ERRATA SHEET

to

ICES COOPERATIVE RESEARCH REPORT NO. 203

Joint Report of the ICES Advisory Committee on Fishery Management
and the Advisory Committee on the Marine Environment, 1994

Page 2 (List of Participants) should be replaced by
the corrected table on the reverse side of this sheet

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ICES COOPERATIVE RESEARCH REPORT

RAPPORT DES RECHERCHES COLLECTIVES

No. 203

JOINT REPORT OF THE ICES ADVISORY COMMITTEE ON FISHERY MANAGEMENT AND THE ADVISORY COMMITTEE ON THE MARINE ENVIRONMENT, 1994

International Council for the Exploration of the Sea
Palægade 2-4, DK-1261 Copenhagen K
DENMARK

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FOREWORD

This report represents the first ICES advice issued jointly by the Advisory Committee on Fisheries Management (ACFM) and the Advisory Committee on the Marine Environment (ACME). The advice was generated mainly at a joint meeting of the ACFM and ACME and is based on the work of the Working Group on Ecosystem Effects of Fishing Activities (WGECO) which is a working group answering to both of the Advisory Committees. This joint meeting represents a milestone in that these two Committees have not previously met together. It is, however, anticipated that increasing concern over ensuring ecologically sound practices in the management of living resources in the sea will generate requests for ICES advice in the future which will require input from both of the Advisory Committees. Such advice will be presented in joint reports from the ACFM and ACME.

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Chairman ACFM

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SCIENTIFIC CRITERIA FOR THE ESTABLISHMENT OF UNDISTURBED AREAS IN THE NORTH SEA FOR SCIENTIFIC PURPOSES

1 BACKGROUND

At the Intermediate Ministerial Meeting held in Copenhagen on 7 - 8 December 1993 within the framework of the International Conferences on the Protection of the North Sea, it was agreed, *inter alia*,

> *"to invite the CEC through the services of ICES to investigate the scientific criteria for the establishment, on an experimental basis, of undisturbed areas in the North Sea for scientific purposes, in order to assess the recovery and redevelopment of the marine ecosystem . . . ."*

In this context, the European Commission asked ICES to respond to the requests indicated below, at least on a preliminary basis:

1) Review existing fishery and other economic activities in the North Sea on a geographical scale as detailed as possible.

2) Define the criteria to be considered in the context of whether or not an area might be closed, including ecological considerations and consequences for fisheries and other economic activities.

3) Review available information which would make it possible to define the consequences of establishing closed areas.

4) Define the investigations required to obtain currently missing information.

5) Define, if possible, areas in the North Sea which might be closed, in the light of items (1) - (4) above.

Based on this request, the ICES Working Group on Ecosystem Effects of Fishing Activities (WGECO) considered the scientific criteria for the establishment of undisturbed areas for scientific purposes at their meeting on 20 - 27 April 1994. The following is a summary of relevant sections of their report, as amended and accepted by the Advisory Committee on Fishery Management (ACFM) and the Advisory Committee on the Marine Environment (ACME), and should be considered a preliminary answer to the question of the experimental use of closed areas for scientific research.

2 INTRODUCTION

There is a growing perception among scientists and the general public that human use of the marine environment may have led to marked and widespread changes in the North Sea ecosystem. Of these activities, fishing has received considerable attention as an agent for change. In recent years an increasing amount of information has been collected, indicating that some fisheries are likely to impose a considerable mortality on a variety of non-target species, including fish, benthos and marine mammals. It is thus probable that fishing has led to the local extinction of individual species, to habitat alteration, and to some changes in the structure and functioning of the ecosystem.

In the context of scientific investigations, it is a problem that no reference is available for most species and communities. Without altering the levels of fishing, it can therefore be difficult to obtain a reliable picture of the true impact of fisheries. Options for experimental reductions in fisheries impacts include general effort reductions, area closures or gear restrictions and/or modifications. The present discussion is limited to considerations pertaining to the use of area closures for scientific purposes.

In addition to the use of closed areas for scientific purposes, the ACFM/ACME recognized that closed areas of appropriate size in the future may present an important measure aimed at mitigating effects caused by the pressure of human activities. Although the utility of such an approach has yet to be evaluated, the results of an experimental closure for scientific purposes may ultimately be used for setting future integrated management goals, based on sustainable use of the marine ecosystem. However, it is necessary to stress that the criteria to be set for closed areas for improved management of the marine environment will be quite different from the criteria discussed here, which apply specifically to areas closed to fisheries to enable the conduct of scientific research in order to assess the impact of fisheries. In particular, the criteria for establishing areas for management purposes are likely to include considerations of nature conservation, which fall outside the scientific domain.

3 AVAILABLE INFORMATION ON THE CONSEQUENCES OF AREA CLOSURES

Roberts and Polunin (1991) and Dugan and Davis (1993) reviewed the literature on areas closed to fishing in coastal marine zones (reefs, kelp forest). They concluded that the efficacy of these refugia in fisheries management is virtually untested. The few studies available indicate an increase in abundance and increases in size and age of target species in these areas. There is scarce evidence that refugia replenish target species outside the area. On the community level there is some evidence that species richness is higher in marine reserves compared to the areas outside.

Studies of the effects of closed areas for trawl fisheries are scarce. The studies available at the WGECO meeting concerned closed areas in the Northwest Atlantic, the Bering Sea, and the North Sea. In Canadian waters there are currently at least two area closures implemented for fisheries management and research purposes. None of these closures are directed at the study of ecosystem responses to a cessation of trawling. One was put in place to address specific management problems or perceived problems in the fisheries, while the other was established in order to accommodate a research programme on the impacts of otter trawling. Although there exist a number of closed areas in the northeastern Atlantic region, including the North Sea (Anon., 1993a), only the plaice box is discussed here. The other boxes are, for instance, directed at protecting spawning populations of herring or protecting juvenile fish, but the effect of none of these has been properly evaluated.

1) Western and Emerald Banks haddock nursery area closure. This closure, directed at improving haddock recruitment on these banks on the Scotian Shelf (off Nova Scotia), has been in place since 1987. It excludes all mobile groundfishing gear from an area of approximately 4400 nm^2. Since 1993, all fixed gear have also been excluded. Scallop dredging is still permitted. There have been some indications of improved recruitment to haddock stocks in the area of the closure. There have been no studies to evaluate changes in the benthos or the ecosystem.

2) Grand Banks of Newfoundland trawling impact study area closure. This closure, directed at the protection of an area set aside for trawling impact studies, has been in place since 1992. It excludes all mobile fishing gear from an area of approximately 100 nm^2. Over the past two years there has been a major benthos sampling programme in the area. As yet there are no results which might indicate possible effects, since the closure has been established so recently. The subsequently introduced moratorium on fishing for all demersal fish stocks on the Grand Banks effectively precludes any comparison of changes in this area with the surrounding area.

3) Eastern Bering Sea: pot sanctuary. Until 1980 a pot sanctuary was closed to trawling to protect red king crab from by-catch losses (Armstrong *et al.*, 1993). Relaxation of the restrictions in 1981 led to an escalation of by-catches and to an emergency closure of a smaller pot sanctuary in 1987. The effectiveness of the by-catch refuge was studied, but no significant change in abundance of the target species in the four years after closure could be observed.

4) North Sea plaice box. In the coastal zone of the southeastern North Sea, an area of about 1000 nm^2 has been closed to trawling in the second and third quarters of the year since 1989. Prior to establishing this box, the expected effects on flatfish exploitation were estimated (Anon., 1987; Rijnsdorp and van Beek, 1991). The objective was to improve the exploitation of flatfish (mainly plaice) by protecting juveniles. Fishing effort of heavy beam trawlers and other trawlers was banned from the box. For socio-economic reasons an exemption was made for trawlers <300 hp (221 Kw), which were allowed to continue their fishing operations within the box. Since 1994 the plaice box regulation has been extended to the fourth quarter of the year. The effectiveness of the box has been evaluated (Anon., 1994). Research vessel surveys showed that catch rates of plaice increased in the box after its implementation. This was particularly pronounced for the marketable-sized fish. Of necessity, fishing effort was absorbed by the surrounding areas after the box was implemented. Recordings of the spatial distribution of the beam trawl effort of large vessels showed that during the time when the box was closed, the large beam trawlers were mainly concentrated along the borders, suggesting that catch rates were particularly high in this area. Log book information showed that, as soon as the box was opened in the fourth quarter, the beam trawl fleet moved in, in response to the increased abundance of fish within the box. Fishing effort of the exemption fleets has increased since 1989, partly due to new investments, reducing the expected effects of the box.

   Potential effects on other fish species have not yet been analysed. The effects on the benthic community are expected to be limited because beam trawling is still allowed in the area: by all vessels during the first and fourth quarters (since 1994 only during the first quarter) and by the smaller beam trawlers (<300 hp) throughout the year.

The above review shows that available studies of closed areas have mainly focused on effects on target species and have not addressed the more general ecosystem

effects. The results indicate though that target species show a positive response to the relaxation of fishing by an increase in abundance and an increase in mean size and age. No information is yet available on the effects of the exclusion of bottom trawling on the benthic community, but the Canadian study on the Grand Banks may provide information in the near future.

