ICES COOPERATIVE RESEARCH REPORT

RAPPORT DES RECHERCHES COLLECTIVES

NO. 182

REPORT OF THE ICES WORKING GROUP ON THE EFFECTS OF EXTRACTION OF MARINE SEDIMENTS ON FISHERIES

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December 1992

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EFFECTS OF EXTRACTION OF MARINE SEDIMENTS ON FISHERIES

Report of the ICES Working Group on the Effects of Extraction of Marine Sediments on Fisheries

EXECUTIVE SUMMARY

Background

Aggregates are required principally for construction purposes and land reclamation and beach replenishment schemes. As acceptable land-based sources are being diminished, pressure is increasing in many ICES member countries to meet the demand with marine deposits. This in turn is leading to greater potential for conflict between the marine aggregate extraction industry and other users of ocean space, in particular the fishing industry.

The ICES Working Group on the Effects of Extraction of Marine Sediments on Fisheries was convened in 1986 with the aim of increasing our knowledge and understanding of the impact of marine aggregate extraction activities upon fisheries in particular, and the marine environment in general, as well as reviewing management practices adopted by member countries to control such activities. Members of the Working Group have met regularly to exchange information on these matters: the following report is a synthesis of the information compiled.

Objectives

The objectives of this report reflect those of the Working Group. They are to review:

1. marine aggregate extraction activities in the coastal and shelf environments of ICES member countries;

2. the effects of extraction activities on living resources and fisheries;

3. the management of aggregate extraction operations.

Progress

Thirty-three representatives from ten different ICES member countries contributed data to this report, or assisted in its preparation. All material was reviewed by members of the Working Group.

Marine Aggregate Extraction

The marine aggregate extraction industry is well established and growing in a number of ICES member countries, contributing up to 15% of some nations' demands for sand and gravel.

While the report notes advantages accruing from marine aggregate extraction there are nonetheless a number of concerns relating to its negative implications for fishing, navigation, coastal protection, and benthic ecosystems.

The principal uses of marine aggregates (sand and gravel) are in construction projects, beach replenishment and land reclamation schemes, and the creation of artificial islands.

Physical and Chemical Impacts

Physical impacts of marine aggregate extraction arise from substrate removal and alteration of the bottom topography, creation in the water column of a turbidity plume, and sediment redeposition from this and from screening. The nature of these impacts varies according to the dredging method, the magnitude, and the location (Section 3.1).

The physical impacts of trawling are similar in certain respects to those of dredging but in most areas affect a far greater proportion of the benthic environment (Section 3.5).

Chemical impacts of extraction are considered to be minor owing to the low organic and clay mineral content of extracted material (Section 3.2).

Environmental Impacts

The biological impact of an extraction operation is largely dependent upon the nature of the physical impacts and of the indigenous benthic communities and so is very much site specific (Section 3.3).

Species considered to be potentially at risk as a result of marine aggregate extraction operations include sandeels,

herring, and edible crab, as well as coregonid and other bottom-spawning fishes and maërl (Section 3.3).

An approach to determining the scale of the effect on marine life and fisheries as a consequence of aggregate extraction is outlined. Rough calculations for the North Sea suggest that, unless spawning grounds are disturbed, effects on fish stocks are likely to be negligible overall although there may be areas of local significance (Section 3.4).

Beneficial interactions of marine aggregate extraction operations may occasionally arise, such as the concentration of fish stocks over dredged pits (Section 4.2.2).

Licensing

Most ICES member countries for which information is available have legislation and established review procedures for dealing with proposed aggregate extraction operations in the marine environment (Section 4.1.1).

Scientific considerations to be taken into account when issuing all extraction licences should include potential effects upon shoreline stability, modelled where appropriate. The method of dredging, total quantity of aggregate to be extracted, and the extraction rate should all be stipulated in the extraction licence as a means of controlling the potential impact of the operation (Section 4.1.2).

A "Code of Practice for the Extraction of Marine Minerals" is presented; it is designed to promote a good working relationship between the dredging industry and other ocean space users. Emphasis is placed on evaluating applications for prospecting and extraction in order to minimize the potential conflict between the dredging and fishing industries and to optimize the use of marine resources (Annex 1).

Resource Mapping

On the basis of available information, seabed sediment mapping is progressing well in most ICES member countries; resource mapping programmes have been initiated by some countries, but they generally lag behind those for seabed sediments (Section 4.2.1).

Monitoring

The use of electronic monitoring devices on board dredging vessels should be encouraged as beneficial to both the dredging company and the regulatory authority (Section 4.3.1).

Physical and biological monitoring of extraction operations can be of great value in the protection of coastal and marine environments and fisheries resources (Sections 4.3.2 and 4.3.3).

1 INTRODUCTION

The following report is the result of cooperative research undertaken from 1986 to 1990 by the ICES Working Group on the Effects of Extraction of Marine Sediments on Fisheries (Marine Environmental Quality Committee). Previously (1972–1979) this Working Group was known as the Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction.

The terms of reference of this Working Group are:

a) to update the present status of marine extraction operations and their impact on the marine environment;

b) to examine the recent results of national research programmes on the effects of marine extraction operations on the marine environment, particularly the influence on fisheries;

c) to compare the national codes of practice for the control of dredging activities and to evaluate the changes since 1979;

d) to provide information on activities in the near future and their possible impact on the marine environment and effects on fisheries;

e) to advise on major issues where an ICES policy is needed;

f) to make recommendations on management and research, as necessary.

This Group includes representatives of research organizations and government agencies involved in fisheries, geological surveying, environmental monitoring, and licensing and regulation of marine minerals extraction. Members of the Working Group contributing to this report are listed in Annex 5.

The structure of the report reflects the wide interests of the Working Group. Considered in detail are:

i) aggregate dredging and coastal engineering on the continental shelf of ICES member states;

ii) effects of extraction activities on fisheries;

iii) resource management including regulatory practice, conflict resolution, and monitoring.

The Working Group has also produced a Code of Practice (attached as Annex 1) based on the information contained in this report and on the regulatory experience of member nations. This Code of Practice is intended to cover all superficial mineral deposits on the continental shelf. It has been formulated to promote a good ethic of operation thereby ensuring that the marine mining industry exists in harmony with other ocean space users and no unregulated extraction takes place. The Code of Practice specifically considers the interaction of marine mining and fisheries. Particular emphasis has been placed on deposit thickness, fines generation, and residual substrate character. This document is intended to serve as a set of basic guidelines for ICES member nations and others for the management and regulation of marine mining in such a way that fisheries and other ocean users are adequately protected.

2 AGGREGATE DREDGING, COASTAL ENGINEERING, AND RELATED ACTIVITIES IN THE COASTAL AND SHELF ENVIRONMENTS OF ICES

2.1 Marine Dredging for Sand and Gravel

2.1.1 Status of the marine aggregate extraction industry in ICES countries

A brief description of the marine aggregate industry in each of the ICES countries for which data were available to the Working Group is provided in the following sections.

Belgium

Aggregate dredging occurs in two zones off the Belgian coast – on the Zealand Banks and on the Flemish Banks. Dredging continues at a level of about 1 million m^3 per annum.

Canada

There was no mining for marine aggregates or minerals in the Canadian offshore in 1989. Appreciable quantities of sand and gravel have been dredged previously in the Beaufort Sea. This practice will likely resume should a decision be made to proceed with additional offshore oil and gas development. Elsewhere there is growing commercial interest in sand and gravel and placer deposits of gold, chromium, and titanium.

Denmark

Extraction of sand and gravel for construction occurs in several areas in the inner Danish waters and in one location in the North Sea (Horn Reef). Marine sources supply 10 to 15% of the country's needs. In 1989 a total of 7.7 million m^3 was mined. Of this 2.7 million m^3 were used for construction and 5 million m^3 for creation of artificial land in reclamation projects, especially the Great Belt tunnel and bridge project.

An average of about 1 to 1.5 million m^3 per annum is extracted, primarily in the North Sea for various beach nourishment projects along the Jutland west coast.

Finland

The city of Kotka extracted about 1 million m^3 of sand and gravel for harbour facility expansion. The material was dredged mainly from two locations in shallow water (5–15 m water depth). A total of 2.5 million m^3 is planned for extraction during this project.

The city of Helsinki will extract a total of 1.5 million m^3 in 1990 (a permit has been issued for 5 million m^3) for two landfill projects: a housing scheme and harbour facility.

A total extraction of 17 million m^3 has been planned for the period 1990–1997 in three main areas: Helsinki, Kotka, and the land bridge to Hailuoto Island.

France

Offshore aggregate extraction in France has been stable in recent years around a figure of 3 million tonnes per annum of sand and lithic gravel. Imports of these aggregates have decreased by 7% and amounted to 900 000 tonnes in 1988. However, extraction of calcareous aggregate (maërl and calcareous sand) increased from 500 000 tonnes in 1987 to 630 000 tonnes in 1988.

A trend away from fluvial dredging and towards offshore dredging was noticeable in 1989 which, if it persists, should lead to an increase in offshore dredging activities in the coming years. Current programmes for marine aggregate resource assessment include:

a) an inventory of sand suitable for construction purposes, around Guadaloupe;

b) an inventory of maërl and calcareous sand deposits in Brittany.

Since 1985 IFREMER has made available to marine aggregate extraction companies geological information concerning the deposits as well as maps on the nature and morphology of the seabed in and around the extraction areas. These maps contain information for environmental impact studies on the specific benthic communities for each type of seabed sediment and also on the sediment transport rates. These offshore maps have been published for northernmost France and part of the Brittany coast. Much valuable information is also contained in the unpublished reports produced for the dredging industry.

Ireland

There has been no significant extraction of marine aggregates off Ireland in recent years, though there is occasional interest in deposits of *Lithothamnion* (maërl).

The Netherlands

Sandy sediments only are extracted from the Dutch sector of the North Sea and its adjacent estuaries. Figures on sand extraction for landfill schemes rose from 2.0 to 9.2 million m^3 per annum between 1986 and 1989. At least 80% of this quantity is derived from the access channel to the Amsterdam harbours. This rise in the extracted quantities reflects the Government policy of stimulating extraction at sea and limiting extraction on land as much as possible. In addition an average of about 5 million m^3 per annum is extracted for various beach nourishment projects. In 1988 and 1989 no major projects were carried out, but in 1990 several nourishment projects are planned which will involve 6.8 million m^3 in total. The amounts per project vary from 0.2 to 3.0 million m^3. Recently the coastal protection policy has been reviewed. Beach nourishment emerged as one of the most economical methods of coastal protection, and a need for 5 to 10 million m^3 per year is estimated.

Sand extraction in the Wadden Sea is limited, because it is thought that the natural subsidence of the area is balanced by the tidally induced import of sand from the North Sea. There is a tendency towards gradually diminishing the quantities extracted since it is thought that extraction encourages the erosion of the nearby coastline.

Gravel extraction in the Dutch sector of the North Sea has not yet started on a regular basis. The only interesting area is the Cleaver Bank area about 150 km northwest of Den Helder. A pilot project was conducted in the summer of 1989. It included an extraction of about 330 000 m^3 of sandy gravel, and a pre- and post-dredging benthic survey. An environmental impact assessment will be carried out if extraction looks economically feasible.

Another potential gravel resource, to the west of Texel (Texelse Stenen), is currently under investigation by the Geological Survey (RGD). At present gravel is either extracted from land-based resources (e.g., from former river beds in Limburg) or imported. Should extraction continue at the present level then the land-based resources are likely to be depleted in 30 or 40 years' time. As Dutch marine gravel resources are also limited, new ways must be found to meet future demand. To help alleviate demand upon aggregate reserves emphasis is laid upon re-use of stony or hard materials such as crushed concrete and bricks.

Norway

Available information on sand and gravel extraction in Norway is incomplete as a consequence of minor extractions taking place without official licences. Since 1970 the extraction has been regulated by Norwegian law. Licences are given for two-year periods. Officially 66 000 m^3 of marine sand, gravel, and shell sand were extracted in 1989. The shell sand is used for agricultural purposes.

Sweden

The extraction of marine aggregate in Sweden is very limited owing to the large deposits of sand and gravel on land in eskers. In 1989 a total of 70 500 m^3 was extracted from the seabed in three areas off the west coast and in one area off the east coast of Sweden.

Some 30 500 m^3 were obtained in the area of Stora Middelgrund, 35 500 m^3 from the Kattegat at Vasraat Haken, 1600 m^3 from the Sounds at Sandflyttan, and 2400 m^3 in the Baltic east of the island of Gotland.

United Kingdom

The United Kingdom is the second largest producer of marine-dredged construction aggregates in the world (after Japan). Over 16% of the sand and gravel used in England and Wales each year is dredged from the seabed. Supplies to Merseyside, Tyneside, the Severn Estuary, and London conurbations are particularly important in overcoming shortages and supply problems with land-won aggregates. Marine dredging reduces the pressure to work land of agricultural, amenity, or environmental value by producing sand and gravel equivalent to the yield from about 350 hectares of land working each year.

Supplies of marine dredged aggregates currently come from six broad areas:

- the Humber;
- the East Coast;
- the Thames Estuary;
- the South Coast;
- the Bristol Channel;
- Liverpool Bay.

The Humber, East Coast, Thames Estuary, and South Coast areas supply the Southeast market. As the accessible Thames Estuary deposits have become worked out, the Humber and East Coast supply areas have become more important. The Bristol Channel supplies South Wales and some parts of the Southwest. Liverpool Bay supplies sand to Merseyside.

In South Wales and the Southeast of England, marine sand and gravel are crucial elements of the aggregate supply. In South Wales marine-dredged aggregates account for over 80% of the region's sand and gravel consumption. Over 95% of the marine-dredged aggregate landed in South Wales is sand, providing the region's principal source of fine aggregates. The Southeast is dependent upon marine-dredged sand and gravel to make up the shortfall in its production of concreting aggregate. At the present time over 11 million tonnes, about 37%, of the sand and gravel used in the Southeast were marine dredged and the majority of this material is used as concreting aggregate. The sand and gravel dredging industry supplies approximately 15% of the demand for such products as ready-mixed concrete, concrete blocks, and other prefabricated concrete products. In 1989 over 23.5 million tonnes of marine aggregate were landed at wharfs in the United Kingdom with another 2.5 million going for export to mainland Europe. The recent growth of the industry has been very rapid, with production nearly trebling since the early 1960s. The total quantity of aggregate reserves that lie in UK territorial waters has yet to be fully quantified. Present reserves probably lie between 400 and 500 million tonnes and at the current rate of use will become exhausted within the next 20 years or so.

United States

Sand and gravel are being dredged in New York Harbor and marketed for use as fill material and construction aggregate. This is the only active, commercial marine mining operation in the US. Material is being removed from the dredged, main shipping channel at a rate of about 800 000 m^3 per year. There has been continued interest in both expanding mining in New York waters and starting operations in New Jersey, Connecticut, Rhode Island, and Massachusetts, especially around Boston, but there are no definite plans as yet to begin operations. Other dredging operations have been used to supply sand for construction uses, primarily beach nourishment on a case-by-case basis. There is no central compilation of beach nourishment projects, but an estimated 2 to 5 million m^3 are provided from offshore sources each year. About half of this is provided by the routine dredging of inlets.

2.1.2 Land *versus* marine supplies of aggregate

Traditionally, sources of aggregate for the construction industry have been mainly land based, i.e., sand and gravel pits and hard rock quarries. In recent years, the continued use of these sources of aggregate has been challenged, particularly on environmental and aesthetic or amenity grounds, for the following four reasons:

1) sand and gravel deposits may coincide with the best quality agricultural land. (This is the case in the UK but not, for example, in Finland);

2) land-based sources of aggregate are not considered to be good neighbours because of the noise and dust generated;

3) transport of such bulky materials can be a problem, particularly where access to rail or inland waterways is limited;

4) sand and gravel pits and quarries often cause significant permanent changes in the landscape and, after use, can threaten sensitive interests such as underground water supplies.

Marine dredging, especially trailer suction dredging, properly controlled, has relatively little impact on the physical make up of the seabed, and the topography may revert quite quickly once the dredging ceases. Although the start-up costs are high with marine aggregates, the economies of scale are very substantial: one 2000-tonne cargo is equivalent to one hundred 20-tonne lorry loads.

Nevertheless, there are concerns associated with marine aggregate mining related to fishing, navigation, coastal protection, and disruption of benthic ecosystems. Fishing gear, particularly fixed gear, can be sensitive to disruption and damage by towed dredging equipment. In some cases, outwashings or the screening of fines from the dredged cargo may result in excessive siltation of the seabed, with a detrimental impact on benthic populations, including shellfish stocks such as bivalve molluscs. Excessive siltation can also affect benthic nursery grounds and may even affect species such as crabs and lobsters which depend on a silt-free environment for feeding and breeding. Aggregate dredging in shipping lanes or shipping routes in relatively restricted waterways can interfere with the safe passage of other vessels. Offshore aggregate production can affect coastal protection, either by interfering with the supply of sand and gravel to the beach or by reducing offshore wave protection and thereby changing the wave energy and/or direction reaching the coast.

2.2 Uses of Marine Aggregate

Extensive use is made of marine aggregates worldwide in construction, beach replenishment, land reclamation, and island and reef construction.

The use of marine sand and gravel as construction aggregate is limited to relatively few countries, principal among which are Japan, the United Kingdom, the Netherlands, France, Belgium, Sweden, Denmark, and Finland. In certain of these countries, marine sand and gravel supply a significant proportion of the aggregates used by their construction industries. There may be a prejudice against the use of marine aggregate for certain applications such as prestressed concrete because of unfounded fears concerning the salt content (Gutt and Collins, 1987). Marine aggregates offer advantages related to quality, availability, and ease of transport and delivery.

Compared with land-extracted aggregates, marine-dredged aggregates are usually of comparable or higher quality and may be substituted directly for similar-specification material in most major applications, including concrete production. In addition, they are often available in substantial quantities close to centres of heavy demand.

Major construction projects at sea often require the aggregate to be put on site over a relatively short period to minimize the risk of loss, particularly during adverse weather conditions. The limited capacity of land- based pits and restrictions preventing continuous work schedules may make them unsuitable for large-scale marine reclamation.

The effective utilization of marine aggregates requires the availability of suitable wharfs or wharf sites. These are usually available convenient to major centres of demand through existing port infrastructures or in waterfront areas zoned for industrial use where wharf development may be permitted. Transport and distribution systems for reaching consumers are similar to those required for land-extracted construction aggregates.

Coastal and offshore construction sites often have limited access from the land, but are readily approachable from the sea. At docks and harbours or areas where there is a sufficient tidal range, the dredger can deliver the sand and gravel directly on site where conventional earth-moving equipment can then make the final placement. Even where marine access is restricted, e.g., because of water depth, a modern dredger linked to the shore by flexible pipeline can deliver even stony cargoes to the beach and transport sandy material many kilometres for reclamation.

2.2.1 Construction aggregates

Marine-dredged aggregates are direct substitutes for land-extracted aggregates in most applications where market conditions and current working practices in individual countries permit. Optimal utilization of marine-dredged aggregates may be achieved if current technical specifications and construction industry working practices developed principally for land-based resources are reviewed.

In Japan, the UK, and Denmark, marine-dredged aggregates form a significant part of the total construction aggregates consumption. Increasing quantities are being used in Belgium, the Netherlands, and France. Marine aggregates may provide an important source of supply in areas with high population density in coastal areas where existing built development, amenity constraints, and lack of natural resources (either of sufficient quality or quantity) restrict the availability of land-extracted construction aggregates. For example, the Southeast of England is dependent upon marine-dredged sand and gravel to make up the shortfall in its production of concreting aggregates, and the eastern and northern parts of Denmark are dependent on marine-dredged material to supply high-quality construction aggregates. Marine-dredged materials have been used as construction aggregates in the UK and Denmark for over 60 years, and currently over 20 million tonnes a year are used in the UK, the majority for concrete production.

2.2.2 Land reclamation

Land reclamation occurs throughout the inhabited world. Pressure for this essentially stems from increasing populations allied to increasing gross national product. Land may be reclaimed for agricultural, residential, recreational, or commercial use.

Different methods of reclamation can be applied. One of the principal methods consists of pumping the material to the appropriate site. Another consists of containing a section of sea by sinking a sheet piling. The sea water is then displaced with a fill material such as gravel, sand, or heavy mud which is then left to consolidate before being capped. Often the sheet piling is reinforced and a structure constructed on top to prevent incursion by the sea. Alternatively, in locations where the water conditions are reasonably placid, the land can be extended over the required area without first installing a sheet piling. In such cases, concrete walls or sheet piling may be installed afterwards for further protection.

2.2.3 Beach replenishment

Beach profiles are dynamic and constantly changing because of the energetic nature of beach environments. They are also strongly influenced by any change in the onshore/offshore movement of seabed sediments and the littoral drift of sediment.

The benefits of using marine sand and gravel for beach replenishment, especially where the beach has a high amenity value, are obvious. The new beach will have a "natural" look. Marine sand and gravel are usually well mixed and readily form a stable base which allows rapid colonization by plants and animals endemic to the original beach.

It has been traditional to protect vulnerable coastlines from wave attack with sea walls and groynes (hard protection). Such protection is designed to stop littoral drift and prevent erosion. This has led in many instances to an interruption in the supply of sand to the coast adjacent to the remedial work. In other cases, the protective structures have caused an increase in erosion because of the reflected wave energy from the sea wall. In recent years there has been a move towards "soft" coast protection either on its own or in conjunction with sea walls and groynes.

There are many beach replenishment projects on the east coast of the United States. Along this coast over 200 operations have been documented at more than 90 sites during the last 20 years (Pilkey and Clayton, 1988). Over the past eight years, more than 18×10^6 m^3 of fill material were supplied from marine sources. This supply was about equally divided between offshore borrow areas and the dredging of navigation channels.

There have been 43 projects in the Netherlands since 1952. The largest, in 1971/1972, involved placement of about 19×10^6 m^3 of dredged sediment from the Rotterdam Harbour approaches. In a recent evaluation of nine Dutch projects, it was concluded that five of these have fulfilled expectations with regard to their predicted lifetime (5 to 10 years), and a further three probably will fulfil them. Further, it was concluded that beach nourishment is a cost effective way of combating coastal erosion. Thus in the coastal defence policy analysis, beach nourishment schemes are seen as the most attractive means of protecting coastal stretches. It is estimated that about 5×10^6 m^3 per annum will be involved.

In Germany, the major beach replenishment activity has been around the east Frisian Islands. The advantages of beach nourishment over the more conventional hard structures have also been recognized on the Georgian coastline of the Black Sea in the former Soviet Union. The UK has carried out a number of beach replenishment projects over the last 30 years, the most extensive ones having been at Hengistbury Head on the south coast of England, where more than 1.5×10^6 m^3 of sand and shingle were used to protect about 15 kilometres of coastline. In 1987 1.5×10^6 m^3 were placed on 2.5

kilometres of beach at Seaford, again on the south coast of England. Recently an up-to-date and comprehensive source of information on beach replenishment projects has been published (C.U.R., 1987). This excellent review considers coastal processes, design, execution, and the environmental aspects of such projects. A literature survey and an evaluation of some specific case studies are also included.

2.2.4 Island and reef construction

Artificial islands have been built for a variety of purposes, including increasing available land in densely populated areas such as Japan and Hong Kong. They have also been used by the offshore oil industry and for venting undersea coal mines. Artificial islands have served as depots in the United States for the disposal of contaminated dredged material (Hubbard and Herbich, 1977). Dredged sediments have been used in estuaries and other coastal areas to create small islands and wetlands for use by wildlife.

The recent trend towards larger ships has led to the consideration of the construction of artificial islands and reefs as alternative port facilities. Such islands could solve the many problems related to the increased draft of ocean-going vessels. These problems include:

- the destruction of coastal habitats to provide new deep water ports;
- upgrading and maintenance of existing ports by dredging;
- coastal erosion associated with port activity.

Artificial reefs or breakwaters are built mainly for protection against wave attack. In Japan 4000 breakwaters have been built in the last 20 years. In addition to these traditional uses, however, artificial reefs have been built to promote fishing activity. In the United States the National Fishing Enhancement Act of 1984 has promoted the use of artificial fishing reefs. The concept has also been applied in the United Kingdom where Southampton University has built a trial fishing reef of concrete blocks.

2.2.5 Coastal protection and breakwater construction using glacial erratics

In some Scandinavian countries glacial-derived (erratic) boulders (0.2 – 10 tonnes in weight), lying on the surface of the seabed, are frequently used for construction of breakwaters and for coastal protection. These boulders are extracted by special vessels called "stone fishers" which are fitted with large claw-type grabs. On average around 20 000 tonnes of boulders have been extracted annually from Scandinavian waters during the last decade.

3 EFFECTS OF EXTRACTION ACTIVITIES ON LIVING RESOURCES AND FISHERIES

This chapter describes the various impacts (physical, chemical, and biological) of dredging extraction activities on the seabed and the water column and thence on living resources. This is followed by an estimate of effects and consequences. The chapter concludes with a paragraph on the impact of trawling on the seabed, which, although minor on a local level compared with dredging, is much greater on a regional basis owing to the widespread distribution of trawling activities.

3.1 Nature of the Physical Impacts on Seabed and Water Column

Before discussing the nature of the physical impact of sand and gravel extraction it is necessary to outline the processes involved in mining aggregate at sea.

The two methods most commonly practised in aggregate extraction in northern European waters are anchor hopper dredging and trailer suction hopper dredging (Dickson and Lee, 1973; de Groot, 1979b). In the former, the dredger anchors over the deposit and mines it by forward suction through a pipe (Figure 1A). Large pits are thus formed on the sea floor, up to 20 m in depth and 75 m in diameter (Cruickshank and Hess, 1975). Most aggregate dredging in Denmark is conducted by this method. Trailer dredgers, in contrast, extract the deposit by backward suction through one or two pipes whilst underway, thereby forming shallow furrows on the sea floor (Figure 1B). These are generally 20—30 cm deep and up to 2 m broad. Apart from the Bristol Channel and Liverpool Bay the majority of aggregate dredging in UK waters is now by trailer suction dredger.

In both instances the aggregate and water are piped aboard to the ship's hopper. As the hopper fills, the aggregate displaces the water, which overflows back to the sea, carrying with it suspended mud and silt, and forming a turbidity plume. On some dredgers, screening of the aggregate is carried out and excess sand or pebbles are returned to the sea floor to maintain a specific sand to pebble ratio in the cargo.

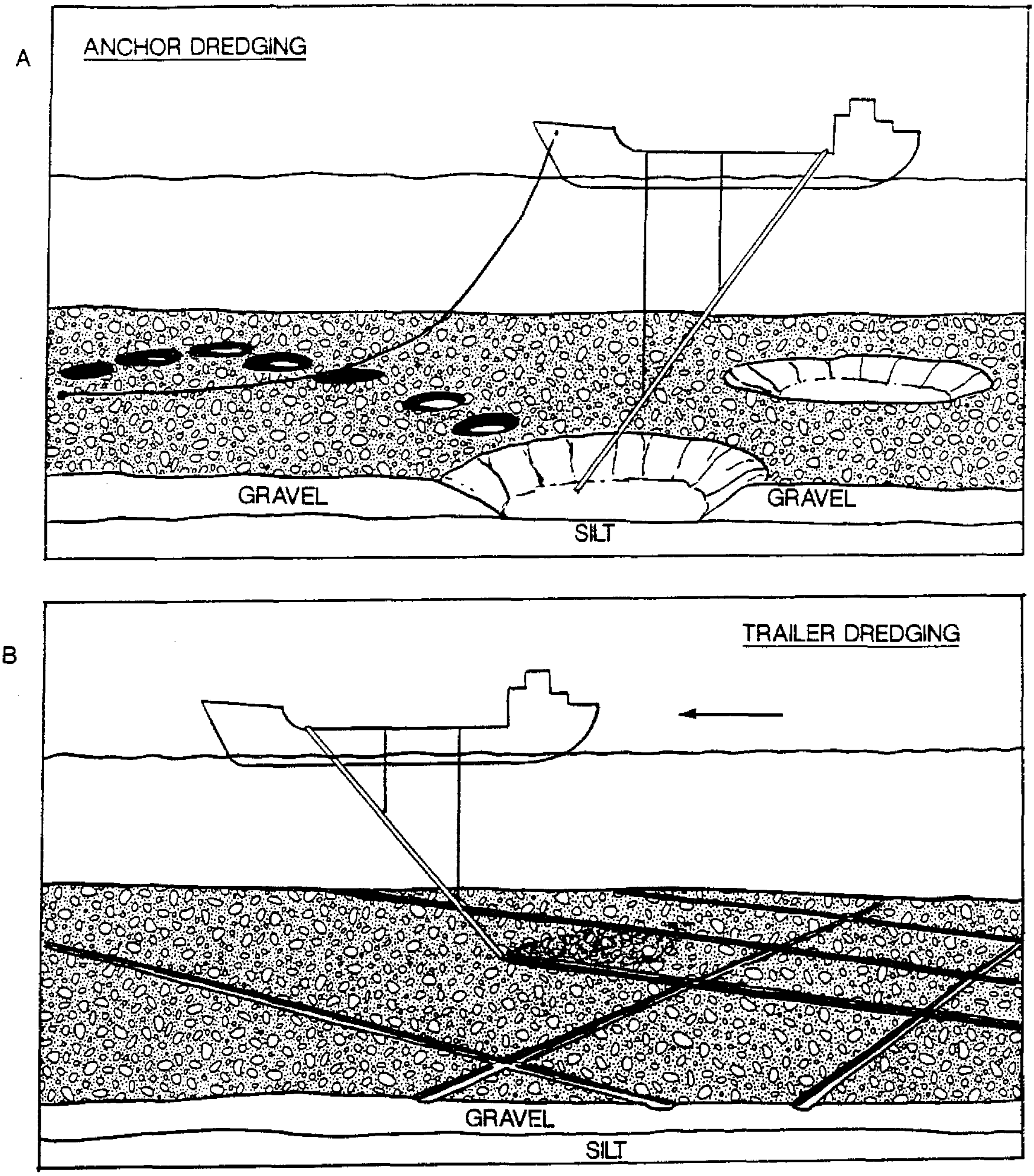

Figure 1 Commonly practised methods of dredging for marine aggregate. A: Anchor Dredging. B: Trailer Dredging.

The most serious physical impacts resulting from these activities are:

a) substrate removal and alteration of the bottom topography;

b) creation of turbidity plumes in the water column;

c) redeposition of fines from turbidity plumes;

d) oversanding and other problems related to screening.

a) Substrate removal and alteration of the bottom topography

The most obvious impact of sand and gravel extraction is the removal of the substrate and the resulting destruction of its infaunal and epifaunal biota. Once created, infill of the pits and furrows is dependent upon the ability of bottom currents to move the surrounding sediment. Except in areas of mobile sand this tends to occur very slowly (Eden, 1975). For example, Van der Veer *et al.* (1985) describe the recovery of pits formed in sandy substrates in the Dutch Wadden Sea. Those situated in tidal channels filled within one year of formation whilst others in tidal watersheds took five to ten years to fill and those dug in tidal flat areas were still visible after fifteen years.

Dickson and Lee (1973) and Millner *et al.* (1977) studied the recovery of test pits and furrows dredged in gravel in the Hastings Shingle Bank and the Southwold area, respectively. They found that even furrows which were only 20 - 30 cm deep when formed were still clearly visible on sector-scan sonar records made up to four years later. Shear stress measurements taken in both areas showed that even the strongest tidal currents are incapable of transporting gravel from the adjacent sea floor into the depressions. Infill therefore occurs extremely slowly, largely through sediment fallout from suspension. Long-term dredging of an area will result in the sea floor being cratered or traversed by numerous furrows.

A further implication of the formation of a pit, or the removal of a significant thickness of sediment by trailer dredging, is a localized drop in current strength associated with the increase in water depth. This results in reduced strength of the bottom currents and hence deposition of finer sediment. Infilling of dredge pits in a variety of settings with sediment finer than that constituting the surrounding substrate has been noted by a number of authors (e.g., Kaplan *et al.*, 1975; Hily, 1983; Van der Veer *et al.*, 1985; this report, Annex 4).

Other consequences of aggregate removal may include oxygen depletion within bottom waters in the depressions (Bonsdorff, 1983; see also Section 3.2), the exposure of a substrate type differing markedly from that above it (see de Groot, 1979a), and the alteration of wave and tidal current patterns which may affect coastal erosion.

Fisheries interests may be seriously affected by the dredging process where spawning grounds coincide with the deposit to be mined (ICES, 1975). A prime example is that of the herring, certain groups of which spawn on stony or gravelly substrates influenced by strong bottom currents in the North Sea and are hence most vulnerable (de Groot, 1979b). Sandeels and edible crabs may be similarly affected. In addition, the uneven sea floor topography created by dredging can cause snagging of long lines and bottom trawls in pits or around boulders exposed by removal of the surrounding substrate (Cruickshank and Hess, 1975). Finally, certain demersal fish species may be affected by the removal of benthos forming part of their food source (ICES, 1975).

Complete benthic recovery in a dredged area may take from one month to fifteen years or more depending upon the stock of colonizing species and their immigration distance (Bonsdorff, 1983). De Groot (1979a) has estimated that, subsequent to large-scale sand dredging in the North Sea, full benthic recovery may be expected to occur in three years.

b) Creation of turbidity plumes in the water column

An increase in water turbidity is associated with the dredging process, the magnitude of which is related to the proportion of mud and silt in the aggregate and the natural turbidity of the water. The duration of the plume in the water column depends upon factors such as water temperature, salinity, current speed, and the size range of the suspended material. Eight- to one hundred-fold increases in turbidity during different dredging activities have been recorded by various authors (Collinson and Rees, 1978; Poiner and Kennedy, 1984; Van der Veer *et al.*, 1985).

The main implications for fisheries have been outlined by de Groot (1979a). Avoidance of the turbid area by visual feeders such as mackerel and turbot may occur. Alternatively, some fish species may be attracted to the area by the "odour stream" of the crushed benthos. Similarly, primary productivity within the water column may be either increased or decreased depending upon the ability of the feeding zooplankton to deal with the increase in nutrients and other suspended material.

