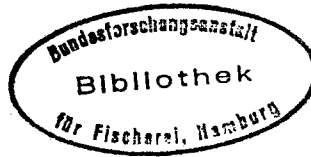


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International Council for the
Exploration of the Sea



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PRELIMINARY

**REPORT OF THE STUDY GROUP ON
SEABIRD-FISH INTERACTIONS**

Aberdeen, 5-7 September 1994

This document is a report of a Study Group of the International Council for the Exploration of the Sea and does not necessarily represent the views of the Council. Therefore it should not be quoted without consultation with the General Secretary.

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1 INTRODUCTION

1.1 Participation

The following nominated members of the Study Group participated in the meeting:

P. Andersen-Harild	Denmark
R.T. Barrett	Norway
P.H. Becker	Germany
R. W. Furness	UK
S.P.R. Greenstreet	UK
J.R.G. Hislop	UK
G.L. Hunt (Chairman)	USA
C.R. Joiris	Belgium
W.A. Montevecchi	Canada
G. Nehls	Germany
M.L. Tasker	UK
P.J. Wright	UK

M. Leopold of the Netherlands represented C.J. Camphuysen, who was not able to attend.

1.2 Terms of Reference

At the 81st Statutory meeting, it was agreed (C. Res.-1993/) that the Study Group on Seabird-Fish Interactions should produce a report, and that the Study Group should meet at the Marine Laboratory, Aberdeen, 5-7 September 1994. The terms of reference were:

- a) evaluate the evidence for the potential effects of fisheries on the local abundance of prey species in the context of the spatial and temporal scales relevant to seabirds, particularly with the regard to the North Sea;
- b) assess the consumption of shellfish by seabirds and shorebirds, as well as possible interactions with shellfish fisheries within the ICES area;
- c) collate data on the diets of the major consumers in seasons and areas presently under sampled and perform additional analysis of fish consumption by age class;
- d) synthesize appropriate data sets on seabirds, prey populations and physical oceanographic phenomena that could elucidate spatial and temporal variability in the North Sea ecosystem.

1.3 Health Warning

The mandate and working time frame of our Study Group were such that data base manipulations and calculations were made over a few days with minimal time available for rigorous checking and full discussion of data sources and analysis procedures. Thus the values presented and the interpretations presented should be taken as preliminary and subject to revision.

1.4 Overview

This report continues the work commenced last year in the areas of fish and shellfish consumption by seabirds, waterfowl and waders (Anon. 1994a). In that report, the Study Group provided an assessment of the consumption of fish by seabirds in the North Sea. In the present report, the Study Group has expanded on last year's report by providing an assessment of the data available on the age classes of fish consumed by seabirds (Term of Reference c). The Study Group now has also reviewed evidence for the potential for competitive interactions between seabirds and fisheries in the exploitation of sandeels (Term of Reference a).

Last year, the Study Group also conducted preliminary estimates of seaduck consumption of shellfish in the Wadden Sea. In that report, the Study Group expressed the need for additional time to assemble the data necessary to provide a more comprehensive view of shellfish consumption. In the present report, the Study Group has refined the estimates of shellfish consumption in the Wadden Sea (Term of Reference b). The Study Group was unable to provide a more comprehensive view of shellfish consumption for other ICES areas because it lacked the necessary experts and access to the appropriate data.

The Study Group has also opened a new area of inquiry, the investigation of the patterns in the spatial and temporal variations in seabird reproduction as related to prey populations and physical oceanographic phenomena (Term of Reference d). Despite considerable research into seabird breeding ecology at many sites around the North Sea, data from these sites have not been drawn together to examine interannual variability, the spatial scales over which such variation correlates among colonies, and the biological and physical oceanographic factors that may force seabird responses. In approaching these analyses, the Study Group has sought the council of fisheries biologists and oceanographers at the Marine Laboratory in Aberdeen. The task of assembling the multiplicity of data sets within and between disciplines has proven a greater task than originally envisaged, and the preliminary analyses presented in this report are intended as examples of the potential for a much wider variety of investigations. The preliminary investigations of the available data have demonstrated that there exist adequate time series for

meaningful analysis, that the initial results make biological sense, and that there is the potential for results of interest to a broad range of marine scientists.

Several lines of evidence indicate that such an approach is a potentially useful one. First, we now have considerable data on the potential ranges that may be covered by breeding seabirds that are obliged to return periodically to their nests to relieve mates or to feed young (e.g., Anker-Neilsen and Lorentsen 1990; Becker *et al.* 1993). When at sea, seabirds show preferences for particular water masses, reflecting not only differences in the productivity of the water (e.g. as primary production), but also qualitative differences in their ecological structure (such as grazing of primary production by zooplankton and the higher trophic levels to pelagic fish and seabirds versus recycling by bacterioplankton and benthos, and demersal fish)(Joiris 1978, 1983; Joiris *et al.* 1982; Schneider *et al.* 1986, 1987). Some local very high concentrations of seabirds are also encountered, often at biologically active fronts. These concentrations of feeding seabirds are often concordant with groups of marine mammals and reflect local concentrations of food. Interannual shifts of prey abundance within water masses, or fluctuations in the position of currents, water masses or fronts where seabirds forage, can result in fluctuations in aspects of seabird reproductive ecology (Anderson and Gress 1984; Blake 1984; Hislop and Harris 1985; Anker-Neilsen 1987, 1992; Barrett and Furness 1990; Vader *et al.* 1990; Furness and Barrett 1991; Bailey 1991; Hamer *et al.* 1991; Franck 1992; Monaghan *et al.* 1992a, 1992b).

Two of the Study Group's Terms of Reference, sections a and d, address the responses of seabirds to changes in the availability of prey in the marine ecosystem. In section a, the focus is the potential for a fishery to deplete a local prey stock to the extent that the availability of prey to seabirds is affected. In section d, the focus is on responses of breeding seabirds to fluctuations in the marine habitats where they forage. Although the causes of these fluctuations are not specified, or in many cases known, it has been the working hypothesis of the Study Group that there are interannual fluctuations in the availability of prey at the scale of water masses and fish stocks to which the birds respond. In evaluating the availability of prey to seabirds, the Study Group does not see the issue as one in which either fisheries or natural variation would control prey availability. Rather, the view is that both have the potential to be important, and that the importance of fisheries interactions is likely to be dependent on both the state of the fish stocks in question and the spatial and temporal scales of the interactions.

In the interpretation of the Terms of Reference, the Study Group attempted to focus on specific questions and on species and locations for which there were sufficient data for meaningful analyses. Given time, these analyses could be expanded to other data sets. In the introductions to the following sections of the report, the applicable Term of Reference has been identified, as have the Study Group's interpretation of its charge and the factors influencing the analyses.

1.5 Acknowledgements

The Study Group wishes to thank the many scientists who have contributed unpublished data to the UK Joint Nature Conservation Committee (JNCC) data base on seabird monitoring, the European Seabirds at Sea and Wadden Sea seaduck and wader data bases, and the direct contributions of data to the Study Group. We thank the Marine Laboratory at Aberdeen for access to data on sandeel stocks and age/length keys for sandeels and sprat. We also thank the UK Department of the Environment, the World Wide Fund for Nature and the Royal Society for the Protection of Birds for access to unpublished reports. We thank Prof. A. Hawkins for inviting the Study Group to meet at the Marine Laboratory at Aberdeen, and for the gracious hospitality of the Laboratory during our meeting. The staff of the Laboratory provided pleasant and invaluable support in the preparation of our report, and we are very appreciative of their assistance.

2. EVIDENCE FOR THE POTENTIAL EFFECTS OF FIN-FISHERIES ON LOCAL ABUNDANCE OF PREY SPECIES

2.1 Introduction

Many of the small species of fish preyed upon by seabirds are also exploited by fisheries. This common utilisation of a fish resource has led to concern over potential competition between fisheries and seabirds. Section 2 deals with the evidence for the potential effects of fisheries on the local abundance of prey species in the context of the spatial and temporal scales relevant to seabirds (Term of Reference a). Discussion of this subject is limited by the lack of integrated studies of fisheries, fish stocks and seabirds. Nevertheless, it is possible to consider the relevant scales at which interactions between seabirds, fish and fisheries may occur. Evidence for competition between seabirds and fisheries for a prey resource is then discussed.

2.2 Spatial and temporal interactions

Before considering whether competition between fisheries and seabirds occur, it is useful to first consider the various scales at which interactions between seabirds, prey-fish species, and fisheries take place in the North Sea. The spatial and temporal scales for the activities of fisheries, seabirds and prey-fish populations are not the same, either in time or space, and consequently the likelihood of finding direct effects of fisheries, on prey-fish populations, and consequently on seabird populations, is considerably reduced. In this section, we briefly describe the scales

at which the main groups of avian predator, three of their most important prey-fish, and the fisheries on these prey-fish, operate.

2.2.1 Distribution of seabirds in the North Sea

When breeding, seabirds are more restricted in their foraging area than outside the breeding season. This restriction influences the geographical location of large breeding colonies, which are usually situated close to a local food source. Nevertheless, seabirds can frequently forage elsewhere if the local food source becomes less abundant or less available. Although changes in foraging range may be reflected in some of the more sensitive breeding parameters, such as length of time spent at the nest, they do not necessarily affect overall breeding output (Monaghan *et al.* 1992a).

Prey fish availability is not predictable from year to year, even in the absence of a fishery, and seabirds have evolved in response to this fluctuating food supply. Their adaptations include the ability to switch from one prey to another, a relatively long life span (so that lifetime reproductive output is not affected greatly by a few poor years), delayed maturity (providing a long learning period prior to foraging for food for chicks), not breeding in years of poor food supply (removing the constraint of having to forage near the colony), and abandoning breeding attempts if food supply becomes critically low. These buffering mechanisms mean that it is difficult to demonstrate the effects of short-term variations in prey abundance on the long-term dynamics of seabird populations (Cairns 1987).

Three species of auk; guillemot (*Uria aalge*), razorbill (*Alca torda*) and puffin (*Fratercula arctica*), range across much of the North Sea, and are present throughout the year. These species can dive to considerable depths (180m in the case of guillemot, Piatt and Nettleship 1985) to take their prey. Adult birds are constrained in their distribution during the breeding season by their colony location, but for at least the last one-third of the year are free of the need to return to land. Thus for much of the year, they have a relatively restricted area over which they can interact with their prey. Nearly all colonies of auks in the North Sea are located in the north and west, away from the centre of sprat and herring distribution. In these regions, guillemot and razorbill, in particular, appear to prefer to feed their chicks on older age-classes of sandeel. Many guillemots and razorbills move to the southern and eastern parts of the North Sea in winter, but with a substantial proportion remaining near their breeding sites. Puffins tend to move towards the centre of the North Sea.

Most seabirds cannot dive to any great depth and are constrained to take food near the surface. Those species that rely mostly on fish caught at the surface include some of the *Larus* gulls, kittiwake (*Rissa tridactyla*) and the terns (*Sterna* spp.). The breeding distribution of gulls and terns is more widely spread than that of the

cliff-nesting diving species in the North Sea, with more colonies in the southern and eastern North Sea. Terns in particular appear to be constrained to feed within 10-20 km of colonies (Becker *et al.* 1993). As with diving seabirds, surface-feeding seabirds disperse following the breeding season. Many move away from the North Sea in winter; terns migrate southwards (one species as far as the Antarctic), and others such as fulmars and gulls may also switch from more natural foods to discarded fish and offal produced from fishing boats.

2.2.2 Distribution of prey fish in the North Sea

The three most important prey species of diving seabirds are small herring (*Clupea harengus*) (generally of less than 16 cm long), sprat (*Sprattus sprattus*) and sandeel (predominantly *Ammodytes marinus*). All of these are pelagic species which can form dense schools, although the size and density of schools shows marked seasonal and even diel changes.

Small herring are mostly distributed across the central and eastern North Sea, most are found south of 58° 30'N, north of 53°N and east of 3°E; but with some in the Moray Firth and in the Skagerrak (see Anon. 1993). Smaller fish tend to be distributed closer to the shore than larger fish. In the one year (1991) for which quarterly estimates of abundance are available, there was an indication that herring were farther south in the eastern North Sea in summer compared to winter (Jensen *et al.* 1994). This size class of herring appears to have a restricted distribution in the North Sea, although the extent of distribution may vary between years and may be regulated by factors occurring outside its main distributional range.

Currently, sprat tend to be found farther south in the North Sea than the bulk of the herring population. The distribution of the North Sea population extends into the eastern part of the English Channel. However, sprat distribution is patchy, and highly variable between years. Concentrations in the northern and western North Sea have varied considerably in their extent and location in the 1970s and 1980s (Bailey and Edwards 1981; Anon. 1992b). During the 1980s, the highest densities of sprat were in the south-eastern North Sea; prior to this their distribution extended much farther into the north-western North Sea. Sprat spawn in spring and summer in areas about 100 km off the eastern coast of Britain, along the southern edge of the Dogger Bank, around the Orkney Islands, and in the inner German Bight. Sprat distribution thus appears to be more patchy, localised and variable than that of herring.

The distribution of the lesser sandeel varies with age. Juvenile 0-group fish are widely distributed across the North Sea. Larger 0-group sandeels settle in areas of sandy substrates, usually in depths of <100 m. These areas include many coastal regions (<12km from shore) around the northern UK and Denmark, and large sand banks in the northeast and central North Sea. Once settled, sandeels appear to be

relatively sedentary. Sandeels are thus available over a wide area when young, but are considerably more localised when older (see Anon. 1994b for distribution). Sandeel availability to seabirds and fisheries is also strongly seasonal. Between October and March, sandeels generally remain buried in the sediments, with the exception of a period in December or January when they emerge to spawn. Sandeels also exhibit a daily pattern of emergence during the summer months when they are active, moving up into the water column during day light. This vertical migration makes them accessible to surface feeding seabirds.

2.3 Spatial distribution and temporal trends of North Sea fisheries on small herring, sprat and sandeel

All three species/size classes of fish are taken predominantly for industrial purposes (fish meal and fish oil) in the North Sea. Fish caught for industrial purposes have a low unit value, and large catches and catch rates must be achieved if the fishery is to be economically viable. The expansion of the industrial fishery in the North Sea before 1975 was described by Popp-Madsen (1975). From 1975, information about the industrial fisheries in the North Sea can be found in the reports of the Industrial Fisheries Working Group (now named Working Group on the Assessment of Norway pout and sandeel), and the Herring Assessment Working Group for the area south of 62°N.

Most small herring are fished in the southern and eastern North Sea in the third and fourth quarters of the year. Areas exploited tend to be relatively close to the Danish coast in July, expanding further offshore in August and September, and emphasising this offshore area in the final three months of the year. The overall biomass of herring and the amount taken by fisheries in the North Sea has varied considerably during recent years, but the spatial patterns of abundance and the fishery have not. North Sea annual landings of small herring varied between 4,000 and 177,000 t in the 1980s.

Currently, sprat are fished predominantly in the south and central North Sea from July to December. Catches have varied between 32,000 and 299,000 t since 1980. In the mid-1970s, the North Sea sprat stock was at a high level, and was estimated at more than 1 million tonnes. At that time, sprats were more widely distributed. The fishing effort increased in the same period, and the catch peaked at more than 600,000 t in 1975 and 1976 (Burd and Johnson 1983). After 1978, the biomass of sprat decreased significantly, and there was a decreasing trend in catches after 1979. The fishery is unlikely to have been the only factor behind this decrease, as environmental influences on larval survivorship may also have been important (Anon. 1990). Surveys indicated that the decrease in abundance was accompanied by shoals becoming more patchily distributed in coastal waters. The International Bottom Trawl Survey (IBTS) data indicate that the stock biomass decreased early in the 1980s, but has recovered slightly in more recent years.

Strong year-classes in 1986 and 1988 led to a significant increase in the sprat stock in the 1990s (Anon. 1992b).

Sandeels (predominantly *A. marinus*) have been caught in the North Sea in significant quantities since the 1950s. Sandeels are taken on or close to the seabed using light demersal trawling gear. The fishery is thus limited to times of year and day when sandeels emerge from the sand.