4 RATIONALE AND OBJECTIVES OF AREA CLOSURES FOR SCIENTIFIC PURPOSES

The basis for establishing closed areas for scientific purposes can be framed in terms of the following broad hypothesis:

Current fishing activity has led to reversible changes in biota, and the establishment of areas closed to fisheries will lead to directional changes in the biomass, species and size composition of the benthic and demersal fish communities as a consequence of (1) the reduction in mortality caused by fishing, (2) changes in settlement patterns, and (3) behavioural responses of species to decreased disturbance.

There are a number of distinct fisheries in the North Sea which will affect the system in different ways. Because the fleets employing different gear types are not homogeneously distributed over the area, considerations of scale (e.g., size of closed area, duration of the study) suggest that area closures are likely to be effective for examining only a sub-set of the effects imposed by all fisheries. Because of the inherent limitations, experimental closures should be restricted to the study of those environments that can be expected to react most clearly. In this respect, the most obvious candidate for study is the effect of bottom trawling on benthic and demersal fish communities.

The above broad hypothesis leads to the following main objective:

> To investigate whether the closure of an area to fisheries has measurable effects on marine habitats and benthic communities.

Based on this main objective, the following sub-objectives can be identified:

a) To describe how the benthic communities and fish fauna assemblages develop within an area closed to fisheries in comparison to the development outside that area;

b) To study the processes taking place in the communities in order to explain the observed changes;

c) To investigate whether the establishment of an area closed to fisheries leads to changes which radiate into the surrounding areas.

In order to make full scientific use of any experimental closure, a detailed set of testable hypotheses should be framed from the outset. Although the details will depend on the ultimate choice of areas closed for fishing, it is important to define the types of testable hypotheses that might be addressed. The following hypotheses were identified concerning the changes which can be expected to occur in areas where fisheries are excluded:

1) Due to the reduction in the level of fishing-associated mortality, increases in population densities will occur for:

   a) Shallow burrowing and epibenthic species (e.g., *Modiolus modiolus*, Bryozoa, sea pens, anemones);

   b) Longer-lived benthic species (e.g., *Arctica islandica*); and

   c) Demersal fish.

   In the short term, species with high reproductive rates will show the greatest increases in densities, while deeper burrowing species (e.g., *Callianassa* spp., *Upogebia* spp.) and those that have been shown to be less susceptible to mechanical damage by the passage of a trawl will show less marked changes than the species in (a) and (b) above.

2) Decreases in population densities will occur for:

   a) Demersal scavenger species which exploit discarded material and/or individuals that are left damaged in the path of the trawl, owing to a reduction in food availability. This effect may either result from a true population decline or from the emigration of individuals from the closed area;

   b) Scavenging sea birds, because the closed area will provide less food;

   c) Breeding success (measured as number of chicks/nest) will decrease for scavenging sea birds nesting at colonies which previously exploited discards in the closed area.

3) The mean age and size in the populations of long-lived species will show a general increase.

4) The ratio of polychaetes to molluscs will decrease owing to the differential effect of trawling on the mortality rates of these two phyla and differences in their reproductive strategies.

5) The overall Production:Biomass ratio for the community will decrease owing to a shift in size structure towards larger individuals.

6) The physical complexity of the closed area will increase owing to increases in populations of reef-building species such as *Sabellaria*.

7) The stomach contents of species which feed on the benthic community will change in comparison with species which feed outside the closed area.

8) There will be differences in dispersal rates of fish tagged within and outside closed areas due to differences in disturbance.

5 CRITERIA FOR THE SELECTION OF CLOSED AREAS

5.1 Location

Fishing impact

In order to study the effect of fishing, an area must be selected which at present is heavily exploited by bottom trawl fisheries, because only then can a maximum response of the benthic communities to the cessation of fishing be expected. In selecting potential locations for a closed area, possible confounding factors must be taken into account. Thus, areas should be avoided where the expected background level of natural disturbances of the seabed due to tidal currents and storm surges are large. These effects are directly related to water depth, and shallow areas are therefore less suitable. Another important confounding factor would be if during a closure the benthic community were affected by oxygen deficiencies, because the direct and indirect effects of such events are undoubtedly larger than those caused by fisheries. Therefore, areas should be avoided in which mass mortalities caused by lack of dissolved oxygen in bottom waters have been reported.

Representativeness

Areas to be selected for experimental closure should be representative of larger marine areas in terms of habitat types, the fauna they support, and the fishing activity they experience. The habitat type and the benthic communities are mainly determined by the sediment type and the water depth and, therefore, such factors must be taken into account.

Homogeneity

Uniformity of sediments and communities within the closed area is an important criterion in order to minimize sampling variance. This is particularly important, because it is likely that any differences in sediment types and associated communities will also be reflected in the micro-distribution of fishing effort before the area was closed. Therefore, coastal areas showing marked depth gradients are in general less suitable, but also deeper areas with marked variations in depth or substrate should be avoided.

The development of the communities within closed areas must be evaluated against the development in the surrounding areas which will continue to be fished. Therefore, the homogeneity of a larger region, in which the closed area is chosen, is an important criterion.

Sensitivity of the communities

As a general rule, benthic communities in rocky areas or in areas with gravel and stones are characterized by higher biomasses of epifauna, whereas in the more silty areas the infauna is better developed. All trawl fisheries can be expected to have an impact on the epifauna, but beam trawls and dredges also disturb the surface layers of the sediment and therefore impact the infauna to a varying degree, depending on sediment type and the preferred depth of the organisms. Because sedentary organisms are probably more sensitive to gear scraping over the bottom than many free-moving animals, gravel and rocky areas are probably more sensitive to bottom trawling in general, whereas silty areas will be particularly affected by beam trawls. The sensitivity of the bottom fauna to trawling gear obviously varies and effects of trawl fisheries can therefore be expected to be very different in different regions. Extrapolation of the results from one habitat type to another will be problematic if not impossible.

Biodiversity

Although biodiversity would clearly be a criterion for protecting marine habitats, this does not apply to experimental closures, because in this case the primary interest would be to investigate whether the number of species would increase in an area after it has been heavily impacted relative to reference areas.

Historic data

If possible, the areas to be closed should include sites which have been the subject of intensive study of the benthic communities in the past, so that historic trends in various parameters can be used in order to evaluate future developments.

5.2 Size and Shape

There is no general *a priori* criterion for defining the size and shape of a closed area for investigating the impact of trawl fisheries and they will largely be determined by the type of hypotheses that one might wish to include in the research programme. However, an important consideration is the grid system on which data have been collected in the past. For instance, in the ICES area, an extensive database has been built up regarding the distribution of fishing effort, commercial catches and survey abundance based on the approximately 30 nm by 30 nm grid system, as defined by ICES statistical rectangles. Therefore, scientific evaluation of the effects of experimental closures would be greatly facilitated if the boundaries of a closed area corresponded to one or a multiple of ICES rectangles. Other considerations that might be taken into account are existing regulations with respect to fisheries management in order to facilitate legal enforcement.

Important means of monitoring the development of benthic communities and fish assemblages include the use of grab sampling and bottom trawling gear by research vessels. Because the latter in particular should not interfere with the undisturbed development of biota, the areas chosen must be large enough to reduce the amount affected by sampling to a negligible fraction. Trawl hauls typically sweep an area of approximately 30 m by 1.5 nm and some ten repetitive hauls might have to be made during any one survey. This suggests that a closed area should cover an area of at least 30 nm x 30 nm. For the less mobile benthic species, such a size would make it possible to identify border effects of the closure and/or the development of possible gradients within the area. Larger areas undoubtedly offer greater protection to more mobile animals such as fish, and possible radiating effects on the surrounding areas would undoubtedly also be more pronounced.

5.3 Duration

Marine biota at temperate latitudes typically reproduce on an annual cycle, which means that there is only one period of settlement or arrival of young organisms each year. Given the marked interannual variation in recruitment and the longevity of many of the organisms belonging to the benthic fauna and the demersal fish assemblages, it cannot be expected that the community response in an undisturbed area will be very rapid. It would probably take at least five years before statistically significant trends might be observed. The ultimate goal of closing an area for scientific purposes is to give advice on the consequences of closed areas in the marine environment compared with other possible management measures. There is no basis for predicting how many years a box must be closed before the scientific evidence is available to give advice on the utility of the concept of closed areas in general. Still, it would seem appropriate to evaluate the results after a period of five years. If at that stage either no response or a significant response is detected, then a continuation of expensive research may not be the logical road to follow. If there are still scientific uncertainties as to the effects, then a prolongation by another five years may be required. However, if scientific research into the development of benthic communities in the absence of fishing were accepted as a goal in itself, then the area should be closed indefinitely.

5.4 Consequences for Fisheries

Closing an area to all fishing will undoubtedly be perceived as causing an economic loss and, therefore, the fishing industry might strongly argue for selecting an area where fishing is not very intensive. However, as stated under the scientific considerations, the basic idea of setting closed areas is to study the development in regions which have been subjected to heavy fishing pressure after this impact is removed. If information is available on the relative amount of fishing in the area selected for closure or, even better, if the value of the fishery in the area is known, this is useful in obtaining a first estimate of the extent to which the industry will be affected. However, such data cannot be used to estimate the true losses. Because the closure of an area may merely result in a shift of fishing effort to other areas, the losses will partly be compensated, particularly because many commercially important fish species perform considerable annual migrations and dispersal is generally high. The partial protection of these species in the closed area is therefore expected to be small, because the fish will be caught sooner or later when they move out of the box. If a loss in overall yield were to be observed, this might be interpreted as a significant result, because it would imply that a closed area contributes to the protection of the species in question. The same argument does not apply to, e.g., *Nephrops* and shrimp fisheries, because of the sedentary habits of these species. There is no virtue in investigating the relevance of closed areas for protecting such species, because that is self-evident. If coastal areas are closed, this may also impact the artisanal fishermen relative to commercial fleets, because the former may have no choice to fish elsewhere.