In high energy areas close to eroding coastlines, such as parts of the North Sea and the Bay of Fundy, few problems are anticipated from turbidity caused by outwash fines owing to high natural background levels of turbidity. For example dredging in Dutch waters is expected to cause an increase in turbidity due to overflow fines of 3 mg l^{-1} during maximum tidal current conditions and 32

A

B

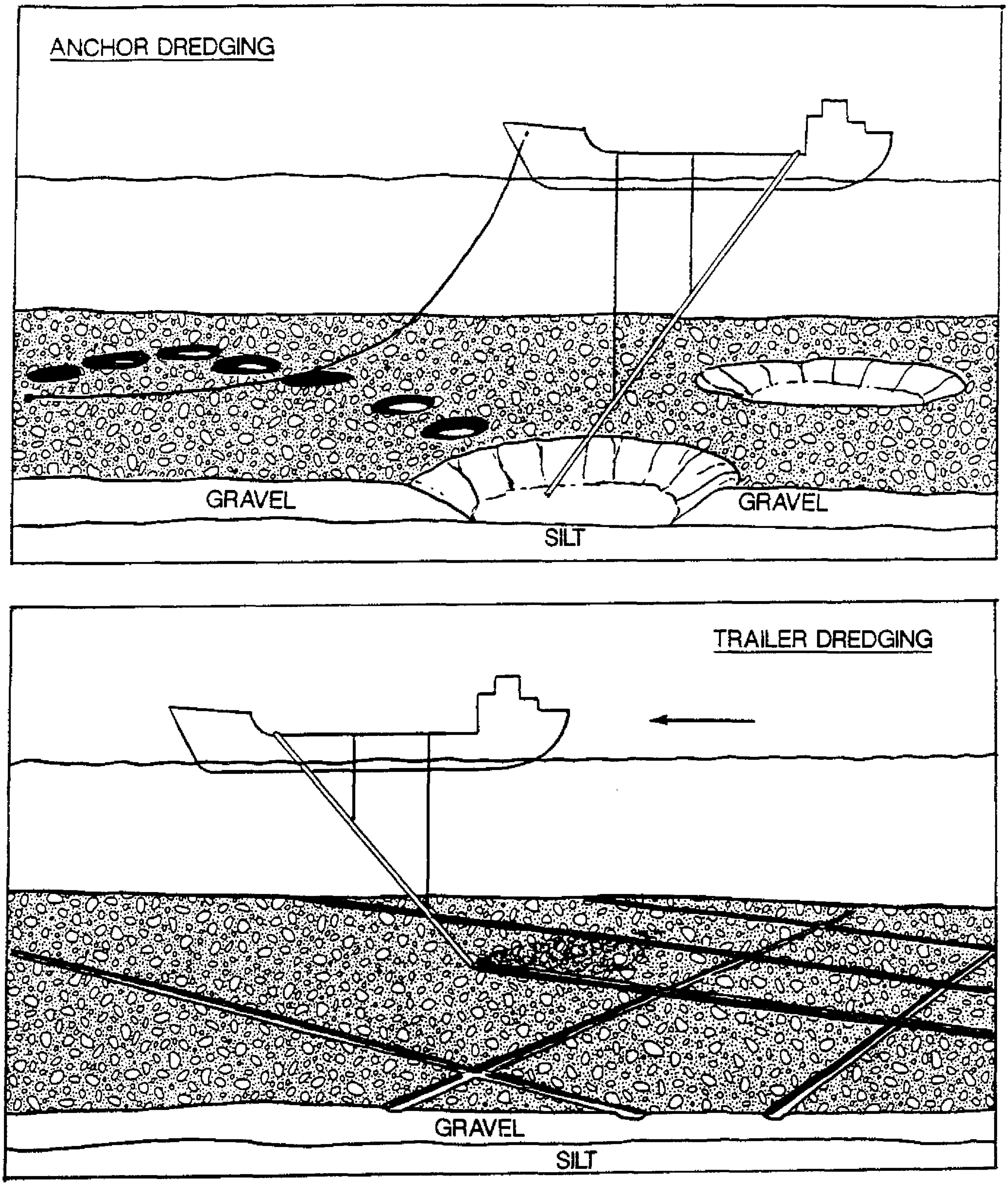

Figure 1 Commonly practised methods of dredging for marine aggregate. A: Anchor Dredging. B: Trailer Dredging.

The most serious physical impacts resulting from these activities are:

a) substrate removal and alteration of the bottom topography;

b) creation of turbidity plumes in the water column;

c) redeposition of fines from turbidity plumes;

d) oversanding and other problems related to screening.

a) Substrate removal and alteration of the bottom topography

The most obvious impact of sand and gravel extraction is the removal of the substrate and the resulting destruction of its infaunal and epifaunal biota. Once created, infill of the pits and furrows is dependent upon the ability of bottom currents to move the surrounding sediment. Except in areas of mobile sand this tends to occur very slowly (Eden, 1975). For example, Van der Veer *et al.* (1985) describe the recovery of pits formed in sandy substrates in the Dutch Wadden Sea. Those situated in tidal channels filled within one year of formation whilst others in tidal watersheds took five to ten years to fill and those dug in tidal flat areas were still visible after fifteen years.

Dickson and Lee (1973) and Millner *et al.* (1977) studied the recovery of test pits and furrows dredged in gravel in the Hastings Shingle Bank and the Southwold area, respectively. They found that even furrows which were only 20 - 30 cm deep when formed were still clearly visible on sector-scan sonar records made up to four years later. Shear stress measurements taken in both areas showed that even the strongest tidal currents are incapable of transporting gravel from the adjacent sea floor into the depressions. Infill therefore occurs extremely slowly, largely through sediment fallout from suspension. Long-term dredging of an area will result in the sea floor being cratered or traversed by numerous furrows.

A further implication of the formation of a pit, or the removal of a significant thickness of sediment by trailer dredging, is a localized drop in current strength associated with the increase in water depth. This results in reduced strength of the bottom currents and hence deposition of finer sediment. Infilling of dredge pits in a variety of settings with sediment finer than that constituting the surrounding substrate has been noted by a number of authors (e.g., Kaplan *et al.*, 1975; Hily, 1983; Van der Veer *et al.*, 1985; this report, Annex 4).

Other consequences of aggregate removal may include oxygen depletion within bottom waters in the depressions (Bonsdorff, 1983; see also Section 3.2), the exposure of a substrate type differing markedly from that above it (see de Groot, 1979a), and the alteration of wave and tidal current patterns which may affect coastal erosion.

Fisheries interests may be seriously affected by the dredging process where spawning grounds coincide with the deposit to be mined (ICES, 1975). A prime example is that of the herring, certain groups of which spawn on stony or gravelly substrates influenced by strong bottom currents in the North Sea and are hence most vulnerable (de Groot, 1979b). Sandeels and edible crabs may be similarly affected. In addition, the uneven sea floor topography created by dredging can cause snagging of long lines and bottom trawls in pits or around boulders exposed by removal of the surrounding substrate (Cruickshank and Hess, 1975). Finally, certain demersal fish species may be affected by the removal of benthos forming part of their food source (ICES, 1975).

Complete benthic recovery in a dredged area may take from one month to fifteen years or more depending upon the stock of colonizing species and their immigration distance (Bonsdorff, 1983). De Groot (1979a) has estimated that, subsequent to large-scale sand dredging in the North Sea, full benthic recovery may be expected to occur in three years.

b) Creation of turbidity plumes in the water column

An increase in water turbidity is associated with the dredging process, the magnitude of which is related to the proportion of mud and silt in the aggregate and the natural turbidity of the water. The duration of the plume in the water column depends upon factors such as water temperature, salinity, current speed, and the size range of the suspended material. Eight- to one hundred-fold increases in turbidity during different dredging activities have been recorded by various authors (Collinson and Rees, 1978; Poiner and Kennedy, 1984; Van der Veer *et al.*, 1985).

The main implications for fisheries have been outlined by de Groot (1979a). Avoidance of the turbid area by visual feeders such as mackerel and turbot may occur. Alternatively, some fish species may be attracted to the area by the "odour stream" of the crushed benthos. Similarly, primary productivity within the water column may be either increased or decreased depending upon the ability of the feeding zooplankton to deal with the increase in nutrients and other suspended material.

In high energy areas close to eroding coastlines, such as parts of the North Sea and the Bay of Fundy, few problems are anticipated from turbidity caused by outwash fines owing to high natural background levels of turbidity. For example dredging in Dutch waters is expected to cause an increase in turbidity due to overflow fines of 3 mg l^{-1} during maximum tidal current conditions and 32 mg l^{-1} during slack water conditions (Vink, 1988). This latter value is comparable to that during storm conditions.

c) Redeposition of fines from turbidity plumes

Redeposition of fines will be concentrated within the dredging area but like the turbidity plume will also extend beyond it, depending upon the current strength, storm resuspension, water salinity and temperature, and the grain size of the suspended material. Once settled on the sea floor, the sediment will still be liable to resuspension or transport over the substrate, although on gravelly or rocky substrates it will tend to accumulate in crevices and behind stones and other projections, where currents are weakest.

The prime risks of redeposition are the smothering of fish eggs on spawning grounds, such as those of the herring and sandeel, and the suffocation of filter-feeding benthos such as mussels (see Collinson and Rees, 1978). In addition, certain shellfish such as lobsters may be put at risk by habitat loss through silting up of the crevices in which they live, and edible crabs which become torpid while brooding may be especially susceptible to smothering and suffocation by sediment fallout (Howard, 1982).

d) Oversanding and other problems related to screening

The practice of screening out sand directly back to the sea floor may significantly alter the substrate and change a stable gravel bank into an area of mobile sand. Whether this process will be adopted much by the extraction industry is open to question, as the sand cover so formed will, with time, prohibit trailer dredging of deeper gravel deposits (Nunny and Chillingworth, 1986). Little research has been carried out on the effects on fisheries interests of oversanding, but it is anticipated that the fauna colonizing the sand deposits could be relatively sparse or have a different species or size composition compared with the benthic communities that previously inhabited the gravel floor (this report, Annex 4).

Hypothetically, the converse case may arise where pebbles and boulders are returned to the sea to maintain an ideal gravel mix on ships. In this case the newly formed pebble and cobble layer would be completely immobile, and benthic recovery should occur once silt and sand have infilled the interstices between the stones.

In summary, the potential physical impact of sand and gravel extraction is site-specific depending upon numerous factors such as the extraction method employed, bottom current strength, sediment mobility and bottom topography.

3.2 Nature of the Chemical Impact on Seabed and Water Column

The bulk of aggregates are sands and gravels which because of their composition, low surface area, and low surface activity show little chemical interaction with the water column. The components of aggregates which may have some effect are the organic material and clays. However, as aggregate of marketable quality is low in these materials, the effects are of only minor importance.

Aggregate dredging can have marked physical impacts on the seabed and water column, as discussed in Section 3.1, and these may result in some chemical effects. First, sediments are disturbed at the seabed, resulting in mixing of the sediment with the overlying water and, secondly, fine sediments are discharged to the water surface as overflow during processing. A third physical effect is the mixing of sediment particles with water in the suction pipe.

The disturbance of sediment at the seabed will result in the mixing of interstitial waters with sea water and thus the possible release of chemical components from sediment to the overlying sea water. The composition of the interstitial water is likely to be most strongly affected by organic matter within the sediments. For example, the decomposition of this material can lead to *inter alia* nutrient and metal release from particulate to dissolved phases.

Decomposition of organic matter, desorption of components from organic matter and clay minerals, and dissolution of soluble material may also occur when sediment particles and water are mixed by disturbance, uptake, or discharge. The effects of mixing on the water column are likely to include increased consumption of oxygen by decomposing organic matter and release of nutrients (de Groot, 1979a) and metals by the same. As an example, assuming trailer suction during one hour, covering an area of 1500 m by 200 m extracting 5000 m^3, with a specific weight of 1.6 t m^{-3}, containing 5% by weight of particles smaller than 80 microns, it has been calculated that, if the overflow fines contained 1 tonne of material which could be mineralized, then the oxygen consumption would be about 0.03 mg O_2 l^{-1} h^{-1} (Anon., 1990). On the other hand, suspended clay minerals, owing to their surface activity, may act as surface adsorbents of some dissolved species, e.g., trace metals.

However, it must be re-emphasized that the chemical effects of aggregate dredging are likely to be minor on account of the very low organic and clay mineral content of the sediments. In addition, dredging operations are generally of limited spatial extent and only of short duration, which further limits the chemical impact.

3.3 Identification of Biological Targets and the Nature of the Biological Impacts

Dredging activities cause changes in the existing biological community. The impacts range from a temporary reversion of a small area of seabed to an earlier stage of succession to, at the other extreme, permanent changes in the community structure, including the elimination of some species. In the following sections the nature and significance of these changes are examined and vulnerable species identified.

3.3.1 Less sensitive communities and species

Recovery or readjustment[1] of a benthic community after dredging depends primarily upon the nature, magnitude, and duration of the dredging operation, the nature of the new sediment which is exposed or subsequently accumulates at the extraction site, the larval and adult pool of potential new colonizers, and the nature and intensity of the stresses which the community normally withstands.

The influence of these factors will be looked at in turn, prior to consideration of which communities and species may be least sensitive to this form of disturbance. Finally, benthic sensitivity to sediment redeposition from the dredger's outwash will be discussed briefly.

a) Nature and magnitude of dredging operation

It is obvious that the scale of any dredging operation significantly influences the severity of its impact upon the benthic community: the more extensive the operation the greater the initial defaunation and the greater the immigration distance colonizing species must travel. Within a shipping channel in Coos Bay, Oregon, studies by McCauley *et al.* (1977) of a maintenance dredging operation at one site revealed that sediment had not been removed uniformly from the channel floor by the suction head. Instead, as a result of imprecise ship navigation and a low number of passes, furrows were created, separated by undisturbed hummocks of sediment, containing adult populations of benthic organisms capable of repopulating the dredged furrows. The result was, naturally, a high variability in faunal density ("replicate" grabs revealed 6 organisms/1000 cc and 937 organisms/1000 cc sediment, respectively!) but, more importantly, readjustment progressed twice as rapidly at this station, because of the immediate proximity of dredged tracks and undredged hummocks, as at other stations where sediment removal was more extensive, and the site has even returned to its pre-dredging condition.

The mode of dredging too is important — the immediate impact of anchor dredging upon the sea floor and its biota is severe but localized whilst that of trailer dredging is less profound but more widespread (Dickson and Lee, 1973; Cruickshank and Hess, 1975). In general, the latter method is to be preferred as it is more likely to leave the sea floor in a condition similar to its pre-dredged state and hence more suitable for recolonization by the ambient fauna. Moreover, as water circulation is usually reduced within anchor dredge pits, periodic or long-term oxygen depletion within the bottom waters in the pits may result, thereby inhibiting faunal development (Bonsdorff, 1983; Oulasvirta *et al.*, 1987).

"Stone fishing" is a distinct form of dredging activity practised in some Scandinavian countries whereby large boulders of glacial origin are removed by grab from the seabed to be used for coastal protection or breakwater construction purposes. These boulders are generally extracted from shallow sea areas of substantial biological value. The boulders, which occur as erratics upon finer glacial deposits, are essential habitats for large species of algae such as *Laminaria* and act as shelters and breeding areas for certain species as well as feeding grounds for fish, seabirds, etc. Very little is known at present about the consequence of removing them and much future research is necessary. However, their probable importance may be compared with the importance to birds of random tree refuges in open fields on land.

b) Nature of new sediment in extraction site

The character of the sediment which is exposed or subsequently accumulates in the extraction site after dredging is completed significantly controls the structure and composition of the colonizing benthic community. If the composition and topography of the exposed or accumulating substrate resemble that which originally existed, then recolonization of it by the same bottom fauna may also proceed (e.g., see Windom, 1976). This may occur if a finite thickness of sediment is removed uniformly over a large area of the dredging ground, exposing sediments similar to those which originally existed. Such mining strategy would consequently appear prudent in minimizing environmental impact, though in practice the precise navigation necessary may be difficult to exercise (see Nunny and Chillingworth, 1986, p.114).

[1] McCauley *et al.* (1977) have proposed that the term "readjustment" be used instead of "recovery" when describing the consequences of dredging activity upon a benthic community, as the community may never "recover" to the stable state in which it existed prior to dredging. Herin the term "recover" is used only when it has been demonstrated that a benthic community has returned to its pre-dredging condition.

The more typical consequence of suction dredging is the creation in the substrate of numerous furrows or pits. Sediment may accumulate in these dredge pits or tracks by one or more of the following means:

i) through bedload transport of mobile sand;

ii) by natural deposition of fines from the water column;

iii) through slumping of the pit walls;

iv) by deposition of outwash fines from the dredger.

Of these, infill by transport of mobile sand into the dredge pit or track is the most rapid and dominant process, if the dredge site is located in an area of active sand transport. By contrast, pit infill in sites outside of such areas is generally very slow (Eden, 1975). Indeed, complete and rapid regeneration of a dredged deposit to its former state tends to occur only in areas of mobile sand transport. This is because the current regime which acts upon the extraction site after removal of the sediment is frequently dissimilar to the one which laid down the deposit originally. Gravel deposits are a prime example. The majority of these on the northeast North American and northwest European continental shelves were deposited by fluvial and fluvio-glacial processes during the Quaternary, when sea level was considerably lower than at present, and then submerged as the sea level rose again (Anderton *et al.*, 1979, p.272; Reineck and Singh, 1980, p.413). The tidal currents which now affect the gravel are too weak to transport the pebbles, and so once the aggregate is removed only silt or sand may accumulate in its place (e.g., this report, Annex 4).

Shelton and Rolfe (1972) and Millner *et al.* (1977) have studied the fauna of dredged gravel substrates in the southern North Sea and English Channel. Dredge pits and tracks excavated up to four years before their surveys were still recognizable on side-scan records even though certain dredge tracks had been only 30 cm deep when formed. Such infill as had occurred was generally of silt or sand. Shelton and Rolfe further noted that the fauna colonizing the new substrates were characteristic of the introduced sediment type and thus differed from the biota colonizing adjacent undredged gravel substrates. A similar relationship has also been observed for the fauna colonizing a gravel extraction site off Dieppe (this report, Annex 4).

In areas of active sedimentation the dredging activity itself may sufficiently alter the sea-floor topography or increase water depth such that currents will slow down over the dredged tracks or pits, thereby causing deposition of finer sediment. This process has been noted by Kaplan *et al.* (1975), Hily (1983), and Van de Veer *et al.* (1985) as a result of various dredging and extraction operations. Again, changes in species composition of the colonizing benthic community, where this was studied, resulted from and, in general, reflected the changes in substrate type.

A final example of the effect on benthic community type of altering the substrate through sand extraction is described by de Groot (1979a). In a small area of the Seine Bay, sand and gravel overlying a rocky substrate were removed by French scientists and the recolonization process was studied. No deposition of sediment upon the exposed pebbly and rocky ground occurred and, as a result, a hard-ground fauna subsequently developed which had less food value for demersal fish species than the previous soft-bottom fauna. In this particular example it was concluded that more widespread dredging might seriously affect local fish stocks. In practice, however, a gravel or sand deposit will never be removed entirely by dredging because the removal of the last part of the resource would be uneconomic.

In contrast to the aforementioned situations in which dredging results in development of an altered substrate type, extraction of sediment from areas of mobile sand has a far more transient effect on sea-floor topography. Infill of the excavated site is of sediment similar to that removed by the dredger and hence the colonizing benthic community is similar in composition to that originally present. The timescale of benthic recovery is also reduced; Van der Veer *et al.* (1985) recorded readjustment of benthos following dredging in sub-environments of the estuarine Dutch Wadden Sea. In one tidal channel, pit infill and benthic recovery occurred within a year of excavation. In contrast, dredge pits on tidal flats, where rates of sediment transport were much lower, were not completely infilled even after eleven years.

c) <u>The stock of colonizing species</u>

With the exception of certain errant epifaunal species or deep-burrowing biota which might display avoidance reactions to an oncoming draghead, dredging may result, initially, in complete defaunation within the dredged pits. The subsequent pattern of colonization may therefore be similar to that which ensues after the abatement of organic pollution (Hily, 1983) or severe storms (Millner *et al.*, 1977). Classically, this proceeds with an influx of "opportunistic" species and then, assuming no further dredging occurs, succession proceeds towards a more diverse and stable community dominated by larger, long-lived, species. If, however, dredging continues periodically, succession may be impeded so that opportunistic species continue to predominate. The precise composition of the communities then depends upon the supply of adult and larval species to the extraction site and their suitability for living in it (Wildish, 1977).

Naturally, the adult species most readily available for immediate colonization of the newly exposed sediment will be mobile epibionts inhabiting adjacent undisturbed sediments. Indeed, the disturbance of the sediment caused by dredging may have the immediate effect of increasing food availability to epifaunal scavengers and carnivores, attracted by the presence of crushed and injured biota left in the wake of the dredgehead. Mature sessile epibionts and infaunal species, by contrast, will be unable to exploit the dredged area immediately except where slumping of the pit walls or survival following storm redistribution occurs.

The potential for colonization through larval recruitment is less tightly constrained by proximity of undisturbed communities and the habits of the species concerned. A wide range of benthic species are planktonic as larvae, and so immigration by such species is more dependent upon current direction and velocity and the species composition of the substrates over which they flow, the time of year at which larvae are shed, and the duration of the planktonic stage (Wildish, 1977). Because, however, many sessile biota such as corals and erect hydroids and bryozoa take a number of years to reach maturity, stabilization of a community in which they form a part may still be prolonged (see Rees, 1987).

One further potential source of both adult and juvenile biota is from the overflow of the dredger itself (Van der Veer *et al.*, 1985). It is likely that small, shelled organisms such as certain bivalves and gastropods will be most resistant to the turbulence inflicted by the suction process and so will have a greater potential for survival.

Thus different faunal groups are variously suited to colonizing a dredged area, depending upon their abundance in surrounding undisturbed grounds, their ability to migrate into it as adults or settle onto it from the water column as larvae, and their suitability for living in the sediment accumulating there.

d) Recovery potential of benthic communities in "high stress" areas

Soft sediment communities in areas exposed to strong tidal currents and/or periodic storm disturbance are often dominated by short-lived "opportunistic" colonizers, at least in surface layers.

Studies of the consequences of dredging upon such communities indicate that they are more adept at readjustment to the impact of dredging operations than are more stable and diverse communities. For instance, in their study of the effect upon benthic infauna of maintenance dredging within a busy shipping channel in Coos Bay, Oregon, McCauley *et al.* (1977) noted that, in addition to the impact of periodic dredging, the community was subject to disturbance through tidal scour, propwash from passing marine traffic, and discharge of industrial, domestic, and shipping wastes. Readjustment by the benthic community to pre-dredging conditions occurred within 28 days, a consequence, the authors suggested, of the community's being suitably adapted to a naturally stressful environment.

Similarly, certain infaunal species inhabiting shifting sand deposits such as sand waves, bars, and megaripples may be capable of withstanding displacement from the sandy substrate during storms and so are conditioned to deal with stressful physical impacts. Such communities therefore will be less severely affected by mining operations than those on more stable substrates (see de Groot, 1979a).

Summary of Benthic Sensitivity to Sediment Removal

It is clear that many factors influence the ability of a benthic community to readjust to the stresses of sand and gravel extraction or dredging, the most important of which have been outlined above.

With respect to the impact of such operations on the benthic ecosystems of the northwest European continental shelf, the least sensitive communities are those inhabiting continuously reworked or mobile sand deposits such as sand waves or sand bars.

Few benthic species in the immediate path of the draghead are insensitive to the dredging operations save those resilient enough to withstand suction onto the dredger, followed by settlement from the ship's overflow, such as certain small thick-shelled molluscs, and those deep-burrowers and mobile epifaunal species capable of displaying fast avoidance reactions. Even those opportunistic species which may proliferate upon a newly dredged track or pit can only remain dominant whilst instability of the community continues, for instance through repeated dredging. Otherwise it may be anticipated that the community will mature and stabilize to its pre-dredged state, provided that the new substrate and hydrodynamic conditions resemble those which originally existed at the site (Augris and Cressard, 1984).

Thus, with the exception of those groups of organisms cited above, no benthic species are insensitive in themselves to disturbance by sand and gravel extraction; they must instead rely upon cessation of the dredging operation, physical recovery of the dredging ground to its previous state, and an adequate supply of colonizing individuals, from adjacent undisturbed grounds or through larval recruitment, before they can fully re-establish themselves.

Benthic Sensitivity to Sediment Redeposition

Where studies have been carried out of benthic recolonization following dredging in areas subject to sediment fallout from the ship's overflow but not directly disrupted by dredging itself, the impact upon the ecosystem has been observed to take one of four forms:

a) defaunation within the affected area is initially virtually complete, similar to that in the dredging ground itself, but recolonization progresses more rapidly (e.g., Oulasvirta *et al.*, 1987);

b) defaunation is less pronounced than in the dredging ground and recolonization is more rapid (e.g., McCauley *et al.*, 1977);

c) species richness and abundance is enhanced in the area of sediment fallout (e.g., Poiner and Kennedy, 1984);

d) negligible effect is detected (e.g., Millner *et al.*, 1977).

Thus, the impact upon the benthic ecosystem of sediment redeposition is not normally so severe as that resulting from the direct removal of the substrate and its indigenous fauna. Benthic species least sensitive to such deposition will naturally be species capable of burrowing rapidly through the sediment and most motile epifauna. The degree to which they cope with the sediment influx will depend upon the taxa, the amount of the influx, and the rate of sedimentation.

Sessile epibionts generally have greater difficulty withstanding increased turbidity and sediment deposition. However, as such species predominate on gravelly and rocky substrates, the strength of the currents in such areas could well be strong enough to transport most fine material elsewhere, ameliorating its effect. Only shellfish species which reside within rock crevices, for example, may be affected through habitat loss resulting from accumulation of the sediment in such places (see Howard, 1982).

It has been proposed that the effects of sediment redeposition at an extraction site in the southern North Sea should be minimal owing to the natural high turbidity of the area (Millner *et al.*, 1977). The corollary that detrimental effects should be enhanced where water clarity is greatest does not necessarily hold true, however; Poiner and Kennedy (1984) found that species richness and abundance actually increased within the region of sediment deposition from a turbidity plume resulting from dredging of a sublittoral sand bank off Queensland, Australia. The cause of this, they suggested, was that the redeposited sediment represented an increase in resource availability upon the sea floor which was sufficient to enhance the biota yet was not so pronounced as to smother them. Turbidity levels before and after dredging averaged 3 mg l^{-1}, increasing to 25 mg l^{-1} during the operation.

Thus the magnitude of the effect of sediment redeposition upon a benthic ecosystem depends largely on the nature of the indigenous fauna, the deposition rate, and the increase in water turbidity relative to the region's natural turbidity.

3.3.2 Sensitive species and communities

Certain marine species, because of the substrates upon which they live or their choice of breeding or spawning grounds, may be particularly vulnerable if aggregate extraction activities coincide with these areas. In the following section the potential risk to five such species, which are also of commercial value, is discussed.

a) Sandeels

The sandeel is a non-migratory species to which dredging clearly poses a threat where there is a major industrial fishery based on a few restricted areas of the seabed. According to the first ICES report on sand and gravel extraction (Anon., 1975) Danish and British fisheries for this species exist between 53°–54°N and west of 3°E, which coincides with one of the major gravel deposit areas.

Sandeels lay their eggs in the sand, and sand grains of a certain size adhere to them. When the eggs are fully covered with fine material, the development of the embryo will be arrested. The outwash fines released during dredging may result in a less successful hatching. Therefore, it is advisable that dredging not be allowed during the spawning season of the sandeel in any area where there is an important fishery for this species. On the other hand, sandeels contribute to the diet of many important gadoid species as well as the turbot. The value of the sandeel as fish food is therefore likely to be indirectly much greater and more important than the landings of this species for the fishmeal industry of Denmark or the UK.

Since 1973 sandeel catches from ICES Divisions IVb and IVc (Central and Southern North Sea, respectively) have been on the decline while those from Division IVa (Northern North Sea) have increased.

The diurnal habits of the sandeel make them more vulnerable to dredging than nearly any other fish species. Feeding and swimming activity is limited by light, and when the fish cannot feed, they remain in the sand, either completely buried or partially emerged (Winslade, 1974). Therefore the fishery on this species takes place only during the daylight hours, catches at night being very small (Macer, 1966).

Still, it must be possible for the two industries to work side by side in a harmonious manner, if the knowledge of both parties is brought together to reduce the effects of dredging.

b) Herring

Harmful consequences for the herring and its fisheries from the impact of the dredging of its spawning grounds were pointed out at the first meetings of the ICES Working Group on Effects of Marine Sand and Gravel Extraction (ICES, 1975; 1977).

The herring, *Clupea harengus* L., is found on both sides of the Atlantic within the North Boreal zone. The herring can be divided into seven main races which spawn in different seasons and on different grounds. Spawning populations on certain banks on the west central North Sea and the "Downs" in the English Channel are directly affected by marine gravel mining.

Herring lay demersal eggs which adhere to stones or gravel (Bolster and Bridger, 1957; Parrish *et al.*, 1959; Hemmings, 1965; Drapeau, 1973; Dorel and Maucorps, 1976; and Oulasvirta *et al.*, 1987) or algae (Tibbo *et al.*, 1963), and the spawning beds are small. Bolster and Bridger (1957), for example, found that the spawn of the Downs herring was generally attached to flints, 2.5–25 cm in length, where these occurred over gravel; the heaviest concentration was found within an area 3.5 km long and 400 m wide. The average composition of the sediment was boulders 42.2%, gravel 34.0%, and sand 23.8% (Dorel and Maucorps, 1976). Spawning on seaweed, such as green algae or *Fucus* spp, accentuates the environmental requirements of the herring, because seaweeds thrive in clear water with a high current velocity. Not only is the fact that herring spawn on gravel of importance, but also that in a gravel area they select certain specific gravel beds year after year (Harden Jones, 1968). The majority of recruits spawn on the parent ground, but the data are not conclusive, and it is difficult to prove, if at all, that recruits are survivors of a particular group of larvae hatched in a certain spawning area. It is also very difficult to determine how herring returning to the spawning ground recognize the old spawning (hatching) site.

From all that is mentioned above it is clear that changes in the structure of the spawning ground, caused by dredging, will negatively influence the return of herring to the spawning sites, and therefore their successful reproduction, to a high degree. In addition, excessive siltation could smother eggs during the period of incubation (Hildebrand, 1963).

c) Coregonids

Abundant stocks of coregonid fishes occur in the brackish waters of the northern Baltic Sea. The sea-spawning species present are whitefish (*Coregonus lavaretus* Malgren) and vendace (*C. albula* L.). Both species spawn on sand, gravel, and pebble surfaces in water between 1 m and 5 m deep. However, the exact location of many spawning sites is unknown.

For the first two months after hatching the larvae live in shallow-water, sandy areas. On reaching approximately 5—6 cm in length, the fish leave the nursery areas and move to deeper water overlying sand, gravel, or stony bottoms.

The coregonids are fished as intensively as the herring which also spawn in similar areas.

d) *Cancer pagurus* (Edible crab)

Stocks of the edible or brown crab (*Cancer pagurus*) in the English Channel support important fisheries based at numerous ports in England, France, and the Channel Islands. From the English viewpoint, Channel crab landings represent 70% of total crab landings in England and Wales, and contribute approximately £4 million to the total first-sale value of £22 million for England and Wales shellfish as a whole.

Most of the Channel crab catches come from west of the Isle of Wight, and in the last ten years the Devon and Cornwall fishery has expanded significantly to exploit grounds in mid-Channel. Fishing has also increased, however, east of the Isle of Wight, and although this fishery is still relatively small overall, it is locally important to individual groups of fishermen. Since the eastern Channel is also now seeing an increase in requests for licences to prospect for, or extract, gravel, a conflict of interest has arisen with fishermen over access to the seabed. Shellfish biologists are also concerned about whether gravel dredging could adversely affect crab populations. At present the main areas of conflict are the Shingle Bank, approximately seven miles south of Hastings, where prospecting has suggested that there are large gravel deposits ready for extraction, and the area between Bembridge and Selsey, just east of the Isle of Wight, where extraction has already disturbed the seabed and where other prospecting is going on or is planned. The present concern for these areas dates from about 1985.

Fishery studies in the western Channel show that the main fishery occurs in the autumn, when the catch is predominantly ripe females which tagging shows to have migrated westwards (Brown and Bennett, 1980; Bennett and Brown, 1983). In the small spring catch, males predominate. Biological studies show that at the onset of winter mature females cease feeding and enter an over-wintering phase during which the eggs are extruded and then brooded under the abdomen until they are released the following June (Edwards, 1979). Ovigerous crabs cannot be caught in pots, and chance diving observations suggest that at this life history stage crabs may seek the protection of rocky outcrops and ledges in deep water (Howard, 1982).

Preliminary studies at Shingle Bank show that the crab fishery there is also based mainly on a seasonally high catch rate of mature female crabs in autumn. Local wreck divers also report seeing ovigerous crabs dormant at several sites in the vicinity in winter. Log-book data suggest that the distribution of autumn catches shifts progressively westwards and, taken together, the evidence suggests an underlying biological pattern similar to that in the western Channel. This suggests in turn that eastern Channel gravel beds support overwintering concentrations of ovigerous crabs vulnerable to seabed disturbance during dredging.

This has been accepted as a basis for interim restrictions on dredging at Shingle Bank. The aim is to limit the amount of gravel removed, and to confine dredging to that part of Shingle Bank least likely to be a crab wintering ground.

Preliminary studies at Shingle Bank have involved using divers, suspended cameras, and a remote observations vehicle (ROV).

Results from two plankton cruises in the English Channel in summer 1981 show that some crab larvae were present in the Royal Sovereign area that year, however, and it is hoped that a planned crab larval survey will describe and pinpoint eastern Channel crab larval populations in more detail. In the meantime local fishermen have been asked to monitor their catches using log books in order to watch for any unexpected changes once gravel extraction begins.

e) Maërl and maërl infaunal communities

The commercial exploitation of marine calcareous algae for use as fertilizers and soil conditioners is based on deposits of the rhodolith-forming members of the Corallinaceae which are collectively known as maërl. Interest is centred on deposits off the coasts of France, England, and Ireland where the algae are found in sufficient quantities to make commercial utilization worth while.

Small quantities of maërl have been dredged off the coast of France since at least the 19th century and in 1984 the amount had increased to 5.25 x 10^5 m^3. No large-scale extractions have taken place off the coasts of either England or Ireland, although proposals to dredge for maërl are being considered in both countries.

Systematics and Structure

The two species which predominate in maërl deposits in southern boreal waters are *Lithothamnium corallioides* Crouan and *Phymatolithon calcareum* (Pallas) Areschoug.

