPB Beached Bird Survey were dead. The position of corpses will be influenced primarily by current and wind direction rather than the place at which death occurred. It is thus likely that birds found beached will have died some distance away. This is confirmed by the presence of auks, species of maritime habit, amongst the beached sample.

The single Shelduck casualty found on the Gwent coast during the beached bird survey could have died from causes other than the oil spill, and the two Shelduck found in South Glamorgan, one of which was heavily oiled (Table 3.3.2), could have been washed up from Gwent or the English side of the Severn. Other visibly oiled bird species such as the gulls, the Dunlin, and two Pochard are frequently recorded beached after oiling incidents (Camphuysen, 1989). However, whilst oiling can cause mortality, the deaths of the beached birds found cannot be attributed with certainty to the Llanwern oil spill or to oiling from another source.

During the low tide counts, the species most commonly found to be oiled were Shelduck, Dunlin, Redshank and Black-headed Gulls. No oiled Curlew were seen. It is probable that the number of oiled waders, such as Curlew, is under-represented due to their brown plumage against which oil stains would not show up well from a distance, particularly on mudflats. Oil should show up better on the pale underside of wintering Dunlin. The relatively large number of oiled individual Black-headed Gulls recorded may well be a reflection of their overall white colour, leading to dark oil stains being clearly visible. Oiling is thought to be a major cause of death for gulls (Camphuysen, 1989), but this spill cannot necessarily be implicated here because oiled gulls were reported to the RSPB from the Gwent and South Glamorgan reservoirs both before and after the Llanwern incident.

Large percentages, from 17.4% to 66.7%, of oiled Shelduck were found in the outer estuary sections of Clevedon to Magor (Figure 3.3.1), sections that had not held very high densities of Shelduck over the 1988/89 winter (Figure 3.1.1). High proportions of oiled Shelduck were found in the most badly oiled areas, such as Clevedon and Portishead, as well as in areas that were close to the source of the initial leak, such as Magor and Caldicot. 16% of Shelduck found in Oldbury were oiled, even though this area was not considered to have been oiled. These oiled birds may have come from other sections. The areas that had large numbers of Shelduck, namely Bridgwater Bay, Taff-Ely, Peterstone and St. Brides had either no or very small percentages of oiled Shelduck.

All of the oiled Dunlin were found in Caldicot and Clevedon (Figure 3.3.2). Caldicot did not hold many birds in 1988/89, unlike Clevedon (Figure 3.1.2), although Clevedon held many fewer Dunlin during the 1990/91 winter (Warbrick, *et al.,* 1991). Both sections were oiled; Clevedon badly so.

All the oiled Redshank were found in the Clevedon section (Figure 3.3.3), not a section that held many Redshank in 1988/89 (Figure 3.1.4), but probably the most badly oiled part of the Severn.

Oiled Black-headed Gulls were widespread in both the outer and the inner estuary (Fig. 3.3.4). The highest proportions of oiled birds were found in Clevedon, a heavily oiled section, and the oiled Severn Beach, Caldicot and Magor sections.

Other species found oiled during the low tide counts included Mallard, Common, Great Black-backed, Lesser Black-backed and Herring Gulls (Table 3.3). Of the four species that were found to be commonly oiled during the low tide counts, most oiled individuals were found in sections that had been affected by the oil.

Gulls and seabirds are often found oiled because of their dependence on open water for both roosting and feeding. Oil has its greatest impact on these species when it is floating on top of the water column. Many of the auks, gannets, gulls, grebes, Swans and Pochard will have been oiled during the initial stages of the spill when the floating oil was moving from Llanwern and spreading over the estuary, moving with the tide. In proportion to their large numbers, waders were less badly affected, as is normally the case in estuaries (Camphuysen, 1989). This may be due to waders feeding largely on mudflats cleared of water which makes avoidance of small localised patches of oil easier. Furthermore, by the time oil was beached it would be less liquid through the loss of its more volatile fractions and would therefore have adhered less to feathers.

Whereas it is not possible to estimate accurately the total number of bird deaths from the above figures, it is likely that the bird kill will have been in the order of several hundreds rather than the tens of thousands suggested in some of the press. These estimated deaths are small in proportion to the total Severn waterfowl population of over 60,000 birds (Kirby *et al.*, 1991).

Summary: the first birds were affected by the oil within a day of the oil escaping into the Severn. These were swans, gulls and Shelduck. The area of Clevedon which was to be heavily oiled by the spill held its first oiled birds on the 13 February, two days after the accidental release of the fuel oil. By the 16 February oiled birds were seen as far as Steepholm. The species most commonly found oiled were gulls, especially Black-headed, Shelduck, Dunlin and Redshank, this being reflection of the frequency of the species on the Severn as well as feeding and roosting behaviour. Most oiled birds were found in sections that were oiled, implying that afflicted birds did not move far. As a proportion of the total Severn population, there were relatively few waterfowl deaths.

Section 4

Oiled sites and estuary usage by feeding birds

4.1 Introduction

Oil pollution can kill waterfowl and other birds dependent on estuaries by poisoning or smearing leading to the loss of body heat and buoyancy. The birds also suffer from exposure to sub-lethal levels of oil which can lead to behavioural changes and greater susceptibility to illness through general weakness. Oil also affects estuarine birds indirectly by potentially smothering feeding grounds and vegetation, as well as killing invertebrate prey by poisoning or smothering (Section 1).

Objective 2 of this study was to appraise changes in bird feeding distribution that could be related to the Llanwern oil spill. Such changes are not always easy to detect against a background of naturally occurring fluctuations. The numbers of birds using mudflats may change with time, certain mudflats becoming depleted of their invertebrates and less desirable as feeding areas.

Changes in distributions were investigated by analysing the numbers of feeding birds using selected oiled and unoiled sections both before and after the spill. Any major effects of the spill should be reflected in diminished proportions of birds on the areas considered to have been most affected by the oil, with possible attendant increases in the proportions on the unoiled sites (Clark *et al.*, 1990).

4.2 Data collection and analysis

The data gathered by the BTO in its twice monthly low tide counts give a good indication of the numbers of birds feeding on the 151 Severn Estuary mudflats surveyed during the 1990/91 winter (Figure 3.2). The two counts carried out just before the spill were on the 12/13 January and the 26/27 January, the two counts immediately after the spill were on the 16/17 February and the 2/3 March.

Due to many of the counts being made by volunteers, occasional counts were missed. For the purpose of this analysis oiled and unoiled sections with no missing counts for the four above counts in January to March 1991 were required. The four oiled sections chosen were Weston Bay, Severn Beach, Caldicot and Magor. Bridgwater Bay, the Oldbury Silt Lagoon, St. Brides and Peterstone were taken to be representative of unoiled sections. Each section was divided into a minimum of two and a maximum of six mudflats, each mudflat being considered as one counting unit for bird numbers of each species. In total 15 oiled and 21 unoiled mudflats were included in the analysis.

Bird numbers decline in late winter as many species using estuaries for wintering leave for their breeding grounds. Thus it is not possible to compare directly numbers of birds found in January to numbers in February and March. To overcome this problem the number of birds feeding on the oiled mudflats in the summed January counts was compared to the number of feeding birds using the same mudflats in the summed February and March counts. This method was also applied to the unoiled mudflats.

The feeding bird numbers on each mudflat were transformed using $log(x + 1)$ to normalise the data and to compensate for zero values (Sokal & Rohlf, 1981; Fowler & Cohen, 1987). The numbers of feeding birds in the two January counts were then plotted against the number of feeding birds in the February and March counts, for both oiled and unoiled sites. Regression analyses were performed on the two data sets to determine the significance of the analysis, the slope and the intercept of each best-fit line. The two separate lines were compared for significant differences in both slope and elevation. If oiled mudflats were avoided by birds, one would expect the slope of the best-fit line for the oiled mudflats to be significantly less than that for the unoiled mudflats; that is the proportion of birds in January to birds in February and March on oiled mudflats to be greater than the proportion of birds in January to birds in February and March on unoiled mudflats:

$$\frac{\text{January (Count 1 + Count 2) on oiled mudflats}}{\text{(February + March) counts on oiled mudflats}} > \frac{\text{January (Count 1 + Count 2) on unoiled mudflats}}{\text{(February + March) counts on unoiled mudflats}}$$

If oiling did not markedly interfere with the ability of birds to feed on mudflats the two lines would show no significant differences.

All of the analysis was carried out using SAS® V6.0 General Linear Modelling (SAS, 1989b).

Four species of bird were used for the purpose of this analysis; Shelduck, Dunlin, Curlew and Redshank. These were chosen as they are common, internationally important and widespread in the Severn Estuary. All of these species are dependent on mudflats for feeding and should show numerical declines on oiled mudflats if oil had interfered with feeding or lessened feeding success.

4.3 Results

4.3.1 Shelduck

The most numerically important mudflats, both oiled and unoiled, held fewer Shelduck during the February and March counts than in the two January counts, as can be seen by the statistically significant gradients of 0.528 and 0.480 respectively (Figure 4.3.1). The differences in the slopes (t = 0.03) and elevations (t = 0.49) of the two regression lines for the oiled and unoiled mudflats are not significant at the 5% level.

4.3.2 Dunlin

As for Shelduck, there were fewer Dunlin on the most used mudflats, both oiled and unoiled, in the February and March counts than in the two January counts, as can be seen by the statistically significant gradients of 0.591 and 0.806 respectively (Figure 4.3.2). The differences in the slopes (t = 0.12) and elevations (t = 0.20) of the two regression lines for the oiled and unoiled mudflats are not significant at the 5% level.

4.3.3 Curlew

As for the two above species there were fewer Curlew on the most used oiled and unoiled mudflats in the February and March counts than in the two January counts as can be seen by the statistically significant gradients of 0.780 and 0.699 respectively (Figure 4.3.3). The differences in the slopes (t = 0.05) and elevations (t = 0.34) of the two regression lines for the oiled and unoiled mudflats are not significant at the 5% level.

4.3.4 Redshank

Similarly to Shelduck, Dunlin and Curlew there were fewer Redshank on the most used oiled and unoiled mudflats in the February and March counts than in the two January counts as can be seen by the statistically significant gradients of 0.640 and 0.670 respectively (Figure 4.3.4). The differences in the slopes (t = 0.02) and elevations (t = 0.18) of the two regression lines for the oiled and unoiled mudflats are not significant at the 5% level.

4.4 Discussion

For the four species analysed, Shelduck, Dunlin, Curlew and Redshank, there were no significant differences in the slopes and elevations of the regression lines produced from the oiled and the unoiled mudflats when the January low tide counts were compared to those of February and March. This shows oiling not to have had a significant effect on the distribution of feeding birds on the Severn mudflats.

If the estuary was at carrying capacity, *i.e.* if it was sustaining the maximum possible number of birds, the waterfowl might have very little choice as to where to feed by the end of the winter. The birds might then have to either leave the estuary or else feed in sub-optimal conditions, including oiled mudflats. There is indeed some evidence that the south-west estuaries of Britain, which include the Severn, are indeed at carrying capacity for such species as Dunlin, Curlew and Redshank (Clark, 1989). Were this scenario to be correct, the fact that there were no significant differences in the numbers of birds using oiled and unoiled mudflats might have been a reflection of the lack of extra suitable feeding areas forcing waterfowl into sub-optimal, oiled areas.

For each species, the elevation of the slopes of numbers feeding on unoiled mudflats was generally greater than that on oiled mudflats (Figures 4.3.1 to 4.3.4). This showed that there was a tendency for more birds to be on the unoiled sites than on the oiled sites, though the difference in elevation in each case was never significant.

To summarise: no significant differences were found between oiled and unoiled mudflat usage before and after the spill. The oiling did not have a significant effect on the distribution of feeding birds.

Section 5

Timing of bird movements away from the Severn

5.1 Introduction

Section 4 of this report looked at the usage made of both oiled and unoiled mudflats by feeding birds. There did not appear to be significant differences in the numbers of birds feeding on oiled and unoiled mudflats. Another possible effect of the spill would have been to make birds leave the Severn Estuary, or at least certain sections of it, early. This might be the case if feeding and roosting conditions were not suitable for the waterfowl populations, owing to the habitat being damaged by the spill.

Data from the Birds of Estuaries Enquiry can be used for long term comparisons and trends of how individual bird species are faring in Britain as well as how waterfowl usage of an individual estuary is changing with time. These long-term data are especially valuable when trying to assess the impact of such incidents as the Llanwern oil spill in the context of naturally occurring large annual fluctuations in bird numbers.

To allow the impact of the spill to be assessed, BoEE data of Severn waterfowl numbers from the four previous winters of 1987 to 1990 were compared to that of the 1991 winter. The changes in bird numbers in the period just before the spill (January count) and after the spill (February and March) were compared with the aim of detecting any immediate or slightly longer-term effects of the oil spill on Severn Estuary bird numbers.

This fulfils the second part of Objective 2 which required an assessment of the numbers and timing of migration of the birds on the Severn.

5.2 Data collection and analysis

The data from five years of BoEE Severn counts were used covering the periods January to March 1987 to 1991. As for the low tide counts, some sections of the Severn are counted less regularly than others by the largely volunteer counters, thus sections were chosen that had good data over the five year period.

Similarly to the low tide data analysis reported in section 4, the four common and widespread species, Shelduck, Dunlin, Curlew and Redshank, were used as indicator species.

Three analytical tests and methods were used, the χ^2-test, regression analysis and lastly an analysis of variance (ANOVA).

For the regression analysis, sections were not included in the analysis if they had data missing for more than one month from the four control years of 1987 to 1990, nor were they included if any data was missing from 1991. Data from the following sections were used: Bridgwater Bay, Berrow, Clevedon, River Avon, Severn Beach, Oldbury Silt Lagoon, Guscar (Aylburton), Slimbridge, Mathern, Redwick, Peterstone and the Taff-Ely. Of these, Clevedon, River Avon, Severn Beach and Redwick were oiled sections.

The bird numbers in each section were transformed using $log(x+1)$ to normalise the data and to compensate for zero values (Fowler & Cohen, 1987; Sokal & Rohlf, 1981). The numbers of birds in February 1991 (just after the spill) were then compared to the numbers in January 1991 (just before the spill), and similarly March 1991 numbers were compared to January 1991. Regression lines were calculated using SAS® V6.0 General Linear Modelling (SAS, 1989b). This procedure was repeated for the pooled data from the four years of 1987 to 1990, comparing February BoEE data to January BoEE data as well as March BoEE data to January BoEE data. The February 1991 to January 1991 best-fit line was then compared to that generated from the pooled February 1987 to 1990 and January 1987 to 1990 data, to look for significant differences in both slope and elevation. This was repeated for the March and January comparisons. The January 1991 count was carried out before the oil spill, whilst the February and March 1991 counts were both carried out after the spill. As mentioned in Section 4 of this report, fluctuations in bird numbers are expected as the winter progresses and it is thus not necessarily possible to attribute a decline in February or March bird numbers to the oiling. It is more valuable to compare the change in numbers that occurred in 1991, between January and February, to changes that occurred in previous years during the same periods. If the oiling of February 1991 affected bird numbers on the Severn, significant differences would be expected in the slope and elevation of the regression line generated from 1991 data compared with those from 1987 to 1990 data. Similarly, if the oiling effect lasted until March, these significant differences should have been found when the March data was compared to that of January.

The χ^2-test was used to compare untransformed waterfowl numbers from the oiled and unoiled sections in January and February 1991, using both data from individual sections and then lumping oiled and unoiled sections together. The χ^2 analysis, carried out using only 1991 data, included the two unoiled sections of St.Brides and Rhymney, as these had complete data for the year, as well as data from the sections used in the aforementioned regression analyses.

For the analysis of variance, ANOVA, February and March data were compared to data from January to alleviate the problem of yearly natural population fluctuations. For each of the four species, the proportion of February 1991 to January and February 1991 numbers summed was calculated. This was repeated for the March 1991 numbers. This gave an indication of the proportional change in numbers from January counts, before the 1991 oil spill, to February and March counts, after the oil spill. The values were then arcsine transformed as should be all proportions or percentages to normalise such data (Fowler & Cohen, 1987; Sokal & Rohlf, 1981). The above analysis and transformation was repeated for the four years of 1987 to 1990 data. The analysis was based on a three-factor main effects model ANOVA, where the effects were oiling, year and section. The analysis was carried out using SAS® V6.0 General Linear Modelling (SAS, 1989a & 1989b). As this type of analysis allows for missing data the sections of Nash and Undy were included in the analysis, the latter being considered oiled (Figure 2.1). ANOVA analyses are the most complete for this sort of data in that they limit type I errors by using the three variables of year, section and oiling simultaneously. Repeated tests using one variable at a time are more prone to type I errors (the likelihood of rejecting a correct null-hypothesis).

5.3 Results

5.3.1 Shelduck

The χ^2 analysis showed that there were very significant differences ($P<0.001$) between the numbers of Shelduck in individual sections as well as between pooled oiled and unoiled sections (Tables 5.1a and b) in January, February and March 1991.

A comparison of the two statistically significant ($P<0.0001$) best-fit lines generated when equating numbers of Shelduck in January 1991 to February 1991 and in January to February for the years 1987 to 1990 (Figure 5.3.1.1) showed that the differences in the slopes ($t = 0.13$) and elevations ($t = 0.29$) of the two regression lines were not significant at the 5% level. Similarly the comparison of the January to March data (Figure 5.3.1.2) showed no significant differences ($P>0.05$) in the slopes ($t = 0.15$) and elevations ($t = 0.10$) of the two regression lines. The slope or rate of increase in Shelduck numbers in January compared to both February and March was greater for the 1991 data than the pooled 1987 to 1990 data.

The three-factor ANOVA showed that the overall model of year, section and oiling did not account for a significant proportion of the variability in the dependent variable (Table 5.2), Shelduck numbers in February as a proportion of January and February ($P = 0.79$). The individual effects of year ($P = 0.99$), section ($P = 0.56$) and oiling ($P = 0.56$) were not significant, thus the variation in the numbers of Shelduck between oiled and unoiled areas was not significantly greater than the variation found between sections and between years. Similarly when the dependent variable was Shelduck numbers in March as a proportion of January and March (Table 5.3) the ANOVA showed that the overall model did not account for a significant proportion of the variability ($P = 0.29$), with none of the individual effects being found to significantly explain any variation: section ($P = 0.28$), year ($P = 0.26$) and oiled or not ($P = 0.82$).