5.5 Consequences for Other Uses of the Sea

Apart from fisheries, there are several other uses of the sea that need to be taken into account when closed areas are considered. The major ones are sand and gravel extraction, the offshore industry, cable laying, shipping, military activities, and dumping. Due to the scale of these activities, the effects on the benthic systems are thought to be less than those of fisheries. However, when selecting the location of areas closed to fishing on the criteria set out above, it is likely that a number of

alternative sites may be possible. Since pollution and contamination may have an additional impact on benthic communities, it would seem wise to choose an area for study as far away as possible from point sources of discharges and major sources of contaminants, such as estuaries of rivers draining highly industrialized catchment areas.

Sand extraction and maintenance dredging

Sand extraction, especially with standard dredging techniques using outwash to remove the very fine sand particles, creates so-called 'dredge plumes' of fine material. These plumes may spread over large distances (up to 10 – 20 km) before the material is completely dispersed and resettled on the bottom. The same is true when shipping channels are deepened using maintenance dredging. Hence, closed areas should not be situated near shipping routes which are regularly dredged.

Licences for sand extraction should not be given for sites close to closed areas where there is a realistic risk that fine material from the outwash will resettle within the closed area. Thus, a closed area and reference sites should have an additional buffer zone where no sand extraction is allowed. The width of such a zone should be determined by the hydrological and sedimentological characteristics of the area involved. In consequence, the buffer zone may be wider on some sides of the closed area than on others.

Gravel extraction

Deposits with an adequate concentration of gravel to support exploitation are relatively rare and are mainly found off England, in areas such as on the Channel coast and the Norfolk coast, and on the French Channel coast, e.g., in the Dieppe area. Smaller gravel areas are found in the central North Sea, e.g., the Silver Pit area and on the Cleaver Bank. It is now becoming a more common practice to mine gravel resources rather than simply to dredge them. The difference is that, when mined, a sand and gravel mix is dredged in an area with a high gravel content and it is brought in total to the port of delivery. When gravel is dredged the former way, the sand is washed out at the hold via an overflow (outwash).

Gravel deposits are leased by governments for a number of years with a limit on the amount allowed to be taken. Black boxes and various control systems ensure that only the leased area is affected. Gravel extraction will only take place in areas with a high gravel content. The more favourable economics of gravel extraction should make it possible to carry out such extraction in areas well removed from closed areas. Gravel, commanding a much higher price than sand, can be economically transported over much greater distances. Hence, it should be possible to avoid conflicts between industry requirements and closed areas.

Offshore oil and gas industry

Governments control the exploitation of offshore oil and gas reserves by a system of concessions. Initial reconnaissance licences are given for exploratory seismic surveys. However, once an area has been investigated with 3D seismic (in a few cases, with 2D seismic) surveys, further surveys are generally not required. Seismic surveys cause limited damage from the arrays (up to six meters) for most species. However, fish with swim bladders that are swimming above hard bottoms or in enclosed areas (fjords) may be affected over greater distances (several kilometres). Seismic surveys are carried out within restricted time frames after which exploration licences may be issued and exploratory drilling takes place. When apparent reserves warrant exploitation, platforms of a different nature are installed for longer periods (10 – 20 years). Closed areas should not be established near new oil or gas fields. Near established fields it should be recognized that occasionally additional wells may be drilled. Also, there will be a daily stream of traffic to and from the working and manned platforms, and production water will be discharged. At an early date administrators dealing with the licensing of oil and gas exploration activities should be counselled concerning whether the establishment of a closed area is in conflict and/or whether measures can be taken to avoid conflicts. When determining the location of closed areas, all information on concessions granted should be available before a final decision is made.

Marine pipelines are the safest method of transporting gas and oil over long distances. The life span of a pipeline is about 30 – 50 years depending on the diameter. Small-diameter pipelines have a shorter life span than larger ones. In very few cases are pipelines taken up and re-used after a field becomes exhausted. The effects of burying pipelines (trenching) are of short duration. In some areas of the North Sea, pipelines sand themselves in via a process of self-burial. Even if a pipeline has to cross a closed area, the disturbing effects will be local and of short duration: one-half to two years, depending on the method of laying.

Telephone cables and power cables

Old wire telephone cables are being phased out and are often recovered. The new glass fibre cables are very easily damaged. They are therefore ploughed directly into the seabed. Power cables, due to their weight, usually sand themselves in. However, in areas with a high risk of damage they are directly buried. International laws regulate the laying of cables. Governments have no right to interfere with cables connecting other

countries, even if these cables run over their continental shelves. For a closed area, cables offer no serious hindrance.

Shipping

Large areas in the southern North Sea are designated as shipping routes. Except when disasters occur, shipping causes no great impact on the organisms on the sea bottom. Fishing vessels and research vessels operating in shipping routes may cause a danger. Notwithstanding recommended shipping routes based on sound safety regulations, vessels at present cannot be forced to follow the routes. Areas with heavy shipping traffic should be avoided when establishing closed areas. In relatively shallow water, large draught ships may disturb the bottom with their pressure waves and propeller wash.

Military exercise areas

All military exercise areas are well indicated on charts. It is known that fish with swim bladders may be affected, and that sea urchins crawl out of the sediment when exposed to pressure waves from large explosions. Therefore, areas where these type of activities take place should be avoided.

Dumping areas of dredged material

It is common practice to dump clean or lightly contaminated harbour dredgings into the sea. Also, when maintenance dredging is carried out in seaways, the material is dumped in the vicinity. Closed areas should be chosen far away from dumping sites and regularly dredged shipping lanes.

5.6 Other Considerations

There are a number of other issues directly related to the establishment of closed areas for scientific purposes which should be carefully considered before actually embarking on their establishment. Probably the most important issue is the funding of the appropriate research programmes, both in the closed area and in the reference areas. This also requires the continued commitment of research institutes over the duration of the closure. A second important issue is the adequacy of the legal instruments to enforce the restrictions imposed on fisheries, because only when enforcement can be guaranteed can significant scientific results be anticipated. Lastly, the ultimate application of closed areas lies within the management of the marine environment, with emphasis on habitat protection and nature conservation. Therefore, all other things being equal, wildlife protection criteria could form the basis for the selection of the area.

6 AREAS IN THE NORTH SEA WHICH MIGHT BE CLOSED

It was not possible to investigate fully the most appropriate areas to be selected for area closures, because there is a wide scope of different perspectives from which proposals could be made. However, as a first step it did seem appropriate to approach the problem from the negative side and indicate which areas would not be suitable on the basis of the considerations and criteria outlined above.

The major sediment types in the North Sea include sand, silt, and gravel (Figure 1). The hydrography of the North Sea is characterized by a well-mixed zone in the southern North Sea, a large area with summer stratification in the central and northern parts, and a transition zone with frontal systems between these regions (Figure 2). These features have led to the development of different benthic communities (Figure 3) and fish assemblages (Figure 4). In the coastal zone, many organisms are distributed along depth gradients.

Given the complex depth structure, the strong tidal regime, and the substrate of moving sand dunes, which are heavily affected by storm surges, the area south of 53°N does not seem to provide appropriate sites for closed area studies. Similarly, the coastal zones can be excluded because of inhomogeneous conditions. This also applies to specific areas around the Dogger Bank, and along the Norwegian Deep and the shelf edge.

In recent years, a large area in the German Bight and along the continental coast to the east and north has been reported to be affected by events of oxygen deficiency in bottom waters (Figure 5), which in some cases have led to complete extinction of the local benthic communities. This area is therefore not suitable.

The distribution of the various demersal trawl fisheries by ICES statistical rectangle, based on the Scientific and Technical Committee for Fisheries (STCF) database, is shown in Figure 6. Among these, the beam trawl fleet is estimated to have the largest impact (Anon., 1992). Figure 6A shows a large concentration of beam trawl effort in the southern and southeastern North Sea. A study of the effect of beam trawling is a prime candidate for a closed area investigation and effort is largely concentrated south of 55°N. The industrial trawl effort (Figure 6B) is more widely distributed over the central and eastern North Sea, whereas the otter trawl effort (Figure 6C) is particularly concentrated off the northwestern edge of the North Sea. Minor concentrations occur along the east coasts of England and Scotland. According to these data, there is relatively little effort in a central band running from the Dogger Bank area up to the northern North Sea.