Both species have a branching calcareous thallus or rhodolith which can vary considerably both in size and shape depending on age and exposure to water movement. Examples of the range of shapes which occur naturally are given in Cabioch (1970) and Blunden *et al.* (1975). The characteristic coloration of living maërl is a reddish-purple, but the dead algae which form the basis of the material extracted for fertilizers turn a yellowish or greyish-white colour after they have been broken down and abraded by the sea.

Distribution

Maërl-forming species of algae are widely distributed throughout the North Atlantic (Adey and Adey, 1973) although they only occur abundantly in a rather limited number of areas where the environmental conditions are suitable. The main requirements for satisfactory growth would appear to be protection from heavy swell, relatively strong currents to prevent smothering by silt, and lack of abrasion from waterborne particles (Cabioch, 1968; Adey and McKibbin, 1970). The limiting factor to depth distribution is the penetration of light for photosynthesis. As a result, in the relatively clear water of the Mediterranean, deposits of maërl occur down to depths of 70 m or greater (Jacquotte, 1962), whereas in the more turbid waters off the coast of Brittany maximum depths appear to be about 20 m (Gautier, 1971).

The distribution of maërl banks around the Brittany coast of France is given in Figure 2, which is based on the more detailed map of Gautier (1971). These banks constitute the most important deposits in terms of commercial exploitation of maërl. More detailed surveys of certain deposits around the coast of Brittany are given in Boillot (1961, 1964) and Cabioch (1968).

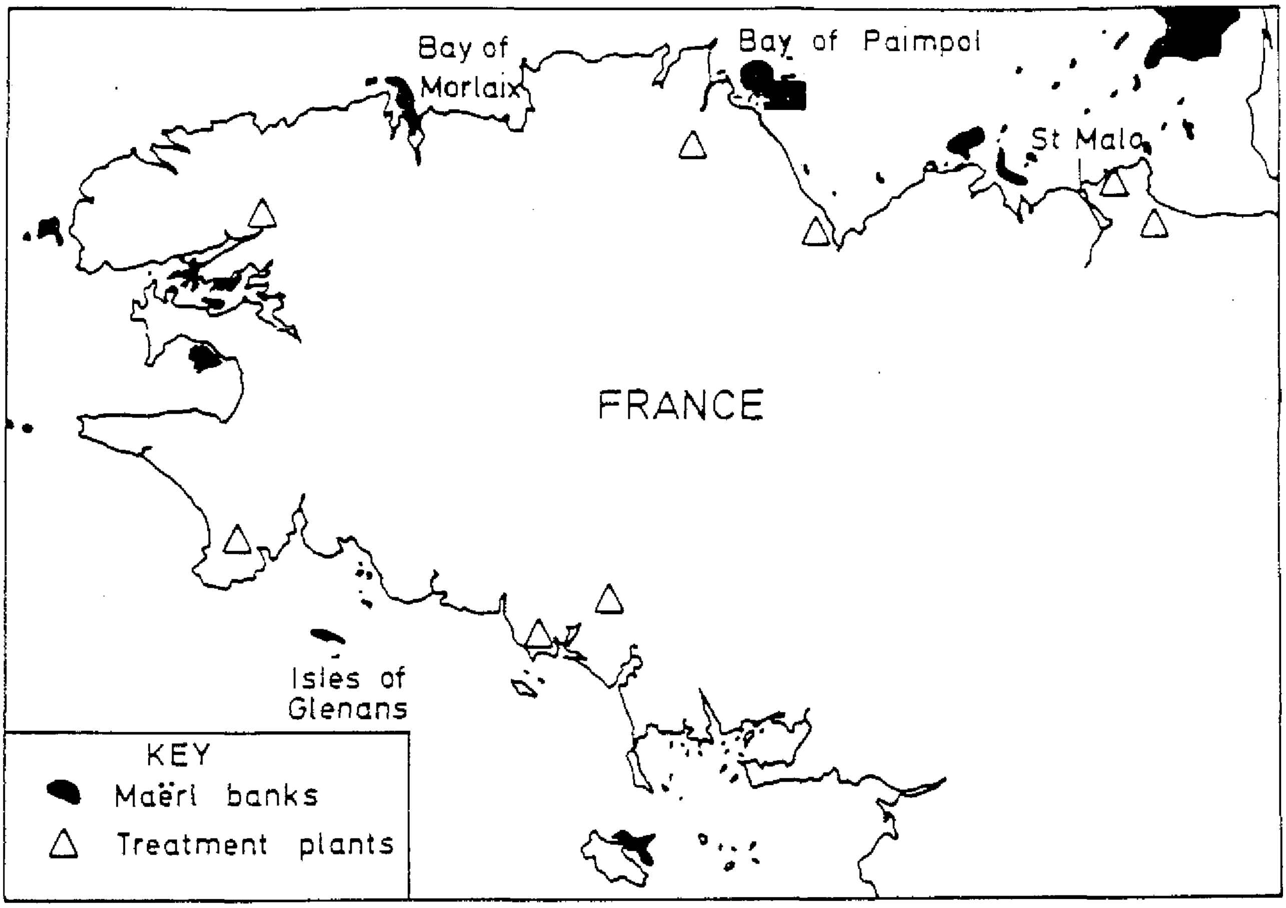

Figure 2 Distribution of maërl banks around the coast of Brittany, France (simplified from Gautier, 1971).

The distribution of maërl sediments around the United Kingdom has not been studied in any detail except for the deposits in the Falmouth area of the English Channel, where commercially exploitable quantities have been found.

Maërl is only found on the west coast of Ireland (Figure 3) and licences to dredge for the material have been submitted for areas around Galway Bay. The distribution of calcareous sediments in Kilkieran Bay on the north shore of Galway Bay has been studied in some detail by Deeny (1975). It is the subject of ongoing research by B. Keegan, UCG, and D. Minchin, Fisheries Research Centre and the Geological Survey. Offshore Canadian calcium carbonate resources were reviewed by Packer (1987).

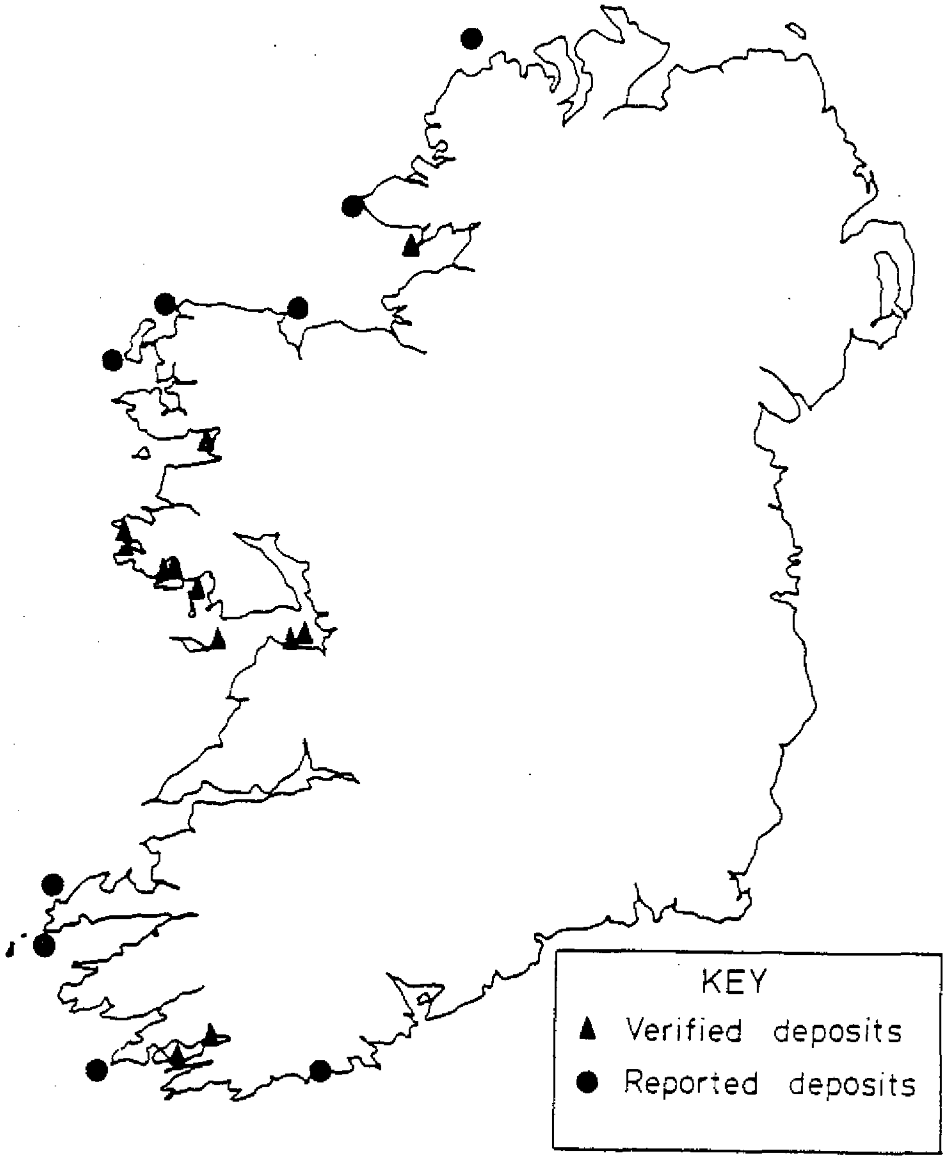

Figure 3 Distribution of maërl deposits around Ireland.

Fauna of Maërl Beds

The dominating factor which affects the animal community associated with maërl deposits is the natural condition of the algae. Deposits of dead material are in general much poorer both in numbers of species and numbers of individuals than the living maërl.

Cabioch (1968) in his study of the Channel fauna and their association with different sediment types suggested that the fauna of living maërl beds was sufficiently different from the animal communities of other sediments to be considered as a separate and extremely rich biocoenosis. However, two communities were distinguished in maërl beds off the north Brittany coast and these bore resemblances to communities from other deposits in the western Channel. Deposits of *Lithothamnium corallioides* var. *corallioides* were associated with an endofauna typical of the *Venus fasciata* community, whereas banks made up of *L. corallioides* var. *minima* contained a community typified by the *Pista instata* community of heterogeneous muds.

Keegan (1974) found a considerable variety of animal groups in association with deposits of *L. corallioides* var. *corallioides* in Galway Bay on the west coast of Ireland. The local characteristics of the deposit, that is, the percentage of living or dead material, position in relation to currents, and associated material such as mud, sand, or shell, were important in determining the faunal community. However, the general pattern was consistent with the findings of Cabioch.

Rolfe (1976), in a brief survey of the Falmouth Bay maërl beds, found the living material to be rich in animal life with over 3814 individuals of 25 species being obtained from the crevices of rhodoliths collected in a single 0.1 m^2 box sample. Crustaceans and small bivalves dominated the samples examined.

In contrast, the dead maërl was relatively poor in numbers of species, although the coarse open matrix and varying amounts of "fines" trapped within it was considered to demonstrate the "specialized ecological habitat that maërl deposits provide".

Effects of Exploitation

The extensive banks of dead algae which form the commercially exploitable deposits are either formed beside the actively growing maërl, as off the coasts of Brittany and Ireland, or appear to be quite separate from the present-day growing areas, as in Falmouth Bay. In both cases the banks require strong currents for their formation and are the result of the collection of dead material over very considerable periods of time.

Replenishment of the banks is likely to be very slow, because maërl species have been observed to grow only about 1 - 2 mm per year (Adey and McKibbin, 1970). Similarly, the formation of new plants occurs largely by the release of reproductive spores, in itself an infrequent and slow process.

In the long term the effect of dredging will be to exhaust all supplies of maërl within the extraction zone. When living maërl is closely associated with dead material, a rich and productive animal community will also be destroyed. The slow growth rate of the species means that replacement of the banks could not be expected in the foreseeable future.

3.4 Estimation of Scale of Effects and Consequences

The scale of effect of sediment extraction projects and corresponding consequences for marine life and fisheries is dependent on the environmental characteristics of the area (for example, the wave and current climate, geology, turbidity, and bathymetry), the nature and extent of the extraction operation, and the time for recovery or readjustment of the benthos.

In principle, an estimation of the scale of effects and consequences is possible for any given site-specific sediment extraction project. For example, intensive studies are being carried out to assess the effects of major dredging operations related to the construction of a fixed link between Zealand and Funen in Denmark (Storebæltsforbindelsen, 1990). As with all marine resource impact assessments, the general approach is to identify those components of the ecosystem which may experience change as a result of the activity, and to conduct a consequence analysis to determine the effect of such changes. Thereafter, predictive models are used in an attempt to quantify any biological effects on the marine ecosystem and in particular on valuable resources such as fisheries. A final stage employed in some marine resource impact assessments is the assessment of the effects on other users of these resources such as fishermen. Such approaches have been used where economic assessments of damage or loss of resources have been necessary or where an activity may have a significant effect in a localized area, such as sea reclamation projects which impinge on coastal shellfish fisheries.

There are no published examples of a complete assessment of any specific sand or gravel extraction project, but in general the approach would identify:

1) the effect of the project on any sensitive spawning areas, in particular discrete and concentrated grounds such as herring spawning grounds;

2) the loss of organisms in the extracted sediments;

3) the effect of deposition of fines lost from the dredger in regard to both:

   a) temporary water column effects of suspended fines on primary production, and

   b) longer-term change in the character of the benthos;

4) the effect of 1), 2), and 3) above on other components of the ecosystem, and in this case on higher trophic levels in the food chain;

5) the effect on the balance between deposition and erosion both in the area in question and in the surrounding areas.

While a number of techniques can be applied for the numerical evaluation of the scale of effects and consequences, it is important to stress that it is unlikely that effects on higher trophic levels in the food chain could be expected to be observed in practice against the background of environmental noise. Indeed, if it were possible to do this, then an immediate conclusion from such monitoring would be that the effects were of such magnitude as to present cause for concern.

Elsewhere in this document (Section 3.3.2) the risks posed to herring and sandeel populations from the extraction of seabed material in areas serving as their spawning grounds are reviewed. An extreme case would be the complete destruction of a sensitive spawning area and the loss of eggs, juveniles, and potential recruits to the fish stock that would otherwise be provided by this area. Given the discrete nature of the herring spawning grounds in the North Sea, an assumption that the loss of future recruits was in direct proportion to the spawning area lost could result in a significant predicted reduction in the size of spawning stock biomass in future years. Although such a simplistic assumption may be contested, it nonetheless illustrates the sensitivity of localized spawning areas for this species. Licensing of such areas for aggregate extraction should be resisted.

The overall immediate loss of biota in the extracted sediments can be approximated from the areal extent of extraction and an analysis of biota in benthic samples representative of the area. While our understanding of the contribution of benthic organisms to the diets of other marine organisms, such as demersal fish species, is not sufficient to provide an accurate determination of the effects of this loss through each component of the food web, it is usual to adopt a simple approximation for food chain efficiency and apply this to each trophic level of a simple food web model (see, for example, French and French, 1989). In some areas a proportion of the benthic biota lost may have a direct value to a commercial shellfish fishery (see below).

The effect of suspended fines of increasing turbidity and hence lowering primary production in the water column can be approximated by a simple dispersion/settling model using averaged current data and any available particle-size distribution data for the discharged fines. Primary production can be reduced accordingly or assumed void in the zone within which higher than background turbidity levels are predicted to occur. While again one can extrapolate the effects of the loss of primary production through a simple food web model, it can be seen that with the available surface area of 575 000 square kilometres in the North Sea the loss of primary production over even a few square kilometres during aggregate extraction operations will be negligible.

Again, the use of a simple dispersion/settling model will enable predictions to be made of the extent of any change to the sediment character of the benthos brought about by the deposition of fines, which may similarly be extrapolated through a food web model.

Assessment of direct losses to fishermen arising from sand and gravel extraction activities depends entirely on the fishery concerned and the nature of effects on it. Extraction operations on a commercial shellfish ground may directly destroy potential catches that would otherwise be taken by commercial fishing. Here a direct assessment would be made of the loss to the fishery and to the fishermen exploiting this ground until full recovery was anticipated. With finfish fisheries the plume of suspended fines does result in avoidance behaviour by some species. The loss argued by some fishermen in these circumstances is in the nature of a loss of access to traditional grounds rather than a direct loss of fish. The fish (like the fishermen) are merely redistributed elsewhere. In some circumstances fishermen know that a discrete area supports an important, local seasonal fishery of migrating fish. Any redistribution of fish or fishermen may have economic consequences for local vessels, and the best approach in these circumstances is to time extraction operations so as to permit access to fishermen during this seasonal window. Annex 2 provides a worked example of the effects of aggregate extraction in the North Sea as a simple illustration of the method described above.

3.5 Fishing Activity (Trawling) as a Physical Impact

The trawling of fishing gear over the seabed will alter the top layer of the bottom sediment causing certain changes to occur. In most cases the physical effects will remain visible for a relatively short period as the movement of the bottom current will flatten the trawl tracks.

But the movement of the bottom gear (otter trawl or beam trawl) will also directly or indirectly influence the benthic fauna. The most obvious direct effect is caused by scraping of the various gear parts which are in direct contact with the bottom (e.g., underside of the trawl door, trawl shoes, groundrope, tickler and other chain arrays and, finally, the belly of the trawl with additional codend protection (chafers)). However, the pressure itself of the gear parts on the bottom during the process of sliding along the bottom can also exert an effect on the benthos. The penetration depth of doors and shoes will mainly be determined by the type of sediment and the critical relation between trawling speed and weight of the gear. Under normal fishing conditions the gear skims the sediment surface, the rigid part of the net as well as the netting material staying just on the bottom. In such circumstances the effect of the pressure on the bottom is negligible (the same pressure per cm^2 as a bicycle tyre). It has been calculated that the pressure at a beam trawl shoe is 0.15 kg/cm^2 and that of a tickler chain 0.11 kg/cm^2 (a car tyre is about 0.8 kg/cm^2).

In the past, it has been established that an otter trawl door digs into a soft bottom by about 8—10 cm. The chain arrays (up to 15 chains) dig into a silty soft bottom by about 3 cm. The effect of the increase in the total weight of, for example, the beam trawl as observed over the last twenty years is fully compensated by an increase in trawling speed (e.g., for beam trawl 7–8 knots). The increase in fishing speed in fact gave rise to the increase in weight of the beam trawl gear as it would have been impossible otherwise to keep the gear in full contact with the sea floor.

Contact of the gear with the bottom will cause a number of effects. Fine bottom sediment will be resuspended. The mud clouds of a trawl are essential to its catching performance. The coarse fraction of the resuspended material will soon settle, but the fine fraction may only settle out after being transported some distance by bottom currents, depending upon the current velocity at the time. Another potentially harmful aspect is the possible release of reducing substances into the water column, especially in the coastal zone. The grain size distribution of the bottom sediment may also alter owing to the disturbance by the trawls, such as when the so-called chain marks remove and displace stones and other coarse material. Reefs of, for example, the worm *Sabellaria* may be entirely destroyed, even sufficiently so that recovery is impossible.

Four different aspects of the bottom disturbance caused by the trawl fisheries to benthic organisms may be recognized, the extent of each of which depends upon the penetration depth of the gear, sediment composition of the bottom, and fishing intensity:

a) Direct destruction of benthic organisms and the crushing or damaging of organisms in and on the bottom.

   Research in the 1970s and earlier concentrated on this aspect of bottom trawling. Divers, film recordings, and benthos samples (before and after fishing) were used. The influence of the number of tickler chains on the catch and damaged benthos was studied. The effects on fragile species, such as crab-like species, echinoderms, and bivalves, was demonstrated. A positive side effect for fish was found in that previously unavailable food was made available in the zone of disturbance created by the passing trawl.

b) The resuspension of sediment (with or without harmful substances) by the trawl gear and resultant deposition of the fine material in areas with a low tidal current.

   There is no information available on harmful substances released by bottom trawl gear. Additional mud clouds caused by fishing in areas where physical reworking of the substrate by currents or storms takes place scarcely disrupt the benthic fauna.

   The benthic organisms are adapted to living under these circumstances. In areas with low current velocities, however, it is possible in theory that benthic organisms will be smothered by sediment deposition if they cannot excavate themselves.

c) A change in the bottom structure of an area which will result in a different recolonization pattern, thereby resulting in a benthic community different in composition from that encountered before trawling operations began.

   The effects on *Sabellaria* reefs (German Wadden Sea) caused by heavy chains, mentioned previously, is an example of this.

d) A cumulative effect caused by frequent fishing in the same area, which may result in long-term changes in diversity, biomass, and productivity of benthos.

   Frequent disturbance of the bottom in a particular area will lead to an increase in mortality of benthic species because the more sensitive organisms will die. If all sensitive species in an area are killed, the mortality will decrease. The diversity (the number of different species) in an area may be influenced as long-lived, slow-growing species disappear to be replaced by a few faster-growing, short-lived species which can reproduce rapidly. German researchers have been able to demonstrate these changes in the marine ecosystem caused by human interference.

After monitoring over a period of sixty years a shift in abundance and species composition could be demonstrated. From the 1920s onwards a decrease in species numbers was observed among the slow-growing molluscs and crustaceans and an increase among the fast-growing polychaetes. Also a shift in dominance was recorded from more or less fragile, relatively slowly reproducing epibenthic species towards fast-growing and fast-reproducing infaunal species.

An indirect cause of long-term changes in benthic communities may perhaps be changes in fish growth and recruitment. In heavily fished areas an increase in growing speed of flatfishes has been observed, with these species feeding especially on polychaetes. It is thought that in such areas more food has been made available for flatfish species. Whether this is also linked with a decrease in food availability for other species has never been proven or demonstrated but may be the case.

In theory, the productivity of benthos will in the first instance increase as older species are replaced by young individuals or the number of opportunistic species increases. But if the disturbance caused by fisheries increases, it is possible that even resistant species will not survive, thereby resulting in a decrease in productivity.

The relative seabed disturbance caused by various activities affecting the seabed is given in Table 1. It can be seen from these figures that the disturbance of the seabed by fishing activity is far greater than that of all other activities. Marine aggregate extraction disturbs 0.03 % of the seabed annually in the North Sea whilst fishing disturbs about 54 %.

Table 1 Physical disturbance of the seabed in the North Sea (1986 data).
Data supplied by Institute of Offshore Engineering (IOE), Heriot-Watt University, Edinburgh.

% Area	Source	Area	Number or amount	Reference/Source
54.	Fishing	309,204 km^2/pa		IOE calculation
0.03	Aggregate extraction	180 km^2/pa	30 $\times 10^6$ t	IOE calculation
0.01	Dredging disposal	72 km^2/pa	72 $\times 10^6$ t	Calculated from OSCOM 13
0.001	Waste disposal	5.5 km^2/pa	5.5 $\times 10^6$ t	Calculated from OSCOM 13
0.001	Sludge disposal	5.5 km^2/pa	5.5 $\times 10^6$ t	Calculated from OSCOM 13
0.05	Platforms	313 km^2	399	IOE calculation
0.05	Wellheads	300 km^2	382	IOE calculation
1.5	Pipelines	8,374 km^2	8,374 km	IOE calculation
1.27	Cables	7,322 km^2	7,322 km	IOE estimate
0.05	Wrecks	284 km^2	7,100	IOE calculation
0.0001	Cuttings disposal	0.5 km^2/pa	593,741 t	IOE calculation
56.96	Total	327,000 km^2		

OSCOM 13 = Report of the Thirteenth Meeting of the Oslo Commission (1987) (Convention for the Prevention of Marine Pollution from Ships and Aircraft).

4 MANAGEMENT

4.1 Regulatory Practices

4.1.1 Legislation and review procedures

General comments and observations

Seven out of the twelve countries surveyed have more than one piece of legislation that applies to the extraction of minerals from the ocean. The existence of more than one piece of legislation within a country usually occurs when there is one act applying to territorial waters, and another to the continental shelf. These countries include:

1. Belgium: private extractions *versus* public extractions;
2. Denmark: territorial waters and continental shelf;
3. France
4. Germany: territorial waters and continental shelf;
5. Ireland: foreshore and offshore;
6. Netherlands: territorial waters and dredging;
7. United States.

It is interesting to note that in most countries (11 out of the 12 surveyed) there is specific legislation for the extraction of materials from the ocean; it is not simply a case of on-land legislation being applied offshore.

In examining which countries solicited input from other government departments, the private sector, etc., when making decisions on licensing or permits for mineral extraction, the results are as follows:

- Input from government only: Germany and Ireland;
- Input from government and the private sector: Belgium, Canada, Finland, the Netherlands, Sweden, the United Kingdom, and the United States;
- No input: France;
- Insufficient information: Norway and Denmark.

Eight of the surveyed countries may include specific terms and conditions relating to environmental or fisheries impact management in the extraction licence (e.g., environmental monitoring, compensation, rehabilitation). These countries are: Finland, Sweden, Denmark, Germany, the Netherlands, Belgium (except for public licences), the United Kingdom, and the United States.

Summary of mining legislation

Countries reporting	Countries not reporting
Belgium	Poland
Canada (proposed)	Former USSR
Denmark	
Finland	
France	
Germany	
Ireland	
Netherlands	
Norway	
Sweden	
United Kingdom	
United States	

Belgium

Legislation
- Law of June 1969 concerning the Belgian continental shelf
- Royal decree of 7 October 1974 concerning the granting of concessions for exploration and exploitation of mineral and other non-living resources of the continental shelf
- Royal decree of 16 May 1977 concerning measures on the protection of shipping, sea fisheries, the environment, and other interests by the exploration and exploitation of mineral and other non-living resources.

Administrator
- Ministry of Economic Affairs, Mines Department

Area of application
- Continental shelf, including territorial waters

Materials
- Mineral and non-living resources of the seabed

Review Procedures

Local and public involvement
- Mining Department informs local authorities and organizations when a new location is identified.

Role of other governments or authorities
- For private extractions, the Mines Department has to seek advice from the:
  Ministry of Public Health and the Environment,
  Ministry of Agriculture,
  Ministry of Defence,
  Ministry of Traffic,
  Ministry of Public Works,
  Ministry of Foreign Affairs.
- For defence extractions and for public extractions, which may be an order of magnitude greater than the private extractions, advice may be sought from the above-mentioned ministries.

Terms and conditions

- Ministerial decree of the Ministry of Economic Affairs contains all the conditions and terms put forward by the other ministries, e.g., with respect to safety zones, taxes, avoidance of spawning grounds, environmental monitoring (long term).
- Royal decree of the Ministry of Economic Affairs contains the technical conditions for the exploitation, related to the Ministerial decree mentioned above.

Note: Extraction takes place only on top of sand banks and topography is generally restored naturally.

Canada

Legislation

- Proposed Ocean Mining Act

Administrator

- Cooperative arrangements between federal and provincial governments

Area of application

- All Canadian offshore and continental margin

Materials

- All mineral resources, excluding hydrocarbons

Review Procedures

Local and public involvement

- No information at present

Role of other governments or authorities

- Proposed consultations with federal and provincial offices of fisheries, environment, transport, defence, as well as private industry (e.g., fishing association)

Terms and conditions

- Environmental monitoring and compensation mechanisms will be examined under the proposed new legislation.

Denmark

Legislation

- Raw Materials Act, 1989; Continental Shelf Act, 1979

Administrator

- The National Forest and Nature Agency of the Ministry of the Environment

Area of application

- Inland areas and territorial waters

Materials

- All sediments, including sand, gravel, stones, peat and similar deposits, excluding oil and gas

Review Procedures

Local and public involvement

- Larger dredging activities require special procedures.
- Local authorities and fishery organizations are consulted.

Role of other governments or authorities

- Geological, biological and archaeological interests are reviewed by the Forest and Nature Agency.
- Statements from the Ministry of Fisheries and the Coastal Protection Agency are included in the review procedure.

Terms and conditions

- General permissions are given to a number of individual ships.
  The general permissions cover extraction in all Danish waters except in special areas.
- Extractions of more than 250 000 m^3 for reclamation must be reported in advance. Based on a general review of the environmental interests, the Forest and Nature Agency can forbid the extraction or give permission under special conditions.
- Extractions of more than 1 million m^3 require special permission. Based on a general environmental impact statement, the Agency will set up the conditions for the extraction and an environmental monitoring programme.

Legislation

- Continental Shelf Act, 1979

Administrator

- Ministry of Energy. The administration of sand and gravel extraction is delegated to the Forest and Nature Agency.

Area of application

- Continental shelf

Materials

- All natural living and non-living resources

Review Procedures

- Same procedures as for territorial waters

Finland

Legislation

- Act on Soil Extraction; Water Act

Administrator

- National Board of Water and Environment (part of the Ministry of Environment)

Area of application

- State-owned waters within the territorial sea and the area beyond to the median line (EEZ)

Materials

- All sediments, including sand and gravel

Review Procedures

Local and public involvement

- Company should consult local fishing organizations prior to dredging.

Role of other governments or authorities

- Municipalities give permission for private and near-shore waters.

- Permit from the Water Court is needed when a risk of environmental deterioration is expected.

Terms and conditions
- Monitoring is prescribed for sand and gravel extraction.
- When problems arise, they are referred to the Water Court.

France

Legislation
- Continental Shelf Law, 1968; Related Decree, 1971

Administrator
- Ministry of Industrial and Scientific Development (Mines Department)

Area of application
- All continental shelf and territorial sea areas

Materials
- All natural resources

Review Procedures

Terms and conditions
- Extraction operations are small; no specific environmental regulations are required.

Legislation
- Mineral Law, July 1976; Various Decrees, 1980

Administrator
- Le Conseil Général des Mines, et Service Maritime de l'Équipement

Materials
- All natural resources, excluding hydrocarbons

Review Procedures
- No further information

Germany

Legislation
- Continental Shelf Declaration, 1964; Act on Provisional Determination of Rights Relating to the Continental Shelf, 1964 (amend. 1974)

Administrator
- Inside Territorial Waters (3 n.m.) - Regional mines inspectors
- Outside Territorial Waters - Chief Mining Board

Area of application
- Continental shelf, including territorial waters

Materials
- All natural resources, including sand and gravel

Review Procedures

Role of other governments or authorities
- Bundesamt für Seeschiffahrt und Hydrographie
- Provincial fishery offices when inside 2-n.m. zone
- Fisheries Research Centre when outside 2-n.m. zone

Terms and conditions
- Environmental monitoring before, during, and after the mining operation is part of the licensing procedure.
- After extraction, the seabed has to be restored to its former state.
- Security bonds are posted.
- Liability assurance in favour of the fishermen is prescribed.

Ireland

Legislation
- Foreshore Act

Administrator
- Department of the Marine

Area of application
- Foreshore (between high-water mark and low-water mark)

Materials
- Intended for coastal protection

Legislation
- Continental Shelf Act, 1968

Administrator
- Department of Energy

Area of application
- Offshore below low-water mark

Materials
- Intended for hydrocarbons, but also applies to minerals identified under the Minerals Development Act, 1960.

  The Minerals Development Act, also administered by the Department of Energy, is applied to mining operations on land.

Note: Discussions regarding changes in the existing legislation are going on to combine various aspects into one piece of legislation for the offshore areas.

Review Procedures

Local and public involvement
- Local authorities, planning boards under planning laws
- Fisheries and environmental interests are looked after by the Department of the Marine.

Role of other governments or authorities
- Monitoring of operations is licence-specific.

Netherlands

Legislation
- Sediment Extraction Act, 1965

Administrator
- Ministry of Transport and Public Works

Area of application
- Territorial waters (12 miles) and inland, excluding the construction, change, and maintenance of public works

Materials
- All sediments, including sand and gravel, but excluding oil and gas

Note: A new extraction act is planned for adoption within a few years which will also apply to the continental shelf.

Review Procedures

Local and public involvement
- Local authorities, and local newspapers, "Staatscourant"

Role of other governments or authorities
- Ministry of Agriculture, Nature Management, and Fisheries
- State Archaeological Survey
- As a consequence of the General Provisions Act of 1986 the Ministry of Housing, Physical Planning, and Environmental Management becomes involved when an Environmental Impact Statement is to be drawn up (e.g., when the extraction area is larger than 500 hectares).

Terms and conditions
- Sand extraction for landfill or beach nourishment is prohibited landward of the 20-m isobath.
- It is possible to require restoration of the entire area, or part of it, to its original state.
- Sea defence works do not need a licence.
- Dredging is prohibited within a distance of 500 m from the border of the sea defence.

Legislation
- Regulation for Dredging, 1934

Administrator
- Ministry of Transport and Public Works

Area of application
- Territorial waters and inland

Materials
- All materials to be dredged

Review Procedures
- No further information

Norway

Legislation
- Act 12: Scientific research and exploration for and exploitation of sub-sea natural resources other than petroleum resources

Administrator
- Ministry of Industry

Area of application
- All national waters

Materials
- All natural resources, excluding petroleum

Review Procedures

Local and public involvement
- No information

Role of other governments or authorities
- No information

Terms and conditions
- Activities must avoid disturbing shipping, fishing, aviation, marine fauna or flora, and submarine cables.

Sweden

Legislation
- Act on the Continental Shelf, 3 June 1966

Administrator
- Geological Survey of Sweden (SGU)

Area of application
- All public waters as well as sea areas outside of territorial limits

Materials
- All natural resources, including sand and gravel

Review Procedures

Local and public involvement
- Local fishery organizations, county administration, local municipalities, etc., are consulted prior to issuing the permit. Intent to conduct work is published in local papers.

Role of other governments or authorities
- Swedish Environmental Protection Agency
- National Board of Fisheries
- Central Board of National Antiquities and the National Maritime Museum
- National Swedish Administration of Shipping and Navigation
- Swedish Meteorological and Hydrological Institute

Terms and conditions
- Normally the Water Rights Court decides on an environmental monitoring programme. The court may also decide on financial compensation where appropriate. The SGU may withdraw the licence if the extraction has unacceptable detrimental effects.

United Kingdom

Legislation
- Continental Shelf Act, 1964; Crown Estate Act, 1961; Territorial Sea Act, 1987

Administrator
- Crown Estate Commissioner

Area of application
- Territorial sea and continental shelf

Materials
- All natural resources, except hydrocarbons

Review Procedures
Local and public involvement
- Requires statutory review by Department of Transport, and non-statutory consultation process between government departments and other interested parties (including environment, coastal protection, fisheries, etc.).
- Consultation known as "The Government Review Procedure" is administered by Department of the Environment.

Terms and conditions
- Code of Practice is followed by dredgers and fishermen. The Code relates to working guidelines of both industries, and aims to increase liaison.
- Environmental monitoring carried out by the Ministry of Agriculture, Fisheries and Food as required.

