

ICES COOPERATIVE RESEARCH REPORT

RAPPORT DES RECHERCHES COLLECTIVES

NO. 247

Effects of Extraction of Marine Sediments on the Marine Ecosystem

Edited by

The Working Group on the Effects of Extraction of Marine Sediments on the Marine
Ecosystem

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Palægade 2-4 DK-1261 Copenhagen K Denmark

November 2001

TABLE OF CONTENTS

Section	Page
EXECUTIVE SUMMARY	1
BACKGROUND	1
1 INTRODUCTION.....	3
2 AGGREGATE DREDGING, COASTAL ENGINEERING AND RELATED ACTIVITIES	6
2.1 Extraction of Marine Sediment	6
2.1.1 Status of marine aggregate extraction industry	6
2.1.1.1 Belgium.....	6
2.1.1.2 Canada	6
2.1.1.3 Denmark.....	7
2.1.1.4 Finland	7
2.1.1.5 France.....	7
2.1.1.6 Germany.....	8
2.1.1.7 Ireland	8
2.1.1.8 The Netherlands	8
2.1.1.9 Norway.....	8
2.1.1.10 Poland	8
2.1.1.11 Russia.....	9
2.1.1.12 Sweden.....	9
2.1.1.13 United Kingdom.....	9
2.1.1.14 United States of America	9
2.1.2 Monitoring/research.....	9
2.1.2.1 Belgium.....	9
2.1.2.2 Canada	10
2.1.2.3 Denmark.....	10
2.1.2.4 Finland	10
2.1.2.5 Germany.....	10
2.1.2.6 The Netherlands	10
2.1.2.7 Poland	11
2.1.2.8 Sweden.....	11
2.1.2.9 United Kingdom.....	11
2.1.2.10 United States of America	11
2.1.3 Supply and demand for marine aggregates	11
2.2 Uses of Marine Sediments	12
2.2.1 Concreting/construction/cement production	13
2.2.2 Contract fill/reclamation.....	13
2.2.3 Coastal protection	13
2.2.4 Other uses	13
2.2.5 Conclusions.....	14
2.2.6 Recommendations.....	14
3 THE EFFECTS OF EXTRACTION ACTIVITIES ON LIVING RESOURCES AND FISHERIES.....	14
3.1 The Natural Environment of Marine Aggregates.....	14
3.2 Regional Variability of Marine Aggregate Fauna and Flora.....	15
3.2.1 Fauna.....	15
3.2.2 Flora.....	16
3.3 Environmental Effects of Dredging	16
3.4 Nature of the Physical Effects.....	17
3.4.1 Substrate removal and alteration of the bottom topography	17
3.4.2 Impact of turbidity plumes.....	17
3.4.3 Nature of chemical impacts.....	18
3.5 Nature of the Biological Effects.....	18
3.5.1 The “role” of macrobenthos	19
3.6 Case Studies of the Environmental Responses to the Effects of Dredging	19
3.6.1 CNEXO experimental study site (France)	19
3.6.2 Dieppe recolonisation study (France)	20
3.6.3 North Norfolk experimental dredge site (United Kingdom)	21
3.6.4 Klaverbank study (Netherlands)	21
3.6.5 RIACON Project (Netherlands, Denmark, Germany, Belgium, and Spain)	21
3.6.6 Kriegers Flak (Denmark)	22

3.7	Summary of Impacts and Ecological Response	22
4	MANAGEMENT	22
4.1	Regulatory Policies	22
4.1.1	Resource management/planning	22
4.1.2	Update of legislation and review procedures	23
4.2	Guidelines for the Preparation of an Environmental Impact Assessment Evaluating the Effects of Seabed Aggregate Extraction on the Marine Environment	27
4.2.1	Introduction.....	27
4.2.2	Nature of the deposit.....	28
4.2.3	Dredging proposals	28
4.2.4	Physical impact	30
4.2.5	Biological impact.....	30
4.2.6	Interference with other legitimate uses of the sea.....	30
4.2.7	Evaluation of impact	32
4.3	Review of Approaches to Environmental Impact Assessment (EIA)	32
5	SEABED SEDIMENT MAPPING PROGRAMMES OF ICES MEMBER COUNTRIES	41
5.1	Introduction.....	41
5.2	Belgium.....	42
5.3	Canada	44
5.4	Denmark.....	44
5.5	Estonia	46
5.6	Finland	46
5.7	France.....	46
5.8	Germany.....	49
5.9	Ireland.....	51
5.10	Latvia	51
5.11	Lithuania.....	53
5.12	The Netherlands	53
5.13	Norway.....	58
5.14	Poland	58
5.15	Portugal.....	61
5.16	Russia (Kaliningrad and St. Petersburg regions).....	61
5.17	Spain	61
5.18	Sweden.....	62
5.19	United Kingdom.....	66
5.20	United States.....	69
5.21	Conclusions and recommendations.....	69
6	DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS.....	70
7	REFERENCES.....	73
	ANNEX A: STANDARD OPERATING PROCEDURES: SAMPLING AND ANALYSIS OF THE MACROBENTHIC FAUNA FROM GRAVEL SEDIMENTS.....	78
	ANNEX B: CONTRIBUTORS TO THE REPORT	80

EXECUTIVE SUMMARY

Background

Aggregates are used for construction purposes and for land reclamation and beach replenishment schemes. There is increasing pressure in ICES Member Countries to meet more demand for aggregates from marine deposits. This is partly due to a decline in suitable land-based sources, but also to increasing environmental constraints on onshore production.

Marine aggregate extracting makes use of areas of the sea which may also support commercial fisheries and other important biological communities, and it is recognised that there are potential conflicts between the extraction industry and other interests in the seabed and ocean space.

The ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) produced a *Cooperative Research Report* in 1992 (ICES, 1992) which reviewed our scientific knowledge and understanding of the impact of marine aggregate extraction on fisheries, in particular, and the marine environment in general. One of the principal activities of the Working Group has been that of identifying and recommending future research needs. This earlier report identified fourteen key research themes and, in the subsequent years, the Working Group has been able to monitor progress in these and in individual research projects designed to improve our scientific knowledge in these areas. Accordingly, this *Cooperative Research Report* provides a synthesis of these most recent advances in our knowledge and understanding of ecosystem effects resulting from the extraction of marine sediments.

Sound resource management, which can provide for the sustainable development of marine aggregate resources, depends first and foremost on a rigorous scientific appreciation of the nature and distribution of the resource. Resource mapping and associated scientific and technical developments affecting such surveys remain an important focus for the Working Group. The elaboration of scientific research aimed at improving our understanding of the effects and impacts on the marine ecosystem has also been a key ingredient of our work. Importantly, the Working Group has always sought to present and review this knowledge in a context where the scale of marine aggregate extraction and the legal regime and environmental safeguards that govern such operations are fully appreciated. This *Cooperative Research Report* thus presents a synthesis of recent information compiled by the Working Group.

Objectives

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

1. Marine aggregate extraction activities in the coastal and shelf environments of ICES Member Countries;
2. Developments in marine resource mapping essential to the sound management of aggregate extraction;
3. The effects of extraction activities on the ecosystem;
4. The management of marine aggregate extraction operations.

Progress

Thirty-three contributors from twelve ICES Member Countries have participated in the production of this report or have contributed data to it. All material has been reviewed by the Working Group.

Marine Aggregate Extraction Activities

The marine aggregate extraction industry is well established and continues to grow in a number of ICES Member Countries, contributing up to 15 % of some nation's demand for sand and gravel. Demand for construction has remained relatively stable, with most major increases in extraction being associated with land reclamation for major projects, or for beach replenishment. Some major projects being considered would substantially increase annual demand in the years of their construction.

Since 1992 further reserves of sand and gravel have been reported in both the Baltic Sea and the North Sea. Reserves are not evenly distributed and the reserves of coarse marine aggregates must be considered finite, as should sand reserves in the Baltic. Fine sands are abundant in the North Sea and adjacent areas.

There are no realistic alternatives to the use of marine aggregate material for most beach replenishment and major coastal reclamation schemes. Strategic planning is essential for the future supply of materials, particularly for major construction projects. Most countries have reported concerns about the extraction of aggregates from both the land and sea, and the sustainable use of finite reserves is seen as a key issue for the future. Many countries are encouraging better use of alternative waste materials where they are appropriate in construction and landfill contexts.

Environmental Effects

Changes to seabed morphology, in the nature of surficial sediments, and effects on associated macrofauna are more profound and long lived where extraction operations are more intensive, or where extraction sites occur in stable environments. In the latter case, sediment stability encourages increased diversity and abundance which can contribute to highly productive fisheries for shellfish and provide important sources of food for commercially exploited finfish species.

Several recent studies in highly dynamic areas have shown that marine aggregate extraction may have only a short-lived impact. In such areas the physical recovery and recolonisation of the seabed is rapid (of the order of three years) and the recolonising community may exhibit a higher biomass than that observed originally or in adjacent areas. Depressions in the seabed topography may represent a more heterogeneous habitat and provide niches for certain fish species. Fish densities have been observed to be higher on some dredged sites.

Environmental Monitoring

Environmental monitoring programmes are necessary mostly to determine that license conditions are being properly implemented. Owing to the time and effort that monitoring work usually requires, it is important to ensure that the monitoring programme is properly designed to meet its objectives in the most effective way.

The primary matters for consideration when scoping and implementing a programme of monitoring are:

1. Identify the environmental concerns that the monitoring programme is to address;
2. What parameter measurements are necessary to identify the significance of a particular effect;
3. What sampling equipment and techniques are best suited to measure the identified parameters;
4. What are the most appropriate locations at which to take samples;
5. How many samples are required to take statistically meaningful measures of biological/ecological responses;
6. How often and for how long should such measurements be made.

As information on the effects of marine aggregate extraction becomes more available from longer-term monitoring studies, monitoring requirements can be revised, and thus it is essential that monitoring data are made widely available so that all may benefit from our better understanding.

Resource Mapping

Reconnaissance mapping of the seabed sediments (with an adequate density of data points both spatially and with depth) forms the basis for qualitative delineation of marine aggregate occurrences and provides information for planning and best practice in the use of potential resources in marine and inshore zones.

Detailed resource mapping is essential to obtain reliable quantitative information on seabed resources and the depth of deposits. Reconnaissance mapping is progressing at variable rates in the ICES Member Countries, with resource mapping often lagging behind.

Only countries with advanced and adequate reconnaissance and resource mapping programmes are able to formulate realistic aggregate extraction (and environmental) policies. Most ICES Member Countries have not yet reached this stage, so their policies are generally based on assumptions and a broad theoretical approach rather than known data. Large parts of the ICES shelf areas are at present unmapped in any detail, and many of the mapped areas lack information on the depth of the resource.

It is therefore important that reconnaissance and resource mapping continue to be funded and that this work develops from a sound understanding of the requirements of governments and the dredging industry. While new developments in technology and our classification of seabed biotopes may lead to habitat mapping requirements being a key feature of the management of future marine aggregate extraction, it is nonetheless important to remember that basic reconnaissance and resource mapping are still incomplete over substantial areas of ICES Member Countries' coastal seas and shelf areas.

1 INTRODUCTION

Marine aggregate extraction from offshore areas started in the 1960s. During the 1980s, the demand for aggregates throughout Europe from both land-based and marine sources steadily increased. The presence of large quantities of “high quality” marine aggregate near to large conurbations requiring building materials, provided an ideal opportunity to meet the increased demand. Consequently, over recent years marine aggregate has increased its share but remains small compared with the total aggregate production.

From an environmental point of view, during the 1960s concern was expressed over the potential impact of marine aggregate extraction on the macrofauna and the effect this would have on commercial fisheries. At that time, the Ministry of Agriculture, Fisheries and Food (MAFF) in the UK began a programme of research to determine the impacts of dredging on the feeding and spawning grounds of economically important finfish species, such as sandeels (*Ammodytes* spp.; MAFF, 1981). Research was also directed towards understanding how the seabed sediments were altered and how persistent these changes would be. In the 1970s the issue became one of international importance when the International Council for the Exploration of the Sea (ICES) established a scientific Working Group on the effects of extraction of marine sediments on fisheries. This provided an opportunity for Member Countries, especially the UK, Denmark, the Netherlands, and France as the leading European producers of marine aggregate, to report on their environmental research and monitor the exploitation of the resource.

In 1992 the Working Group produced its report “The Effects of Extraction of Marine Sediments on Fisheries”, published as *ICES Cooperative Research Report* No. 182. That report made a number of recommendations and significant advances have been made in our understanding of the effects of aggregate extraction on the marine environment over the last five years in a number of these areas. Much of the research undertaken has sought to fulfil three main objectives, namely:

- 1) To determine the natural faunistic variation in commercial coarse aggregate deposits in different regions and to help assess the likely scale of impacts and the relative importance of marine aggregate extraction compared with other man-made and natural effects.
- 2) To quantify the initial impacts of aggregate extraction on the macrobenthos and sediment and to assess the rate and type of recolonisation post-dredging.
- 3) To develop quantitative biological sampling methods for hard-bottom habitats.

Table 1.1 lists the recommendations in the previous *Cooperative Research Report* (ICES, 1992) and provides a brief description of the progress on each one, referencing the relevant parts of this report which review the research undertaken on this topic. This report is an update and extension of the previous *Cooperative Research Report* (No. 182). It reviews the current state of knowledge which is the result of cooperative research undertaken by ICES Member Countries participating in Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem, which reports annually to the ICES Marine Habitat Committee.

In compiling this report, the Working Group has drawn on its wide scientific, professional, technical, planning, and administrative experience provided by its diverse and multi-disciplinary membership. This diversity is one of the major strengths of the group. In presenting this review, the Working Group has focused on findings and developments in our understanding of the effects of aggregate extraction from reported and published studies. Discussions on present research and ongoing studies are a regular feature of meetings of the Working Group and the reports of these annual meetings can be referred to for more recent discussions and review of unpublished work.

Contributors

A complete list of those who have contributed to this report can be found in Annex B. Particular acknowledgement should be given to the Section Editors and Rapporteur, and the Chair of the Working Group during this period, Dr S.J. de Groot.

Table 1.1. Review of recommendations made in the previous report and references to work reviewed in this report of relevance to each of them.

RECOMMENDATION made in Cooperative Research Report No 182	Geographical Location	Page number reference to this report	References and published reports
1) 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.	North Norfolk (UK) Dieppe (France) Klaverbank (Netherlands)	Pages 13–15	Kenny and Rees (1994, 1996) Sips and Waardenburg (1989) Desprez (1992) Kenny <i>et al.</i> (1991) ICES WGEXT Annual Reports (1992–1998)
2) 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.	North Norfolk (UK) Dieppe (France) Klaverbank (Netherlands) Kriegers Flak (Denmark) RIACON Project	Pages 17–21	Kenny and Rees (1994, 1996) Sips and Waardenburg (1989) Desprez (1992) Kenny <i>et al.</i> (1991) ICES WGEXT Annual Reports (1992–1998) Øresundskonsortiet (1998a, 1998b)
3) The recolonisation of gravelly substrates following the cessation of disturbance of defaunation due to dredging. Time scale is an important consideration.	North Norfolk (UK) Dieppe (France) Klaverbank (Netherlands)	Pages 17–21	Kenny and Rees (1994, 1996) Sips and Waardenburg (1989) Desprez (1992, 1997) Kenny <i>et al.</i> (1991) ICES WGEXT Annual Reports (1992–1998)
4) 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.	North Norfolk (UK) Klaverbank (Netherlands) Kattegat (Denmark)	Pages 17–21	Kenny and Rees (1994, 1996) Sips and Waardenburg (1989) DMU (1997)
5) 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.	The Øresund Link (Denmark) Netherlands land reclamation projects Great Belt (Denmark)	Pages 17–21	Øresundskonsortiet (1998a, 1998b) Storebælt (1997)
6) The distribution of spawning grounds for bottom-spawning fish and shellfish overwintering grounds in areas where marine sediment extraction may occur.	Denmark Ireland Kotka – Eastern Gulf of Finland		Report available only in Finnish
7) Dredging-related impacts, such as nutrient or suspended solid release, on growth rates of relevant species such as shellfish.	Kriegers Flak (Denmark)	Pages 21	Øresundskonsortiet (1998a, 1998b)
8) Changes in species composition following recolonisation of a disturbed or defaunated substrate, particularly where the substrate type has changed.	North Norfolk (UK) Dieppe (France) CNEXO (France)	Pages 17–21	Desprez (1996, 1997) Kenny and Rees (1994, 1996) ICES WGEXT Annual Reports (1992–1998)
9) Fish populations at historical dredge sites where extraction has now ceased. Ideally, investigation should focus on species composition and population dynamics of finfish communities in an area prior to extraction, after extraction, and at intervals after.	CNEXO (France) data limited to video survey for species composition; no data on population dynamics		Desprez (1996) ICES WGEXT Annual Reports (1992–1998)

Table 1.1. Continued.

RECOMMENDATION made in Cooperative Research Report No 182	Geographical Location	Page number reference to this report	References and published reports
10) The role of outwash fines in the scavenging of trace metals from the water column.			no further information
11) Effects of the generation of turbidity plumes on fish behaviour, including avoidance and/or concentration of individuals.	Kriegers Flak		Øresundskonsortiet (1998a, 1998b)
12) The fate of marine organisms travelling through the suction pipe dredger hopper.	English Channel (UK)		MAFF Paper: Lees <i>et al.</i> (1992)
13) The behaviour of the dredge head at the seabed investigated by such means as video camera monitoring.	Laesoe (Kattegat) English Channel (UK)		Hitchcock and Drucker (1996)
14) The environmental effects of the removal of boulders from the seabed by “stone fishing”.	Denmark		ICES WGEXT Annual Reports (1992–1998)

2 AGGREGATE DREDGING, COASTAL ENGINEERING AND RELATED ACTIVITIES

2.1 Extraction of Marine Sediment

The modern industry, dredging offshore areas with purpose-built ships, started in the 1960s. Since then it has grown into a major industry particularly in the United Kingdom and the Netherlands. Total extraction of marine aggregates in ICES Member Countries has increased significantly in recent years, from 37 million m³ in 1992 to 54 million m³ in 1997.

As the volume of material extracted has grown, so has the size and sophistication of the dredging fleet. Dredging is almost entirely by trailing suction dredgers, which typically dredge in water depths up to about 40 metres (the larger contract dredgers can dredge to at least twice this depth). Cargo sizes generally vary from 1500 to 3000 cubic metres but this can be more than 15,000 cubic metres (sand and gravel) for the largest contract dredgers and the trend is for ever bigger and more sophisticated vessels.

One of the major advances in recent years has been the increased accuracy of the navigation equipment. The ready availability of satellite navigation systems and, in particular, Differential GPS has meant that dredgers can work with unprecedented accuracy and repeatability to produce cargoes of the required quality time after time even from small or poorly sorted reserves. The other development following from the improvement in navigational equipment is the installation of equipment on dredging vessels to monitor compliance with license conditions.

2.1.1 Status of marine aggregate extraction industry

This section gives an overview of aggregate extraction from fourteen countries over the past six years. This information has been collected from previous annual reports of the ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT).

Country	Total marine sand and gravel extraction 1992 to 1997 (m ³)
Belgium	11,000,000*
Canada	325,000
Denmark	30,500,000
Finland	3,500,000
France	13,200,000
Germany	7,000,000**

Ireland	—
Netherlands	104,200,000*
Norway	710,000
Poland	6,700,000***
Russia	7,200,000
Sweden	35,500
UK	81,600,000
USA	7,400,000

*Mainly sand **Baltic Sea only ***1993–1997

The annual extraction for each country from the main dredging areas is detailed in the following paragraphs. Detailed information for the UK, the Netherlands, and Denmark is available in Construction Industry Research and Information Association Report RP571.

2.1.1.1 Belgium

Since 1990 the annual aggregate dredging total has increased from 1,420,000 m³ to 1,669,488 m³, the increase occurring from five new licenses. The material is dredged from three areas, namely Kwintebank (90 %), Oost Dyck bank (6 %), and Buiten Ratel (3.3 %).

Year	Aggregate extraction (m ³)
1992	1,218,000
1993	1,448,000
1994	1,604,000
1995	1,699,000
1996	1,433,000
1997*	3,500,000
Total	10,902,000

* Estimated

2.1.1.2 Canada

The extraction of marine aggregates in Canada has been small owing to extensive exploitation of aggregates onshore. But in 1991, interest was expressed in the exploration and eventual exploitation of placer deposits on the Scotia Shelf. Even though this is still the case, the lack of a legislative framework remains the biggest deterrent to further investment and investigation.

In 1993, extraction of marine aggregates dropped from the previous year, most of which came from the dredging of shipping lanes and harbour channels for use in beach replenishment (New Brunswick). Experimental studies of the extraction of gold-rich deposits on the Scotia Shelf were initiated and the results published in 1996.

1994 saw the MDA-3 project go forward (initiated by the Geological Survey of Canada), whereby extensive aggregate surveys took place along the Scotia Shelf.

Also, the Prince Edward Island bridge connection project was in its construction phase.

In July 1998 the Canadian provincial and federal governments decided to formally investigate the possibility of marine mining.

Year	Aggregate extraction (for construction) (m ³)
1992	325,000
1993	-
1994	-
1995	-
1996	-
Total	325,000

2.1.1.3 Denmark

Since 1995 the extraction of marine sand and gravel has represented 10–13 % of the total production of materials for construction and reclamation. The amount of marine materials used for construction purposes has been more or less constant over the past five years due to low house building activity, though a minor increase has been recorded in the extraction of coarse aggregates. It is expected that marine sand and gravel will increasingly replace land materials due to the increasing environmental conflicts on land.

Year	Aggregate extraction (m ³)*
1992	3,300,000
1993	4,300,000
1994	5,200,000
1995	5,300,000
1996	6,200,000
1997	6,200,000
Total	30,500,000

*Increase from 1992 to 1997 mainly due to additional quantities of landfill and beach nourishment.

2.1.1.4 Finland

The marine dredging industry in Finland has shown little activity over the past three years, with annual extraction figures under 500,000 m³. This increased slightly in 1995 due to the amount of marine sand needed in the coverage operation of the Estonia ferry which sank in 1994. The main areas for extraction are in the coastal areas off the cities of Helsinki, Kotka, Pori, and the land bridge to Hailuoto Island.

Year	Aggregate extraction (m ³)
1992	< 500,000
1993	< 500,000
1994	< 500,000
1995	< 500,000
1996	< 500,000
Total	< 2,500,000

2.1.1.5 France

France has seen a lot of change in its marine dredging industry over the past 5–6 years but due to conflicts with the fishing industry, growth has been limited. One area which is seen to have “marine aggregate exploitation” potential is the Bay of Seine. Since 1990 this area has had extensive but preliminary gravel location surveys, new licenses, sedimentological and biological studies. Future growth is due to the predicted increase in demand and the limitations on extraction of alluvial deposits onshore.

As conflicts of interest are high, particularly between the dredging industry and ecologists/fishing industry, it has taken a long time for the government to grant any production licenses. But a move to create an ecological Geographic Information Systems (GIS) has been initiated in the Bay of Seine which it is hoped will enable the management of “least constraint” exploitation areas. It is predicted that by the turn of the century 4.2 million m³ of aggregate will be dredged per year in this area. Other areas where extraction activities are occurring include: the Dieppe area, Brittany, Loire estuary, La Rochelle area, and the Gironde estuary.

Since 1994, a total of 25 km² of seabed has been dredged for marine aggregates, with licenses issued to only six provincial departments, for a total amount of 3 million m³ in that year. 600,000 m³ were imported from the United Kingdom. France has also seen a recent increase of calcareous sands production from 120,000 m³ in 1994 to 450,000 m³ in 1995. Siliceous aggregate extraction totalled 2,700,000 m³ in 1995. Calcareous aggregates in 1995 totalled 560,000 m³, calcareous sand about 180,000 m³, with a further extraction of 380,000 m³ of *Lithothamnium* in this year.

Year	Aggregate extraction (m ³)
1992	2,228,900
1993	2,078,300
1994	2,210,800
1995	2,210,000
1996	2,210,000
1997	2,210,000
Total	13,148,000

2.1.1.6 Germany

North Sea

The largest amount of sediment extraction derives from maintenance dredging within the waterways inside estuaries. This has resulted in an annual dredging and dumping figure ranging between 27 million m³ and 33 million m³ from estuaries.