The total landings from the North Sea have fluctuated between 536,000 and a peak of 1,039,000 t over the period 1980-1992. In the northern North Sea, catches are predominantly composed of 1 year old fish, whereas there are a greater proportion of older age-classes in southern North Sea catches (Warburton 1982; Anon. 1994b). During the last 20 years, there have been significant changes in the distribution of exploitation, such as the development of fisheries around the Fisher banks in the 1980s and Wee and Marr Bankie, off the Scottish east coast, in the 1990s (see Anon. 1993). The fishery on sandeel in the North Sea is carried out between April and July, the period when post-settled sandeels are foraging above the sediment.

The sandeel (almost entirely *A. marinus*) fishery around Shetland Isles was relatively small. It started in 1974 on several grounds close (<5 km) to the islands. Annual landings increased steadily from less than 9,000 t in 1974 to 52,600 t in 1981. The fishing season lasted from March to October. Sandeels around Shetland recruit to the fishery usually in June or July, when approximately 7-9 cm long, and the major part of the catch after July consisted of 0-group recruits. The spawning stock biomass of sandeels at Shetland decreased in the early 1980's and fell from about 35,500 t in 1984 to about 6,000 t in 1992 following a series of poor year-classes. This trend was halted by the strong 1991 year-class which matured in 1993, leading to a large increase in spawning stock biomass. Since 1991, the sandeel fishery around Shetland has been closed.

Currently the northeastern Atlantic is divided into four regions for sandeel assessment purposes. These divisions are based on regional differences in growth rate (Anon. 1991), and evidence for a limited movement of adults within divisions. However, whilst adult sandeels appear largely sedentary (Kunzlik *et al.* 1986; Popp-Madsen, pers comm.), the larvae are planktonic. Consequently, passive dispersal of larvae by currents may lead to gene flow between geographically discrete spawning areas.

2.4 Large scale comparison of the distribution of seabirds, fish and fisheries

As shown above, seabirds, their prey and fisheries on those prey operate at different spatial and temporal scales in the North Sea. Jensen *et al.* (1994) studied the overlaps in spatial and temporal distributions between the groups

described above. Significant correlations between sprat and guillemot and sprat and razorbill abundance were found in February (correlation coefficients between 0.299 and 0.468 for $n > 10$). These correlations coincided with changes in the distribution of the birds. After 1987, correlations between the distributions of the three bird species became fewer, especially for the guillemot-puffin and puffin-razorbill combinations. Sprat biomass also increased after 1987. Abundances of herring and guillemot were negatively correlated. The interaction between razorbill, guillemot and sprat, as described above, took place mainly off the UK coast, and in the southern part of the North Sea.

Comparisons between the three bird species and sandeel abundance showed significant positive correlation in seven cases out of twelve in the third quarter of the year, but not for any other quarter. Correlation coefficients ranged between 0.296 and 0.578. This association between birds and sandeel occurred mainly off the northeast Scottish coast and around Shetland. The Moray Firth area, and the coast off eastern Scotland to the south of Aberdeen appear to be the areas where guillemots, puffins, and razorbills are most likely to forage on sandeels in the third quarter.

Correlations between fisheries and birds at the scale of ICES rectangles showed no general trend in spatial overlap between fisheries and bird distribution. However when making comparisons by year (using averages of months), some of the same trends were seen for sprat-razorbill and sprat-guillemot, as were found in similar comparisons of the abundances of birds and fish. Some significant positive correlations were found between sandeel catches and guillemot density. This suggests that some fisheries and some birds are exploiting the same fish species in the same places, but at different times of the year. Fisheries for sprat have taken place mainly in autumn and winter, and spatial overlap was found mainly in winter.

The Study Group's review has highlighted some inherent deficiencies in the bird data. Due to the inability to sample the whole North Sea using budgets available to ornithologists, there were significant variations between months in the areas of the North Sea sampled. If this problem could be solved, considerably more powerful analyses would be possible. Surveys such as those carried out in the past during the IBTS programme could provide suitable strategic coverage.

2.5 Small-scale comparison of the distribution of seabirds, fish and fisheries

Wright and Bailey (1993) demonstrated that changes in the local abundance of sandeels are influenced by density-related changes in overall stock distribution. Seabird-fish interactions have been studied at a small-scale (2-6 km) in Shetland waters (Wright and Bailey 1993). During the period of that study, the overall abundance of sandeels in south Shetland waters changed markedly, with the lowest abundance occurring in 1990 and the highest in 1991. Significant

correlations were found between the densities of sandeel, Arctic tern, guillemot, and shag only in 1990. Sandeel density was also a highly significant predictor of Arctic tern and shag abundance in 1990 and guillemot and shag abundance in 1991, once the effect of distance from colony had been removed. It was concluded that seabirds only needed to feed in areas of relatively elevated prey density in 1990 but not in 1991 and 1992. Consequently, seabirds only appeared to track prey densities when sandeels were relatively scarce in the vicinity of their colony (Figure 2.1).

2.6 Competition between fisheries and seabirds

Many studies have indicated a link between changes in seabird and prey-fish populations (see Table 1.2 in Anon. 1994). However, only a few such studies have demonstrated that declines in prey availability were related to fishery exploitation. Examples of fishery induced changes in prey availability include the slow recovery of "guano birds" following recruitment overfishing of the Peruvian anchovy, *Engraulis ringens* (Nelson 1978), and the repeated breeding failures of puffins at Røst (Lid 1981; Anker-Nilssen 1987) that coincided with the reduction in Norwegian herring stocks (Hamer 1988; see Anon. 1994a). In most other cases/studies in which a fishery-induced change in prey availability has been inferred, there is little or no direct evidence for such an effect from fishery assessments. This is because changes in prey availability can often be ascribed to natural variations in fish recruitment for a given spawning stock size. Continued fishing pressure following periods of reduced recruitment may delay the recovery of a stock (Murphy 1977), but this can be difficult to distinguish from other factors influencing the recovery of a stock. It is also possible that the scale at which fish stocks are monitored may be too large to account for reductions in prey-fish in the vicinity of seabird colonies (Monaghan 1992).

2.6.1 Competition for sandeels

A. marinus predominates both in the diet of seabirds (Anon. 1994a) and the in landings of industrial fisheries in the North Sea (Anon. 1992b). Seabirds prey on all age-classes of sandeels. However, the species of seabirds that have been found to be most vulnerable to declines in sandeels are those that feed predominantly on young of the year (0-group), close (<0.5m) to the sea surface. These include terns, kittiwakes and Arctic skuas (*Stercorarius parasiticus*). In addition, the diet and breeding success of puffins, a small shallow-diving species which mainly feeds on 0-group sandeels, appears sensitive to changes in sandeel availability.

It is unlikely that there is much direct competition between seabirds and fisheries for 0-group sandeels during the chick rearing period because most fishing mortality

on 0-group occurs after 1 July. 0-group sandeels only become accessible to the fishery once they have metamorphosed to the juvenile stage and settled. 0-group settlement extends from late May to July. Due to the limited scope for direct competition between seabirds and fisheries for 0-group sandeels, it may be assumed that the main impact on prey availability is through reductions in spawning stock biomass, and hence egg production. The main question, so far as the target stocks themselves are concerned, is therefore whether fishing is capable of reducing the stocks to a level at which recruitment is affected as a result of insufficient egg production (recruitment overfishing). This is an area of great uncertainty because it is not clear how low the spawning stock has to be before recruitment is affected.

In the case of Shetland, the sudden recovery of the stock may partly be explained by changes occurring outside the traditional assessment area. Studies by Wright and Bailey (1993) indicated that these changes were related to immigration of juvenile 0-group sandeels. This view is supported by the presence of a much larger spawning concentration to the north and west of Orkney and the coincidence between years of high recruitment at Shetland and a continuous distribution of juvenile 0-group sandeels between Orkney and Shetland. The possible involvement of an additional and unsampled spawning stock may therefore explain the lack of any apparent relationship between recruitment and spawning stock biomass in the Shetland sandeel stock assessments even at low stock levels.

The need for a better understanding of sandeel population structure has been highlighted by recent changes in the breeding success of seabirds near the Firth of Forth and at Shetland. A sandeel fishery close to the Scottish east coast has expanded rapidly since 1990. The Scottish east coast grounds are regarded as part of the southern North Sea division, for the purposes of assessment. However, sandeel concentrations from the Scottish east coast grounds are geographically isolated from other areas of fishing operations, and so their inclusion in the large southern division may be questionable. Clearly, if sandeel grounds on the Scottish coast are distinct from those in other parts of the North Sea, the current scale at which North Sea sandeel stocks are monitored will be too large to consider the impact of local fishing pressure.

2.6.2 Competition for sprat

Sprat are an important prey species for many seabirds, particularly in the winter (Anon. 1994). Harris and Bailey (1992) demonstrated that overwintering survival of guillemots from the Isle of May was correlated with changes in North Sea sprat stocks (Figure 2.2). This would indicate that the decline in the North Sea sprat stock did have an influence on seabird survival. As discussed in section 2.3, the sprat fishery is believed to have been involved in the stock decline and hence it

may be argued that the fishery could have indirectly affected seabird survival. A lack of dedicated studies on the interaction between seabirds, sprats and fishery makes it difficult to consider the question more fully.

2.7 Overview

It seems unlikely that questions about seabird-fishery interactions in the Northeast Atlantic Ocean can be answered satisfactorily until the present differences in scale at which fisheries, seabirds and fish stocks are monitored are reduced, and the work of ornithologists, oceanographers and fishery scientists is more closely integrated. However, several studies have clearly shown that variations in prey availability can have profound effects on the population parameters of seabirds, including breeding success and overwintering survival. From this review it appears more important to focus on local changes in prey concentration, in areas important to seabirds, than on overall stock changes at a North Sea scale. With respect to this, there is a need to monitor changes in the scale and spatial distribution of both established and developing fisheries, particularly when these occur in areas which are known to be important for seabirds.

3 SHELLFISH CONSUMPTION BY SEADUCKS AND WADERS

3.1 Introduction

In response to the second Term of Reference, the Study Group undertook an analysis of shellfish consumption by birds. This analysis was constrained to examining the situation in the Wadden Sea and adjacent waters because we lacked the resources to complete a more comprehensive evaluation. Close to 10 million seaducks live on shellfish in northwest Europe throughout the winter, as do over 1 million waders and several hundreds of thousands of gulls (population sizes from Rose and Scott 1994, Durinck *et al.* 1994). However, at present it is not possible to provide information on all ICES areas and species of either shellfish or birds. As the most detailed information available to the Study Group was from the southeastern North Sea, including the Wadden Sea, Dutch delta and adjacent coastal strip of the North Sea, this report concentrates on this area. Key species involved are: the eider (*Somateria mollissima*), common scoter (*Melanitta nigra*), oystercatcher (*Haematopus ostralegus*), and herring gull (*Larus argentatus*). The most important shellfish species, to birds and fisheries alike are: mussels (*Mytilus edulis*), cockles (*Cerastoderma edule*) and trough shells (*Spisula subtruncata* and *S. solida*). The Study Group acknowledges that interactions, such as those observed in the area of present focus, also occur in other areas of interest to ICES. Areas

for which a great deal of information has been gathered include many estuaries around the British Isles.

3.2 Bird numbers by area

Four abundant bird species occurring in the Wadden Sea and adjacent waters have a substantial proportion of bivalves in their diets. Total estimated numbers of these birds in summer, autumn, winter and spring are shown in Tab. 3.1 (Meltofte *et al.* 1994; Swennen *et al.* 1989; Skov *et al.* in press).

Eiders Total numbers in northwest Europe: 3,000,000
Eider ducks originating from Baltic breeding grounds occur in the Wadden Sea throughout the year. During most of the year, the numbers exceed a quarter of a million birds in the Wadden Sea itself, with up to 100,000 occurring in the waters off the Wadden Sea. Only small numbers breed in the Wadden Sea (Tab. 3.1).

Common scoter Total numbers in northwest Europe: 1,300,000
The common scoter is an Arctic-breeding bird, mainly breeding in the northern part of European Russia and in the northwestern part of Siberia. At present, it is almost entirely found in the waters off the Wadden Sea. Wintering numbers reach 250,000, with the main concentrations found in Dutch and Danish waters. Substantial numbers are also found in summer during moult. In recent years, numbers were as high as 100,000 birds, but in the 1960's far higher numbers were reported alone off the Danish part of the study area. Common scoters arrive from the breeding grounds in October/November and some leave the area in April/May (Tab. 3.1), whereas others moult and oversummer in the area.

Oystercatcher Total numbers in northwest Europe: 874,000
The oystercatcher is a local breeding bird (approximately 40,000 pairs), but birds from Scandinavia and NW Russia also spend the winter in the Wadden Sea. The numbers peak in autumn, and exceed $0.5 \cdot 10^6$ from autumn to spring. Most birds winter in the Dutch and German parts (Tab. 3.1).

Herring gull Total numbers in northwestern Europe: 2,700,000
Herring gulls breed in the Wadden Sea, with an estimated population of 90,000 pairs. The Wadden Sea population of herring gulls is mostly resident, but in autumn and winter birds from Scandinavia, the Baltic area and NW Russia join this population. Maximum numbers recorded in the Wadden Sea reach 330,000 individuals (Tab. 3.1)

3.3 Status of Bivalve populations

Mussels

The blue mussel is a key species of the benthic fauna of the Wadden Sea, and is important in terms of biomass, filtration rate, and by generating habitats for other animals (Asmus 1987; Dankers 1993). Mussel beds reach biomass values of up to $1.8 \text{ kg} \cdot \text{m}^{-2}$ AFDW (ash free dry weight) (Asmus 1987; Nehls and Ketzenberg in press), which greatly exceeds average values for the area ($26 \text{ g} \cdot \text{m}^{-2}$ AFDW, see Beukema 1981). Stock assessments are available only for the Dutch part, and for the Schleswig-Holstein part of Germany. Culture beds cover only a portion of the areas designated for mussel culture (Table 3.2), and landings of mussels vary interannually (Table 3.3).

Standing stocks in the intertidal part of the Dutch Wadden Sea range from 65,000 to 187,000 t wet weight. Sublittoral stocks were estimated to have 165,000-204,000 t wet weight, and stocks found on the cultures were up to 350,000 t wet weight (Dekker 1989). Total stocks may thus reach about 600,000 t wet weight, with half of the mussel stocks found on the cultures and on average less than a quarter on intertidal beds. The total area of intertidal beds was estimated to 3360 ha (Dijkema *et al.* 1989), which represents about 3% of the intertidal area.

Mussel stocks in Schleswig-Holstein are lower and almost restricted to the northern half where islands offer shelter against storms from the west (Nehls and Thiel 1993). Intertidal stocks may reach 60,000t wet weight but they have been lower in most years (Fig. 3.1). Sublittoral stocks are generally low (around 10,000 t wet weight,) but may reach 40,000 t wet weight in some years. Total stocks, including the cultures, may reach 100,000 t wet weight. The area covered by intertidal mussel beds reaches 2000 ha when the population is high, which represents about 1% of the intertidal area. In the Danish parts, mussel beds were estimated to cover up to 1000 ha, representing about 1.5 % of the intertidal area (Kristensen 1994). However, as mentioned for the whole Wadden Sea, the area covered by mussel beds is subject to large annual variations. Total mussel stocks in the Wadden Sea are thought to have increased over the last decades, possibly due to eutrophication and mussel fisheries (van der Veer 1989; Dankers 1993).

Cockles

The cockle is the other dominant species of the benthic fauna in the Wadden Sea. Dense beds may reach biomass values of $350 \text{ g} \cdot \text{m}^{-2}$ AFDM (Ruth unpubl.). On the intertidal parts of the Dutch Wadden Sea, cockles make up a sixth of the total biomass of the benthic communities ($4.2 \text{ g} \cdot \text{m}^{-2}$ AFDM of an average total of $26.6 \text{ g} \cdot \text{m}^{-2}$ AFDM, Beukema 1981). Data on stock assessments are available for the Dutch Wadden Sea and Delta area. Total stocks varied from 10 to 220,000 t wet flesh weight (Fig. 3.2). Cockle stocks in the Wadden Sea exhibit marked annual fluctuations, mainly as a result of high mortality in cold winters. Total stocks have

been increasing over the last decades, probably as a result of eutrophication (Beukema & Cadée 1986).