United States

Legislation
- Submerged Lands Act, 1953; Outer Continental Shelf Lands Act, 1953; National Environmental Policy Act, 1969; Marine Protection, Research and Sanctuary Act, 1976
- Other legislation including the Clean Water Act, 1976, and the Rivers and Harbors Act, 1899, may also apply depending on the mining location.

Administrators
- Department of the Interior
- US Geological Survey
- Minerals Management Service
- US Environmental Protection Agency
- Department of Defense
- US Army Corps of Engineers

Area of application
- The OCS Land Act covers areas of the EEZ on the shelf beyond 3 miles from shore.
- The Submerged Lands Act applies within three miles of the shore, which is the responsibility of the individual states.
- The Marine Protection, Research and Sanctuary Act provides protection against undue degradation of marine waters.

Materials
- All mineral resources

Review Procedures
- Environmental Impact Statements are subject to review by relevant agencies, public notification, and review and public hearings.

4.1.2 Scientific considerations to be taken into account when issuing extraction licences

As a basis for both the environmental impact studies and the monitoring programme carried out in connection with extraction operations, a baseline study is needed before operations commence. This should contain all relevant information on the conditions of the area in question, such as the topography, geology, hydrography, bottom flora and fauna, and other biological features of the area. This should be conducted in sufficient detail to ensure that any changes that may occur as a consequence of the extraction activities can be determined, and the environmental impact ascertained.

It is desirable that parts of the baseline study (e.g., hydrography, biology, and sediment dynamics) include monthly as well as annual data where practicable. This may allow seasonal and longer term fluctuations to be determined (large variations are known to occur, for example, in data for stormy and calm years).

Conditions attached to the permit or licence for extraction operations should, where appropriate, include a requirement to carry out baseline studies. Such studies are useful in assessments of recovery following the cessation of dredging operations, or for ensuring the restoration of the seabed which may be a condition attached to the permit in some circumstances (e.g., where damage has occurred as a result of malpractice or bad management by the licensee).

Both the total quantity of material removed from the seabed and the extraction rate are important when considering the potential impact of aggregate dredging on the marine environment.

In terms of biological and chemical impact, however, the extraction rate is probably less important than the extraction technique. Trailing suction dredging will disturb a greater surface area of seabed which will nevertheless be able to re-establish similar populations of plants and animals if the surface sediment remaining is similar. Dredging from a stationary vessel will have a greater impact but in a localized area. The seabed between the dredging pits will remain relatively undisturbed, but the pits may well be recolonized by a different community of plants and animals better adapted to the changed conditions. In areas with marked density stratification of the water column (e.g., the Sound) reduced conditions may occur in the bottom waters of the dredging pit as a result of limited circulation and organic material trapped within the pit. Such conditions have a negative impact on the bottom fauna. In such areas trailing suction dredging is preferable.

The impact of marine aggregate extraction on the chemistry of the seabed and the overlying water column will depend to a large extent on the amount and composition of fine material in the seabed sediment. Dredging techniques which involve the separation of material at sea will tend to have a greater impact on the adjacent seabed and water column than techniques which retain most of the cargo on board and discharge ashore. All suction dredging (fixed or trailing) will involve outwashings from the cargo hold irrespective of whether screening is required to modify the natural proportions of sand or stone in the cargo. Grab or bucket dredgers do not lend themselves to screening or other on-board treatment and, therefore, the loss of fines overboard is minimized.

The rate of extraction and total quantity removed is particularly relevant when the physical impact of marine aggregate dredging on the coastline is being considered. Coastal impact can be considered under two main headings: a) seabed sediment movement; and b) seabed topography.

a) Seabed sediment movement

In the highly energetic environment inshore of the wave breaker line, seabed material is constantly being suspended and moved by the prevailing tidal and wind-driven currents. Generally speaking, larger particles are moved inshore towards the beach whilst smaller particles move offshore to calmer waters. However, in periods of intense storms this general progression can be overturned and huge quantities of material removed or deposited on the beach in a matter of hours.

Water depth, wave height, and sediment particle size are the critical factors relating to the movement of seabed sediments offshore. The deeper the water, the less energy in any given wave that reaches the bed; the lower the energy at the seabed, the smaller the particle that will be moved. It is possible to develop reasonably accurate mathematical models that will predict seabed sediment movements under given wave conditions and water depth, providing that the model has been calibrated with field measurements from a reasonably similar environment. On the basis of the above, it is possible to predict the impact of marine aggregate extraction on seabed sediment movement and hence the likely impact on the supply of sediment to the adjacent beaches.

For the Dutch sea defence policy and extraction plan, model calculations were carried out for one location considered to be more or less representative of the Dutch situation. These calculations showed that the extraction of 0.2, 1.0, and 10 million m^3 at the 16-m and 20-m isobaths (9 km and 11 km offshore) would have no direct effect on the coastline by changing current patterns and wave climate. Negative effects on the coastline due to landward migration of the dredged pits are not expected within a period of 200 years.

b) Seabed topography

Offshore sandbanks can play a major role in reducing the amount of wave energy reaching the adjacent coastline and influencing the direction of this wave energy. Essentially the shallower the water over the crest of the sandbank and the nearer the sandbank to the shoreline, the more important the sandbank is likely to be in protecting the adjacent coastline, particularly if it is in the path of the prevailing winds and hence waves. By the use of mathematical models it is possible to predict the effect of changing the height of the sandbank on both the wave energy reaching the shore (refraction) and the direction of the wave energy (diffraction).

Using these mathematical models, the results of field studies and existing hydrographic information, it is possible to predict the effect of the extraction of a given quantity of material and to determine whether it will have a significant impact on the adjacent coastline/beach profile.

4.2 Resource Use Planning

4.2.1 Resource mapping

Introduction

Throughout the world ever-increasing demands are being made on the coastal and offshore marine environment as an exploitable resource. The growing interest in these activities has resulted in an increased risk of conflicts between the different modes of exploitation and conservation. The demand for more systematic coordination has increased, and there is also an increased need for better knowledge about the marine environment. Present-day techniques allow accurate seabed mapping. During the last decade most nations have set up their own mapping programmes. However, there is, with some exceptions (e.g., the countries around the Baltic Sea and North Sea), limited information exchange between different nations. Recently, however, the Western European Geological Survey's Sub-Group on Marine Geology has been established.

The following section describes seabed and mineral resource mapping activities in ICES member countries. Information was gathered from questionnaires which were sent out to all members, but the rate of response was rather low. As a consequence, much information was compiled by individual Working Group members. Exploration of the marine environment by ICES member countries varies considerably in scope, nature, and progress. In some countries, seabed sediment mapping is well under way as an integral part of a composite geological mapping programme for the offshore area. In most cases the seabed sediment mapping shows lithological and other information that is of interest to the aggregate extraction industry. However, the quality, density, and usefulness of the information varies from one country to another. In addition, a trained geologist is often needed to digest and understand all the possible implications and applications of the information contained in the seabed sediment maps. Mapping of marine aggregate resources is usually carried out either on an *ad hoc* basis or as a formal programme which usually trails far behind the seabed sediment mapping as a consequence of the greater detail required.

In other countries without systematic seabed sediment mapping or a well-advanced resource mapping programme, emphasis has been put by the administrative authorities on *ad hoc* resource mapping projects to suit the consumer's needs. This approach has led to good results seen from the perspective of the aggregate extraction industry, but lacks the overview that would be needed for a thorough management of resources or a well-founded extraction policy.

Review of the current state of seabed sediment and resource mapping programmes in ICES member countries

A brief review of the seabed sediment and resource mapping programmes of ICES member countries is presented below. Further details concerning staffing, equipment, and budgets are given in Annex 3, along with information on relevant maps and reports which are available.

Belgium

In Belgium, the Ministry of Public Health and the Environment, represented by the Management Unit of the Mathematical Model of the North Sea and the Scheldt Estuary in Brussels, is coordinating the mapping of the Belgian nearshore area which is being carried out by, amongst others, the HAECON Corporation, Ghent, based on data from the Ministry of Public Works.

The same organization will also coordinate the future mapping of seabed sediments in the Belgian sector based on data from Ghent University, the Fisheries Research Station in Ostende, and others.

The Belgian Geological Survey in Brussels, a component body of the Ministry of Economic Affairs, is responsible for geological mapping, which in the offshore area is carried out with the help of the Renard Centre of Marine Geology of Ghent University and the HAECON Corporation. Early results were reported to the Ministry.

No special resource mapping is being done.

Canada

The Geological Survey of Canada (GSC) is carrying out a regular mapping programme within the 200-n.m. zone. This is an area of about 1.6 x 10^6 km^2. Reconnaissance mapping has been conducted in 30% of the area, a total of 10% having been mapped in detail. Bedrock reconnaissance maps have been made of 60% of the area, and detailed geological maps are available for 20% of the area. A summary of these maps is presented in the 1989 DNAG volume at 1:1000 000 scale. Individual areas have been mapped on varying scales: Scotian shelf 1:250 000, Grand Banks 1:350 000, Labrador shelf 1:300 000, and southeast Baffin shelf 1:1000 000.

Types of maps include bed form, sea floor, grain size, deposit thickness, formation, surficial bedrock, seabed features, trawler and fishing activities, hazards, iceberg scours, shallow gas, etc. There is not much interest on the part of GSC in relating the mapping to surface resources, but other organizations have published material on resources. In general there is not much cooperative work with universities, but there is with, for example, the Canadian hydrographic services. Since large vessels are used, most mapping is carried out in deeper water. Thus there is a "zone of ignorance" between 0 and 25 m in water depth although this area is receiving more attention now, *viz* Fader (1988).

Denmark

In Denmark, the Forest and Nature Agency is responsible for the planning and coordination of the resource mapping in territorial waters and on the continental shelf. Since 1991 geological mapping has been carried out by the Danish Geological Survey.

Reconnaissance mapping started in 1979 and has been conducted on a 2 km by 5 km seismic grid over 70% of the inner Danish waters and in a small part of the North Sea. The seismic surveys are accompanied by surface sampling, coring, and full-scale test dredging. Detailed mapping has been conducted in 30 areas.

Mapping for raw materials is accompanied by biological and archaeological investigations.

The results of the mapping programme are presented in a number of technical reports and "Blue Sea Reports". The reports include maps of sand and gravel resources at a scale of 1:100 000, seabed sediments, and biological and archaeological details.

Finland

The Geological Survey of Finland (GSF) is responsible for and carries out the regular mapping programme of the Finnish continental shelf (in the Baltic Sea). Detailed sea-floor mapping started in the late 1970s, and by 1983 a working routine had been established.

France

In France, the Bureau de Recherches Géologiques et Minières (BRGM) - the French Geological Survey - based in Orléans is responsible for geological mapping, both onshore and offshore.

IFREMER - the French Institute for Marine Research - in cooperation with various universities is in charge of offshore thematic maps.

Germany

For a long time it has not been clear which organization was responsible for the geological mapping of the German sector of the North Sea.

At present the Federal Office for Shipping and Hydrography is in charge of the mapping of surface and near-surface sediments, while the Federal and State Geological Surveys are responsible for the study of the deeper geology. Some resource mapping has been carried out by these bodies. In addition, Kiel University has published some maps of the seabed sediments of the Baltic Sea on an *ad hoc* basis.

Greenland

The Geological Survey of Greenland, based in Copenhagen, is responsible for geological activities on the Greenland shelf. A recent publication provides a good overview of the Greenland shelf and includes references to preliminary mapping activities in the 1970s (see Appel and Kunzendorf, 1989). No information is at present available regarding the organization of the current mapping programme.

Iceland

No information is at present available regarding the organization of a mapping programme of the continental shelf around Iceland. Details of surficial sediments may however be obtained from the Icelandic Geological Survey, Reykjavík.

Ireland

The Geological Survey of Ireland (GSI), Marine Section, is responsible for and carries out the mapping of aggregates and surface sediments within the continental shelf of Ireland. The resource-based mapping programme, which started in 1976, is concentrated on the following topics:

1) resources such as sand and gravel down to 20-fathoms depth along the southeastern coast of Ireland. As well as producing its own map, GSI has cooperated with the British Geological Survey (BGS), and the results are included in the BGS maps of the area;

2) offshore coal in the Kish Bank Basin east of Dublin. Some results from this work are included in the BGS maps;

3) investigations on the south coast related to hydrocarbon exploration activities, where the GSI purpose is geochemical mapping and identifying suitable submarine routes for pipelines. The investigation area extends from 1 n.m. off the coast to about 10 n.m. offshore;

4) geological mapping in the Galway Bay area out to 11°W, with particular emphasis on the Quaternary history and the occurrence of paleo-shorelines. Techniques used are mostly geophysical but include some benthic sampling;

5) for fisheries use, thematic mapping (side-scan sonar) of fishing grounds off NW Donegal (NW Ireland) on behalf of the Sea Fisheries Board of Ireland (BIM);

6) mapping heavy mineral beach sand occurrences and their extensions offshore.

Netherlands

The Geological Survey of the Netherlands (RGD), a component body of the Ministry of Economic Affairs, is responsible for geological mapping, including resources assessments, both onshore and offshore. RGD started reconnaissance surveying of the Netherlands sector of the North Sea as early as 1968.

Systematic reconnaissance mapping at a scale of 1:250 000 started in 1980 when RGD joined the British Geological Survey in mapping the five sheets straddling the median line.

A systematic detailed mapping programme at a scale of 1:100 000 was initiated in 1985. Emphasis is on sediment properties and resource potential. Initial surveys are concentrating on nearshore areas.

Mapping of exploitable sands and gravel for industrial use was formerly done by RGD on an *ad hoc* basis. From 1985 to 1988 mapping of the various types of (near) surface sands within a distance of 50 km from the main seaports was done at the request of the North Sea Directorate of Rijkswaterstaat (Ministry of Transport and Public Works). Increased sand and gravel exploitation offshore would be in line with the national policy to put restrictions on further aggregate exploitation on land.

All mapping programmes are carried out in close cooperation with the North Sea Directorate of Public Works (Rijkswaterstaat) at Rijswijk which, amongst other things, provides the shiptime for the survey work.

Norway

The Geological Survey of Norway (NGU) is responsible for geological seabed mapping of the Norwegian continental shelf. The coastal areas are mapped by NGU in parallel with the Quaternary land mapping programme. Farther offshore the Norwegian Continental Shelf Research Institute (IKU) carries out the investigations, but NGU coordinates the mapping programme. The Norwegian Polar Institute carries out mapping in the Barents Sea and around Spitsbergen.

Poland

Organization of mapping programme: No data available.

Portugal

Organization of mapping programme: No data available.

Russia

Organization of mapping programme: No data available.

Spain

Organization of mapping programme: No data available.

Sweden

The Marine Geology Division of the Geological Survey of Sweden (SGU) is responsible for and carries out the regular mapping programme of the continental shelf of Sweden. The programme started at the beginning of the 1970s, but was not established as a regular programme until 1982.

United Kingdom

The British Geological Survey (BGS), a component body of the Natural Environment Research Council (NERC), is responsible for the geological mapping of the UK, both onshore and offshore, and also for any mapping of mineral resources. The offshore mapping includes 1:250 000 scale seabed sediment maps of particular relevance to this Working Group (see Figure 13).

Recently the BGS has been involved in a programme of marine aggregate resource mapping of selected areas around the British Isles.

United States

The US Geological Survey's Minerals Management Service (MMS) has specific responsibility for the organization of the seabed mapping programmes. General marine mapping of bottom sediments using available data is being done under the CONMAP Program at a scale of 1:1000 000. In the northeast the US Geological Survey has also conducted regional seismic surveys. The MMS has provided $20 000 to $30 000 per year to individual state geological surveys for local mapping or the analysis of existing vibrocores for heavy minerals. Many of the cores and surficial samples were collected in the early 1960s by the US Army Corps of Engineers, Coastal Engineering Research Center for the Inner Continental Shelf Sediments Program, which was a general survey of offshore sand resources for beach nourishment (e.g., Williams, 1981). Others were the result of a joint effort between the National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution in 1970 (e.g., Schlee and Pratt, 1970). Still other samples were collected by diverse, local mapping efforts, some of which were conducted by NOAA (e.g., Freeland, 1981) or individual states (e.g., Bokuniewicz, 1979).

Conclusions

In the course of the compilation of this chapter, the following points of interest have emerged:

- Not all countries appear to have a fully fledged mapping programme.
- Few countries have advanced seabed sediment mapping programmes on scales more detailed than 1:100 000.

- Resource mapping is generally lagging behind the seabed sediment mapping.

- There is some exchange of ideas regarding mapping procedures amongst ICES member countries. Especially around the North Sea there is a clear tendency towards harmonization.

- Notwithstanding this exchange, continuous attention should be given to ways to standardize the various national mapping programmes and to correlate mapping results across median lines.

- There is a need for an international seabed mapping group where harmonization and coordination of mapping programmes may be achieved and where information can be exchanged, leading amongst other things to an improvement in survey techniques and presentation methods.

4.2.2 Beneficial interactions

Although marine aggregate mining projects are scheduled to avoid conflicting uses, they have not been designed to provide beneficial interactions. A benefit has been realized in New York Harbor where mining has been conducted by fixed dredges to produce borrow pits. The pits were constructed in water less than about 8 m deep and extended 3 or 4 m below the ambient sea floor. Such pits have served to concentrate finfish, much like a fishing reef, and the recreational fishery has been attracted to the area. Finfish surveys were done by trawling at both borrow-pit sites and nearby sandy shoals (Pacheco, 1983; National Marine Fisheries Service, 1984; Conover *et al.*, 1985). Gut contents were also examined. Fish catches were consistently higher at the pit sites than at the shoal sites. Over a 12-month period, catches were about four times higher at the borrow pits. The causes of these differences are uncertain. The substrate in the pits was mud, and the difference in substrate between the pits and the shoal may explain the differences in catch. Temperature, salinity, dissolved oxygen, and benthic food sources were also considered, but these parameters did not seem to control fish populations in the pits (Conover *et al.*, 1985).

It has also been noted that disturbance of the sea floor by dredging may, under certain conditions, enhance benthic productivity and result in increases in commercial yields (Rhoads *et al.*, 1978). In finer-grained sediments, disturbances, as caused by dredging, can result in high population densities of colonizing organisms for short periods of time. Repeated disturbances might be used to maintain such a system in a state of continuous recruitment and high productivity which may serve as a food resource for commercial species (Rhoads *et al.*, 1978). The conditions under which this would occur or the magnitude of any effect, however, have not been studied, so any potential benefits due to this phenomenon are speculative.

4.3 Surveillance and Monitoring

4.3.1 Electronic monitoring devices

Marine mining activity should be monitored on a continuous basis to provide a permanent record which should be available to both the regulatory authorities and the mining company. The information provided will allow the regulatory authority to monitor the activities of the mining vessel to ensure compliance with specific conditions within the mining licence/permit and to investigate third party allegations of illegal dredging activities.

The mining company can make use of the information recorded by the Electronic Monitoring Device (EMD) to improve its management control of mining activities within licensed/permitted areas. Mineral resources are seldom distributed evenly throughout the licensed area. Detailed records of quality and quantity of minerals accurately located within the mining area will provide essential information for the efficient utilization of these resources.

The level of detail to which information is stored by the EMD will depend on the requirements of the individual regulatory authority and the mining company's needs for management purposes. The degree of security of stored information will also be a matter for the individual regulatory authority. Generally, the higher the level of security the more complicated the equipment and the more time-consuming the transfer of the data from the mining vessel to the regulatory authority. Minimum requirements for data storage should include:

a) the position of the mining vessel on a 24-hour basis according to an agreed level of accuracy;

b) the deployment of dredging equipment;

c) the operation of dredging equipment.

The frequency of recording will vary depending on the status of the vessel (e.g., infrequent records when laid up at the dockside, but frequent records when mining). The position should be recorded in latitude and longitude or other agreed procedures such as Decca, Loran, or National Grid Reference. The position of the dredge pipe and the draghead should be continuously recorded in relation to the seabed and the sea surface. The recording device will register whether the dredging device pumps are operating and whether aggregate or water is being pumped.

The above are considered to be the minimal requirements to enable the regulatory authority to monitor operation of the licence in accordance with any conditions attached to it. Additional information may be required at the discretion of the regulatory authority and/or the mining company in pursuance of its own management requirements.

In the summer of 1990, the UK initiated the investigation of a trial operation of this type of equipment. Three major dredging companies participated in the trial with a view to having the majority of the UK dredging fleet equipped with this system within three years. The Dutch Ministry of Transport and Public Works has already obtained encouraging results with these devices on dredging vessels.

4.3.2 Physical monitoring

Physical monitoring of marine aggregate extraction sites is necessary for a number of reasons. Primarily, it may:

A. Ensure compliance with licence conditions.

Licensed aggregate extraction is frequently dependent upon compliance with a range of conditions designed:

- to protect the marine environment and the fisheries resources in the area concerned and ensure minimal conflicts of interest;

- to ensure avoidance of areas of the sea or sea floor already utilized in other important ways, such as busy shipping lanes, waste disposal sites, and pipeline and cable routes;

- to prevent significant changes in the sediment transport regime and wave and tidal current conditions from taking place, which might have harmful consequences for the shoreline or seabed.

Typically these conditions take the form of constraints upon the area which may be dredged, the method of dredging, the time during which the dredging is permitted, the annual or total tonnage that may be extracted, or the maximum thickness of substrate which may be removed.

Finally, if complaints from fishermen are received or coastal erosion problems arise, despite compliance with the licence conditions, then it may be possible to evaluate the role of dredging by recourse to data generated by such surveys.

B. Form an integral component of any impact assessment studies.

Accurate delineation of the extent and focus of dredging activity is of great importance in assessing the impact of a dredging operation upon benthic communities. This provides a basis for the interpretation of trends or patterns in any biological data that have been collected. In addition, identification of the most heavily dredged parts of an extraction area allows a future biological or physical study to be targeted appropriately, thus maximizing the chances of distinguishing any impact caused by dredging from natural variations in benthic communities or substrate.

C. Present information on natural variability and trends of sea-floor sediments and conditions.

Sand resources, especially, may be situated in areas with highly unstable seabed conditions. It is imperative to understand the natural development of the seabed in order to understand the dredging impact. It is important to check whether there are unexpected changes in major physical conditions during the lifetime of a site, in particular changes in the overall depths of the site and in discrete topographic features such as banks or channels. Generally this monitoring should be done on an annual basis. However, in sensitive areas with rapid natural changes in seabed topography, it may be necessary to undertake more frequent surveys.

D. Further delineate aggregate reserves.

Many of the techniques employed in the physical monitoring of aggregate extraction areas (see below) are identical to those which are used when prospecting for marine aggregate reserves. Thus, the data generated during monitoring may usefully supplement those obtained when prospecting and allow the quality and location of the reserves to be more precisely determined.

Physical monitoring surveys may employ one or more of the following techniques:

A. Side-scan sonar

This technique relies on the oblique transmission of sound waves, perpendicular to the ship track, from a "fish" towed behind a vessel, and the subsequent receipt of signals reflected back from the irregularities on the seabed to build up an acoustic picture or sonograph of the sea-bottom topography. In addition, substrates of different types produce reflections of different strengths on the sonograph and may thus be distinguished, although sediment sampling is still generally required to calibrate each textural type. The side-scan sonar is most valuable in this context for displaying the location and size of dredged pits and tracks, thereby indicating the focus of dredging activity, and for illustrating the distribution of certain broadly different deposits. Echo sounding may usefully be employed in conjunction with the side-scan sonar to provide an accurate record of bathymetry.

B. Sediment sampling

Surface sediment samples may be obtained by grab samplers (Orange Peel Bucket, Day, Van Veen, or Shipek) or, where larger samples are required, the deployment of large diameter vibrocorers or anchor or rock dredges. Direct sampling by divers is particularly useful when sampling within dredged pits or tracks because they have the ability to discriminate these features from the sea bottom (e.g., Dickson and Lee, 1973). Vibrocoring, vibro-hammer coring, impact coring, or rotary coring is generally required to provide sediment samples from depth to calibrate seismic sections (see below). Sediment sampling is a vital component of monitoring surveys as it provides evidence of substrate changes resulting from dredging and is essential in the interpretation of side-scan records and biological data.

C. Underwater video and still photography

Both of these techniques may be used in clear water to provide a qualitative description of the seabed, including sediment type and dominant epibenthic species. The equipment can be used either remotely from a vessel or directly by divers. Photographs may also provide a quantitative record of these features.

D. Seismic and/or sub-bottom profiling

This technique makes use of low-frequency pulses projected from a ship-towed sound source towards the seabed where part of the energy penetrates into the substrate to be reflected back from various "geological" surfaces. The echoes are received in a hydrophone array towed by the survey vessel. Following proper amplification and filtering, the results are displayed on a graphics recorder thus providing a permanent record of the cross-section of the sea bottom. Profiling in this manner is useful for monitoring any changes in the thickness of an aggregate reserve and hence for determining if underlying beds, perhaps of different character from the reserve, are likely to be exposed.

4.3.3 Biological monitoring

Biological monitoring provides the basic data for the assessment of impacts on the biosphere of man-made environmental changes. Monitoring changes in a vulnerable biological community of species at the site of impact is assumed to provide a measure of the severity of the impact. The benthos, because of its sedentary nature and location on the sea floor, is an obvious choice as a vehicle for biological monitoring of the short- and long-term effects of seabed mining. Macrofaunal life-spans allow the integration of effects over a period of years, while meiofauna respond to changes in the order of months.

In its most common application, biological monitoring is used to measure the rate of recolonization and establishment of a productive benthic community on a newly dredged sea bottom.

Immediately following dredging, an area will first be settled by small short-lived species. Subsequent successional stages will consist of longer-lived forms. The time required to establish the final assemblage will depend on the type and stability of the sediment. Benthos on well-sorted fine to coarse sand subject to periodic storm-induced resuspension are retained in an early stage of succession. Under such conditions, sediments of this composition attain their final form quickly. Low-energy areas with fine-grained sediments can take as long as 10 years to reach the final stages of community succession (Rhoads and Germano, 1982). Aggregate extraction requires a product with a minimum amount of fine material, so fine sediments are dredged only for navigational purposes. The successful regeneration of a gravel assemblage on newly exposed substrate is also likely to take several years. For example, it may depend on the initial establishment of erect hydroid and bryozoan colonies on the upper surface of the stones during the first year. Associated fauna follow during the next several years as colonies mature (Rees, 1987).

The re-establishment of a benthic community similar to the original is dependent on the retention of a sediment surface of the same structure and composition as the original. As an example, the physical properties of the sediment surface of the Hastings Shingle Bank after dredging have been described by Dickson and Lee (1973). The bottom was found to consist of a complex of pits and furrows filled with fine slurry which eventually compacted into muddy sand. They concluded that, because of the infrequent movement of the shingle, it will be decades before the surface of the bank regains its original configuration. The associated changes in the benthos were described by Shelton and Rolfe (1972), who proposed that the bottom of depressions formed by anchor dredging in this area may initially be colonized by a muddy sand fauna which is then replaced by a clean sand fauna as the finer fractions are washed out. The variability between the stations sampled on the Southwold area off the English East Coast after dredging may indicate that the same process occurs here (G. Lees, pers. comm.). It has been suggested by Dickson and Lee (1973) that the use of trailer suction dredges, since their extraction depth is less and they cover a wider swathe than do anchor dredges, would leave the bottom less irregular.

Dredging operations will always increase the amount of fine material available for resuspension, producing effects beyond those of the dredging operation itself. An initial source of fine material is the outwash plume, while subsequent sources are the winnowing of fines from the newly exposed gravel during storm events. This latter source will continue until a stable lag deposit is re-established in equilibrium with existing current and wave energy. The fate of this material depends on net water movement. Its effects are biologically diffuse and, particularly in downstream areas, can be widespread. It will attenuate as the fines settle in low-energy basins from which they can no longer be resuspended. The effect of suspended fine material is considered by Rees (1987) to be temporary on the Hastings Shingle Bank since it is rapidly removed as it enters the normal transport pathways under the influence of tidal currents and wave action.

Biological monitoring is not a very useful technique for assessing the effects of suspended sediment. Unlike recolonization rates where the gradient ranges from abiotic conditions to stable benthic communities, the effects of sediment load are sublethal and of low impact. It has not been possible to demonstrate the effects of increased turbidity caused by aggregate dredging. It is suggested by Millner *et al.* (1977) that the ambient turbidity in the Southwold area is sufficiently high as to mask any effects resulting from the discharge of outwash fines. In addition, it has been suggested that the effects of dredging are so widespread as to extend to the control area used (ICES, 1979). A control area must be free from the effects to be measured while at the same time being of the same sediment type and in the same water mass as the study area.

Benthic communities have been found to change suddenly in response to changed rates of organic input or abnormal winter temperatures (Buchanan and Moore, 1986). Also, benthic macrofauna are subject to variability in the survival of their larval stages that can result from environmental conditions far from both study area and control. Additional temporal and spatial variation can result from biological interactions (Eagle, 1975). The problems inherent in the use of benthos for environmental monitoring are discussed by Gray (1976).

Many techniques have been developed to measure differences between biological communities which result from man-made perturbations that could be applicable to the effects of dredging. The most widely used are diversity indices, whose use and shortcomings are discussed by Green (1979), Routledge (1979), and Wolda (1981). With the increased availability of computers, multivariate techniques and cluster analysis are being more often used. A dendrogram provides an excellent visual representation of community similarity. A good discussion of the operation and limitations of these techniques can be found in Gould (1981).

All of the above-noted methods require the sorting and taxonomic identification of samples. These are labour-intensive processes that result in a high cost per sample. The number of samples required may be reduced by sequential sampling (Jackson and Resh, 1989). Taxonomic identification may be eliminated by the use of allometric methods (Schwinghamer, 1988). This is particularly useful when it is desired to include the meiofauna because of the difficulties in taxonomy. Rhoads and Germano (1986) describe a rapid method of benthic monitoring of soft sediment by remote sensing that obviates the need for laboratory processing of large numbers of samples. Such an approach may be useful in identifying key locations for regular follow-up monitoring.

Beyond showing that a change has taken place in a benthic community, biological monitoring in relation to suspended sediment does not directly address the cause and can only provide suggestions for further study. An alternative approach would be to estimate the total amount of sediment released into suspension along with its residence time and geographical distribution. Further studies on the responses of different marine communities to increased but sublethal levels of suspended sediment might provide more information on expected long-term effects.

5 CONCLUSIONS

Aggregate Dredging, Coastal Engineering, and Related Activities in the Coastal and Shelf Environments of ICES

1. In some member countries such as Canada, the extraction of marine aggregate is a minor industry, but in most, the industry is well established and growing. Reserves are now recognized as finite and in some cases (e.g., the UK and the Netherlands) total depletion dates are being predicted.

2. The provision of aggregates from marine locations is an alternative to land-based operations and therefore resolves a number of problems associated with those traditional sources. In some cases, there are also advantages related to quality and availability as well as transport and delivery.

3. Major uses of marine aggregates include construction (where quality is acceptable), land reclamation, beach replenishment, and island and reef construction in the offshore industry. Despite the general acceptance of marine aggregate extraction, there are concerns for related environmental damage and for conflict with other ocean space uses including fishing and shipping.

Effects of Extraction Activities on Living Resources and Fisheries

Physical Impact

4. Substrate removal and alteration of the bottom topography, resulting in the destruction of its infaunal and epifaunal biota, is the most immediate consequence of dredging activity. The removal of a significant thickness of sediment by trailer suction dredging may cause a localized drop in current strength associated with the increase in water depth. This results in reduced strength of the bottom currents and hence the deposition of finer sediment. Infill of the dredged pits and furrows, except in areas of mobile sand, tends to occur very slowly. Fisheries interests are most seriously affected by the dredging process where spawning grounds coincide with the deposit to be mined.

5. The creation of a turbidity plume in the water column is associated with the dredging process. Its magnitude is related to the proportion of mud and silt in the aggregate and the natural turbidity of the water. The duration of the plume in the water column depends upon factors such as water temperature, salinity, and the size range of the suspended material. Avoidance of the turbid area by visual feeders, such as mackerel and turbot, may occur. Alternatively, some fish species may be attracted to the area by the "odour stream" of crushed benthos. Similarly, primary productivity within the water column may be either increased or decreased depending on the ability of the feeding zooplankton to deal with the increase in nutrients and other suspended material.

6. Redeposition of fines from the turbidity plume will be concentrated within the dredging area but will also extend beyond it depending upon the current strength, water salinity and temperature, and the grain size of the suspended material. The prime risk of redeposition is smothering of fish eggs on the spawning grounds, such as those of the sandeel, and suffocation of filter-feeding benthos such as mussels.

7. Screening out of sand directly back to the sea floor may significantly alter the substrate and change a stable gravel bank into an area of mobile sand.

Chemical Impact

8. The bulk of aggregates are sands and gravels which, because of their composition and low surface activity, show little chemical interaction with the water column. The components of aggregates which may have some effect are the organic material and clays. The chemical effects are likely to be minor due to the very low organic and clay mineral content of the sediments. Also, dredging operations are generally of limited spatial extent and short duration, which further limits the chemical impact.

Biological Impact

9. The impact of a dredging operation on a benthic community depends primarily upon the magnitude and duration of the operation and the mode of dredging employed. Recovery of the community afterwards is also influenced by the nature of the new sediment surface that is exposed or subsequently accumulates at the extraction site, the larval and adult pool of potential new colonizers, and the nature and intensity of the stresses which the community normally withstands. Complete benthic recovery may take from one month to fifteen or more years.

10. Predictably, the intensity of the dredging operation influences the severity of its impact upon the benthic community. The more extensive the operation, the greater the initial defaunation and the greater the immigration distance colonizing species must travel.

11. The mode of dredging affects the nature of the impact. The immediate effect of anchor dredging upon the sea floor and its biota is severe but localized, whilst that of trailer dredging is less profound but more widespread. In general, the latter method is to be preferred as it is more likely to leave the sea floor close to its pre-dredging condition and hence more suitable for recolonization by the ambient fauna.

12. The nature of the new sediment that is exposed or subsequently accumulates in the extraction site after dredging strongly influences the structure and composition of the colonizing benthic community. Expo-

sure or accumulation of a substrate resembling that which originally existed promotes recolonization by a similar bottom fauna. However, complete and rapid regeneration of a dredged aggregate deposit to its former state, in the northwest European and North American shelf regions, tends to occur only in areas of mobile sand transport.