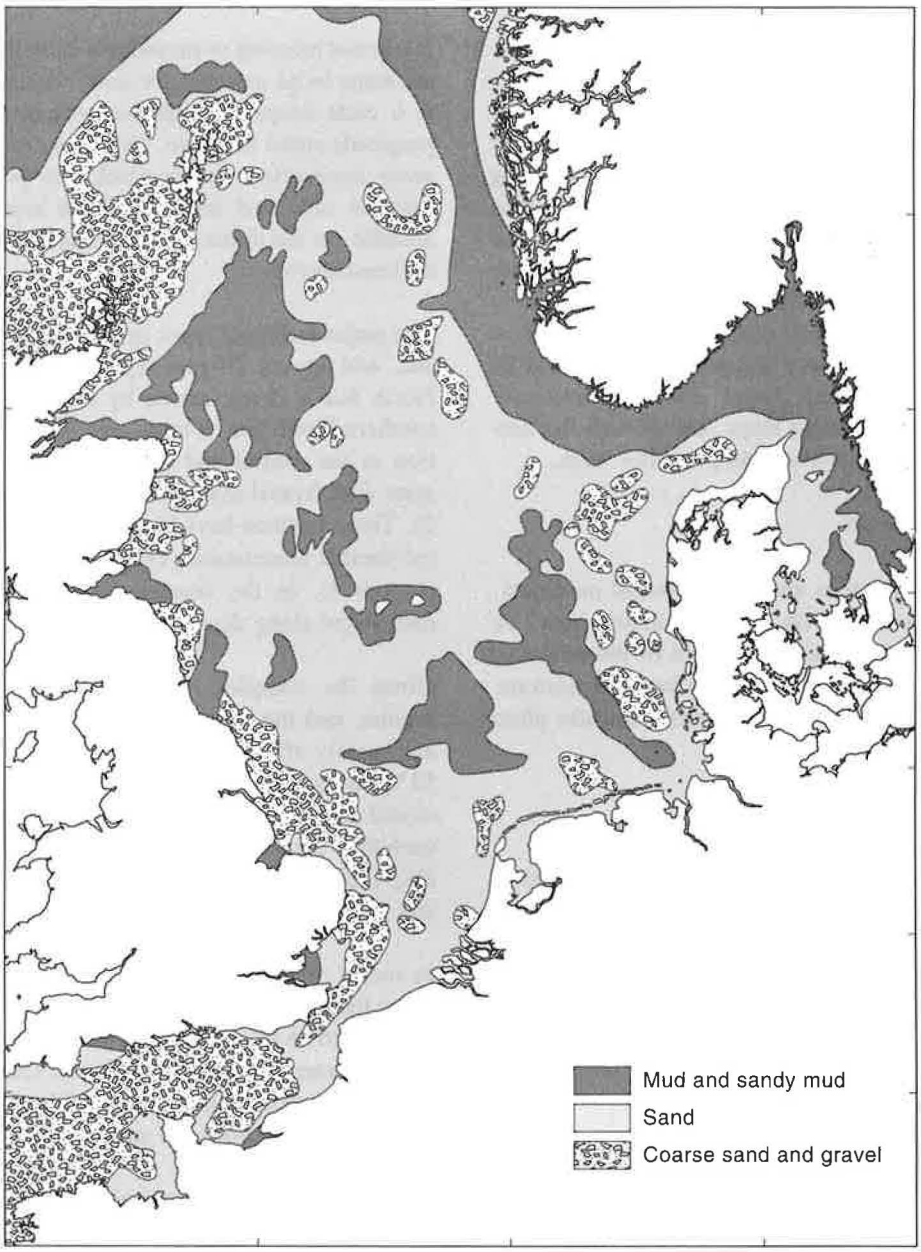


Figure 1. North Sea sediment types (after Eisma, 1981).

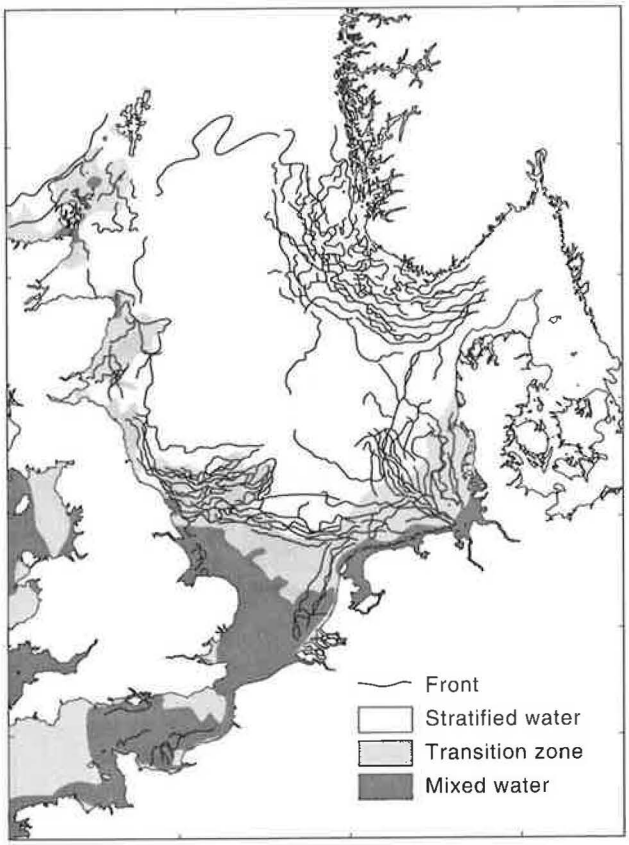


Figure 2. Transition zones between mixed and stratified water in the North Sea. Thermal fronts are deduced from satellite (IR) images; transition zones are calculated from the stratification parameter. Source: Becker (1990).

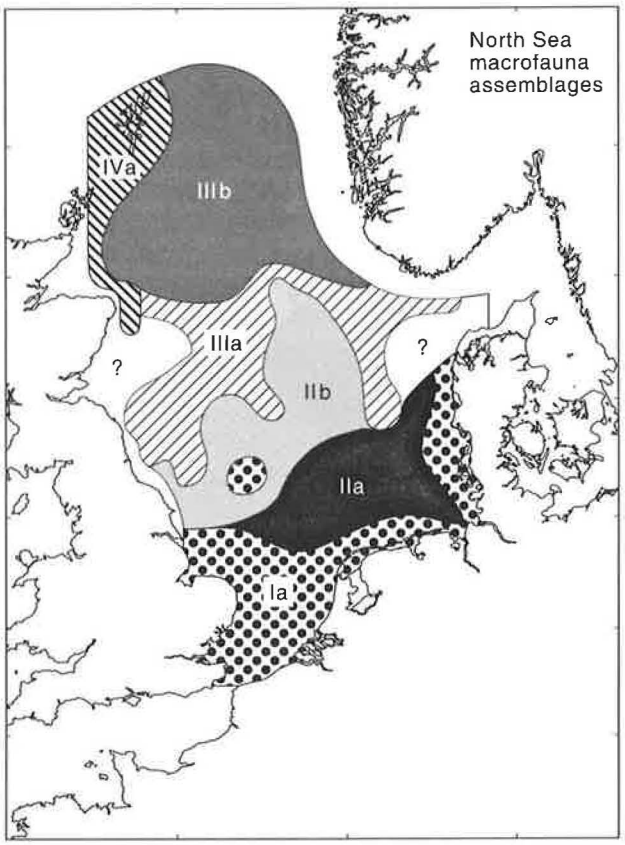


Figure 3. Distribution of some macrofauna assemblages in the North Sea. Source: Künitzer *et al.* (1992). Infauna assemblages of the subtidal North Sea, excluding the Channel, Skagerrak, and Kattegat.

A coastal assemblage in the southern North Sea and on the Dogger Bank at depths shallower than 30 m (group Ia, 52 stations, 27 ± 8 species per station, 805 ind./m^2, 9.5 g organic weight/m^2).

An offshore assemblage on fine sand at 40–70 m depth in the central North Sea (group IIb, 61 stations, 43 ± 10 species per station, 1093 ind./m^2, 7.6 g organic weight/m^2), and a similar offshore assemblage (group IIa, 40 stations, 44 ± 9 species per station, 1995 ind./m^2, 12.6 ± 7.5 g organic weight/m^2) in the southern North Sea, on muddy sand at 30–50 m depth.

An offshore assemblage occurring deeper than 100 m in the northern North Sea (group IIIb, 41 stations, 51 ± 13 species per station, 2863 ind./m^2, 3.5 g organic weight/m^2), and an offshore assemblage at 70 to 100 m water depth in the central North Sea (group IIIa, 46 stations, 54 ± 16 species per station, 1224 ind./m^2, 7.4 g organic weight/m^2).

A northwestern offshore assemblage in the region of the Orkney-Shetlands and off the Scottish coast (group IVa, 12 stations). The two northern North Sea assemblages IIIa and IVa have many indicator species in common that do not occur in the shallower areas of the southern North Sea.

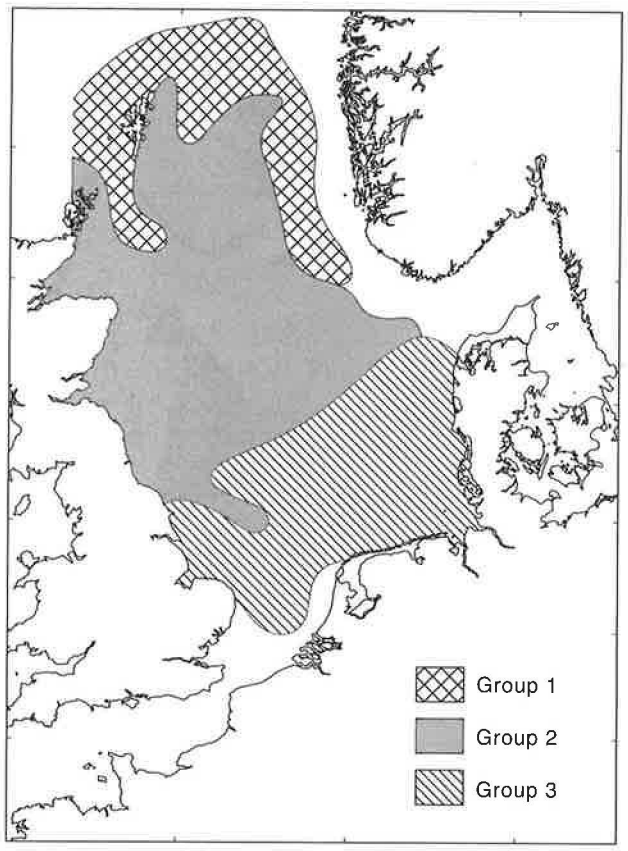


Figure 4. Typical North Sea fish assemblages, with species in order of abundance. Source: Daan *et al.* (1990).