Trough shells

Spisula spec. have probably been the most abundant bivalves in the coastal, southeastern North Sea in recent years. In the Dutch Delta area, stock sizes were estimated to vary from 1.6 to >50,000 t of flesh (equivalent to 430-13,300 t AFDW). In a study plot chosen on the basis of seaduck presence off the Wadden Isle of Terschelling, some $8.2 \pm 2.1 \cdot 10^9$ individuals (median length 28 mm) were present in February 1993, and $3.65 \pm 1.57 \cdot 10^9$ individuals in May 1993 (den Hollander 1993). In terms of biomass, this amounts to 5,775,000 and 2,625,000 t of flesh, respectively (1 gram of AFDW is equivalent to 3.75 grams of fresh flesh weight; van Stralen and Kesterloo-Hendrikse 1993). The *Spisula*-bank extended to at least the Dutch/German border (Leopold in prep.). In Denmark two areas have been found to be rich in juvenile *S. solida*, i.e. at Horns Reef and on the shallow 'Rode Klitsand' (Kristensen 1994). In June/July 1993, 15,000 and 54,000 t total weight were present on these two locations, respectively (Kristensen 1994). Using a flesh content of 12%, which is slightly less than the 15% used for the less robust *S. subtruncata*, (van Stralen and Kesterloo-Hendrikse 1993), this amounts to 1,800 and 6,500 t of flesh.

For the German part, no stock assessments exist to date, but fisheries for adult *S. solida* take place in the waters west of Amrum.

3.4 Bivalve Fisheries

Mussels

Mussel fisheries in the Wadden Sea today mainly take place by means of bottom cultures which are stocked with seed mussels (<25 mm) or half grown mussels (25-40 mm) from natural mussel beds. Harvested mussels are generally larger than 50 mm. Mussel cultures are situated in more or less sheltered, shallow subtidal areas where growth conditions are higher and mortality lower than on natural beds (CWSS 1991). Culturing started 1949, and has rapidly increased since then. About 10,760 ha are presently declared as culture lots, but only part of them are permanently used (Table 3.2). In Denmark no cultures are allowed, and fisheries take place on natural beds. Seed fishing takes place on intertidal and subtidal beds, depending on the availability of mussel spat. In Schleswig/Holstein, spatfall in subtidal areas seems to be more predictable, and has supplied the main share of seed mussels in the last years (Nehls & Ruth 1994, Ruth in prep.). Total landings in the Wadden Sea fluctuate from 78,000 to 166,000 t (Table 3.3). Annual landings often include a substantial part of the overall mussel stocks of the different areas of the Wadden Sea. The data available imply that half of the stocks found on the cultures in a year are harvested in the course of the winter. On

average this will reduce the mussel population by a quarter but the proportion may be considerably higher in some years.

Cockles

Cockle fishing is permitted in the Dutch Wadden Sea and Delta area and to a very limited extent in Denmark. Annual landings in The Netherlands range from nearly zero to about 7000 t of flesh or 50,000 t wet weight (Smit 1994). The proportion of total stocks harvested by the fisheries is below 10% in most years, but may reach 40% when cockle stocks are low (Fig. 3.3).

Trough shells

Fisheries for *Spisula* commenced around 1990 in Denmark, Germany and the Dutch Delta area, and has increased since then. In Denmark, three vessels are licensed to fish 5000 t *S. solida* per year. No landings statistics are available for Germany and the Netherlands. Up to 7 vessels have been seen fishing simultaneously off the Dutch Wadden Sea in 1993 (M. F. Leopold, pers. obs.).

3.5 Food Choice and Intake of Bivalve-eating Birds

Eiders

Bivalves form the main share of the eiders' diet in the Wadden Sea. In the Dutch part, mussels and cockles each make up about 40% of eider diet (Swennen 1976). In Schleswig-Holstein, eider diets are about 75% cockles with mussels comprising most of the rest (Nehls 1991). However, eider diets and distributions on the feeding grounds are subject to marked annual fluctuations. Recently, approximately 100,000 eiders moved to the North Sea, where they joined common scoters on *S. subtruncata* banks (Leopold 1993).

The size of mussels taken by eiders range from 5 to 65 mm, with a median sizes between 32 and 52 mm (Nehls & Ketzenberg in press). About 80% of the mussels consumed by eiders fall in the size range of 30 to 55 mm, and are thus slightly smaller than mussels of commercial interest. For cockles, no clear pattern of size selection has been found. The sizes of cockles taken by eiders are usually similar to the size distribution of the stocks (Nehls 1991 and unpubl.). Total annual food consumption by eiders was estimated at 164,000 t, of which 60,000 t would be mussels and almost 100,000 t would be cockles (Tab. 3.4).

Common scoter

Scoter diets in the study area are mainly inferred from where major concentrations have been found. In the 1960's, approximately 40,000 scoters wintered in the western Wadden Sea and presumably took primarily mussels and cockles. In the coastal North Sea in the 1970's and 1980's, concentrations of scoters have been observed over banks of cockles, several species of smaller tellins, and recently exclusively over banks of *S. subtruncata* (Netherlands and Belgium, van Steen

1978; Leopold *et al.* in press) and *S. solida* (Denmark). Stomach analysis of oil victims in The Netherlands showed a rather catholic diet in the Delta area in 1988, with a majority of the diet consisting of *S. subtruncata* (Offringa 1991) and a mixture of *S. subtruncata* (majority) and *Donax vittatus* off Terschelling in 1993 (den Hollander 1993). Farther north, off Jutland, scoters preyed mainly on *S. subtruncata* in 1987 (Durinck *et al.*, 1993). In all areas, the ducks did not show obvious selection for certain sizes. As the ducks returned to a bank of *S. subtruncata* where no recruitment occurred, off The Netherlands for 4 consecutive years, age classes 1-4 (median length 9 to 30 mm) were taken in subsequent years. Based on numbers and daily food requirements, annual consumption of common scoters is estimated at 35,000 t wet weight, mainly consisting of *Spisula* (Tab. 3.4).

Oystercatcher

Individual oystercatchers tend to specialize on certain prey types making it difficult to estimate diet composition of oystercatchers over large areas. Highest densities of oystercatchers are reached on mussel beds where mainly mussels are taken (Zwarts & Drent 1981, Meire 1993), and on dense cockle beds (Meire 1993). Alternative food species include several species of shellfish and worms. However, in most areas, bivalves are the most important prey species. It is estimated that about 75% of the winter food of oystercatchers consists of cockles and the rest mainly of mussels (Lambeck *et al.*, in press). These proportions are consistent with the low proportion of intertidal areas covered with mussel beds. Oystercatchers select mainly mussels of 30-45 mm length, but take other lengths if the preferred length-classes are not available. When feeding on cockle, oystercatcher prefer the larger age classes of 15 to 40 mm (overview in Bos 1994). Total food consumption of oystercatchers in the Wadden Sea amounts to 160,000 t of bivalves (wet weight) and is thus of the same magnitude as that taken by eider (Table 3.4).

Herring Gull

The food of herring gulls includes a large variety of smaller animal species that occur in the Wadden Sea (Spaans 1971, Vauk & Prüter 1987, Dervedde 1993). Molluscs form a high proportion of the diet during all times of the year. In pellets collected on the island of Sylt, the presence of mussels averaged about 40% and cockles about 10% (Dervedde 1993). Due to the lack of quantitative data on food intake in terms of energy equivalents, we assume a proportion of 25% of molluscs (mussels and cockles) in the diet of herring gulls in the Wadden Sea. The consumption of molluscs would then amount to 12,000 t wet weight (Tab. 3.4).

3.6 Avian Impacts on Bivalve Stocks

The data presented above suggest an average annual consumption by birds of about 20% of the average stocks of cockles and mussels in the Wadden Sea.

However, because mussel and cockle stocks exhibit marked annual fluctuations the proportion of bivalve stocks demanded by birds varies accordingly. It must be noted that the mentioned bird species select preferred feeding areas and size classes, so that bird predation is not evenly distributed over all parts of the bivalve stocks. Still, the impact of birds on bivalve stocks seems to be moderate even within preferred feeding areas. Predation of mussels by oystercatchers reached 25 - 40% of preferred size classes (Zwarts & Drent 1981). For eiders, no effect of intense predation on the biomass of a mussel bed could be shown, although a reduction of preferred size classes was evident (Nehls & Ketzenberg in press). Likewise, no effect on the biomass of mussel cultures intensively utilized by eiders could be found (Nehls & Ruth 1994).

3.7 Synthesis: interactions between shellfish, fisheries and birds

Over the last years, two possible interactions of birds and fisheries in the Wadden Sea have emerged. On the one hand, fisheries have been suspected to reduce the food stocks available to birds and thus affected bird numbers in the Wadden Sea (Swennen 1991; Laursen *et al.*; Leopold 1993). On the other hand, fishermen have often claimed that birds feeding at cultures or natural mollusc stocks reduce their income and measures have been taken to expel the birds (Brull 1963, Esser 1988; Nehls pers. obs.). Regarding the dynamics of mussels and cockles in the Wadden Sea and amounts fished per year, competition between birds and fisheries is most likely to occur in situations where natural variation in stock size and/or fishery impacts have resulted in low stocks.

Mytilus numbers are probably regulated by the availability of suitable substrate and their biomass is regulated by the food brought in by the tide (Dankers 1993). High mortality occurs during severe winters. In years with rich mussel stocks, fisheries reduce the biomass by about 25%, but locally and in some years, by a far higher percentage. As food resources needed by birds are in the order of 20% of the average standing stock of mussels, birds can in some cases be short of food. They are then forced to switch to alternative prey, to leave the area or be subject to increased mortality or reproductive failure.

Cockle stocks exhibit high interannual variation. Severe winters may reduce the stocks extremely. In years with low stocks, fisheries can remove a fairly high proportion of the cockles (see above). Predation by birds will on average amount to about 20% of standing stock, but in years with a low biomass, birds will need to utilize a higher proportion of the standing stock of cockles. The reduced food availability may force the birds to feed in less suitable feeding areas (Bos 1994) with the increased risk of starvation, or cause them to leave the region.

In years of low bivalve stocks, fisheries may reduce the stocks below the level of natural variation. Recruitment of mussels and cockles in the Wadden Sea does not

happen annually and predictably (Beukema *et al.* 1993). For mussels, successful recruitment is partly dependent on the existence of stable beds with adult mussels (McGrorty *et al.* 1990; Dankers 1993). Effects of fisheries on bivalve stocks may thus last over several years, particularly when natural, older beds are fished. A combination of failing recruitment and continuous intensive fishing in the Dutch Wadden Sea led to a reduction of both mussel and cockle stocks in 1990, and in following years. The result was extremely low mollusc stocks in this part of the Wadden Sea. As a consequence, numbers of eiders and oystercatchers declined (Swennen 1991; Smit 1994). However, this change was paralleled by increased mortality of alternative prey species which, could not compensate for the lack of mussels and cockles (Beukema 1993). A similar incident occurred in the Danish Wadden Sea after 1986 (Laursen and Frikke 1987). In general, birds such as oystercatchers that are restricted to the intertidal flats will be more strongly affected by fisheries, as they are immediately affected by the removal of mussel spats, whereas eiders may also utilize the culture plots and other subtidal areas.

The fishery for the two *Spisula* species is a relatively new one. It potentially interacts with wintering seaducks, particularly common scoters, for which the coastal zone of the southeastern North Sea is an important habitat (Skov *et al.* 1994). In several of the areas where fisheries and seaducks sought *Spisula* on the same banks, numbers of ducks decreased significantly (Leopold *et al.* 1994). This happened in the Dutch Delta area in 1990, off the Dutch Wadden islands in 1993 and off the Dutch mainland coast in 1994. Seaduck counts in the two areas off the Danish and German coasts where *Spisula* fisheries started in 1992 have not been sufficiently frequent to monitor bird numbers. Fisheries at Horns Reef and Amrum Bank probably took place in areas without significant numbers of seaducks present, and are unlikely to have caused harm to seaducks (Skov *et al.* 1994). Interaction of fisheries and seaducks only occurs when both use the same area, which are areas of high *Spisula* densities.

To the present, there is no firm evidence that birds affect the yield of the fisheries. The proportions of mussels and cockles taken by birds are of the same order of magnitude as the fisheries yield, but bird predation extends over the year. Because production of benthic bivalves in the Wadden Sea is food-limited and density dependent growth regularly occurs (Dankers 1993), predation is likely to be partly compensated. Large numbers of eiders may utilize the cultures, but even in heavily used cultures, no effects on mussel production has been found (Nehls and Ruth in press). Most birds also focus their predation on juvenile molluscs where other causes of natural mortality are very high. For *Spisula* species, the stock sizes, and especially production and fishery harvests are generally unknown, which makes a comparison of (relative) impacts of fisheries and seaducks impossible at present.

4 ANALYSIS OF FISH CONSUMPTION BY AGE CLASS

4.1 Introduction

This section addresses the fourth of the Study Group's Terms of Reference; collate data on the diets of the major consumers in seasons and areas presently under-sampled and perform additional analyses of fish consumption by age class. The first part of this term was derived from a recommendation in the first report (Anon., 1994a) and it is not possible to deal with it since relevant data has not been collected between meetings. The second part of the term is important in understanding the impact of seabird predation on prey-fish populations and is required for multi-species virtual population analysis. There has never been a systematic survey of seabird diet for any given year, as has been undertaken for fish diets, e.g., ICES Year of the Stomach. Consequently, there are many inadequacies in the coverage of seabird diets for both areas and seasons. Many of the reported data on lengths of prey only provide a mean or range in length rather than the length frequency composition. Sample sizes are also generally small (often less than 100). Nevertheless, available data can be used to give an indication of prey size for at least the most important area of prey-fish consumption (ICES area IVa west) (Anon. 1994a).

4.2 Diet analysis

Studies of seabird diet in the North Sea were summarised in the 1993 Seabird-Fish interaction study group report (section 2.2.2, Anon. 1994a). The methods used in these studies have varied from direct-measurements of loads brought by adults to chicks to measuring hard parts in regurgitates or stomach samples. These latter measurements are combined with predetermined relationships between the growth of hard parts and body length to infer fish body length. The problems involved with such indirect estimates of length have been discussed by Johnstone *et al*, (1991). In the case of fish brought to chicks, or intact fish recovered from the stomachs of sampled birds, it is possible to determine the age of the fish. This has been done on a few occasions.

Age-length keys (ALKs) have been constructed for the three main prey species, sandeels, sprats and herring for use in the ICES fish-stomach sampling programme. Separate ALKs have been constructed for standard North Sea Roundfish areas and for each quarter of the year. However, age/length data for sandeels was incomplete. Further, Wright and Bailey (1993) have demonstrated that there can be marked changes in sandeel ALK due to interannual differences in growth rates. Using information on mean or range in length of prey together with these keys, the mean or range in age of prey consumed for a given study has been estimated.

There have been very few studies on the selection of prey in relation to prey abundance in the sea. Wright and Bailey (1993) showed that diving birds tended to bring in a higher proportion of older age-classes of sandeel than would be expected if they were selecting fish randomly. This would be expected given the high energetic cost of carrying fish to the colony.

4.3 Predation on sandeels

Age 1+ and older sandeels often appeared in the diets of guillemot, razorbill and shag during the summer breeding season (quarters 2 and 3). At least in the case of guillemots, the large prey taken in the summer may not reflect adult diets because most prey assessments were based on loads brought to colonies for chicks. The predominance of 0-group sandeels in the bird diets during quarter 4 and the same year-class in quarter 1 of the following year (now aged 1) suggests a seasonal shift in the size of prey taken. As 0-group sandeels are generally the most abundant age-class, this diet shift may simply reflect the availability of different age-classes.