13. The pattern of recolonization may be similar to that which ensues after the abatement of organic pollution or severe storms. With the exception of certain errant epifaunal species or deep-burrowing biota which might display avoidance reactions to an oncoming draghead, dredging may result, initially, in complete defaunation within the dredged pits. The adult species most readily available for immediate colonization of the newly exposed sediment will be mobile epibionts inhabiting adjacent undisturbed sediments. The potential for colonization through larval recruitment is less tightly constrained by the proximity of undisturbed communities and the habits of the species concerned.

14. Recovery takes place readily in soft sediment communities in areas exposed to periodic disturbances which are often dominated by short-lived "opportunistic" colonizers. One study of the consequences of maintenance dredging upon such communities indicates that they are adept at readjustment to the impact of the dredging operation and so should be less severely affected by mining operations than those on more stable substrates.

15. The magnitude of the effect of sediment redeposition upon a benthic ecosystem depends largely on the nature of the indigenous fauna, the deposition rate, and the increase in water turbidity relative to the region's natural turbidity. The impact upon the ecosystem has been observed to take one of four forms:

a) defaunation within the affected area is initially virtually complete, similar to that on the dredging ground itself, but recolonization progresses more rapidly;

b) defaunation is less pronounced than on the dredging ground and recolonization is more rapid;

c) species richness and abundance are enhanced in the area of sediment fallout;

d) negligible effect is detected.

Sensitive Species and Communities

16. The sandeel is a non-migratory species for which there are important fisheries in the North Sea, some coincident with gravelly substrates, and which contributes to the diet of many commercially caught fish species. Sandeels lay their eggs on sand. Where aggregate extraction coincides with spawning grounds, the eggs are therefore at risk either from smothering by outwash fines or by direct removal. Mature sandeels are also particularly vulnerable owing to their habit of burying themselves in the sand at night.

17. The harmful consequences for the herring and its fisheries arise from the impact of dredging by the marine gravel industry upon its spawning grounds. The majority of recruits seem to spawn on the parent ground, but the data are not conclusive. Nevertheless, changes in the structure of the spawning ground caused by dredging will negatively influence the return of herring to the spawning sites, and therefore their successful reproduction, to a high degree.

18. Whitefish and vendace in the northern Baltic Sea spawn on sand, gravel, and pebble surfaces in water between 1- and 5-m depth. The exact location of many spawning sites is unknown, but the coregonids are fished as intensively as the herring which spawn in similar areas. As a result, the impact of dredging on these species would be comparable to that on the herring.

19. Stocks of the brown crab in the English Channel support important fisheries based at numerous ports in England, France, and the Channel Islands. Since an increase in requests for licences to prospect for, or extract, gravel in the eastern Channel is also now occurring, a conflict of interest has arisen with fishermen over access to the seabed. As the eastern English Channel gravel beds support overwintering concentrations of crabs, it has been accepted as an interim restriction on the development of the Hastings Bank reserve that dredging be confined to that part of the Shingle Bank least likely to be a crab wintering ground.

20. Marine calcareous algae (maërl) are used as fertilizers and soil conditioners. Interest is centred on deposits off the coasts of France, England, and Ireland. In the long term, the effect of dredging will be to exhaust all supplies of maërl within the extraction zone. When living maërl is closely associated with dead material, a rich and productive animal community will also be destroyed. The slow growth rate of the species means that replacement of such

deposits could not be expected in the foreseeable future.

Estimation of Scale of Effects and Consequences

21. The scale of effects of sediment extraction projects and corresponding consequences for marine life and fisheries is dependent on the environmental characteristics of the area, the nature and extent of the extraction operation, and the time for recovery or readjustment of the benthos. There are no published examples of a complete assessment of any specific sand or gravel extraction project but, as the report illustrates, quantitative assessments can and should be undertaken.

Impact of Fishing Activity

22. Trawling of fishing gear (otter or beam trawls) over the sea floor also directly or indirectly affects the benthic fauna, in the following ways:

    a) the direct destruction of benthic organisms and the crushing or damaging of organisms in and on the bottom;

    b) the resuspension of sediment (with or without harmful substances) by the trawl gear and the resultant deposition of fine material in areas with a low tidal current;

    c) a change in the bottom structure of an area which may result in a different recolonization pattern, thereby resulting in a benthic community different in composition from that encountered before trawling began;

    d) a cumulative effect caused by frequent fishing in the same area which may result in long-term changes in diversity, biomass, and productivity of the benthos.

<u>Management</u>

Regulatory Practices

23. In eleven of the twelve countries surveyed, specific legislation governs the submarine extraction of minerals. Seven of these countries include in the licences specific terms and conditions related to environmental or fisheries impact management.

24. The total quantity of mineral removed from the seabed and the extraction rate are important factors affecting the potential impact of aggregate dredging on the marine environment.

25. The rate of extraction has less effect on the biological and chemical impact than the extraction technique utilized. Trailing suction dredging will disturb large areas of seabed, which will, however, be quite quick to re-establish former flora and fauna. Dredging from a stationary vessel will influence a localized area. The seabed between dredged pits will remain rather unaffected, but the pits themselves will probably be colonized by a new community of plants and animals better adapted to the changed conditions.

26. The rate of extraction and the total quantity removed are relevant when evaluating the physical impact of marine aggregate dredging on the coastline. Water depth, wave height, and sediment particle size are critical factors affecting the movement of seabed sediments. With proper background information, it is possible to predict the impact of marine aggregate extraction on seabed sediments and also its likely impact on the supply of sediment (e.g., to adjacent beaches).

27. Mathematical models can be used to predict the effect of altered seabed morphology on wave energy influencing adjacent shores. It is important to check that no unexpected changes occur during the life of the extraction site. Monitoring should be conducted on an annual basis. In specially sensitive areas, with rapid changes in seabed topography, it may be advisable to undertake more frequent surveys.

Resource Mapping

28. Most countries have gathered geological data from their offshore regions and many have recently developed offshore geological mapping programmes. The survey methods and techniques, mapping scales, information shown, and progress of map publication are variable. Some countries (e.g., the United Kingdom) are well advanced with the systematic mapping of their offshore areas.

29. Most countries which undertake offshore geological surveys are producing maps showing the distribution of seabed sediments. This information is of interest to the marine aggregate industry but the detail shown, and the scale of the maps, are often insufficient for accurate resource appraisal.

30. Resource mapping programmes have recently been developed by some countries, resulting in the publication of maps and reports. Information is shown at varying levels of detail and 1:100 000 is commonly the chosen map scale.

31. Data exchange and exchange of ideas concerning mapping procedures commonly take place amongst

ICES member countries. On occasion this has resulted in a joint publication of certain maps (e.g., between the British and Dutch Geological Surveys in the southern North Sea).

Beneficial Interactions

32. Although marine aggregate mining projects are scheduled to avoid conflicting uses, they have not been designed to provide beneficial interactions. A benefit has however been realized in New York Harbor (USA) where the formation of borrow pits in the sea floor has served to concentrate finfish stocks at the pits.

33. Under certain conditions, disturbance of the sea floor resulting from dredging activities may enhance benthic productivity and result in increased commercial yields. The manner in which this might occur and the magnitude of any effect have not been studied, so any potential benefits due to this phenomenon are speculative.

Monitoring

34. Marine mining activity should be monitored on a continuous basis to provide a permanent record which should be available to both the regulatory authorities and the mining company. The information provided will allow the regulatory authority to monitor the activities of the mining vessel to ensure compliance with specific conditions in the mining licence/permit and to investigate third party allegations of illegal dredging activities.

35. Minimum requirements for data storage by electronic monitoring devices should include:

    a) the position of the mining vessel on a 24-hour basis according to an agreed level of accuracy;

    b) the deployment of dredging equipment;

    c) the operation of dredging equipment.

    Additional information may be required at the discretion of the regulatory authority and/or the mining company in pursuance of its own management requirements.

36. Physical monitoring of marine aggregate extraction sites is necessary for a number of reasons. Primarily it may:

    a) ensure compliance with licence conditions;

    b) form an integral component of any impact assessment studies;

    c) provide information on natural variability and trends in sea floor sediments and conditions;

    d) further delineate aggregate reserves.

37. Physical monitoring surveys may employ a variety of techniques including side-scan sonar, sediment sampling, underwater video and still photography (used either remotely from a vessel or directly by divers), and seismic/sub-bottom profiling.

38. The benthos, because of its sedentary nature and location on the sea floor, is an obvious choice for biological monitoring of the short- and long-term effects of seabed mining. Macrofaunal life-spans allow the integration of effects over a period of years, while meiofauna respond to changes in the order of months. In its most common application in this field, biological monitoring is used to measure the rate of recolonization and establishment of a productive benthic community on a newly dredged sea floor.

39. Biological monitoring is less useful for assessing the effects of suspended sediment. Unlike recolonization rates, where the gradient ranges from abiotic conditions to stable benthic communities, the effects of sediment load are sublethal and of low impact.

40. Many techniques have been developed to measure differences between biological communities that result from man-made perturbations which could be applicable to the effects of dredging. The most widely used are diversity indices, though certain shortcomings have been recognized in these. With the increased availability of computers, multivariate techniques and cluster analysis are being used more often. Dendrograms provide good visual representations of community similarity. All of these techniques require the sorting and taxonomic identification of samples. These are labour-intensive processes that result in a high cost per sample. The number of samples required may be reduced by sequential sampling. Taxonomic identification may be eliminated by the use of allometric methods.

6 RECOMMENDATIONS FOR FUTURE RESEARCH

Marine aggregate extraction operations take place in many ICES member countries. Comparatively few detailed studies on the biological impacts of these operations have however been reported, and as a result our knowledge of the implications of such activities for benthic communities and the fisheries they support remains patchy.

Much research still needs to be conducted before definitive statements on the effects on fisheries of marine aggregate extraction can be made. The Working Group has identified the following key areas of research which warrant detailed study:

a) Improved quantification of the structural and functional properties of gravel assemblages and their relation to fisheries via the food chain. Improvements in remote and diver-operated sampling methodology on gravel substrates are prerequisites for such work.

b) The nature of impacts on benthic communities at currently dredged locations. The investigations should include consideration of the survival of different types of benthic organisms following redistribution from the hopper with outwash fines.

c) The recolonization of gravelly substrates following the cessation of disturbance or defaunation due to dredging. Time scale is an important consideration.

d) The effects of physical disturbance on gravel communities as demonstrated by small-scale manipulative experiments conducted under controlled conditions. The impact of repeated disturbances of these communities should also be investigated.

e) The effects on local fish and shellfish distributions of disturbance due to very large-scale dredging over a short time span and/or defaunation of an extraction area, for example, large-scale civil engineering projects: are populations actually reduced in a real sense or are they simply displaced?

f) The distribution of spawning grounds for bottom-spawning fish and shellfish overwintering grounds in areas where marine sediment extraction may occur.

g) Dredging related impacts, such as nutrient or suspended solid release, on growth rates of relevant species such as shellfish.

h) Changes in species composition following recolonization of a disturbed or defaunated substrate, particularly where the substrate type is changed.

i) Fish populations at historical dredge sites, where extraction has now ceased. Ideally, investigation should focus on the species composition and population dynamics of finfish communities in an area prior to extraction, immediately after extraction, and at various intervals following the termination of extraction.

j) The role of outwash fines in the scavenging of trace metals from the water column.

k) Effects of the generation of turbidity plumes on fish behaviour, including avoidance and/or concentration of individuals.

l) The fate of marine organisms travelling through the suction pipe and dredger hopper.

m) The behaviour of the dredge head at the seabed, investigated by such means as video camera monitoring.

n) The environmental effects of the removal of boulders from the seabed by "stone fishing".

7 REFERENCES

Adey, W.H., and Adey, P.J. 1973. Studies on the biosystematics and ecology of the epilithic crustose Corallinaceae of the British Isles. Br. phycol. J., 8: 343-407.

Adey, W.H., and McKibbin, D.L. 1970. Studies on the maërl species *Phymatolithon calcareum* (Pallas) nov. com. and *Lithothamnium corallioides* Crouan in the Ria de Vigo. Botanica mar., 13: 100-106.

Anderson, F.E., and Meyer, L.M. 1986. The interaction of tidal currents on a disturbed intertidal bottom with a resulting change in particulate matter quantity, texture and food quality. Estuar. coast. Shelf. Sci., 22: 19-29.

Anderton, R., Bridges, P.H., Leeder, M.R., and Sellwood, B.W. 1979. A dynamic stratigraphy of the British Isles. George Allen & Unwin, London. 301 pp.

Anglin, C.D., MacIntosh, K.J., Baird, W.F., and Werren, D.J. 1987. Artificial beach design, Lake Forest, Illinois. Proceedings of Coastal Zone '87, Seattle, Washington, pp. 1121-1129.

Anon. 1989. Prince Edward Island aggregate resources. Department of Energy and Forestry, Prince Edward Island, Canada. 141 pp.

Anon. 1990. Regionaal ontgrondingen plan Noordzee. Rijkswaterstaat Directie Noordzee, 1 July 1990. Rijswijk, The Netherlands.

Appel, P.W.U., and Kunzendorf, H. 1989. Possibility of offshore mineral deposits in Greenland waters. Mar. Mining, 8: 155-162.

Ardus, D.A., and Harrison, D.J. 1990. The assessment of aggregate resources from the UK continental shelf. Ocean Resources, 1:113-128.

Augris, C., and Cressard, A.P. 1984. Les granulats marins. Publications du Centre National pour l'Exploitation des Océans. Rapp. scient. techn., 51. 89 pp.

Balsan, P.S., and Harrison, D.J. 1986. Marine Aggregate Survey Phase 1: southern North Sea. Brit. Geol. Surv. mar. Rep., 86/38.

Bennett, D.B., and Brown, C.G. 1983. Crab (*Cancer pagurus*) migrations in the English Channel. J. mar. biol. Ass. U.K., 63: 371-398.

Blunden, G., Binns, W.W., and Perks, F. 1975. Commercial collection and utilisation of maërl. Econ. Bot., 29: 140-145.

Boillot, G. 1961. La répartition des sédiments en baie de Morlaix et en Baie de Siec. Cah. Biol. mar., 2: 53-66.

Boillot, G. 1964. Géologie de la Manche occidentale. Annls Inst. Océan., 42. 220 pp.

Bokuniewicz, H.J. 1979. Volume of sand and gravel reserves in the lower bay of New York Harbor. State University of New York, Marine Sciences Research Center, Special Rep., 32, Ref. 79-16. 34 pp.

Bolster, G.C., and Bridger, J.P. 1957. Nature of the spawning area of herring. Nature, Lond., 179: 638.

Bonsdorff, E. 1983. Recovery potential of macrozoobenthos from dredging in shallow brackish waters. Oceanologica Acta, Spec. Vol., Proc. 17th European Symposium on Mar. Biol., December 1983, pp. 27-32.

Bouchot, G., Cabioch, L., Caillot, A., Chardy, P., Cressard, A., Desaunay, Y., Gentil, F., Kurc, G., Paille, A. et Entreprise Gagnerand. 1975. Effets des extractions de sables et graviers marins sur l'environnement et la pêche. Bilan des études effectuées depuis mars 1974 dans le cadre d'une exploitation expérimentale. ICES, Doc. C.M.1975/E:17. 7 pp.

Bowers, A.B. 1969. Spawning beds of Manx autumn herring. J. Fish Biol., 1: 355-359.

Brown, C.G., and Bennett, D.B. 1980. Population and catch structure of the edible crab (*Cancer pagurus*) in the English Channel. J. Cons. int. Explor. Mer, 39: 88-100.

Buchanan, J.B., and Moore, J.J. 1986. Long-term studies at a benthic station off the coast of Northumberland. Hydrobiologia, 142: 121-127.

C.U.R. 1987. Manual on artificial beach nourishment. Civieltechnisch Centrum voor Uitvoering Research en Regelgeving (Centre for Engineering Research and Regulations) Report 130, Rijkswaterstaat and Delft Hydraulics, Gouda, The Netherlands. 195 pp.

Cabioch, L. 1966. Contribution à l'étude morphologique, anatomique et systématique de deux Mélobesiée *Lithothamnium calcareum* (Pallas) Areschoug et *Lithothamnium corallioides* Crouan. Botanica mar., 9: 33-53.

Cabioch, L. 1968. Contribution à la connaissance des peuplements benthiques de la Manche occidentale. Cah. Biol. mar., 9 (5) (Supplément): 493-720.

Cabioch, L. 1970. Le maërl des côtes de Bretagne et le problème de sa survie. Penn ar Bed, 63: 421-429.

Cameron, T.D.J., Laban, C., and Schüttenhelm, R.T.E. 1984. Flemish Bight, sheet 52°N-02°E, 1:250000 series, Sea bed sediments. British Geological Survey and Geological Survey of the Netherlands.

Collinson, R.I., and Rees, C.P. 1978. Mussel mortality in the Gulf of La Spezia, Italy. Mar. Pollut. Bull., 9: 99-101.

Conover, D., Cerrato, R., and Bokuniewicz, H. 1985. Effect of borrow pits on the abundance and distribution of fishes in the Lower Bay of New York Harbor. State University of New York, Marine Sciences Research Center, Special Rep., 64. 68 pp.

Cruickshank, M.J., and Hess, H.D. 1975. Marine sand and gravel mining. Oceanus, 19: 32-44.

Daan, N. 1973. A quantitative analysis of the food intake of North Sea cod *Gadus morhua*. Neth. J. Sea Res., 6: 479-517.

de Groot, S.J. 1979a. An assessment of the potential environmental impact of large scale sand dredging for the building of artificial islands in the North Sea. Ocean Mgmt, 5: 211-232.

de Groot, S.J. 1979b. The potential environmental impact of marine gravel extraction in the North Sea. Ocean Mgmt, 5: 233-249.

de Groot, S.J. 1980. The consequences of marine gravel extraction on the spawning of herring, *Clupea harengus* Linné. J. Fish Biol., 26: 605-611.

de Groot, S.J. 1984. The impact of bottom trawling on benthic fauna of the North Sea. Ocean Mgmt, 9: 177-190.

de Groot, S.J. 1986. Marine sand and gravel extraction in the North Atlantic and its potential environmental impact with emphasis on the North Sea. Ocean Mgmt, 10: 21-36.

De Veen, J.F. 1978. Changes in North Sea sole stocks (*Solea solea* (L.)). Rapp. P.-v. Réun. Cons. int. Explor. Mer, 172: 124-136.

Debyser, J. (Ed.). 1975. Les problèmes de l'environnement liés à l'exploitation des sables et graviers marins. Note technique, 51. Centr. National pour l'Exploit. des Océans. 11 pp.

Deeny, D.E. 1975. The sediments of Kilkieran Bay (Co. Galway) between Kilkieran and Dinnish Shoals. Thesis, Geology Dept, University College, Galway, Ireland. 63 pp.

Department of the Environment (UK), 1975. Aggregates: the way ahead. Report of the Advisory Committee on Aggregates. Chairman: Sir Ralph Verney. 223 pp.

Dickson, R., and Lee, A. 1973. Gravel extraction: effects on seabed topography. Offshore Serv., 6: 32-39, 56-61.

Dorel, D., and Maucorps, A. 1976. Note sur la granulométrie des frayères de hareng en Manche orientale. ICES, Doc. C.M.1976/H:20.

Drapeau, G. 1973. Sedimentology of herring spawning grounds on Georges Bank. ICNAF Res. Bull., 10: 151-162.

Drapeau, G., and King, L.H. 1972. Surficial geology of the Yarmouth - Browns Bank map area. Information Canada, Ottawa. 6 pp.

Eagle, R.A. 1975. Natural fluctuations in a soft bottom community. J. mar. biol. Ass. U.K., 55: 865-878.

Eden, R.A. 1975. North Sea environmental geology in relation to pipelines and structures. Oceanol. Int., 75: 302-309.

Edwards, E. 1979. The edible crab and its fishery in British waters. Fishing News Books. 142 pp.

Fader, G.B.J. 1988. The fixed link crossing of Northumberland Strait: comments on seabed and shallow surface conditions and potential dredging opportunities. Dredging Seminar, Techn. University of Nova Scotia, Canada, 13-15 December 1988. 19 pp.

Fader, G.B., King, L.H., and Josenhans, H.W. 1982. Surficial geology of the Laurentian Channel and the western Grand Banks of Newfoundland. Mar. Sci. Pap., 21. 37 pp.

Fader, G.B., King, L.H., and MacLean, B. 1977. Surficial geology of the Gulf of Maine and Bay of Fundy. Mar. Sci. Pap., 19; Geol. Surv. Can. Pap., 76-17. 23 pp.

Fader, G.B., and Pecore, S. 1989. Surficial geology of the Abequeit Passage area of Northumberland Strait, Gulf of St. Lawrence. Geol. Surv. Can. Open File 2087. 4 pp.

Folk, R.L. 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. J. Geol., 62: 344-359.

Freeland, G. 1981. Surficial sediment of the New York Bight Apex area. Environmental Research Laboratories, Atlantic Oceanographic and Meteorological Laboratories National Oceans Survey, Washington, D.C.

French, D.P., and French, F.W., 1989. The biological effects component of the natural resource damage model system. Oil and Petrochemical Pollution, 4: 125-163.

Fridriksson, A., and Timmermann, G. 1951. Herring spawning grounds off the south coast of Iceland during spring 1950. J. Cons. int. Explor. Mer, 17: 172-180.

Gautier, M. 1971. Le maërl sur le littoral de Bretagne. Cah. Océanogr., 23: 171-191.

Gibbs, P.J., Collins, A.J., and Collett, L.C. 1980. Effect of otter prawn trawling on the macrobenthos of a sandy substratum in a New South Wales estuary. Aust. J. mar. Freshwat. Res., 31: 509-516.

Gould, S.J. 1981. The mismeasurements of man. W. W. Norton and Co., New York. 344 pp.

Gray, J. 1976. Are marine base line surveys worthwhile? New Scientist, 29: 219-221.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York.

Gushue, J.J., and Kreutziger, K.M. 1977. Case studies and comparative analyses of issues associated with productive land use at dredged material disposal sites. Techn. Rep. D-77-43. Environmental Effects Laboratory, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Gutt, W., and Collins, R.J. 1987. Sea-dredged aggregates in concrete. Building Research Establishment Information Paper IP 7/87. July 1987. Building Research Establishment, Garston, Watford, England.

Hale, P.B. 1987. Canada's offshore non-fuel mineral resources - opportunities for development. Mar. Min., 6: 89-108.

Hamblin, R.J.O., and Harrison, D.J. 1988. Marine Aggregate Survey Phase 2: South Coast. British Geological Survey Mar. Rep., 88/31.

Hamblin, R.J.O., and Harrison, D.J. 1989. The marine sand and gravel resources of the Isle of Wight and Beachy Head. British Geological Survey Techn. Rep., WB/89/41C.

Harden Jones, F.R. 1968. The herring. *In* Fish migration, pp. 86-143. Edward Arnold, London.

Harrison, D.J., Laban, C., and Schüttenhelm, R.T.E. 1987. Indefatigable, sheet 53°N-02°E, 1:250000 series, Sea bed sediments. British Geological Survey and Geological Survey of the Netherlands.

Hemmings, C.C. 1965. Underwater observations on a patch of herring spawn. Scott. Fish. Bull., 23: 21-22.

Hildebrand, S.F. 1963. Fishes of the western North Atlantic, family Clupeidae. Sears Foundation for Marine Research, Memoir, 1: 274-293.

Hily, C. 1983. Macrozoobenthic recolonization after dredging in a sandy mud area of the Bay of Brest enriched by organic matter. Oceanologica Acta, Spec. Vol., Proc. 17th European Symposium on Mar. Biol., December 1983, pp. 113-120.

Holme, N.A. 1983. Fluctuations in the benthos of the western English Channel. Oceanol. Acta, 1983 (SP): 121-124.

Howard, A.E. 1982. The distribution and behaviour of ovigerous edible crabs (*Cancer pagurus*), and consequent sampling bias. J. Cons. int. Explor. Mer, 40: 259-261.

Hubbard, B.S., and Herbich, J.B. 1977. Productive land use of dredged material containment areas: international literature review. Center for Dredging Studies, Rep., 199. Texas A & M University College Station, Texas.

ICES. 1975. Report of the Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction. Coop. Res. Rep. Cons. int. Explor. Mer, 46. 57 pp.

ICES. 1977. Second report of the ICES Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction. Coop. Res. Rep. Cons. int. Explor. Mer, 64. 26 pp.

ICES. 1979. Third report of the Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction. ICES, Doc. C.M.1979/E:3.

Ismail, N.S. 1985. The effects of hydraulic dredging to control oyster drills on benthic macrofauna of oyster grounds in Delaware Bay, New Jersey. Int. Rev. Gesamt. Hydrobiol., 70: 379-395.

Jackson, J.K., and Resh, V.H. 1989. Sequential decision plans, benthic macroinvertebrates and biological monitoring programs. Environ. Mgmt, 13: 455-468.

Jacquotte, R. 1962. Étude des fonds de maërl de Méditerranée. Rev. Trav. Stat. mar. Endoume, 26: 141-235.

Jones, R. 1954. The food of the whiting and a comparison with that of the haddock. DAFS mar. Res., 1954 (2). HMSO, Edinburgh.

Kaplan, E.H., Welker, J.R., Kraus, M.G., and McCourt, S. 1975. Some factors affecting the colonization of a dredged channel. Mar. Biol., 32: 193-204.

Keegan, B. 1974. The macrofauna of maërl substrates on the west coast of Ireland. Cah. Biol. mar., 15: 513-530.

King, L.H. 1970. Surficial geology of the Halifax - Stable Island map area. Mar. Sci. Pap., 1. 16 pp.

Klugt, P.C.M. van der. 1991. Onderzoek grindvoorkomens in het gebied van de Texelse Stenen. Report OP 6505. Geological Survey of the Netherlands, Marine Geology Division.

Kunz, H. 1987. Shoreline protection of the East Frisian Islands of Norderney and Langeroog. Proceedings of Coastal Zone '87, Seattle, Washington, pp. 1082-1096.

Laban, C., Cameron, T.D.J., and Schüttenhelm, R.T.E. 1984. Geologie van het Kwartair van de Zuidelijke Bocht van de Noordzee (Geology of the Southern Bight of the North Sea). Meded. Werkgr. Tert. Kwart. Geol., 21: 139-154.

Le Gall, J. 1935. Le hareng *Clupea harengus* Linné. I. Les populations de l'Atlantique Nord-Est. Annls, Inst. Océanogr., Monaco, 15. 215 pp.

Lee, A.J., and Ramster, J.W. 1976. Atlas of the seas around the British Isles. Tech. Rep., MAFF Fish. Lab., 20. 4 pp., charts.

Lee, A.J., and Ramster, J.W. 1981. Atlas of the seas around the British Isles. MAFF, Direct. Fish. Res. HMSO, London. 102 pp.

Leonard, L.A., Pilkey, O.H., and Clayton, T.D. 1988. An assessment of beach replenishment parameter. Duke University, Durham, North Carolina, USA. Unpublished manuscript. 13 pp.

Ludwig, G., and Figge, K. 1979. Schwermineralvorkommen und Sandverteilung in der Deutschen Bucht. Geol. Jb., D32: 23-68. 10 Ktn, Hanover.

MacLean, B., Fader, G.B., and King, L.H. 1977. Surficial geology of the Canso Bank and adjacent areas. Mar. Sci. Pap., 20; Geol. Surv. Can. Pap., 76-15. 11 pp.

MacLean, B., and King, L.H. 1971. Surficial geology of the Barquereau and Misaine Bank map area. Mar. Sci. Pap., 3; Geol. Surv. Can. Pap., 71-52. 19 pp.

McArdle, P., and Keary, R. 1986. Offshore coal in the Kish Bank Basin: its potential for commercial exploitation. Geol. Surv. Ire., Rep. Ser., 86/3.

McCallister, P., and Kavalar, R.J. 1982. Confined disposal program for polluted maintenance dredged in the Great Lakes. Proc. Oceans '82 Conf. Mar. Tech. Soc., Inst. Electrical and Electronics Engineers, and the Council of Ocean Eng., Washington, D.C., pp. 1042-1045.

McCauley, J.E., Parr, R.A., and Hancock, D.R. 1977. Benthic infauna and maintenance dredging: a case study. Water. Res., 11: 233-242.

Macer, C.T. 1966. Sand eels (Ammodytidae) in the south-western North Sea, their biology and fishery. Fish. Invest. Min. Agric. Fish. Food (U.K.) (2 Sea Fish.) 24(6): 1-55.

Miller, C.K., and Fowler, J.H. 1987. Development potential for offshore placer and aggregate resources of Nova Scotia. Mar. Min., 6: 121-140.

Millner, R.S., Dickson, R.R., and Rolfe, M.S. 1977. Physical and biological studies of a dredging ground off the east coast of England. ICES, Doc. C.M.1977/E:48.

Nagalhuskanam, A.K. 1964. On the biology of the whiting (*Gadus merlangus*) in Manx waters. J. mar. biol. Ass. U.K., 44: 177-202.

National Marine Fisheries Service. 1984. Seasonal occurrence of finfish and larger invertebrates at eight locations in Lower and Sandy Hook Bays, 1982-83. Rep. to NY District, U.S. Army Corps of Engineers. 79 pp.

Nederlof, H.P. 1990. Geologisch onderzoek zandwingebied ten westen van Scheveningen ten behoeve van een strandsuppletie. Report Br. nr. 91140. Geological Survey of the Netherlands, Marine Geology Division.

Nederlof, H.P. 1991. Onderzoek korrelgrootteverdeling in de draaicirkel van de IJ-geul ten behoeve van zandwinning. Report. Br. nr. 912052. Geological Survey of the Netherlands, Marine Geology Division.

Niessen, A.C.H.M., and Schüttenhelm, R.T.E. 1986. Oppervlaktedelfstoffen (Raw materials at or near the surface). Rijks Geologische Dienst, Haarlem. Map.

Nunny, R.S., and Chillingworth, P.C.H. 1986. Marine dredging for sand and gravel. HMSO, London. 193 pp.

Oulasvirta, P., Rissanen, J., and Lehtonen, H. 1987. The effects of marine sand extraction on fisheries and the benthic macrofauna. Report of the Working Group on Marine Sand, Min. of Env. Ser. C/23/1987, pp. 141-195. (In Finnish).

Pacheco, A.L. 1983. Seasonal occurrence of finfish and larger invertebrates at three sites in lower New York Harbor, 1981- 1982. Rep. to NY District, U.S. Army Corps of Engineers by NOAA-NMFS, Northeast Fisheries Center, Sandy Hook Laboratory, Highlands, New Jersey. 49 pp.

Packer, T. 1987. Canadian offshore calcium carbonate: an assessment of development potential. Ocean Mining Report, Ocean Mining Division, EM&R Canada. 60 pp.

Palermo, M.R., Shields, F.D., and Hayes, D.F. 1981. Development of a management plan for Craney Island disposal area. U.S. Army Corps of Engineers, Waterways Experiment Station, Tech. Rep. EL-81-11. 170 pp.

Pantin, H. 1991. Seabed sediments around the United Kingdom. British Geological Survey, Offshore Reports, 2.

Parrish, B.B., Saville, A., Craig, R.E., Baxter, I.G., and Priestley, R. 1959. Observations on herring spawning and larval distribution in the Firth of Clyde in 1958. J. mar. biol. Ass. U.K., 38: 445-453.

Pilkey, O.H., and Clayton, T.D. 1988. Beach replenishment - the national solution? Proceedings of Coastal Zone '87, Seattle, Washington, pp. 1408-1419.

Poiner, I.R., and Kennedy, R. 1984. Complex patterns of change in the macrobenthos of a large sandbank following dredging. 1. Community analysis. Mar. Biol., 78: 335-352.

Postuma, K.H., Saville, A., and Wood, R.J. 1975. Herring spawning grounds in the North Sea. ICES, Doc. C.M.1975/H:46.

Postuma, K.H., Saville, A., and Wood, R.J. 1977. Herring spawning grounds in the North Sea. Coop. Res. Rep. Cons. int. Explor. Mer, 61: 1-16.

Rae, B.B. 1967. The food of cod in the North Sea and on west of Scotland grounds. DAFS mar. Res., 1967 (1). HMSO, Edinburgh.

Rees, H.L. 1987. A survey of the benthic fauna inhabiting gravel deposits off Hastings, southern England. ICES, Doc. C.M.1987/L:19.

Reineck, H.-E., and Singh, I.B. 1980. Depositional sedimentary environments. Springer-Verlag, Berlin, 2nd ed. 551 pp.

Reise, K. 1982. Long-term changes in the macrobenthic invertebrate fauna of the Wadden Sea: are polychaetes about to take over? Neth. J. Sea Res., 16: 29-36.

Rhoads, D.C., and Germano, J.D. 1982. Characterisation of organism sediment relations using sediment profile imaging: An efficient method of remote ecological monitoring of the sea floor (REMOTS TM System). Mar. Ecol. Progr. Ser., 8: 115-128.

Rhoads, D.C., and Germano, J.D. 1986. Interpreting long term changes in benthic community structure: A new protocol. Hydrobiologia, 142: 291-308.

Rhoads, D.C., McCall, P.L., and Yingst, J.Y. 1978. Disturbance and production on the estuarine seafloor. American Scientist, 66: 577-586.

Riesen, W., and Reise, K. 1982. Macrobenthos of the subtidal Wadden Sea: revisited after 55 years. Helgol. Wiss. Meeresunters., 35: 409-423.

Rolfe, M.S. 1976. Notes on *Lithothamnium* in the River Fal estuary, with particular reference to living rhodoliths on St Mawes Bank. Unpub. rep., Fisheries Lab., Burnham-on-Crouch, UK.

Routledge, R.D. 1979. Diversity indices: Which ones are admissible? J. theor. Biol., 76: 503-515.

Runnström, S. 1941. Quantitative investigations on herring spawning and its yearly fluctuations at the west coast of Norway. Fiskeridir. Skr. (Havunders.), 6 (8). 71 pp.

Schlee, J., and Pratt, R.M. 1970. Atlantic Continental Shelf and Slope of the United States - gravels of the northeast part. U.S. Geological Survey Professional Paper 529-H. 39 pp.

Schüttenhelm, R.T.E. 1980. The superficial geology of the Dutch sector of the North Sea. Mar. Geol., 34: 27-37.

Schwinghamer, P. 1988. Influence of pollution along a natural gradient and in mesocosm experiment on biomass size spectra of benthic communities. Mar. Ecol. Progr. Ser., 46: 199-206.

Storebæltsforbindelsen. 1990. Environmental impacts caused by dredging, reclamation and disposal operations. Total impact assessments and lee effects around Sprogoe. Unpub. report of Danish Hydraulic Institute and COWIconsult/Water Quality Institute. DHI/LIC-COWI/VKI.