In 1997, sand extraction continued for coastal protection of the island of Sylt. The extraction area is situated 7 km west of Sylt at a water depth of 14 m. Maximum extraction volume is limited to 2 million m³ per year.

Commercial sand extraction is planned for the area of the Weisse Bank.

Baltic Sea

No extraction of marine sediments has taken place during the last ten years on the coastal shelf of Schleswig-Holstein, and no extraction is currently planned.

On the coastal shelf of Mecklenburg-Vorpommern there are seventeen extraction fields for which permission has been granted by national authorities. The majority of the extraction sites are used for coastal defence purposes. These sites are used periodically when there are coastal defence projects executed in the respective region. Four fields: the sea area off Kühlungsborn, Greifswalder Bodden, Adlergrund, Plantagenetgrund produce sand and gravel for construction (concrete, landfill, road base, etc.).

Year	Aggregate extraction (m ³)*
1992	372,000
1993	468,000
1994	814,000
1995	919,000
1996	2,158,000
1997	2,269,000
Total	7,000,000

*Baltic Sea only

2.1.1.7 Ireland

Prior to 1995, the only marine dredging activity of note was the extraction in 1990 of *Lithothamnion*.

In 1995 two licenses to extract marine sediments were considered by the Department of the Marine. These relate to an exploratory license to extract medium grade sand off Waterford in the southeastern corner of Ireland, and an application to extract cobble and sand from the Codling Bank in the Irish Sea off Greystones Co. Wicklow. No extraction has taken place in relation to these projects to date.

2.1.1.8 The Netherlands

Up to 1990, the Netherlands mainly extracted marine sand from maintenance and capital dredging of navigational channels. This reached an annual total of 8.4×10^6 m³ due to the increase in annual beach nourishments. 1993 saw the introduction of sand extraction from the Dutch Continental Shelf, which increased the total to 13.4×10^6 m³. This has further increased to 23×10^6 m³ (this latest increase being mainly for landfill). The main use for this material is beach nourishment and landfill.

Part of the sand extracted in the southern part of the Dutch Shelf has been used for construction purposes in Belgium.

Year	Aggregate extraction (m ³)
1992	14,800,000
1993	13,400,000
1994	13,000,000
1995	16,800,000
1996	23,200,000
1997	22,800,000
Total	104,000,000

2.1.1.9 Norway

Traditionally, sources of aggregate for the construction industry have been based on land-based gravel pits and hard rock quarries. In Norway, marine extraction of sand and gravel has been in modest quantities. The amount of marine aggregates has never exceeded 1 % of the total volume of aggregates produced. Carbonate sand extraction has been fairly constant at 60,000 m³ to 90,000 m³ per annum, predominantly from Hordaland and Rogaland on the west coast.

Year	Aggregate extraction (m ³)
1992	-
1993	100,000–150,000
1994	100,000
1995	100,000–150,000
1996	155,000
1997	100,000–150,000
Total	~710,000

2.1.1.10 Poland

Sand has been taken for beach replenishment for many years. In the period 1989–1997, sand was extracted from four sites in Puck Bay and from the open sea for coastal

defence measures on the Hel Peninsula. A total of 6.7 million m³ was extracted between 1989 and 1997.

2.1.1.11 Russia

In the St. Petersburg region of Russia, sand and gravel resources are exploited from three extraction sites. The annual extraction amounts to 1.2 million m³, with a total of about 7 million m³ between 1992 to 1997.

2.1.1.12 Sweden

Between 1991 and 1993 offshore aggregate extraction only took place in two areas, the Stora Middelgrund area and at Sandflyttan. Most of the demand was met from the large deposits of sand and gravel on land. By the end of 1993 dredging activity ceased due to political concern and no new applications for marine sand extraction were made to the Swedish government.

Even though large dredging operations have been planned to take place between 1994–1998, only one new permit for 2.8 million m³ (till and limestone) has been granted in 1997 to extend the Flint shipping channel between Saltholm Island and the coast of Scania.

Year	Aggregate extraction (m ³)
1992	35,511
1993	-
1994	-
1995	-
1996	-
1997	-
Total	35,511

2.1.1.13 United Kingdom

Marine sand and gravel production takes place almost entirely in England and Wales. Scotland has accounted for less than 2 % of UK production and Northern Ireland has had no marine aggregate production over the past five years.

In 1993 the quantity of marine aggregate extracted for the UK construction industry fell from a record high in 1989 of 14.2 million m³ to 12.1 million m³ in 1992. Over the same period, exports rose by 2.27 million m³ to give a total of 10.38 million m³. A total of 5.89 million m³ was extracted for beach nourishment and contract fill between 1989 and 1992. Since 1993, the UK aggregate demand remained fairly static but exports rose to 3.8 million m³ in 1992. In 1995, 1996, and 1997 the quantity of material used for beach nourishment increased substantially, bringing the combined total to 10.42 million m³.

A limited amount of calcareous seaweed was extracted from the Falmouth Estuary before 1997 and none in the

subsequent two years. A small amount of waste coal was extracted from the Bristol Channel.

Year	Aggregate extraction (m ³)*
1992	12,062,500
1993	11,187,000
1994	12,937,500
1995	13,096,000
1996	12,120,000
1997	12,470,000
Total	73,873,000

*Excluding beach nourishment and contract fill

2.1.1.14 United States of America

Over the years 1992–1997, extraction rates changed very little. The only commercial marine mining is undertaken in New York Harbor. Though this activity is limited, a substantial increase in extraction occurred over this time, up to 2.2 million m³ in 1997.

Beach nourishment along the Atlantic Coast also increased substantially between 1992–1994, where it is estimated that between 6×10^6 and 8×10^6 m³ of marine sands were applied.

The total amount of sediment dredged in the USA in 1996 was 30 million m³, mainly from maintenance dredging of navigation channels.

Year	Aggregate extraction (m ³)
1992	1,200,000
1993	1,200,000
1994	2,200,000
1995	1,400,000
1996	1,400,000
1997	2,200,000
Total	9,600,000

2.1.2 Monitoring/research

A number of ICES Member Countries have undertaken research into the impact of dredging at particular locations relating to existing or potential extraction of marine sediments. These studies have been primarily to look at capital and navigational dredging, extraction of material for construction, landfill, and also other materials such as placer gold deposits.

2.1.2.1 Belgium

A general monitoring programme has been commissioned by the Ministry of Economic Affairs concerning the Flemish Banks and the Gootebank

(Westbank programme). The Sea Fisheries Department at Ostend has been monitoring three sand banks within the licensed area since the late 1970s. The Research Unit of Marine and Coastal Geomorphology at the University of Ghent has been monitoring the geo-morphology of the licensed areas since 1990. 1996 saw additional research involving a geo-morphological study at the University of Ghent, called "Westbank 3".

2.1.2.2 Canada

Extensive research projects, such as those involving multibeam bathymetric data, are growing in number and producing accurate surveys concerning the quantitative measurement of placer and aggregate deposits (including placer gold deposits off Newfoundland) off Canada's coast. But, in general, aggregate exploitation in the marine environment is on hold.

Research on aggregates is being undertaken by Canada in the Bay of Fundy. The multibeam technology used has provided a completely new insight into the nature of marine sedimentary bedforms and processes on a scale which could not be detected using more conventional acoustic sampling methods.

2.1.2.3 Denmark

Implementation of monitoring programmes is a condition in all new permissions. The monitoring may include spill measurements, sediment spread readings, and studying fauna and flora. Monitoring is currently carried out in northern Kattegat (sand for cement production), in the North Sea (beach nourishment), and the Baltic Sea (sandfill for the Øresund Link). Baseline studies have been carried out in the Bight of Aarhus prior to the dredging of 4 million m³ of sand fill for land reclamation.

From 1989 to 1993 more than 9 million m³ of sandfill and till were dredged for the Great Belt Bridge and Tunnel development. Monitoring included flora and fauna and fish spawning grounds.

Computer-aided modelling systems have been developed (by the Danish Hydraulic Institute) to help assess the environmental consequences of present and future dredging projects. This system has been used along with field sampling and observations to assess the impact of dredging limestone and marine sand for the fixed link across the Øresund between Denmark and Sweden. The construction involves a total of 7 million m³ to create an artificial island, an immersed tunnel, and the foundations for bridge piers and pylons.

In order to assess the environmental impact, monitoring programmes have been established by the contractor, the owner (Øresundskonsortiet), and the environmental authorities. The monitoring programmes are expected to be the most comprehensive and detailed in the world so far. The programmes include monitoring of sediment spreading and sedimentation, water quality, eelgrass,

algae, benthos, migrating fish (herring), birds, and coastal morphology.

A detailed resource assessment and an environmental impact assessment (EIA) of the dredging of sandfill has been carried out on Kriegers Flak in the Baltic by the Øresund Consortium. The assessment was prepared in accordance with the EC Directive 85/337.

Preliminary results from the spill monitoring programme on Kriegers Flak indicate that the spill rates are strongly dependent on the type of dredger. Spill rates range from 0.7 % to 4.8 %. The release of fines and nutrients is very low. Bottom fauna were resampled in the autumn of 1996 and 1997. Preliminary results indicate, in accordance with the EIA, that there is no environmental impact outside 1000 m from the dredging area.

Danish stone reefs are glacial deposits of boulders, stones, pebbles and gravel, found on a seabed consisting of sand and clay. These stone reefs are subject to dredging for construction and engineering purposes. Waves and currents have removed the fine-grained sediment from the mixed glacial deposits, leaving a hard, solid substrate. Biologically they are very valuable, representing the only natural substrate for hard-bottom communities of marine benthic flora and fauna. Reefs covered by boulders (> 60 cm in diameter) in areas between 1 m² to 10 m² mixed with areas of sand or gravel (< 5 cm to 10 cm) are amongst the most diverse sublittoral hard-bottom habitats in Denmark.

2.1.2.4 Finland

Research into herring spawning grounds and the effect of marine dredging upon them took place at the beginning of the 1990s off Helsinki. As with the aggregate extraction statistics, official results of this survey are unknown.

2.1.2.5 Germany

An ongoing joint research project from the Federal Agency of Nature Conservation (BfN) and the University of Rostock, partly funded by the Federal Foundation for the Environment (DBU), is analysing the effects of dredging on sensitive species in the Baltic Sea. The extraction area is situated close to Wustrow (Darss-Zingst-Peninsula) and was dredged in November 1997.

A research project is planned by the BSH (Bundesamt für Seeschifffahrt und Hydrographie) to look at the processes involved in the natural refilling of deep pits and large-scale extraction channels in the Baltic Sea and North Sea including the Wadden Sea.

2.1.2.6 The Netherlands

Environmental research projects conducted in the Netherlands are summarised below:

RIACON Project

In 1993, 2.5×10^6 m³ of sand was extracted for coastline nourishment off the coast of the island of Terschelling in a water depth of about 20 metres. Within the framework of the EU-MAST Project RIACON, the effects on the benthic fauna were monitored for two years, both in the extraction area and in the nourishment area. In the RIACON 2 Project, this monitoring will be continued for four years after the extraction.

PUNAISE 2 Project

Two beach nourishment projects were executed using deep (~18 m) borrow pits in shallow water (~8 m). A monitoring programme on benthic fauna, sediment properties, and morphological behaviour of the temporary pits has been undertaken.

Borrow pits

In 1998 sand was extracted from two 10-m deep borrow pits for the storage of dredged material from Rotterdam harbour. A morphological and ecological monitoring programme was carried out.

Major new projects

The policy on sand extraction is being reviewed, particularly in the light of reclamation plans for the enlargement of Rotterdam harbour and a proposed island airport. Although these projects are in the preliminary stage, several studies have already been carried out. These include physical model studies on the morphological behaviour of extraction pits, and studies of water movement in and around the pits and the consequences for sediment transport and ecosystem effects. Other studies include modelling of overflow from hopper dredgers and the effects of the overflow on the ecosystem, both on the water column and at the seabed.

2.1.2.7 Poland

Geological and ecological research projects were carried out on the Slupsk Bank (Baltic).

2.1.2.8 Sweden

Because of concern about the dredging operations for the fixed link between Sweden and Denmark, the Swedish National Fisheries Agency carried out laboratory studies to examine the effects of suspended sediment on cod eggs and larvae and the behaviour of adult herring and cod.

2.1.2.9 United Kingdom

Environmental research projects in the UK over the period 1992–1997 are briefly listed below:

1) Seabed Sediment Mobility Studies—Isle of Wight

These studies investigated the mobility of seabed sediments, clarified the physical processes, and developed techniques for zoning the seabed based on seabed mobility.

2) Recovery of the Seabed

This was a jointly funded project by the Crown Estate and MAFF looking at recovery of an experimental dredging plot off North Norfolk. The site recovered after about three years but monitoring will continue to confirm that the seabed and biota have stabilised fully.

3) Cumulative Impact Study

A jointly funded project by the Crown Estate and MAFF commenced in January 1998 to investigate the combined effects of dredging from adjacent areas on the seabed environment and fisheries off Lowestoft (east coast of England) and the Isle of Wight.

4) Seabed Habitat Mapping

The BioMar team at the University of Newcastle has developed a technique using acoustic signals for broadscale mapping of habitats on the seabed. Pilot surveys around the UK coast are being undertaken.

5) Anglian Coastal Authority Group (ACAG)

This study looks at the sediment transport pathways in the North Sea out to the 50-m depth contour from the Holderness Coast to the Thames Estuary.

6) Beach Recharge/Resource Study

The study, undertaken in 1994, provided a quantitative estimate of the national demand for beach recharge material and the resources to meet the demand over the next twenty years.

7) Thames Estuary Study

This report, describing the marine aggregate reserves in the Thames Estuary, was published in spring 1996.

2.1.2.10 United States of America

Dredging of the New York Harbor shipping channel continued. Because of public concern about hypoxia as the channel becomes over-deepened, levels of dissolved oxygen were monitored weekly.

2.1.3 Supply and demand for marine aggregates

Marine aggregates are used in at least fourteen ICES Member Countries but there are only two major producers, the Netherlands (mainly sand, but with some gravel amounting to 30 million m³) and the UK (sand and gravel), followed by Denmark and France. Many of the ICES Member Countries, particularly those bordering the North Sea, have surveyed their seabeds and identified considerable resources of marine sand and gravel which should last well into the 21st century at current forecast rates of extraction. Interest is also being shown in the extraction of aggregates from the Baltic Sea by countries

in the Helsinki Convention area. Poland has identified three deposits to date, totalling about 90 million m³. In Germany, a total of about 36 million m³ has been identified in the Baltic (Gosselck *et al.*, 1996). In Denmark a total of 3.9 billion m³ has been identified so far, primarily in the Baltic Sea. Most of the materials are fine to medium sands. Relatively little seems to be known about marine aggregate resources in North America, mainly because of the availability of extensive resources onshore. The Geological Survey of Canada has identified 700 million m³ of coarse gravelly sand on the Scotia Shelf and a large silica sand resource on Eastern Shoal. In Russia deposits of sand and gravel have been found on the Sambian-Curonian plateau and depression; preliminary calculations suggest 4.5 million m³ including some scattered material over paleogenic rocks. Potential gravel resources have been identified in the southeastern part of the Vistula lagoon harbours, but no estimate of quantities is available.

Marine aggregates have two main advantages in the market place. Because they are carried in bulk the unit cost of transport is relatively low and they can be delivered economically to points a considerable distance (well in excess of 150 km) from the point of extraction. They can also be delivered close to the centre of major towns and cities which, for most countries, are concentrated in a relatively narrow coastal strip.

The contribution from marine sources will depend on the availability, quality, and cost of alternatives such as land-based sand and gravel, crushed rock, and recycled/secondary material. Belgium, France, the Netherlands, Denmark, and the UK have reported increasing difficulties in obtaining permission to extract land-based materials. On the other hand countries such as Norway and Spain are looking to increase their output of crushed rock from coastal super quarries which could be exported to countries with a shortfall in "home-based" production. Some countries, e.g., the UK are looking to provide suitable deep-water wharves near their major markets to accommodate large bulk carriers.

Sustainable exploitation of marine resources is a basic principle in several national regulations and beneficial use of dredged materials is being encouraged through planning policy, differential taxation, and license procedures. An increasing amount of material dredged for navigational purposes is being used as land fill and for construction purposes in the Netherlands and Denmark, while glacial till and limestone are being used for land reclamation in Denmark. In some areas, sand from capital and navigational dredging is of high quality calcium carbonate and may be used for making cement. Careful planning of the use of dredged material from large-scale construction works has proven to be economically and ecologically acceptable and could reduce the pressure on land-based reserves, particularly of sand.

The availability of material, particularly from the areas off the Thames Estuary and the east coast of England, has been instrumental in the development over the last

few years of a substantial export market from the UK to mainland Europe. Over the last five years some fifteen million m³ of material have been delivered to the Netherlands, Belgium, France and Germany. This market has stabilised for the moment at 3.9–4.2 million m³ per annum, but the supply would be available to meet a modest increase in demand.

Overall, the contribution of marine aggregates to ICES Member Countries is not large, e.g., 14 % of the total demand for sand and gravel in the UK, one, if not the major, user of marine aggregates. They are, however, making a significant contribution to overall supply requirements in a number of countries and, in certain areas and for certain uses, they provide a major/predominant source of supply. The UK, Netherlands, Belgian, and French markets around the major points of landing such as the Thames, Amsterdam, Antwerp, Dunkirk, and Flushing very much depend on supplies of marine material. In the Netherlands and the UK, beach nourishment and land reclamation have accounted for more than 20 million m³ of marine material per annum. The dredging industry has the ability to supply large quantities of material directly to the point of use quickly and efficiently with the minimum of disruption.

2.2 Uses of Marine Sediments

Marine aggregates are a viable option technically and commercially. Modern technology and control systems ensure that all products are of a consistently high quality and a high standard in terms of performance compared with land-based alternatives. Because they are carried in bulk, the unit cost of transport is relatively low so they can be delivered economically to points a considerable distance (well in excess of 150 km) from the point of extraction.

There are three main uses for marine aggregates: 1) construction, mainly for making concrete; 2) land reclamation, e.g., infilling of docks, road base and other ground works; and 3) coastal protection, e.g., beach replenishment. Small quantities of marine sand are used in agriculture to improve soil structure and to cover oil and gas pipelines.

The use of marine sediments within ICES Member Countries varies greatly depending to a large extent on alternative sources of material and the availability of suitable marine sediments within national boundaries. The distribution of marine sediments is not even. In the North Sea basin, sediments generally become finer from west to east, which is reflected in the extraction patterns from countries bordering the North Sea. The UK extracts probably about 80 % of the gravel (excluding sand), whilst the Netherlands extracts a similar percentage of the sand.

2.2.1 Concreting/construction/cement production

Marine sand and gravel constitute a very important raw material for the construction industry for building purposes, primarily for use as aggregates in the manufacture of concrete. Washed and graded marine sand and gravel are normally combined in the proportion of 60 % stone and 40 % sand. Marine sand is also often used “as dredged” in combination with crushed rock.

Research carried out by national institutes responsible for the testing of construction material and specification has established the suitability of marine sand and gravel addressing concerns about chloride, shell content and alkali-silica reactions. Marine sand and gravel have the benefit of superior workability and lack of contamination from soft materials compared with land-won sand and gravel.

A significant advantage of marine sand and gravel is that it can be delivered directly by the dredging vessel to highly populated urban areas, avoiding the import of large quantities of land materials by road.

Marine aggregates (stone and sand) are used extensively in the UK (7.8 million m³ in 1997) for making concrete. Some Baltic countries also use marine material for this purpose. In Denmark the use of dredged materials from navigational channels for cement production and construction has increased.

2.2.2 Contract fill/reclamation

Marine dredged material has been used for a number of major contracts. In the UK, about 1.2 million m³ have been used in the construction of the Cardiff Bay Barrage in South Wales. Navigational dredgings have been used in Southampton on the south coast of England to extend port facilities and also at Felixstowe's Trinity Dock on the east coast. A major road improvement scheme in Kent made use of marine dredged material.

The Netherlands has carried out several major beach nourishment schemes since 1991. In 1996 approximately 15.5 million m³ of marine sand were used mainly for land fill. In Denmark from 1989 until 1993 more than 9 million m³ of sand and glacial till were used in the construction of the Great Belt Bridge and tunnel project. In constructing the fixed link between Denmark and Sweden, 3 million m³ of sand and 7 million m³ of glacial till and limestone will be used for reclamation and as hydraulic fill in the construction of the bridge and tunnel. Up to 5.5 million m³ of sand are expected to be used for the enlargement of the harbour of Aarhus.

2.2.3 Coastal protection

There is a growing trend to use a “soft” engineering approach to prevent coastal erosion and protect coastal communities from inundation by the sea. Material for beach recharge schemes has to meet tight specifications in terms of grading and range from sand (200–300 µm)

up to cobbles many centimetres in diameter, depending on the nature of the indigenous material forming the beach.

Most of the ICES Member Countries make use of marine material for beach replenishment schemes and this use is likely to grow substantially in the 21st century. In the United States of America about 7 million m³ of material were used for beach nourishment along the Atlantic coast between 1992 and 1994. In 1997, Denmark used 3 million m³ for beach replenishment on the west coast of Jutland. A substantial proportion of the 11 million m³ extracted by Germany from Jade Bay and the North Frisian Coast between 1991 and 1995 was used for coast protection and beach nourishment. On the German Baltic coast, amounts varying between 80,000–1,900,000 m³ are used annually for coast protection. The Netherlands used approximately 8 million m³ of sand for its beach nourishment programme in 1996. Between 1989 and 1997 Poland used about 6.7 million m³ of material to replenish the beaches on the western part of the Hel Peninsula. In the UK about 9 million m³ of marine sand and gravel have been used to replenish beaches, mainly on the east and south coasts with lesser quantities on the south and north coasts of Wales.

2.2.4 Other uses

For many years, calcareous seaweed (maerl) has been used to improve structure and replenish minerals in soil in the UK and France. In 1994, 0.5 million m³ of shelly sand and maerl were produced in France, with much smaller quantities from Falmouth Harbour on the south coast of England. Recently, a license was issued in Scotland (Orkney) to extract maerl up to a maximum of 4,000 m³ for specialist use in wastewater purification and biological filtration applications. The material extracted is not being used in agriculture. *Lithothamnion* sand occurs along the southern and western coasts of Ireland, but only smaller quantities have been extracted. Carbonate sand and gravel occur along the whole western coast of Norway, but most extraction occurs in the southwest either as *Lithothamnion* sand (maerl), or as shell or shell fragments, with minor amounts of barnacles, echinoids, and bryozoans. Carbonate sand extraction along the western coast of Norway has occurred since about 1960. Most of this has been utilised for agricultural purposes, mainly as a soil conditioner. During the past ten years, average extraction has been between 60,000 m³ and 90,000 m³. A more extensive discussion on the effects of extraction can be found in the ICES (1992).

In the Netherlands, shell is extracted from the Wadden Sea up to a maximum permitted volume of 200,000 m³. In Denmark, extraction of shell gravel has taken place for many years in Roskilde Fjord (oyster beds). In 1997, a volume of 145,000 m³ was extracted, but this activity was due to finish at the end of 1997.

A small quantity of waste coal is extracted in the UK for use in commercial power generation. Placer deposits of gold, silver, and tin have been investigated principally in

Canada and the UK, but to date they have not been produced commercially. Poland has identified deposits of sand enriched with heavy minerals such as garnet, zircon, rutile, ilmenite, magnetite, and monazite. In the past, marine sand has been used to make glass in Sweden.

2.2.5 Conclusions

- 1) The number of ICES Member Countries reporting on the use of marine aggregates has increased since 1992, especially those bordering the Baltic Sea. The UK remains the main producer of aggregates for the manufacture of concrete, whilst the Netherlands produces and uses the largest quantity of sand. Since 1992 further reserves of sand and gravel have been reported in both the Baltic Sea and the North Sea.
- 2) Beach nourishment and fill for construction purposes and land reclamation accounts for much of the increased quantities extracted. Use for concreting has remained fairly static.
- 3) Sand and gravel reserves are not evenly distributed. The reserves of coarse marine aggregates must be considered as finite and this applies also to sand reserves in the Baltic Sea. Fine sand reserves in the North Sea and adjacent areas are abundant.
- 4) Improvements in dredging technology and the ready availability of more accurate and reliable navigation systems such as Differential Global Positioning Systems enables more efficient recovery and effective management of resources.
- 5) Most countries reported increasing concerns about the extraction of aggregate from the land and the sea. The sustainable use of finite reserves is seen as a key issue for the future.
- 6) There are no realistic alternatives to the use of marine aggregate material for most beach recharge and major coastal reclamation schemes. Strategic planning for these uses is essential for the future supply of suitable materials.