Group 1: Slope edge association: saithe (44%), haddock (12%), Norway pout (11%), whiting (9%), blue whiting (4%), cod (4%), other (16%).

Group 2: Central North Sea: haddock (42%), whiting (14%), cod (9%), Norway pout (5%), saithe (4%), other (26%).

Group 3: Southeastern North Sea: dab (22%), whiting (22%), grey gurnard (13%), plaice (6%), cod (6%), other (31%).

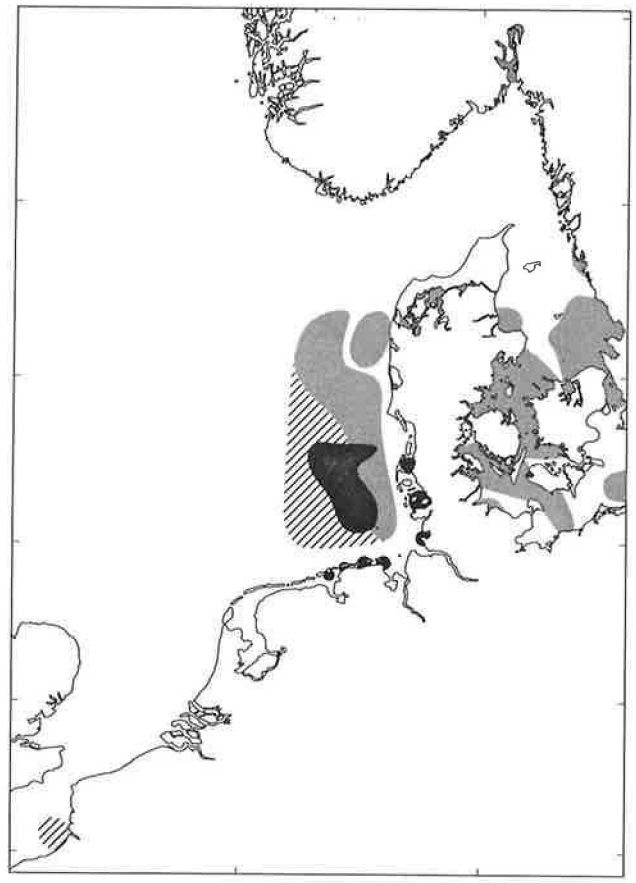


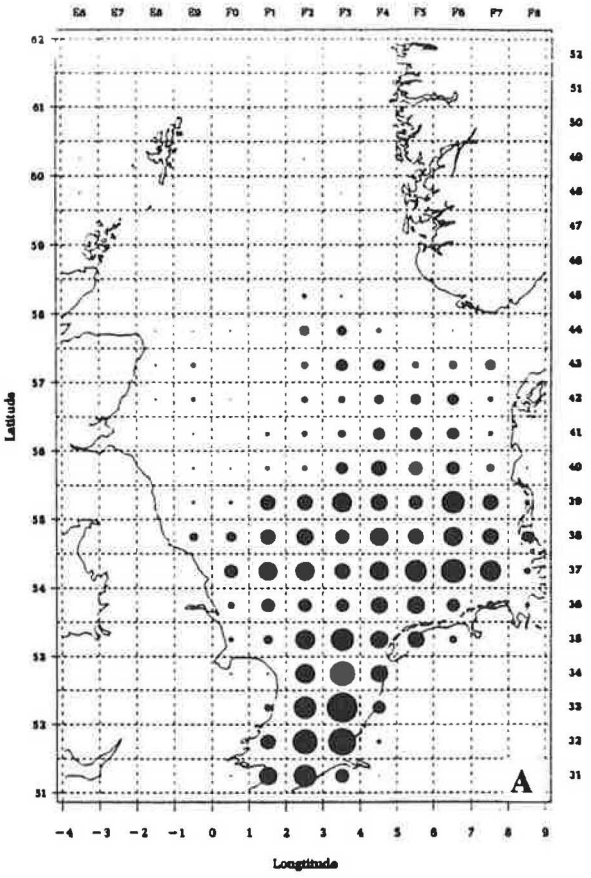
Figure 5. Oxygen deficiency in various zones of the North Sea. Source: OSPARCOM (1992).

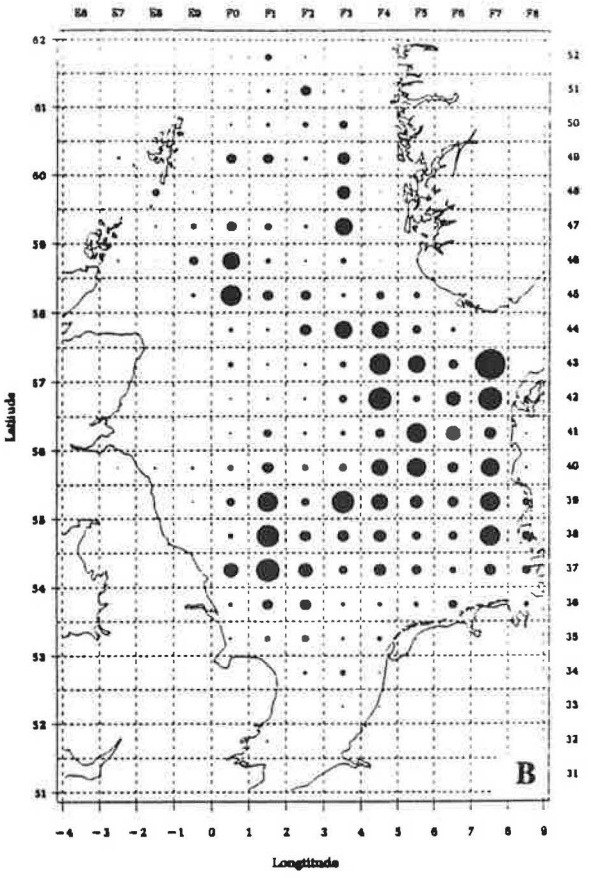
Oil and gas platforms are locally concentrated (Figure 7) and some statistical rectangles can be identified as having relatively high densities. In the central and northern North Sea, many pipeline systems have been laid. They have a web-like formation, as they are often interlinked. Large trunklines run through the whole of the North Sea. In the foreseeable future, many field lines will be connected to the trunklines.

Notwithstanding the fact that sand is a common commodity on the North Sea bottom, it is not always of the size required for industry. The fine sand resources can be seen as renewable resources, while coarse sand for building purposes (concrete, mortar) is limited to the southeastern North Sea. Transport costs limit the mining of sand, with distance to a major port being the main factor. Since coastal areas were already excluded, sand extraction does not impose further constraints.

Figure 8 provides data on species richness (Figure 8A on species of macrobenthos and Figure 8B on demersal fish species), indicating differences in different regions. However, as discussed earlier, this is not a useful criterion for selecting areas.

Figure 9 provides data on the economic value of the North Sea fishery by statistical rectangle based on the STCF data for 1989 (Figure 9A) and 1991 (Figure 9B). These data refer to all gears, and exchange rates between different national currencies are based on 1989 figures. Although these data indicate a relatively high economic yield from the area along the Norwegian Deeps the fish are largely taken by gears which have little or no impact on the bottom.





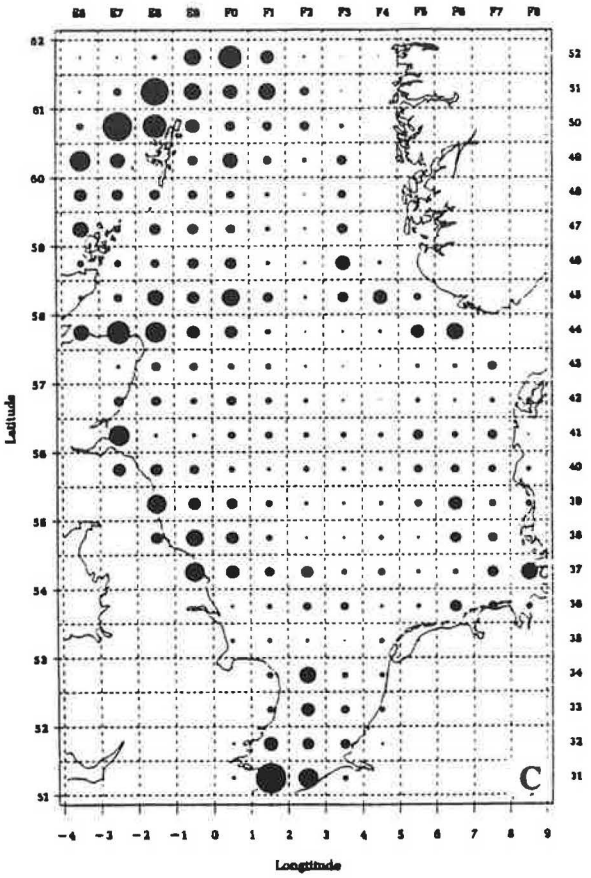


Figure 6. Distribution of fishing effort by gear (Source: STCF database).