Shelton, R.G.J., and Rolfe, M.S. 1972. The biological implications of aggregate extraction: recent studies in the English Channel. ICES, Doc. C.M.1972/ E:26.

Steele, J.H. 1965. Notes on some theoretical problems in production ecology. Mem. 1st Ital. Idrobiol. Dott. Marco de Marchi 18 Suppl., pp. 383-398.

Tibbo, S.N., Scarratt, D.J., and McMullon, P.W.G. 1963. An investigation of herring (*Clupea harengus* L.) spawning using free-diving techniques. J. Fish. Res. Bd Can., 20: 1067- 1079.

Van Alphen, J.S.L.J., and Damoiseaux, D. 1989. A geomorphological map of the Dutch shoreface and adjacent continental shelf. Geol. Mijnb., 68: 433-443.

Van der Veer, H.W., Bergman, M.J.N., and Beukema, J.J. 1985. Dredging activities in the Dutch Wadden Sea: effects on macro-benthic fauna. Neth. J. Sea Res., 19: 183-190.

Vink, J.S.L. 1988. Bijdrage Milieu - effect rapportage Zandwinning Noordzee, onderdeel waterkwaliteit. Rijkswaterstaat, Dienst Getijdewateren, Notitie GWWS 88.256. 's Gravenhage. 15 pp.

Wang, H. 1988. Short course on principles and applications of beach nourishments, Chapter 1. Ed. by T. Campbell, R. Dean, A. Mehta, and H. Wang. Dept. of Coastal and Oceanographic Engineering, University of Florida. 28 pp.

Wiersma, J., and Schüttenhelm, R.T.E. 1984. Grindvoorkomens in het Klaverbankgebied. IRO-Journal, 8 (51/52): 1-2.

Wildish, D.J. 1977. Factors controlling marine and estuarine sublittoral macrofauna. Helgol. Meeresunters., 30: 445-454.

Williams, M.L., and Kana, T. 1987. Beach nourishment at Myrtle Beach, South Carolina: an overview. Proceedings of Coastal Zone '87, Seattle, Washington, pp. 1106-1120.

Williams, S.J. 1981. Sand resources and geological character of Long Island sand. Coastal Engineering Resource Center, U.S. Army Corps of Engineers, Tech. Pap. 81-3, 65 pp. Fort Belvoir, Virginia.

Windom, H.L. 1976. Environmental aspects of dredging in the coastal zone. Critical Rev. environm. Control, 6: 91-110.

Winslade, P. 1974. Behavioural studies on the lesser sand-eel, *Ammodytes marinus* (Raitt). II. The effect of light intensity on activity. J. Fish Biol., 6: 577-586.

Wolda, H. 1981. Similarity indices, sample size and diversity. Oecologia, 50: 296-302.

Zonneveld, P.C. 1990. Geologisch onderzoek in de IJ-geul II. Report OP 6547. Geological Survey of the Netherlands, Marine Geology Division.

Zonneveld, P.C. 1991. Geologisch onderzoek in de Maas- en Eurogeul. Report OP 6533. Geological Survey of the Netherlands, Marine Geology Division.

ANNEX 1

Code of Practice for the Commercial Extraction of Marine Sediments (including minerals and aggregates)

1 INTRODUCTION

This code of practice is intended to promote sound management to ensure that the dredging industry operates in harmony with fisheries and other ocean space users. These guidelines are intended to provide a flexible framework that any country can adopt within its own regulatory system.

The following code of practice provides step-by-step advice on how marine dredging should be conducted in order to minimize conflicts with other users of the sea and optimize the use of marine resources. Specific consultation procedures with respect to fisheries are outlined in Appendix 1. Because of radical differences in approach by each country, this generalized code of practice is not intended to apply to navigational dredging. These recommendations relate primarily to prospecting and extraction of sedimentary materials, including sand and gravel, phosphorite, placer minerals, waste coal, and maërl.

The guidelines are intended to ensure that sufficient information is produced to enable an environmental impact assessment, covering the effects of the proposals on other interests including fisheries, to be carried out and an environmental impact statement to be produced as necessary.

2 PROSPECTING GUIDELINES

1. All potential conflicts between marine mining and other uses of the sea should be identified by the regulatory authority, along with relevant sea users and interest groups (government and non-government).

2. Before the application for a prospecting licence is considered, the applicant should consult the groups identified in (1), above. It should be the responsibility of the regulatory authority to identify areas of particular sensitivity (e.g., herring spawning beds, marine conservation areas, archaeological sites, pipelines and cables) before any prospecting activity proceeds. The regulatory authority must ensure that appropriate prospecting techniques are adopted.

3. The regulatory authority should ensure that an appropriate multi-level liaison network is established to permit timely decision-making at all stages of the exploration/development programme.

4. Full details of the proposed prospecting programme should be submitted by the applicant to the regulatory authority for approval. There must be provision for a conflict-resolution procedure in which the regulatory authority, the applicant company, the fishery, and other interests participate. The exact procedure will depend on existing national practice.

5. Prospecting should cover the whole licensed area in order to provide a complete picture of the geological setting. All prospecting information compiled by industry should be submitted to the regulatory authority. Normal commercial confidentiality considerations should apply.

Details of a prospecting licence will vary according to the requirements of the individual regulatory authority; however, it is recommended that the following elements be included:

1. Identification of target commodities;

2. Duration of prospecting licence;

3. Specification of whether access to the prospecting area is exclusive or shared;

4. Location of prospecting area (geographical coordinates);

5. Types of prospecting techniques to be used (e.g., hydro-acoustic methods, dredging, grab sampling, or coring);

6. Details of the prospecting programme (e.g., timing and duration, vessel characteristics, geophysical line spacing, number and location of sample sites, volumes of material to be recovered, sample processing plans);

7. Provision for notifying other marine users;

8. Liaison arrangements with other sea users and interest groups, as identified in Section 2.1.

An example of guidelines for consultation or liaison with fisheries interests is given in Appendix 1. Similar guidelines could be devised for other interest groups (e.g., conservation, navigation, military).

3 MINING GUIDELINES

Applicants for mining licences should submit outline proposals for informal discussions with the regulatory authority. The regulatory authority should undertake consultations with authorities or agencies responsible for the following interests, as appropriate:

a) Wildlife/conservation/environmental,
b) Fisheries and mariculture,
c) Defence,
d) Energy,
e) Navigation and harbours,
f) Coastal protection,
g) Engineering and construction works (e.g., cables and pipelines, sewer outfalls),
h) Littoral areas (local planning authorities),
i) Recreation/amenity interests,
j) Waste disposal.

These consultations should include all relevant government and non-government organizations and interest groups likely to be affected by the proposal. The proposal should be published, indicating where relevant information can be obtained and providing an administrative address for all representations. All consultees should be informed of the outcome of the consultations and the decision of the regulatory authority.

The regulatory authority should consider all representations received from consultees on the outlined proposals. Discussions and negotiations should take place as appropriate. A report should be prepared which sets out the proposals, the representations which have been received from those whose interests might be affected, and possible mitigating measures. This report should summarize the arguments for and against the proposal so that the merits of the proposal can be judged by the regulatory authority. In all cases, an environmental impact statement (EIS) should be prepared. If appropriate, the regulatory authority may also decide that an environmental impact assessment should be made in order to form the basis for a balanced decision.

Details of a mining licence will vary according to the requirements of the individual regulatory authority; however, it is recommended that the following elements be included:

1. The type of commodity to be mined;

2. Period of the mining licence and provisions for premature termination of the licence;

3. Specification of whether or not the permit for extraction is assignable, exclusive; or non-exclusive;

4. Location (by coordinates) of the licensed area for extraction and any additional area for manoeuvring;

5. Total quantities permitted for extraction/processing within the period of the licence. The point of measurement should be specified in the licence (for example, whether in the hopper or when landed). Extraction rates over specified time intervals could also be included, for example, an annual extraction limit rather than a total amount;

6. The minimum water depth for extraction, stipulated where necessary, and a maximum permitted sediment depth of extraction, stipulated where appropriate;

7. A requirement to leave behind a substrate of specified composition, where appropriate (in most cases, this will be similar to that which existed before extraction);

8. The methods of dredging in detail;

9. Specification of whether screening or other forms of processing may be carried out, and if so, where;

10. Incorporation of an agreed and appropriate programme for monitoring the effects of extraction activities;

11. Provision for access and on-board/on-site inspection by an appropriate authority to the dredger's log, company's records, etc., allowing surveillance to ensure that amounts stipulated by the licence are not exceeded, areas are not transgressed, and physical conditions are observed;

12. Appropriate means of ensuring compliance (i.e., electronic monitoring devices), as requested by the regulatory authority;

13. A minimal navigational standard on the dredging vessel, stipulated by the regulatory authority;

14. Regular return of information on quantities extracted, supplied to the appropriate authority by the dredging company;

15. Provision for seasonal or temporal restrictions, including the suspension of dredging where appropriate.

APPENDIX 1

Guidelines for Fisheries Consultations

These guidelines provide a framework for the information exchange required during consultations. Regulatory authorities should ensure that all appropriate topics have been addressed in sufficient detail to enable them to make an informed decision about the license application and any conditions necessary to protect fisheries interests. It is anticipated that dredging information will be supplied by the mining company and fishery information will be supplied by the fishing authorities.

1. Information on dredging

   a) Area specification.

      - Exact coordinates, detailing the area for practical exploitation of the resource, taking into account manoeuvring of the dredging vessel.

      - Any zoning of larger areas into smaller strips for extraction on an agreed time scale; this may be related to seasonal fishing patterns and the need for general access by others.

      - Any marking/buoying of extraction areas to assist identification at sea.

   b) Types of dredger.

   c) Types of dredging activity in sufficient detail to permit assessment of the level of disturbance likely to occur.

   d) Routes to and from the dredging site where there is particular potential for conflict.

   e) Required state and condition of the mining area after extraction.

   f) Maximum thickness of sediment which can be taken, having regard to operational parameters and monitoring capability.

   g) Siltation from outwashing, level of screening, and quality of fines discharged.

   h) Rates of extraction and estimated lifetime of resource.

   i) Provisions for regular review of this information and revision of the work plan.

2. Information on the fishery resource and the intensity of fishing activity

   a) Location of spawning grounds and the identification of spawning seasons.

   b) Sensitive nursery areas.

   c) Location of shellfish beds.

   d) Feeding grounds of finfish and crustaceans and cephalopods.

   e) Migratory routes of finfish and crustaceans and cephalopods.

   f) Number of fishermen and vessels fishing the areas.

   g) Types of gear used (e.g., potting, long-lining, fixed nets, trawls, drift nets).

   h) Areas and periods of intense fishing activity.

   i) Points of contact with fishery organizations (e.g., government authorities and local fishermen's associations).

   j) Size of the catch per species.

ANNEX 2

Illustration of Estimation of Scale of Effects and Consequences

A worst case overview for North Sea sediment extraction activities is presented below based on the calculations of one member of the Working Group. It is included here as an example calculation rather than an authoritative quantification of effect.

1. Assume that 35 x 10^6 m^3 of sediment is extracted annually. If the extraction depth is only 20 cm (worst case) and dredgers work only new ground, the area affected directly by the extraction of sediments is 175 x 10^6 m^2. Using Steele (1965), an average estimate for benthic production in North Sea sediments is 3 gC m^{-2} yr^{-1} (Figure 4); of this, the contribution to demersal fish production (10% ecological efficiency) is 0.14 gC m^{-2} yr^{-1}.

2. Assuming that macrobenthic production remains void in these areas throughout the following 12 months, the loss of sediment over an area of 175 x 10^6 m^2 represents a loss of macrobenthic production of 525 x 10^6 gC yr^{-1} (525 tC yr^{-1}) and of demersal fish production of 24.5 tC yr^{-1}, which is roughly 294 t wet weight of demersal fish.

3. The actual loss of standing stock biomass from the benthos can in most cases be accurately calculated for the area concerned. Assuming a 50 g m^{-2} biomass in the benthos (this would not include the microbenthos), the extraction of sediment over 175 x 10^6 m^2 would result in a direct loss of 8750 t. This figure will be highly variable, from a few grams per square metre to several hundred. The figures given here are wet weights. The proportion of this represented by commercially valuable shellfish stocks will also vary from area to area (from a few per cent to over 10%). Assuming 7%, then a further 613 t of commercial shellfish are lost directly in the extraction operation.

4. It has proved impossible to find data on amounts, particle size distribution, and period for loss of fines from a typical dredging operation to which a dispersion/settling model could be applied. Nunny and Chillingworth (1986) report, however, that "theoretical fallout and accumulation rates have been calculated for worst case conditions and are minimal beyond 1 km of the dredger." Taking this value as a radius, the area of plume in which primary production may be affected is 3.1 km^2 for each operating dredger. Given an average hopper capacity on a dredger of 5000 t (2800 m^3), removal of 35 x 10^6 m^3 in the North Sea would require 12 500 vessel trips per year on a 24-hour cycle, and with discharge of fines occurring continuously during daylight hours, there will be 43 vessels giving rise to such a plume during any day. The total surface area of all such plumes combined is equal to 133.3 km^2 (43 x 3.1 km^2).

5. If we assume that such areas are void of primary production, the corresponding loss is 13 330 tC yr^{-1}. The loss of demersal and pelagic fish production based on (1) above is thus calculated to be 22.7 tC yr^{-1} and 79.9 tC yr^{-1}, respectively, or 272 t wet weight of demersal fish and 960 t of pelagic fish.

6. The further effect of fines deposition on the benthos is difficult to estimate, partly because the resulting change in productivity is not known, but principally because the total area affected is indeterminate. It can be concluded that a worst case would be a covering of the benthos over an area twice that of the area actually mined. The area thus affected is 350 x 10^6 m^2. If, albeit unrealistically, we assume an entire loss of production then, using a similar calculation as that for extracted sediments, the loss of demersal fish production is 588 t wet weight. The direct loss of shellfish stock, assuming these species are smothered, would be 1226 t. The latter figure seems particularly unreasonable as larger and non-sedentary species would be able to survive such conditions.

7. The calculation of shellfish loss (commercially taken species) is based above on the direct loss of standing stock biomass, rather than on food chain production. As shellfish are more static in their distribution than finfish and vulnerable to direct extraction this seems reasonable. Obviously the production each year of macrobenthos biomass will be several times greater than the standing stock biomass, but larger organisms such as those taken in commercial fisheries will overall show a much lower productivity. In the absence of data on recovery times, and given that the proportion of commercially valuable species in any particular area will be very variable, this seems reasonable. Arguably, there will be a loss of shellfish also from the water column effect, lowering primary production and hence perhaps total detritus, but this will be small.

8. The above calculation is put forward as a first attempt at an estimation. Such estimates will be very site-specific in practice and the validity of taking the North Sea as a whole must be open to question. It does, however, suggest the following order of magnitude values:

Annual Losses of Commercially Valuable Stocks

	Shellfish	Pelagic fish	Demersal fish
Sediment extraction	600 t	-	300 t
Water column effects	(<50 t)	950 t	275 t
Sediment smothering	(<1,200 t)	-	600 t
	<1,850 t	950 t	1,175 t

9. Put into context: the total fish biomass of the North Sea is approximately 10 x 10^6 t (demersal and pelagic), of which roughly 2.5 x 10^6 t is taken in commercial catches each year.

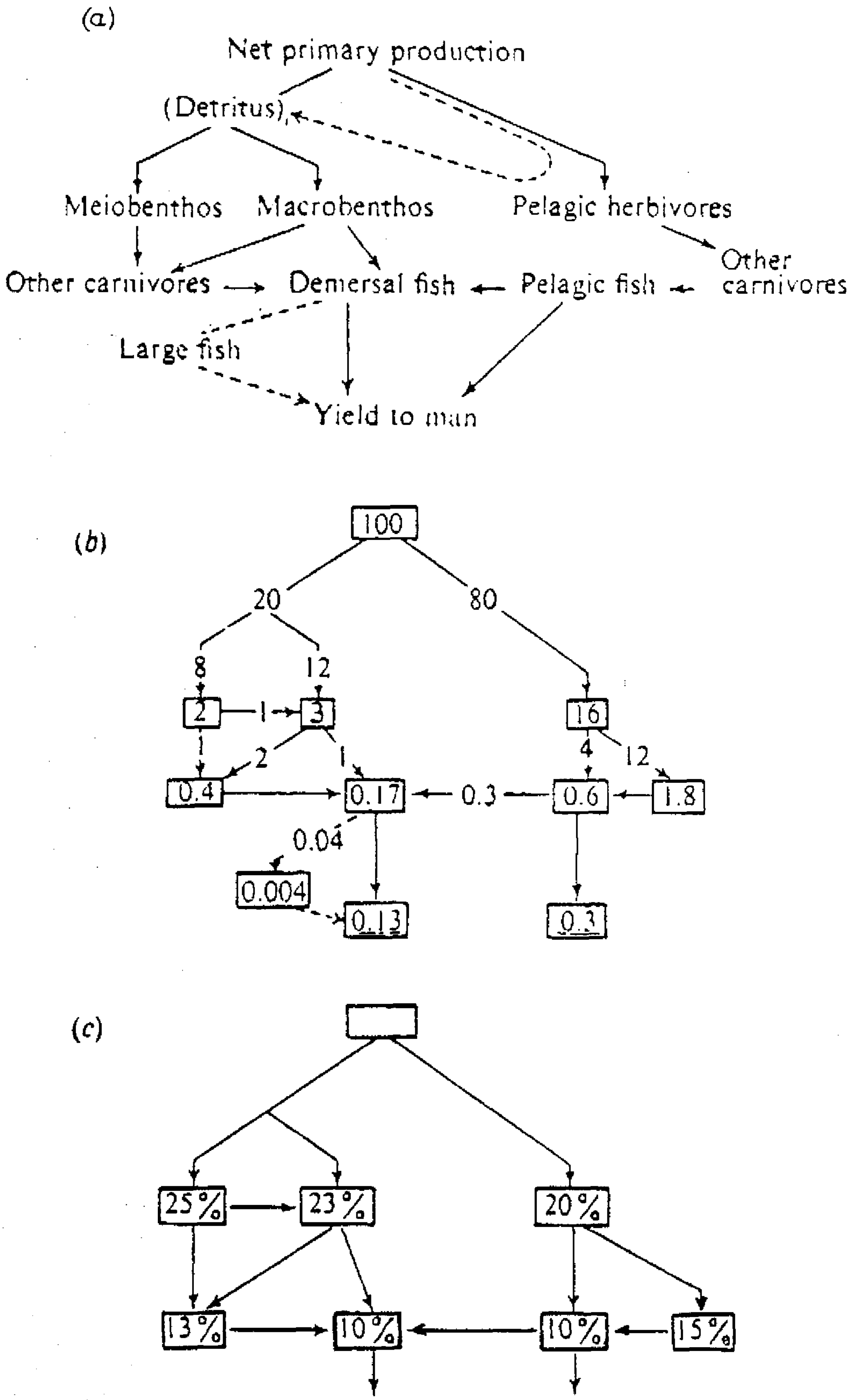

Figure 4 The food web in the North Sea (Steele, 1965).
(a) Simplified food web; (b) production in each group;
(c) ecological efficiency in each group.

ANNEX 3

Details of National Seabed Sediment Mapping Programme

Belgium

Staff: The various institutes that take part in seabed sediment mapping in the Belgian sector include:
- Belgian Geological Survey, Brussels: 1 person
- Fisheries Research Station, Ostende: 3-4 persons
- Ghent University, Renard Centre of Marine Geology: shallow geophysics, 3 persons; superficial sediments, 2–3 persons
- HAECON Corporation, Ghent: 4–5 persons
- Management Unit of the Mathematical Model of the North Sea and the Scheldt Estuary (MUMM), Brussels: several persons

Equipment
- the shared use of various multi-purpose research vessels
- various lines of shallow geophysical equipment (Ghent University) including boomer, sparker
- various corers and grabs (Ghent University, Fisheries Research Station)

Budget: No information available on budget for mapping. The Ministry of Public Works funds HAECON for their nearshore work.

Maps: Recent mapping activities include:

- A general map on scale 1:100 000, Mercator projection, showing the different surficial sediments (sand classification, sand quality, mud content, gravel content) based on van Veen grabs, data from Ministry of Public Works, published in 1989 but dated 1987. Legends in English. Available from Management Unit. Code MUMM/SED/87/01.

- Seven lithological maps, on scale 1:40 000, of areas of special interest in nearshore area not more than 15 km from the shore. Areas include the western (Kwinte Bank) sand extraction area. Legends in English. Published in 1989 with date 1987. Maps are available from the Management Unit. Codes MUMM/SED/87/02 to 08. An explanatory note for these maps has been published ("Les sédiments superficiels de la zone des Klaamse Banken", G. Ceuleneer et B. Lauwaert, 1987. Text also in Dutch).

- A seabed sediments map on scale 1:250 000, UTM projection, is being compiled by HAECON for the Belgian Geological Survey, complementing those of the British and Dutch sections being prepared by the respective Geological Surveys. This map follows the set-up of the British and Dutch 1:250 000 map series. Draft map ready in 1989, published in 1990/1991. Available from the Belgian Geological Survey, Jennerstraat 13, Brussels.

List of maps (see Figure 5):
- MUMM/SED/87/01: North Sea Flemish Banks Superficial sediments. Scale: 1:100 000
- MUMM/SED/87/02: North Sea Oost Dijck, Buiten Ratel, and Kwinte Bank Bathymetry. Scale: 1:40 000
- MUMM/SED/87/03: North Sea Oost Dijck, Buiten Ratel, and Kwinte Bank Percentage gravel. Scale: 1:40 000
- MUMM/SED/87/04: North Sea Oost Dijck, Buiten Ratel, and Kwinte Bank Percentage mud. Scale: 1:40 000
- MUMM/SED/87/05: North Sea Oost Dijck, Buiten Ratel, and Kwinte Bank Sorting of the fraction <4 mm. Scale: 1:40 000
- MUMM/SED/87/06: North Sea Oost Dijck, Buiten Ratel, and Kwinte Bank Median grain size. Scale: 1:40 000
- MUMM/SED/87/07: North Sea Oost Dijck, Buiten Ratel, and Kwinte Bank Morphostructure. Scale: 1:40 000
- MUMM/SED/87/08: North Sea Ratelkop Bathymetry. Scale: 1:20 000

Future mapping projects:
- Other surficial sediment maps are planned, based on detailed scientific research by universities and the Ministry of Agriculture and Fisheries.

Canada

Staff: The Geological Survey of Canada (GSC) has close to 130 persons involved in marine mapping, including mapping by the hydrocarbon group. Excluding the latter, some 40–50 persons are involved.

Equipment: GSC owns several larger survey vessels (e.g., "Hudson", "Dawson") and a few smaller ones. Shiptime for the mapping programmes amounts to three months per year. GSC possesses the standard suite of marine geological and geophysical equipment including high-resolution seismic systems, side-scan sonar, magnetics, vibrocorers, piston corers, grabs.

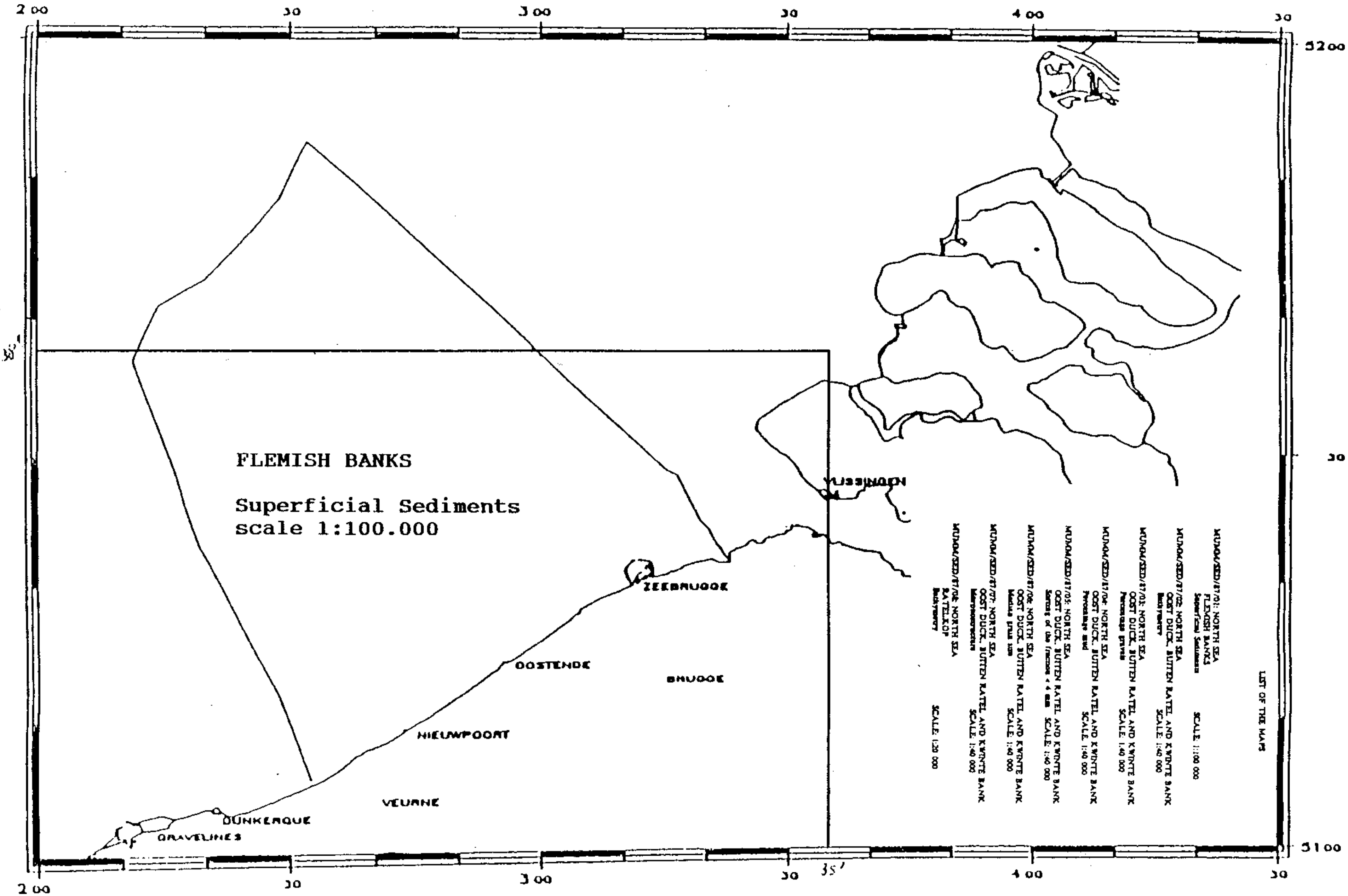

Figure 5 Map of the Belgian Continental Shelf showing coverage of published marine geological maps.

Budget: Total expenditure per ship-month is about $70 000. Total field expenditures for all field programmes both onshore and offshore are about $2 500 000/year.

Published maps: Beyond 50-m water depth all of the east coast has been mapped to some extent, at a scale of 1:1000 000 or 1:2000 000, in Lambert and Mercator projections. Maps are available for the Scotian shelf and Grand Banks. Data on the contents of the maps, the classification used, and the density of sample points/lines may be found in the references listed below. An outline map showing the locations of the published maps is to be produced. Published surficial geology maps include Drapeau and King (1972), Fader *et al.* (1977), Fader *et al.* (1982), Fader and Pecore (1989), King (1970), MacLean *et al.* (1977), and MacLean and King (1971). Other examples include Hale (1987), Miller and Fowler (1987), and Anon. (1989).

Localized aggregate extraction operations take place landward of the 50-m isobath. Such resources have not been systematically mapped in the past. The first map detailing these, for the region immediately off Cape Breton Island (ENE Nova Scotia), was published in 1989. Similar maps of coastal waters showing the distribution and thickness of shallow bedrock, surficial sediments, and seabed features are being prepared for the Bay of Fundy, the Scotian shelf, the southern Gulf of St. Lawrence, and off southern Newfoundland. Maps were published in 1989 and 1990. Nearshore mapping is to be carried out in Halifax Harbour and Cape Split in the Bay of Fundy.

Ordering: Maps may be ordered at cost from the Atlantic Geoscience Centre and Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada B2Y 4A2; or the Department of Energy, Mines and Resources, 580 Booth Street, Ottawa, Ontario, Canada K1A 0E4.

Denmark

Staff: In the Forest and Nature Agency six persons are involved in administration, planning, and coordination of resource mapping and dredging activities. The marine section of the Danish Geological Survey has a permanent staff of 10 persons. A number of scientists are available on a part-time basis. Scientists from universities and private companies are occasionally involved.

Equipment: Research vessels are shared with the Environmental Protection Agency. The equipment of the Danish Geological Survey includes:
- positioning system (Syledis)
- echo sounder
- pinger
- boomer
- sparker
- 100 kHz side-scan sonar
- various corers and grabs
- air-lift suction system
- video sea-floor cameras

Budget: £200 000. Staff are not included in this figure.

Map content: Resource maps are prepared at a scale of 1:100 000 in UTM projection and cover approximately 1000 km^2 each. The surveyed areas are documented in internal reports describing the geology of the area and the distribution and lithology of the sand and gravel resources. The reports include maps at a scale of 1:100 000 showing bathymetry, geophysical lines and sample stations, and the distribution of surface sediments and sand and gravel resources. Today 70% of the seabed in Danish domestic waters has been mapped (see Figure 6). Detailed investigations, including supplementary shallow seismic profiling and coring, are made in areas of special interest.

Published maps: The biological, fishery, geological, and cultural history assets in each area are evaluated. Existing information is gathered from scientific reports as well as from private organizations and the fishing and dredging industries.

All available information is published in "Blue Sea Reports" describing geology, sand and gravel resources, biology, and archaeology. Each report includes maps showing:
- bathymetry (1:100 000)
- geophysical lines and sample stations (1:100 000)
- distribution of sand and gravel resources
- seabed sediments (1:200 000)
- potentially conflicting interests (1:200 000)

See list of publications, below.

Special maps:
- Positive and negative raw material indications (1:750 000)
- Structural map of top chalk group (1:500 000)

Future maps:
- Seabed sediments (1:500 000)

Ordering: Skov- og Naturstyrelsen, Havbundsundersøgelsen, Slotsmarken 13, DK-2970 Hørsholm.

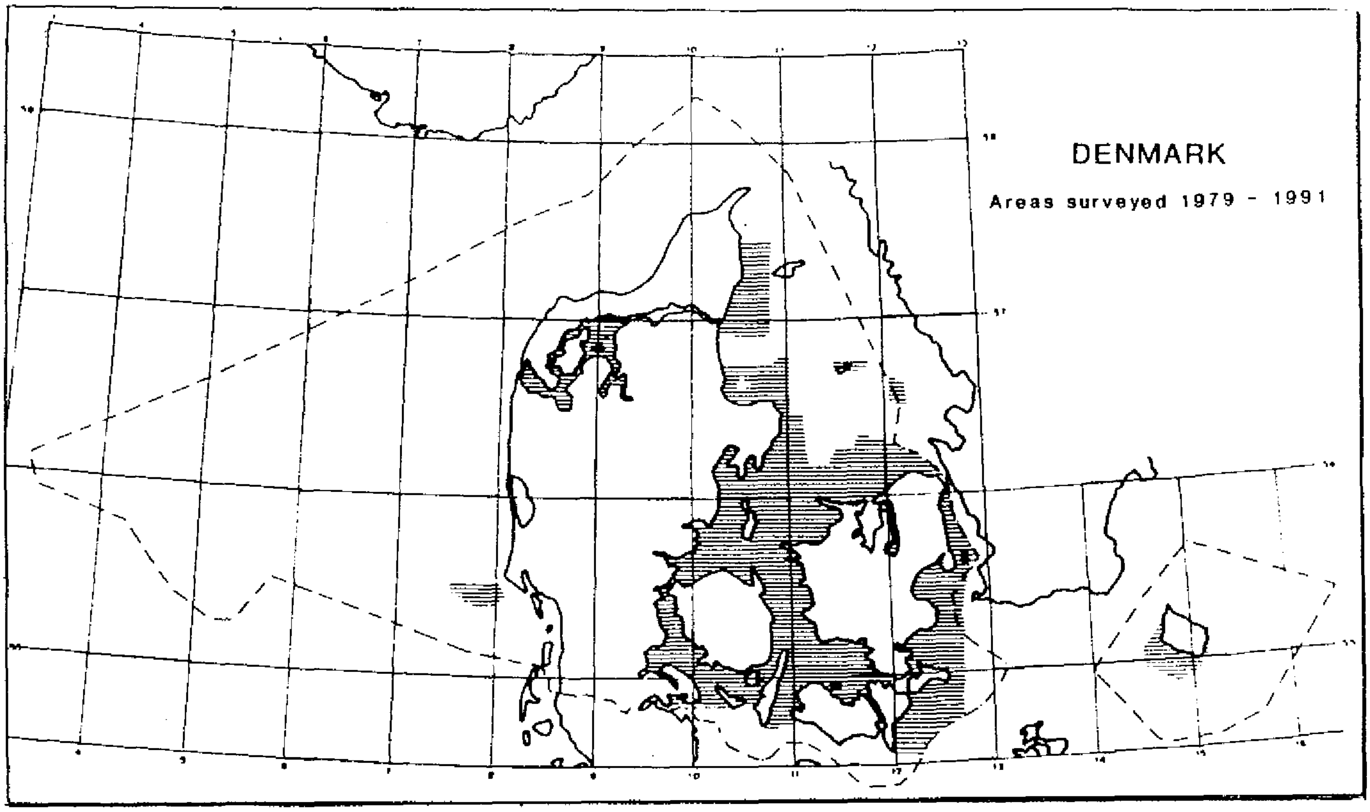

Figure 6 Map of the Danish Continental Shelf showing coverage of published marine geological maps.

List of publications:

Data reports

Blue Sea Reports.
Havbundsundersøgelser: Råstoffer og fredningsinteresser.
Marine studies: raw materials, and conservation interests map sheets:
Djursland Nord. Oversigt 1986.
Bornholm. Oversigt 1986.
Fakse Bugt. Oversigt 1986.
Lillebælt. Oversigt 1986.
Nordsjælland. Oversigt 1987.
Smålands farvande. Oversigt 1987.
Grenå. Oversigt 1987.
Samsø-Nordøst. Oversigt 1987.
Sjællands Rev. Oversigt 1987.
Roskilde Fjord. Oversigt 1988.
Hornbæk. Oversigt 1989.
Sejerø Bugt. Oversigt 1989.
Storebælt. Oversigt 1989.
Samsø Sydøst. Oversigt 1990.