Information is not adequate to assess consumption by age class for the whole North Sea. Most information exists on Area IVa (west) and, by making several assumptions, it is possible to attempt to model the consumption of sandeels in this area (Table 4.1). The figures presented are based on those in Table 2.35 of Anon. (1994a). There is no evidence to apportion the sandeels consumed by gannet (*Sula bassanus*) and great black-backed gulls (*L. marinus*) to age classes. From this information it can be seen that over a third of the predation in this region is on potential spawners (i.e. sandeels > 2 years old).

4.4 Predation on sprats

Data on the sizes and ages of sprat consumed by seabirds are scarce. Available information suggests that seabirds mainly take sprat of between 40 - 90 mm total length (TL) in winter, and around 120 mm TL in summer (Blake *et al.* 1985; Harris and Wanless 1985). The majority of the fish in this size range will belong to the same year-class (0-group in winter, 1-group in summer).

4.5 Overview

There is a need to elaborate the model of fish consumption by seabirds presented by Anon. (1994a) to allow multi-species models to incorporate seabirds adequately. This is not possible at present, but future sampling of seabird diet should, where possible, include an assessment of the age of fish in the diet. This will require seabird researchers to record the lengths of prey fish and, ideally, to

collect scales and/or otoliths. Furthermore, it appears that most of the studies of seabird diet in the North Sea have been made in summer, and were based on an analysis of the food brought to the chicks. There is therefore a need to investigate the food of breeding adults, non-breeding and subadult seabirds throughout the year. A coordinated study of the diets of both adult seabirds and their chicks throughout a single year is desirable.

5 SPATIAL AND TEMPORAL VARIABILITY IN THE BREEDING ECOLOGY OF SEABIRDS

5.1 Introduction

The terms of reference included the synthesis of appropriate data sets on seabirds, prey populations and physical oceanographic data that could elucidate spatial and temporal variability in the North Sea ecosystem (Term of Reference d). In this section we have considered two approaches which are complementary. Both the cases outlined below represent preliminary analyses and are reported as examples of the ways in which further studies could be developed. Firstly (Section 5.2) we examine geographical patterns in the breeding success of kittiwakes around the British Isles, with a view to identifying separate domains within which reproductive success of seabird colonies fluctuates among years in a concordant fashion, but in a pattern distinct (statistically uncorrelated) with that found in other domains. Then (Section 5.3) we examine at a local level the relationships between breeding performance of a single seabird species, the common tern, in relation to measures of fish abundance in the area close to the breeding colonies.

5.2 Concordance in breeding success of kittiwakes

Seabird ecologists tend to collect seabird breeding data (e.g. numbers of breeding pairs, breeding success, chick growth etc.) from a single site and from one or a few study species at that site, but often over a period of years. No integrated research programme has been set up to study the variations among sites in breeding ecology and performance of seabirds over spatial scales appropriate for interpretation in relation to oceanography or fish stocks. However, many studies have been carried out at seabird sites around the British Isles, and since 1986 data have been collected using standardised methods from many seabird colonies by the Joint Nature Conservation Committee seabird monitoring programme administered by JNCC and the RSPB. These include data from various independent studies and from monitoring work supported by JNCC and The Seabird Group. Those data sets have been used to prepare annual summaries of the breeding performance of seabirds around the British Isles from 1986 to 1993 (Walsh *et al.* 1990, 1991, 1992, 1993). Longer data sets, spanning periods from the early 1970s, exist for a

rather small number of sites (such as Foula in Shetland, Isle of May in Firth of Forth, Skomer in South Wales). However, in this analysis we have concentrated our attention on the JNCC data set for breeding success (chicks per nest) of samples of kittiwakes from 33 colonies around the British Isles between 1986 and 1993 (Figure 5.1, Table 5.1). This analysis extends the work of Harris and Wanless (1990). Smaller data sets (for the same years, but for fewer and not necessarily the same colonies) for guillemots and shags were also examined.

Overall variation in breeding success was low in the common guillemots ($n=41$ means of annual breeding success at individual colonies; overall average mean 0.73 chicks per pair, $CV=11.5\%$). For shags, breeding success was more variable ($n=42$ means, overall mean 1.39 chicks per nest, $CV=34.5\%$). However, kittiwakes showed by far the greatest variation in breeding success ($n=248$ means, overall mean 0.72 chicks per nest, $CV=60.6\%$). A number of biological interpretations are available for this result. Guillemots and shags as diving species may be less sensitive to variations in food supply than the surface-feeding kittiwake. Also, guillemots feed their chicks on large sandeels (12-14 cm typically) whereas kittiwakes and shags feed more on smaller sandeels and so will be more sensitive to interannual variations in sandeel recruitment.

Kittiwakes are surface feeding seabirds and forage over moderately large ranges from the colony (typically up to 50 km). Reductions in breeding success (from the average of about 2 eggs laid per nest) are to a considerable extent due to losses of growing chicks related to food supply, though breeding success can also be affected by predators (especially gulls and skuas) at some colonies. Diets of breeding kittiwakes have been examined at a number of colonies around the British Isles, and during chick-rearing, they consist largely of 0-group sandeels at many sites (Pearson 1968; Galbraith 1983; Harris and Riddiford 1989; Furness 1990; Bailey *et al.* 1991; Furness and Barrett 1991; Wanless and Harris 1992). However, particularly in the southern areas, sprats and zooplankton also may occur (Coulson & Thomas 1985, Anon 1994a).

The greater variance in kittiwake breeding success suggested that this species would be particularly suitable for an analysis of geographical concordance of interannual variation in breeding success. In addition, data were available for a large number of colonies (we used only those for which breeding success had been monitored in at least six of the eight study years).

Examining the variances in breeding success among years at colonies in particular regions, it is evident that breeding success was much more variable at Shetland than at Orkney, with variation at other sites tending to be intermediate (Table 5.2). This pattern of low variance at Orkney but high variance at Shetland coincides with low variance in 0-group sandeel abundance among years at Orkney but high variance at Shetland in the June/July sandeel surveys from 1969-88 (Wright & Bailey 1993, and Figure 5.2).

Pearson product moment correlation coefficients between kittiwake breeding success at pairs of colonies over the eight years showed high correlations (>0.8 is significant at $p < 0.05$ for these samples of 8 years of data) for many pairs of colonies that are geographically close. For example, within Shetland, breeding success of kittiwakes at Foula correlated with that at Fair Isle ($r = 0.89$), Troswick ($r = 0.84$), Sumburgh ($r = 0.90$), and Noss ($r = 0.83$). In contrast, breeding success of kittiwakes at Foula did not correlate with breeding success at colonies in southern Britain. Using cluster analysis (Distance = Pearson, Linkage = Complete), a dendrogram was produced (Figure 5.3) that showed fairly consistent grouping of kittiwake colonies into geographically (and presumably oceanographically) coherent units (Figure 5.4). In the case of Shetland, we know that the poor breeding success that occurred in all those kittiwake colonies in 1988-1990 was a consequence of the birds having difficulty in finding sandeels (Hamer *et al.* 1994) during a period of low sandeel recruitment (Wright and Bailey 1993).

The cluster analysis was based only on year-to-year variation in breeding success (correlations in pattern between colonies) and ignored differences in absolute breeding success between colonies. The latter also shows variation between regions. For example, kittiwake colonies in two of the domains show higher average breeding success than in the other three (Table 5.2). In principle, it would be possible to use the mean breeding success as a second axis to separate colonies.

The high dependence of Shetland kittiwakes and guillemots on sandeels to feed chicks despite the high coefficient of variation of sandeel 0-group abundance at Shetland, and so the high variance in kittiwake breeding success at Shetland (and lower mean value than at Orkney) suggests that Shetland might be a marginal breeding area for these seabirds. That this is not the case is evident from the population sizes. There were estimated in the mid-1980s to be 163,000 guillemot adults and 50,000 kittiwake nests at Shetland compared with 183,000 guillemot adults and 64,000 kittiwake nests at Orkney, so that Shetland and Orkney are very similar in terms of the numbers of these two species that they support (Lloyd *et al.*, 1991). Alternatively, the high CV may indicate that Shetland is a marginal area for sandeels, and this conclusion is supported by the areas relative unimportance as a sandeel spawning ground (Wright and Bailey 1993).

We suggest that the reproductive success of kittiwakes around the British Isles may be divided into distinct domains. In our analysis, five such domains were evident: 'Shetland', 'northeast', 'south', 'southwest' and 'northwest'. We hypothesize that the variations between regions in kittiwake breeding success are predominately driven by variations in local prey availability. An alternative model, that breeding success varies among years according to local variations in weather, is considered less likely, but cannot be ruled out at this stage. However, the ornithological literature suggests that kittiwake breeding success is less susceptible

to effects of weather than to effects of food supply. The patterns suggested by this analysis invite further study, and in particular may suggest regional structuring of kittiwake food (perhaps particularly in stocks of sandeels?) into a number of distinct units with differing dynamics. Perhaps the domains of kittiwake breeding success correspond to major water masses. In particular it would be useful to investigate whether similar regional groupings are identified by analysis of other seabird data sets, such as guillemot chick growth rates or tern numbers or breeding success, or from analysis of fish stock structure or communities. Interpretation of such patterns also invites input from physical oceanographers.

5.3 Relationships between Fish Populations and the Reproductive Ecology of Common Terns in the Wadden Sea

5.3.1 Introduction

Because the reproduction of seabirds depends on marine food sources, several parameters of their reproductive biology can be used as indicators of the availability and distributions of prey species on which they feed (review: Montevecchi 1993). Also the analysis of food taken by the seabirds and fed to mates or chicks can provide valuable information about the state of the food supplies. In this respect terns are especially useful as indicators of the marine resources they use because:

- owing to small body size, their energy reserves are low, and the actual food availability immediately affects body condition and reproduction in adults (Monaghan *et al.* 1989; Frank and Becker 1992) and growth of young (Mlody and Becker 1991);
- the transport of single food items in the bill makes it possible for ornithologists to get information on prey identity;
- the distribution of common and Arctic terns (*Sterna hirundo*, *S. paradisaea*) on the coasts around the North Sea as well as the accessibility of many colony sites make them suitable as monitors of the temporal and spatial population trends of the small prey organisms which form the necessary basis for successful reproduction.

One well studied example of interactions of terns with food is the Arctic tern on the Shetlands and Orkneys during the period of low sandeel availability in the 1980s (Furness 1987, Monaghan *et al.* 1989, 1992a,b; Uttley 1992). In the southern North Sea, however, sandeels are not so important as prey for terns; two commercially important species, the clupeoids, herring and sprat, are the dominant prey (Table 5.3).

5.3.2 Spatial and Temporal Trends in Breeding Success of four Common Tern Colonies

Since 1981, long-term studies of Common Tern reproductive and foraging ecology have been carried out on the Wadden Sea coast. At the island of Griend, The Netherlands, the mean breeding output was low (0.38 ± 0.20 fledged chicks per pair per year, $n=12$, Stienen & Brenninkmeijer, 1992, Brenninkmeijer & Stienen, 1993), compared with three colonies at the Jade Bay, Germany: at the island of Minsener Oldeog 0.76 ± 0.58 , and at two coastal sites, at Wilhelmshaven 1.11 ± 0.55 and at Augustgroden 0.83 ± 0.63 chicks fledged ($n=13$ each, Becker 1991 and unpubl. data). Correlations between the annual reproductive output of the colonies were positive, but not significant, with the exception of Oldeog/Augustgroden (Table 5.4). The reason is that tern reproductive success is not only influenced by food availability but also by factors like predation and flooding which vary strongly among sites. In consequence, to focus on interactions between reproduction and food supply, parameters should be studied which are more directly affected by food availability, which has been preliminarily done for the common terns on Minsener Oldeog.

5.3.3. Tern Reproductive Performance and Fish Stocks at Minsener Oldeog

5.3.3.1 Temporal Trends

Reproductive biology: Except for 1981, when many common terns moved to the new, man-made sandy island of Minsener Oldeog, the number of breeding pairs fluctuated between 1,500 and 2,500 pairs (Figure 5.5). In both 1985 and 1988, the low numbers of breeding pairs may be linked to the low breeding output during the previous year (Figure 5.5). It may be that after the previous year's failure some adults did not breed owing to poor condition, or moved to another colony site. Clutch size variations were low with the exception of 1991, when the weather was cold and water temperature low in spring, and herring from an already reduced stock (Figure 5.5, see below) migrated late into the Wadden Sea, and were not available during the courtship period of the terns.

Tern reproductive output fluctuated greatly between years (range, 0 to 1.6 chicks fledged, e.g., > 18 d of age, per pair per year) owing to the annual fluctuations in the availability of food, as well as to the influence of various predators (1987: rats, 1993: gulls). The very low output in 1984 was due to a stormy period at the end of June, when most chicks died because the adults were not able to bring enough food for their young. This can be seen also by the annual losses of chicks by the factors food availability and/or weather (Figure 5.5). The highest levels of chick mortality were found in 1984 and 1981, the lowest in 1983 and 1986-1988, when the breeding success peaked (except 1987, rat-predation). These years were also characterized by a growth rate of chicks (g/d during linear phase of

growth, 3- 13d of age) above the average (Figure 5.5). The lowest growth rate was found in 1984, when food shortage led to high chick mortality and an advanced age at fledging of the chicks which survived (Figure 5.5) (Data from Becker 1991; Becker and Finck 1985, 1986; Becker and Specht 1991; Mlody and Becker 1991, and unpubl.).

Fish stocks: The size of the herring stock (Herring Index, < 20 cm, no./h; ICES young fish survey, Dornheim and Wegner, 1993) was lowest in 1981, increasing constantly to the peak in 1987 (Figure 5.6). From this year onwards the stock decreased again to levels of about 2,000 in 1992. At the Wadden Sea island of Minsener Oldeog, the catches of clupeoids and all animals in a stationary stow net, deployed during the breeding season in 6 years, peaked in 1986 and 1987 (Figure 5.6). Of the animals caught by the stow net, $70 \pm 20\%$ were clupeoids, and herring was the dominant species of clupeoid in all years (e.g. 1991: herring = 99%, sprat = 1%, $n=5145$). The highest sprat index occurred in 1989 (< 10 cm, no./h, see above) but the sprat index fluctuated strongly between years, more so than the herring index (Dornheim and Wegner 1993). Both 1982 and 1983 were characterized by high indices of the sandeel population in the Wadden Sea (Tiewes 1989).

Chick diets: The percentages of clupeoids in chick diet (studied 84-86 and 91-92) were highest in 1984, and lowest in 1991 (Frank 1992, unpubl. data).

5.3.3.2 Correlations of Fish Stocks and Tern Reproduction

For all the variables mentioned, the Spearman correlation coefficient was calculated and presented in case of $r_s > 0.5$ and $n > 5$. Within the fish stock data, no clear correlations were found (clupeoids in stow net with herring index: $r_s=0.37$, n.s., $n=6$). Within the tern reproduction data, growth rate and chicks fledged/pair were negatively correlated with age at fledging (Table 5.5); chick losses by weather and food correlated positively with clutch size and age at fledging, and negatively with growth rate.

With respect to the correlations of fish stocks and reproductive biology, the data in Table 5.5 showed no significant correlations, but interesting tendencies were present:

- the frequency of clupeoids in the stow net as well as the stow net total were negatively correlated with chick losses by starvation and weather and with age at fledging;
- the herring index was positively correlated with growth rate and negatively with chick losses by starvation and weather.

The sample sizes are often very low, and we can expect that a better data base (more years) would result in stronger correlations.

The most important time series showing the relationships between the herring stock and the growth rate of common tern chicks (positive) as well as with chick mortality (negative) are combined in Figure 5.6. The correlations with herring stock data are not significant because the growth rate in 1983 was very high (presumably facilitated by a high sandeel availability, see above), and the chick losses in 1984 and 1985 were higher than average because of extreme weather effects (see above, and Becker and Specht 1991).