<u>5.3.2</u> <u>Dunlin</u>

The χ^2 analysis showed that there were very significant differences ($P<0.001$) between the numbers of Dunlin in individual sections as well as between pooled oiled and unoiled sections (Tables 5.4a and b) in January, February and March 1991.

A comparison of the two statistically significant ($P<0.0001$) best-fit lines generated when equating numbers of Dunlin in January 1991 to February 1991 and in January to February for the years 1987 to 1990 (Figure 5.3.2.1) showed that the differences in the slopes ($t = 0.25$) and elevations ($t = 0.30$) of the two regression lines were not significant at the 5% level. Similarly, the comparison of the January to March data (Figure 5.3.2.2) showed no significant differences ($P>0.05$) in the slopes ($t = 0.22$) and elevations ($t = 0.26$) of the two regression lines. The gradient or rate of increase in Dunlin numbers in January compared to both February and March was greater for the 1991 data than the pooled 1987 to 1990 data.

The three-factor ANOVA showed that the overall model of year, section and oiling did not account for a significant proportion of the variability in the dependent variable (Table 5.5), Dunlin numbers in February as a proportion of January and February (P = 0.59). The individual effects of year (P = 0.67), section (P = 0.46) and oiling (P = 0.53) were not significant, thus the variation in the Dunlin numbers between oiled and unoiled areas was no greater than the variation found between sections and between years. When the dependent variable was Dunlin numbers in March as a proportion of January and March (Table 5.6) the ANOVA showed that the overall model accounted for a significant proportion of the variability (P = 0.0001), but the individual effects found to be significant in explaining this variation were section (P = 0.0002) and year (P = 0.0017), while a section being oiled or unoiled was not significant (P = 0.83).

5.3.3 Curlew

The χ^2 analysis showed that there were very significant differences (P<0.001) between the numbers of Curlew in individual sections as well as between pooled oiled and unoiled sections (Tables 5.7a and b) in January, February and March 1991.

A comparison of the two statistically significant (P<0.0001) best-fit lines generated when equating numbers of Curlew in January 1991 to February 1991 and in January to February for the years 1987 to 1990 (Figure 5.3.3.1) showed that the differences in the slopes (t = 0.02) and elevations (t = 0.17) of the two regression lines were not significant at the 5% level. Similarly the comparison of the January to March data (Figure 5.3.3.2) showed no significant differences (P>0.05) in the slopes (t = 0.07) and elevations (t = 0.12) of the two regression lines. The gradient or rate of increase in Curlew numbers in January compared to both February and March was greater for the 1991 data than the pooled 1987 to 1990 data.

The three-factor ANOVA showed that the overall model of year, section and oiling did not account for a significant proportion of the variability in the dependent variable (Table 5.8), Curlew numbers in February as a proportion of January and February (P = 0.14). The individual effects of year (P = 0.28), section (P = 0.11) and oiling (P = 0.55) were not significant, thus the variation in the numbers of Curlew between oiled and unoiled areas was no greater than the variation found between sections and between years. When the dependent variable was Curlew numbers in March as a proportion of January and March (Table 5.9) the ANOVA also showed that the overall model did not account for a significant proportion of the variability (P = 0.36), and that the individual effects did not significantly explain any variation: section (P = 0.31), year (P = 0.45) and oiled or not (P = 0.38).

5.3.4 Redshank

The χ^2 analysis showed that there were very significant differences (P<0.001) between the numbers of Redshank in individual sections as well as between pooled oiled and unoiled sections (Tables 5.10a and b) in January, February and March 1991.

A comparison of the two statistically significant (P<0.0001) best-fit lines generated when equating numbers of Redshank in January 1991 to February 1991 and in January to February for the years 1987 to 1990 (Figure 5.3.4.1) showed that the differences in the slopes (t = 0.10) and elevations (t = 0.17) of the two regression lines were not significant at the 5% level. When the January 1991 data was compared to that of March 1991 no significant correlation was found between the two (P = 0.21). The comparison of the two lines generated from the two sets of January and March data (Figure 5.3.4.2) showed no significant differences (P>0.05) in the slopes (t = 0.00) and elevations (t = 0.45) of the two regression lines. The gradient or rate of increase in Redshank numbers in January compared to February was greater for the 1991 data than for the pooled 1987 to 1990 data. The rate of increase of Redshank numbers in January compared to March was very slightly smaller for the 1991 data than for the pooled 1987 to 1990 data (0.404 cf. 0.407).

The three-factor ANOVA showed that the overall model of year, section and oiling did not account for a significant proportion of the variability in the dependent variable (Table 5.11), Redshank numbers in February as a proportion of January and February (P = 0.13). The individual effects of year (P = 0.37), section (P = 0.085) and oiling (P = 0.94) were not significant, thus the variation in the numbers of Redshank between oiled and unoiled areas was no greater than the variation found between sections and between years. When the dependent variable was Redshank numbers in March as a proportion of January and March (Table 5.12) the ANOVA showed that the overall model accounted for a significant proportion of the variability (P>0.0020), but the only individual effect found to be significant in explaining this variation was section (P = 0.0009) while year (P = 0.21) and oiling (P = 0.86) were not significantly influential in explaining the variability.

5.4 Discussion

The χ^2 analyses carried out on the four species, Shelduck, Dunlin, Curlew and Redshank, showed that there were significant differences ($P<0.001$) between the numbers of birds in the various sections and in the pooled oiled and unoiled sections in January, February and March 1991. These differences were mostly due to monthly changes in the distribution of the birds, as can be seen from the unpooled analysis, and thus cannot be taken to be a result of the various sections being oiled or not.

For all species the dependent variables, February or March numbers, could be predicted from January numbers using 1991 data and lumped 1987 to 1990 data with only one exception: the numbers of Redshank in March 1991 were not significantly predictable from numbers in January 1991 ($P = 0.21$). In all cases the differences in both the slopes and the elevations were not significant between 1991, the year of the oiling, and the years of 1987 to 1990 not affected by oiling. There is thus no statistically significant evidence of Shelduck, Dunlin, Curlew and Redshank numbers declining more rapidly on the Severn Estuary in February and March 1991 after the Llanwern oil spill compared to the four previous unoiled years.

The three-factor ANOVA analysis confirmed the lack of statistical evidence for any effect of the oil on the number of birds in the oiled and unoiled sections compared to naturally occurring fluctuations in sections and years. None of the variations in Shelduck and Curlew numbers were explained by section, year or oiling when using either the February or March data. For Dunlin some of the variation in March numbers could be explained by section and year; similarly some of the variation in March Redshank numbers could be explained by the sections. This partly confirms the suspicion that the significant changes in bird distributions in January, February and March, found in the various sections by the χ^2 analyses, are a result more of seasonal differences in the distribution of the birds than the oiling of parts of the Severn.

To summarise, there was no evidence for any changes in numbers of Shelduck, Dunlin, Curlew and Redshank in February or March 1991 that could be attributed to the Llanwern oiling incident, nor is there any evidence that the birds left the estuary early.

Section 6

Numbers, distribution and breeding success of Shelduck on the Severn

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Summary: sectors of the Severn estuary were visited in a series of seven low-tide counts during the early incubation period of Shelduck (3 May to 13 May 1991) and then the whole estuary was counted on five one-day counts on 15 May, 11 June, 9 July, 26 July and 12 August 1991. All adult and juvenile Shelduck were counted and marked on maps. Counts were compared to similar counts made in 1989 and 1990 to see whether any effects of the oil spill of 11 February 1991 on numbers, distribution and breeding success of the local population of Shelduck could be detected. The pattern of counts in 1991 differed little from those of previous years and differences that occurred were probably natural fluctuations. Because Shelduck are known to migrate considerable distances in response to cold weather, and because the pollution incident occurred at the end of the severest spell of such weather in the winter of 1990/91, it is possible that any birds affected by the oil spill were not from the local breeding population.

6.1 Introduction

The majority of Shelduck in north-west Europe are found at estuaries and it is the only wildfowl species in the region which depends on this habitat for the whole of its life cycle. A total of 50,000 were counted in Britain in March 1990 (Kirby *et al.* 1990) and Owen *et al.* (1986) calculate that 70% of British Shelduck are counted each year, so that the population in March is about 71,500. Monval & Pirot (1989) estimate the north-west European flyway population to number about 250,000. The majority of the flyway stock migrate in mid-July to the Heligoland Bight in the German Wadden Sea to moult. The birds stay there at least until September, and many do not return to their wintering areas until January (Ridgill & Fox 1990). Since 1958, several much smaller moulting concentrations have been discovered at British estuaries (Eltringham & Boyd 1960, Bryant 1978, Bryant 1981, Tasker 1982) the largest and best known of these being on the Severn at Bridgwater Bay. The origin of these birds has never been ascertained, but in 1990, at least 800 birds at Bridgwater Bay were considered to be non-local breeders (Delany 1991). The British breeding stock apparently accounts for the majority of our wintering birds (Patterson 1982) but significant winter movements occur during cold weather (Ridgill & Fox 1990).

The Severn Estuary holds internationally important numbers of Shelduck in winter and in summer, and any pollution incident such as that which occurred on 11 February 1991 is potentially very damaging to that interest. The Wildfowl & Wetlands Trust has monitored the summering population of Shelduck on the estuary since 1988. Estimates of the breeding population have varied from 200 to 350 pairs, and the pre-moult concentration at Bridgwater Bay regularly numbers around 3,000 birds, a varying number of which remain to moult through

August and September (Fox & Salmon in press, Delany 1991). The aim of this report is to compare counts of Shelduck in 1991, the season following the oil spill, with those of the previous two summers to see whether any effects on their number, distribution and breeding success can be detected.

6.2 Count methods

A preliminary series of counts was organised between 3 and 14 May 1991, during the average early incubation period of Shelduck when the population is most stable. For these counts the estuary was divided into seven sections, each of which was covered within two to three hours of low tide. All Shelduck present were counted and their positions marked on 1:50,000 Ordnance Survey maps.

The whole of the Severn Estuary was then counted on five one-day visits between 15 May and 12 August 1991. Three teams of up to four observers from The Wildfowl & Wetlands Trust mapped all Shelduck on the estuary in three sections: Longney to the Severn Bridge, Severn Bridge to Bridgwater Bay and Severn Bridge to Cardiff Bay. The dates chosen for the counts were those with an early morning high tide at Bridgwater Bay and were within one week of dates used for similar counts carried out in 1990. This ensured maximum accuracy of counts at the most difficult site (Bridgwater Bay) and maximum comparability of counts between years. Figure 6.2.1 illustrates the sections used for counts and also those affected by oil.

Because of their habit of nesting inland in burrows, the only practicable method of assessing breeding success of Shelduck is to count juveniles. Once they have been taken to the estuary by their parents, young Shelduck are considered to be fairly sedentary until they can fly (Delany 1991).

6.3 Changes in numbers

Only small numbers of oiled Shelduck were reported in the days immediately after the spill (see Section 3).

Figure 6.3.1 illustrates the total numbers of adult Shelduck counted on the Severn estuary on all one-day counts in the last three summers. Their pattern of occurrence was broadly similar in each year, being dominated by the build up through May and June to a peak in July, followed by a varying decline into August. In 1991, the May, June and early July counts were all slightly higher than the equivalent 1990 counts (by 5.5%, 8%, and 3.6% respectively) but in late July and early August numbers were considerably lower (35.4% and 35.9% down on 1990 respectively). This is the steepest decline into August yet recorded, but considering the similarity of counts early in the summer to those of previous years, it seems unlikely to be related to the February oil spill.

6.4 Changes in distribution

Table 6.1 gives the proportions of Shelduck present on sections of the estuary that were oiled in February 1991 relative to totals for the whole estuary on each count. Figures are presented for the equivalent sections and dates in 1989 and 1990 for comparison. It can be seen that the percentage of Shelduck using the sections affected by the oil spill in 1991 differed little between years, and no simple relationship can be demonstrated between Shelduck distribution in the summer of 1991 and the areas affected by the oil spill. By late July, very few birds are found on any section of the estuary away from Bridgwater Bay.

6.5 Breeding productivity

Broods and creches of young Shelduck were counted from June onward, and the results, together with those from 1989 and 1990 are shown in Table 6.2.

Counts of juveniles are less representative than those of adult birds because, until they are well grown, young Shelduck are inconspicuous, frequently hiding in creeks and pills or under the edge of the saltmarsh. Counts should therefore be regarded as minimum estimates. The number of ducklings counted in 1991 on sections oiled in February totalled 114 and represented 45% of all ducklings counted on the estuary. This is higher than the proportion of birds using the same sections in previous years. Overall productivity of young was apparently lower in 1991 than in either of the previous summers, but this is unlikely to be related to the oil spill because the sections of the estuary affected by oil produced a higher than usual proportion of young Shelduck.

6.6 Discussion

The number and distribution of Shelduck on the Severn Estuary in the breeding season of 1991 differed only slightly from the previous two summers, and counts detected no adverse effects on the local population from the oil spill on 11 February 1991. Early summer counts were markedly similar in 1990 and 1991, but from mid-July onwards 1991 numbers were the lowest yet recorded, probably because of a reduction in moult migration to Bridgwater Bay. The spill coincided with the coldest spell of weather in the winter of 1990-91. The minimum temperature recorded at the weather station at Slimbridge on 10 February was -11.8°C, the lowest of the whole winter, and the temperature on each of the previous seven nights was below -4°C (Wildfowl & Wetlands Trust data). Ridgill & Fox (1990) demonstrated that Shelduck show significant cold weather movements away from major wintering estuarine resorts of the Wadden Sea to east and west Britain and Ireland, and Fox and Salmon (in press) demonstrated that some sectors of the Severn received large numbers of Shelducks in the hard winters of 1978/79, 1981/82 and 1984/85. In the light of this, it seems possible that any Shelduck oiled on the Severn on 11 February 1991 were from a population other than that which breeds locally, and that the full effects of the oil spill will never be known.

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Section 7

Factors which mitigated the spill impact

From the previous sections it seems apparent that the 11 February 1991 spill did not have a major impact on the Severn waterfowl. Several factors may have contributed towards there being only a small number of birds killed by the heavy fuel oil.

Major bird kills such as occurred after the *Amoco Cadiz* are due to very large amounts of oil being released in a relatively small area of sea and shoreline. The 1989 Mersey incident, a much smaller spill than that of the *Amoco Cadiz*, was found to have only a small to moderate impact mitigated by wind and tide. The amount of oil released from the Llanwern works was smaller than that of the Mersey incident and not very large compared to the size of the estuary. Furthermore much of it may have been lost to the sea, while some was recovered out in the estuary, and some probably sank and would only have affected the subtidal benthos.

Oil mainly kills invertebrates and plants by smothering. The beached oil was never present in the large quantities required to smother mudflats and sediments leading to widespread plant and invertebrate deaths. The oiling was always localised and patchy (NRA, 1991).

The estuary was never completely affected by the oil as some sections of the estuary remained free of the pollutant. These `clean' sections included Bridgwater Bay, amongst others, which is of importance to large numbers of feeding birds (Clark, 1989; Clark, 1990). This gives the possibility of refuges from the oil although there is little evidence for such movements on a regular basis (Clark 1983).

The heavy fuel oil released had relatively low proportions of the lighter, more volatile fractions which are more harmful to life than the heavier, less volatile, fractions. Moreover the analysis of the oil samples recovered from the estuary showed that the lighter fractions were rapidly weathered and lost to the atmosphere (NRA, 1991) before beaching. The heavier oils smear, but are less poisonous to invertebrate and bird life.

Lastly, and importantly, as far as possible no detergents were used in the clean-up operation. As emphasised in Section 1.4 of this report there are many examples of the deleterious effects of these substances (*e.g.* Wilson, 1988), such as the poisoning of biota which can lead to deaths or behavioural changes. The areas of the Severn important for their amenity value were just cleaned mechanically by the physical removal or burial of oiled material. This caused little environmental harm.

RECOMMENDATIONS FOR FURTHER WORK

This report has shown that there were no detectable effects of this oil spill on the waterfowl populations on the Severn Estuary. It is, therefore, recommended that no further monitoring of bird populations should be undertaken in relation to this spill. However, the report has shown the need for regular monitoring of sensitive estuarine bird communities in order to be able to detect the effect of pollution events.

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Tables

Species	Av. Peak Winter Count (Nov.-Mar.)	% of British population	% of Flyway ** population
SHELDUCK *Tadorna tadorna*	2833	3.8	1.1
OYSTERCATCHER *Haematopus ostralegus*	709	0.3	0.1
RINGED PLOVER *Charadrius hiaticula*	312	1.4	0.6
GOLDEN PLOVER *Pluvialis apricaria*	19	0.0	0.0
GREY PLOVER *Pluvialis squatarola*	1039	5.0	0.7
LAPWING *Vanellus vanellus*	2854	0.3	0.1
KNOT *Calidris canutus*	3188	1.5	0.9
SANDERLING *Calidris alba*	10	0.1	0.0
DUNLIN *Calidris alpina*	48365	11.3	3.5
RUFF *Philomachus pugnax*	18	*	0.0
SNIPE *Gallinago gallinago*	174	*	0.0
BLACK-TAILED GODWIT *Limosa limosa*	25	*	0.0
BAR-TAILED GODWIT *Limosa lapponica*	71	0.1	0.1
CURLEW *Numenius arquata*	3641	4.0	1.0
REDSHANK *Tringa totanus*	2956	3.9	2.0
TURNSTONE *Arenaria interpres*	438	1.0	0.6

* No population estimate available.
** East Atlantic Flyway for waders; N.W European population for wildfowl.

An additional seven species (Jack Snipe, Green Sandpiper, Common Sandpiper, Spotted Redshank, Greenshank, Purple Sandpiper and Avocet) had average peak counts of less than ten birds.