2.2.6 Recommendations

- 1) ICES Member Countries should be encouraged to supply information about their marine aggregate industries.
- 2) The dredging industry should continue to improve dredging technology and the sustainable management of these valuable sand and gravel reserves.

3

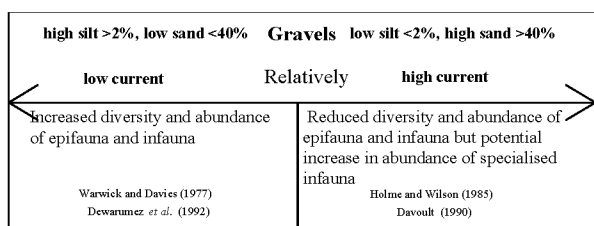
THE EFFECTS OF EXTRACTION ACTIVITIES ON LIVING RESOURCES AND FISHERIES

3.1 The Natural Environment of Marine Aggregates

Marine sediments are influenced by many processes, both physical and biological. Of the physical forces, the effects of tidal currents and waves are the most significant. The action of tides and waves may transport and sort the sediment which, in part, will determine the structure of the associated benthic community. In areas where the tides are weak and exposure to wave action low, suspended inorganic particles may settle out and accumulate, resulting in predominantly muddy sediments. Physically stable fine sediments tend to be dominated (in term of biomass) by deep burrowing infaunal organisms that rework the sediment. They, in turn, will have the greatest physical effect on the structure and stability of the sediment (Rhoads and Boyer, 1982). However, in areas subjected to strong tidal currents and surface waves with increased height and period, the seabed sediments may become suspended, transported, sorted, and redeposited. The resulting increase in sediment transport may, in some areas, be large enough to have a major influence on the structure of the benthic community (Rees *et al.*, 1977). In order to understand the ecology of macrobenthic communities, it is essential to appreciate the nature and scale of the natural physical processes that act upon them. Although wave effects are cited as the source of most sediment disturbance on continental shelves (Hall, 1994), the effects of tidal currents, arguably, are of greater significance in determining the long-term macrobenthic community structure.

Coarse marine aggregate in its natural state exists as a mixture of sand, gravel, shell, and mud in various proportions. Given this large sediment heterogeneity and the variations in exposure to tide and wave stresses, it is not surprising that the macrofauna associated with coarse aggregate is extremely variable both within and between regions (Kenny *et al.*, 1991). Under certain conditions of reduced tidal flow with increased amounts of fine sediment, gravels are capable of supporting a highly diverse and productive macrofauna (Dewarumez *et al.*, 1992). By contrast, an aggregate with a relatively high proportion of sand exposed to strong nearbed currents supports only an impoverished sessile epifauna (Holme and Wilson, 1985; Kenny *et al.*, 1991), although a specialised infauna adapted to living in a mobile sandy sediment may develop. Alternatively, when the proportion of sand in the aggregate is low, a relatively diverse epifauna may develop even under conditions of high nearbed currents (Davoult, 1990; Holme and Wilson, 1985), although the lack of fine sediment may result in a much reduced infauna (Davoult, 1990). The following text figure summarises the main community attributes which

may develop under the physical extremes of disturbance referred to above.



It is recognised that the local hydrodynamics, which play an important role in determining the behaviour and stability of the sediment, are a major factor governing the composition of the macrobenthos. Gray (1974) argued that sediment sorting, as a measure of structural complexity, may be a determinant of species diversity. Therefore, a greater species diversity would be found on those sediments which are poorly sorted (i.e., those apparently exposed to less severe hydrodynamic conditions) because a wider variety of particle types are available for utilisation by the benthos. For example, coarse particles are likely to be important in determining the available space for settlement by sessile epibenthic suspension feeders such as hydroids and bryozoans and, to a lesser extent, certain ascidians, polychaetes, molluscs, and crustaceans. On the other hand, the percentage silt/clay fraction within the sediment may be important in determining the type and abundance of food resources for deposit-feeding animals such as *Abra alba*. In conclusion, coarse aggregate has the potential to support a large number of species as a result of its structural complexity. However, it has been recognised that in some areas the abrasive effects of sand shifting under strong tidal currents coupled with the effects of wave disturbance during storms may result in an impoverished community. This has been observed for coarse aggregate deposits off Lowestoft (Kenny *et al.*, 1991) and in certain areas of the English Channel (Holme and Wilson, 1985).

3.2 Regional Variability of Marine Aggregate Fauna and Flora

3.2.1 Fauna

A great deal of the early work on gravel communities was undertaken in the English Channel. For example, Ford (1923), at the Plymouth Laboratory, described the fauna of shell-gravel deposits off the Eddystone rock, which was followed by a rare quantitative survey undertaken by Holme (1953). More recently, wide-scale surveys of the western and central English Channel have been carried out by Holme (1961, 1966) and Cabioch (1968), and in the eastern English Channel by Davoult *et al.* (1988), Davoult (1990), and Dewarumez *et al.* (1992). They identified a number of communities that were closely related to the physical environment. Similarly, the results from a wide-scale survey of the Bristol Channel (Warwick and Davies, 1977) allowed a definitive relationship to be established between the prevailing tidal conditions and the resultant sedimentary and community characteristics

(Warwick and Uncles, 1980). On a more local scale, studies off the Isle of Wight (Lees *et al.*, 1990; Collins and Mallison, 1983, 1989), Hastings (Rees, 1987), Dieppe (Desprez, 1992), Southwold (Millner *et al.*, 1977), North Norfolk coast (Hammond, 1963; Kenny and Rees, 1994, 1996), Lowestoft (Kenny *et al.*, 1991), and central English Channel (Holme and Wilson, 1985) have provided descriptions of the biology of coarse aggregate deposits, either in their natural state or in relation to the impact of marine aggregate extraction.

The work of Holme and Wilson (1985) provides an excellent account of the epifauna typically associated with a “clean” coarse aggregate subjected to varying degrees of tidal scour by sand. Examples of these conditions can be found in many areas of commercial gravel including those sampled by Kenny *et al.* (1991) and Desprez (1992). They surveyed an area (about 6 km²) in the north central English Channel, using underwater TV cameras, which provided a description of three major community types. The *type A* community consisted of a stable epifauna with a diverse sponge, hydroid, ascidian, and bryozoan cover which was present on bed rock, pebbles, and cobbles. This community developed in areas where the substrate had not been scoured by sand or gravel and had remained stable for a considerable number of years. The *type B* community was again present on cobbles and pebbles but was subject to periodic scour and submergence by sand. Three sub-types of the *type B* community were identified. The first (*B-1*) was defined as a “well-developed faunal assemblage with *Polycarpa violacea*” and was noticeably different from *type A* on account of the paucity of sponges. The second (*B-2*) was subject to considerable sand scour and periodic submergence by sand and gravel. Sponges were absent, as were various bryozoans, notably *Pentapora foliacea*, which had been replaced by the more “robust” *Flustra foliacea*. The third (*B-3*) community was defined as an “impoverished *Balanus* - *Pomatoceros* assemblage”. It was found on hard substrates which were frequently scoured and submerged by sand and gravel. The fauna was restricted to fast-growing colonisers which could establish themselves in the short periods of physical stability during the summer months. The third major type of community, *type C*, was described as a “cobble floor covered by sand”. The dominant animals present were members of the *type B-2* community, namely *Urticina felina*, *Flustra foliacea*, and *Sabellaria spinulosa*.

By contrast, gravels that are not subjected to tidal scour by sand and gravel, but contain a greater proportion of fine sediment, will favour the development of a diverse and abundant macrofauna (Dewarumez *et al.*, 1992; Warwick and Davies, 1977; Kenny *et al.*, 1991). Under these conditions the horse mussel, *Modiolus modiolus*, may be present in densities large enough to give rise to a “*Modiolus*” community (Davoult, 1990; Dewarumez *et al.*, 1992; Warwick and Davies, 1977; Roberts, 1979). Although Warwick and Davies (1977) point out that *Modiolus* may be found on a wide range of bottom types, it was their “mixed ground *Modiolus* community” which best describes the macrofauna associated with a muddy, gravelly sand. Dewarumez *et al.* (1992) described a “pebbles community with muddy faces” in which

Modiolus and *Pisidia longicornis* (another species typically associated with the *Modiolus* community and, in particular, the foliose erect bryozoan *Flustra foliacea*: Stebbing, 1971) had a percentage mean abundance (PMA) of 0.8 and 7.5, respectively. Davoult (1990) described a “*Modiolus modiolus* facies” in which both *Modiolus* and *Pisidia* had a much greater PMA, 34.4 and 18, respectively. Whilst for a community off North Norfolk, Kenny *et al.* (1991) observed a PMA of 13.6 for *Modiolus* and 18.5 for *Pisidia*. Although these figures indicate a potentially large variation in the PMA of *Modiolus* and *Pisidia*, there is nevertheless a great deal of similarity between the communities in terms of their overall species composition.

In general, it would appear that macrobenthic communities associated with relatively clean (< 5 % fines) “commercial” gravel deposits are dominated by either large densities of short-lived (one to three years) *r*-strategists such as *Dendrodoa grossularia*, *Balanus crenatus*, *Abra alba*, *Pomatoceros* sp. and *Lagis koreni*, or are relatively impoverished, supporting few individuals and numbers of species. The exceptions to this are stable deposits of gravel and cobbles which support a “luxuriant” growth of colonial epifauna (mainly sponges, hydroids, and bryozoans) as observed in Lyme Bay (Greening and Kenny, 1996) and other parts of the English Channel (Holme and Wilson, 1985). So far there has been very little interest in exploiting deposits in these areas, although where they coincide with beds of maerl, as observed in Lyme Bay off southern England, or have other conservation value, their commercial dredging would cause concern or be prevented.

Given that the majority of aggregate deposits of commercial value are located in nearshore environments, subjected to frequent natural disturbance, it is not surprising that the macrobenthic communities are maintained at an early developmental stage (i.e., one that is dominated by *r*-strategists; Osman, 1977). The ability of a community dominated by *r*-strategists to withstand a disturbance and quickly return to the pre-dredged condition will be high. Such community attributes have been defined as “resistance” and “resilience” (see May, 1975; Boesch and Rosenberg, 1981). For example, a community may resist an initial disturbance because it is dominated by “robust” individuals, but once changed it may also recover relatively quickly (i.e., the community is resilient). In a community dominated by individuals which are long-lived (> 5 years) and have large biomass, as represented by the *Modiolus* community, the initial resistance to certain types of physical disturbance (such as storms) may be high. However, *Modiolus* is unlikely to resist the primary impacts of dredging. Once mortality occurs, the ability of the community to recover is limited by the time required for the biomass dominants, present before disturbance, to settle and grow, a process which may take several years.

3.2.2 Flora

The most common species of benthic vegetation found associated with sandy bottoms in coastal areas of the

Baltic Sea, the Mediterranean, and the Wadden Sea are *Zostera* sp., *Posidonia* sp., *Ruppia* sp., and *Potamogetum* sp. Stony reefs, found in the Baltic Sea within sandy bottoms, tend to be colonised by various species of green, red and brown algae, such as *Cladophora* sp., *Ceramium* sp., and *Fucus* sp.

The macrophytes provide an important habitat resource for many other organisms such as benthic invertebrates, fish, and birds. For example, many fishes utilise the algae for shelter and food, and as a spawning habitat. Macrophytes are sensitive to changes in light intensity and oversanding. Species of perennial fucoid (*Fucus* sp.) and eelgrass (*Zostera*) are the algae thought to be the most in decline.

Seagrasses (*Zostera marina* and *Z. noltii*) have been recorded in the Dutch Wadden Sea for many centuries. The closure of the Zuiderzee in 1932 (now Yessel Lake) coincided with an outbreak of disease in the seagrass beds. The disease seems to be correlated with abnormally high summer temperatures. Current research is trying to establish factors which are important for the growth of seagrass beds and identify potential areas suitable for the species. The occurrence and disappearance of seagrasses seem to be cyclical, however, Dutch seagrass beds are still well below levels recorded in 1932 when estimates of about 15, 000 ha. of seagrass were recorded. The present area of seagrass is estimated to be between 500–1000 ha. Similarly, the Danish and the German seagrass beds in the Wadden Sea are also thought to be in decline.

3.3 Environmental Effects of Dredging

As a result of the large number of maintenance and beach recharge projects throughout the world, particularly in the USA, a substantial literature exists on the environmental effects of dredging. Yet the majority of these studies describe fine-sediment community responses which are not directly applicable to impacts on gravel. Specific examples are provided by Pagliai *et al.* (1985), Johnson and Nelson (1985), McCauley *et al.* (1977), Taylor and Saloman (1968), van Dolah *et al.* (1984), van der Veer *et al.* (1985), Poiner and Kennedy (1984), Kaplan *et al.* (1975), Jones and Candy (1981), and many others. General reviews on the environmental impacts of suction-hopper dredging are provided by Johnston (1981), Hurme and Pullen (1988), de Groot (1979, 1986), Gayman (1978), Kranck and Milligan (1989), and Nunny and Chillingworth (1986), but again these largely concern effects on soft sediment communities.

By contrast, there have been very few studies describing the biological effects of marine gravel extraction. This lack of research is understandable when one considers the small number of countries possessing exploitable gravel resources. The United Kingdom is one of the world's largest producers and consequently has been responsible for much of the environmental research. During the 1970s, the Ministry of Agriculture, Fisheries and Food (MAFF) examined the impacts of suction-anchor dredging on Hastings shingle bank in the English Channel (Shelton and Rolfe, 1972; Dickson and Lee, 1972), while Millner

et al. (1977) examined the impacts of suction-trailer dredging off Southwold in the southern North Sea. More recently, Lees *et al.* (1990) reported on the impacts of suction-trailer dredging at a licensed extraction area off the Isle of Wight.

However, due to difficulties of sampling coarse sediments, the above studies were unable to quantify accurately the initial impacts of marine aggregate extraction on the benthos. A notable exception was a controlled dredging study off North Norfolk, which was initiated in 1992 to investigate the processes of recolonisation upon cessation of dredging (Kenny and Rees, 1994, 1996). Also, the effects of aggregate extraction were quantitatively examined on the Klaverbank, in the southern North Sea, undertaken by Dutch scientists (van Moorsel and Waardenburg, 1990, 1991; van Moorsel, 1993). Both the British and Dutch studies used quantitative sampling techniques before and after dredging to describe the physical and biological impacts.

3.4 Nature of the Physical Effects

The choice of dredging method will largely determine the nature of the impact on the seabed. For example, cutter-suction, bucket, clamshell grab, and anchor suction dredgers are used mainly for capital or maintenance projects, and this type of dredging will tend to create both wide (75 m) and deep (20 m) pits on the seabed. By contrast, the most common form of dredging of marine aggregates in Europe is suction-trailer hopper dredging (Dickson and Lee, 1972; de Groot, 1979). Suction-trailer hopper dredging extracts the deposit by suction through one or two backward-directed pipes. It has been observed, at present, that each one dredges on average 20 cm to 30 cm deep and up to 2 m wide. Using this method of dredging large areas of seabed can be covered, removing a thin upper layer of sediment across an entire area.

For both types of dredging, aggregate and water are piped aboard the dredger into a hopper, where the aggregate displaces the water which then overflows back to the sea, carrying with it suspended sediment that generates a turbidity plume in the water column. Occasionally, screening of the aggregate is required to maintain a specific sand-to-gravel ratio in the cargo. In this instance, increased quantities of either coarse or fine aggregate will be discharged back to sea.

There are three sources of physical disturbance arising from dredging which may have an impact on the biota; these are: 1) substrate removal and alteration of the bottom topography; 2) creation of turbidity plumes in the water column; and 3) plume deposition on the seabed. Each of these is briefly described below.

3.4.1 Substrate removal and alteration of the bottom topography

The most obvious impact of dredging is the removal of substrate, which alters the topography of the seabed. Once

created, infill of these pits, or furrows, is dependent upon the natural stability of the sediment. The erosion of dredge tracks in areas of relatively low wave exposure and reduced tidal currents may take between three and seven years (Eden, 1975; Millner *et al.*, 1977; Kenny and Rees, 1996; Essink, 1998); however, in areas where the sediment (mainly sand) is more mobile, the erosion of tracks may occur in less than one year. At an experimental dredge site off Norfolk (Kenny and Rees, 1994, 1996), in 25 m of water, dredge tracks were completely eroded within three years.

Long-term dredging of an area may result in the seabed being significantly lowered in relation to the surrounding seabed (Dickson and Lee, 1972; Norden Andersen *et al.*, 1992; Winterhalter, 1990; Desprez, 1996). The consequence of a significant change in bathymetry is the potential for a localised drop in current strength, resulting in the deposition of finer sediments (Kaplan *et al.*, 1975; Hily, 1983; van der Veer *et al.*, 1985; Desprez and Duhamel, 1993) which may result in a localised depletion of oxygen (Norden Andersen *et al.*, 1992; Bonsdorff, 1983).

3.4.2 Impact of turbidity plumes

Another factor which may have significance for the benthos in the vicinity of dredging is that of sediment re-suspension. The draghead itself can agitate the sediment, causing a noticeable increase in the amount of nearbed suspended solids. However, the outwash from spillways on the dredger generates a far greater quantity of suspended material (Moran, 1991).

The morphology and behaviour of fine sediment plumes, under varying hydrodynamic regimes, have been investigated by Pennekamp and Quaak (1990). Historically, however, there are fewer references to similar studies involving the dredging of non-cohesive material; only very recently have similar studies been performed in connection with major dredging projects such as those currently under way in Hong Kong (Hitchcock and Drucker, 1996) and off the east coast of England (DFR, 1996) and in Denmark (Øresundskonsortiet, 1998a, 1998b).

Plumes of suspended material can arise from three distinct sources, namely: 1) the mechanical disturbance of seabed sediments by the draghead; 2) overspill of surplus sediment/water mixture from the vessel hopper; and 3) the rejection of unwanted sediment fractions by screening.

Plumes associated with the latter two sources have been termed surface plumes and their volume and duration are linked to the particle size of the sediment (mud content) and to the local hydrodynamics (wave and tidal actions).

A recently commissioned study in the UK indicated that the "bulk" of a dredge plume (approximately 80 % of the total discharged sediment by weight is composed of sand-sized particles) collapses to the seabed within a few hundred metres of the dredger. This observation was also made in a recent study of aggregate plume dynamics in

the English Channel by Hitchcock and Drucker (1996). They were able to demonstrate that suspended sediment (> 0.063 mm) decayed to background levels over a distance of 200 m to 500 m from the point of release. Nevertheless, the remaining 20 % of sediment in the plume will largely be composed of particles < 0.063 mm in diameter and this fraction will potentially be dispersed over much greater distances due to the very low settling velocities of these particles. Similar work in Dieppe has confirmed these findings (Desprez, 1997).

The impact of increased sediment resuspension caused by dredging in deposits of clean mobile sands or in areas with high natural background levels of turbidity, such as at the mouth of estuaries, or in high energy areas close to eroding coastlines such as parts of the North Sea and the Bay of Fundy, is arguably of less concern because of naturally high loads of suspended sediment caused by tide and wave action in these areas (Millner *et al.*, 1977). Recent results from analyses of sediment samples taken from Danish marine aggregate areas have shown that the content of fines exceeds 5 % only in a few samples (Nielsen, 1997). Dredging mainly for sand in Dutch coastal waters is expected to cause a maximum turbidity plume of 32 mg l^{-1} , during slack water conditions. However, turbidity levels in excess of this figure, for the same area, were measured during storm conditions (Vink, 1988).

3.4.3 Nature of chemical impacts

During dredging, reducing substances bound in the sediment (e.g., organic matter, sulfides, ammonium) may be released to the water column. In sheltered areas where the content of these compounds in the sediment may be high, a lowering of the oxygen level of the sea water to concentrations that are critical to fish and benthos may occur. However, it should be emphasised that the chemical effects of aggregate dredging are likely to be minor on account of the very low organic and clay mineral content of commercial aggregate deposits. The bulk of sands and gravels that are commercially dredged show little chemical interaction with the water column. In addition, dredging operations are generally of limited spatial extent and only of short duration, which further limits any chemical impact.

3.5 Nature of the Biological Effects

The most obvious impact of sand and gravel extraction is the removal of the substrate and the resulting destruction of the benthic biota. However, not all of the benthos will be retained in the hopper; for example, it was observed during a study of dredger spillway outwash contents that a significant quantity of the dredged benthic fauna was returned back to sea (Lees *et al.*, 1992). Nevertheless, the possibility of any dredged fauna surviving the extraction process and re-establishing itself on the seabed is very unlikely, although such fauna will probably provide a very valuable source of food for scavenging benthic invertebrates and fishes.

The Dutch studies of van Moorsel and Waardenburg (1990, 1991) and van Moorsel (1993) showed that, soon after dredging, a reduction had occurred in the abundance (70 %), biomass (80 %) and, to a lesser extent, the number of species (30 %). The large reduction in biomass was attributed to a loss of large molluscs, particularly *Arctica islandica* and *Dosinia exoleta*. They concluded that while the densities and number of species returned to pre-dredged levels within one year, the biomass had not recovered some two years later. These findings were supported by work carried out in the UK which examined the biological and physical responses following a controlled dredging event off North Norfolk (Kenny and Rees, 1994, 1996). The trends observed for the densities and numbers of species during the above studies are also supported by research carried out elsewhere. For example, in areas where sediment transport was high, due to strong tidal currents or wave action, the community had recovered within one year of dredging (Pagliai *et al.*, 1985; Johnson and Nelson, 1985).

Results obtained by Johnson and Nelson (1985), McCauley *et al.* (1985), and van Dolah *et al.* (1984) showed that within a few weeks of dredging, significant reductions in animal densities were observed, although the numbers of species were unaffected. A possible explanation for the latter observation was provided by Hall *et al.* (1991), who suggested that a likely pathway for early post-dredging recolonisation was by passive translocation of animals during storms. Indeed, the presence of adult infauna in a channel within hours after dredging was noted by van Dolah *et al.* (1984). He concluded that their presence was due to sediment sliding down the walls of the dredged channels from nearby unaffected areas.

It seems likely that many species are capable of being transported naturally by small-scale sediment disturbances (Rees *et al.*, 1977; Hall *et al.*, 1991; van der Veer *et al.*, 1985; van Dolah *et al.*, 1984). However, large-scale disturbances are most likely to be species-selective (Rees *et al.*, 1977). These disturbances could involve a large amount of sediment being transported for a short time (storms) or, indeed, a smaller amount of sediment being transported over longer periods (tides). Both types of disturbance may result in a reduced and specialised fauna more resilient than a diverse or "biologically accommodated" fauna (Boesch and Rosenberg, 1981). Species characteristic of a community subjected to large-scale physical disturbances are likely to utilise passive translocation as a major strategy for colonisation of new habitats (van der Veer *et al.*, 1985). Maurer *et al.* (1981a, 1981b) carried out experiments on the lethality of sediment overburden on selected macro-invertebrates. They concluded that many motile epibenthic and infaunal animals could withstand a light overburden of sediment (about 1 cm), especially when the overlying sediment was native to their habitat. They also found that increased depth and frequency of burial caused greater mortality, a finding confirmed in Dieppe studies (Desprez, 1997). In addition, mortality was linked to water temperature, such that mortality was greater during the summer months than in the winter.

Another factor which may have significance for the benthos in the vicinity of dredging is that of sediment resuspension. The draghead itself can agitate the sediment, causing a noticeable increase in the amount of nearbed suspended solids. However, the outwash from spillways on the dredger generates a far greater quantity of suspended material (Moran, 1991). The effect of suspended inorganic particles on aquatic marine life has been reviewed by Moore (1977) and Newcombe and MacDonald (1991). Marine benthic invertebrates vary greatly in their tolerance to the amount and type of suspended solids (Newcombe and MacDonald, 1991) but there seems to be some correlation between the normal habitat of the species and its sensitivity to suspended particles (McFarland and Peddicord, 1980). Hard-bottom communities tend to be dominated by epibenthic grazers and suspension feeders which are generally more sensitive to excessive amounts of suspended sediment (McFarland and Peddicord, 1980). Suspension-feeding organisms may be stressed by the abrasive effects of sediment passing over their feeding and respiratory structures. In addition, surface grazers and deposit-feeders may be sensitive to changes in the composition of the microscopic fauna found on the surface of stones and shells (e.g., diatoms, bacteria, and protozoa commonly known as the “microbial film”) since this often constitutes a major part of their diet (Turner and Todd, 1991).