Resource prospecting:
Bornholm sydvest. Detaljerede undersøgelser. With supplement: Seismik, bundprøver og laboratorieanalyser. Editor: Jørn Bo Jensen. Skov- og Naturstyrelsen, 1988.

Geological and land-use planning maps:
Positive og negative råstofindikationer i de indre danske farvande. Editors: John Tychsen, Poul Erik Nielsen, Birgitte Larsen. Fredningsstyrelsen, 1986. ISBN: 87-503-6358-1

Bornholm. Geological map of Mesozoic formations. Editor: Niels Erik Hamann. The National Forest and Nature Agency, 1987. ISBN: 87-503-6889-3

Kalkoverfladens struktur. Danmark 1:500 000. (Structural map of top chalk group. Denmark 1:500 000.) Editors: Niels Ter-Borch and John Tychsen. Published by: Skov- og Naturstyrelsen, Havbundsundersøgelsen, Dansk Olie- og Gasproduktion A/S. Skov- og Naturstyrelsen, 1987. ISBN: 87-503-7053-7

Store Bælt. Kort over råstofforekomster. Editor: Poul Erik Nielsen. Skov- og Naturstyrelsen, 1987. ISBN: 87-503-6959-8

Atlas over Miljøministeriets marineundersøgelser. 1:2000 000. (Atlas of marine investigations made by the Ministry of the Environment) with 32 maps. Editor: Poul Erik Nielsen Skov- og Naturstyrelsen, 1990.

Seabed sediment maps:
Overfladesedimenter i den danske del af Øresund 1:100 000. (Surface sediments in the Danish part of the Sound 1:100 000). Compiled by: A. Kuijpers, B. Larsen, P. E. Nielsen. Published by: National Forest and Nature Agency and Geological Survey of Denmark, Ministry of the Environment of Denmark, 1990.

Surface sediments in the Inner Danish Waters (Kattegat and Danish part of the Baltic) 1:500 000. In prep.

Marine studies - Biology:
Dyre- og plantesamfund ved Samsø Østre Flak - pilotundersøgelse. (Animal and plant life at Samsø Østre Flak - a pilot study). Ole G. Norden Andersen. Skov- og Naturstyrelsen, 1987.

Køge Bugt. Monitering af indvindingsområder. Marts 1989. (Køge Bight. Monitoring of extraction sites. March 1989). Skov- og Naturstyrelsen and Danmarks Fiskeri- og Havundersøgelser, 1989.

Sletter havet sporene? Effects on marine ecology and fisheries of sand and gravel extraction. With English summary. 96 pp. Miljøministeriet, Fredningsstyrelsen, 1982.

Annual reports:
Fredningsstyrelsens Havbundsundersøgelser. Aktiviteter 1985. Editor: John Tychsen. Fredningsstyrelsen, 1986. Havbundsundersøgelser. Aktiviteter 1986. Editor: John Tychsen. Skov- og Naturstyrelsen, 1987.

Havbundsundersoegelser. Aktiviteter 1987. Editors: John Tychsen and Hans Christensen. Skov- og Naturstyrelsen, 1988.

Havbundsundersøgelser. Aktiviteter 1988. Editor: Hans Christensen. Skov- og Naturstyrelsen, 1989.

Brochures:
Havbundsundersøgelser.
Skov- og Naturstyrelsen, 1987.

- Marinbiologisk kortlægning. (Marine biological mapping).
- Marinarkæologisk kortlægning. (Marine archaeological mapping).
- Seismiske undersøgelser. (Seismic research).
- Marin—seismisk metode og udstyr. (Marine seismic methods and equipment).

Havet skjuler store rigdomme. Editors: John Tychsen and Hans Christensen. Skov- og Naturstyrelsen, 1988.

Great riches are hidden in the sea. Editor: John Tychsen. The National Forest and Nature Agency, 1988.

Other publications:

Hvad skjuler Kattegat? (What is hidden in the Kattegat?). Poul Erik Nielsen and Esben Møller. *In* Varv, 1985, no. 1: 3-7.

Kortlægning af havbundens råstoffer (sand, grus mm.). (Mapping of the inorganic submarine resources). Torsten Christensen, Poul Erik Nielsen, and Anne Grete Swainson. *In* Tidsskrift for Dansk Kartografisk Selskab, 1982, no. 2: 5-14.

Kortlægning af råstoffer på havbunden. (Mapping of submarine resources). Poul Erik Nielsen and Torsten Christensen. *In* Varv, 1984, no. 1: 14-20.

Ocean management in Danish waters. Hans Christensen and John Tychsen. *In* Proceedings of Sixth Symposium on Coastal and Ocean Management, ASCE, July 11-14, 1989, Charleston, South Carolina, pp. 4000-4009. Havbundsundersøgelser. Reprint 2. Miljøministeriet, Skov- og Naturstyrelsen, 1989.

Finland

Staff: A permanent marine geological staff of seven persons is employed for the purpose of seabed sediment and resource mapping. Additional personnel are employed for the field season, including a master for the research vessels.

Equipment: The Geological Survey of Finland (GSF) has two research vessels (13 m and 40 m long, respectively) equipped as follows:

- positioning system, including MRDP survey processor (Motorola Miniranger III)
- reflection and refraction seismics (air guns and ELMA-electromagnetic sound source)
- echo sounder (pinger)
- 100 kHz side-scan sonar
- vibro-hammer corer (6/12 m)
- piston corers
- various other corers and grabs
- underwater television, sea-floor camera systems
- scuba-diving equipment

Map content: The fieldwork (with a coverage of virtually 100% of the sea floor) is conducted with maps at a scale of 1:20 000. Each map sheet covers an area of 100 km^2 and shows the Quaternary deposits according to character and genesis. Both superficial sediment distribution and sections are presented.

Published maps: Currently Finland has data from over 80 maps from several areas along the Gulf of Finland (see Figure 7). These maps will not be published, but the data are available for the qualified user as computer plotted maps. Generalized maps are being compiled at a scale of 1:100 000 and will be printed. The first map in this series (Map sheet - Kotka) is in print. Data on exploitable sand and gravel deposits have been made available to regional planning associations. In the future, mapping is to be carried out in the southwestern archipelago.

Ordering: Additional information can be obtained from: Geological Survey of Finland, Marine Geology, Kivimiehentie 1, SF-02150 Espoo, Finland.

France

Staff: The equivalent of 10 scientists are available for the geological projects on the continental shelf. They are made available by BRGM, IFREMER, and the universities.

Equipment: The French marine geological community essentially works in deep water areas. For coastal management and shelf problems there are four coastal ships, for the Channel, for Brittany, for the Bay of Biscay, and for the Mediterranean, respectively. The main types of equipment are:

- high-resolution seismics
- mobile positioning system (Syledis)
- side-scan sonar
- camera system
- heavy corer (7 tonnes), 12 metres
- vibrocorers (BRGM and IGBA)
- various other corers and grabs

Budget: In the last 10 years IFREMER-CNEXO (Centre National pour l'Exploitation des Océans) has spent more than 2 million FF per year on sand and gravel exploration. At present the budget is 0.5 million FF per year for sand and gravel projects. Staff, shiptime, and overhead costs are not included in the budget mentioned above.

Maps: Published maps include:

- A geological map on scale 1:1 500 000 showing the continental shelf of France (BRGM), published in 1980.
- A geological map of the North Sea/Channel, 1:250 000.
- A sediment map on scale 1:500 000, two sheets "La Manche" and "Le Golfe de Gascogne" and Mediterranean (BRGM + IFREMER).
- Superficial sediment maps including seabed morphology off Boulogne and off Dunkirk, scale 1:43 400, Mercator projection, published in 1987 (IFREMER).
- Detailed coastal maps on scale 1:15 000 for, e.g., the Bay of Douarnenez (Brittany).
- Fishing charts on scale 1:60 000 for the "Golfe de Lion" area from Marseille to the Spanish border.

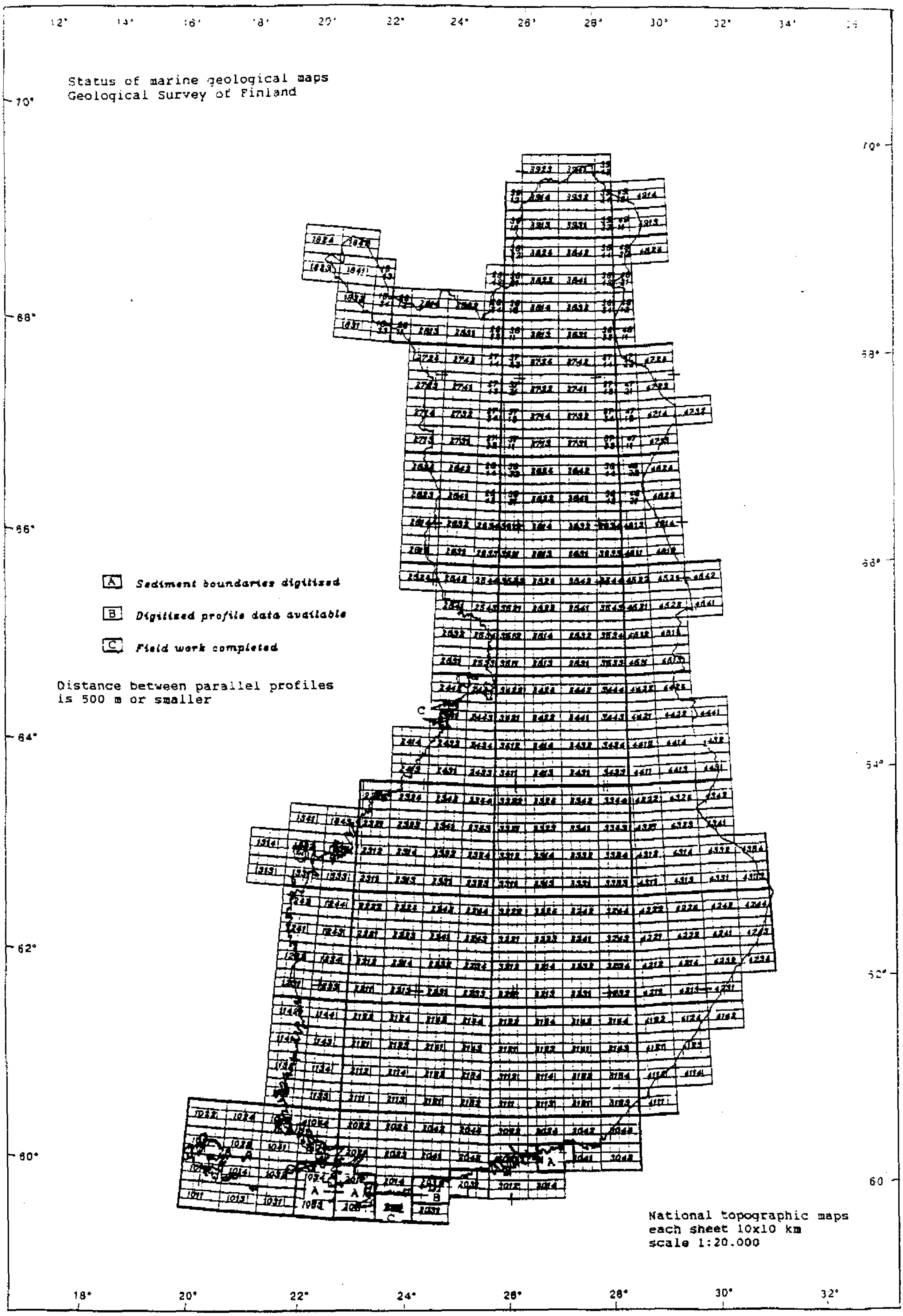

Figure 7 Map of the Finnish Continental Shelf showing coverage of published marine geological maps.

- Many other maps based on seismic and side-scan sonar data, appearing in reports and other publications.
- Numerous reports on offshore resources, in part with maps. See "Les Granulats Marins" (1987), published by CNEXO (IFREMER) in which more than 60, mainly French, reports are listed.

Future programmes:
These include the setting-up of a database on the French EEZ (11 x 10^6 km^2). A team of 15 scientists, 4 months' shiptime/year, and an extra budget of FF10 million are envisaged. The project leader would be IFREMER in cooperation with other research institutions, oil companies, and universities. Bathymetric maps will be published at three scales: those from shallow water areas will be at 1:250 000, while those from deeper water areas will be at 1:500 000 or 1:1000 000. Other maps will include surface sediments, solid geology, mineral resources (aggregates, nodules, crusts, sulphides), geological hazards, etc.

Ordering: IFREMER publications may be ordered from: IFREMER/Centre de Brest, BP 70, 29263 Plouzané, France; and IFREMER, 66 Avenue d'Iéna, Paris 75116, France. BRGM publications may be ordered from: BRGM, Orléans, France.

Germany

Staff: The Federal Office for Shipping and Hydrography (BSH) has made several persons available for seabed sediment studies in the North Sea. Staff from the Geological Surveys are made available on an *ad hoc* basis.

Equipment: Standard equipment is employed by BSH and the Federal and State Surveys.

Budget: No data available.

Maps: List of the seabed sediment maps:

Jarke, J. 1956. Der Boden der südlichen Nordsee. 1. Beitrag: Eine neue Bodenkarte der südlichen Nordsee. Deutsches Hydrogr. Zeitschr., 9, 1-9, 1 Karte, Hamburg. Area: Southern North Sea from 51°20'N to 55°20'N. Scale: 1:1000 000. Content: Representation of the grain size distribution of the surficial sediments.

Figge, K. 1981. Karte de Sedimentverteilung in der Deutschen Bucht, Nordsee. Deutsches Hydrographisches Institut, Karte Nr. 2900 (mit Beiheft), Hamburg. Area: German Bight, western boundary 6°E, northern boundary 55°05'N. Scale: 1:250 000. Projection: Mercator. Content: Grain size distribution of the uppermost 10 cm according to the depth penetration of the grab sampler.

Figge, K. 1989. Thickness of the Holocene sediments in the German sector of the North Sea. Area: German sector of the North Sea. Projection: Mercator. Content: Thickness of the sediments overlying the first strong reflector appearing in boomer records and regarded as the basis of North Sea sediments (Holocene).

Other publications:

Bundesanstalt für Bodenforschung. 1973. Geologische Übersichtskarte 1:200 000, Blatt CC 2310 Helgoland. Hanover. Area: German Bight, western boundary 7°20'E, northern boundary 54°24'N. Content: Representation of the grain size distribution of the seabed sediments based upon maps of the Deutsches Hydrographisches Institut.

Other maps are published in the literature. These cover small areas at different scales.

Maps in relation to mineral resources:
Ludwig, G., and Figge, K. 1979. Schwermineralvorkommen und Sandverteilung in der Deutschen Bucht. Geol. Jb. D 32: 23-68, 10 Ktn. Hanover.

Ordering: Seabed sediment maps may be obtained from: Federal Office of Shipping and Hydrography, Bernhard Nocht Strasse 78, Postfach 220, D-2000 Hamburg, Germany. Geological maps may be obtained from: Federal Geological Survey, Hanover; and the State Geological Surveys of Lower Saxony, Hanover, and Schleswig-Holstein.

Ireland

Staff: The Marine Section of the Geological Survey of Ireland has a staff of two persons. However, for projects such as those listed in Section 4.2.1, scientists from the universities are also occasionally involved.

Equipment: 6–9 weeks' shiptime per year on the state-funded RV "Lough Beltra". The section is equipped as follows:
- positioning system (Decca)
- shallow seismics (sparker, boomer)
- pinger
- side-scan sonar
- dredge samplers

Map content: Most of the results are shown on different thematic maps. On surface sediment distribution maps, areas are classified according to grain size distribution in mud, sand, and gravel. Outcrops of rock are also shown. As a consequence of exploratory work on beach deposits the presence of heavy minerals, lithium, gold, etc. is indicated in some investigations. The map scales vary but are the same as the Admiralty charts. The projection is Mercator, UTM. The maps produced in association with the BGS are at a scale of 1:250 000.

Published maps: Seabed sediment maps of the Anglesey, Cardigan Bay, and Nymphe Bank regions of the Irish Sea (Figure 13), produced in association with the BGS, have recently been published.

Maps are available for consultation at the Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin 4, Ireland.

Future programme:
- Continued mapping of the continental shelf.
- Mapping the continental shelf margin.
- A Marine Institute will probably be set up in Ireland. The Marine Section of the GSI may move to this new institute.
- Outline map showing recent activities on the Irish continental shelf will be provided by GSI.

The Netherlands

Staff: At the Geological Survey of the Netherlands (RGD) there are 15 – 20 persons available on a part-time basis for the various offshore mapping programmes, of which roughly one-third are scientists and two-thirds technicians and assistants. The North Sea Directorate, mentioned above, provides the ship's crew and the positioning staff.

Equipment: The North Sea Directorate has several multipurpose vessels that are made available for the mapping programme. The principal types of RGD equipment are:
- various van Veen grabs and Hamon (gravel) grabs
- electric, air-driven and hydraulic vibrocorers
- a combined airlift-counterflush drilling/vibrocoring system (Geodoff II) and an air-lift counterflush system using flexible hoses (Roflush)
- various piston corers and boxcorers
- high-resolution seismics including waterguns, sleeve guns, sparkers, boomers, and pingers with single- and multichannel streamers and data processing facilities
- underwater camera system
- side-scan sonar systems (North Sea Directorate)
- various positioning systems (North Sea Directorate and RGD)

Budget: About 400 000 Dutch guilders are spent by RGD each year largely for the various mapping projects. Staff, shiptime, and overhead costs are not included in this figure.

Seabed sediment maps: Reconnaissance mapping of seabed and Holocene (and older) sediments on both sides of the median line is presently being carried out by the British Geological Survey (BGS) and the Geological Survey of the Netherlands (RGD). BGS and RGD are jointly publishing a series of 1:250 000 maps of North Sea areas straddling the median line (see Figure 8). The map series consists of pre-Quaternary (solid), Quaternary (Pleistocene), and seabed sediments (Holocene) maps. RGD is now continuing this series towards the German sector in cooperation with the Geological Survey of Lower Saxony and the Federal Office of Shipping and Hydrography.

The Quaternary map shows a number of seismo- and lithostratigraphic units (formations) ranging from deltaic and marine transgressive sediments, tidal flat deposits and lacustrine clays to various non-marine, including glacial, deposits (see Laban *et al.*, 1984). Relevant properties of the formations are shown.

In addition, the sediments of the Holocene marine transgression have been subdivided into separate formations, each with a characteristic lithology. Various properties of the (near) surface sediments are shown on the seabed sediment maps, as these are the main target for sand and gravel exploration and exploitation offshore.

At present, seabed sediment (Holocene) maps are available at BGS and RGD for the Flemish Bight area (52°-53°N, 2°-4°E) and the Indefatigable area (53°-54°N, 2°-4°E) (see Cameron *et al.*, 1984, and Harrison *et al.*, 1987), the Silver Well area (54°-55°N, 2°-4°E) (1989), the Dogger area (55°-56°N, 2°-4°E), and the Ostende area (51°-52°N, 2°-4°E). The latter map was prepared in cooperation with the Geological Survey of Belgium (BGD), while the Dogger area map was made with contributions from German and Danish surveys. In addition mapping of nearshore areas is being conducted at present by RGD. A small number of maps, at a scale of 1:100 000, are now available (see Figure 9).

The systematic geological reconnaissance mapping on scale 1:250 000 of the Netherlands North Sea continues at a rate which will allow the remaining maps to be published before the year 2000.

Resource maps:
- The Netherlands and the Netherlands North Sea: reconnaissance map of raw materials at or near the surface.

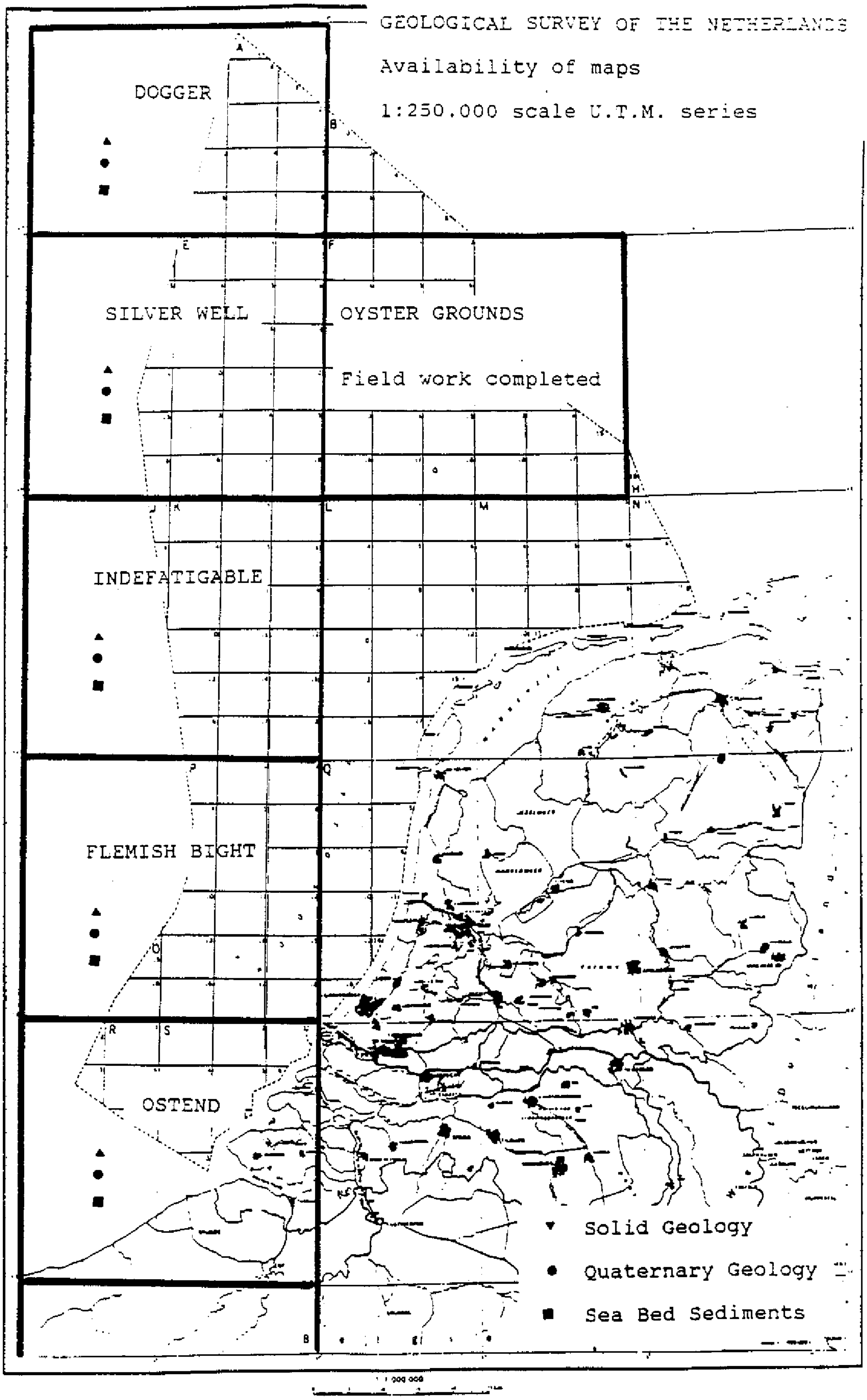

Figure 8 Map of the Netherlands Continental Shelf showing coverage of 1:250 000 scale marine geological maps published by the Geological Survey of the Netherlands.

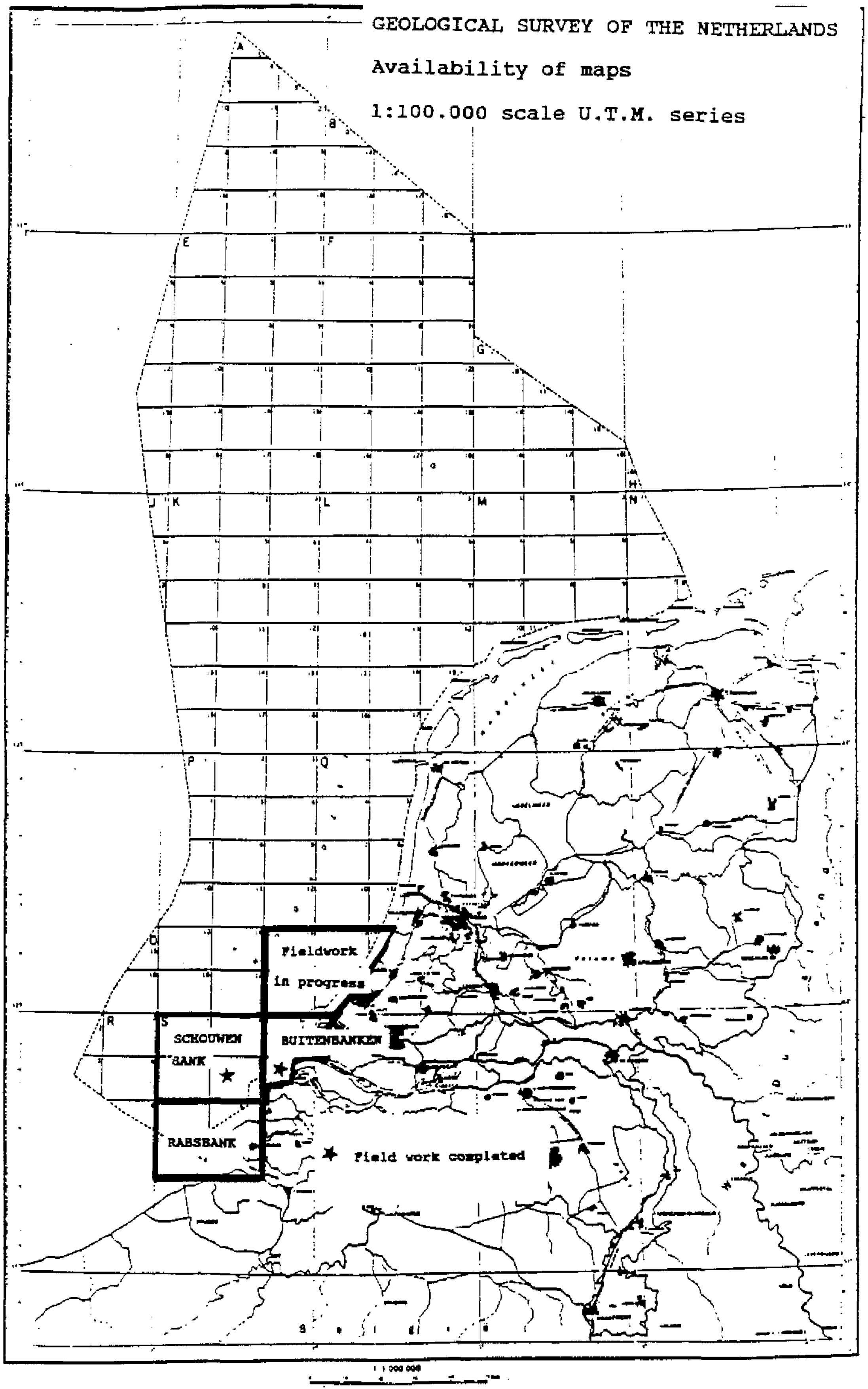

Figure 9 Map of the Netherlands Continental Shelf showing coverage of 1:100 000 scale marine geological maps published by the Geological Survey of the Netherlands.

This 1:1000 000 map (Niessen and Schüttenhelm, 1986), in a local stereographic projection, is, as regards the offshore part, an updated version of a superficial geology map (same scale, Mercator projection) of the Dutch sector (Schüttenhelm, 1980). The map depicts the composition of the uppermost 50 cm using international phi (Wentworth) units. The map is available at the Geological Survey of the Netherlands.

The data show that surface sediments of the Dutch sector of the North Sea contain only relatively small to very small quantities of coarse sand and gravel. Medium sand is being extracted in the southern part where it occurs over large areas. Fine sand is present in the central, the northernmost, and the northeastern parts of the shelf. Very fine sand and mud occur mainly in the Oyster Ground area, the north-central part of the Netherlands North Sea. In Schüttenhelm (1980) some particulars are given on the composition, distribution, and origin of these surface sediments.

- Mapping of exploitable sands for industrial use in the nearshore areas of the Netherlands North Sea.

Sand properties were studied down to 5 m below the surface. Sand for land reclamation and beach replenishment is present in large quantities in the Dutch sector of the North Sea (van der Klugt, 1991; Nederlof, 1990, 1991). Studies are being carried out to establish potential occurrences of concrete and mortar sand in shipping routes to Rotterdam and Amsterdam (Zonneveld, 1990, 1991).

The present draft of the "Regional aggregate exploitation plan for the Netherlands sector of the North Sea" (draft of January 1990) defines the sand classifications which are now in use. These are:

Concrete sand	d50 > 400 μm, mud content < 2% lime content < 25%
Mortar sand	300 μm, < d50 < 1000 μm, mud content < 2%
Infill sand	63 μm < d50 < 250 μm, mud content < 8%
Sand for beach nourishment	d50 > 200 μm

Exploration for gravel occurrences

In 1980, a gravel deposit was discovered in an area a little over 150 km northwest of Den Helder. Successive studies showed that the deposit extends over parts of the blocks K1 and E16, southeast of the Dogger Bank. The water depth here is 30 - 40 m or greater. Gravel content varies from less than 30% to 80%. The gravel layer is 0.2 - 2 m thick. Sand ribbons locally cover the gravel. The gravel is related to the limit of a Weichselian land ice sheet that covered large parts of the western side of the North Sea. The amount of gravel at water depths of less than 40 m is estimated at 40 to 50 million tonnes, which is about three times the annual gravel consumption in the Netherlands (Wiersma and Schüttenhelm, 1984).

At present the gravel is offered to industry for exploitation. In 1989 some pilot dredging was carried out. The gravel deposit is the first such deposit discovered in the Netherlands sector since systematic marine geological reconnaissance and mapping started in 1968. During recent surveys of small areas northwest of the islands of Texel and Vlieland, occurrences of local gravelly sand accumulations within a large sand area have been mapped and gravel volumes estimated (van der Klugt, 1991).

Other maps: In 1989, the Ministry of Transport and Public Works published a series of four morphological maps of the Dutch nearshore areas on a scale 1:250 000. See van Alphen and Damoiseaux (1989).

Future maps: In 1985, a more detailed geological mapping programme on a scale 1:100 000 in the nearshore areas was started. The first maps will be available within a few years. This mapping programme will include detailed studies of the surface and near-surface sediments, their properties, and their use.

Ordering: Seabed sediment and marine geological maps may be ordered from: Geological Survey of the Netherlands, P.O.Box 157, 2000 AD Haarlem. The Netherlands resource maps and morphological maps may be ordered from: North Sea Directorate of Rijkswaterstaat, Koopmanstraat 1, Rijswijk, The Netherlands; or the Geological Survey of the Netherlands (see above).

Norway

Information about staff and budgets is lacking.

Equipment: standard equipment is employed.

Published maps: A series of ten maps has been produced of the Norwegian continental shelf (see Figure 10). Two maps of the mid-Norwegian continental shelf published by the Norwegian Continental Shelf Research Institute (IKU) deal with the sediments: (a) thickness of Quaternary deposits (IKU Publication No. 119); (b) distribution of Quaternary sediments (IKU Publication No. 120).

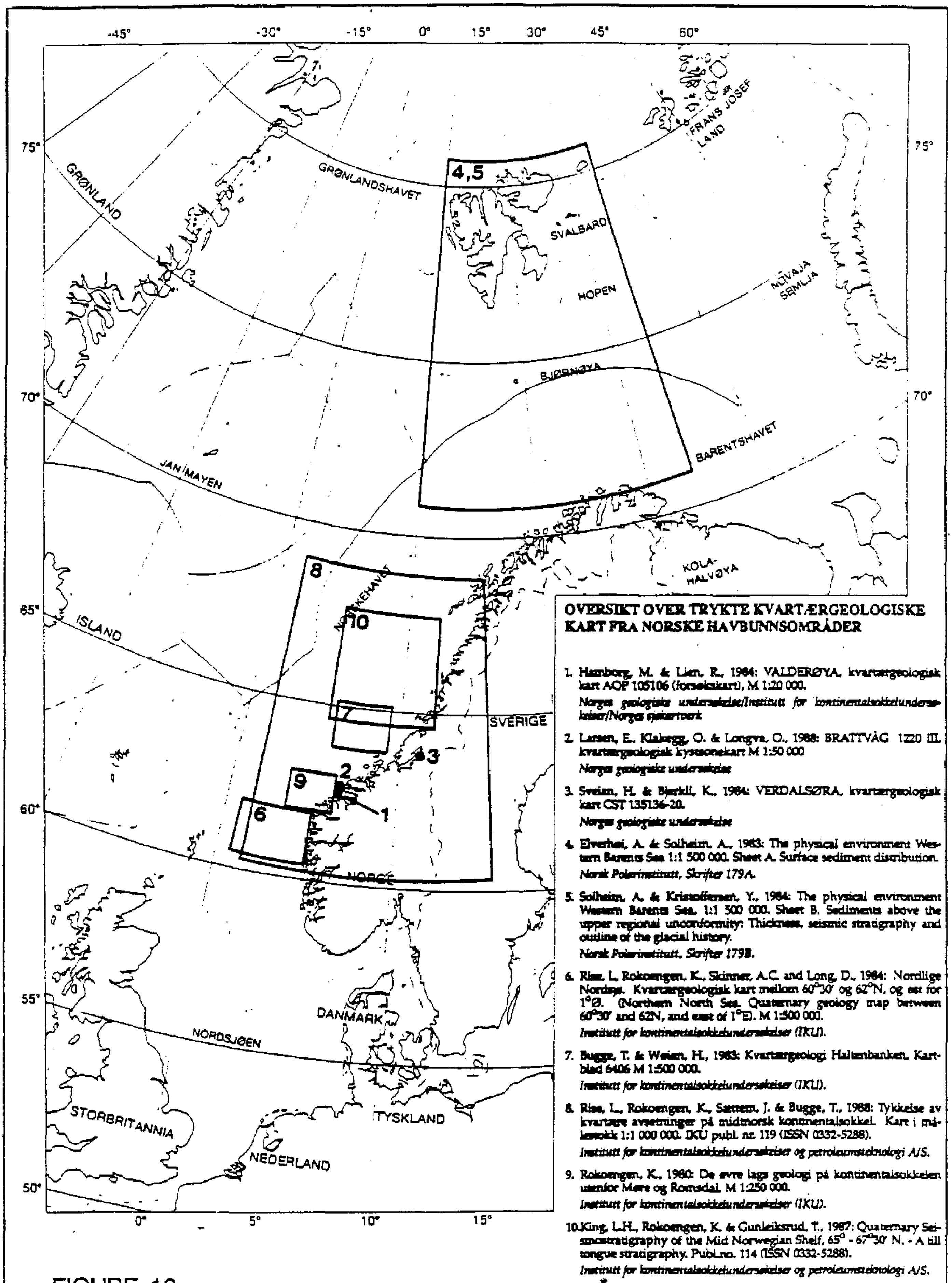

FIGURE 10

Map of the Norwegian Continental Shelf showing coverage of published marine geological maps.