5.3.4 Conclusions

The data show that the reproduction of terns on the southern North Sea coast is linked with the herring stock. The fishery on this economically important fish species (industrial fishery on small herring in the North Sea, Jensen *et al.* 1994; bycatch of the shrimp fishery in the Wadden Sea, Walter and Becker 1994) has the potential to interact negatively with the most important food supply of the terns and other seabirds by affecting their reproductive output and population size. Unfortunately the data presented are limited and incomplete, constraining the analysis. This underlines the importance of long term data series as the basis for understanding interactions between seabirds and fish. To investigate interactions between tern reproduction and fish stocks, not just breeding success but other parameters should be studied which are directly related to food availability, such as chick growth or chick starvation.

The results from Minsener Oldeog also indicate the value of fish population data from seabird colony areas as a source of information on local fluctuations in fish stocks. The stow nets is relatively easy to use and cheap. In comparison with catches by fishery vessels, the stationary stow net has the advantage of being installed year by year at the same site and to catch even the small fish, which are required for many seabirds during reproduction.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. The potential impact of fisheries on seabirds is greater at the local scale than at the scale of the North Sea as a whole.
2. Adequate assessment of fisheries/seabird interactions will be possible only if fisheries data are collected and analysed at smaller scales than is common practice. These assessments will require closer integration of the work of ornithologists, oceanographers, and fisheries scientists.

3. Based on estimates of prey consumption by age class for ICES Area IVa west, more than a third of the predation of seabirds on sandeels is on potential spawners.
4. A large-scale spatial pattern in the interannual variation of kittiwake breeding success is evident and may reflect geographic variations in fish stocks and/or oceanography. Investigations of the causal mechanisms underlying such patterns may therefore provide clearer insights into the relationships between seabirds and their prey and the potential impacts of fisheries.
5. In the Wadden Sea, the consumption of bivalves by birds is of the same order of magnitude as that taken by the fisheries.
6. In years of low shellfish abundance, shellfish-eating birds in the Wadden Sea are potentially subject to fishery-induced starvation.
7. Fisheries for *Spisula* spp. currently compete with seaducks because they concentrate on the banks where the ducks forage.

6.2 Recommendations

1. There is a need to develop small-scale, properly integrated multidisciplinary studies to focus on locales with a high potential for interactions among seabirds, predatory fish, fisheries and prey fish. As a first stage to the development of these studies, the various research vessel data bases could be analyzed with respect to small scale spatial variation in fish abundance and community structure.
2. Based on the Study Group's analyses, we stress the need for future sampling of seabird diets to include an assessment of the age of the fish in the diets. These data should be collected from breeding adult, non breeding and subadult seabirds throughout the annual cycle.
3. There is a need to consider the impact of the harvest of fish that compete with seabirds for prey, and the possibility that seabird populations have increased as competing fish predators have been removed from the marine ecosystem.
4. Further analyses of large-scale patterns of reproductive ecology of seabirds in relation to prey stocks and physical oceanography need to be addressed.
5. The Study Group should review the use of discards by scavenging seabirds.
6. The prey requirements of shellfish-eating seabirds should be incorporated into Wadden Sea management protocols.

7. There is a need for more extensive assessment of the two *Spisula* species that are currently fished in the German and Southern Bights so that the impact of the fishery on seaduck prey stocks can be evaluated.

8. Fishing for *Spisula* spp. should concentrate on areas not used by large flocks of seaducks. To this end, the location of the major scoter flocks should be assessed annually.

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Table 3.1

Number of individuals (in thousands) in different seasons in the Wadden Sea for the most important bivalve feeders. Numbers according to Meltofte *et al.* (1984) and total numbers are average estimates for a 10 year period (1981-1991). Numbers in the different countries are maximum numbers during the same period

Species		Summer	Autumn	Winter	Spring
Oyster catcher	Total	103	739	593	481
	NL	57	302	324	166
	G	103	386	280	323
	DK	10	60	25	45
Herring gull	Total	79	328	157	141
	NL	39	123	82	43
	G	35	231	64	112
	DK	20	32	40	16
Eider duck	Total	250	250	331	140
	NL	40	40	147	50
	G	220	200	174	50
	DK	25	23	67	18
Common scoter	Total	96	242	300	196
	NL	12	35	100	100
	G	15	40	40	48
	DK	69	167	160	48

Table 3.2

The areas designated for culture lots and the areas covered with mussels for the majority of the time in the different parts of the Wadden Sea

	Designated culture lots (see Figures)	Culture lots covered with mussels for the majority of the time
The Netherlands	About 7,000 ha	About 3,750 ha
Niedersachsen	About 960 ha	About 250 ha*
Schleswig-Holstein	About 2,800 ha	About 1,000 ha

*Presently this number is very low. In general it can be said that of all culture lots available only between 30 to 70% are covered with mussels, which shows a high fluctuation rate in the coverage

Table 3.3

Landings of blue mussels in tonnes in the Netherlands (Wadden Sea and Delta), Denmark and Germany (Niedersachsen and Schleswig-Holstein) since 1965

Year	NL		DK	G		Total
	WS	Delta		SH	Nds	
1965	40,000	51,300	0	3,500	3,977	98,777
1966	33,100	48,400	0	6,900	4,367	92,767
1967	49,200	34,200	0	6,900	4,090	94,390
1968	71,400	36,200	0	6,900	4,213	118,713
1969	48,800	39,700	0	1,900	4,549	94,949
1970	32,600	43,000	0	5,300	4,245	85,145
1971	80,600	38,200	0	1,500	4,826	125,126
1972	122,100	35,700	0	2,750	5,169	165,719
1973	66,000	35,300	0	6,100	4,239	111,639
1974	69,000	34,500	0	10,600	4,642	118,742
1975	58,300	31,000	0	11,250	5,736	106,286
1976	56,200	33,200	0	15,300	7,979	112,679
1977	95,300	32,300	0	5,000	6,085	138,685
1978	63,400	39,900	0	7,200	5,341	115,841
1979	41,900	40,200	305	2,000	894	84,299
1980	34,100	33,300	293	8,300	2,017	78,010
1981	89,300	36,300	131	5,800	4,579	136,110
1982	111,400	46,800	1,144	11,800	5,033	176,177
1983	74,300	34,800	2,147	20,600	11,009	142,856
1984	27,500	39,200	14,533	34,600	24,731	140,564
1985	72,900	33,400	27,099	15,500	5,423	154,322
1986	38,600	25,800	17,564	23,800	5,076	110,840
1987	57,100	29,600	17,384	20,000	5,467	129,551
1988	36,700	27,300	1,161	19,800	9,842	94,803
1989	80,500	28,600	1,403	9,525	9,024	129,052
1990	69,659	22,511	1,190	15,625	3,775	111,710

Source: Miljøministeriet Skov- og Naturstyrelsen; Fischereiamt Kiel; Staatliches Fischereiamt Bremerhaven; Ministerie van Landbouw, Natuurbeheer en Visserij-Directie Visserijen

Note: Dutch data are seasonal, eg 1965 = 1 July 1965 - 1 April 1966

Table 3.4

Estimated average annual consumption (in tonnes wet weight) of the main bivalve eating birds in the Wadden Sea. Eider consumption after Swennen (1976), common scoter after Offringa (1990), oystercatcher after Bos (1994), herring gull after Anonymous (1994)

	Mussel	Cockle	Spisula species
Eider	60,000	100,000	750
Common scoter	-	-	35,000
Oystercatcher	40,000	120,000	-
Herring gull	10,000	10,000	-

Table 4.1

Consumption by age-class of sandeels in IVa west

	First	Second	Third	Fourth
Fulmar	n/a	20% 0-group 80% 1-group	All 0-group	n/a
Shag	All 2-group	All 2-group	All 2-group	All 2-group
Kittiwake	n/a	20% 0-group 80% 1-group	All 0-group	n/a
Guillemot and razorbill	75% 1-group, 25% 2-group	10% 0-group 40% 1-group 25% 2-group 25% 3-group	25% 0-group 25% 1-group 25% 2-group 25% 3-group	All 0-group
Puffin	All 1-group	20% 0-group 80% 1-group	All 0-group	All 0-group

Consumption of 0-group

	First	Second	Third	Fourth	Total
Fulmar	0	2,345	4,790	0	7,135
Kittiwake	0	1,052	3,681	0	4,733
Guillemot	0	3,676	4,090	1,923	9,689
Razorbill	0	301	769	511	1,581
Puffin		814	2,582	41	3,437
Total	0	8,188	15,912	2,475	26,575

Consumption of 1-group

	First	Second	Third	Fourth	Total
Fulmar	0	9,378	0	0	9,378
Kittiwake	0	4,208	0	0	4,208
Guillemot	745	14,704	4,089	0	19,538
Razorbill	646	1,204	769	0	2,619
Puffin	395	2,605	0	0	3,000
Total	1,786	32,099	4,858	0	38,743

Table 4.1 (continued)

Consumption of 2-group

	First	Second	Third	Fourth	Total
Shag	1,062	1,447	1,291	1,086	4,886
Guillemot	1,748	9,189	4,089	0	15,026
Razorbill	215	725	769	0	1,709
Total	3,025	11,361	5,459	1,086	21,621

Consumption of 3-group

	First	Second	Third	Fourth	Total
Guillemot	0	9,189	4,089	0	13,278
Razorbill	0	725	769	0	1,494
Total	0	9,914	4,858	0	14,772

References: Blake *et al.* (1985); Furness (1990); Wanles and Harris (1985)

Table 5.1

Seabird colonies in the JNCC database 1986-1993 from which kittiwake data sets were taken in this analysis. For locations of colonies see Figure 5.1

Abberton Reservoir	98	Fastnet Rock	158	Lindisfarne	83	Saltburn	90
Ailsa Craig	1	Fetlar	56	Loch of Strathbeg	71	Sands of Forvie	73
An Dun, St Kilda	7	Firth of Forth	76	Long Craig	77	Sandside Head	19
Anglesey	128	Flannan Isles	8	Lough Swilly	164	Scolt Head	92
Annet, Scilly	116	Flotta	21	Lowestoft	95	Shiant Islands	9
Auskerry	33	Forth Estuary	76	Lumbister, Yell	53	Shotton Steelworks	132
		Foula	46	Lundy	117	Skirza Head	63
Bardsey	124	Foulness / Maplin	144	Lushan basin	25	Skokholm	121
Bempton	91	Foulney	133			Skomer	122
Berry Head	112	Fowl Craig	29	Marsden Rock	88	South Foreland	100
Big Doon	156	Fowl Sheugh	74	Marrowick Head	24	South Ronaldsay	36
Blakeney Point	93	Gateshead	87	Mawbray	137	South Stack	127
Bradda	140	Glen Maye	142	Maywick	41	South Walney	134
Breil Nook	91	Great Ormes Head	130	Minsmere	96	Spainneavaig	14
Bressay	59	Great Saltee	151	Moray Firth	66	St Abb's Head	82
Brownsea Island	108	Great Skellig	160	Mousa	61	St Bee's Head	136
Bull Rock	159	Green Island	147	Muckle Green Holm	31	St John's Head	20
Bullers of Buchan	72	Gronant	131	Mull Head	34	St Kilda	7
		Gruney	52	Mulroy Bay	163	Stac Shuardail	11
Calf of Man	139	Grutness	39	Newhaven -	103	Start Point	113
Canna	6	Guernsey	114	Peacehaven		Strangford Lough	146
Carlingford Lough	147	Gugh, Scilly	116	Nigg	68	Strathbeg	71
Cellar Head, Lewis	13	Gulberwick	60	North Roe	51	Stronsay	32
Chesil	110	Gultak	35	North Rona	15	Sule Skerry	18
Chichester Harbour	105	Handa	16	North Ronaldsay	30	Sumburgh Head	38
Clift Sound	43	Hascosay	57	North Shields	86	Swan Island	145
Cliffs of Moher	161	Havergate	97	North Sutor	67	Tantallon	80
Colonsay	3	Helvick Head	154	Northmavine	49	Tiupan Head	12
Coquet Island	85	Hermaness, Unst	54	Noss	58	Tormisdale, Islay	2
Coستا Head	26	Hirta, St Kilda	7	Noss Hill	40	Traie Vane - Gob	141
Covesea	69	Hodbarrow	135	NW Solent	107	yn Ushtey	
		Holm of P. Westray	29	Old Head of Kinsale	157	Treshnish Islands	4
Devil's Truck	119	Hoy	22			Trewavas Head	115
Douglas	138	ICI Wilton	89	Pagham Harbour	104	Troswick Ness	62
Dun, St Kilda	7	Inchmickery	78	Papa Stour	48	Troup Head	70
Dunbar	81	Inishmore	162	Papa Westray	29	Unst	55
Dunbar	81	Iresgeo	64	Peel Hill	143		
Dungeness	101	Isle of May	75	Portally	153	Weisdale Voe	44
Dunmore East	152	Isles of Scilly	116	Puffin Island	129	West Bay / Burton	111
Durlston Head	109	Kettle Ness	42	Ram Head	155	Westerwick	45
		Lady's Island Lake	150	Rathlin Island	144	Westray	28
Easter Vaila Sound	47	Lambhoga, Fetlar	56	Rockabill	148	Weybourne -	94
Eilean Mhuire,	9	Langstone Harbour	106	Round Island, Scilly	116	Sheringham	
Shiant Islands		Larne Lough	145	Rousay	27	Wicklow Head	149
Eilean Mor,	8	Leith Docks	79	Row Head	23	Woody Bay	118
Flannan Islands		Lewis	10	Rum	5	Yell	53
Elegug Stacks	120			Rye Harbour	102	Yns Feurig	126
Eshaness	50					Ynyssoedd Gwylan	123
Fair Isle	37						
Faraid Head	17						
Farne Islands	84						

Table 5.2

The mean breeding success of kittiwakes around the British Isles grouped according to Figure 5.3 (except Orkney)

Group	Mean	SD	CV	N	p	Remarks
Southwest	0.58	0.35	61	69	ns	excl Marwick and Kettla
Northeast	1.01*	0.37	37	52	ns	
Northwest	0.65	0.47	72	23	<0.01	excl Ailsa Craig
Shetland	0.51	0.47	92	46	ns	
South	0.94*	0.39	41	16	<0.01	excl Mull Head
Orkney	1.04*	0.16	15	14	ns	

SD - standard deviation

CV - coefficient of variation (%)

N -

p - significance of differences in breeding success within groups

ns - not significant

* - groups have significantly higher mean breeding success than the three other regions

5.3

Table 4: Geographic variation in the food of the common tern on the Farne Islands (PEARSON 1968), Mousa (Uttley, *et al.*, 1989) and in the Wadden Sea (a) Stienen and van Tienen, 1991; (b) Frank, 1992).
 from ~~1988~~ (1994)
 Augu.

Colony	Year	n	Percent food						
			Clupeoids	Sandeels	Gadids	Sticklebacks	Flatfish	Other and unidenti-fish	Crustaceans
Farne Islands	1961-1963	519	44	38	11	2		5	
Mousa, Shetlands	1988	110		20				80 ^c	
<u>Wadden Sea</u>									
Griend ^a	1989-1990	?	52				7	9	32
Oldeoog ^b	1986	638	60	19		1		18	
Augustgroden ^b	1986	1,457	31	3		55	2	4	1

^cmainly saithe

Table 5.2-2/4

Correlations of breeding success of four common tern colonies on the Wadden Sea coast, southern North Sea, from 1981-1993. Pearson correlation coefficients are presented

	Oldeog	Wilhelmshaven	Augustgroden
Wilhelmshaven	0.11 (13)		
Augustgroden	0.52 (13)*	0.27 (13)	
Griend	0.29 (12)	0.15 (12)	0.20 (12)

n.s.; *p<0.1

Table 5. ~~2.3~~ 5

Spearman correlation coefficients of reproductive parameters in common terns and data on food supply (Wadden Sea, Germany). Only correlations with $n \geq 5$ and coefficients $r_s \geq 0.5$ are presented

Variable a	with	Variable b	r_s	p	n
Growth rate		Age at fledging	-0.76	≤ 0.05	(8)
Growth rate		Herring index	0.53		(9)
Age at fledging		No of animals (stow net)	-0.70		(5)
Age at fledging		No of clupeoids (stow net)	-0.70		(5)
Age at fledging		Chicks fledged/pair	-0.67	≤ 0.05	(9)
Chick loss*		Clutch size	0.57	≤ 0.05	(13)
Chick loss*		Growth rate	-0.85	≤ 0.01	(10)
Chick loss*		Age at fledging	0.77	≤ 0.05	(10)
Chick loss*		No of animals (stow net)	-0.66		(6)
Chick loss*		No of clupeoids (stow net)	-0.66		(6)
Chick loss*		Herring index	-0.52		(12)

*weather and food situation

9 Figures

Figure legends

Figure 2.1. Variation in the strength of the association between the distribution of Arctic terns and the distribution of sandeels as a function of sandeel stock density.