In Denmark for the Øresund project the total amount of spill was limited to 5 % of the total dredged sediment. The EIA model predictions indicated a decrease in eelgrass of around 25 % due to shading from suspended material. Subsequent monitoring showed an actual decline of around 15 % (Øresundskonsortiet, 1998a, 1998b). In the Spanish sub-project of RIACON at the Costa Durada in the Mediterranean, special attention was given to the *Posidonia* (seagrass) community which formerly extended down to 23–24 m, but which now has a narrower depth range. The authors of the report of this study concluded that there is no risk to the seagrass due to dredging activities in the Mediterranean as long as a minimum distance of 1–2 km is maintained (Essink, 1998).

Apart from the impact on adult organisms, a change in the biological and physical composition of the sediment may hinder the settlement of benthic larvae. It has been shown that the presence of a microbial film induced settlement of certain sessile invertebrates such as barnacles (Rodriguez *et al.*, 1993). Any change in the composition or biomass of the film may therefore reduce their potential for settlement. In addition, it has been shown that bed roughness, and composition and texture of the sediment are important factors for larval settlement (Crisp and Barnes, 1954), all of which may be affected by dredging which, in turn, may also alter the types of species which colonise the area.

3.5.1 The “role” of macrobenthos

The organisms which live on or within the seabed are collectively called benthos. In addition, animals which are occasionally associated with the seabed, like cod (*Gadus morhua*), may also be considered as part of the benthos.

Benthic organisms are generally described on the basis of their size and location within the sediment. Peterson (1914) was one of the first people to call benthic organisms which live within the sediment “infauna” and those which live on the surface of the sediment, either attached or free living, “epifauna”. The division of benthos into broad size categories is also useful, particularly when considering the functionality of marine ecosystems. Mare (1942) proposed three size classes: 1 µm to 100 µm (protozoans), 100 µm to 1000 µm (meiofauna), and >1000 µm (macrofauna). Frequently, a 500 µm sieve has also been used to collect specimens of macrofauna since (*inter alia*) this has the advantage of being able to identify temporal trends in the abundance of juveniles (Rees, 1984). However, there are costs associated with using a finer mesh size, notably an increase in the time required to identify small animals in the laboratory and the extra effort needed to sieve samples at sea.

Macrobenthos may have a significant role in coupling the benthic and pelagic ecosystem processes (Sullivan *et al.*, 1991; Buchanan, 1993). For example, it has been shown that the benthos may have an important role in the cycling of carbon and nutrients (Zeitzschel, 1980), while the larvae of many species of macrofauna may influence the structure of planktonic food webs (Young and Chia, 1987). The macrobenthos also provides an important source of food for demersal fish populations (Daan *et al.*, 1990). For example, on Georges Bank (Northwest Atlantic) it was found that the benthos contributed both directly and indirectly to highly productive fisheries of shellfish and bottom-feeding fish such as cod, haddock, and various flounders (Cohen *et al.*, 1980; Sissenwine *et al.*, 1984). Jones (1984) estimated that over 52 % of the primary diet of the demersal fishery in the North Sea was composed of macrobenthic invertebrates. On Georges Bank, macrobenthic invertebrates supported over 70 % of the demersal fishery. Therefore, it is clear from these studies that the benthic invertebrate biomass can provide a vital source of food for commercial fishes.

3.6 Case Studies of the Environmental Responses to the Effects of Dredging

3.6.1 CNEXO experimental study site (France)

The CNEXO (Centre National pour l'Exploitation des Océans) site is located 7 n.m. off Le Havre in the Bay of Seine. Some fifteen years after the cessation of dredging, a side-scan sonar survey of the area clearly showed a pit where the dredging had taken place, indicating that the natural processes of erosion and in-filling were very slow. The following three processes are regarded as the most likely causes regulating the in-filling of the dredged site (Auffret, 1997):

- lateral erosion of sediment (heterogeneous aggregates) sliding down the walls;

- intrusion of sands from the surrounding area;
- local and seasonal mud deposition.

The rate of infilling is thought to be directly linked to the morphology and nature of the seabed. For example, in the western part of the site, the morphology of the excavated area is narrow and deep (12 m below the seabed level). This has the effect of canalising the tidal currents which, in turn, prevents any sedimentation. By contrast in the eastern part, the dredged area is much wider and not so deep (five m below the seabed level). The tidal currents in this part of the dredged site are not so strong and deposits of fine sediment have accumulated on the seabed.

Observations of the seabed using underwater TV revealed that the deposits of fine sediment were restricted in thickness to 25 cm deep and that the underlying strata is composed of a hard clay, as evidenced by the occasional outcrops of this material. In addition, the survey revealed the presence of fish (dab, haddock, dragonet), cuttlefish, and crustaceans (swimming and edible crabs) under the outcrops of clay, whereas hermit and spider crabs dominated in the more silty sand areas.

Quantitative macrobenthic sampling using a Hamon grab at ten stations inside and outside the eastern part of the dredge site showed the following (Desprez, 1996):

- 1) The mean depth within the dredge area is 4.5 m lower compared to the surrounding seabed;
- 2) Sediments are five times more silty within the dredged site;
- 3) The benthic community is two to three times richer within the dredged area measured in terms of number of taxa, abundance, and biomass;
- 4) Mud-dwelling species are dominant within the site, whereas the surrounding seabed is dominated by sand-dwelling species;
- 5) The dominant macrobenthic groups, measured in terms of density and biomass, are amphipods and sea-urchins within the site, whereas the surrounding seabed is dominated by polychaetes and holothuroids.

Following dredging, the original homogeneous sandy sediment was replaced by a heterogeneous muddy substrate. Accordingly, an increase in habitat diversity was observed which has favoured an increase in the richness of benthic macroinvertebrates and fishes alike.

3.6.2 Dieppe recolonisation study (France)

This site, located three nautical miles off Dieppe along the French coast of the eastern English Channel, has been dredged since 1980. Cessation of dredging in the western part of the site occurred in 1994. This provided an opportunity to study the recolonisation of the seabed after dredging and surveys were conducted in 1996 and 1997 (Desprez, 1997).

Ten stations were sampled in and around the former dredged site using a Van Veen grab. The design of the survey was as follows:

- 1) Five control stations, located inside the extraction area, were monitored from 1993;
- 2) Three reference stations were selected to provide information on natural fluctuations of benthic communities from 1986;
- 3) Two stations, located close to the eastern part of the site, were sampled in 1996 and 1997 to quantify the potential impacts of deposition by overflow sediment.

Bedform analysis showed a disturbed topography with large furrows (about 5 m deep) separated by crests of coarse sediment, predominantly shingle. The furrows were partially filled in with sand, which was thought to have originated from the dredger overflow discharge of sand. The sand is transported across the site as a result of the prevailing strong tidal currents which characterise the area (about 1 m s^{-1} during spring tides).

Analysis of the sediment granulometry showed the following: 1) in the dredged area, sediments typically had a bimodal distribution with a dominant coarse gravel/shingle fraction and a fine sand fraction, with a notable proportion of very fine sands; 2) sediments sampled in the reference area also had a bimodal distribution, but without the dominance of fine sands; and 3) in the area most affected by the deposition of dredged plume material, sediments were largely dominated by fine sands, with the outer limit of the affected area characterised by slightly muddy gravels.

Biological monitoring of recolonisation took place in 1996 and 1997, about sixteen and 28 months following the cessation of dredging. It was concluded from the biological analyses that:

- 1) The number of taxa had fully restored to pre-dredged levels in 1996, about 16 months after dredging;
- 2) The densities of macrofauna had reached 56 % of the reference site values in 1996 and this state of recolonisation had stabilised in 1997, with a measured abundance of 58 % of the reference site level;
- 3) The biomass restored to 35 % of the reference site value in 1996 and continued to increase in the second year to 75 % in 1997.

These three parameters indicate that about 28 months after cessation of the dredging, recolonisation had nearly restored the area to its pre-dredged status, except for the densities of animals which remained much reduced.

The following general observations were made: 1) in the western part of the dredged area site, where intrusion of mobile coarse sands was occurring, the new community was dominated by several species characteristic of the reference area, such as the echinoderm *Echinocyamus*

pusillus and the polychaetes *Polycirrus medusa*, *Notomastus latericeus*, and *Syllis* sp.; and 2) in the eastern part, characterised by shingles and fine sands, the community was dominated by some opportunistic species of sessile polychaetes, such as *Pomatoceros triqueter*, and hydroids. Also found were motile epibenthic crustaceans such as *Pisidia longicornis* and *Galathea intermedia*, and these were accompanied by some sand-dwelling species such as the amphipods, *Urothoe elegans* and *Cheirocratus sundevallii*, and the polychaetes, *Spiophanes bombyx* and *Nephtys cirrosa*.

In the deposition area, largely dominated by clean fine sands (more than 60 %), the community was characterised by the annelids *Spiophanes bombyx*, *Nephtys cirrosa*, *Ophelia bicornis*, the bivalve *Tellina pygmaea*, and the amphipod *Urothoe brevicornis*.

Twenty-eight months after the cessation of dredging, it was possible to distinguish a complete gradient of increasing effect from west to east, with no impact detected in the western area and maximal impact in the east.

3.6.3 North Norfolk experimental dredge site (United Kingdom)

In October 1990, a study jointly sponsored by the Crown Estate Commissioners (CEC) and the Ministry of Agriculture, Fisheries and Food (MAFF) was given the task of quantifying the impacts of commercial aggregate dredging and examining the rates and processes of recolonisation post-dredging.

An offshore experimental dredging study was initiated off north Norfolk (UK) in 1992 to investigate the impacts of marine gravel extraction on the macrofauna. A dredged "treatment" site and a non-dredged "reference" site were selected to evaluate the initial impacts and subsequent processes of recolonisation. A survey of the benthos was conducted prior to the removal of 50,000 tonnes of marine aggregate from the treatment site. Thereafter, annual monitoring surveys were conducted commencing immediately after the dredging episode.

It was shown by Kenny and Rees (1994) that natural processes of recolonisation proceeded rapidly after the cessation of dredging and that substantial progress was made towards recovery within the first twelve months following dredging, particularly when measured in terms of the densities and numbers of species. However, the community differed substantially from its pre-dredged state on account of a much reduced biomass at the end of the two-year sampling period. A possible explanation for this is given below.

Before dredging, the macrobenthic community at the treatment site had few biomass dominants. Indeed, some 90 % of the community abundance and 70 % of the community biomass were attributed to just two species, namely *Dendrodoa grossularia* and *Balanus crenatus*, both having small individual body size and life-history traits characteristic of opportunistic or *r*-selected species

(Pianka, 1970). Given that both of these organisms were dominant before dredging and that they recolonised quickly post-dredging, it would seem likely that the community was already exposed to a certain amount of natural physical disturbance. However, evidence from side-scan sonar records and underwater cameras indicated that a considerable amount of sediment transport had occurred during the first two winters following dredging, such that the once well-defined dredge tracks had become infilled with sand and gravel. This source of natural disturbance (post-dredging) is considered to be responsible for maintaining the community at an early developmental stage, dominated by newly settled organisms (mainly *Dendrodoa* and *Balanus*) with low individual biomass.

It was shown that two years after dredging (Kenny and Rees, 1996) complete physical recovery had not been achieved, although there was evidence (from side-scan sonar and sediment particle size analysis) to suggest that significant progress had been made towards this end. However, it was predicted that a return to the pre-dredged physical state would result in a reduction in the rates of mortality of *Dendrodoa* and *Balanus*, and would therefore contribute greatly to an increase in the community biomass, due to their potential for rapid recolonisation and growth and the results of the present study in 1995 suggest that this has indeed occurred, as evidenced by the significant increase in biomass.

In addition, continued sampling for at least an additional two years (1996 and 1997) at the experimental site will ensure that the observed increase in community biomass is persistent and consistent with observations made at the reference site and with the biological model of response.

3.6.4 Klaverbank study (Netherlands)

In order to study the effects of marine gravel extraction on the benthic macrofauna, an experimental study was initiated on the Klaverbank in 1989 (van Moorsel, 1994; Sips and Waardenburg, 1989). Samples of sediment were collected using a Hamon grab for an assessment of the macrofauna and an analysis of particle sizes before, immediately after, and then annually for the first two years following dredging. Both the number of species and their densities were reduced substantially following dredging, by 30 % and 70 %, respectively. In addition, the biomass was also reduced significantly, by 80 %, due mainly to the removal of large bivalve molluscs. Within eight months following dredging both the densities and number of taxa had recovered, however, the biomass remained much reduced compared to its pre-dredged state, even two years after dredging.

3.6.5 RIACON Project (Netherlands, Denmark, Germany, Belgium, and Spain)

Between 1994 and 1996, the Risk Analysis of Coastal Nourishment Techniques (RIACON) project was carried out to evaluate the risks of shoreface nourishment and

sublittoral sand extraction on the benthic communities (Essink, 1997; van Dalen and Essink, 1997). In the North Sea borrow sites, sand extraction caused a reduction in species abundance and biomass. Nonetheless, post-dredging monitoring indicated a rapid increase in the abundance of an opportunistic polychaete species, *Spio filicornis*, within the first year. However, the abundance and biomass of longer-living bivalves and echinoderms have not returned to pre-dredged levels, particularly at the borrow site north of Terschelling (van Dalen and Essink, 1997). Similarly, at the Mediterranean borrow site, a significant increase in opportunistic polychaetes (*Capitella capitata*, *Malacoceros* sp.) was observed.

3.6.6 Kriegers Flak (Denmark)

The Kriegers Flak (western Baltic) is an area of 6.7 km² used by the Øresundskonsortiet for the supply of sand for the fixed link project between Denmark and Sweden. The quantity of sand extracted by trailing suction dredgers (in water depths of 20–22 m) in 1996 was 300,000 m³ and this had increased in 1997 to 600,000 m³. The quantity of sediment spilled in the water column from dredging was 2.7 % (by mass) of the total amount extracted. This material consisted mainly of very fine sand with a small amount of silt and clay. Environmental impacts are accepted in an impact area of 1 km around the dredging area; beyond this no impacts are acceptable. The benthic fauna at Kriegers Flak is a densely populated *Macoma* community dominated by a few species of polychaetes, bivalves, gastropods, and crustaceans. The structure of the benthic community depends on the water depth, the composition of the sediment, and the occurrence of the common mussel *Mytilus edulis*. Investigations of the sediment composition in 1995 showed an increase in the silt/clay content. Immediately following dredging in 1996 a significant reduction in the abundance and biomass of macrofauna in the dredged area was noted, owing to a decrease in abundance of *Mytilus edulis*. This was followed by an increase in both abundance and biomass in subsequent years. However, a large fluctuation in the biomass was observed at the reference site. This was considered to be attributed to natural variations in the recruitment success of, e.g., *Mytilus edulis* and not to changes in the sediment caused by the settlement of fines from dredging (Øresundskonsortiet, 1998a, 1998b).

3.7 Summary of Impacts and Ecological Response

A model of macrobenthic community response to the effects of dredging is now emerging. The response may be divided into three phases, namely, **phase i**, an initial recolonisation by the dominant taxa present before dredging. These animals are predominantly opportunistic in behaviour and they contribute significantly to an increase in the overall abundance and total numbers of species during the first few months following the cessation of dredging. **Phase ii** is characterised by a low community biomass which may persist for several years. This may be caused by increased amounts of sediment (mainly sand) in transport which is also responsible for

the erosion of dredge tracks, infilling of dredge pits, and the scouring of the epibenthos. In time (after about two years at the Norfolk site), the sand transport reaches the pre-dredged equilibrium state, which results in **phase iii** of the recovery, which is characterised by a significant increase in the community biomass.

Clearly, the same biological and physical responses to dredging as observed in the above studies cannot be assumed to occur elsewhere, i.e., the findings are site specific. Nevertheless, it may be concluded that dredging of “commercial” sand and gravel deposits in areas of relatively high natural disturbance, e.g., off the east coast of England (Kenny *et al.*, 1991) and off Dieppe in the English Channel (Desprez, 1997), may be of little long-term (i.e., three years) biological “significance” due to the potential speed of physical and biological recovery following dredging. This conclusion clearly has wider implications for the environmental assessment of aggregate dredging, and therefore requires further validation by quantitative field sampling at these and other locations.

4 MANAGEMENT

4.1 Regulatory Policies

4.1.1 Resource management/planning

In many ICES Member Countries, sand and gravel dredged from the seabed makes an important contribution to the national demand for aggregates, directly replacing materials extracted from land-based sources. This reduces the pressure to work land of agricultural importance or environmental value and, where materials can be landed close to the point of use, there can be additional benefits of avoiding long-distance over-land transport. Marine dredged sand and gravel is also increasingly used in flood and coastal defence, and land reclamation schemes. For beach replenishment, marine materials are usually preferred from an amenity point of view, and are generally considered to be the most appropriate economically, technically, and environmentally.

However, these benefits need to be balanced against the potential negative impacts of dredging. Dredging activity if not carefully controlled can cause significant damage to the seabed and its associated biota, to commercial fisheries and to the adjacent coastlines, as well as creating conflict with other users of the sea. In addition, current knowledge of the resource indicates that while there are effectively limitless supplies of marine sand, there appear to be more limited resources of gravel suitable for current concrete specifications and for beach nourishment.

Against the background of utilising a finite resource, with the associated environmental impacts, it is recommended that regulators develop and work within a strategic framework which provides a system for examining and reconciling the conflicting claims on land

and at sea. Decisions on individual applications can then be made within the context of the strategic framework.

General principles for the sustainable management of all mineral resources overall include:

- conserving minerals as far as possible, whilst ensuring that there are adequate supplies to meet the demands of society;
- encouraging their efficient use (and, where appropriate, re-use), minimising wastage and avoiding the use of higher quality materials where lower grade materials would suffice;
- ensuring that methods of extraction minimise the adverse effects on the environment, and preserve the overall quality of the environment once extraction has ceased;
- protecting sensitive areas and industries, including fisheries, important habitats (such as marine conservation areas), and the interests of other legitimate users of the sea; and
- preventing unnecessary sterilisation of mineral resources by other forms of development.

The implementation of these principles requires a knowledge of the resource, and an understanding of the potential impacts of its extraction and of the extent to which rehabilitation of the seabed is likely to take place. The production of an Environmental Impact Statement, developed along the lines suggested below (see Section 4.2), should provide a basis for determining the potential effects and identifying possible mitigating measures. There will be cases where the environment is too sensitive to disturbance to justify the extraction of aggregate and, unless the environmental and coastal issues can be satisfactorily resolved, extraction should not normally be allowed.

It should also be recognised that improvements in technology may enable exploitation of marine resources from areas of the seabed which are not currently considered as reserves, while development of technical specifications for concrete, etc., may in the future enable lower quality materials to be used for a wider range of applications. In the shorter term, continuation of programmes of resource mapping (see Section 5) may also identify additional sources of coarser aggregates.

This section summarises the regulatory practices and policies of ICES Member Countries. It provides guidance on the content and preparation of environmental impact assessments, including a summary of approaches by member countries, and it discusses methods of surveillance and monitoring.

4.1.2 Update of legislation and review procedures

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, Department of Quality and Safety

Area of application

Continental shelf, including territorial waters.

Materials

Mineral and non-living resources of the seabed.

Review procedures

Local and public involvement

Department of Quality and Safety informs all local authorities and organisations when a new application is identified.

Role of other government departments or authorities

The Department of Quality and Safety seeks advice from the:

- Ministry of the Environment
- Ministry of Agriculture
- Ministry of Defence
- Ministry of Traffic
- Ministry of the Flemish Community
- Ministry of Foreign Affairs.

Terms and conditions

Ministerial Decree of the Ministry of Economic Affairs contains all conditions and terms put forward by the other ministries, e.g., with respect to safety zones, taxes, avoidance of spawning areas, environmental monitoring, etc.

Royal Decree of the Ministry of Economic Affairs contains the technical conditions for the exploration

related to the Ministerial Decree (permit) mentioned above. This Royal Decree is in an amendment process. Its publication is expected in 1997. The most important change is a mandatory requirement for a black-box on-board all dredging vessels.

Canada

Legislation

Ocean Mining Act: not yet in place. (In July 1998 discussions were initiated to establish a marine mining regime.)

Administrator

Cooperative arrangements between federal and provincial governments.

Area of application

All Canadian offshore and continental margins including Pacific, Atlantic, and Arctic Oceans.

Materials

All mineral resources, excluding hydrocarbons.

Review procedures

Local and public involvement

No information at present.

Role of other government departments or authorities

Proposed consultations with federal and provincial offices of fisheries, environment, transport, defence as well as private industry. Initial discussions are under way.

Terms and conditions

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

Denmark

Legislation

Raw Materials Act, 1997;

Continental Shelf Act, 1979.

Administrator

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

Area of application

Territorial waters and continental shelf.

Materials

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

Review procedures

Local and public involvement

New dredging areas are subject to a Government View Procedure including public and private involvement.

Role of other government departments or authorities

Geological, biological, and archaeological interests are reviewed by the Forest and Nature Agency.

Statements from relevant ministries, e.g., the Ministry of Fisheries and the Coastal Protection Agency are included in the review procedure.

Terms and conditions

General permits are given to a number of individual ships.

Impact assessments are carried out within all proposed dredging areas. Permissions may include spill limits, maximum depth of extraction, dredging periods, quantity, and monitoring requirements.

Extractions of more than 1 million cubic metres per year or 5 million cubic metres in total are subject to the procedure in accordance with the EC Directive 85/337 (i.e., an environmental impact assessment is required).

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 procedure

Same procedure as for territorial waters.

Finland

No new information since 1991.

France

Legislation

Continental Shelf Law, 1968; Related Decree, 1971. New regulations are under development.

Administrator

Ministry of Industrial and Scientific Development (Mines Department). Ministry of Industry, Ministry of the Environment, Public Works Administration and Fisheries Administration are involved in the legislation review.

Area of application

All continental and territorial sea areas.

Materials

All natural resources.

Review procedures

Terms and conditions

Extraction operations are small; no specific environmental regulations are required.

Germany

Legislation

Federal Mining Act, last amended in 1995;

Mining Decree for the Continental Shelf, 1994;

Decree on the Environmental Impact Assessment of Mining Projects, 1990.

Administrator

Inside territorial waters: mining authorities of the Federal States;

Outside territorial waters: chief mining board.

Area of application

Continental shelf, territorial waters.

Materials

All natural resources including sand and gravel.

Review procedures

Other governmental authorities involved

Federal Maritime and Hydrographic Agency

Federal Research Agency for Fisheries

Nature Conservation and Fishery Authorities of the respective Federal States.

Ireland

Legislation

Foreshore Act.

Administrator

Department of the Marine and Natural Resources.

Area of application

Foreshore (between high-water mark and outer limit of territorial waters).

Materials

Intended for coastal protection.

Legislation

Continental Shelf Act, 1968.

Administrator

Department of the Marine and Natural Resources.

Area of Application

Offshore below the low-water mark.

Materials

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

NOTE: Discussions regarding changes in the existing legislation are going on to combine various aspects into one piece of legislation for the offshore areas. No progress to be reported until now.

The Netherlands

Legislation

Sediment Extraction Act, 1965, as amended in 1997.

Administration

Ministry of Transport and Public Works. Administrative costs are met by industry as part of the license fee. Royalties have to be paid to the Ministry of Finance.

Area of application

Dutch territorial waters (12 miles), and the Dutch part of the continental shelf excluding areas of public works (e.g., maintenance and harbour

dredging).

Materials

All sediments, for example, sand, gravel and shell, but excluding hydrocarbons.

Review procedures

Local authorities and public involvement by publication in local newspapers and State Gazette.

Role of other government departments or authorities

Consultations with the Ministry of Agriculture, Nature Management and Fisheries and the 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 produced (e.g., when the extraction area is larger than 500 hectares).