Table 1 The National and International Importance of the Severn for wintering waders and Shelduck, 1986/87-1990/91 (figures subject to slight modification if additional data becomes available).

Site	Range of aliphatic hydrocarbons	$\frac{nC17}{Pristane}$ ratio	$\frac{nC18}{Phytane}$ ratio	Weathering	Oil type
Formal sample, Llanwern 11.2.91	nC9 ⇒ nC30+	2.3	2.1	No	Heavy Fuel Oil
British Steel Outlet, Llanwern 11.2.91	nC9 ⇒ nC30+	2.3	2.1	No	Heavy Fuel Oil
Foreshore near British Steel Outlet, Llanwern 11.2.91	nC9 ⇒ nC30+	2.3	2.0	No	Heavy Fuel Oil
Porton House, Redwick 11.2.91	nC9 ⇒ nC30+	2.3	2.1	No	Heavy Fuel Oil
Black Nore Point Portishead 12.2.91	nC9 ⇒ nC30+	2.3	2.2	Yes	Heavy Fuel Oil
Whitmore Bay, Sample 1 21.2.91	nC14 ⇒ nC30+	2.3	2.2	Yes	Heavy Fuel Oil
Whitmore Bay, Sample 2 22.2.91	nC14 ⇒ nC30+	2.3	2.3	Yes	Heavy Fuel Oil
Llantwit Major beach	nC14 ⇒ nC30+	2.2	2.2	Yes	Heavy Fuel Oil

25.2.91					

Table 2.1 Analysis of National Rivers Authority formal and associated oil samples taken from the Severn in February 1991.

Site	Range of aliphatic hydrocarbons	nC17 ratio Pristane	nC18 ratio Phytane	Weathering	Oil type
Battery Point, Portishead 13.2.91	nC14 $\Rightarrow$ nC30+	2.3	2.2	Yes	Heavy Fuel Oil
Battery Point, Portishead 15.2.91	nC14 $\Rightarrow$ nC30+	2.3	2.2	Yes	Heavy Fuel Oil
Lodge Bay, Clevedon 15.2.91	nC14 $\Rightarrow$ nC30+	2.3	2.2	Yes	Heavy Fuel Oil
Steepholm Beach 16.2.91 Sample 1	nC14 $\Rightarrow$ nC30+	2.2	2.2	Yes	Heavy Fuel Oil
Steepholm Beach 16.2.91 Sample 2	nC14 $\Rightarrow$ nC30+	2.2	2.2	Yes	Heavy Fuel Oil
Estuary between Flatholm and Steepholm 16.2.91	nC14 $\Rightarrow$ nC30+	2.2	2.2	Yes	Heavy Fuel Oil
Boat-towed boom sample 15.2.91	nC14 $\Rightarrow$ nC30+	2.2	2.2	Yes	Heavy Fuel Oil

Table 2.2 Analysis of National Rivers Authority Wessex Region oil samples taken from the Severn in February 1991.

Species	Date acquired	Death or release date
Little Grebe 1	15. 2. 91	16. 2. 91†
Great Crested Grebe 1	15. 2. 91	23. 2. 91
Swan 1	12. 2. 91	14. 2. 91†
1 1	13. 2. 91	15. 2. 91†
1	13. 2. 91	9. 3. 91†
	18. 2. 91	18. 2. 91†
Pochard 1	13. 2. 91	17. 2. 91
1	14. 2. 91	17. 2. 91
1_	20. 2. 91	23. 2. 91
Mallard 3_ 3	13. 2. 91	17. 2. 91
4	14. 2. 91	17. 2. 91
2	18. 2. 91	21. 2. 91
3_	18. 2. 91	22. 2. 91
1_	19. 2. 91	22. 2. 91
1_	20. 2. 91	23. 2. 91
	20. 2. 91	11. 3. 91
Shelduck 1	14. 2. 91	17. 2. 91
Black-headed Gull 1	13. 2. 91	24. 2. 91
2	15. 2. 91	17. 2. 91†
Lesser Black-backed Gull	13. 2. 91	21. 2. 91
Glaucous Gull 1	15. 2. 91	11. 3. 91
1	16. 2. 91	11. 3. 91
Dunlin 1	13. 2. 91	16. 2. 91
2	14. 2. 91	16. 2. 91
1	15. 2. 91	16. 2. 91†
1	16. 2. 91	21. 2. 91

† = bird that died

Table 3.1Oiled birds handed in to the Royal Society for the Prevention of Cruelty to Animals.

Coast	OS Grid Reference	Species	State of oiled bird*
Mid Glamorgan	SS779836 - SS884731	Razorbill	No oil (2)
		Little Auk	No oil
		Gannet	No oil (2)
		Pochard	Heavy (2)
		Dunlin	Heavy (3)
		Black-headed Gull	No oil Slight (3) Heavy
		Herring Gull	Slight (3) Heavy
		Kittiwake	No oil
		Common Gull	No oil (3)
South Glamorgan	SS887727 - ST190712	Razorbill	No oil (2)
		Shelduck	No oil Heavy
		Black-headed Gull	Heavy (3)
		Herring Gull	Slight (2) Heavy
		Common Gull	No oil Heavy
		Grey Partridge	No oil
		Woodpigeon	Heavy
Gwent	ST253787 - ST513879	Shelduck	No oil

* numbers recorded in parenthesis.

Table 3.2 Synopsis of Royal Society for the Protection of Birds beached bird survey results for the Welsh Severn coast, birds found dead or alive but oiled are recorded.

Area	Species	February 1991			March 1991		
		∑	Oil	%	∑	Oil	%
Bridgwater Bay	Shelduck	168	3	1.8	273	0	0
	Dunlin	850	0	0	570	0	0
	Curlew	113	0	0	138	0	0
	Redshank	51	0	0	41	0	0
	BH	23	1	4.3	*		
R. Parrett	Shelduck	4	0	0	4	0	0
	Dunlin	325	0	0	0	0	0
	Curlew	20	0	0	0	0	0
	Redshank	19	0	0	24	0	0
	BH	84	3	3.6	0	0	0
	GB	1	1	100	0	0	0
Burnham	Shelduck	0	0	0	5	0	0
	Dunlin	180	0	0	0	0	0
	Curlew	9	0	0	3	0	0
	Redshank	14	0	0	32	0	0
	BH	*			*		
Berrow	Shelduck	0	0	0	3	0	0
	Dunlin	110	0	0	0	0	0
	Curlew	1	0	0	0	0	0
	Redshank	3	0	0	0	0	0
	BH	253	1	0.4	18	0	0
	CM	5	1	20.0	0	0	0
Brean	Shelduck	9	1	11.1	*		
	Dunlin	162	0	0			
	Curlew	11	0	0			
	Redshank	0	0	0			
	BH	133	3	2.3			
Weston Bay	Shelduck	0	0	0	17	0	0
	Dunlin	300	0	0	0	0	0
	Curlew	3	0	0	2	0	0
	Redshank	0	0	0	0	0	0
	BH	1000	P	P	40	0	0
Clevedon	Shelduck	9	5	55.6	*		
	Dunlin	37	6	16.2			
	Curlew	0	0	0			
	Redshank	8	4	50.0			
	BH	9	2	22.2			
Portishead	Shelduck	6	2	33.3	2	0	0
	Dunlin	14	0	0	0	0	0
	Curlew	3	0	0	2	0	0
	Redshank	15	0	0	3	0	0
	BH	308	8	2.6	325	1	0.3

	Mallard	1	1	100	0	0	0

P = Present, but not counted * = No count data
BH=Black-headed Gull GB=Great Black-backed Gull CM=Common Gull

Table 3.3aProportions of oiled birds found during low tide counts carried out on the Severn.

Area	Species	February 1991			March 1991		
		Σ	Oil	%	Σ	Oil	%
Severn Beach	Shelduck	91	39	42.9	68	0	0
	Dunlin	580	0	0	0	0	0
	Curlew	50	0	0	121	0	0
	Redshank	64	0	0	0	0	0
	BH	232	91	39.2	1475	0	0
	HG	4	2	50.0	*		
	GB	2	2	100	*		
	Mallard	21	2	9.5	*		
Oldbury	Shelduck	25	4	16.0	65	0	0
	Dunlin	566	0	0	80	0	0
	Curlew	201	0	0	539	0	0
	Redshank	5	0	0	5	0	0
	BH	1580	3	0.2	3026	0	0
	LB	40	2	5.0	14	0	0
Berkeley	Shelduck	0	0	0	0	0	0
	Dunlin	0	0	0	5	0	0
	Curlew	0	0	0	0	0	0
	Redshank	8	0	0	0	0	0
	BH	28	0	0	240	0	0
Sharpness	Shelduck	0	0	0	2	0	0
	Dunlin	1000	0	0	0	0	0
	Curlew	0	0	0	0	0	0
	Redshank	7	0	0	1	0	0
	BH	821	2	0.2	1142	0	0
	CM	1362	6	0.4	1229	2	0.2
Slimbridge	Shelduck	4	0	0	87	0	0
	Dunlin	40	0	0	700	0	0
	Curlew	21	0	0	0	0	0
	Redshank	2	0	0	0	0	0
	BH	3000	0	0	P	P	P
Rodley	Shelduck	0	0	0	5	0	0
	Dunlin	0	0	0	0	0	0
	Curlew	0	0	0	0	0	0
	Redshank	0	0	0	0	0	0
	BH	720	0	0	980	0	0
Framilode	Shelduck	0	0	0	0	0	0
	Dunlin	0	0	0	0	0	0
	Curlew	0	0	0	0	0	0
	Redshank	0	0	0	0	0	0
	BH	264	20	7.6	193	0	0

P = Present, but not counted   * = No count data
BH=Black-headed Gull GB=Great Black-backed Gull CM=Common Gull

HG=Herring Gull LB=Lesser Black-backed Gull

Table 3.3b Proportions of oiled birds found during low tide counts carried out on the Severn.

Area	Species	February 1991			March 1991		
		Σ	Oil	%	Σ	Oil	%
Mathern	Shelduck	23	4	17.4	23	2	8.7
	Dunlin	150	0	0	325	0	0
	Curlew	44	0	0	23	0	0
	Redshank	3	0	0	5	0	0
	BH	161	0	0	162	0	0
Caldicot	Shelduck	63	14	22.2	164	0	0
	Dunlin	200	7	3.5	120	0	0
	Curlew	30	0	0	11	0	0
	Redshank	0	0	0	0	0	0
	BH	35	9	25.7	*		
Magor	Shelduck	3	2	66.7	3	0	0
	Dunlin	21	0	0	0	0	0
	Curlew	6	0	0	39	0	0
	Redshank	0	0	0	0	0	0
	BH	68	11	16.2	*		
Redwick	Shelduck	46	0	0	27	0	0
	Dunlin	95	0	0	0	0	0
	Curlew	20	0	0	10	0	0
	Redshank	11	0	0	0	0	0
	BH	200	6	3	100	0	0
St. Brides	Shelduck	196	0	0	114	0	0
	Dunlin	4296	0	0	11K	0	0
	Curlew	14	0	0	14	0	0
	Redshank	29	0	0	2	0	0
	BH	*			*		
Peterstone	Shelduck	595	0	0.2	0	0	0
	Dunlin	12750	0	0	0	0	0
	Curlew	47	0	0	0	0	0
	Redshank	409	0	0	0	0	0
	BH	P	?	?	0	0	0
	GB	1	1	100			
Taff-Ely	Shelduck	431	0	0	171	0	0
	Dunlin	0	0	0	71	0	0
	Curlew	24	0	0	29	0	0
	Redshank	164	0	0	195	0	0
	BH	*			*		

P = Present, but not counted   * = No count data

K = x 10^3

BH=Black-headed Gull   GB=Great Black-backed Gull

Table 3.3c Proportions of oiled birds found during low tide counts carried out on the Severn.

Site	Oiled	January	February	March	Σ
Clevedon	yes	110	110	90	310
Severn Beach		56	60	150	266
Redwick		78	52	288	418
Bridgwater	no	240	81	320	641
Berrow		2	0	18	20
Oldbury		20	3	10	33
Aylburton		19	13	80	112
Slimbridge		46	60	183	289
Mathern		41	105	23	169
St. Brides		6	22	142	170
Peterstone		700	556	510	1766
Rhymney		700	500	135	1335
Taff-Ely		446	338	192	976
Σ		2464	1900	2141	6505

$\chi^2_{24} = 1374.16$, $p < 0.001$

Table 5.1aShelduck numbers in individual oiled and unoiled sites on the Severn Estuary in 1991.

	January	February	March	Σ
Oiled sites	244	222	528	994
Unoiled sites	2220	1678	1613	5511
Σ	2464	1900	2141	6505

$\chi^2_{2} = 219.57$, $p < 0.001$

Table 5.1b Shelduck numbers summed for oiled and unoiled sites on the Severn Estuary in 1991.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.63	0.80	0.58	0.41	0.50
River Avon (Seamills)		∞	∞	∞	∞	∞
Severn Beach		0.50	0.48	0.92	0.67	0.52
Undy		*	0.24	0.62	*	1.00
Redwick		0.53	0.82	0.64	*	0.40
Bridgwater Bay	No	0.00	0.39	0.64	0.33	0.25
Berrow		0.00	1.00	1.00	0.25	0.42
Oldbury Silt Lagoon		1.00	0.40	1.00	∞	0.13
Aylburton		0.96	0.65	0.76	0.00	0.41
Slimbridge		*	0.40	1.00	1.00	0.57
Mathern		0.96	0.69	0.51	1.00	0.72
Nash		*	0.55	0.66	*	*
St. Brides		*	0.85	0.00	*	0.79
Peterstone		0.59	0.12	0.00	0.55	0.44
Rhymney		0.42	0.49	0.00	*	0.42
Taff-Ely		0.51	0.65	0.65	0.50	0.43

Winter 1 = 1987   Winter 2 = 1988   Winter 3 = 1989
Winter 4 = 1990   Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Feb. Nos.}}{\text{Jan. + Feb. Nos.}}$$

Table 5.2 The proportion (x_{ij}) of Shelduck found in the month of February relative to the total number found in the two winter months of January to February for each of the five winters of 1986/87 and 1990/91 at each of 16 sites, from BoEE count data.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.69	0.63	0.57	0.58	0.45
River Avon (Seamills)		∞	∞	∞	∞	∞
Severn Beach		0.72	0.45	0.93	0.81	0.73
Undy		*	*	0.34	*	*
Redwick		0.45	0.96	0.52	0.87	0.79
Bridgwater Bay	No	0.91	0.48	0.45	0.51	0.57
Berrow		0.20	∞	1.00	0.25	0.90
Oldbury Silt Lagoon		1.00	0.00	∞	∞	0.33
Aylburton		0.97	0.74	0.88	0.76	0.81
Slimbridge		1.00	0.00	1.00	1.00	0.80
Mathern		0.91	0.64	0.55	1.00	0.36
Nash		1.00	*	*	0.91	*
St. Brides		*	0.81	*	*	0.96
Peterstone		0.61	0.45	0.71	0.62	0.42
Rhymney		0.15	0.64	0.78	*	0.16
Taff-Ely		0.31	0.60	0.67	0.00	0.30

Winter 1 = 1987 Winter 2 = 1988 Winter 3 = 1989
Winter 4 = 1990 Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Mar. Nos.}}{\text{Jan. + Mar. Nos.}}$$

Table 5.3 The proportion (x_{ij}) of Shelduck found in the month of March relative to the total number found in the two winter months of January and March for each of the five winters of 1986/87 to 1990/91 at each of 16 sites, from BoEE count data.

Site	Oiled	January	February	March	Σ
Clevedon	yes	700	1650	80	2430
R. Avon		0	10	0	10
Severn Beach		1800	2500	400	4700
Redwick		5400	1250	650	7300
Bridgwater	no	11000	11000	300	22300
Berrow		7000	5000	14	12014
Oldbury		45	1500	1	1546
Aylburton		320	250	23	593
Slimbridge		900	1500	400	2800
Mathern		80	530	310	920
St. Brides		30	1200	820	2050
Peterstone		2000	3500	850	6350
Taff-Ely		150	300	1200	1650
Σ		29425	30190	5048	64663

$\chi^2_{24} = 22869.50$, $p < 0.001$

Table 5.4a Dunlin numbers in individual oiled and unoiled sites on the Severn Estuary in 1991.

	January	February	March	Σ
Oiled sites	7900	5410	1130	14440
Unoiled sites	21525	24780	3918	50223
Σ	29425	30190	5048	64663

$\chi^2_{2} = 684.84$, $p < 0.001$

Table 5.4b Dunlin numbers summed for oiled and unoiled sites on the Severn Estuary in 1991.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.46	0.58	0.33	0.16	0.70
River Avon (Seamills)		1.00	∞	0.00	0.97	1.00
Severn Beach		0.24	0.62	0.71	0.51	0.58
Undy		*	0.50	0.80	*	0.97
Redwick		0.86	0.05	0.69	*	0.19
Bridgwater Bay	No	0.39	0.48	0.50	0.53	0.50
Berrow		0.05	0.75	0.91	0.49	0.42
Oldbury Silt Lagoon		0.44	0.50	0.77	0.13	0.97
Aylburton		0.29	0.38	0.70	0.48	0.44
Slimbridge		*	0.50	0.20	0.91	0.63
Mathern		1.00	1.00	1.00	0.00	0.87
Nash		*	0.47	0.71	*	*
St. Brides		*	1.00	∞	*	0.98
Peterstone		0.58	0.88	0.20	0.50	0.64
Rhymney		∞	0.33	∞	*	∞
Taff-Ely		0.73	0.70	0.90	0.56	0.67

Winter 1 = 1987 Winter 2 = 1988 Winter 3 = 1989
Winter 4 = 1990 Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Feb. Nos.}}{\text{Jan. + Feb. Nos.}}$$

Table 5.5 The proportion (x_{ij}) of Dunlin found in the month of February relative to the total number found in the two winter months of January and February for each of the five winters of 1986/87 to 1990/91 at each of 16 sites, from BoEE count data.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.15	0.01	0.03	0.00	0.10
River Avon (Seamills)		∞	∞	0.00	0.00	∞
Severn Beach		0.03	0.27	0.33	0.13	0.18
Undy		*	*	0.13	*	*
Redwick		0.31	0.03	0.43	0.00	0.11
Bridgwater Bay	No	0.56	0.04	0.08	0.00	0.03
Berrow		0.09	0.00	0.00	0.00	0.00
Oldbury Silt Lagoon		0.41	0.03	0.15	0.00	0.02
Aylburton		0.08	0.00	0.50	0.02	0.07
Slimbridge		∞	0.03	0.38	0.89	0.31
Mathern		1.00	1.00	0.96	0.05	0.79
Nash		0.05	*	*	0.00	*
St. Brides		*	1.00	*	*	0.96
Peterstone		0.71	0.00	0.96	0.00	0.30
Rhymney		1.00	0.00	∞	*	∞
Taff-Ely		0.80	0.02	0.01	0.00	0.89

Winter 1 = 1987 Winter 2 = 1988 Winter 3 = 1989
Winter 4 = 1990 Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Mar. Nos.}}{\text{Jan. + Mar. Nos.}}$$

Table 5.6 The proportion (x_{ij}) of Dunlin found in the month of March relative to the total number found in the two winter months of January and March for each of the five winters of 1986/87 to 1990/91 at each of 16 sites, from BoEE count data.