Figure 2.2. The relationship between the percentage of guillemots recovered during the first year of life and the estimates of sprat stocks in the North Sea. From Harris and Bailey 1992.

Figure 3.1. Mussel stocks in the Schleswig-Holstein sector of the Wadden Sea. From ???

Figure 3.2. Cockle biomass (kg fresh weight) in the Dutch part of the Wadden Sea in autumn. The yields and the remaining amounts of biomass in densities above and below 50 cockles.m⁻² are represented. Based on Dankers and de Vlas (1992) and van Stralen and Kesteloo-Hendrikse (1992). From ????

Figure 3.3. Fisheries harvest of cockles as a percentage of the total sock in the Dutch portion of the Wadden Sea. From ????

Figure 3.4.

Figure 5.1. Colonies of Kittiwakes in the JNCC database that have been monitored for reproductive success and other parameters. See Table 5.1 for colony names.

Figure 5.2. Interannual variation in the densities of sandeels as measured by pelagic trawl samples near Shetland. From ????

Figure 5.3. Dendrogram of kittiwake colonies showing similarity in patterns of interannual variation in production of young. See Table 5.1 and Figure 5.1 for the location of the colonies.

Figure 5.4. Location of the kittiwake colonies that clustered together on the basis of similarity in interannual variation in reproductive success.

Figure 5.5. Population and reproduction trends in Common Terns on Minsener Oldeog, German Wadden Sea

Figure 5.6. Comparison of the trends of selected data (see Figures 5.1.1, 5.1.2) of Common Tern reproduction (Figure 1) and clupeoid-stock fluctuations (no. of clupeoids in the stow net of Minsener Oldeog, trend of the Herring Index (ICES, North Sea)

Association between Arctic terns and sandeels in relation to overall sandeel stock density

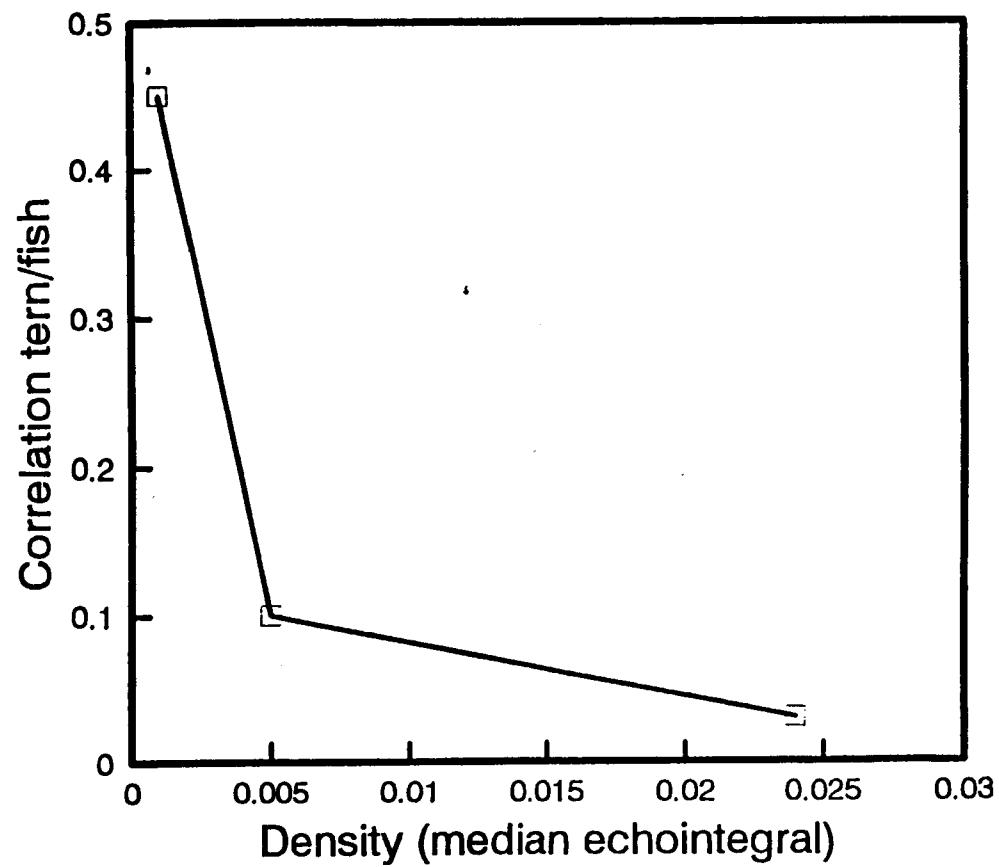


Fig 2.1

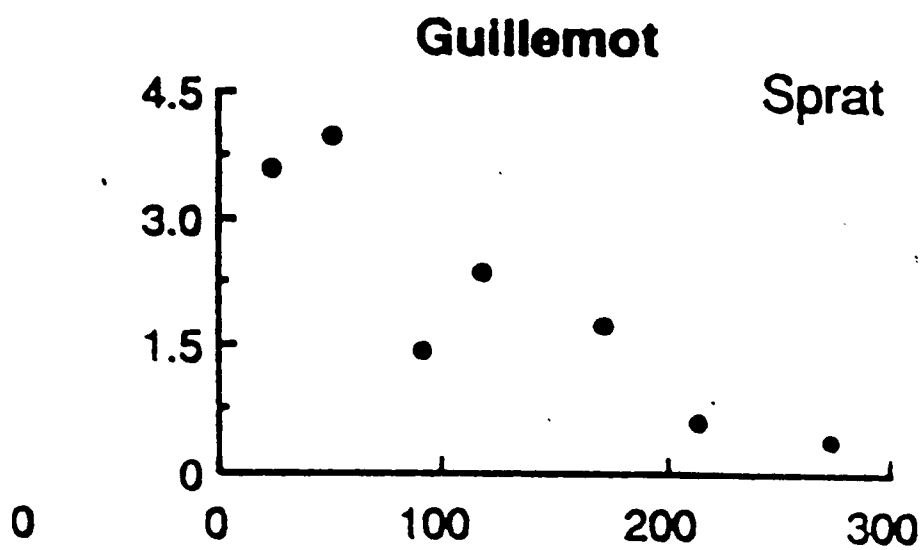


Fig 2.2

durch die Anlage von Kulturbänken, die mit Saatmuscheln von natürlichen Bänken belegt werden. Direkte Anlandung marktfähiger Muscheln von natürlichen Bänken erfolgt nur selten. Die Kulturen befinden sich im flachen Sublitoral in Gebieten, die durch Inseln oder hohe Sände vor Stürmen geschützt sind (CWSS 1991, SEAMAN & RUTH im Druck, RUTH 1994). Die Fischerei nutzt dabei den Umstand, daß der Brutfall von Miesmuscheln meistens in Bereichen erfolgt, die durch suboptimale Wachstumsbedingungen (z.B. hohes Eulitoral) und relativ hohe Mortalität gekennzeichnet sind. Die Verfrachtung in geschützte, sublitorale Bereiche verbessert die Wachstumsbedingungen und erhöht die Überlebensrate der Muscheln. Mit der Anlage von Kulturbänken wurde in der ersten Hälfte dieses Jahrhunderts begonnen, bis 1965 bedeckten diese aber erst 350

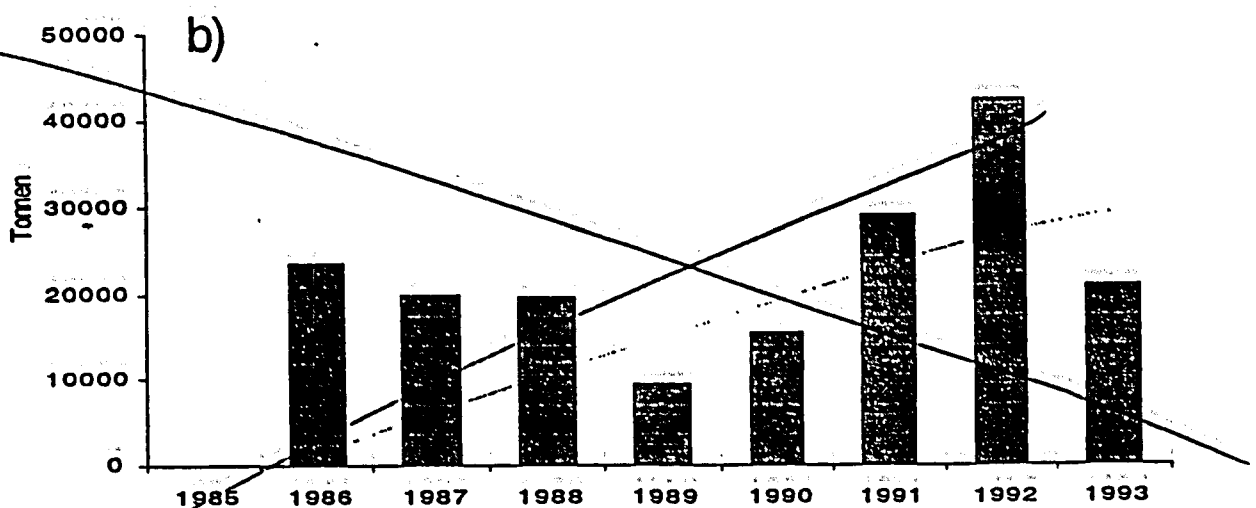
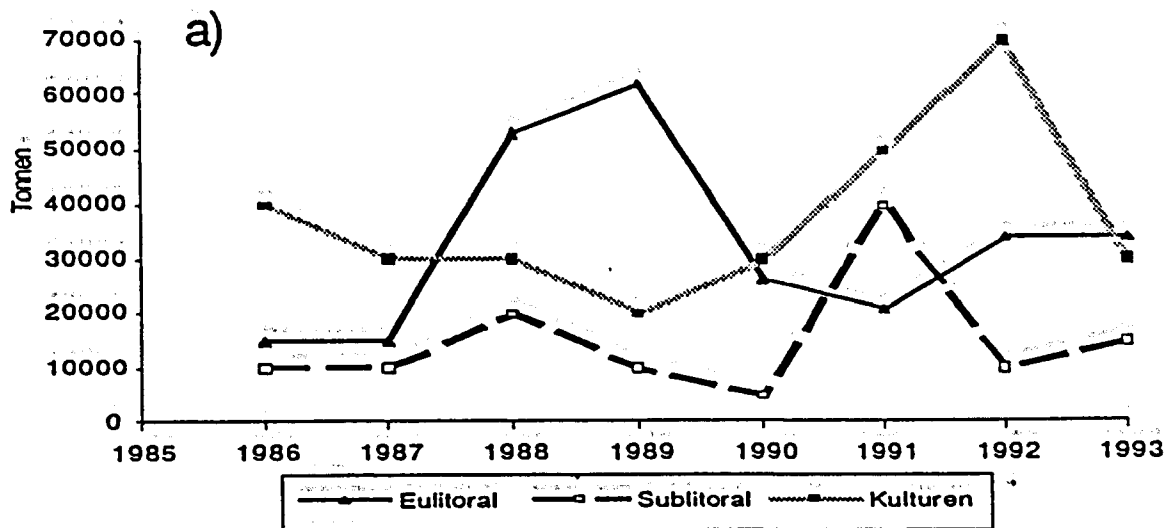
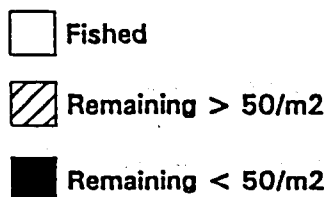
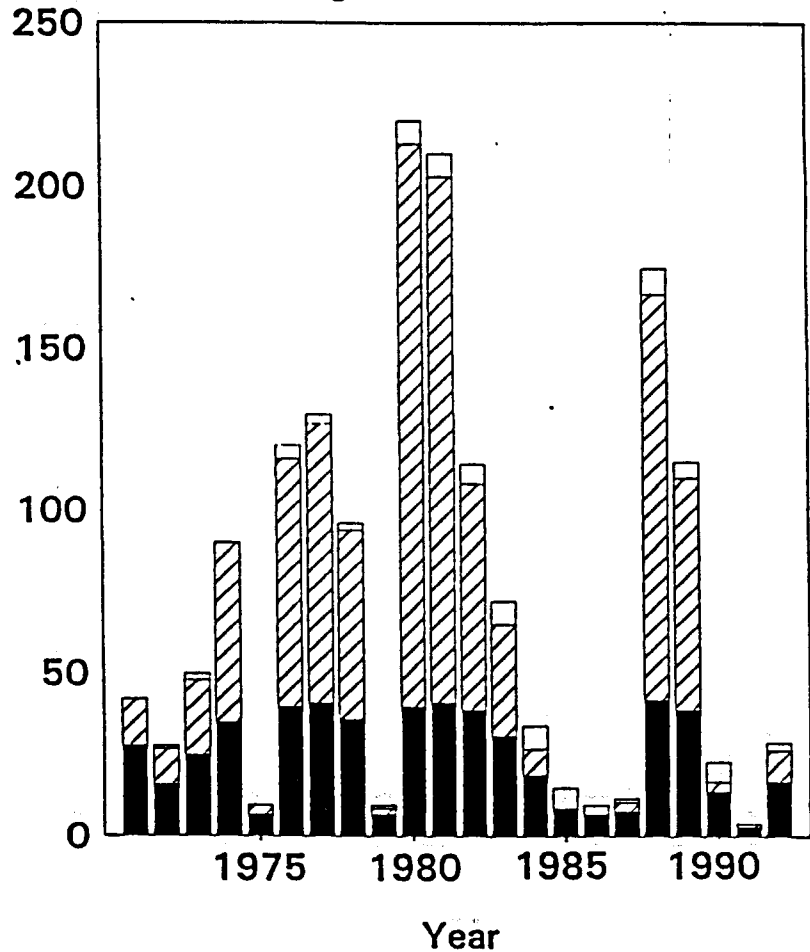


Abb. 2: Entwicklung der Muschelbestände (a) und der Anlandungen der Muschelfischerei (b) im Schleswig-Holsteinischen Wattenmeer 1986 - 92. Alle Angaben in Tonnen Naßgewicht. Die Angaben über die Bestände 1987 und 88 sind Schätzwerte.