A - Beam trawl

B - Industrial otter trawl

C - Otter trawl

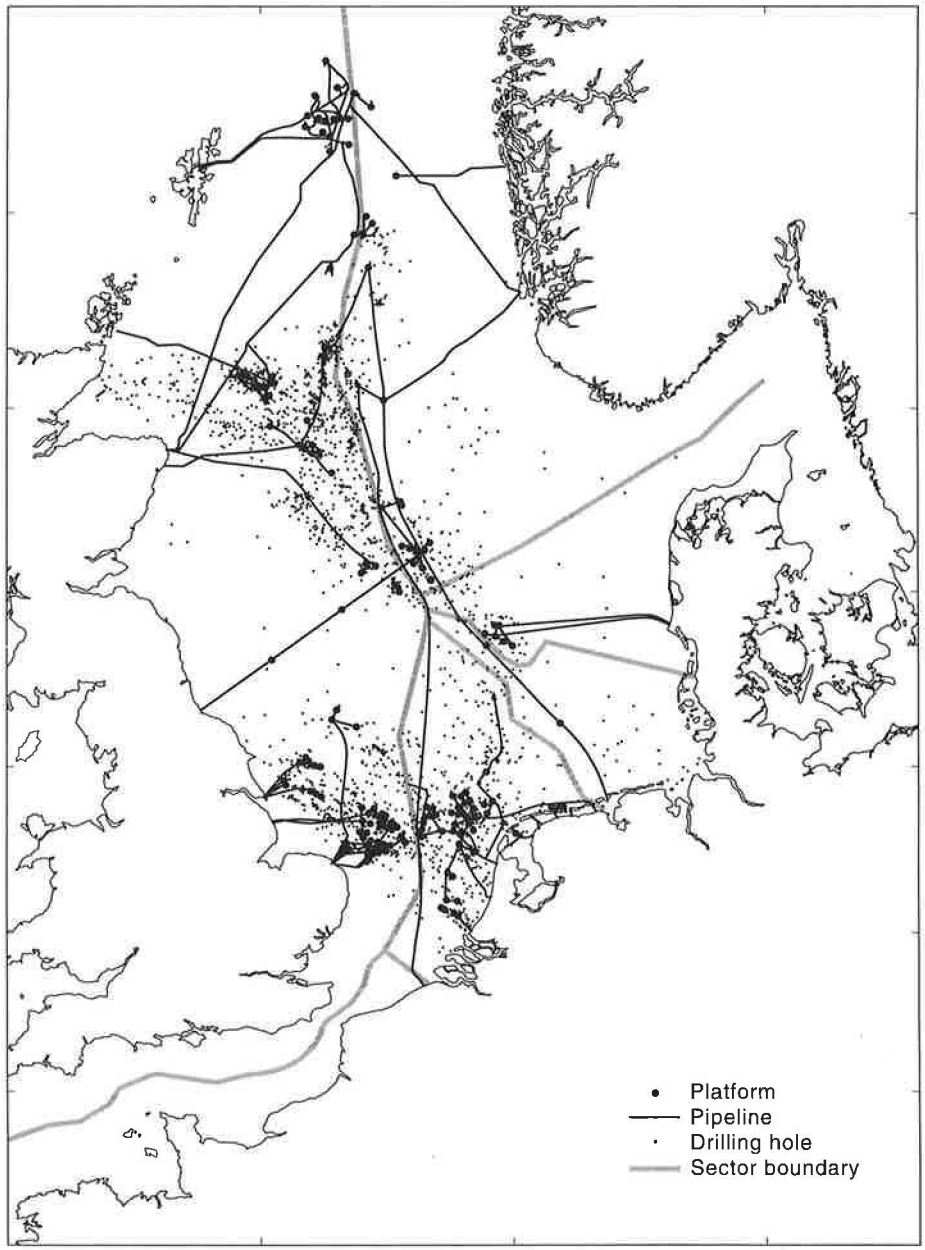


Figure 7. Offshore activities in the North Sea, showing oil and gas production platforms and pipelines in 1991 (after ICONA, 1992), and positions of oil wells and exploration drillings.

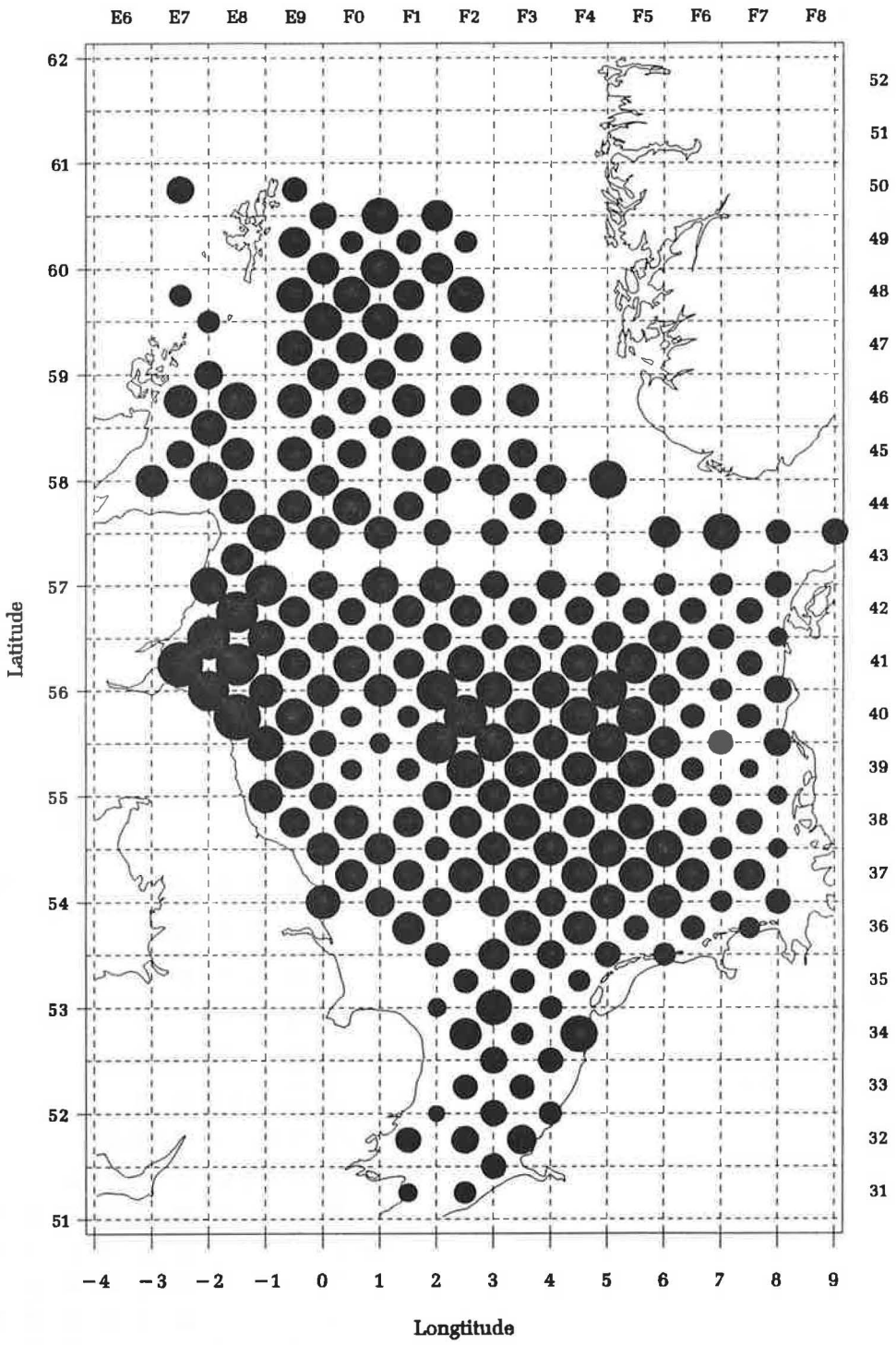
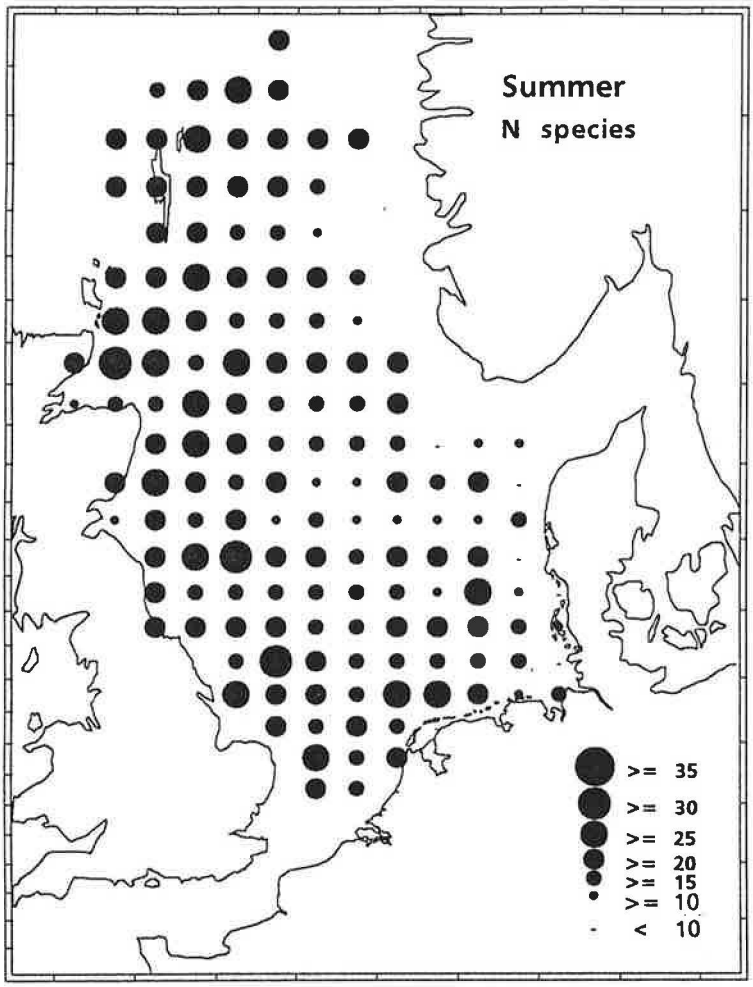