Ordering: Maps and reports for the polar region may be ordered from: Norwegian Polar Institute, Fornebu, Oslo. All other maps from: Geological Survey of Norway, P.O. Box 3006, N-7001 Trondheim, Norway.

Spain

The coverage of published seabed sediment maps of the Spanish continental shelf is shown in Figure 11.

Sweden

Staff and budget: The Geological Survey of Sweden (SGU), Division of Marine Geology, has a permanent staff of eight persons (six marine geologists, one sea captain, one chief) and an annual budget of about 10.3 million SEK in 1991/1992 (including the capital costs of the research vessel). As a consequence of a government decision in 1988 the rate of mapping will increase, so the Swedish part of the continental shelf will be mapped at a scale of 1:100 000 by the year 2050. The programme has been extended with a special sub- programme concentrating on the analysis of some anthropogenic substances.

Equipment: The SGU has a twin-hull, sandwich constructed research vessel, SV "Ocean Surveyor", of 509 brt, 38 m long and 12 m wide. The vessel has 5 winches, A-frame, moon-pool, sediment laboratory, photo- laboratory and a special survey-room for data processing. The division and vessel are equipped as follows:

- dynamic positioning system and HPR
- Doppler log
- Decca MK53, Satellite navigator, GPS, Syledis positioning systems including survey processor
- three work-stations
- shallow seismic system (boomer and sparker)
- 50, 100, 500 kHz side-scan sonars
- pinger 3.5/7 kHz
- echo sounders
- vibro-hammer corer (6 m)
- piston corers
- various corers and grabs
- underwater television, sea-floor camera
- scuba-diving equipment

Map content: Maps are published by the Swedish Geological Survey (SGU) at a scale of 1:100 000 and show the distribution of the superficial Quaternary deposits according to character and genesis. Each map sheet covers an area of 2500 km^2 and is accompanied by a description. Subsidiary maps are produced mainly at a scale of 1:200 000 and show, within the map area, the distribution of pre-Quaternary rocks, till, and glaciofluvial deposits, sand volumes, certain trace elements of environmental interest, coring sites, sites of grab samples, and tracklines. The maps are projected in Gauss with both the Swedish grid net 2, 5c,W 1938 and the longitude and latitude system. Geological sections of the mapped area are also presented in a subsidiary map at a scale of 1:100 000.

Published maps: Currently Sweden has mapped 9% of the Swedish continental shelf (see outline map, Figure 12). The results are published in five maps from the Sounds at a scale of 1:50 000 (SGU Rapporter och Meddelande, no. 13), three maps from the northern Gotland area in the Baltic Sea (SGU Serie Am, no. 1-3) at a scale of 1:100 000 and one map from the southern Kattegat (SGU Serie Am, no. 4). The central Kattegat has recently been mapped and results were to be published in 1991 (SGU Serie Am, no. 5). Mapping of the northern Kattegat started in 1990.

An outline map of the solid geology of the Swedish continental shelf area at a scale of 1:1000 000 (SGU Rapporter och Meddelande, no. 47) was published in 1986.

Ordering: Maps, with description and English summary, can be ordered from: Geological Survey, S-75128 Uppsala, Sweden.

Information: Geological Survey of Sweden, Division of Marine Geology, Box 670, S-75128 Uppsala, Sweden. Tel. +46 18 179000

United Kingdom

Staff: The BGS Marine Group consists of around 100 people largely involved in geological mapping and related matters. The marine aggregates programme involves up to 10 people for short periods of time. BGS has recently initiated the mapping of the UK Coastal Zone and has created a Coastal Geology Group. The staffing of the Group and the areas are prioritized depending on the requirements of the funding agency.

Equipment: For the mapping programme BGS makes use of NERC and chartered vessels and a suite of BGS equipment including:

- high-resolution seismics including airguns, sparkers, pingers, boomers with recording and data processing facilities
- side-scan sonar systems
- grabs, gravity and vibrocorers
- wireline coring system capable of drilling to a depth of 300 m below seabed.

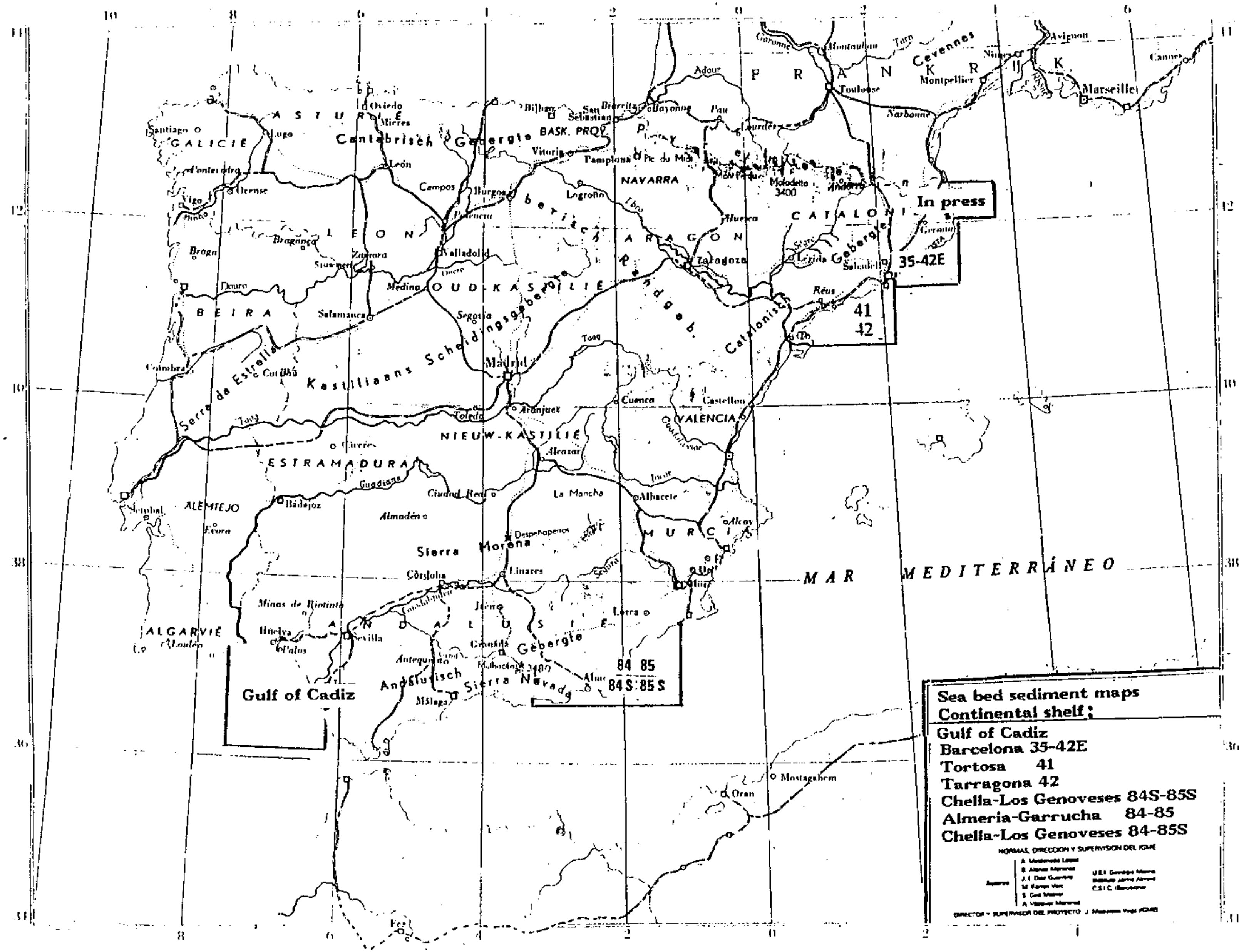

Figure 11   Map of the Spanish Continental Shelf showing coverage of published marine geological maps.

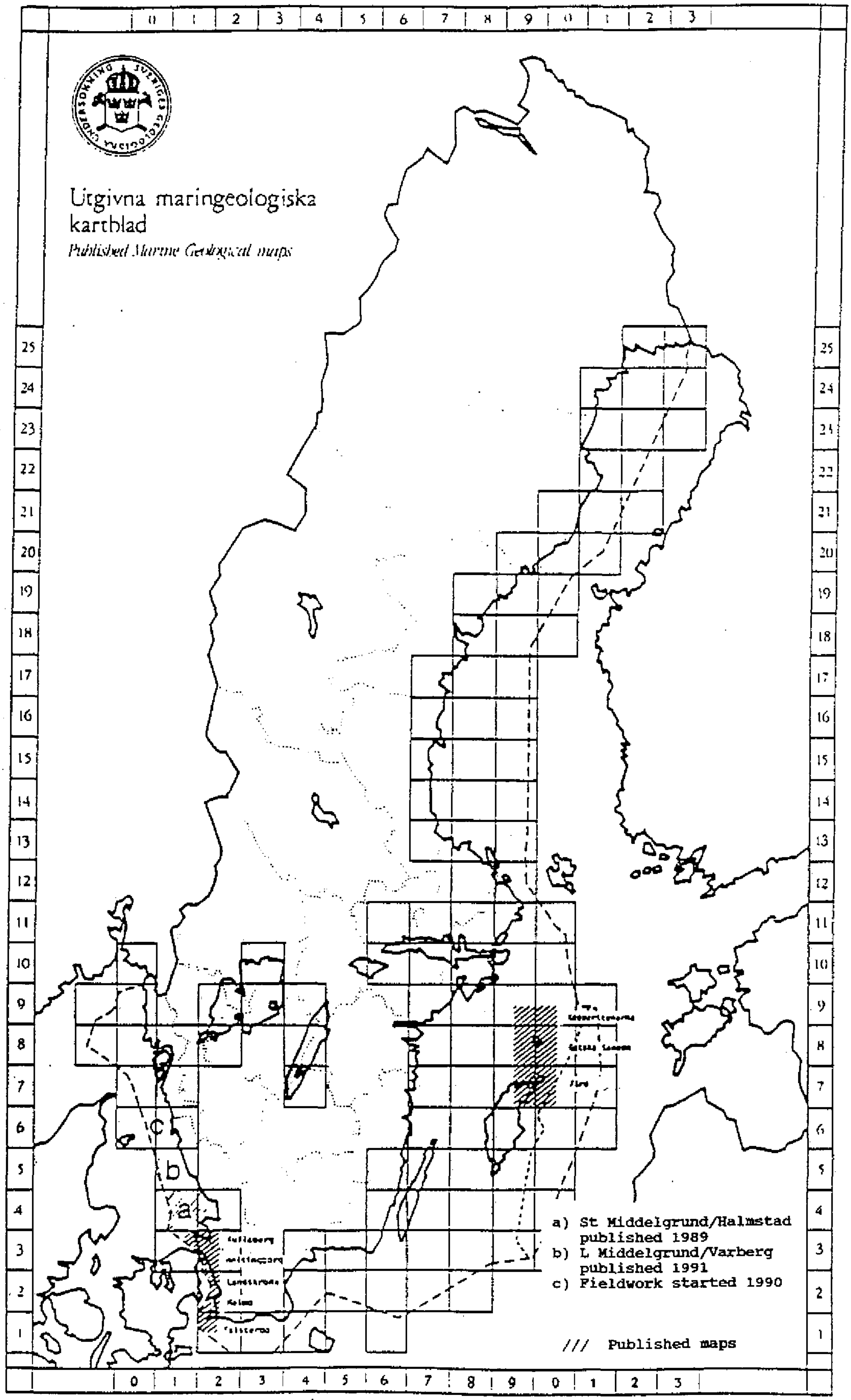

Figure 12 Map of the Swedish Continental Shelf showing coverage of published marine geological maps.

Budget: No data are available on the current offshore geological mapping programme. Costs for resource surveying of Areas 1, 2, and 3 of the marine aggregate programme (see below) are approximately £180 000, £240 000, and £280 000, respectively.

Seabed sediment maps: BGS began mapping the UK continental shelf in 1966. The maps are published at a scale of 1:250 000 in UTM projection, and each sheet covers one degree of latitude and two degrees of longitude (Figure 13). There are 342 maps planned in the series, including separate maps showing gravity anomalies, aeromagnetic anomalies, solid (pre-Quaternary) geology, and Quaternary geology and seabed sediments. In some areas the seabed sediment and Quaternary geology maps are combined to form a single sheet.

As of early 1991 around 94% of the maps were published, including 55 seabed sediment maps, and the complete suite of maps is scheduled for publication by 1992. The maps are based on seismic tracks run with a line spacing of 5—10 km and bottom sample and core stations with a similar spacing. During the survey of the continental shelf over 225 000 km of seismic traverses have been run, bottom samples and shallow cores obtained from more than 30 000 sites, and over 500 boreholes drilled.

Bathymetric, side-scan sonar, bottom current, and tidal data from other sources, including commercial site investigations and naval hydrographic data, are integrated in the seabed sediment maps. Each map shows the bathymetry and the distribution of seabed sediments, defined under a modified Folk (1954) classification. Further information is provided around the margin of the map, including a description of the sediments, topographic sections, oceanographic data, and small maps at a scale of 1:1000 000 giving details of sediment parameters and calcium carbonate contents.

In addition to the 1:250 000 series the seabed sediment maps are summarized on two sheets, covering, respectively, the northern and southern UK shelf areas, at a scale of 1:1000 000 and are described in a summary report (Pantin, 1991).

The samples and data collected by BGS and used in the map preparation are held on open file in the BGS archive and are available for further study.

The maps are available through government bookshops and at the sales outlets listed below.

Information on offshore surveys is available from: Head of Marine Surveys, British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA. Tel. +44 031 667 1000.

Resource maps: In 1986, the Crown Estate and the Department of the Environment jointly commissioned BGS to undertake a programme of marine aggregate resource appraisal based on a two-tier approach. The first stage of this programme, directed and financed by the Crown Estate, is a series of desk studies covering all offshore areas of the UK continental shelf. The first of these studies covering the southern North Sea area (Phase 1) drew together all information concerning geology, distribution of seabed sediments, bathymetry, and the local hydraulic regime in order to identify potential resource areas which merited additional surveys to quantify in broad terms the available resource. These resource assessment surveys form the second stage of the approach. The surveys involve geophysical traversing using side-scan sonar and high-resolution profiling subsequently calibrated by sampling and coring. Marine aggregate resources are classified on their relative proportions of gravel, sand, and fines in the sediment. Gravel is defined as sediment greater than 5 mm, sand as sediment between 5 mm and 0.063 mm, and fines (silt and clay) as material less than 0.063 mm grain size.

The appraisal of resources and the geological interpretation will assist the mineral planning role of the Department of the Environment and the management of resources and licensing of dredging areas by the Crown Estate. The results also provide a geological basis for the detailed evaluations undertaken by the marine dredging industry and will provide persons involved with fisheries interests with useful information on bottom conditions, including sediment type, thickness, and stability, and on the nature of the substrate.

The current status (with publication dates) of the marine aggregates programme is outlined as follows (see Figure 14):

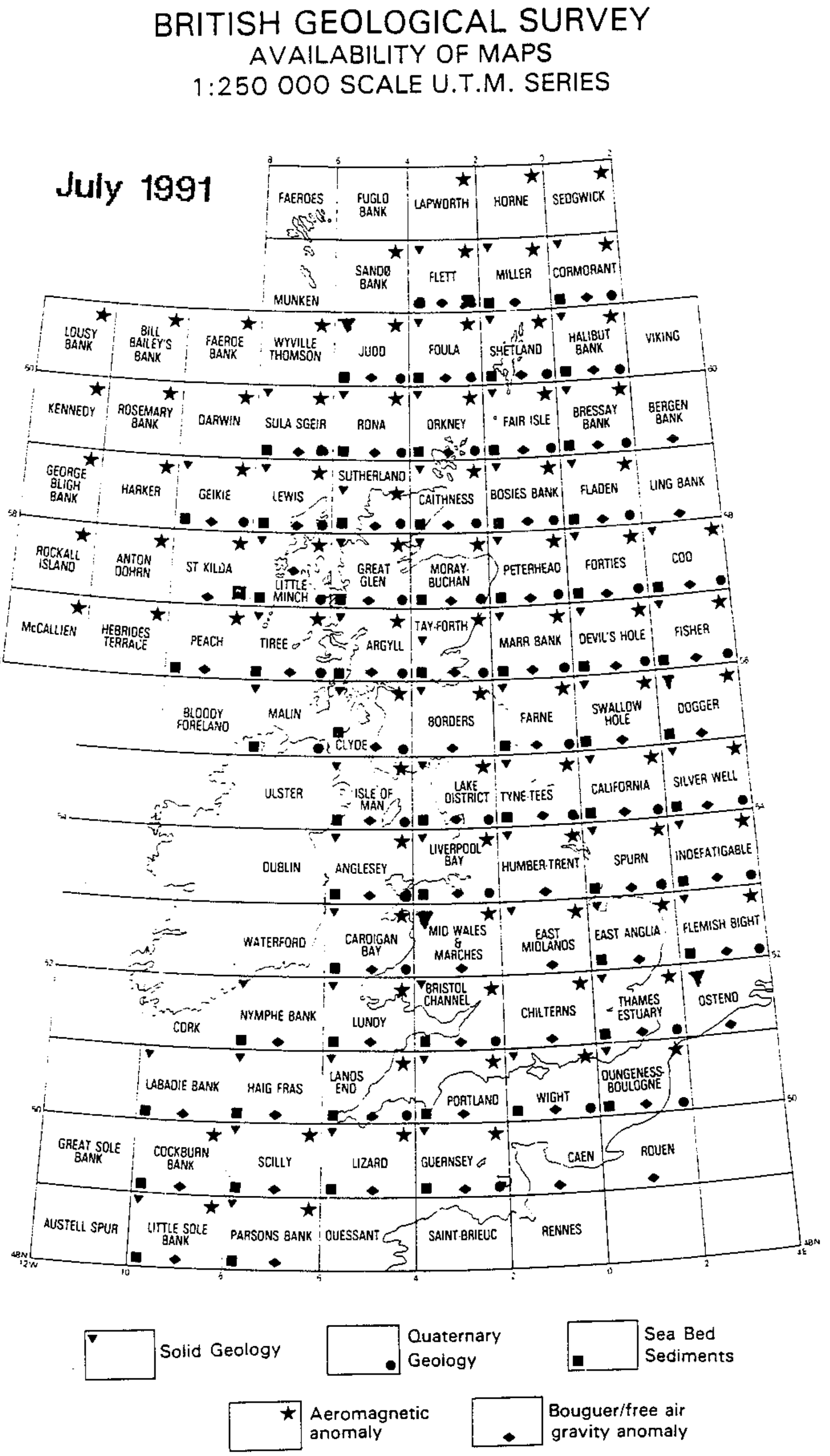

Figure 13 Map of the United Kingdom Continental Shelf showing coverage of marine geological maps.

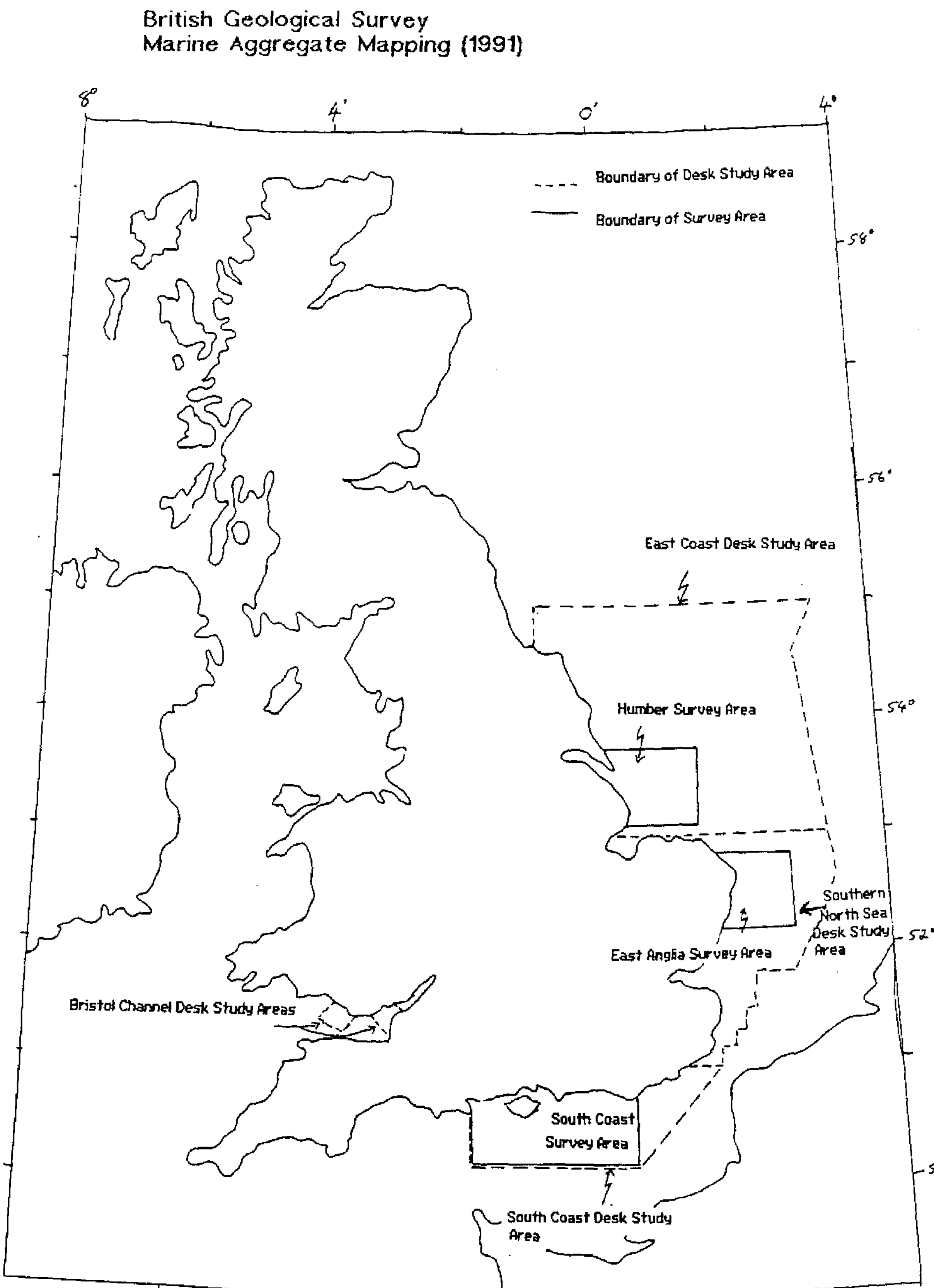

Figure 14 Map of the United Kingdom Continental Shelf showing location of areas surveyed for marine aggregate resources.

Desk studies

Phase 1	Southern North Sea 1986
Phase 2	South Coast 1988
Phase 3	East Coast 1991
Phase 4	Irish Sea 1991?
Phase 5	Southwest Coast 1992? (Parts of the Bristol Channel area were reviewed in a separate desk study in 1988.)

Resource surveys

Area 1	Great Yarmouth to Southwold, East Anglia, 1988
Area 2	Isle of Wight to Beachy Head, 1989
Area 3	Humber (commencing summer 1990). Publication scheduled for 1992
Area 4	Bristol Channel? Commencing 1992?
Area 5	Liverpool Bay. Commencing 1993?

The resource survey reports describe the distribution of resources and the geological controls which determine their quality and quantity. The reports are accompanied by colour-printed maps at the 1:100 000 scale or 1:250 000 scale showing:

1. Bathymetry
2. Geophysical lines and sample stations
3. Seabed sediments and bedforms
4. Thickness of superficial sediments
5. Seismostratigraphy
6. Thickness of palaeovalley sediments
7. Geological map
8. Potential aggregate resources

Ordering: BGS offshore geological maps are available from:

Sales Desk
British Geological Survey
Keyworth
Nottingham NG12 5GG

Sales Desk
British Geological Survey
Murchison House
Edinburgh EH9 3LA
Tel. +44 031 667 1000

BGS Information Office (Orders)
Geological Museum
Exhibition Road
London SW7 2DE
Tel. +44 71 589 4090

London Map Centre
(Ordnance Survey Agent)
22-24 Canon Street
London SW1H 0QU
Tel. +44 71 222 2466

Thomas Nelson and Son
(Ordnance Survey Agent)
51 York Place
Edinburgh EH1 3JD
Tel. +44 031 557 3011

Geological Museum
Bookshop (Counter Sales)
Exhibition Road
London SW7 2DE
Tel. +44 71 589 3444

BGS marine aggregate desk study reports and maps are available from the Crown Estate at:

Marine Estates
The Crown Estate
Crown Estates Office
13-16 Carlton House Terrace
London SW1Y 5AH

BGS marine aggregate survey reports and maps are available from:

Department of the Environment
Minerals and Land Reclamation Division
2 Marsham Street
London SW1E 6RB

The first of these reports (Great Yarmouth—Southwold) was priced at £1000. One year after publication the price was reduced to £126. The pricing policy is being reviewed for the subsequent reports and the South Coast report was priced at £124. Both desk study and survey reports/maps are openly available in BGS libraries two months after publication of desk study reports and one year after publication of survey reports.

United States

Staff: complete information is not available.

Budget: complete information is not available.

Equipment: the mapping effort is generally limited to the re-analysis and integration of existing data and samples. There has been no standard equipment for these historical surveys.

Published maps: there is as yet no central compilation of maps relating to offshore sand and gravel resources.

Future mapping programmes: the CONMAP Program intends to remap the entire Atlantic Coast and the coast of the Gulf of Mexico at a scale of 1:1000 000. The first map of the New England Shelf is in press.

As part of the MMS Program, joint Federal/State Task Forces have been set up on the Atlantic coast in North Carolina (for phosphorite), in Georgia (for phosphorite and heavy mineral placers), and along the Gulf Coast (for sand), but a series of maps is not yet available.

Ordering: CONMAP Program, US Geological Survey, National Center, Mail Stop 195, Reston, Virginia 22092, USA; or Minerals Management Service, Atrium Parkway Building, 381 Eldon Street, Herdon, Virginia 22070, USA.

ANNEX 4

Recent Research at a Marine Gravel Extraction Site off Dieppe, Eastern English Channel

The following report was submitted to the Working Group by M. Desprez after the text for this *ICES Cooperative Research Report* was completed. It is included here because of its relevance to the study of the physical and biological impacts of marine aggregate extraction operations.

TEN YEARS OF BIOSEDIMENTARY MONITORING AT A MARINE GRAVEL EXTRACTION SITE OFF DIEPPE (EASTERN ENGLISH CHANNEL)

Extraction of marine sediments off Dieppe commenced in 1980. The extraction site is located at a depth of 15 m upon a substrate composed of shingle banks thinly covered with ripples of shell sand. The intensity of the extraction operation has varied from year to year, but an average of 400 000 t per annum has been removed in the 10 years since 1980, by suction trailer dredger, over the 3 km^2 of the site.

Biosedimentary monitoring was undertaken to evaluate the impact of this operation on the benthic environment, and to establish the limits and the degree of physical and biological changes of the bottom on and around the extraction site.

On site:

- bottom topography was changed by the creation of extraction channels which were only partly refilled despite the presence of strong currents and mobile sand ripples in this area;

- extraction has progressively eliminated the original sandy gravel and replaced it with fine sand derived primarily from transport by tidal currents and from overflow from the dredger during operation;

- the benthic community has changed from one of coarse sand with the lancelet *Amphioxus* to one of fine sand with the polychaete *Ophelia*.

The most striking change is in the impoverishment of the fauna: within the site there were 2 to 4 times fewer species than in undisturbed sites and the densities were also 2 to 10 times lower (Figure 15). The fauna is however not totally eliminated, and errant species (e.g., amphipods and certain echinoderms) were much quicker to recolonize than sedentary biota (e.g., some annelid and bivalve species). The structure of the community was thus fundamentally changed, with decreases in crustaceans, echinoderms, and bivalves leading to almost complete dominance by annelids.

Around the site:

- no changes in sediment or biota were discerned owing to the restriction of extraction activity to the end of the ebb tide when waters were slack;

- the range of conditions sampled in the study indicated increasing biological richness with increasing substrata heterogeneity;

- monitoring of the control stations showed high natural variability in the benthic populations, owing to the instability of the substrate during strong currents.

Conclusions

The study has greatly improved the fundamental understanding of this part of the English Channel by producing material including:

- a morphosedimentological map from the geophysical profile grid;

- an example of the importance of dynamic factors in the structure and movements of the sediments and associated fauna;

- a list of over 200 macrozoobenthic species;

- a biosedimentary classification of the Dieppe site;

- a refinement of the map of superficial sediments and benthic communities.

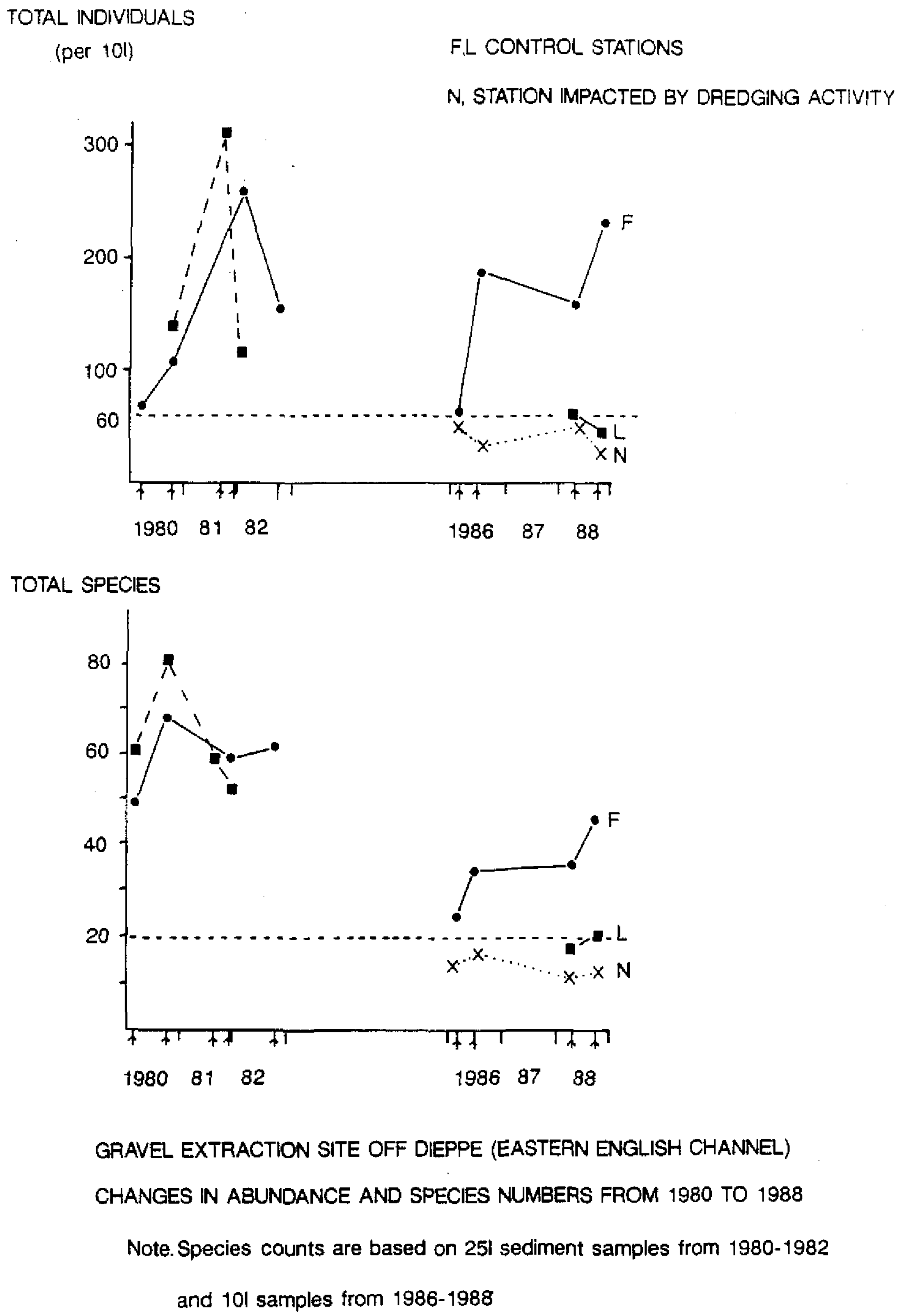

Figure 15 Gravel extraction off Dieppe (Eastern English Channel): changes in abundance and species numbers from 1980 to 1988.

ANNEX 5

Contributors to the Report

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ANNEX 6

Prospecting Licences - Guidelines on Liaison with Fishing Interests: An Example from the United Kingdom

Regulatory Authority (RA) Action

- agree in principle with applicant on prospecting area
- obtain comments from Government Fisheries Authority (GFA)
- advise applicant of GFA comments
- issue formal offer letter to licensee

Mining Company Action

- obtain RA approval of the technical elements of the prospecting programme
- prepare detailed plan of prospecting including:
  - areas, dates, activities
  - name and contact telephone number of mining company liaison representative who will be on board the prospecting vessel
- supply RA and GFA with copy of prospecting plan at least four weeks prior to start
- obtain from RA and GFA the names of fishermen's associations to be consulted
- at least two weeks prior to start, agree with fishermen's associations on a liaison person who will be the channel through which all exchange of information on the prospecting activity will take place, and agree/establish communication links between all parties concerned
- visit prospecting site with local fishermen to establish the exact location of fishing gear
- inform RA and GFA in writing of liaison arrangements and prospecting plan at least 10 days prior to start of prospecting
- four days before start, confirm prospecting plan with liaison person in writing with copies faxed to RA and GFA
- during prospecting provide daily reports to liaison person
- at end of prospecting activities, advise RA and GFA by fax within 24 hours