Figure 1.3

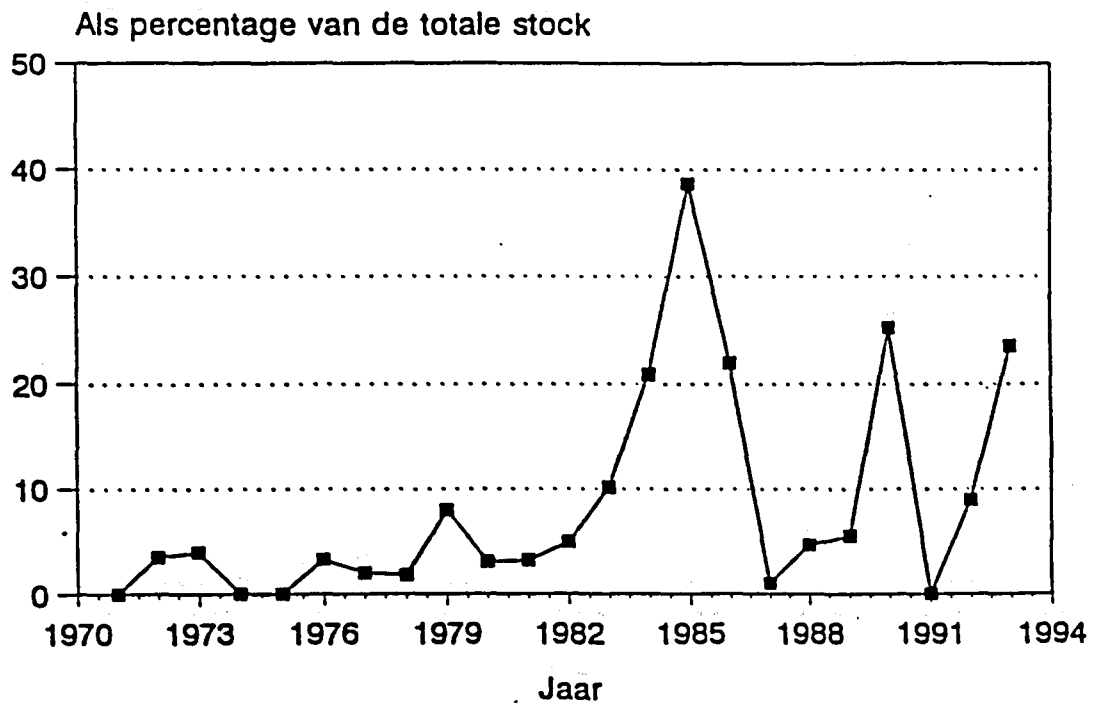
Cockle biomass (kg freshweight) in the Dutch part of the Wadden Sea in autumn. The yields and the remaining amounts of biomass in densities above and below 50 cockles.m⁻² are represented. Based on: Dankers & de Vlas (1992) and van Stralen & Kesteloo-Hendrikse (1992).

**Biomass (million kg)**

On the Wash (UK) numbers of Oystercatchers decreased dramatically to 12.000 in January 1993 after a gradual increase from 15.000 in the seventies to 45.000 in 1988. Body condition of the remaining animals was below average and a large proportion of them was foraging inland there. These phenomena could be explained by a general food shortage for Oystercatchers. Suitable size classes of mussels and cockles were hardly present. Also, the flesh content of the prey was very low (Clark, 1993). Lambeck (1991) and Meininger et al. (1991) reported an abnormally high mortality among Oystercatchers in the Oosterschelde, February 1986. A frost period struck the birds more than in the Wadden Sea (Hulscher, 1989) or Westerschelde, because a reduction in tidal amplitude, caused by the construction of the storm surge barrier, had worsened feeding conditions. More of these examples can be found in Smit (1994).

(de Vlas 1987). Hoewel het aantal vergunningen in 1974 is bevroren op 36 is de vangst sindsdien toegenomen door vergroting van de capaciteit van de schepen en verbetering van de vangstefficiëntie (Dankers & de Vlas 1992). De effecten van de visserij zijn sterk wisselend. In jaren met een meer dan gemiddelde stock (wanneer meer dan 100 miljoen kg kokkelvlees aanwezig is) wordt minder dan 10% opgevist, in jaren met een lage stock (1985, 1986, 1987, 1990) gaat het om 30% van de totale stock, waarbij bijna 100% van de banken met een hoge kokkeldichtheid wordt leeggevist (Dankers 1993). De hoeveelheid Kokkels die jaarlijks uit de Waddenzee wordt verwijderd is tussen 1975 en 1985 toegenomen. Ook het percentage van de bevisbare hoeveelheid dat wordt opgevist is sterk toegenomen (Fig. 7).

Opgeviste hoeveelheid Kokkels Waddenzee



Figuur 7. Het percentage van de beschikbare hoeveelheid Kokkels dat door visserij-inspanning in de Nederlandse Waddenzee is opgevist in de periode 1970-93. Berekend uit gegevens van Wadden Sea Assessment Group (1991) aangevuld met gegevens uit recente jaren (van Stralen, *schrif. med.*).

Onder invloed van de koude winters in de periode 1985-87 valt in het voorjaar van 1987 veel kokkelbroed, waarop in 1988 en 1989 wordt gevist (Dankers & de Vlas 1992). Door het uitblijven van goede broedval na 1988 ontstaat er echter in 1990 een tekort aan volwassen Kokkels in Nederlandse Waddenzee (zie o.a. van Stralen 1990).

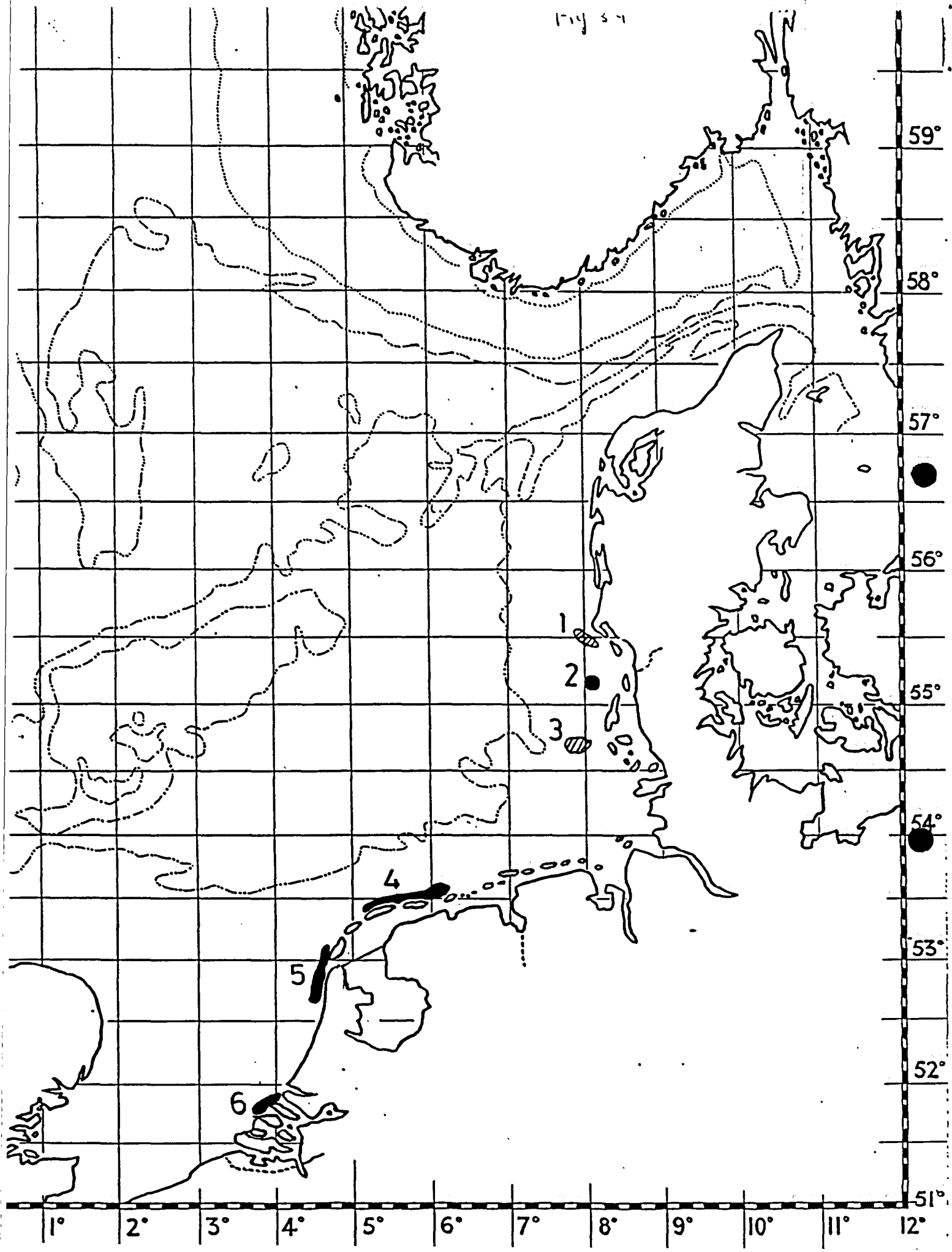


FIGURE 5.1

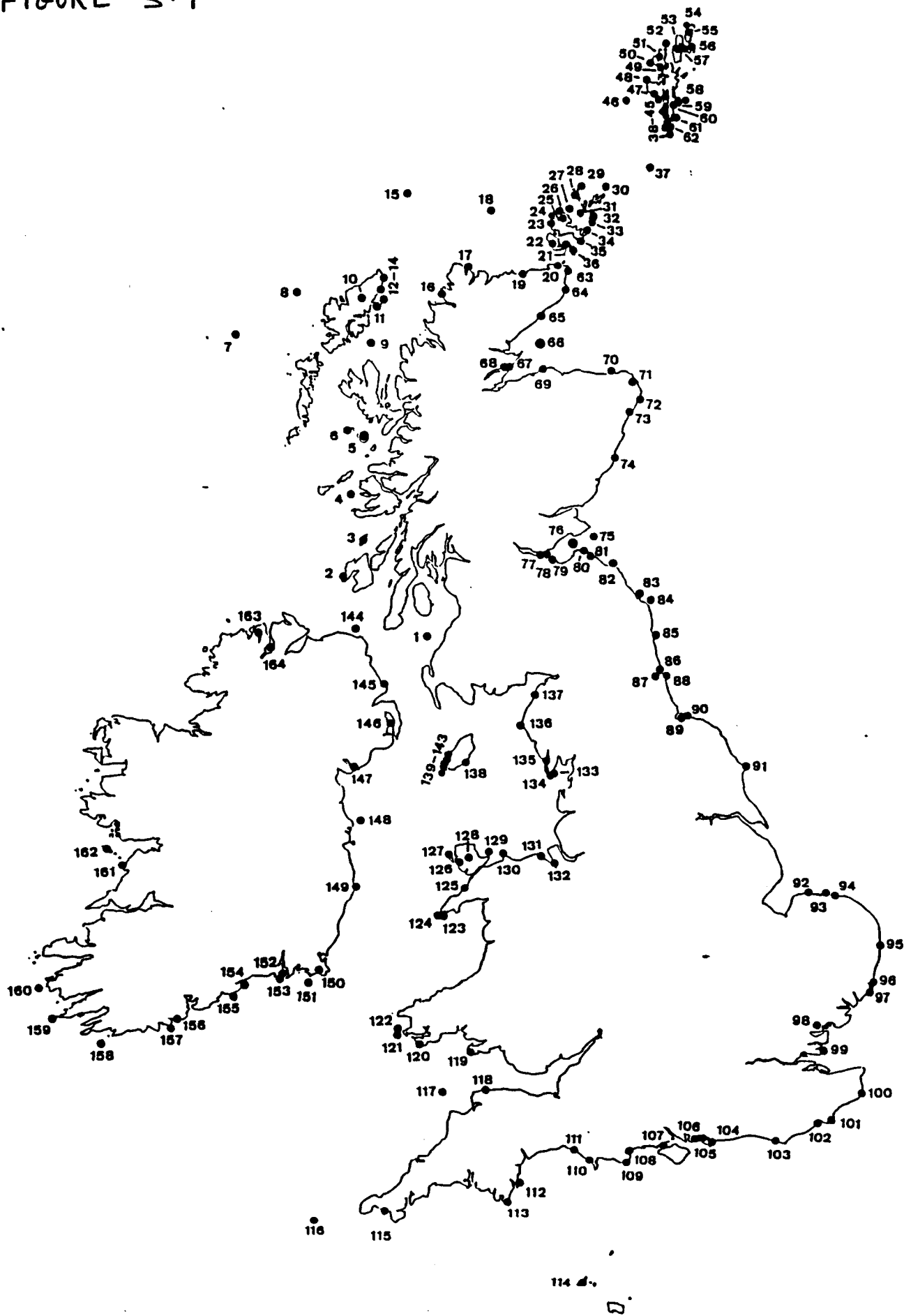


FIGURE 5-L.

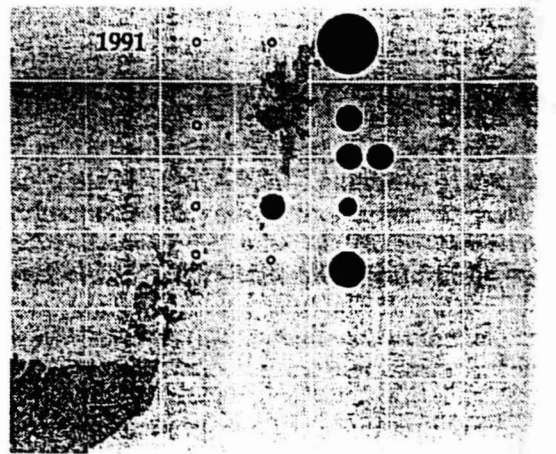
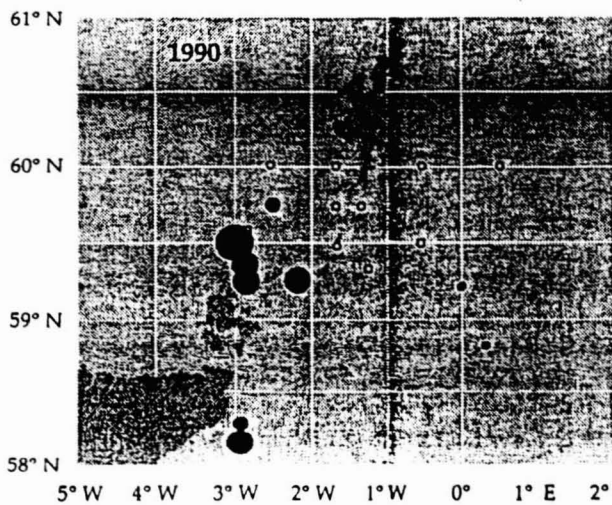
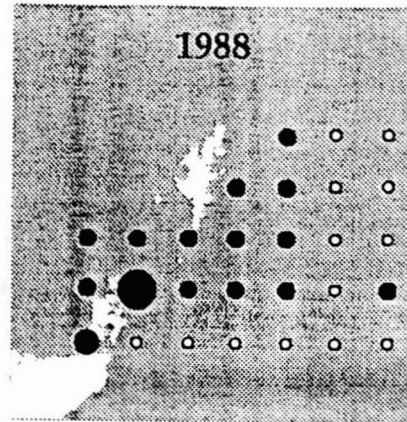
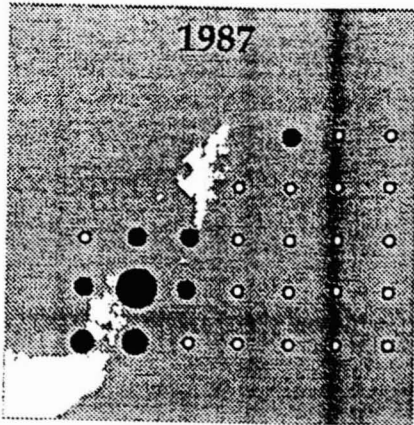
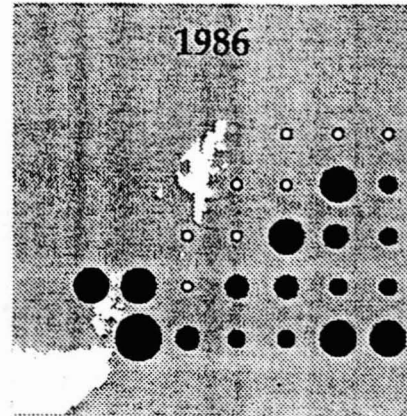
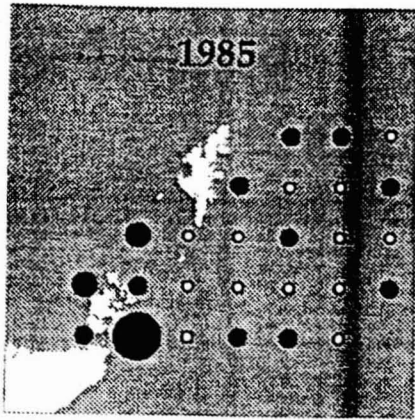


Figure 50b
Pelagic trawl data from June 1990 and 1991. Densities  >10 000,  1000-9999,  100-999,  10-99,  1-9.