Policy approach

Sand extraction for landfill or beach nourishment is prohibited landwards of the 20 m isobath. Extraction is limited to a maximum depth of 2 m below the original seabed level. Only trailer dredgers are to be used. Use of stationary dredgers is prohibited. Shell extraction is only permitted in water deeper than 5 m to protect coastal nature conservation areas. Restoration of the entire area, or part of it, to its original state can be required. Coastal protection works do not need a license. Dredging is prohibited within a distance of 500 m of oil and gas platforms, cables, and pipelines. Dredging in military exclusion zones is permitted subject to certain conditions attached to the license.

Norway

Legislation

Act on the Continental Shelf, 1963. From April 1993 the issuing of permits is delegated to local authorities (county administrations).

Administrator

Department of Industry and Energy.

Area of application

All national waters.

Materials

Sand and gravel, both siliclastic and biogenic;

Review procedures

Terms and conditions

Activities must avoid the disturbance of shipping, fishing, aviation, marine fauna or flora, and submarine cables.

Poland

Legislation

Polish Geological and Mining Law, 1994, supplement 1996.

Administrator

For licensing procedures: License Bureau in the Ministry of Environmental Protection, Natural Resources and Forestry.

For geological and mining surveillance: District Mining Office.

Administrative procedures

License for reconnaissance and exploration (documents required):

- application of investor to Ministry;
- project of geological (exploratory) works;
- environmental impact assessment of exploration;
- criteria of resources balance (proposed by investor and approved by Minister).

License for exploitation (documents required):

- license for exploration;
- geological documentation of resources (approved by Ministry);
- environmental impact assessment of exploitation;
- elimination of mining territory and premises (approved by District Mining Office);
- plan of resource field development and detailed plan of exploitation (approved by Ministry).

Exploitation (documents and reports required):

- license for exploitation;
- annual balance of resources;
- quarterly report on exploitation (for exploitation site).

Law and practice for monitoring and surveillance

Monitoring regulations

Electronic devices for surveillance and monitoring.

Sweden

Legislation

Act on the Continental Shelf, 3 June 1966.

Administrator

Geological Survey of Sweden (SGU); Government.

Area of application

The EEZ including territorial waters.

Materials

All natural resources, including sand and gravel.

Review procedures

Local and public involvement

Local fishery organisations, county administrations, local municipalities, etc., are consulted prior to issuing the permit. Intent to conduct work is published in local papers.

Role of other government departments or authorities

Swedish Environmental Protection Agency

National Board of Fisheries

Central Board of National Antiquities and the National Maritime Museum

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 license if the extraction has unacceptable detrimental effects.

United Kingdom

Legislation

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

Administrator

Department of the Environment, Transport and the Regions (DETR) in consultation with other Government Departments (particularly MAFF), and the landowner (Crown Estate Office).

Materials

All natural resources, except hydrocarbons.

Review procedures

Local and public involvement

Requires statutory review by DETR (Ports Division), 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 DETR.

These arrangements are currently under review. It is proposed that new legislation will give DETR statutory powers to control the dredging of marine sediments (other than for navigational purposes). The procedures will follow those already used to control the working of land-won minerals under Town and County Planning Legislation. The DETR will continue to rely on consultation with MAFF and other consultees when determining applications. The Crown Estate will issue a dredging license subject to the grant of a dredging permission by DETR.

Terms and conditions

A 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 is carried out by the Ministry of Agriculture, Fisheries and Food and the dredging industry, as required.

United States

No new information since 1991.

4.2 Guidelines for the Preparation of an Environmental Impact Assessment Evaluating the Effects of Seabed Aggregate Extraction on the Marine Environment

4.2.1 Introduction

The extraction of sand and gravel from the seabed can have significant physical and biological effects on the marine and coastal environment. The significance and extent of the environmental effects will depend upon a range of factors including the location of the licensed area, the nature of the surface and underlying sediment, coastal processes, the method and amount of extraction, and the sensitivity of habitats and fisheries in the locality.

To enable the organisation(s) responsible for licensing extraction to evaluate the severity of the effects and to decide whether a proposal can proceed, it is necessary that an adequate assessment of the environmental effects be carried out. It is important, for example, to determine whether the application is likely to have an effect on the coastline, or have potential impact on fisheries and the marine environment.

For EU member states, the extraction of minerals from the seabed falls within Annex II of the "Directive on the Environmental Impact Assessment for certain public and private projects" (85/337/EEC). As an Annex II activity, an EIA is required if the member state takes the view that one is necessary. It is at the discretion of the individual member states to define the criteria and/or threshold values which need to be met to require an EIA. The Directive was amended in March 1997 by Directive 97/11/EC. Member states are obliged to transpose the requirements of the Directive into national legislation by March 1999.

The Baltic Marine Environment Protection Commission (Helsinki Commission) adopted HELCOM Recommendation 19/1 on 26 March 1998. This recommends to the Governments of Contracting Parties that an EIA should be undertaken before an extraction permit is issued. Guidelines are provided on the content of the EIA.

The following text provides guidance on the content of an EIA. An EIA should normally be prepared for each extraction area, but in cases where multiple operations in the same area are proposed, a single impact assessment for the whole area may be more appropriate, which takes account of cumulative impacts.

The framework for the content of the EIA should be established by early consultation with interested parties, including the licensing authority, and other statutory consultees. As a general guide, it is likely that the following topics will need to be addressed.

4.2.2 Nature of the deposit

The proposed extraction area should be identified by geographical location and described in terms of:

- 1) the bathymetry of the general area;
- 2) the distance from the nearest coastlines;

3) the geological history of the deposit, including:

- the source of the material;
- type of material;
- sediment particle size distribution;
- the stability of the deposit;
- mean thickness of the deposit and evenness over the proposed extraction area;
- the nature of the underlying deposit;
- the natural mobility of the sediments.

4.2.3 Dredging proposals

The assessment should include an explanation of the proposed dredging operations. It should include, where appropriate, information on:

- the total volume to be extracted;
- proposed maximum annual extraction rates;
- expected lifetime of the resource;
- dredging equipment to be used;
- proposals to phase (zone) operations;
- whether on-board screening will be carried out;
- number of dredgers operating at a time;
- time required for dredgers to complete loading;
- number of days per year on which dredging will occur;
- whether dredging will be restricted to particular times of the year or parts of the tidal cycle.

Photographs of several types of dredges and other relevant equipment are shown in Figures 4.1 to 4.8.

While not directly related to environmental impacts, it may be appropriate, when known, to also include details of the following:

- ports for landing materials;
- servicing ports;
- onshore processing and onward movement;
- project-related employment.

Figure 4.1. Anchor “box” dredge, after Forster (1953).



4.2.4 Physical impact

The main physical impacts include effects on the coastline and changes to the seabed topography and sediment type as a result of removal of material, suspension and resettlement of fines, and the exposure of different textured substrates. To assess the physical impacts, information should be provided on:

- local hydrography including tidal and residual water movements;
- wind and wave characteristics;
- average number of storm days per year;
- estimate of bed-load sediment transport (quantity, texture, direction);
- the topography of the seabed, including occurrence of sandwaves, etc.;
- existence of contaminated sediment, and potential risk of release of contaminants by dredging;
- natural (background) suspended sediment load under both tidal currents and wave action;
- transport and settlement of fine sediment disturbed by the dredging equipment on the seabed, and from hopper overflow or on-board processing and its impact on normal and maximum suspended load;
- implications of extraction for coastal processes, including possible effects on beach draw down, changes to sediment supply to the coast and transport pathways, changes to wave climate at the coast;
- implications for local water circulation resulting from removal or creation of topographic features on the seabed.

4.2.5 Biological impact

The principle biological impacts include disturbance and removal of benthos and alteration of the substrate upon which colonisation depends. This affects its suitability as a fish or shellfish food resource or habitat. It may also cause fish to move away from the area (probably temporarily) because of the noise of dredging activity or increased suspended sediment load.

To assess the biological impact, the following information may be appropriate:

- a description of the benthic community structure (e.g., species type and abundance) within the area likely to be affected by dredging, taking into account temporal and spatial variability;

- information on the fishery and shellfishery resources including spawning areas, with particular regard to benthic-spawning fish, nursery areas, over-wintering grounds for ovigerous crustaceans, and known routes of migration;
- predator/prey relationships between the benthos and demersal fish populations (e.g., by stomach content investigations);
- predicted ease of recolonisation and likely timescale, taking into account initial community structure, and any predicted change of sediment type;
- presence of any areas of special scientific or biological interest in or adjacent to the proposed extraction area, such as sites designated under local, national or international regulations (e.g., Ramsar sites, the UNEP “Man and the Biosphere” programme, Marine Nature Reserves, Marine Consultation Areas, World Heritage Sites, Birds Directive (SPAs) or the Habitats Directive (SACs);
- effects on seabirds and marine mammals.

4.2.6 Interference with other legitimate uses of the sea

The assessment should consider the following in relation to the proposed programme of extraction:

- commercial fisheries in the area including information on seasonal fishing patterns, species and numbers caught, type of gear used, and location and number of boats and fishermen involved;
- shipping and navigation lanes;
- military exclusion zones;
- engineering uses of the seabed (e.g., adjacent extraction activities, undersea cables and pipelines);
- areas designated (licensed) for the disposal of dredged or other materials (e.g., sewage sludge);
- location in relation to existing or proposed licensed aggregate extraction areas;
- location of wrecks and war-graves in the area and general vicinity;
- areas of archaeological importance;
- areas of natural beauty or of significant cultural or historical importance in or adjacent to the proposed extraction area;
- recreational uses;
- general planning policies for the area (international, national, and local).

Figure 4.2. Rallier du Baty dredge.



Figure 4.3. Newhaven scallop dredge.



4.2.7 Evaluation of impact

When evaluating the overall impact, it is necessary to identify and quantify the marine and coastal environmental consequences of the proposal. The EIA should evaluate the extent to which the proposed extraction operation is likely to affect other interests of acknowledged importance in the area.

The environmental consequences should be summarised as an impact hypothesis. The assessment of some of the potential impacts requires predictive techniques, and it will be necessary to use appropriate mathematical models. Where such models are used, there should be sufficient explanation of the nature of the model, including its data requirements, its limitations and any assumptions made in the calculations, to enable assessment of its suitability for the particular modelling exercise.

The impact hypothesis should include consideration of the steps that might be taken to mitigate the effects of extraction activities. These may include:

- the selection of dredging equipment and the timing of dredging operations to limit impact upon birds, benthic communities, and spawning cycles;
- modification of the depth of dredging to limit changes to hydrodynamics and sediment transport and to allow future safe use of fishing gear;
- zoning the area to be licensed or scheduling extraction to protect sensitive fisheries or to respect access to traditional fisheries;
- preventing on-board screening or minimising material passing through spillways when outside the dredging area to reduce the spread of the sediment plume;
- agreeing exclusion areas to provide refuges for important species.

Evaluation of the potential impacts of the dredging proposal, taking into account any mitigating measures, should enable a decision to be taken on whether or not the application should proceed. In some cases it will be appropriate to monitor certain effects as the dredging proceeds. The EIA should form the basis for the monitoring plan.

4.3 Review of Approaches to Environmental Impact Assessment (EIA)

Belgium

Environmental impact assessments are not a legal requirement. However, the Ministry of the Environment asks for one when assessing a new application.

In Belgium there is only one extraction area available for exploitation by private companies that is defined by law.

An environmental impact assessment was prepared in 1993 for the whole of this area. Any changes to the boundaries of the existing extraction area would have to follow a new, more rigorous procedure, making it unlikely to happen.

A permit for sand extraction is granted initially for a trial period of three years. This can be extended to ten years and renewed twice. The maximum permitted period is thus 30 years. Most of the permits are in their second ten-year period.

If it is demonstrated that the dredging is causing negative environmental effects, the permitting authority can, at any time, either close parts of the extraction area or even the whole area, or stop extraction for a certain period of time.

The EIA looked at three main issues: 1) morphological and sedimentological impact, 2) impact on fisheries, and 3) ecological impact.

Canada

Since the 1970s any project on federal land, receiving federal funding or requiring a federal decision-making authority has required screening through the Environment Assessment and Review Process (EARP). This was originally a self-assessment process and, although authorised by Order in Council, it was not a legal requirement. In January 1995, the Canadian Environmental Assessment Act was proclaimed and the review process is now mandatory.

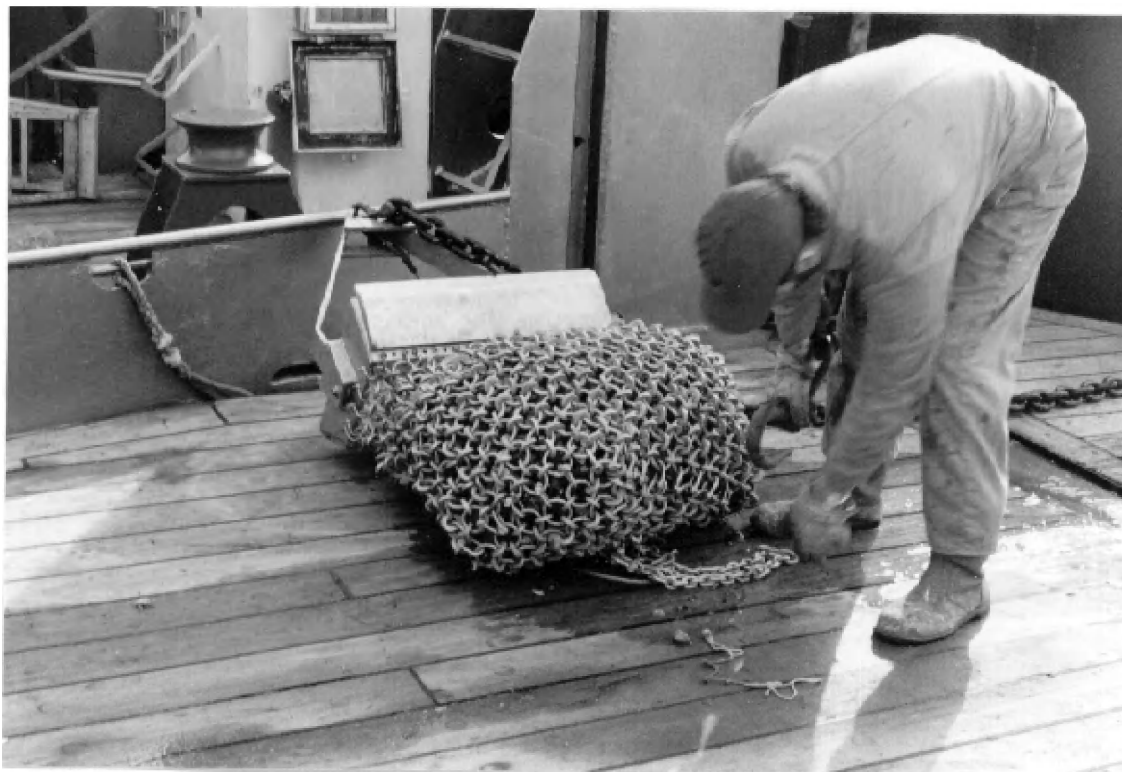
Many projects can be approved following a simple screening that must be registered, but others may proceed to lengthy and costly public reviews.

The review process must respect other regulations and policies such as the fish habitat protection policy, which operates on the principle of “no net loss” of habitat. Unknown environmental impacts are considered to be just cause to cancel a project or refer it to further study and review. A project could be referred for further review, for example, purely because of public concern, regardless of environmental concerns or a lack thereof.

A cooperative study of the effects of bottom fishing gear on the sediments and marine ecosystem has entered a new phase for areas of the Scotian Shelf. A five-year programme, which began in 1996, is investigating selected areas of the continental shelf where fishing has been prohibited for several years. Experimental fishing will take place in these areas, followed by a series of investigations to assess the disturbance on the sedimentology and benthic communities.

Monitoring will follow to evaluate the temporal and spatial recovery of the seabed. This research has direct applications to potential mining of mineral resources on the seabed, as several of the bottom fishing techniques disturb the substrate in a similar fashion to seabed mining.

Figure 4.4. Rock dredge.

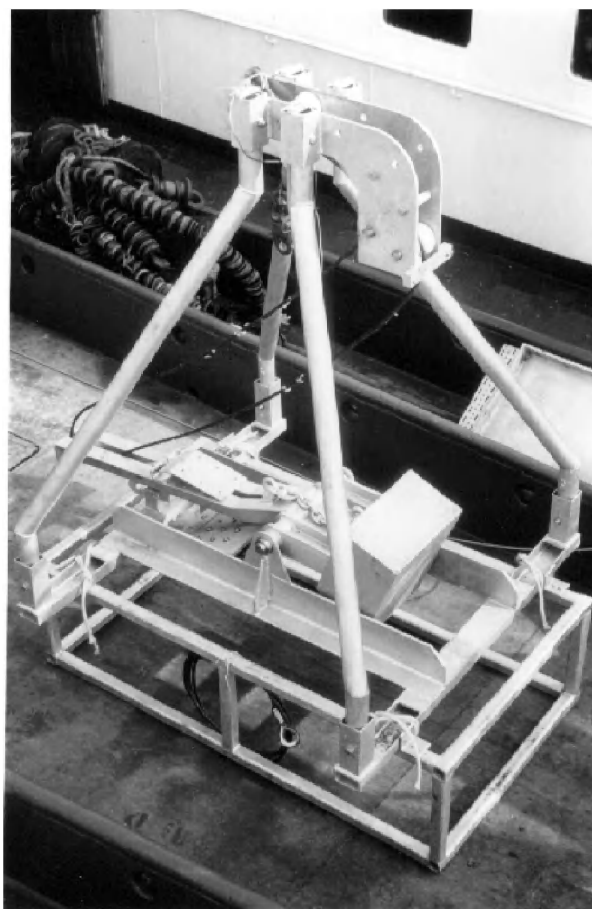


In 1997, the fishing gear effects project was expanded to investigate a clam fishery on Banquereau, a large bank on the eastern Scotian Shelf. Hydraulic clam dredging equipment is used to liquify the sediments in the fishing operation. A preliminary assessment, based on 1996 surveys, showed that the seabed is disturbed for a distance of twice the width of swath of the clam dredge and shallow troughs are formed which are up to 20 cm in depth and many kilometres in length.

Other projects regarding seabed habitat characterisation are planned for Browns Bank to define and understand scallop habitat. The fishing community has embraced the seafloor mapping technologies developed and refined over the last few years as essential tools for a sustainable fishery and to maximise their operations for efficient and safe fishing practices.

A new Canada Oceans Act is currently being developed. This will remove overlap and duplication in current regulations and refocus effort on the most critical concerns.

Figure 4.5. Day-grab.



Denmark

In Denmark the National Forest and Nature Agency is responsible for the administration and licensing of marine aggregates dredging. All new licensed areas are subject to a Government View Procedure which includes public and private involvement. The Agency prepares an environmental statement and requires the preparation of a detailed Environmental Impact Assessment if potentially adverse environmental effects are identified.

Recent environmental impact studies

Øresund Link

Impact assessments were carried out in the Sound between Denmark and Sweden prior to the initiation of the tunnel and bridge project. The studies looked, in particular, at the consequences of dredging in till and chalk.

To assess the environmental impact, monitoring programmes have been established by the contractor, the Owner (Øresundskonsortiet), and the environmental authorities. The monitoring programmes are expected to be the most comprehensive and detailed in the world so far. The programmes include monitoring of sediment spreading and sedimentation, water quality, eelgrass, algae, benthos, migrating fish (herrings), birds, and coastal morphology (Øresundskonsortiet, 1998a, 1998b).

A statement on the condition of the environment is published biannually by the Danish and Swedish authorities.

The management of the dredging operations is based on a feedback monitoring programme run by the Owner. The programme is based on modelling and mapping of sediment spreading and a newly developed eelgrass growth model.

Until now only minor effects have been demonstrated. The effects accord with the forecasts and are within the accepted limits. Sediment spill during dredging in glacial till and limestone using a large dipper dredger was about 4 % on average. The spill from a backhoe dredger is presently 4–6 % and the spill from cutter suction dredging is 4.5 % on average. With more than 80 % of the dredging completed, the average spill rate has been 4.1 %.

A detailed resource assessment and an environmental impact assessment of dredging of sand has been carried out on Kriegers Flak in the Baltic Sea by the Øresund Consortium. The assessment was prepared in accordance with the EC Directive 85/337.

Preliminary results from the spill monitoring programme on Kriegers Flak indicate that the spill rates are strongly dependent on the type of dredger used. Spill rates range from 0.7 % to 4.8 %. The release of fines and nutrients is very low. Bottom fauna have been resampled in the autumn of 1996 and 1997. Preliminary results indicate,

in accordance with the EIA, that there is no environmental impact beyond 1000 m from the dredging area (Øresundskonsortiet, 1998a, 1998b).

Research projects

In 1994, the Forest and Nature Agency initiated a three-year research project on the consequences of marine dredging, in cooperation with the Geological Survey of Denmark and the National Environmental Research Institute. The project includes a study of fines in potential resources, computer models of sediment spreading, the development of ecological models, and field tests. One of the aims of the project is to establish a decision framework (computer-aided Expert System) to evaluate the environmental consequences of existing and future dredging projects based on the content of fines in the resource, hydrography, the spreading of fines, and ecological models.

Results from analyses of a very large number of samples from marine resources have shown that the content of fines, i.e., silt and clay, only exceed 5 % in a few samples. Although the figures are general, they provide a framework for the evaluation of aggregate dredging. A report was published in 1995 (in Danish).

A detailed study of the ecological consequences of dredging in coarse sediments was started in May 1996. It focuses on the evaluation of the effects on the benthic flora and fauna on surrounding stone reefs.

The environmental effects of dredging in gravel deposits have been studied in detail in a highly dynamic area north of Læsø in the Kattegat. Here, a dredging operation carried out with a stationary suction hopper dredger was closely monitored including pre- and post-dredging video inspection of the seabed and algal reefs, spill measurements on-board the dredger, current measurements, and water sampling. The dredged material was screened on-board, and the initial spill from the dredger was measured to be between 70 % and 90 %. Most of the spill was sand, with only 3 % in the silt and clay fraction. Spreading of the sediments was modelled with a program developed by the National Environmental Research Institute (NERI). Most of the spill settled very close to the dredger, partially burying the vegetation, and despite the large initial spill, only 5 % was still in suspension 500 m from the dredger. This was in accordance with the video inspections where a thin layer of sand was seen on the fronds of the algae some distance from the dredger. It is expected that the sand will be re-suspended by stronger currents (DMU, 1997).

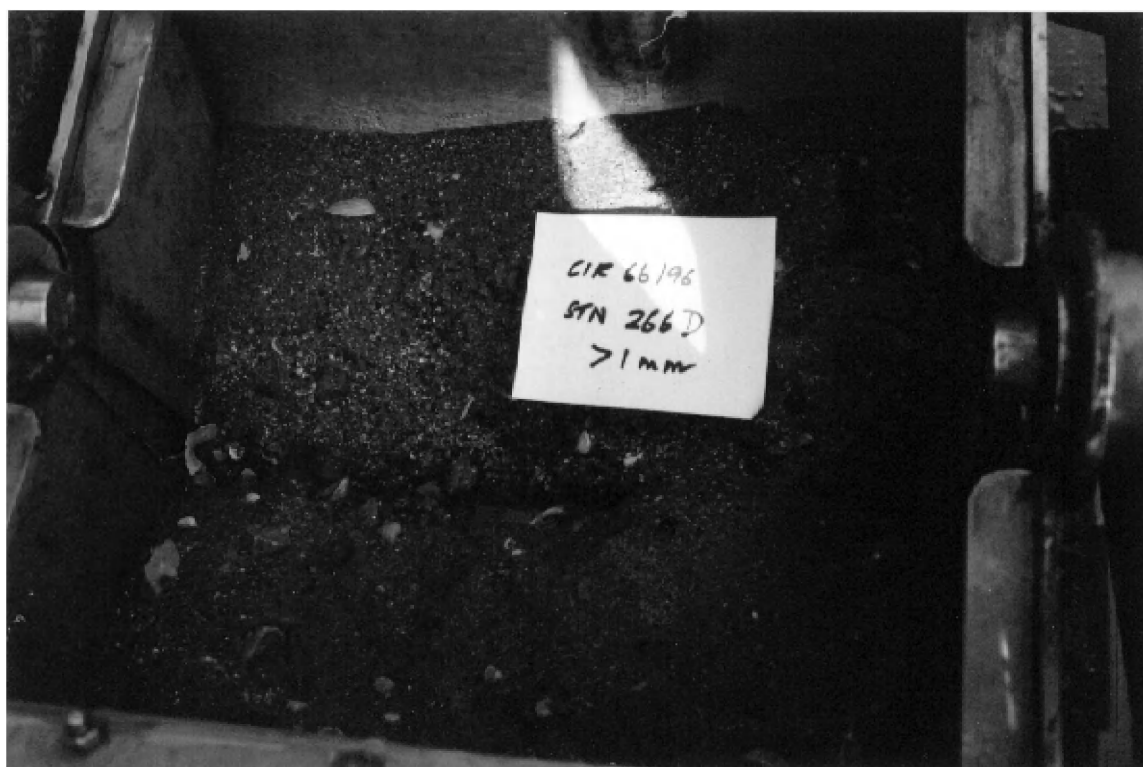
The Forest and Nature Agency and the Coastal Protection Agency have initiated a monitoring programme off the west coast of Jutland to study the effects of dredging of sand for coastal protection. The study is based on a comparison with simultaneous changes in a reference area. The post-nourish temporal development is analysed using the BACI concept (B(e)fore A(fter) C(omparison) I(mpact)). A complete

quantitative recovery including the number of species, the abundance, and the biomass of the bottom occurred in less than one year after the sand extraction.