Site	Oiled	January	February	March	$\sum$
Clevedon	yes	130	40	80	250
R. Avon		13	0	1	14
Severn Beach		70	74	80	224
Redwick		286	218	274	778
Bridgwater	no	173	400	325	898
Oldbury		3	1	25	29
Aylburton		670	450	580	1700
Slimbridge		220	210	100	530
Mathern		8	3	26	37
St. Brides		39	143	25	207
Peterstone		362	192	430	984
Taff-Ely		81	88	325	494
$\sum$		2055	1819	2271	6145

$\chi^2_{22} = 727.13$, $p < 0.001$

Table 5.7aCurlew numbers in individual oiled and unoiled sites on the Severn Estuary in 1991.

	January	February	March	$\sum$
Oiled sites	499	332	435	1266
Unoiled sites	1556	1487	1836	4879
$\sum$	2055	1819	2271	6145

$\chi^2_{2} = 26.07$, $p < 0.001$

Table 5.7bCurlew numbers summed for oiled and unoiled sites on the Severn Estuary in 1991.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.70	0.67	0.63	0.66	0.24
River Avon (Seamills)		∞	∞	1.00	0.07	0.00
Severn Beach		0.59	0.56	0.71	0.78	0.51
Undy		*	0.50	0.09	*	1.00
Redwick		0.97	0.00	0.88	*	0.43
Bridgwater Bay	No	0.67	0.41	0.23	0.42	0.70
Berrow		0.78	0.50	0.00	∞	0.00
Oldbury Silt Lagoon		0.33	∞	∞	0.00	0.25
Aylburton		0.54	0.51	0.44	0.67	0.40
Slimbridge		*	∞	0.56	0.56	0.49
Mathern		0.53	0.63	0.48	0.05	0.87
Nash		*	0.73	1.00	*	*
St. Brides		*	0.94	1.00	*	0.79
Peterstone		0.58	0.05	0.71	0.45	0.35
Rhymney		0.00	∞	∞	*	∞
Taff-Ely		0.37	0.44	0.50	0.21	0.52

Winter 1 = 1987 Winter 2 = 1988 Winter 3 = 1989
Winter 4 = 1990 Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Feb. Nos.}}{\text{Jan. + Feb. Nos.}}$$

Table 5.8 The proportion (x_{ij}) of Curlew found in the month of February relative to the total number found in the two winter months of January and February for each of the five winters of 1986/87 to 1990/91 at each of 16 sites, from BoEE count data.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.59	0.53	0.48	0.16	0.38
River Avon (Seamills)		∞	∞	1.00	0.00	0.07
Severn Beach		0.21	0.25	0.60	0.51	0.53
Undy		*	*	0.44	*	*
Redwick		0.79	0.36	0.71	0.78	0.49
Bridgwater Bay	No	0.46	0.32	0.11	0.38	0.65
Berrow		0.91	0.00	0.00	∞	0.00
Oldbury Silt Lagoon		0.40	1.00	∞	0.22	0.89
Aylburton		0.43	0.38	0.44	0.72	0.46
Slimbridge		1.00	1.00	0.57	0.36	0.31
Mathern		0.51	0.00	0.57	0.36	0.76
Nash		0.10	*	*	0.65	*
St. Brides		*	0.92	*	*	0.39
Peterstone		0.36	0.31	0.74	0.00	0.54
Rhymney		0.00	∞	∞	*	∞
Taff-Ely		0.15	0.00	0.24	0.00	0.80

Winter 1 = 1987 Winter 2 = 1988 Winter 3 = 1989
Winter 4 = 1990 Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Mar. Nos.}}{\text{Jan. + Mar. Nos.}}$$

Table 5.9 The proportion (x_{ij}) of Curlew found in the month of March relative to the total number found in the two winter months of January and March for each of the five winters of 1986/87 to 1990/91 at each of 16 sites, from BoEE count data.

Site	Oiled	January	February	March	$\sum$
Clevedon	yes	110	105	80	295
R. Avon		85	80	38	203
Severn Beach		8	100	50	158
Redwick		15	12	0	27
Bridgwater	no	908	350	345	1603
Oldbury		36	80	28	144
Aylburton		39	55	37	131
Slimbridge		6	0	7	13
Mathern		56	220	63	339
St. Brides		6	0	20	26
Peterstone		0	0	520	520
Rhymney		385	420	0	805
Taff-Ely		100	190	248	538
$\sum$		1754	1612	1436	4802

$\chi^2_{24} = 2279.40$, $p < 0.001$

Table 5.10aRedshank numbers in individual oiled and unoiled sites on the Severn Estuary in 1991.

	January	February	March	$\sum$
Oiled sites	218	297	168	683
Unoiled sites	1536	1315	1268	4119
$\sum$	1754	1612	1436	4802

$\chi^2_{2} = 35.45$, $p < 0.001$

Table 5.10b Redshank numbers summed for oiled and unoiled sites on the Severn Estuary in 1991.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.63	0.37	0.53	0.68	0.49
River Avon (Seamills)		0.58	0.49	0.00	0.49	0.48
Severn Beach		0.30	0.65	0.00	0.75	0.93
Undy		*	1.00	0.12	*	0.00
Redwick		0.75	0.83	0.99	*	0.44
Bridgwater Bay	No	0.48	0.23	0.49	0.39	0.28
Berrow		∞	∞	∞	∞	∞
Oldbury Silt Lagoon		0.00	0.23	0.26	0.28	0.69
Aylburton		0.55	0.47	0.59	1.00	0.59
Slimbridge		*	0.23	0.00	0.50	0.00
Mathern		0.29	0.84	0.56	0.76	0.80
Nash		*	0.59	0.00	*	*
St. Brides		*	∞	1.00	*	0.00
Peterstone		0.00	0.11	∞	0.00	∞
Rhymney		0.42	0.29	0.48	*	0.52
Taff-Ely		0.74	0.57	0.66	0.27	0.66

Winter 1 = 1987 Winter 2 = 1988 Winter 3 = 1989
Winter 4 = 1990 Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Feb. Nos.}}{\text{Jan. + Feb. Nos.}}$$

Table 5.11 The proportion (x_{ij}) of Redshank found in the month of February relative to the total number found in the two winter months of January and February for each of the five winters of 1986/87 to 1990/91 at each of 16 sites, from BoEE count data.

Site	Oiled	Winter 1	Winter 2	Winter 3	Winter 4	Winter 5
Clevedon	Yes	0.60	0.36	0.55	0.63	0.42
River Avon (Seamills)		0.50	0.26	0.00	0.25	0.31
Severn Beach		0.35	0.47	0.67	0.78	0.86
Undy		*	*	0.02	*	*
Redwick		0.59	0.00	0.00	0.01	0.00
Bridgwater Bay	No	0.39	0.73	0.37	0.04	0.28
Berrow		∞	∞	∞	∞	1.00
Oldbury Silt Lagoon		0.20	0.28	0.02	0.00	0.44
Aylburton		0.59	0.55	0.14	1.00	0.49
Slimbridge		0.75	0.28	0.93	0.78	0.54
Mathern		0.65	0.88	0.31	0.16	0.53
Nash		0.52	*	*	∞	*
St. Brides		*	1.00	*	*	0.77
Peterstone		0.96	0.05	1.00	0.36	1.00
Rhymney		0.61	0.00	0.00	*	0.00
Taff-Ely		0.65	0.37	0.20	0.00	0.71

Winter 1 = 1987 Winter 2 = 1988 Winter 3 = 1989
Winter 4 = 1990 Winter 5 = 1991

* = missing value

$$x_{ij} = \frac{\text{Mar. Nos.}}{\text{Jan. + Mar. Nos.}}$$

Table 5.12 The proportion (x_{ij}) of Redshank found in the month of March relative to the total number found in the two winter months of January and March for each of the five winters of 1986/87 to 1990/91 at each of 16 sites, from BoEE count data.

Count Date	Count Total	No of birds on oiled sections	% of birds on oiled sections
Early incubation			
28 Apr-12 May 90	1576	484	31%
3 May-13 May 91	1693	574	34%
18 May 89	1476	474	33%
10 May 90	1559	516	33%
15 May 91	1649	48	30%
5 June 89	1967	436	22%
7 June 90	2373	645	27%
11 June 91	2578	801	31%
3 July 89	3297	427	13%
10 July 90	2854	379	13%
9 July 91	2959	421	14%
24 July 89	2872	156	6%
23 July 90	2026	96	5%
26 July 91	1309	162	12%
14 Aug 89	2747	24	1%
14 Aug 90	1860	11	1%
12 Aug 91	1192	21	2%

Table 6.1 Counts of adult Shelduck on sections of the Severn Estuary oiled in February 1991 compared with sections unaffected by oil, 1989-91

	1989	1990	1991
Oiled Sections	88	88	114
Unoiled Sections	183	227	139
Total	271	315	253
% young counted on oiled sections	32%	28%	45%

Table 6.2 Counts of Shelducklings on sections of the Severn Estuary oiled in February 1991 compared with sections unaffected by oil, 1989-1991

Figures

Figures

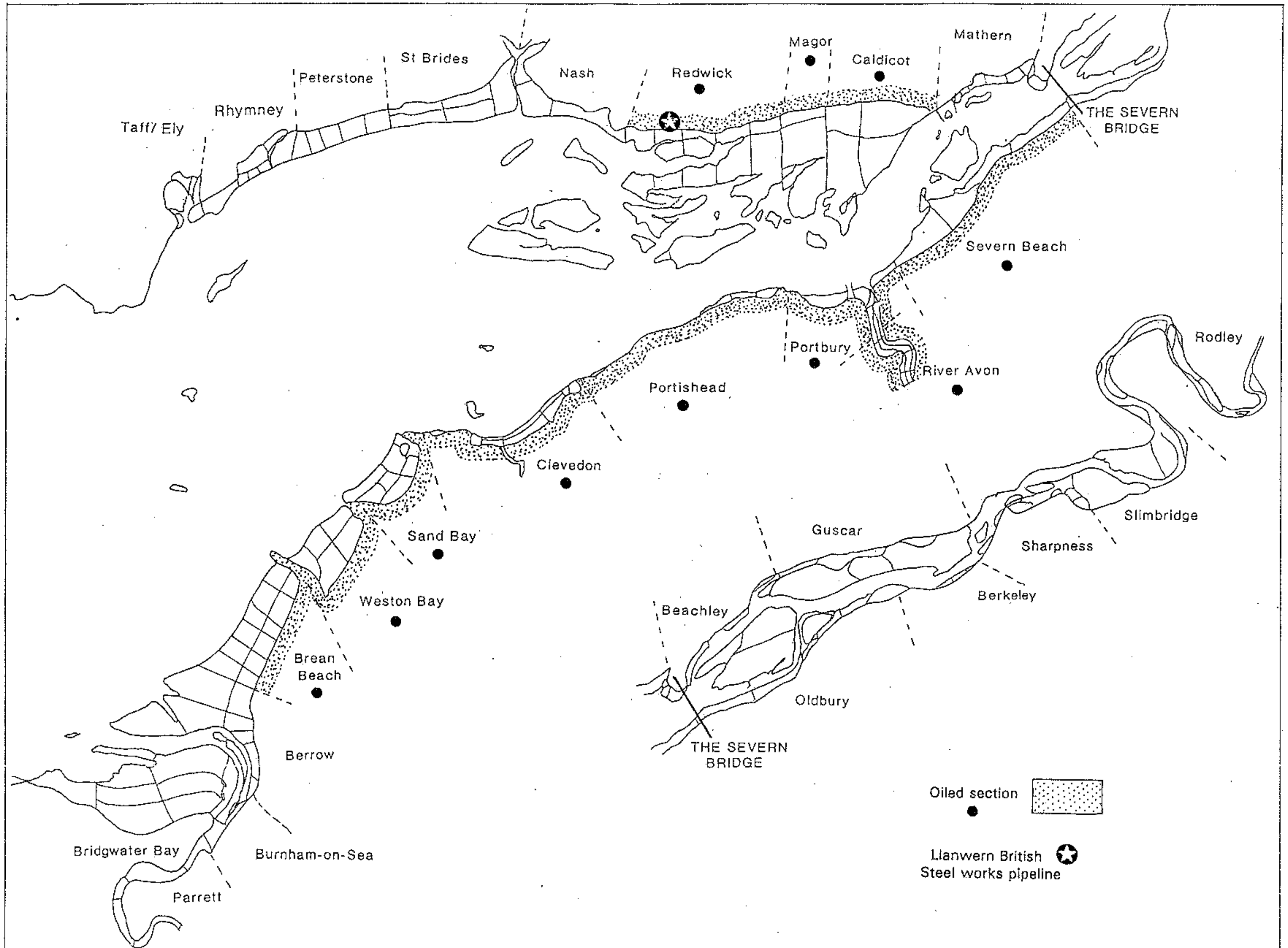


Figure 2.1 The location of the count areas showing oiled sections and the Llanwern British Steel pipeline.

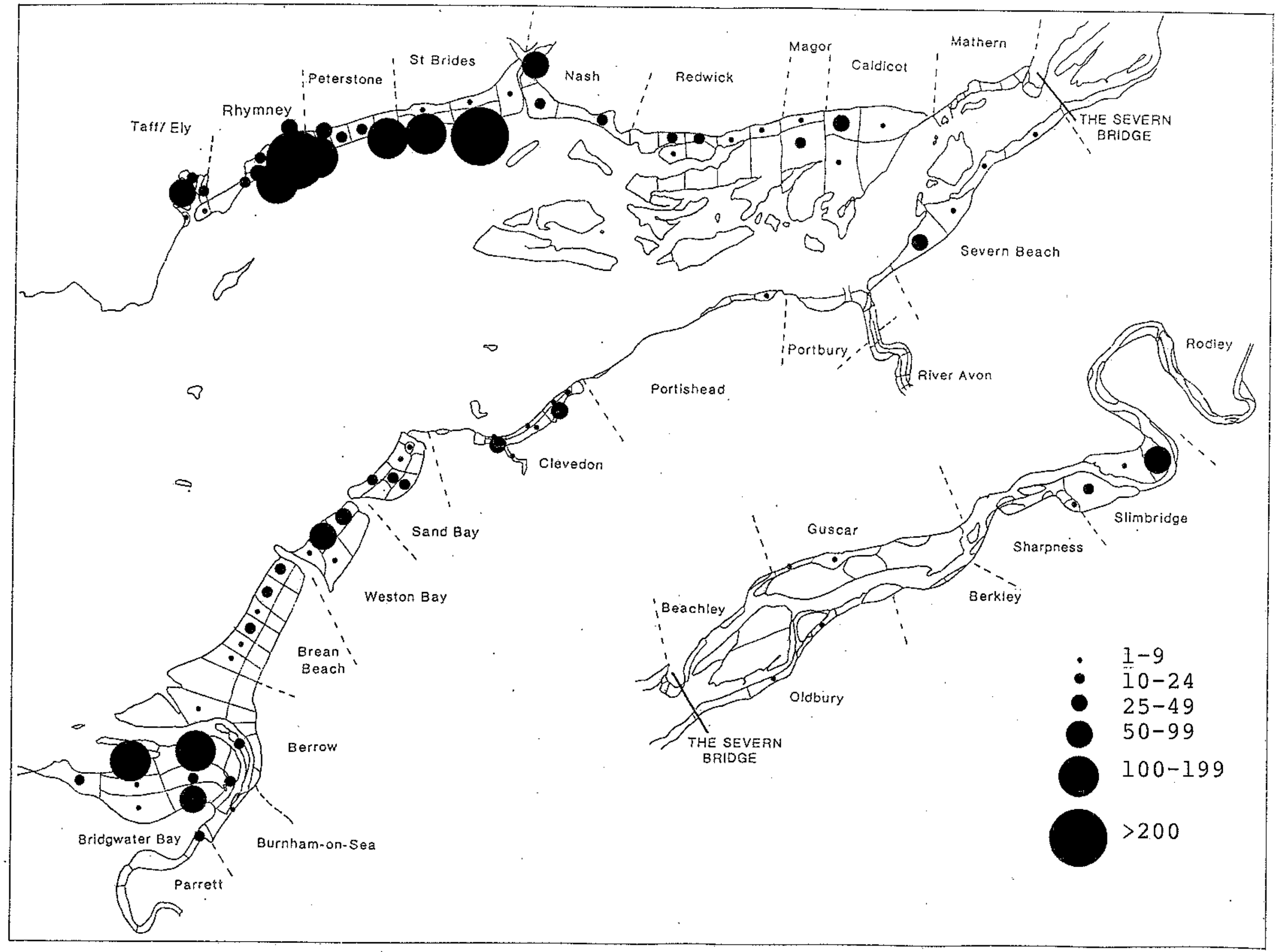


Figure 3.1.1 The average number of Shelduck present at low tide during the 1988/89 winter (ETSU TID 4076).