FIGURE 5.3

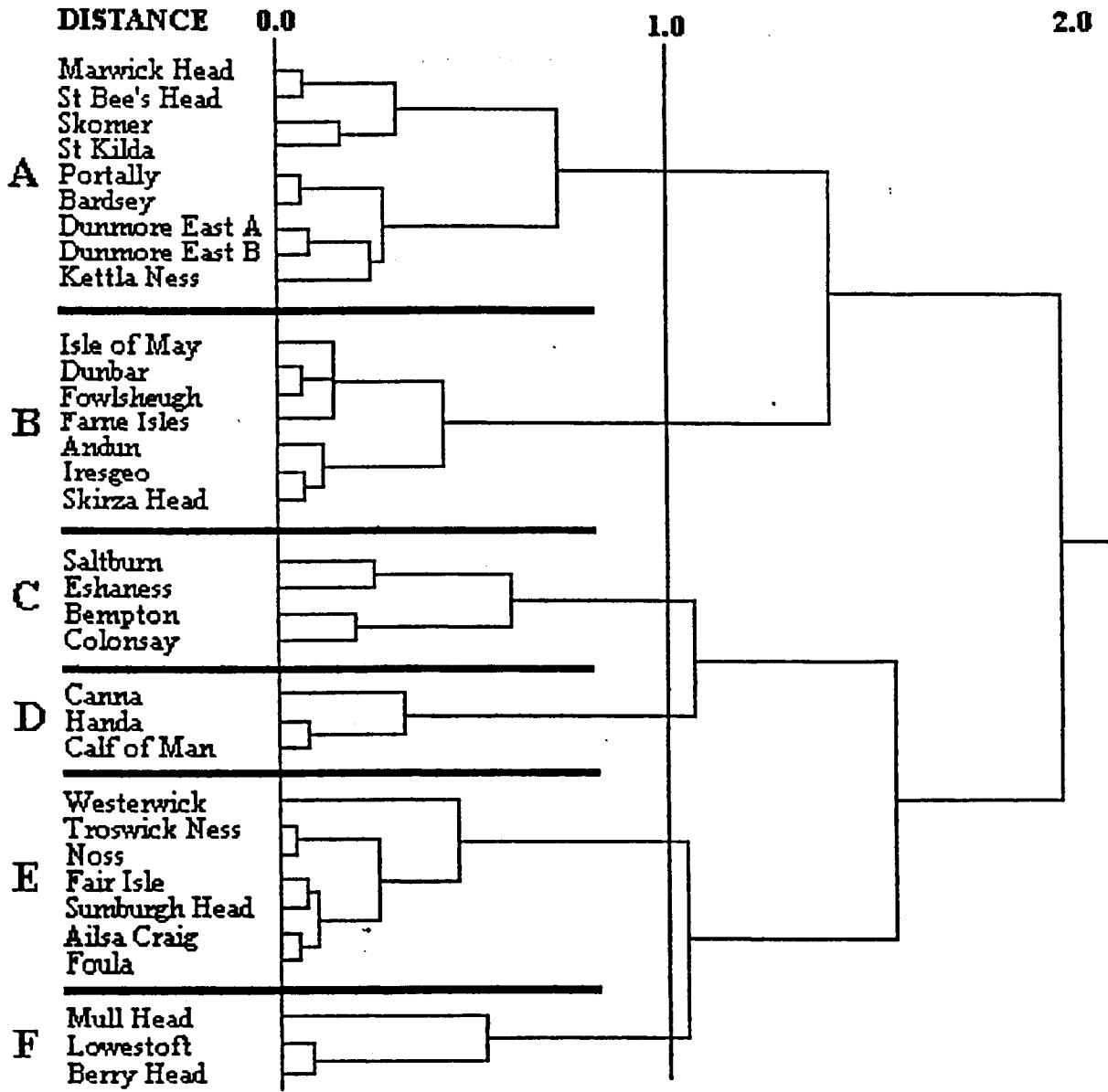
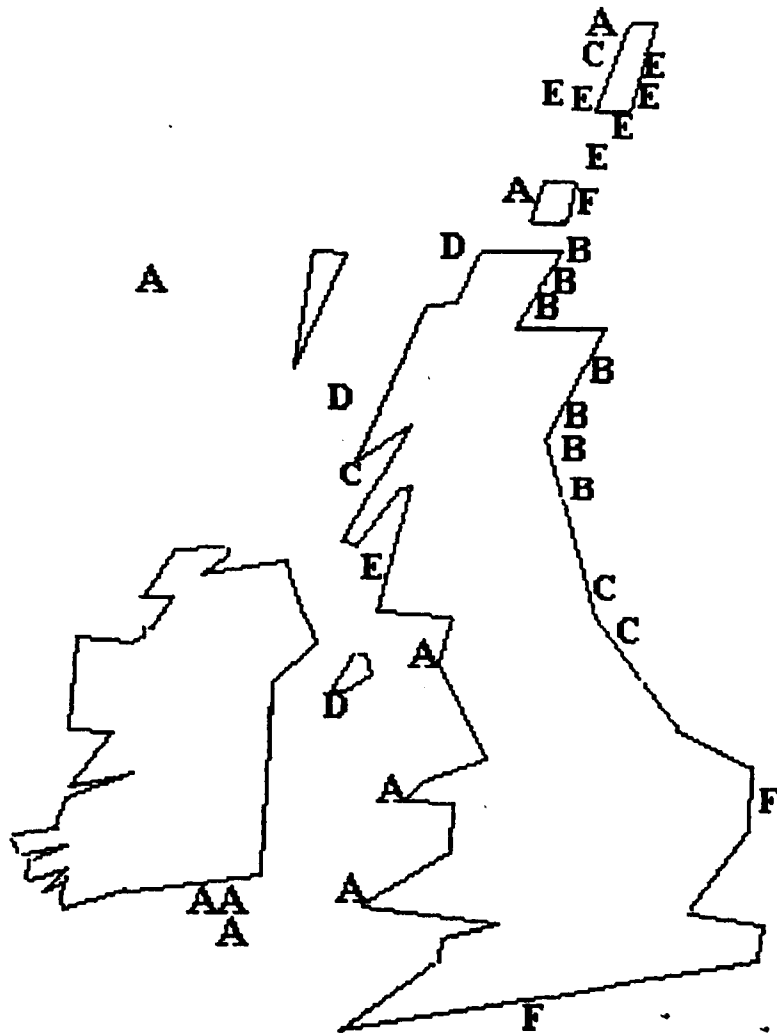


FIGURE 5.4



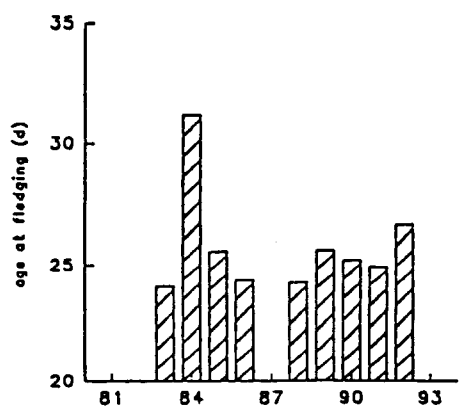
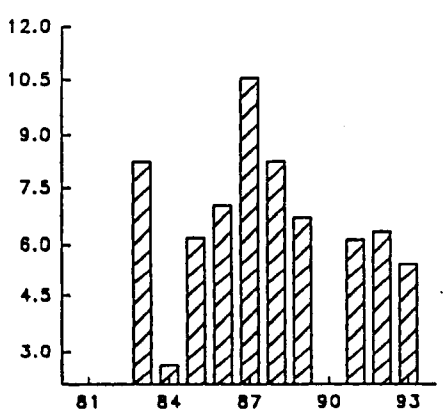
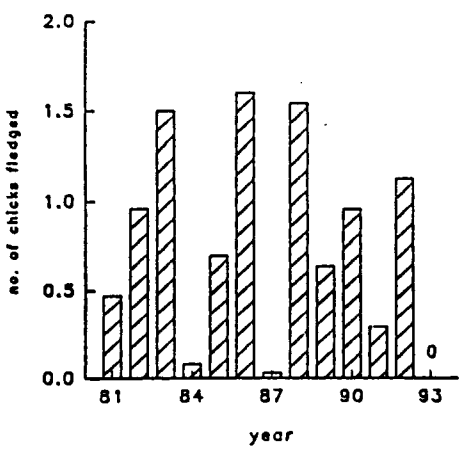
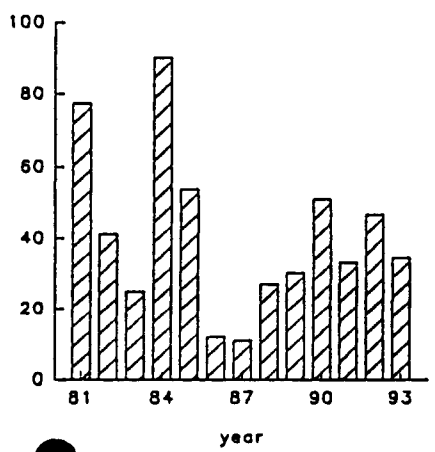
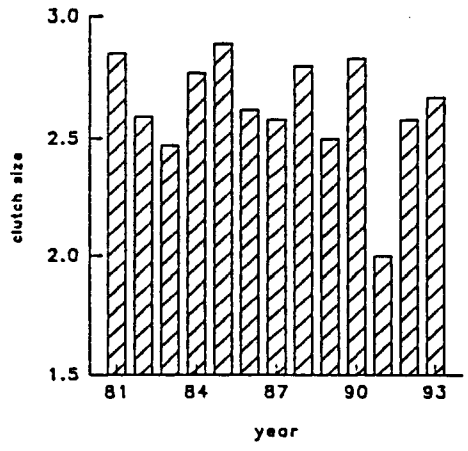
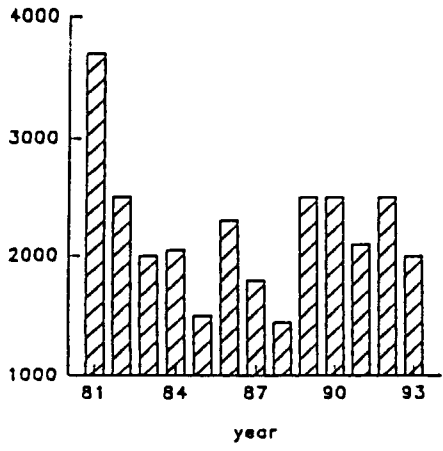


Fig 5.5

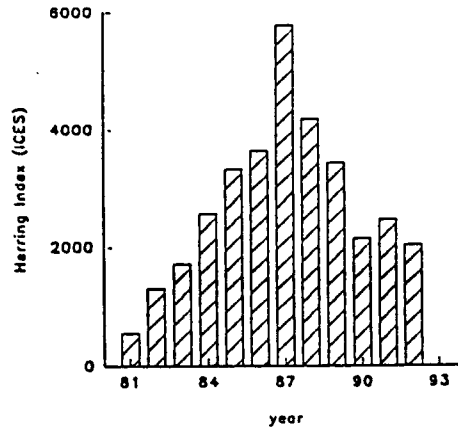
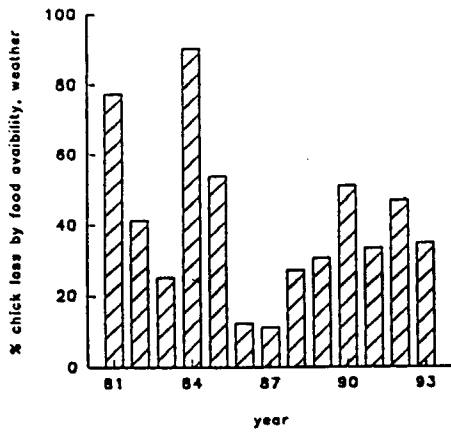
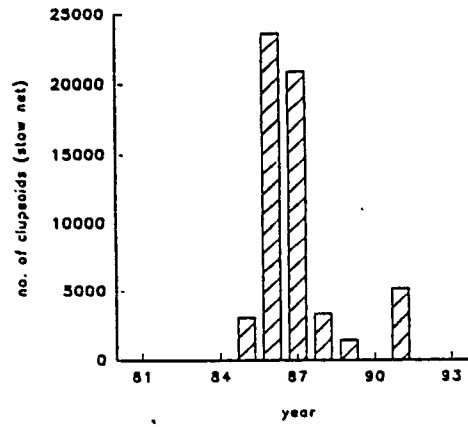
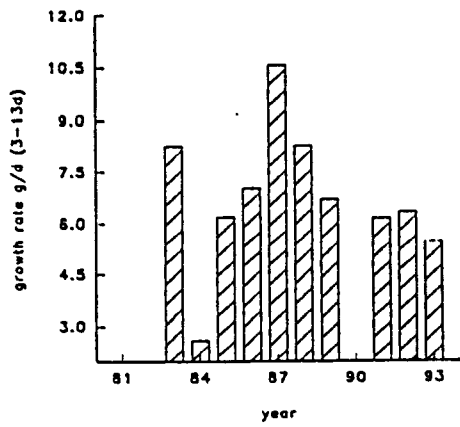


Fig. 5. ~~B~~

10 ANNEXES

10.1 Annex 1

Agenda

Monday, 5 September

- 0900 Meet in the Lecture Hall of the Marine Laboratory, Aberdeen
- 0915 Open Meeting
 - Introductions
 - Agree on Agenda
- 0930 Report on progress by leaders of working sub-groups
- 1200 Break for lunch
- 1300 Break up into sub-groups for Data Analysis and Writing
- 1800 Reconvene in plenary to assess progress
- 1900 Dinner

Tuesday, 6 September

- 0900 Meet in Lecture Hall for discussion of Fish Stocks and Hydrography
- 1100 Break to Subgroups
- 1730 Turn in Diskettes of Text and Tables for Collation of the Report
- 1800 Review draft copy of Report
 - Formulate Conclusions and Recommendations
 - Elect New Chair
- 1930 Break for Dinner

Wednesday, 7 September

- 0900 Meet in Lecture Hall to assess remaining tasks
- 0930 Break to Subgroups
- 1300 Meet in Lecture Hall to finalize report
- 2000 Adjourn

10.2 ANNEX II

ICES STUDY GROUP ON SEABIRD-FISH INTERACTIONS

5-7 September 1994, Aberdeen

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Table 4.1 Consumption by age-class of sandeels in IVa west

	First	Second	Third	Fourth
Fulmar	n/a	20% 0-group 80% 1-group	all 0-group	n/a
Shag	all 2-group	all 2-group	all 2-group	all 2-group
Kittiwake	n/a	20% 0-group 80% 1-group	all 0-group	n/a
Guillemot and Razorbill	75% 1-group, 25% 2-group	10% 0-group 40% 1-group 25% 2-group 25% 3-group	25% 0-group 25% 1-group 25% 2-group 25% 3-group	all 0-group
Puffin	all 1-group	20% 0-group 80% 1-group	all 0-group	all 0-group

Consumption of 0-group

	First	Second	Third	Fourth	Total
Fulmar	0	2345	4790	0	7135
Kittiwake	0	1052	3681	0	4733
Guillemot	0	3676	4090	1923	9689
Razorbill	0	301	769	511	1581
Puffin		814	2582	41	3437
Total	0	8188	1591	2475	2657
			2		5

Consumption of 1-group

	First	Second	Third	Fourth	Total
Fulmar	0	9378	0	0	9378
Kittiwake	0	4208	0	0	4208
Guillemot	745	14704	4089	0	1953
					8

Razorbill	646	1204	769	0	2619
Puffin	395	2605	0	0	3000
Total	178	32099	4858	0	3874
	6				3

Consumption of 2-group

	First	Second	Third	Fourth	Total
Shag	106	1447	1291	1086	4886
	2				
Guillemot	174	9189	4089	0	1502
	8				6
Razorbill	215	725	769	0	1709
Total	302	11361	5459	1086	2162
	5				1

Consumption of 3-group

	First	Second	Third	Fourth	Total
Guillemot	0	9189	4089	0	1327
					8
Razorbill	0	725	769	0	1494
Total	0	9914	4858	0	1477
					2

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PRELIMINARY DRAFT