However, the predominance of a supposed opportunistic species of polychaete (*Spio filicornis*) in the borrow area may indicate a pioneer recolonisation.

The impact of sand extraction on the predator populations is limited due to a patchy exploitation pattern leaving plenty of food on 70 % of the (undisturbed) bottom and a recovery of the benthic biomass in less than one year.

Figure 4.6. Hamon grab.



A study of the environmental impact of gravel dredging in the Limfjord area has been carried out by the Forest and Nature Agency. During dredging the sediments are screened and sand and finer particles are returned to the sea. Detailed spill measurements have shown that the spill rates vary between 60 % and 90 %. Analyses of the spill have shown that most of the material is sand and less than 5 % consists of silt and clay. The spreading of sediments has been evaluated by the hydrographic model MIKE 21 and the spreading module PARTICLE developed by DHI. The tests have shown that despite the large spill rates the spreading of sand is restricted to the dredging area and sedimentation of fines outside the area is very limited (Nielsen, 1996).

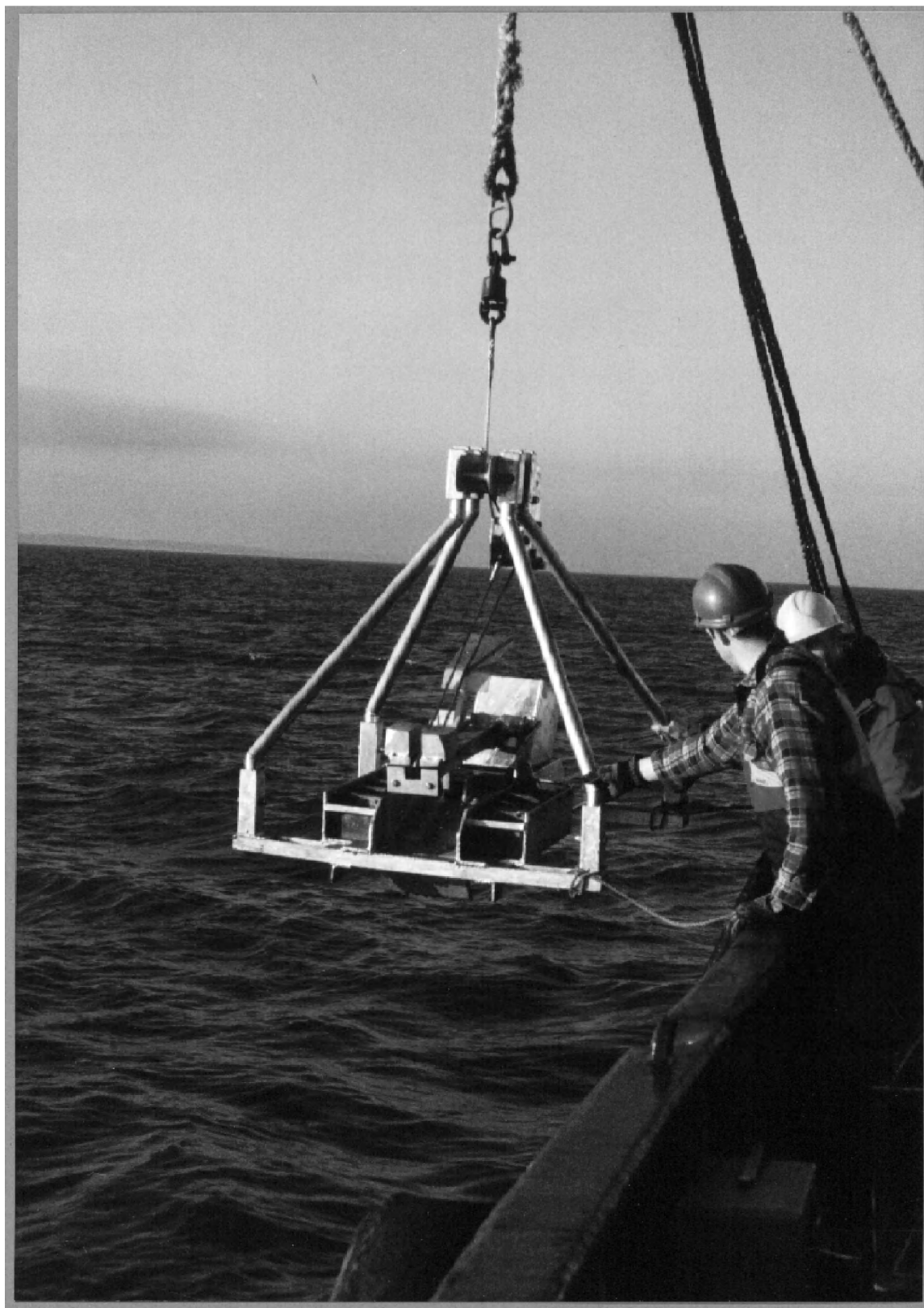
Finland

An environmental survey was undertaken at the Helsinki extraction site prior to extraction. There are areas close to this site which support recreational activity.

The Kotka sand extraction area is situated inside the Eastern Gulf of the Finland National Park although the Park itself includes only the land areas of the islands. Studies made in connection with this extraction site which were conducted in the 1980s (reports are available only in Finnish) concluded that the principal effects of the extraction operation were:

- a) the most harmful effect was erosion of coastal areas and islands in the vicinity of the extraction sites;
- b) fishing activities tend to be made more difficult as a result of changes to the topography of the seabed;
- c) in areas where silt and/or clay layers cover the sand, suspended solids make the water turbid. In such areas avoidance behaviour by fish may occur. Ecologically important *Fucus* belts and eelgrass meadows may also be damaged or destroyed. Potential changes in local fish stock populations and bird populations may also take place.

Figure 4.7. Mini-Hamon grab.



France

A synthesis of baseline information available in the Baie de Seine was published in 1995 to produce an EIA for an experimental dredging site. A scientific programme was proposed in order to define guidelines for the experiment. There were three main objectives:

- 1) to examine a site previously dredged in the 1970s (souille experimentale CNEXO);
- 2) to define recommendations for dredging a new experimental site;
- 3) to develop a methodology for the scientific and technical monitoring of this experiment.

Different extraction techniques will be tested during a four-year period (1999–2002) in order to select an optimal one, which minimises both the impact on the marine environment and the interference of dredging activity with other legitimate uses of the sea, particularly fishing activities.

The following technical characteristics have been adopted:

- trailing suction dredging;
- annual dredging volume of 500,000 tonnes;
- selection of an experimental area of 8 km², on the basis of a good knowledge of its environmental characteristics (bathymetry, superficial sediment, benthic fauna), the absence of spawning and nursery areas and of interference with other users of the sea (navigation, military zones, cables and pipelines, recreational areas and wrecks);
- within this area, two sites of 0.6 km² will be successively dredged with different intensities. One will be dredged in the first year only (1999) to a maximum depth of 1 metre ("fallow" test). This will be used to study the recolonisation rate of the local gravel community. The second area will be dredged for three years (2000–2002) to a maximum depth of 3 metres ("intensive" test), to study the spatial impact of intensive dredging activity;
- on-board screening will be forbidden to limit the outwash plume;
- a timetable for the extraction will be adopted with cessation of dredging activity from August to October when fishing activity is most intensive (sole, cuttlefish);
- dredging operations will be monitored by black-boxes in accordance with the minimal ICES recommendations;
- extraction will be orientated perpendicularly to the direction of bedload sediment transport to facilitate the infilling of the site by mobile sands;
- levelling of grooves and ridges will be tested on one half of the "fallow" site to demonstrate the potential

interest of such a practice on the recolonisation rate of benthic macrofauna and on further trawling of such areas after the cessation of the dredging activity.

The results of this experiment will be used to establish recommendations for dredging activity at a national level.

Initial baseline studies have already covered:

- bathymetry, hydrography, turbidity, sediment quality and heavy metals;
- plankton, benthos, fish and shellfish resources;

The scientific monitoring programme of the experimental site will include annual physical monitoring:

- bathymetry by echo-sounding;
- a morphological survey by side-scan sonar;
- a sedimentological survey;
- continuous recording of turbidity, nutrients, and chlorophyll.

Biological monitoring will cover:

- benthos, with a recolonisation survey of the first site and an impact survey around the second site over three years;
- demersal fish populations, with two autumn cruises: Channel Ground Fish Survey (IFREMER) and Beam Trawl Survey (MAFF);
- trophic relationships between fish and benthos, through a study of stomach contents.

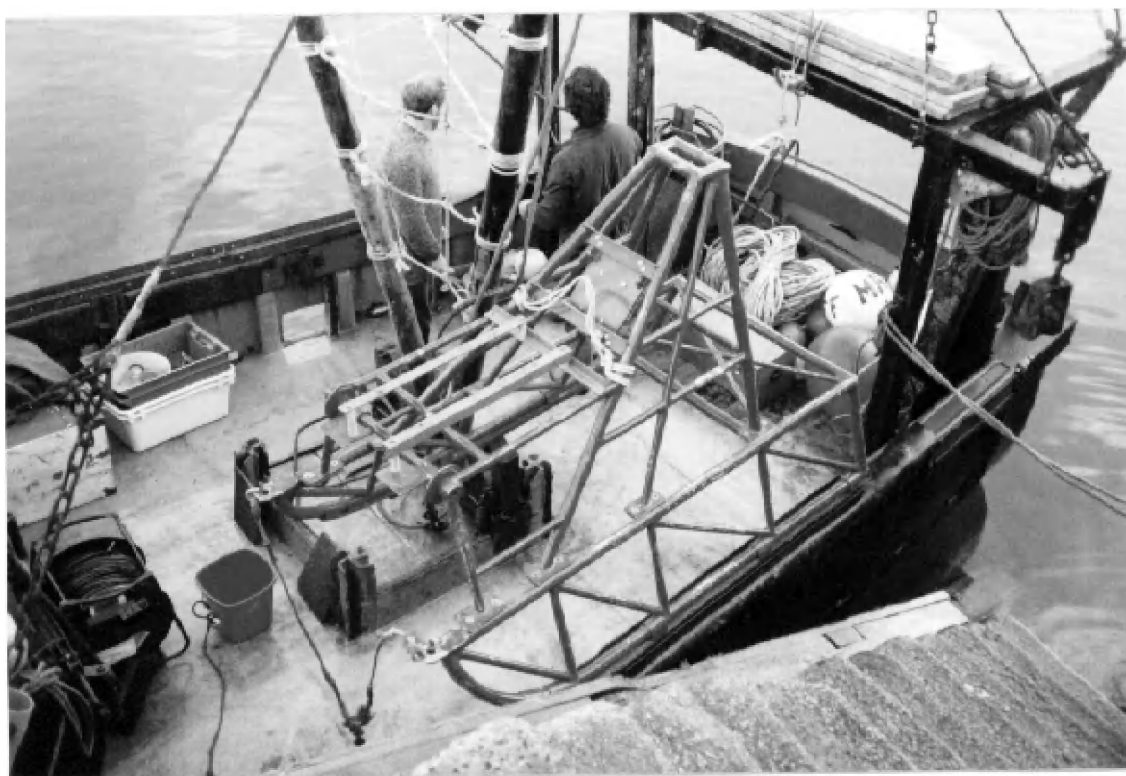
The programme developed in 1994–1995 is funded by the Government and the Regions, except for the monitoring programme, which is funded by the dredging companies.

Germany

A monitoring programme has been set up by the Bundesanstalt für Gewässerkunde (Federal Institute of Hydrology) for the German North Sea estuaries and the Jade Bay to describe the macrozoobenthos along the sea waterways. This monitoring covers the brackish areas and will show the natural variability in areas adjacent to maintenance dredging activities. It will also serve to describe the natural environment of the extraction sites that are used for the maintenance of the waterways.

Stations are distributed along the Ems (5), the Jade (5), the Weser (5), the Elbe (5), and the Eider (3); at each station Van Veen grab samples (60 kg) are taken in triplicate. The sediment is washed through a 0.5 mm sieve. In addition to the taxa list, dry weight and ash-free dry weight are taken for every species.

Figure 4.8. Towed underwater camera sledge.



Physical impact on the seabed caused by dredging is being investigated at the extraction site west of Wester land. Here the pits are stable for several years and H_2S is present in the sediments (Figged, unpublished).

Regier *et al.* (1995) investigated the direct and indirect impact of sand extraction on the macrozoobenthos in the area off the island Sylt (North Sea, area "Lister Tief", area "Salzsand vor Sylt"). They stated the impact as a strong disturbance of short duration in a biotope with the ability of quick regeneration in the light of sedimentation and bioceonosis. Several authors found regeneration times for the macrozoobenthos in dredging and dumping sites between one and three years for tidal and estuarine areas in the North Sea (see Leuchs *et al.*, 1996).

The Department of Coastal and Maritime Nature Conservation at the Federal Agency for Nature Conservation in Vilm funded a programme starting at the end of 1995 to assess the ecological impact of sand and gravel extraction in the southern Baltic Sea. Results show that up to one third of the common species are potentially endangered by dredging because they are unable to resettle quickly in the exploited area (Krause *et al.*, 1996; Arlt and Krause, 1997). The approach adopted is based on the concept of sensitive species established using ACME. Planned extraction activities are discussed for five areas by Arlt and Krause (1997).

In 1996 a desk study on the ecological impacts of sand and gravel extraction on the Baltic ecosystem was elaborated on behalf of the Agency for Environment and Nature of the Federal State Mecklenburg-Vorpommern

(Gosselck *et al.*, 1996). This study is a review of the current state of knowledge of the geology, hydrology, and biology in nine areas where sediment extraction is intended.

The authors of the study assume three main threat factors:

- 1) The layer of extractable sediment is quite thin, on average, less than 1 m in thickness. This will result in extraction over extended areas. The removal of the complete layer will change the habitat, mostly towards a maerl bottom, which makes resettlement of macrobenthic invertebrates impossible.
- 2) The submerged elevations (sills) have a special function in terms of hydrography, i.e., they can prevent upwellings of oxygen-deprived waters from deeper areas into the inner bays. Furthermore, in many cases they are important feeding sites for sea ducks.
- 3) Besides the sills there are also other sand and gravel deposits which coincide with important feeding areas of wintering nordic benthophagous birds (e.g., eiders and scoters, *Somateria* spp., *Melanita* spp., and long-tailed ducks, *Clangula* spp.).

A continuous monitoring programme for macrozoobenthos and macrophytes is being undertaken in the Baltic Sea, funded by the Ministry for Construction, Physical Planning and the Environment of the Federal State of Mecklenburg-Vorpommern.

Ireland

There has been discussion on the draft protocol being proposed by the Department of the Marine for an EIA specifically for the Waterford exploratory license application.

The Netherlands

Guidelines for the extraction of sand, gravel, and shell from the Dutch part of the Continental Shelf are set out in the Regional Extraction Plan for the North Sea. They were approved by the Government in 1993. The guidelines are based on the results of an extensive EIA, which took account of all applications using extracted materials, known extraction techniques, and other users of the North Sea.

In 1997, a start was made on an update of the Regional Extraction Plan for the Dutch Part of the North Sea and Environmental Impact Assessment (RON/EIA). The updated RON/EIA has to be finished in 2000.

In 1996 the North Sea Directorate decided that no further research on the ecological effects of gravel extraction on the Klaverbank would be undertaken.

Preparations are being made to update the Regional Extraction Plan to take into account new nourishment techniques using temporary borrow pits landward of the 20 m depth line, shellfishery, new extraction techniques, extraction in exclusion zones, and other issues which have arisen since the extraction plan was first issued.

Borrow pits

In 1994 a beach nourishment scheme was executed with a pin-point dredge in a borrow pit at the central Dutch coast near Zandvoort/Bloemendaal. The nourishment itself was a success. However, the experiment indicated that technical improvements were possible. In particular, it seems worthwhile to move the control and power supply for the dredger from a support platform in the sea to a support unit on the beach.

It was also shown that ecological effects of the extraction were almost absent at a distance of 125 m from the edge of the pit. Unfortunately, there were no data from within the pit itself. Therefore, information on the direct effects and recolonisation are not available.

To obtain this information and to test technical improvements, another experiment was carried out involving the beach nourishment of Heemskerk/Wijkaan Zee, located just north of IJmuiden at the central Dutch coast in a water depth of 7 m.

The nourishment started in October 1996. Due to technical problems with the flexible part of the connection to the support unit on the beach, the extraction stopped in November 1996. The borrow pit reached a maximum depth of 26 m below the sea floor.

The pit was refilled in January 1997. The nourishment was completed in a classical way.

Before, during, and after the operations, a monitoring programme was executed concentrating on:

- macrobenthic fauna;
- bathymetry;
- sediments;
- turbidity;
- borrow pit / pin-point dredge technique.

The technical problems with the dredge had no negative influence on the monitoring programme.

The repeated measurements of bathymetry and the relatively long period with no possibility to refill the pit (due to rough weather) gave the opportunity to compare the behaviour of the pit with model calculations.

A pre-nourishment and a pre-refill survey on benthic fauna were carried out, followed by a survey just after the completion of the refill. Several further surveys are planned. The results of the monitoring programme are expected in December 1997.

To continue the series of experiments a license has been applied for to use borrow pits only for beach nourishments at six other locations along the Dutch coast. The license also requires a monitoring programme for each borrow pit. Five of these locations are situated at the central Dutch coast; one is situated at the island of Ameland. The locations were chosen from a pre-selection of 27 locations on the basis of the quality of the sand to a depth of 15 m and the need for beach nourishment in the next two years.

To support the request for the above-mentioned license, a modelling exercise was undertaken on the behaviour of a pit near the beach, in water depths of 5–10 m and its effects on coastal erosion. The modelling study showed that in the study areas, a borrow pit at a water depth of more than 7 m has a negligible influence on coastal erosion if the pit is refilled within a month in the winter season and within two months in the summer season.

Norway

Dredging in Norway is exclusively by anchor dredger with grab. The boats are normally small (maximum loading capacity up to 500–1000 tonnes) and the impact on the sea floor is severe, but localised. Sediment plumes are not thought to be significant. The carbonate sands are deposited in high energy areas, which means that the fines content is low, and redeposition of fines is therefore a minor problem.

There are conflicts with fishing interests and environmental movements. The fishery interests are worried that the spawning areas are being destroyed, and

that deep holes depleted of oxygen result from the dredging.

An environmental investigation of the effects of carbonate sand extraction has been undertaken. The authors concluded that generally the effects of extraction are moderate, and are limited to the pit areas.

Poland

Detailed investigations to assess the environmental effects of aggregate extraction from the seabed have been carried out on the eastern part of the Slupsk Bank. In particular, attention was given to changes to hydrological conditions and the dynamics of the seabed, and to effects on the benthos.

Sweden

The Geological Survey of Sweden is responsible for the administration and licensing of the extraction of marine aggregates. Licensing in the EEZ beyond the territorial sea limit is the responsibility of the government. Since 1 July 1992 there has been a requirement in the Swedish Act of the Continental Shelf to carry out an EIA in connection with an application for extraction of marine sediments, and for larger construction works in the marine environment. The EIA has to be paid for by the company applying for the extraction license.

United Kingdom

Although it is not yet a legislative requirement for the dredging companies in the UK to produce a formal EIA, it is accepted that adequate assessment is required to enable MAFF to evaluate the potential impact on fish and the marine environment. It is also required that the potential effects on the coastline are assessed. In general, the approach adopted follows the guidelines of Campbell (1993), although the exact content is based on early consultation with interested parties, and depends to an extent on the nature of the dredging proposal.

Together with the outcome of an assessment by Hydraulics Research Wallingford of the effects on wave conditions, tidal currents and sediment transport, the agreed Environmental Statement identifies the issues upon which monitoring and mitigation measures are based. These measures form an integral part of the Government View decision and are included as conditions in any Crown Estate Production Licence. Such conditions may include seasonal restrictions upon dredging, and a requirement to monitor a range of physical and biological measurements, together with other monitoring conditions. Such conditions are monitored by MAFF and DETR, the Welsh Office and Scottish Office.

For particularly sensitive locations, it is the responsibility of the industry to fund intensive long-term monitoring programmes and to present the results to the relevant agencies and interested parties at annual review meetings. These enable adverse effects to be detected

rapidly, and for changes to be made to the working arrangements as necessary. It also enables the monitoring programme to be modified where it is demonstrated that the initial framework was insufficient to monitor all the relevant factors. Conditions relating to tonnage taken and area dredged are monitored by the Crown Estate as landowner. An increasing number of licenses have conditions limiting the period of the license and requiring a full review before further dredging is permitted.

United States

The impact of dredging on sea turtles and other endangered species is a current issue. The National Marine Fisheries Service requires trained observers on operating dredgers to document encounters with sea turtles. Operations can be suspended if the frequency of encounters becomes too high. The Corps of Engineers has been developing an “excluder” to fit over the draghead and keep turtles from the intake. Current models are only effective in calm conditions.

5 SEABED SEDIMENT MAPPING PROGRAMMES OF ICES MEMBER COUNTRIES

5.1 Introduction

The aim of this section is to present an overview of the seabed sediment and superficial resource mapping activities in the various ICES Member Countries.

Reconnaissance mapping of the seabed sediments forms the framework for delineation of marine sand and gravel resources, and provides strategic information for short-term and long-term planning and best practice use of these resources in the marine and inshore zones.

Detailed resource mapping is required to obtain reliable information on the volume, quality, and composition of the seabed resources to establish their economic viability.

Detailed surface sediment maps, including information on dynamics and morphology, are crucial as a basis for physical and biological impact assessments of marine construction projects and aggregate extraction, and subsequent monitoring of the impact during extraction.

WGEXT is indebted to a great number of people and institutions that have contributed to the present report. Although we feel that we have covered the great majority of the official mapping programmes, we are certain to have missed some, especially mapping results for applied purposes.

5.2 Belgium

Staff: The institutes that have taken part in seabed sediment mapping of the Belgian North Sea sector include:

The Belgian Geological Survey, Brussels, with one person;

Fisheries Research Station, Oostende, with three to four persons;

Gent University, Renard Centre of Marine Geology, shallow geophysics with three persons; superficial sediments with two to three persons;

HAECON Corporation, Gent, with four to five persons;

“Management Unit of the Mathematical Model of the North Sea and the Schelde Estuary” (MUMM), Brussels, with several persons.

Equipment:

The shared use of several multi-purpose vessels;

Various types of very-high-resolution seismic equipment (Gent University);

Various grabs and corers (Gent University, Fisheries Research Station).

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

Mapping: Mapping activities in the Belgian sector peaked in the late 1980s resulting in a number of the maps listed below. At present, not much is happening in this field. The maps include:

- A superficial sediment map (1:100,000, Mercator), showing sand classification, sand quality, mud content and gravel content, legends in English, based on Van Veen grab data from the Ministry of Public Works, published in 1989 but dated 1987. Available from MUMM. See MUMM/SED/87/01.
- Seven lithological maps (1:40,000) with legends in English and explanatory notes by G. Ceuleneer and B. Lauwaert in French (“Les sédiments superficiels de la zone des Vlaamse Banken”) or Dutch, of areas of special interest within 15 km of the shore. Areas include the Kwinte Bank sand extraction area. Published in 1989 with date 1987. Maps are available from MUMM. Codes MUMM/SED/87/02 to 08.