Figure 8A. Number of species of macrobenthos recorded in the 1986 ICES North Sea Benthos Survey.



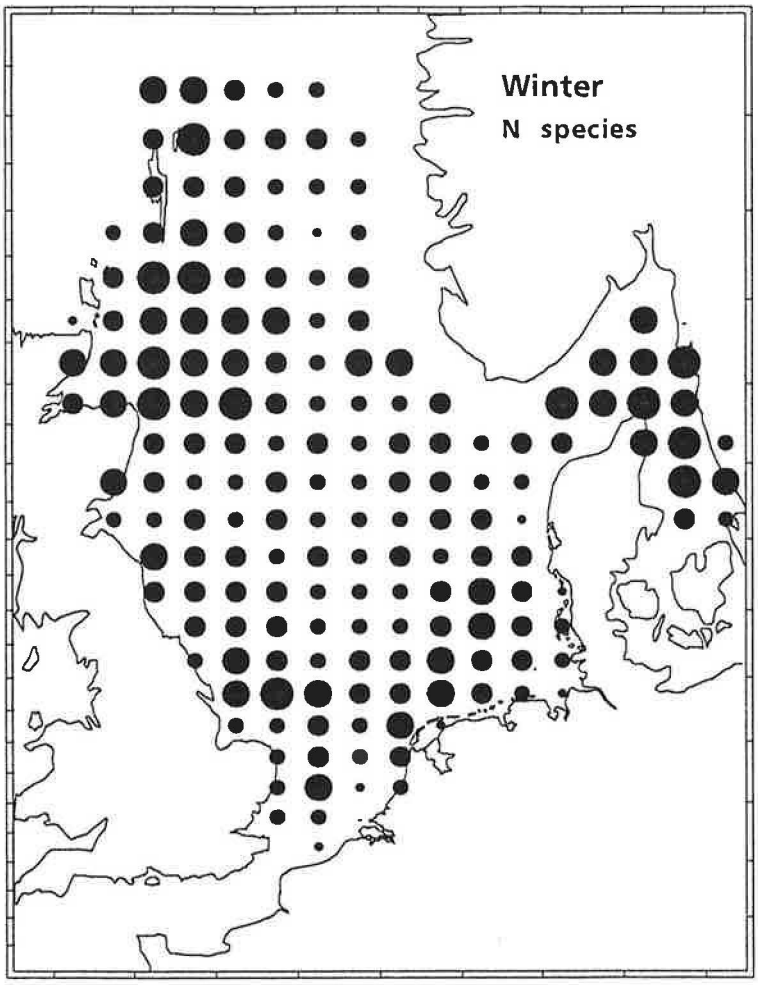


Figure 8B. Number of fish species recorded in bottom trawl surveys. (Source: Database used for the Atlas of North Sea Fishes (Knijn *et al.*, 1993)).

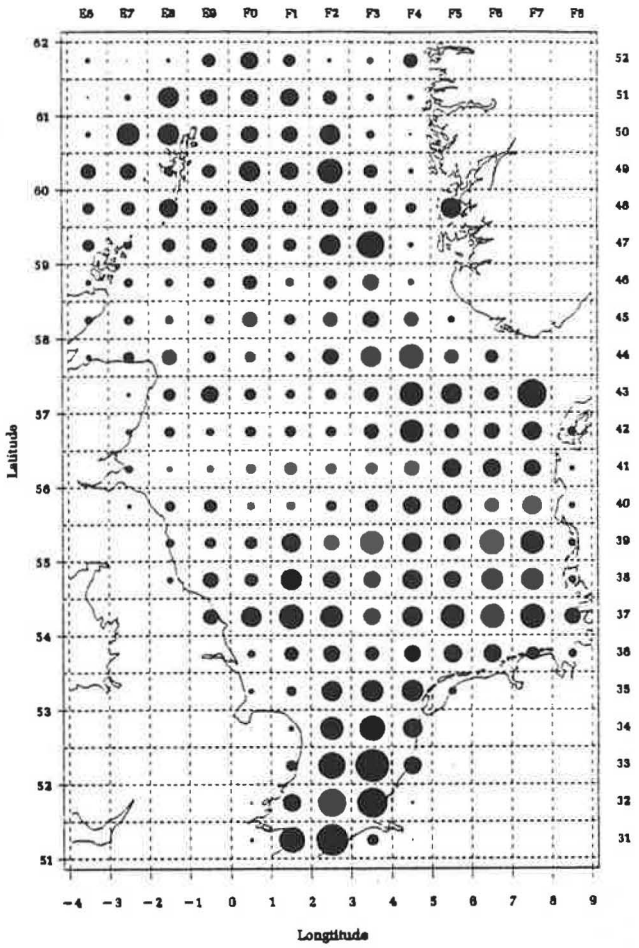


Figure 9A. Relative distribution of total first-hand value of fish landings from the North Sea in 1989 (source: STCF database).

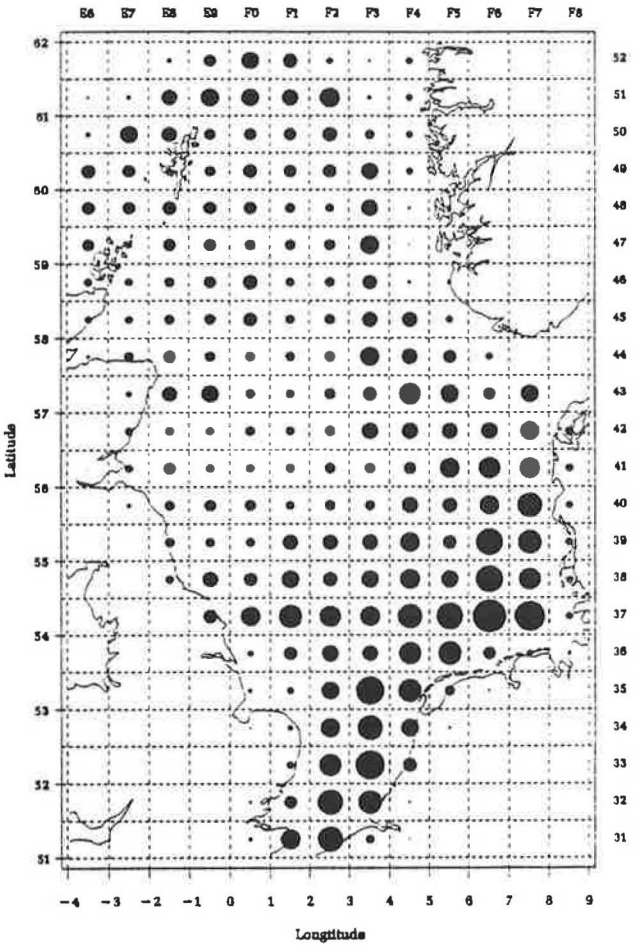


Figure 9B. Relative distribution of total first-hand value of fish landings from the North Sea in 1991 (source: STCF database).

Based on these arguments, Figure 10 identifies the most appropriate areas in the North Sea which could be considered in more detail.

7 SCIENTIFIC INVESTIGATIONS REQUIRED

The following considerations on monitoring and process studies are preliminary. They may serve as a starting point for the detailed planning of the scientific investigations when areas may be closed for scientific purposes in future.

7.1 Monitoring Activities

Monitoring can be defined as the collection of data at a regular interval on abiotic and biotic parameters that describe the essential features of the ecosystem under study. The relevant hypotheses about the effect of fisheries on the ecosystem are specified in Section 4, above. In order to distinguish fisheries effects from other effects, the monitoring programme should be carried out in the closed area as well as in a reference area. Furthermore, it is important that monitoring should start before the closed area is implemented so that the original situation is well described. The following aspects of the ecosystem should be monitored:

- abundance, size or age composition of:
  - epibenthic invertebrates;
  - infaunal invertebrates;
  - demersal fish;
  - birds;
- species richness;
- fishing effort.