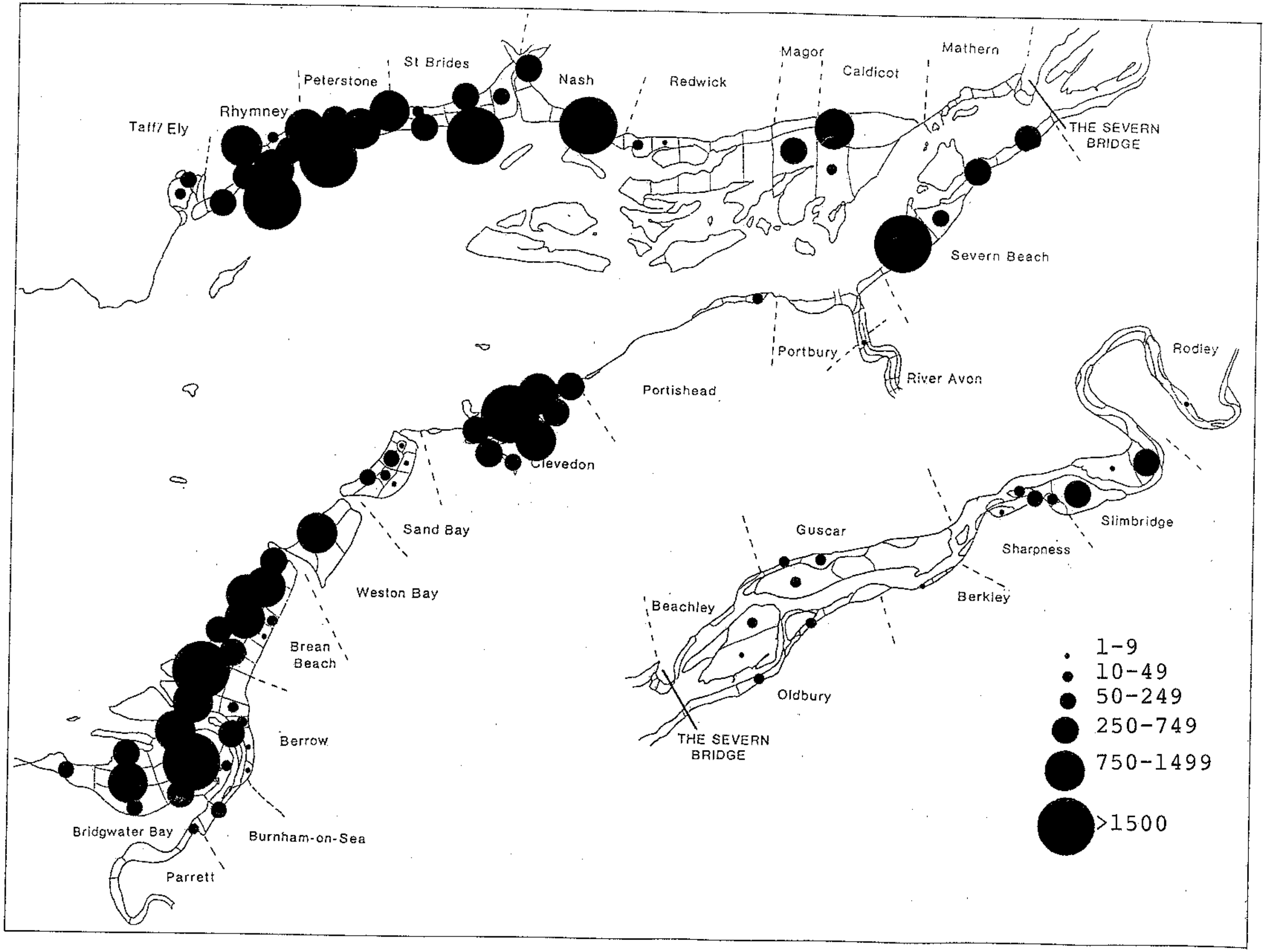


Figure 3.1.2 The average number of Dunlin present at low tide during mid-winter 1988/89 (ETSU TID 4076).

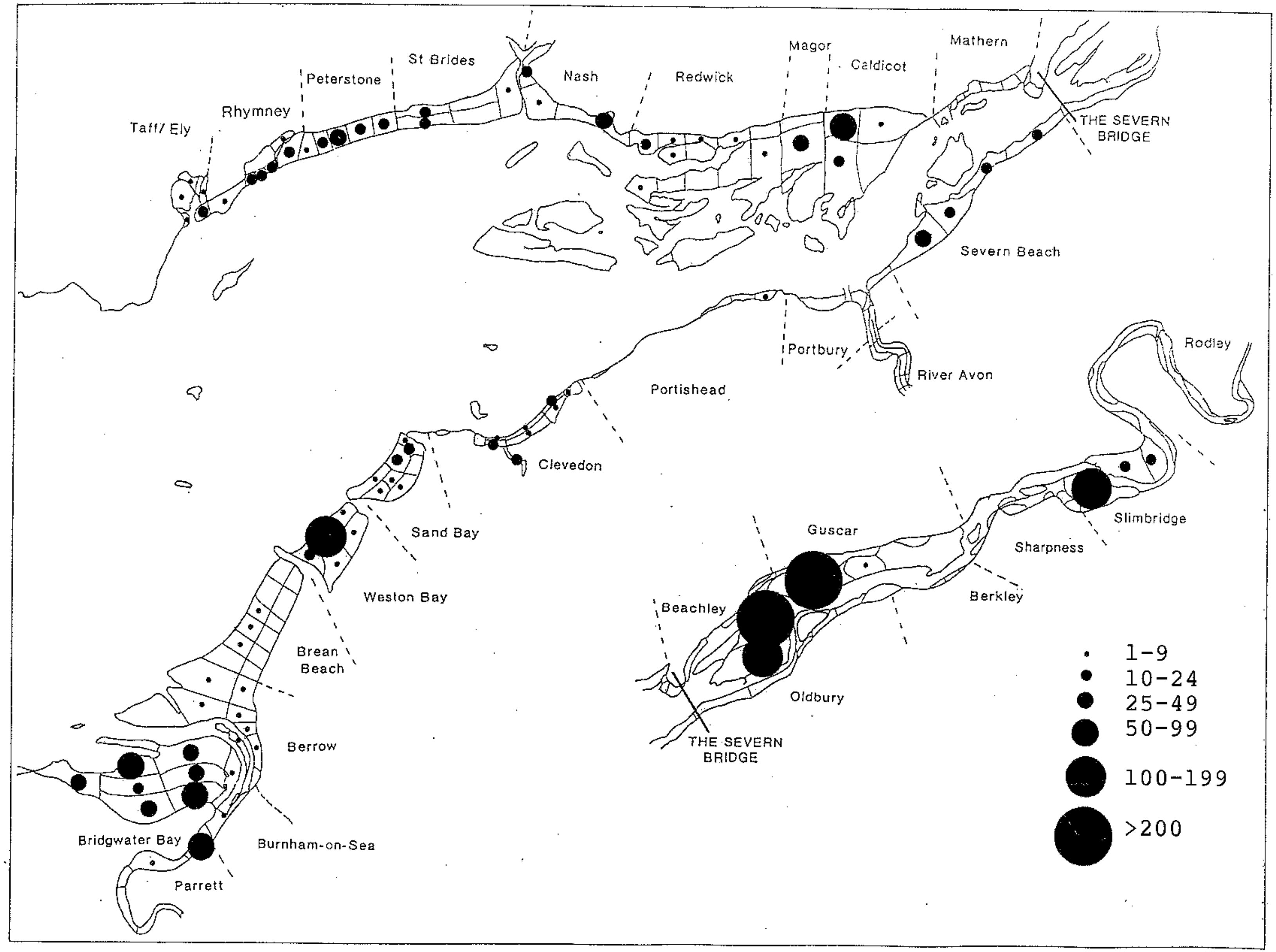


Figure 3.1.3 The average number of Curlew present at low tide during mid-winter 1988/89 (ETSU TID 4076).

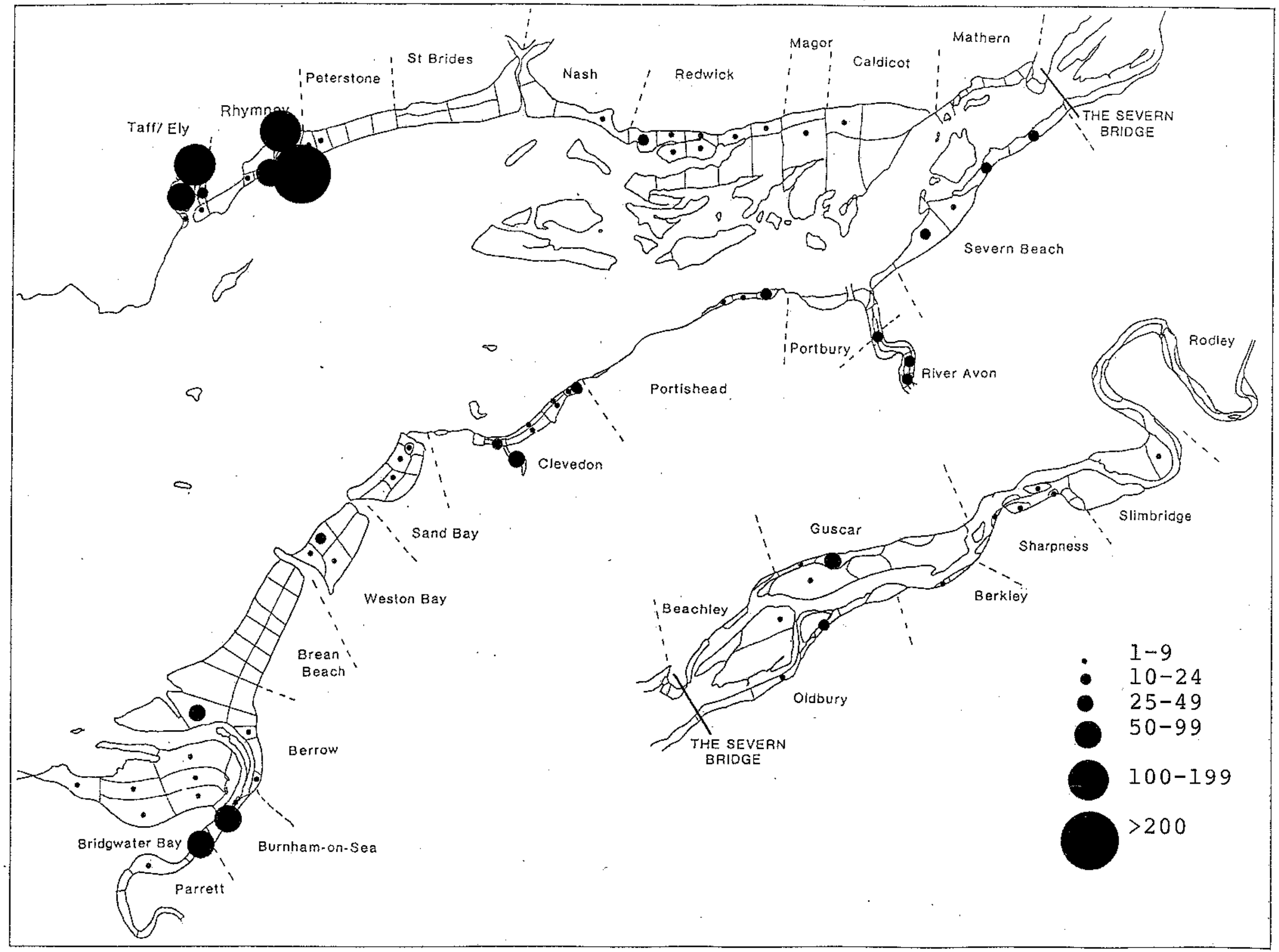


Figure 3.1.4 The average number of Redshank present at low tide during mid-winter 1988/89 (ETSU TID 4076).

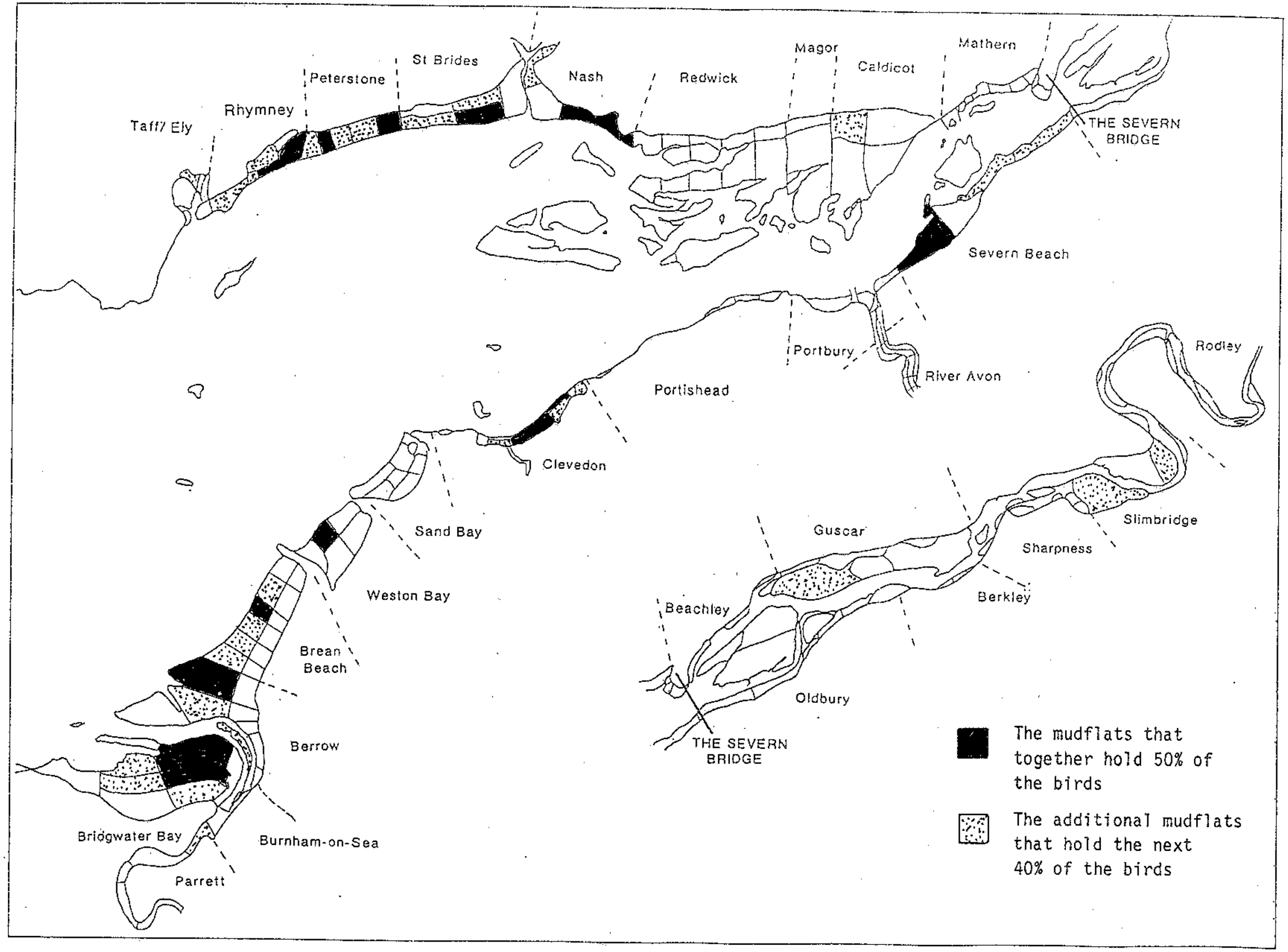


Figure 3.1.5 The areas of the Severn important to waders and Shelduck in the 1988/89 winter (ETSU TID 4076).

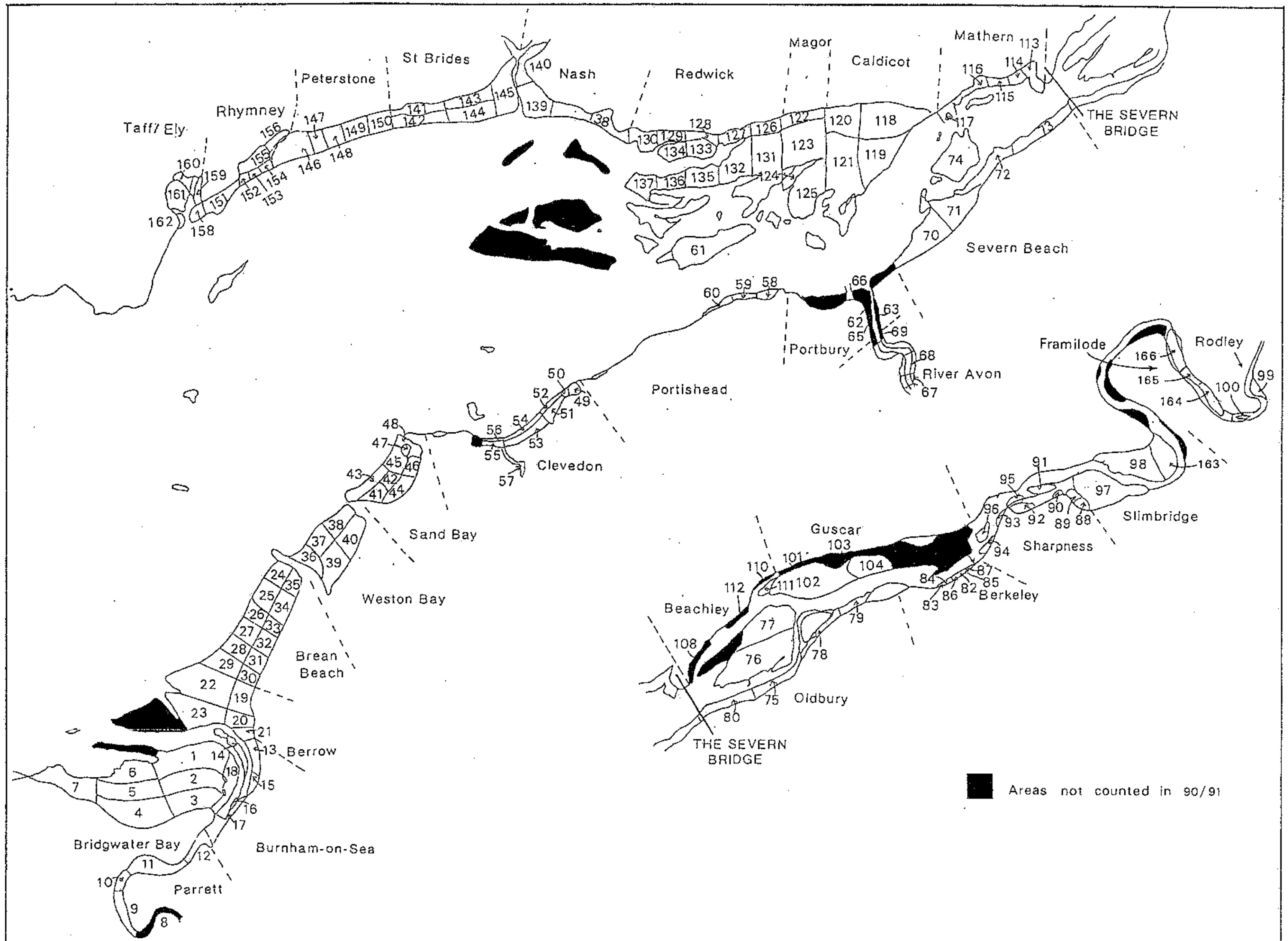


Figure 3.2 The 151 low tide count areas regularly surveyed during mid-winter 1990/91.