- A seabed sediment map (1:250,000, UTM) for the Belgian part was compiled by HAECON for the Belgian Geological Survey, thereby complementing maps of the British and Dutch parts being prepared by the respective Geological Surveys. The resulting map, called Ostend sheet, follows the set-up of the British and Dutch 1:250,000 map series. Published by the three geological surveys in 1991. Available from the Belgian Geological Survey, Jennerstraat 13, B-1040 Brussels, Belgium.

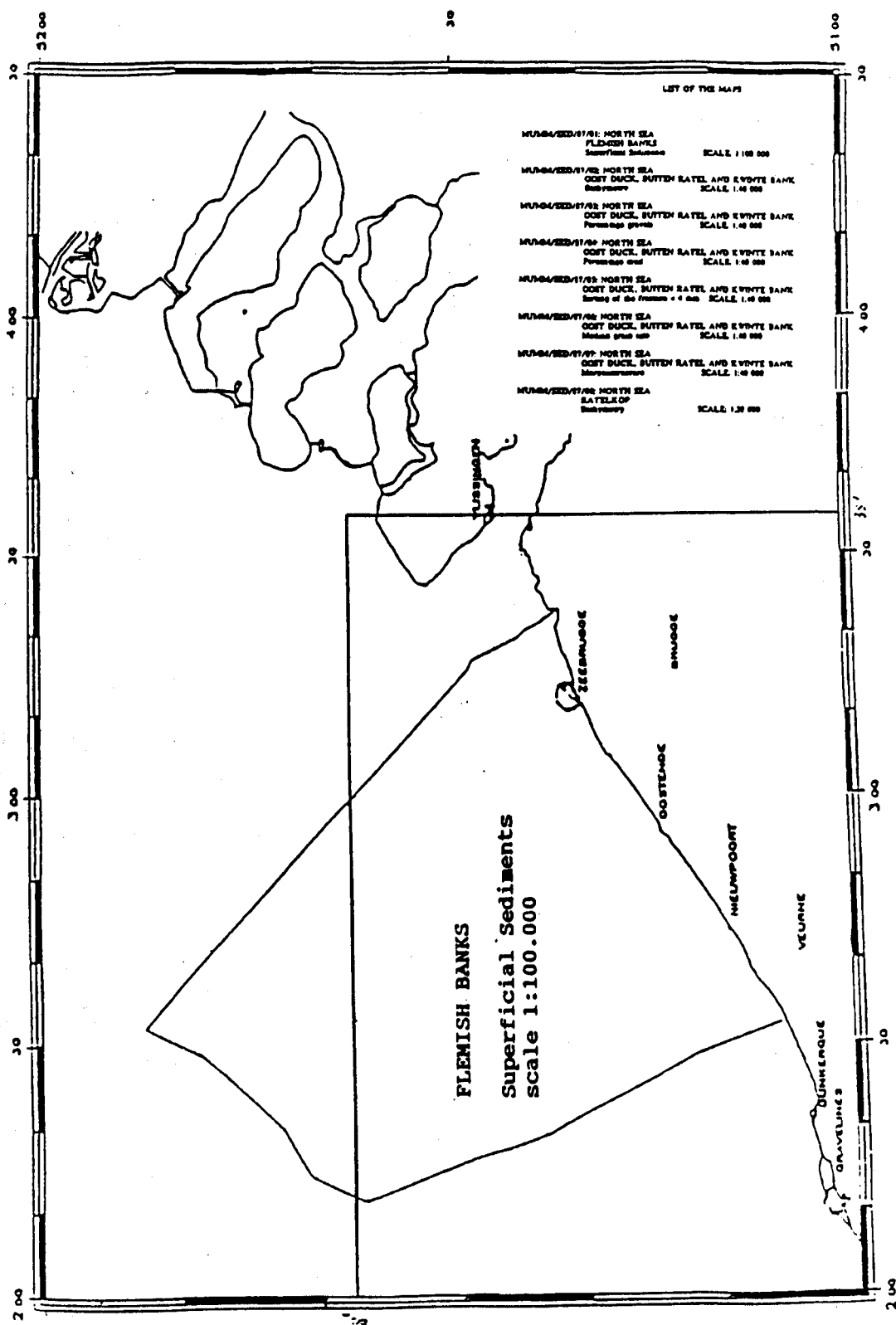
List of MUMM maps (see map of Belgian sector (Figure 5.1.)):

- 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 gravel percentages. Scale 1:40,000.
- MUMM/SED/87/04: North Sea Oost Dijck, Buiten Ratel and Kwinte Bank mud percentages. 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: Further surficial sediment maps are planned, based on detailed scientific research by universities and the Ministry of Agriculture and Fisheries.

Information and ordering: Contact Dr B. Lauwaert, MUMM, Ministry of the Environment, Gulledele 100, B-1200 Brussels, Belgium. Tel. +32.2.7732120. Fax. +32.2.7706972.

Figure 5.1. Map of the Belgian Continental Shelf showing coverage of published marine geological maps.



5.3 Canada

Staff: The Geological Survey of Canada, part of the Federal Department of Natural Resources Canada, has eighty persons involved in marine mapping. They are located on both the Pacific and Atlantic coasts, with the largest group at the Geological Survey of Canada (Atlantic). Some of the research is concerned with deep crustal and hydrocarbon basin analysis. Excluding these research areas, there are thirty researchers directly involved in seabed and shallow sub-surface mapping.

Equipment: The Geological Survey of Canada (GSC) has use of several large research vessels (e.g., "Hudson" and "Parizeau") and many small coastal vessels shared with the Department of Fisheries and Oceans. In the future it will have access to a large number of other vessels under a new amalgamation of the research fleets of the Canadian Coast Guard and the Department of Fisheries and Oceans. Additionally, several vessels fitted with multibeam bathymetric mapping systems are routinely used in cooperation with the Canadian Hydrographic Service, such as the "Creed" and the "Matthew". The GSC has a wide variety of marine geological and geophysical equipment including high-resolution seismic reflection, side-scan sonar, magnetometer, and gravity systems, along with sampling equipment such as corers, bottom grabs, and camera systems. Specialised pore water sampling, sediment shear monitoring systems, and long coring facilities have been developed. Field programmes total over six months each year.

Budget: Expenditures of the marine programme approximate \$6.5 million per year, of which 50 % is dedicated to marine mapping.

Mapping: The southern areas offshore Canada have been mapped at reconnaissance levels largely during the 1970s. The systematic maps (scale 1:300,000) cover the Scotian Shelf and parts of the Grand Banks and concentrate on the continental shelf proper and not the inner coastal zone. Areas to the north have been mapped with much less resolution at scales of 1:2,000,000 and some areas have not been surveyed. Coastal mapping programmes have been developed over the past eight years and have concentrated in urban areas or areas of particular geoscience need. This programme is not systematic. Recently, multibeam mapping of areas of the nearshore and offshore has commenced, producing increased knowledge of seabed sediments and processes. Approximately 3 % of the offshore southern area has been mapped with these systems.

Information and ordering: Maps of surficial sediment and areas surveyed are available from the Geological Survey offices on both the Atlantic and Pacific coasts. The marine geological programme for Canada is now managed from the Geological Survey of Canada (Atlantic) offices, at the Bedford Institute of Oceanography, Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2. Maps and other information may be obtained at this location.

5.4 Denmark

Mapping of the seabed is an integral part of the systematic reconnaissance resource mapping programme in Danish waters.

The mapping programme continues and is concentrated in the North Sea, Kattegat, and the Baltic Sea. Since 1991 mapping programmes have been carried out on Jutland Bank and Horns Reef in the North Sea and in the Femer Belt, Adler Ground, Rønne Banke, and Kriegers Flak in the Baltic. Maps are in scale 1:100,000 of surface sediments, Quaternary geology and sand and gravel resources have been prepared. At present, between 80 % and 90 % of potential resource areas in the Inner Danish Waters have been mapped.

In 1996 reconnaissance mapping was carried out at greater water depths in the central part of the Kattegat and in the North Sea.

Detailed resource mapping programmes have been carried out in some regional extraction areas with materials of high quality and in areas licensed for bridge and tunnel projects.

A map of the surface sediments in the Danish part of the Sound in scale 1:100,000 was published in 1990.

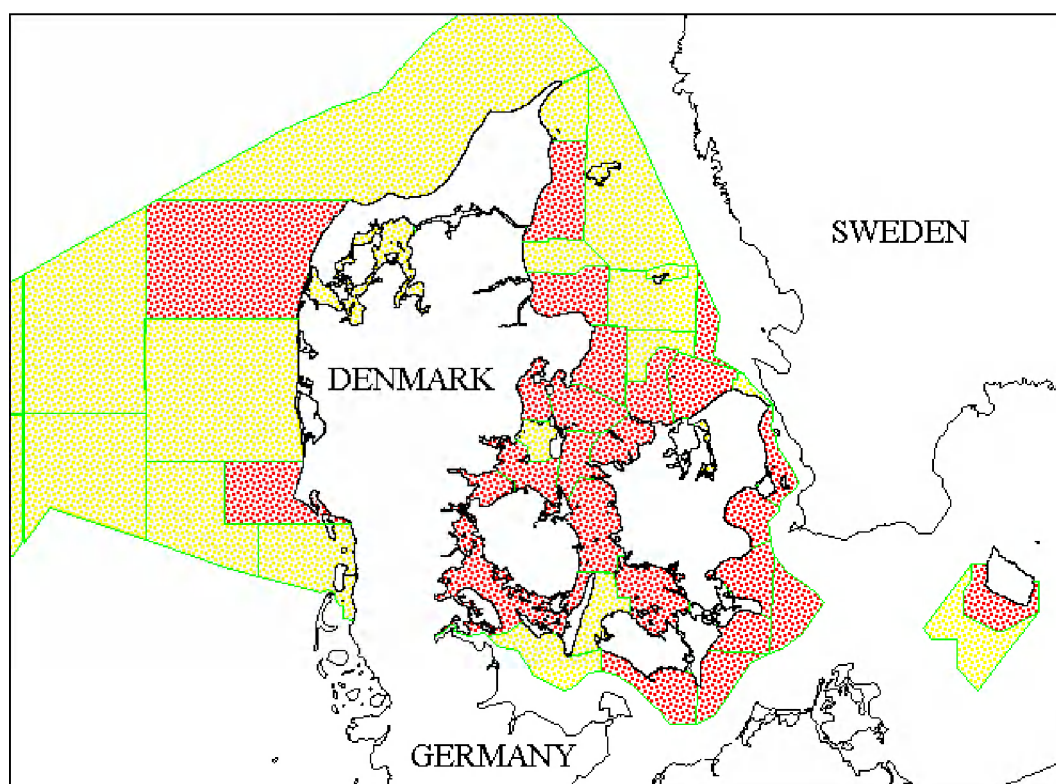
An overview map of the bottom sediments around Denmark and western Sweden in scale 1:500,000 was published in 1992 in a cooperation between the National Forest and Nature Agency, the Geological Survey of Denmark, and the Geological Survey of Sweden.

A detailed map of the Flensborg Fjord area was published in 1994 by the Geological Survey of Denmark.

A surface sediment map from the Femer Bælt - Arkona Basin in scale 1:200,000 was published in 1996 by the Geological Survey.

A surface sediment map from Jutland Bank, North Sea was published in 1997. Some of the most important stone reefs in Danish waters were mapped in 1990–1996 using shallow seismic equipment, side scan sonar, SCUBA-divings and sampling. The project is a cooperation between the National Forest and Nature Agency, the Geological Survey of Denmark, and the University of Copenhagen. Two reports have been published until now. The reports include surface sediment maps, gravel and stone concentration maps, and descriptions of the biology in the areas.

Figure 5.2. Mapping programme in Danish Waters. Dark shaded areas indicate where surface sediment maps have been prepared during the reconnaissance mapping programme (unpublished and published data).



Information and ordering: Skov- og Naturstyrelsen (= National Forest and Nature Agency), Haraldsgade 53, DK-2100 København, Denmark. Tel. +45 39472252, E-mail PEN@sns.dk. Or Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 København NV, Denmark.

5.5 Estonia

Resource mapping: There are four proven deposits of sand and gravel which could be of interest for exploitation in the coastal waters of Estonia (Hiimadala, Naissaare, Praugli and Ikaalo).

Published maps: See Figure 5.3. See also Lithuania and Latvia.

Information: Contact Dr Rein Raudsep, Research Director, Eesti Geoloogiakeskus, Kadaka tee 80/82, EE 0026 Tallinn, Estonia. Tel +372 6579661. Fax +372 6579664.

5.6 Finland

Marine geology has been included in the normal activities of the Geological Survey of Finland (GSF) already for four decades, covering various aspects ranging from Quaternary stratigraphy to geophysics and geochemistry of recent sediments.

Staff: A permanent marine geological staff of seven persons is employed for seabed and resource mapping and for special contract commissions, including cable route surveys, etc.

Additional personnel are employed for the field season. Furthermore, one person has the responsibility of national and international marine geological coordination and research, with two additional persons employed for the duration of the EU-funded BASYS project.

Equipment: The GSF has two research vessels (13 m and 40 m long, respectively) and several smaller craft for coastal, river and lake work, as well as equipment to cover most aspects of marine geological research:

- positioning systems: Motorola Miniranger MRDP, Syledis, DGPS (Magnavox, Trimble);
- reflection and refraction seismics (profiling) utilising air guns, ELMA electromagnetic sound source;
- MD DSS multi-purpose acoustic system with pinger and chirp options;
- Krupp Atlas Deso 10 and Furuno 881 echo- sounders;
- 100 and 500 kHz Klein side-scan sonars;
- vibro-hammer corer (6/12 m);
- piston corers;
- various gravity corers;

- various grabs;
- underwater video and photo cameras;
- SCUBA diving equipment.

Mapping: The seafloor mapping programme is divided into two separate activities. The detailed coastal work with almost 100 % acoustic (side-scan sonar) coverage is based on working maps at a scale of 1:20,000 (100 km² per map). These maps, covering almost the entire coastal area of the Gulf of Finland, are digitised and hard copies are produced on demand at a scale of 1:50,000 or 1:100,000. Detailed mapping of seabed sediments will be extended further west to cover the Åland Archipelago and also north along the coast of the Bothnian Sea. More generalised maps over the Finnish EEZ have been compiled for various purposes. See the map in Figure 5.4.

Data on exploitable sand and gravel resources are extracted from the mapping programme and from dedicated studies. Cable and harbour surveys are also included in the overall activities of GSF.

Information: Geological Survey of Finland, 02150 Espoo, Finland. Tel. +358 20 55 011, Fax +358 20 55 012, e-mail: first name.family name@gsf.fi.

5.7 France

Staff: IFREMER is in charge of offshore mapping: five geologists work on the continental shelf, supported by ten university staff. Cooperation exists with BRGM—in charge of onshore geological mapping—to integrate IFREMER marine data in coastal maps published by BRGM.

Equipment: The French marine geological community is essentially oriented towards deeper water activities. However, for shelf research and coastal management IFREMER has three 25 m coastal research vessels (two Atlantic/Channel, one Mediterranean), while another five similar vessels are run by universities.

Relevant types of IFREMER equipment are:

- very high resolution seismics;
- D-GPS positioning systems;
- side-scan sonar;
- multibeam for shelf;
- various corers;
- grabs.

Budget: at present variable.

Figure 5.3. Map of the Estonian Continental Shelf showing coverage of published marine geological maps

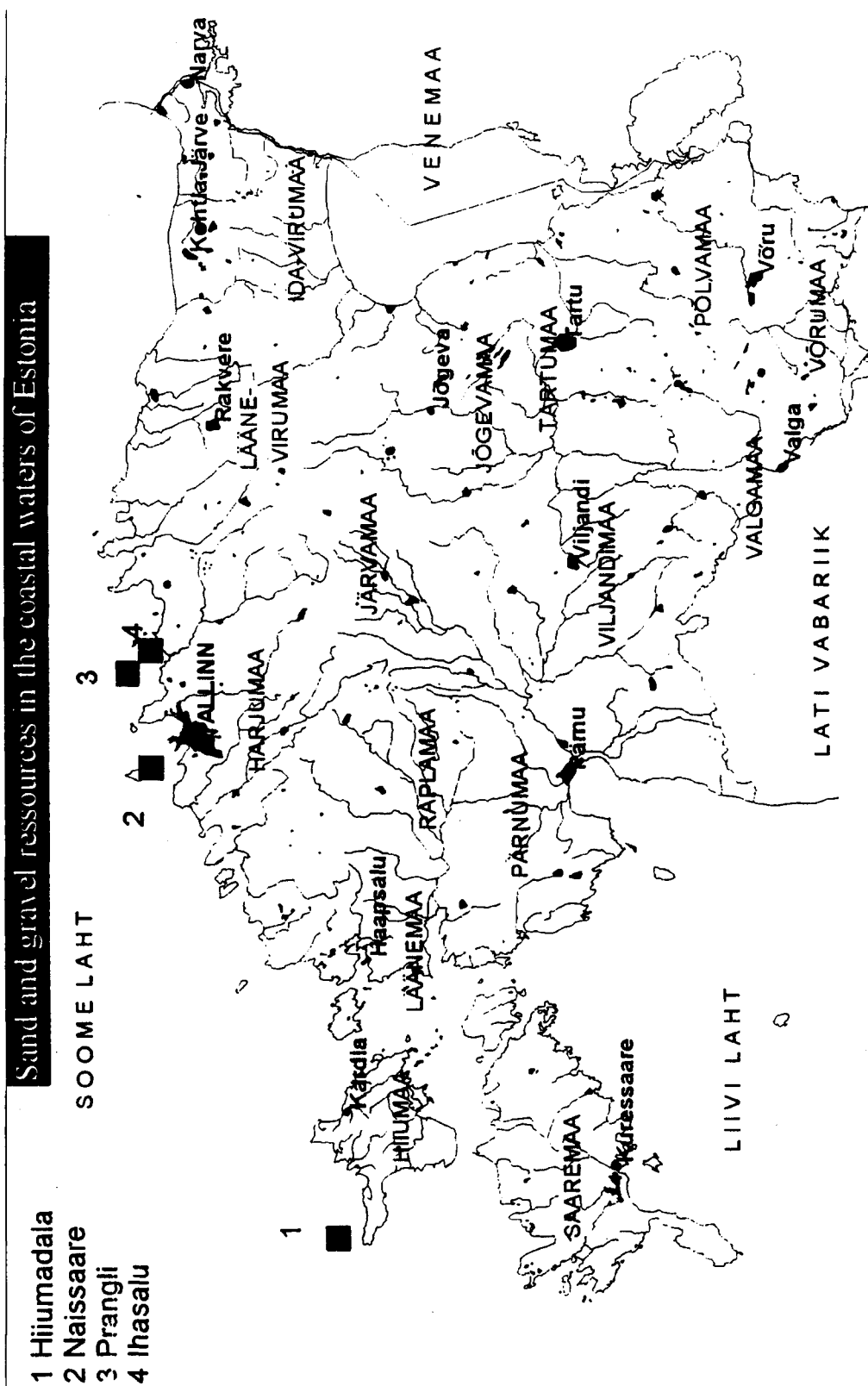
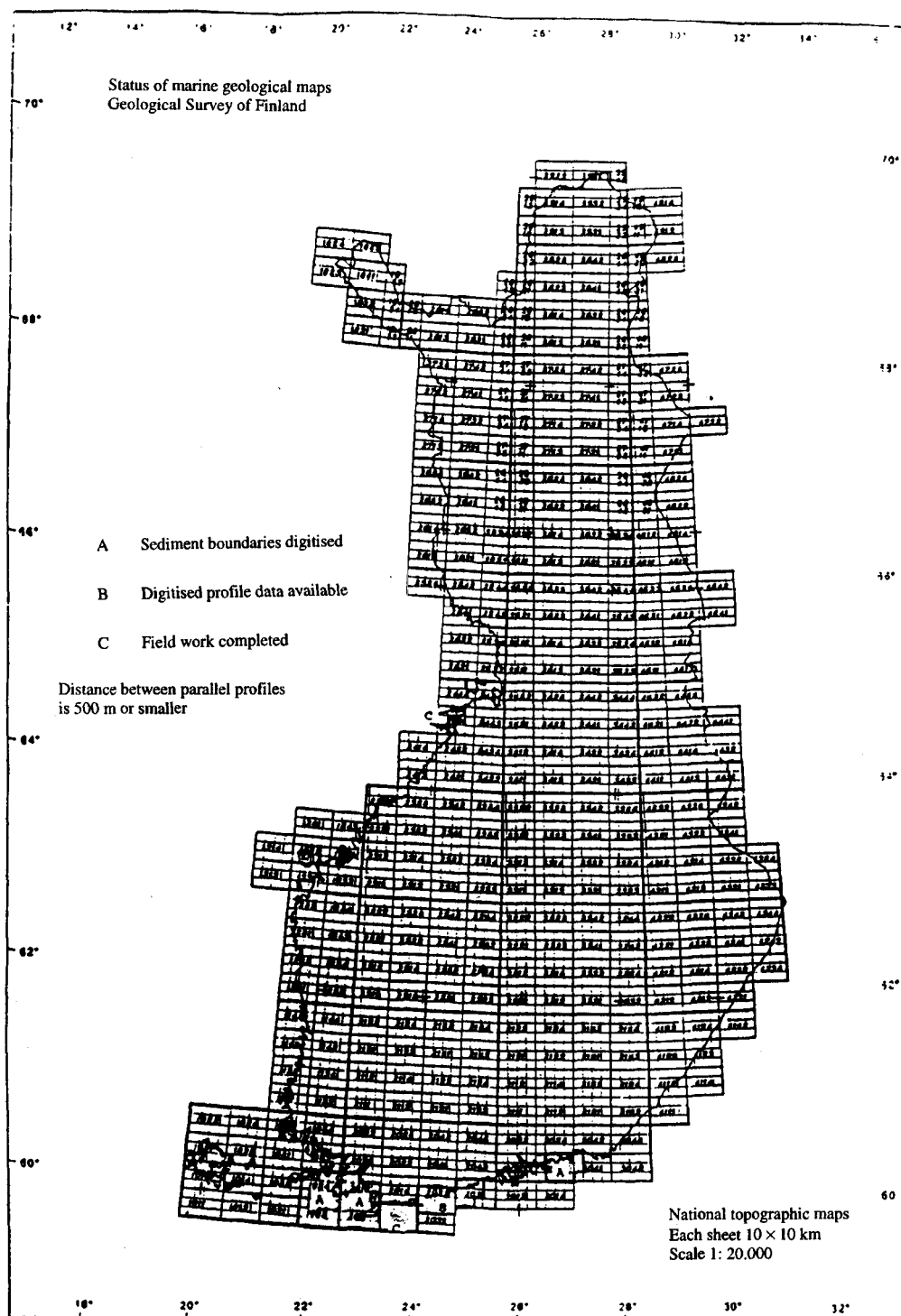


Figure 5.4. Map of the Finnish Continental Shelf showing coverage of published marine geological maps.



Published maps: (see the map (Figure 5.5) on surficial geology maps):

- A geological map (1:1,500,000) of the continental shelf of France (BRGM, 1980).
- A geological map of the North Sea/Channel area (1:250,000).
- Sediment maps (1:500,000), two sheets “La Manche” and “Le Golfe de Gascogne” (BRGM IFREMER).
- 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 cited.
- Superficial sediment map off Boulogne-sur-Mer (1:43,400) by C. Augris, P. Clabaut, S. Dewez, and J.P. Auffret (1987), published by IFREMER + Région Nord - Pas de Calais.
- Superficial sediment map and geological map of the northern part of the “Baie de Douarnenez” (1:15,000) by C. Augris, E. Houlgatte, and J. Rolet (1988), published by IFREMER + Dépt. du Finistère.
- Superficial sediment map off Calais-Dunkerque (1:43,400) by C. Augris, O. Vicaire, and P. Clabaut (1989), published by IFREMER + Région Nord - Pas de Calais.
- Morphological and sediment map of the inshore zone between Dieppe and Le Tréport (Seine Maritime) (1:20,000) by C. Augris, P. Clabaut, and J-F. Bourillet (1993), published by IFREMER + ESTRAN + EDF.
- Map of the superficial deposits in the marine area of Nord - Pas de Calais (1:100,000) by C. Augris, P. Clabaut, and B. Tessier (1995), published by IFREMER + Région Nord - Pas de Calais + Université des Sciences et Technologies de Lille.
- Thematic atlas of the marine environment in the Bay of St. Briec (Côtes d’Armor) coordinated by C. Augris and D. Hamon (1996), 72 pages, twenty maps, published by IFREMER.
- Map of the superficial deposits around Ile de Croix (Morbihan) (1:20,000) by C. Augris, T. Garlan, and O. Vicaire (1996), published by SHOM + IFREMER.