Epifauna and infauna

The size spectrum of epifauna and infauna species is rather wide and different sampling methods are required

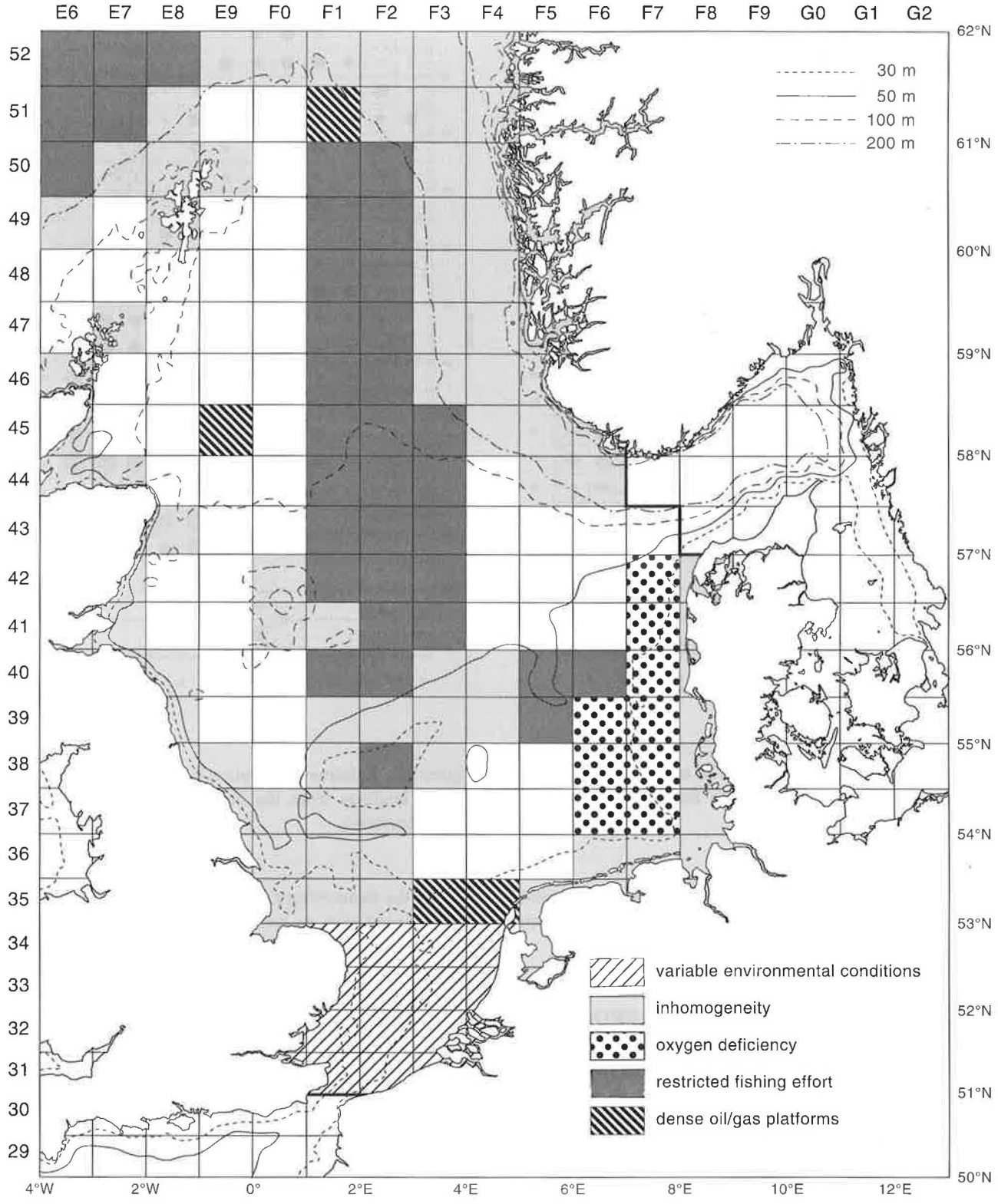


Figure 10. Regions determined, for the reasons shown, to be less suited for the establishment of undisturbed areas for scientific studies of the response of the marine ecosystem to a cessation of fishing activities.

to cover the entire range of macrofauna. Although effects of bottom trawling on the smaller meiofauna cannot be excluded, the effects are likely to be indirect and more suitably addressed in process studies. Appropriate sampling gears for macrozoobenthos include box corers, grabs, triple-D and beam trawls. The triple-D is a newly developed deep-digging dredge (Bergman and van Santbrink, In press). The ongoing BTS survey could potentially be used to sample sparsely distributed larger epifauna and infauna species such as edible crab (e.g., *Cancer pagurus*).

Demersal fish

The demersal fish assemblage in the area may differ between seasons due to the migration of individual species. Hence, at least two (summer and winter), but preferably four, quarterly surveys per year are required. The changes in the demersal fish assemblage should be studied by intensifying the sampling scheme of the ongoing monitoring programmes in the relevant areas: the IBTS (ICES International Bottom Trawl Survey; Anon., 1992) and the BTS (beam trawl surveys; Anon., 1993b). These surveys employ a high opening bottom trawl (GOV) and a beam trawl, respectively. The IBTS has covered the entire North Sea in February effectively since 1974. In the period 1991 - 1995, a quarterly IBTS survey is being carried out to study changes in seasonal distribution. The BTS has been carried out in the southern and southeastern North Sea since 1985. The sampling of both IBTS and BTS is stratified by ICES rectangles. At least one haul is taken per rectangle. The number and size composition of all fish species are recorded and age compositions will be taken from a number of selected species. Because of the mesh sizes employed, the very small fish will be missed (GOV: 1 cm stretched; BTS: 4 cm stretched).

Birds

To be able to address the hypothesis that closure of an area will lead to a decrease in numbers of scavenging seabirds, the number of birds within and outside the area should be established in different seasons. This requires that seabird observers be present on board research vessels during the various surveys. Also, regular bird counts in colonies near the area may be considered.

Fishing effort

Detailed information on the fishing activity in the reference area may be obtained if fishing vessels were equipped with automatic registration of their position by linking data logging equipment to the navigation system. A recent programme in the Netherlands, during which equipment has been installed on board a sample of 25 beam trawlers, has shown the great utility of this method.

7.2 Process Studies

To address the hypotheses formulated above, process-oriented studies are required in addition to monitoring in order to understand the causes of the changes observed. In general, such studies will focus on comparisons between the closed area and the reference area some years after the closure has come into effect. The following important process studies were identified to address the various hypotheses, but the list is by no means complete.

Sediment characteristics

Changes in the benthic communities might lead to changes in the sediment characteristics such as steadiness (e.g., reef building) or aeration, which in turn could lead to other changes in the community. Furthermore, the cessation of trawling may directly lead to alterations in the grain size distribution of the top layers. To understand these processes, the following sediment characteristics should be investigated: grain size distribution, porosity, oxygen profiles and oxygen fluxes, organic carbon content, and nutrient concentrations and fluxes.

Benthic food webs

Once the monitoring programme has identified changes in the benthic communities, it is important to investigate whether these represent a direct result of the reduction in the level of mortality or whether they are mediated through changes in the food web. To investigate this aspect, the food webs within and outside the closed area should be compared by means of stomach analyses of fish and invertebrates. Measuring the respiration rate of the benthic community as a whole should be included in this part of the research programme. At the lowest level of the food chain, it is possible that changes in sediment characteristics will lead to changes in the community structure with respect to micro-organisms and meiofauna, which in turn may induce changes at higher levels of the food chain. Although of low priority, studies on this aspect might be undertaken.

Fish

The local effects of a reduction in fishing mortality depend on the size of the area closed in relation to the migration and dispersion rates of the fish. Therefore, information is necessary on fish movements to allow interpretation of the changes in abundance and size (age) composition. Tagging experiments inside and outside the closed area should provide the necessary information and may also indicate whether fish are attracted to the closed area. The possibility of applying electronic tagging devices to study fish behaviour could be considered.

Food availability for scavengers

Stomach sampling may be carried out on a number of potential scavenger species inside and outside the closed area to quantify the use scavengers make of the food that is made available by fishing (offal, discards or non-catch mortality).

Production:Biomass ratios

Once the monitoring data have identified a change in benthic species composition for certain species, the production:biomass (P:B) ratios of these species in the areas concerned need to be established to address the hypothesis that the P:B ratio of the community as a whole will decrease. Apart from using data from the monitoring programme, more elaborate data obtained throughout a complete growing season may be needed to address this question.

Settlement studies

The question will arise whether observed changes are the result of changes in settlement or in predation. Since the monitoring data will only be collected during a limited time of the year, more elaborate sampling programmes are required at the time of settlement of the species for which changes have been identified.

8 CONCLUSIONS

The usefulness of closed areas as a scientific tool to investigate the effects of fishing on the ecosystem has not yet been firmly established. However, it is only in conjunction with a well-designed monitoring programme that such areas could produce insights into the effect of fishing on the marine environment.

The selection of areas was approached by indicating the areas which would be unsuitable from a scientific point of view. It is likely that a particular closure may only answer a subset of the many scientific questions that may be addressed. Also, the sometimes conflicting selection criteria may carry different weight depending on the priorities set in terms of objectives. While unsuitable regions have been identified, and the necessary size and duration of the closure specified, the final selection of particular areas will involve political considerations. In order to properly define appropriate areas as well as an appropriate research programme, more information must be made available on the relative importance of the questions to be addressed.

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