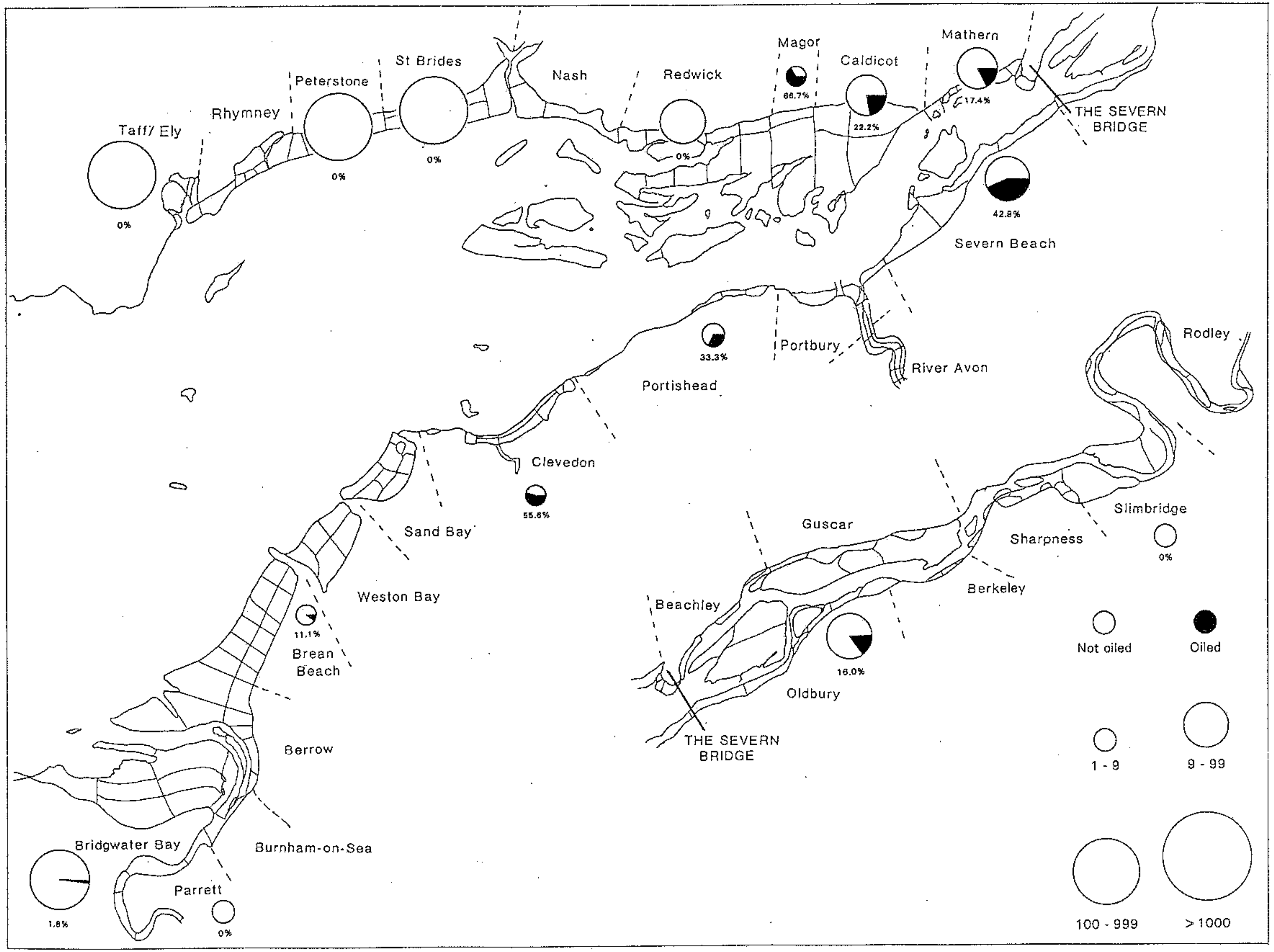


Figure 3.3.1 The percentage of oiled Shelduck on 16/17 February 1991 on the Severn.

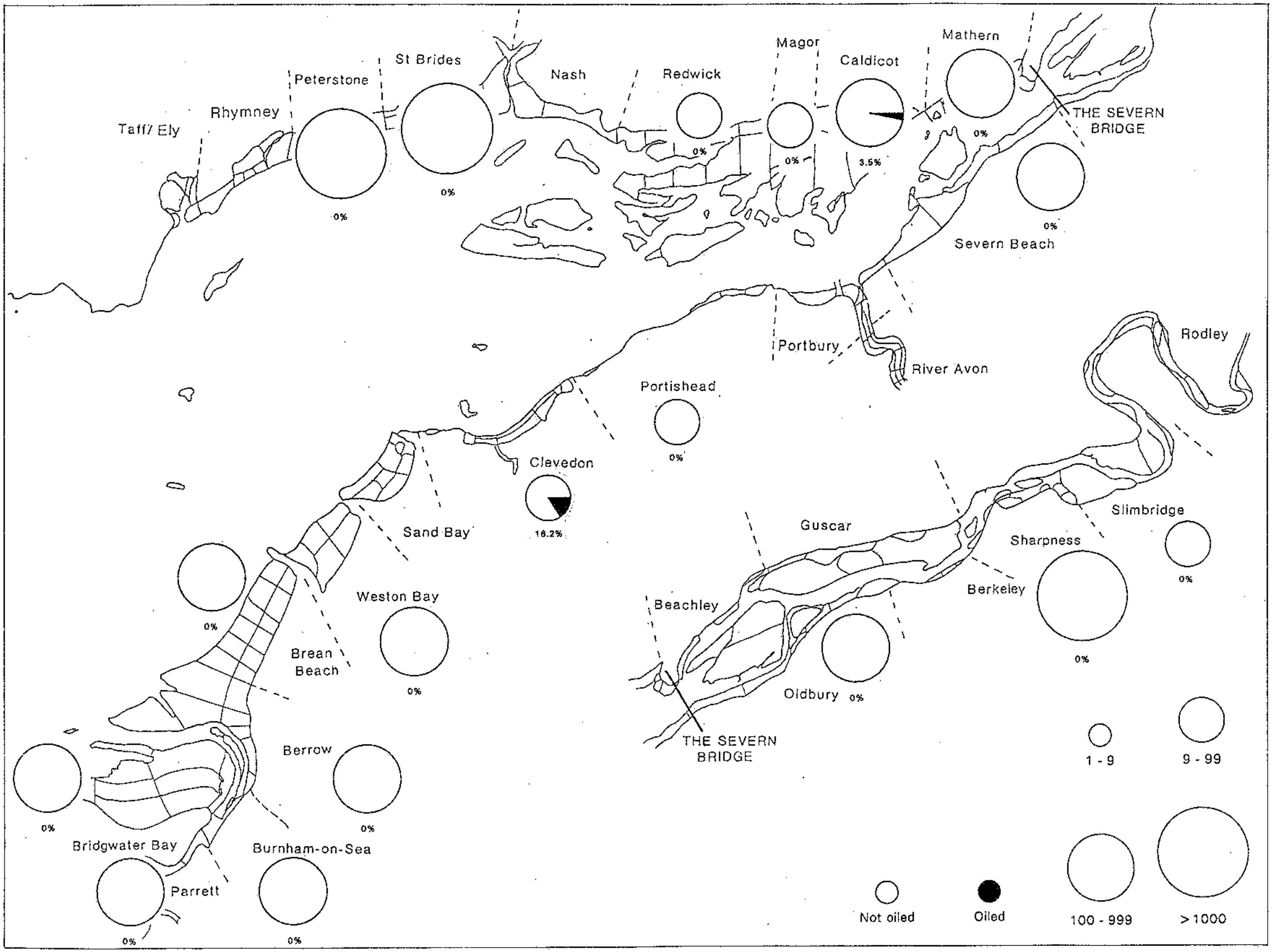


Figure 3.3.2 The percentage of oiled Dunlin on 16/17 February 1991 on the Severn.

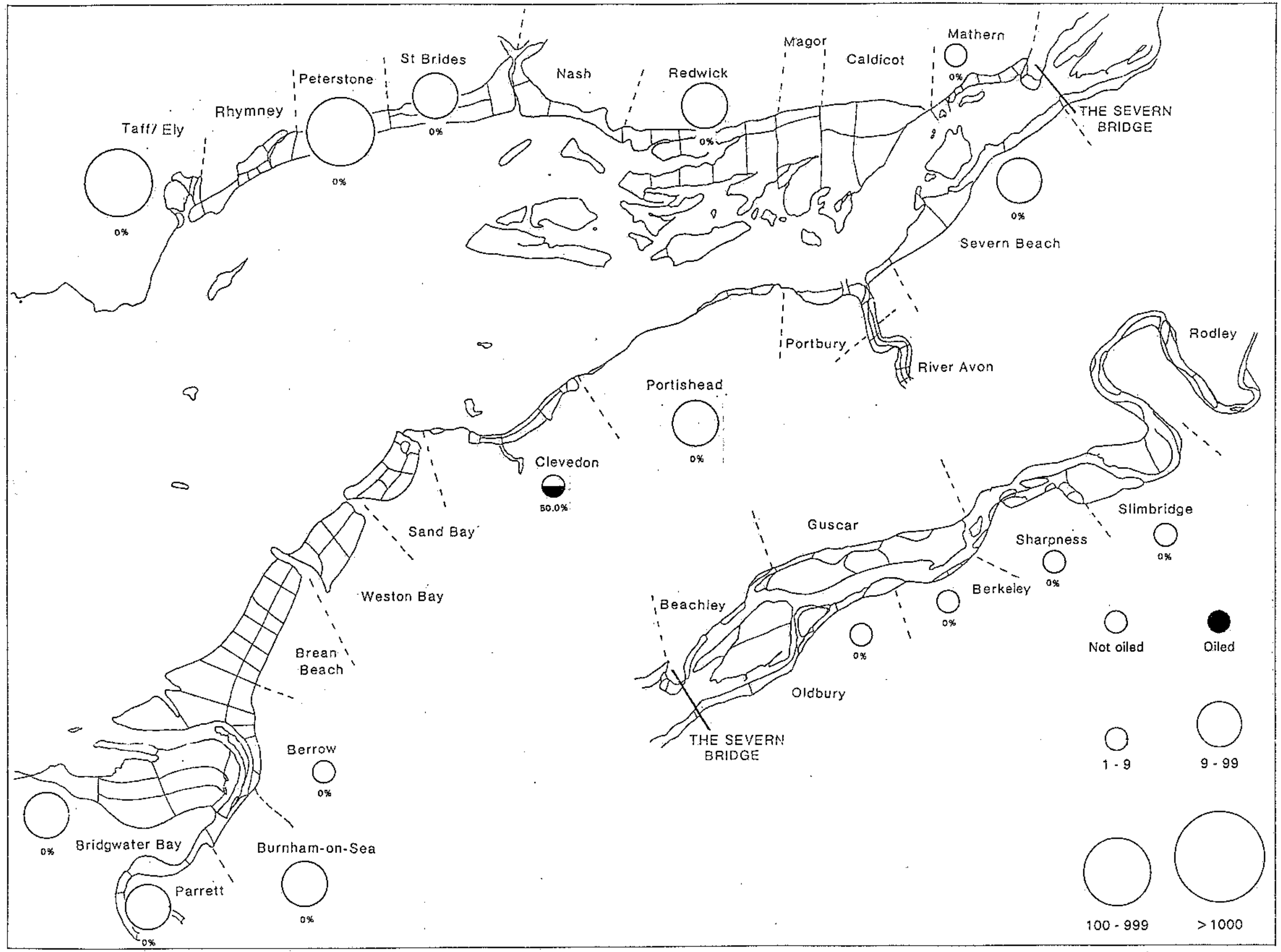


Figure 3.3.3 The percentage of oiled Redshank on 16/17 February 1991 on the Severn.

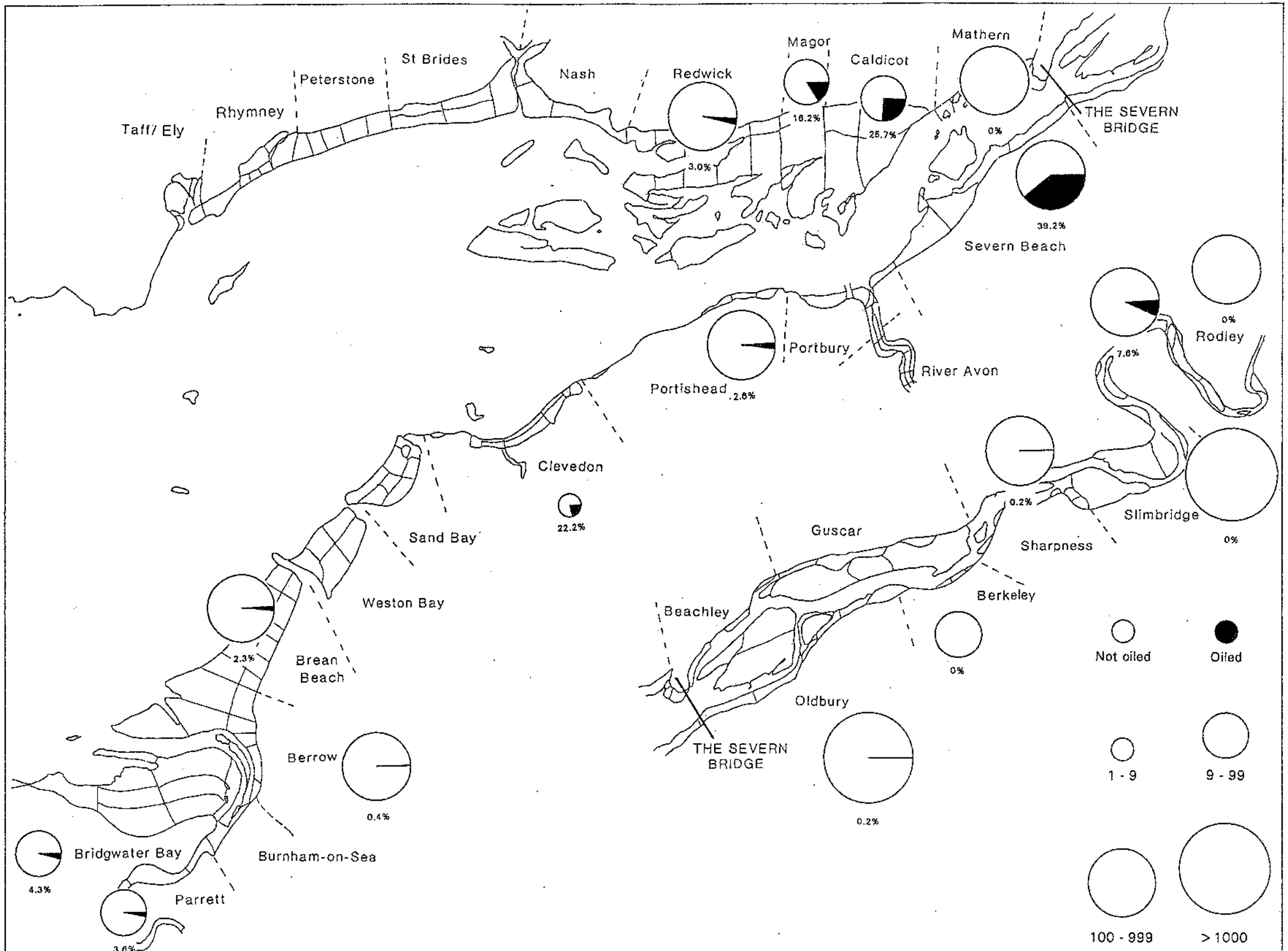
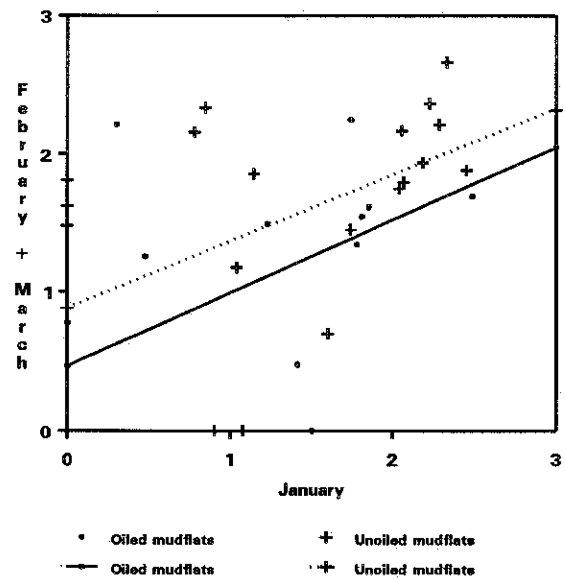


Figure 3.3.4 The percentage of oiled Black-headed Gulls on 16/17 February 1991 on the Severn.

Feeding Shelduck in 1991
Oiled and unoiled mudflats
(numbers logged to the base 10)



Lines of regression fit

Lines of regression for both oiled and unoiled mudflats.

Oiled mudflats:

Log(Feb.+Mar.Nos) = 0.46 + 0.528*Log(Jan.Nos)

R2=30.89%, F=5.81, d.f.=13, P=0.0315

Unoiled mudflats:

Log(Feb.+Mar.Nos) = 0.88 + 0.480*Log(Jan.Nos)

R2=25.48%, F=6.50, d.f.=19, P=0.0196

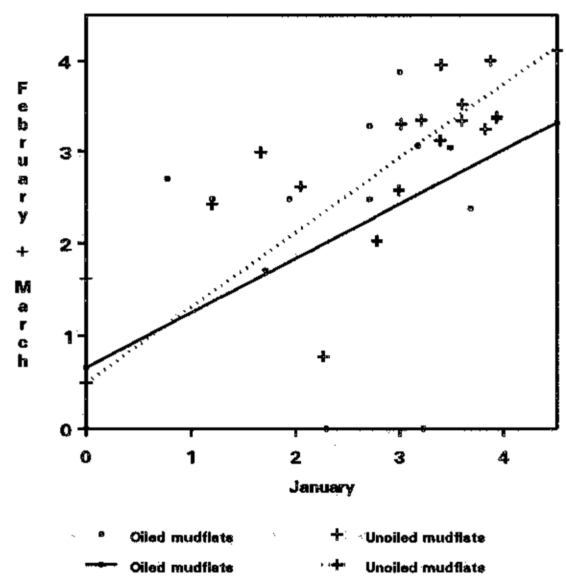
Comparison of two regression lines:

t(difference in slopes) = 0.03, d.f. = 34, P>0.10

t(difference in elevation) = 0.49, d.f. = 34, P>0.10

Figure 4.3.1 The relationship between numbers of feeding Shelduck in January and February/March on oiled and unoiled mudflats at low tide.

Feeding Dunlin in 1991
Oiled and unoiled mudflats
(numbers logged to the base 10)



Lines of regression fit

Lines of regression for both oiled and unoiled mudflats.

Oiled mudflats:

Log(Feb.+Mar.Nos) = 0.65 + 0.591*Log(Jan.Nos)

R2=29.81%, F=5.52, d.f.=13, P=0.0352

Unoiled mudflats:

Log(Feb.+Mar.Nos) = 0.49 + 0.806*Log(Jan.Nos)

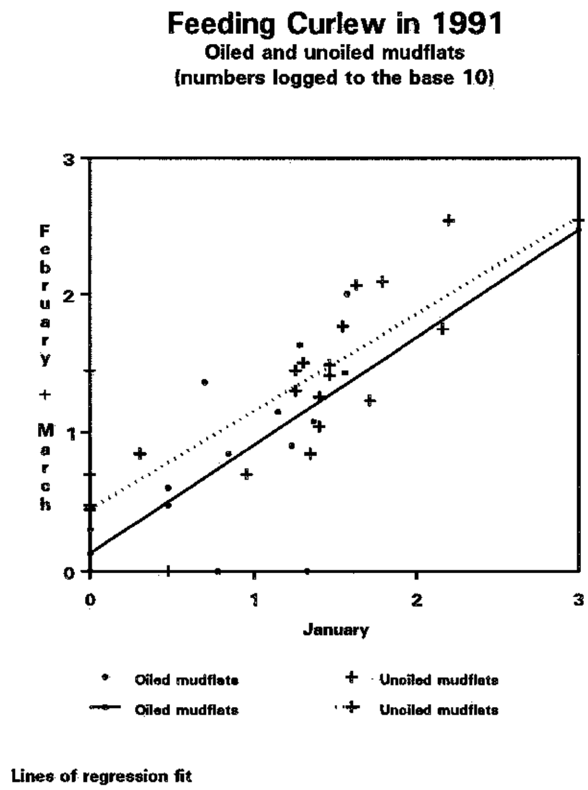
R2=77.12%, F=64.05, d.f.=19, P=0.0001

Comparison of two regression lines:

t(difference in slopes) = 0.12, d.f. = 34, P>0.10

t(difference in elevation) = 0.20, d.f. = 34, P>0.10

Figure 4.3.2 The relationship between numbers of feeding Dunlin in January and February/March on oiled and unoiled mudflats at low tide.



Lines of regression for both oiled and unoiled mudflats.

Oiled mudflats:

Log(Feb.+Mar.Nos) = 0.13 + 0.780*Log(Jan.Nos)

R2=42.10%, F=9.45, d.f.=13, P=0.0089

Unoiled mudflats:

Log(Feb.+Mar.Nos) = 0.45 + 0.699*Log(Jan.Nos)

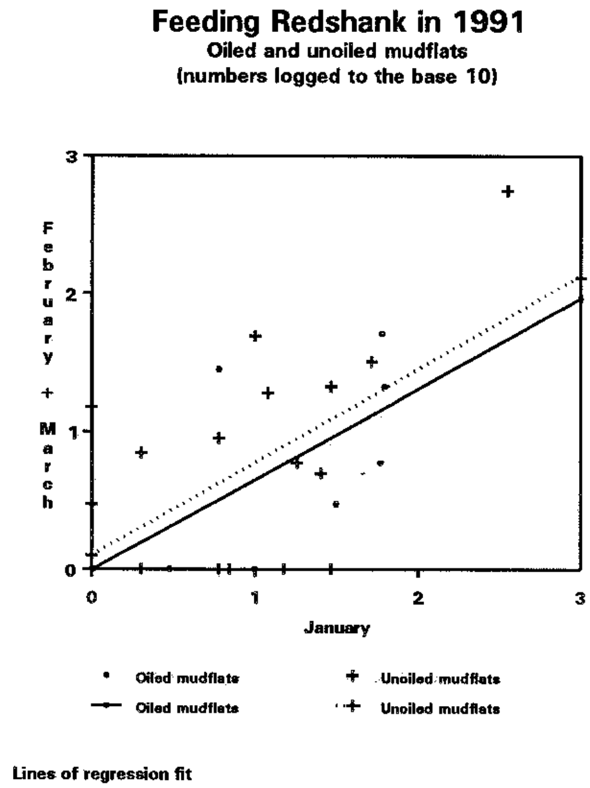
R2=58.02%, F=26.26, d.f.=19, P=0.0001

Comparison of two regression lines:

t(difference in slopes) = 0.05, d.f. = 34, P>0.10

t(difference in elevation) = 0.34, d.f. = 34, P>0.10

Figure 4.3.3 The relationship between numbers of feeding Curlew in January and February/March on oiled and unoiled mudflats at low tide.



Lines of regression for both oiled and unoiled mudflats.

Oiled mudflats:

Log(Feb.+Mar.Nos) =-0.005 + 0.640*Log(Jan.Nos)

R2=60.82%, F=20.18, d.f.=13, P=0.0006

Unoiled mudflats:

Log(Feb.+Mar.Nos) = 0.10 + 0.670*Log(Jan.Nos)

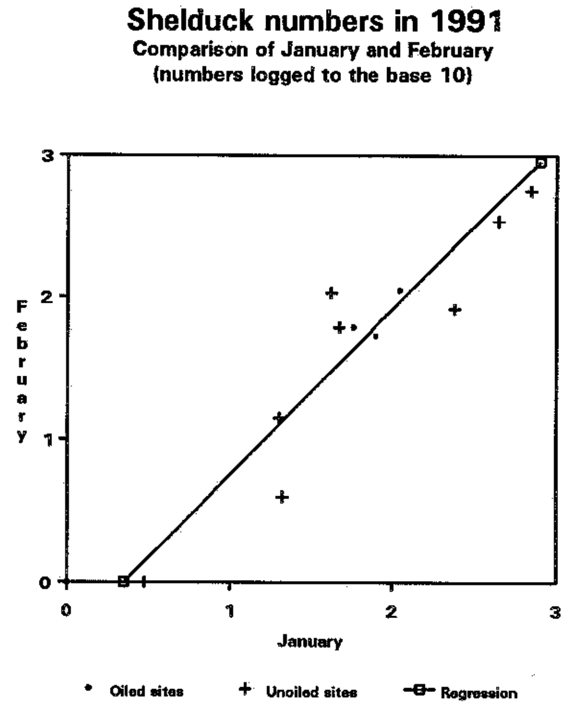
R2=38.04%, F=11.67, d.f.=19, P=0.0029

Comparison of two regression lines:

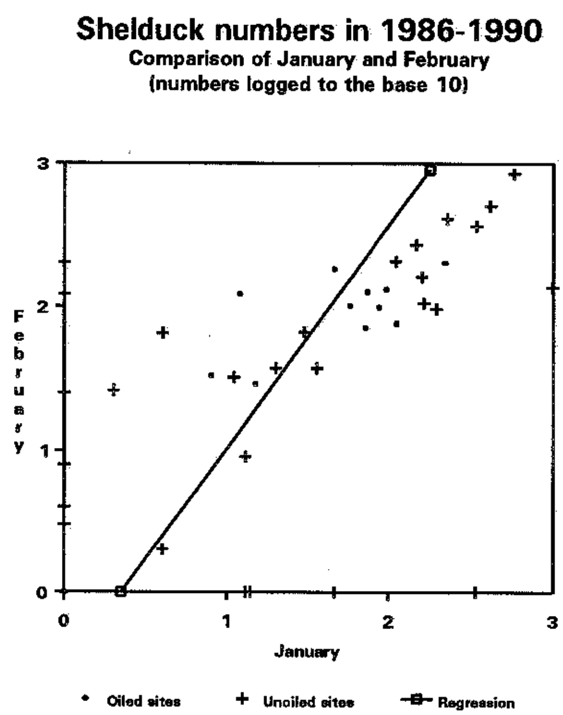
t(difference in slopes) = 0.02, d.f. = 34, P>0.10

t(difference in elevation) = 0.18, d.f. = 34, P>0.10

Figure 4.3.4 The relationship between numbers of feeding Redshank in January and February/March on oiled and unoiled mudflats at low tide.



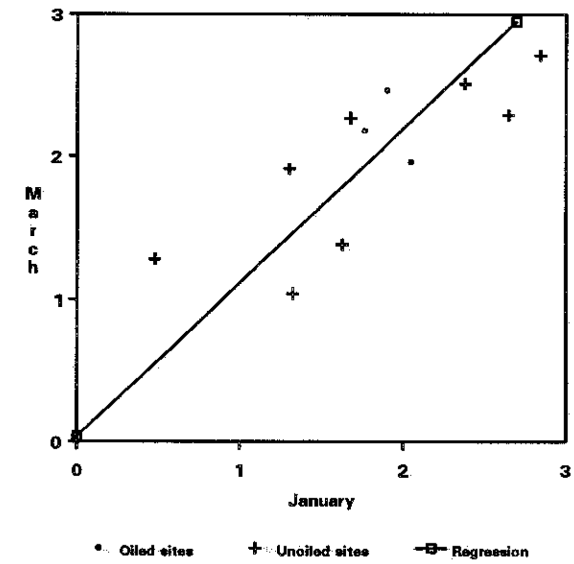
Log(Jan.Nos) = 0.35 + 0.863*Log(Feb.Nos)
R2=89.11%, F=81.85, d.f.=10, P=0.0001



Log(Jan.Nos) = 0.35 + 0.643*Log(Feb.Nos)
R2=38.33%, F=27.34, d.f.=44, P=0.0001

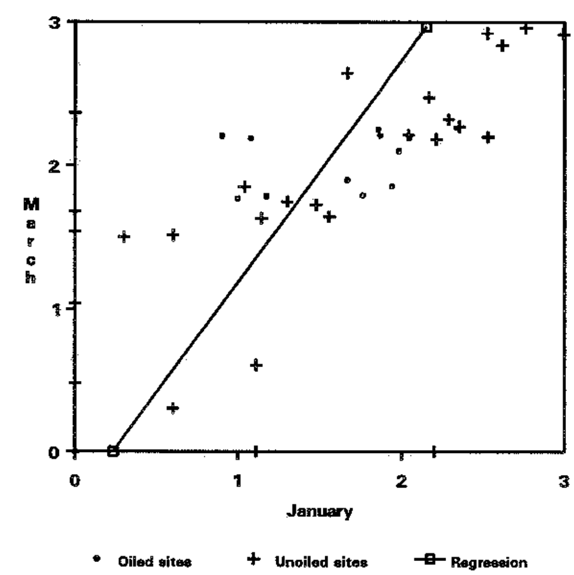
Figure 5.3.1.1 The relationship between BoEE Shelduck numbers in January and February 1991 and 1986-1990.

Shelduck numbers in 1991
Comparison of January and March
(numbers logged to the base 10)



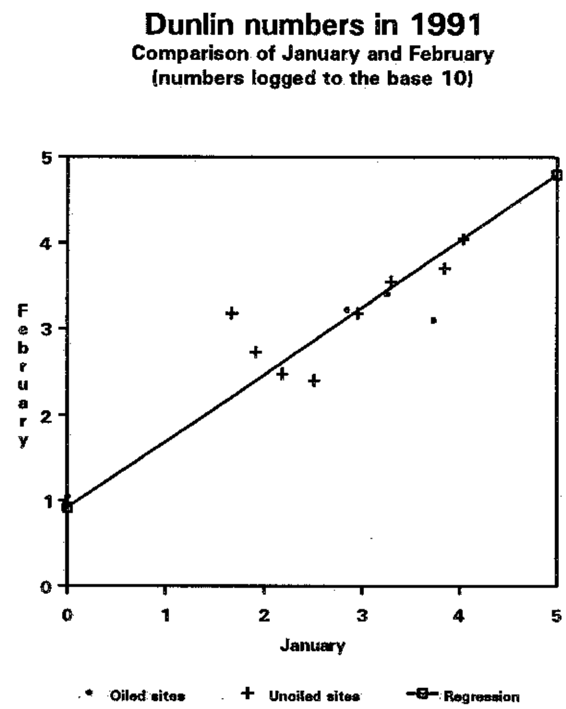
Log(Jan.Nos)= -0.03 + 0.928*Log(Mar.Nos)
R2=76.02%, F=31.70, d.f.=10, P=0.0002

Shelduck numbers in 1986-1990
Comparison of January and March
(numbers logged to the base 10)

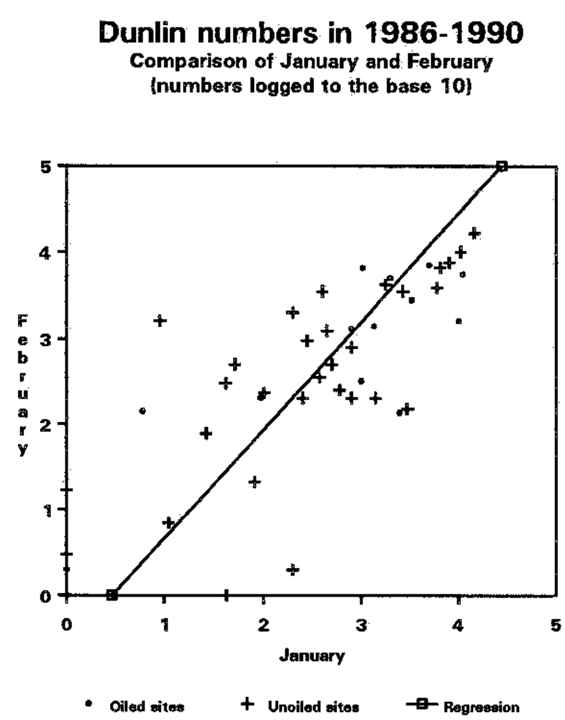


Log(Jan.Nos) = 0.24 + 0.646*Log(Mar.Nos)
R2=43.40%, F=35.28, d.f.=46, P=0.0001

Figure 5.3.1.2 The relationship between BoEE Shelduck numbers in January and March 1991 and 1986-1990.

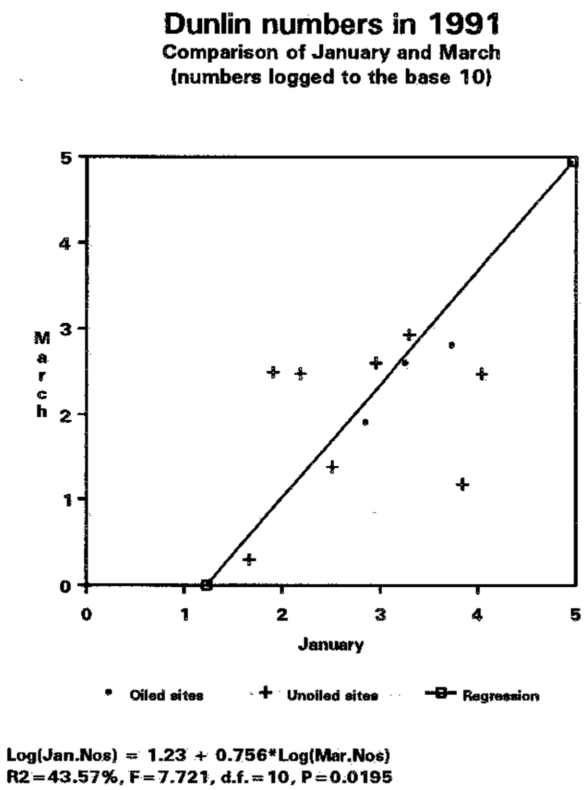


Log(Jan.Nos) = -1.18 + 1.290*Log(Feb.Nos)
R2=78.28%, F=36.03, d.f.=10, P=0.0001



Log(Jan.Nos) = 0.47 + 0.794*Log(Feb.Nos)
R2=62.15%, F=72.24, d.f.=44, P=0.0001

Figure 5.3.2.1 The relationship between BoEE Dunlin numbers in January and February 1991 and 1986-1990.



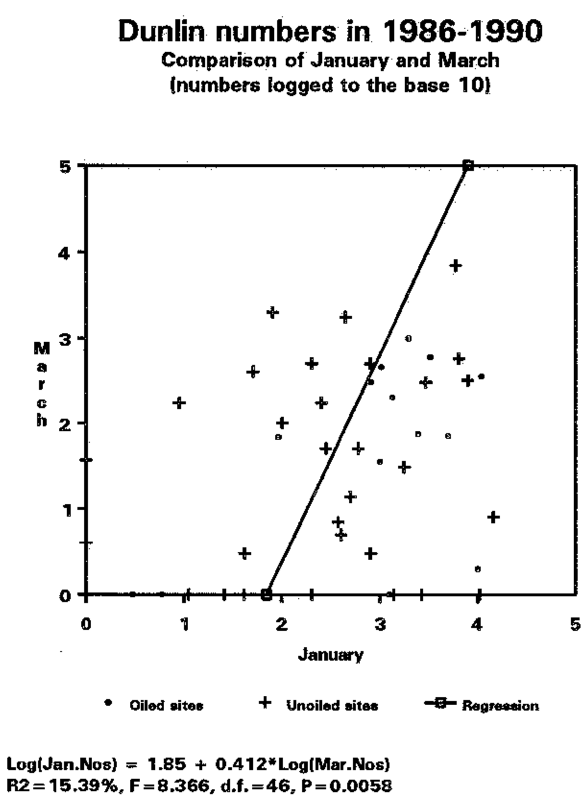
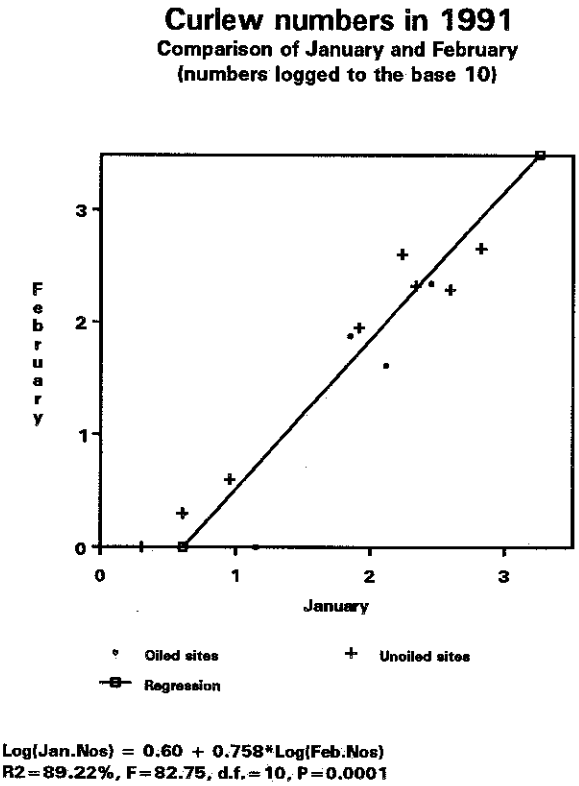


Figure 5.3.2.2 The relationship between BoEE Dunlin numbers in January and March 1991 and 1986-1990.



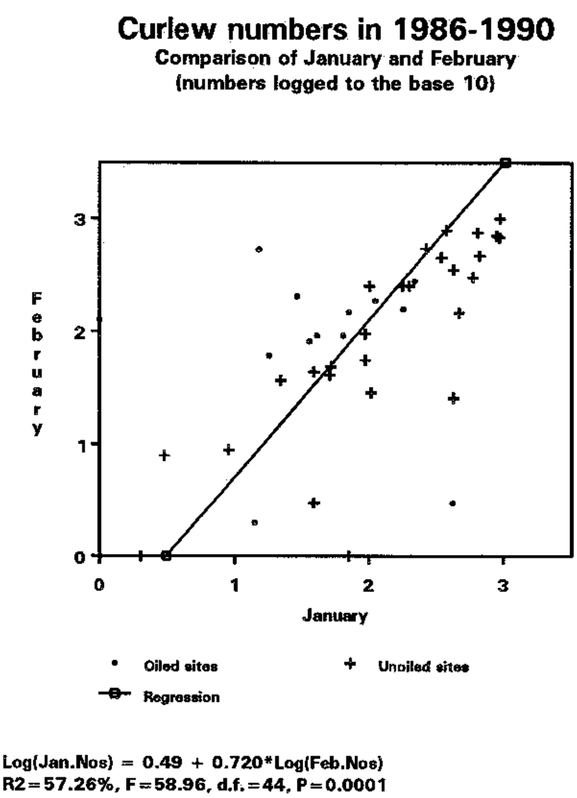
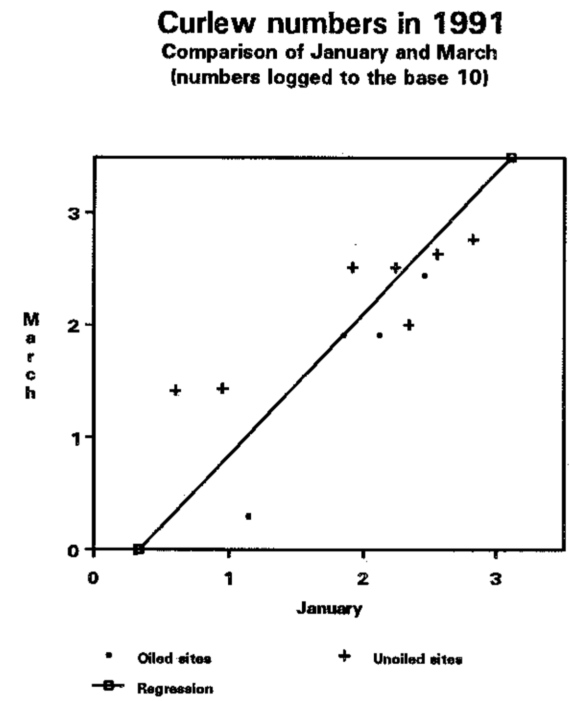
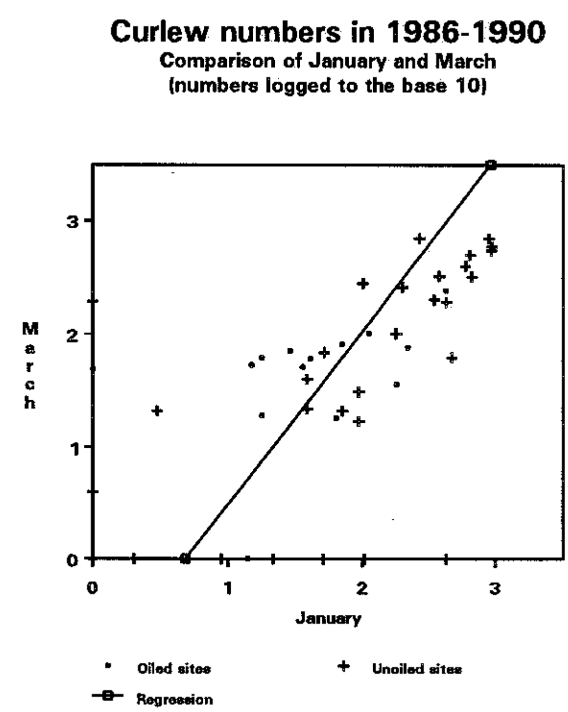


Figure 5.3.3.1 The relationship between BoEE Curlew numbers in January and February 1991 and 1986-1990.



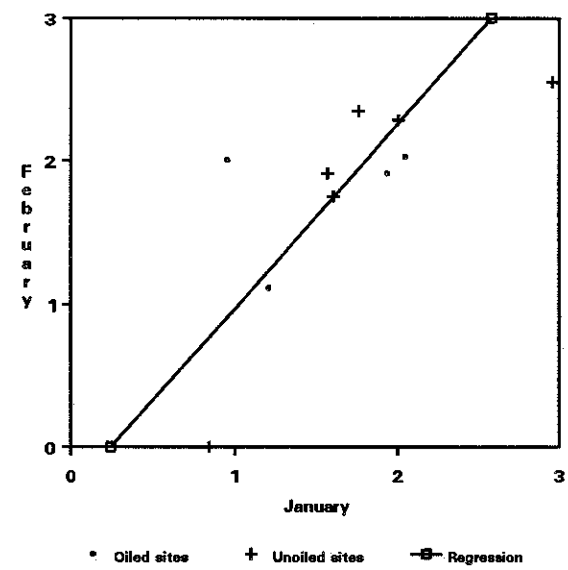
Log(Jan.Nos) = 0.33 + 0.793*Log(Mar.Nos)
R2=74.66%, F=29.47, d.f.=10, P=0.0003



Log(Jan.Nos) = 0.68 + 0.652*Log(Mar.Nos)
R2=42.22%, F=33.61, d.f.=46, P=0.0001

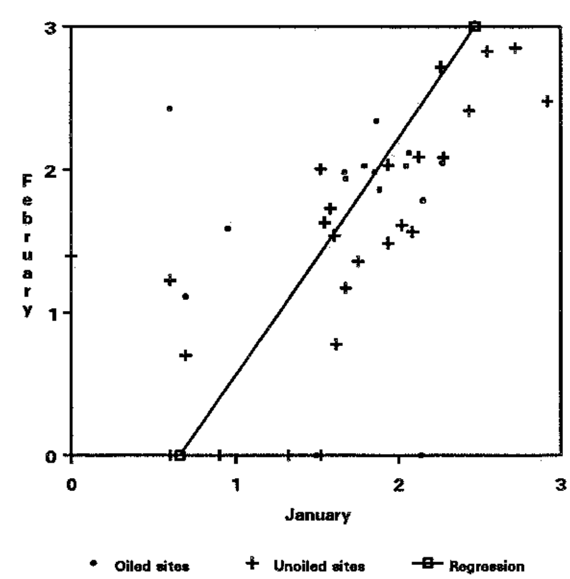
Figure 5.3.3.2 The relationship between BoEE Curlew numbers in January and March 1991 and 1986-1990.

Redshank numbers in 1991
Comparison of January and February
(numbers logged to the base 10)



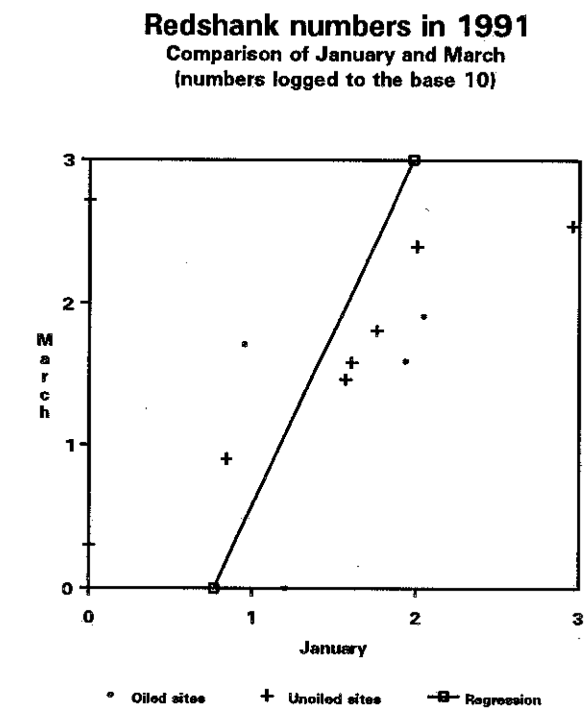
Log(Jan.Nos) = 0.25 + 0.778*Log(Feb.Nos)
R2=75.90%, F=31.49, d.f.=10, P=0.0002

Redshank numbers in 1986-1990
Comparison of January and February
(numbers logged to the base 10)

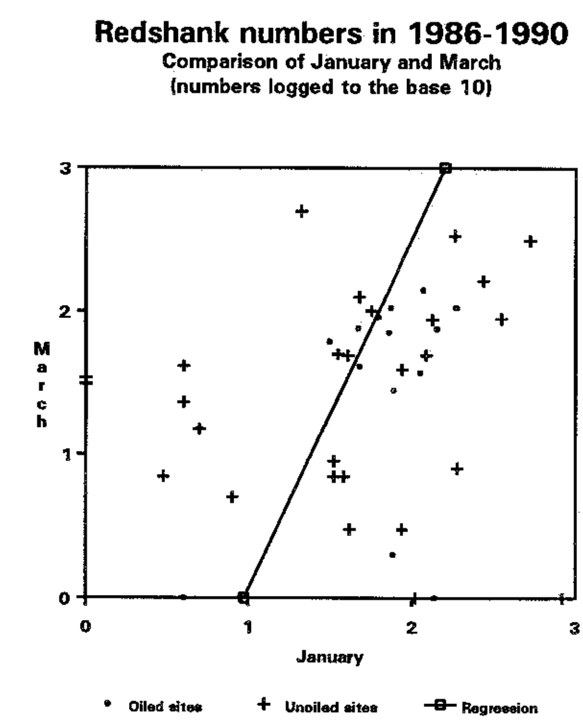


Log(Jan.Nos) = 0.66 + 0.603*Log(Feb.Nos)
R2=47.27%, F=39.45, d.f.=44, P=0.0001

Figure 5.3.4.1 The relationship between BoEE Redshank numbers in January and February 1991 and 1986-1990.



Log(Jan.Nos) = 0.77 + 0.404*Log(Mar.Nos)
R2=15.33%, F=1.81, d.f.=10, P=0.2082



Log(Jan.Nos) = 0.98 + 0.407*Log(Mar.Nos)
R2=17.06%, F=9.46, d.f.=46, P=0.0035

Figure 5.3.4.2 The relationship between BoEE Redshank numbers in January and March 1991 and 1986-1990.

Figure 6.2.1

Sections of the Severn estuary used to break down WWT Counts.

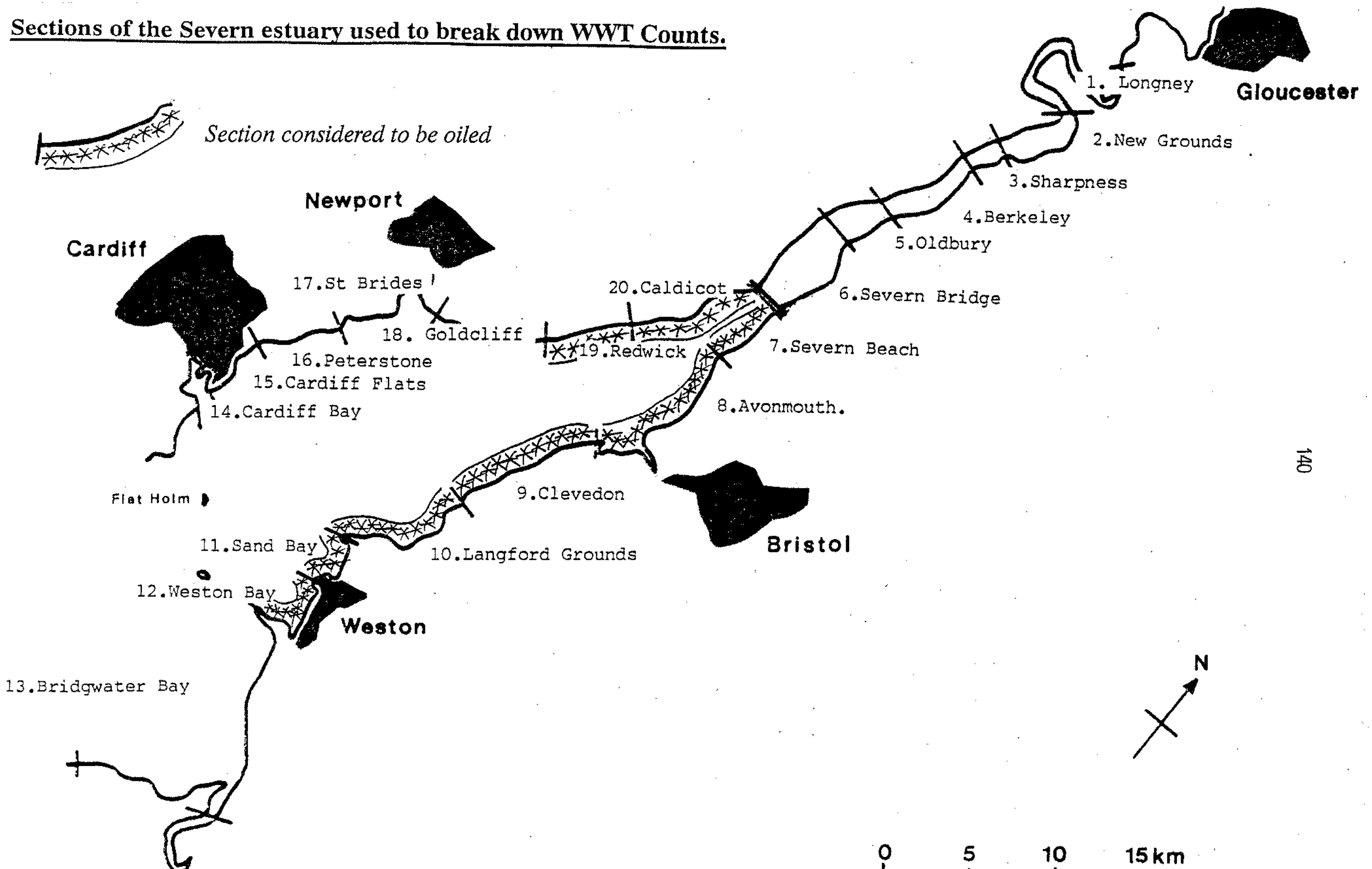


Figure 6.3.1 – Adult Shelduck Totals on the Severn Estuary May–August, 1989–1991.