Future mapping programmes: Mapping of the French EEZ, both of continental France and the overseas territories, is of prime interest for the coming years. Around the mainland, several cruises devoted to EEZ exploration have been carried out and a set of six bathymetric charts at a scale of 1:250,000 is being produced between the mainland and Corsica.

Ordering: IFREMER publications may be ordered from IFREMER, Centre de Brest, B.P. 70, 29280 Plouzané, France and from IFREMER Headquarters, Technopolis 40, 155 rue J.J. Rousseau, 92138 Issy-les-Moulineaux, France. BRGM publications may be ordered from BRGM, Orleans, France.

5.8 Germany

Staff: The Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency, BSH) has made several persons available for mapping of surface and near-surface sediments with regard to navigation, morphology, sediment movement, pollution monitoring, and the effects of seabed mining and offshore infrastructures. Mapping in the German sector of the North Sea is done by BSH itself, while similar activities in the Baltic are, on request from BSH, carried out by IOW (Institut für Ostseeforschung, Warnemünde). Exploration for mineral resources is within the competence of the Geological Surveys. Staff from the Geological Surveys are made available on an *ad hoc* basis.

Equipment: Standard equipment is employed by BSH and the other institutes. BSH equipment includes grabs, 3-m and 6-m vibrocorers, side-scan sonar, sub-bottom profiler, boomer, chirp profiler, and hydro sweep. Processing units include Sonar Enhancement System and ISIS. Data storage is on EPC records and/or magneto-optical discs.

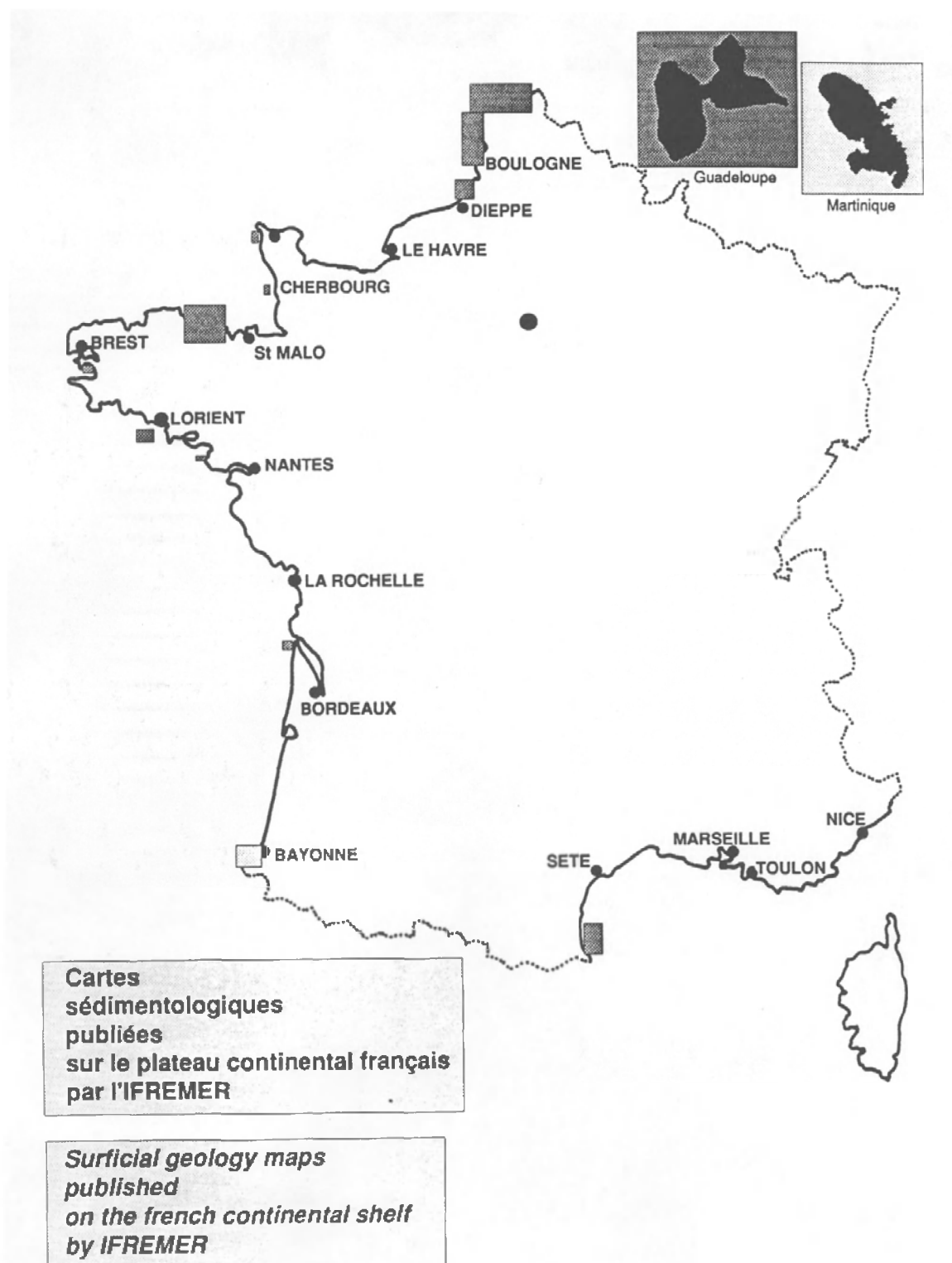
Budget: No data available.

Published Maps (see Figure 5.6):

- 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 1:1,000,000. Content: representation of the grain size distribution of the surficial sediments.
- Figge, K. 1981. Karte der 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.
- 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 on Boomer records regarded as the base Holocene (Unpublished but open file).
- Tauber, F., and Lemke, W. 1995. Sediment distribution in the western Baltic Sea, map sheet Darss. Scale: 1:100,000. Deutsches Hydrogr. Zeitschr., 47/3, pp. 17–78, 1 map.

Further sheets are in preparation.

Figure 5.5. Map of the French Continental Shelf showing coverage of published marine geological maps.



- Figge, K. *et al.* (in prep.). Morphological investigation of the dredging holes west of the island of Sylt and also natural regeneration of dredging holes in the North Sea and in the Baltic.

Other maps and publications:

- Bundesanstalt für Bodenforschung. 1973. Geologische Übersichtskarte 1:200,000, Blatt CC2310 Helgoland. Hannover. Area: German Bight, western boundary 7°20'E, northern boundary 54°24'N. Content: grain size distribution of the seabed sediments based upon maps of the Deutsches Hydrographisches Institut.
- Figge, K., and Zeiler, M. (in prep.). Materialinventur an der deutschen Nordseeküste. Content: Resource mapping along the German North Sea coast.

Maps on scale 1 to 25,000 of the Wadden Sea area are available from the Geological Surveys of Lower Saxony and Schleswig-Holstein.

See also the map with beach recharge borrow locations in the Baltic.

- Ludwig, G., and Figge, K. 1979. Schwermineralvorkommen und Sandverteilung in der Deutschen Bucht. Geol. Jb. D32, pp. 23–68, ten maps, Hannover. Content: heavy mineral and sand distribution.

Ordering: Seabed sediment maps may be obtained from the Bundesamt für Seeschifffahrt und Hydrographie, Postfach 301220, D-20305 Hamburg. Other geological maps may be obtained from the Bundesanstalt für Geowissenschaften und Rohstoffe, Postfach 510153, D-30631 Hannover, regional geological surveys or marine research institutes.

5.9 Ireland

Staff: The Marine Section (one person) of the Geological Survey of Ireland is in charge of seabed sediment and resource mapping. However, for resource mapping projects, university staff are involved occasionally.

Equipment: A few weeks of ship time per year on a state-funded research vessel using survey equipment including positioning systems, high-resolution seismics (sparker, boomer), pinger, side-scan sonar, and dredge samplers.

Map content: Most of the mapping results are shown on various thematic maps. On surface sediment distribution maps, areas are classified according to grain size distribution in mud, sand, and gravel. Outcrops or rocks 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 BGS are at a scale of 1:250,000. The Geological Survey of Ireland (GSI) has recently carried out a campaign of spot seabed sampling between Dublin and Tuskar Rock, extending out to the 15-m isobath.

Seabed sediment maps: Seabed sediment maps of the Anglesey, Cardigan Bay, and Nympe Bank sheets in the Irish Sea, produced in association with the BGS, have all been published. See the continental shelf maps figure in the UK paragraph (Figure 5.14). Work on the Galway Bay area sheet (1:250,000) has been completed. South coast mapping between 8 °W and 10 °W (the Cork – Mizen Head sheet) was in progress. Recent detailed resource mapping activities were concentrated in the Waterford estuary and off the coasts of Clare and Kerry.

5.10 Latvia

Published maps: Bottom sediments of the Gulf of Riga, explanatory note to the bottom sediments map, scale 1:200,000 by O. Stiebrinš and P. Vāling, Riga (1996). Jointly published by the Geological Surveys of Latvia and Estonia. See also Lithuania.

The first map published of the bottom sediments of the Gulf of Riga (scale 1:200,000) has recently been compiled using data from the geological mapping programme (1984–1992) and incorporating generalised results of earlier studies. The map shows the distribution of the bottom sediments and their contemporary conditions of sedimentation. The areas of the occurrence of ferro-manganese nodules are indicated. The explanatory note includes the descriptions of the grain size of the bottom sediments, their mineralogical and chemical composition, physical-mechanical properties, geochemical characteristics, etc., based on the data from more than 4,700 stations.

Information: Contact Dr Oskar Stiebrinš, Geological Survey of Latvia, St Eksporta iela 5, Riga, LV-1010, Latvia. Tel. +371 7320015.

The map shows the coastal region of Stralsund, Germany, with the Baltic Sea to the north. Key features include the islands of Rügen and Hiddensee, and the city of Stralsund. The map is overlaid with a grid and includes labels for various locations and features.

Labels on the map:

- Stralsund
- Stralsund II
- Stralsund III
- Stralsund IV
- Stralsund V
- Stralsund VI
- Stralsund VII
- Stralsund VIII
- Stralsund IX
- Stralsund X
- Stralsund XI
- Stralsund XII
- Stralsund XIII
- Stralsund XIV
- Stralsund XV
- Stralsund XVI
- Stralsund XVII
- Stralsund XVIII
- Stralsund XIX
- Stralsund XX
- Stralsund XXI
- Stralsund XXII
- Stralsund XXIII
- Stralsund XXIV
- Stralsund XXV
- Stralsund XXVI
- Stralsund XXVII
- Stralsund XXVIII
- Stralsund XXIX
- Stralsund XXX
- Stralsund XXXI
- Stralsund XXXII
- Stralsund XXXIII
- Stralsund XXXIV
- Stralsund XXXV
- Stralsund XXXVI
- Stralsund XXXVII
- Stralsund XXXVIII
- Stralsund XXXIX
- Stralsund XL
- Stralsund XLI
- Stralsund XLII
- Stralsund XLIII
- Stralsund XLIV
- Stralsund XLV
- Stralsund XLVI
- Stralsund XLVII
- Stralsund XLVIII
- Stralsund XLIX
- Stralsund L

5.11 Lithuania

Mapping: The programme for marine geological mapping at a scale of 1:500,000 in the Lithuanian EEZ of the Baltic Sea area was formulated in 1992. This is a component part of the geological research programme to be carried out by the Geological Survey of Lithuania between 1993 and 2019. The main objective is the assessment of geological conditions and ecological vulnerability of the sea bottom in the whole Lithuanian nearshore area.

The first marine geological mapping project (M. Repecka, Z. Gelumauskaite, A. Grigelis, etc.) was undertaken between 1993 and 1996. The geological-geophysical research on geological structure, bottom relief, genesis, recent bottom dynamics, and human influence was done in the northern offshore area (1630 km²) between Klaipeda and Šventoji. The results enabled a set of new geological maps (scale 1:50,000) to be compiled: bedrock geology, Quaternary, geomorphology, bottom sediments, seafloor landscapes.

Published maps: Geological map of the Quaternary deposits of the Baltic Sea bottom and adjacent land areas (1:500,000), six sheets. A. Grigelis, editor in chief, printed by the Geological Institute, St Petersburg/Leningrad, 1990. This is a joint publication by the Lithuanian Geological Institute, the All-Russian Geological Scientific-Research Institute, the Institute of Oceanology of the Russian Academy of Sciences, the Latvian Marine Scientific-Production Exploration, the Institute of Geology of the Estonian Academy of Sciences, the Geological Survey of Lithuania, Geological Exploration of Latvia, the Geological Centre of Estonia, and Russian NW Geological Production Exploration.

In a joint Swedish-Lithuanian project (GEOBALT) two maps at a scale of 1:500,000 dealing with bathymetry and bottom sediments of the central Baltic Sea, respectively, were published at the end of 1998 (see further under Sweden).

Information: Contact Prof. Dr Hab A. Grigelis, Geological Survey of Lithuania, Seucenos 13, 2600 Vilnius, Lithuania. Tel/Fax. +370 2 236 408. e-mail: grigelis@geology.aiva.lt

5.12 The Netherlands

Staff: At the Netherlands Institute of Applied Geoscience TNO (NITG-TNO) there are fifteen to twenty persons available on a part-time basis for the offshore geological mapping programmes. One third of them are scientists, the others technicians and assistants. The North Sea Directorate of the Water Management Authority, Ministry of Public Works and Transport provides ship time on their ships and the positioning staff.

Equipment: The North Sea Directorate has several multi-purpose vessels that are made available for mapping programmes several weeks a year.

The principal types of NITG-TNO equipment used for mapping and surveying purposes are:

- various Van Veen and Hamon (gravel) grabs;
- electric and hydraulic vibrocorers;
- a combined airlift-counterflush drilling/vibrocoring system (Geodoff II) and an experimental airlift-counterflush system using flexible hoses (Roflush);
- various piston and box corers;
- high-resolution seismics and acoustics with watergun, sleeve gun, sparker, boomer, chirp profiler, HF profiler, and pinger sources with single and multi-channel streamers and digital data processing facilities;
- underwater camera system;
- side-scan sonar systems (also from North Sea Directorate);
- various positioning systems (North Sea Directorate and NITG-TNO).

Budget: A considerable effort is spent each year by NITG-TNO on marine geological and resource mapping programmes. The equivalent of five to six full-time staff members is engaged in the 1:250,000 and 1:100,000 map series alone. As stated above, ship time is provided by the North Sea Directorate.

Seabed sediment maps (1:250,000): Seabed sediment maps are part of the 1:250,000 geological reconnaissance map series. Other parts are the Solid maps with information on pre-Quaternary sediments and the Quaternary maps showing details of the Pleistocene geology, deposits and their properties. The series was originally set up by the British Geological Survey (BGS). Several sheets straddling median lines have been made together with the British and Belgian Surveys and others.

The seabed sediment map sheets include a main map in UTM on scale 1:250,000 showing the uppermost 10 cm of the seabed following the Folk classification system and various subsidiary maps. These maps on scale 1:1,000,000 include the seismic line grid, thickness of Holocene deposits, depth to the base of the Holocene deposits, distribution of (older) Holocene formations, mean grain size, biogenic and lithic gravel content and/or carbonate content of the sand fraction or lead content of surface sediments, a key to colours and symbols, and a short description.

The complete series will consist of nine mapped areas with three maps each. Six areas have been mapped now while in a seventh area (Terschelling Bank 53–54°N, 4–6°E) mapping is in progress. See map in Figure 5.7. All seabed sediment maps are also available in digital format.

Geology/superficial resource maps (1:100,000): This map series will appear in digital format. A few sheets have been printed. Printed map sheets have geological information on one side and resource information on the other.

The geological information includes a fence diagram with the geological structure of the younger layers (1:1,000,000), a bathymetric map on scale 1:150,000, and 1:250,000 maps on geomorphology, on the occurrence of Holocene formations, on the thickness of Holocene and of Pleistocene deposits, a fence diagram of older sediments, nature and depth of the top Pleistocene and of the top Tertiary, and a short description, i.e., of the stratigraphic units.

The resource information includes a map of the mean grain size and mud content of the uppermost metre on 1:100,000, a similar map of the metre below on a 1:150,000 scale, and 1:250,000 maps on the carbonate content in the first and second metres, on lithic and biogenic gravel contents in the first and second metres, and on interfering (clayey) layers in the first and second metres and finally a short note on methodology, sediment classification, and on the availability of further information.

Three map sheets along the southwesterly coast of the Netherlands are available now in digital format; two of them have been printed (Rabsbank, Buitenbanken). All forthcoming maps will be in digital format only. Four other areas are being mapped at present. Inshore map sheets will be completed first. See the map in Figure 5.8.

Other resource maps: Several 1:1,000,000 scale maps of the whole of the Dutch sector of the North Sea have been made over the last fifteen years or so. Some of them have been printed; most are in digital format only. Some are single-value maps showing the distribution of specific (near)surface layers. Surface sediment maps dating from 1980 and 1986 present information on the composition of the uppermost 50 cm of the seabed using the international phi (Wentworth) units.

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

Increasing demand for the latest information on offshore sand resources is leading to updates of existing, scattered syntheses on the nature and suitability of sand layers, at first down to 1 m and to 2 m below the seabed, followed by information on deeper sand layers and information from the whole of the Dutch sector.

Maps on submarine geomorphology: In 1989, the Ministry of Transport and Public Works published a series of four morphological maps of the Dutch nearshore areas on a scale of 1:250,000. Authors are van Alphen and Damoiseaux.

Geochemical maps: Geochemical distribution maps of surface sediments, as outlined in the ICES WGEXT report in 1996, are available for the 1:250,000 Oyster Grounds sheet and are in preparation for the Terschelling Bank sheet. Moreover, to facilitate correlations with existing BGS results, samples for geochemical analyses have been taken along the UK/NL median line.

Ordering: Seabed sediment, geology/ superficial resource maps and other marine geological maps may be ordered from the Netherlands Institute of Applied Geoscience TNO (NITG-TNO), Department of Geomarine and Coast, P.O. Box 80015, 3508TA Utrecht, the Netherlands. Other resource and morphological maps of the Netherlands North Sea, if published, may be obtained from the North Sea Directorate of Rijkswaterstaat, P.O. Box 5807, 2280 HV Rijswijk, the Netherlands or from NITG-TNO.

Figure 5.7. Progress of the Dutch seabed sediment map series.

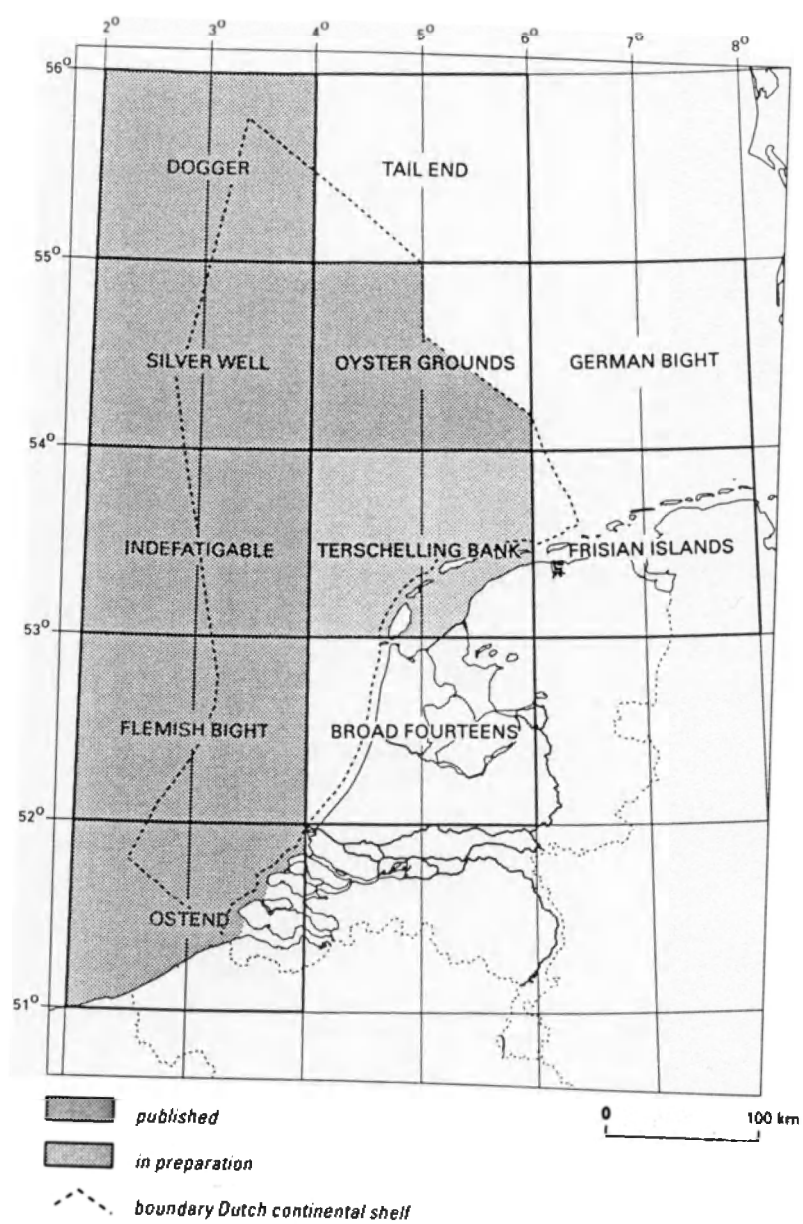


Figure 5.8. Progress of the Dutch geology/superficial resource map series.

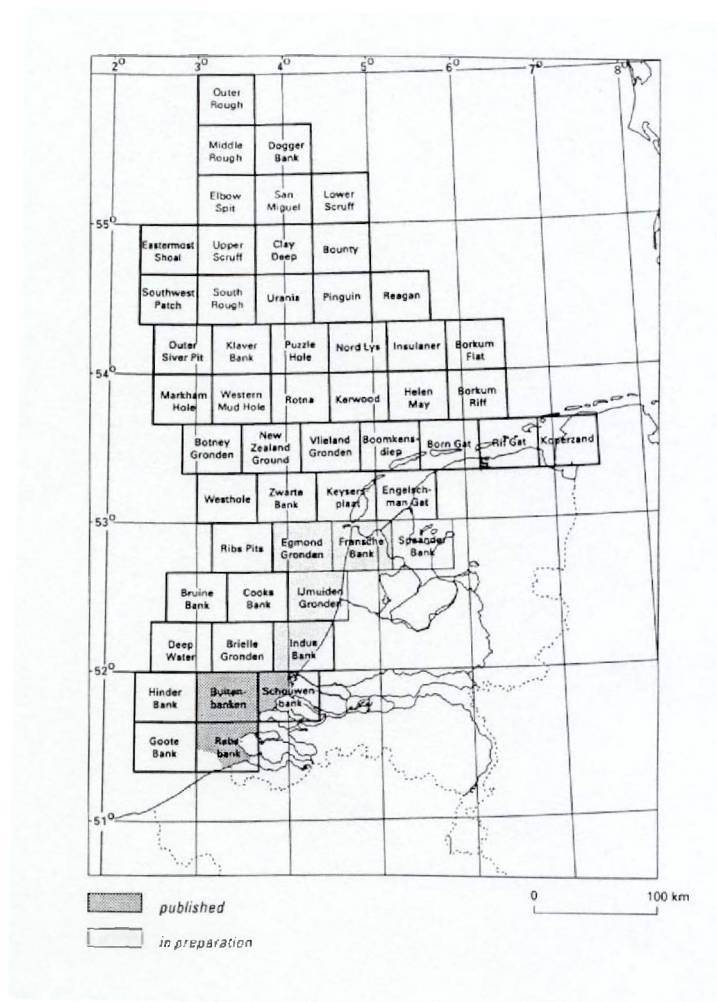
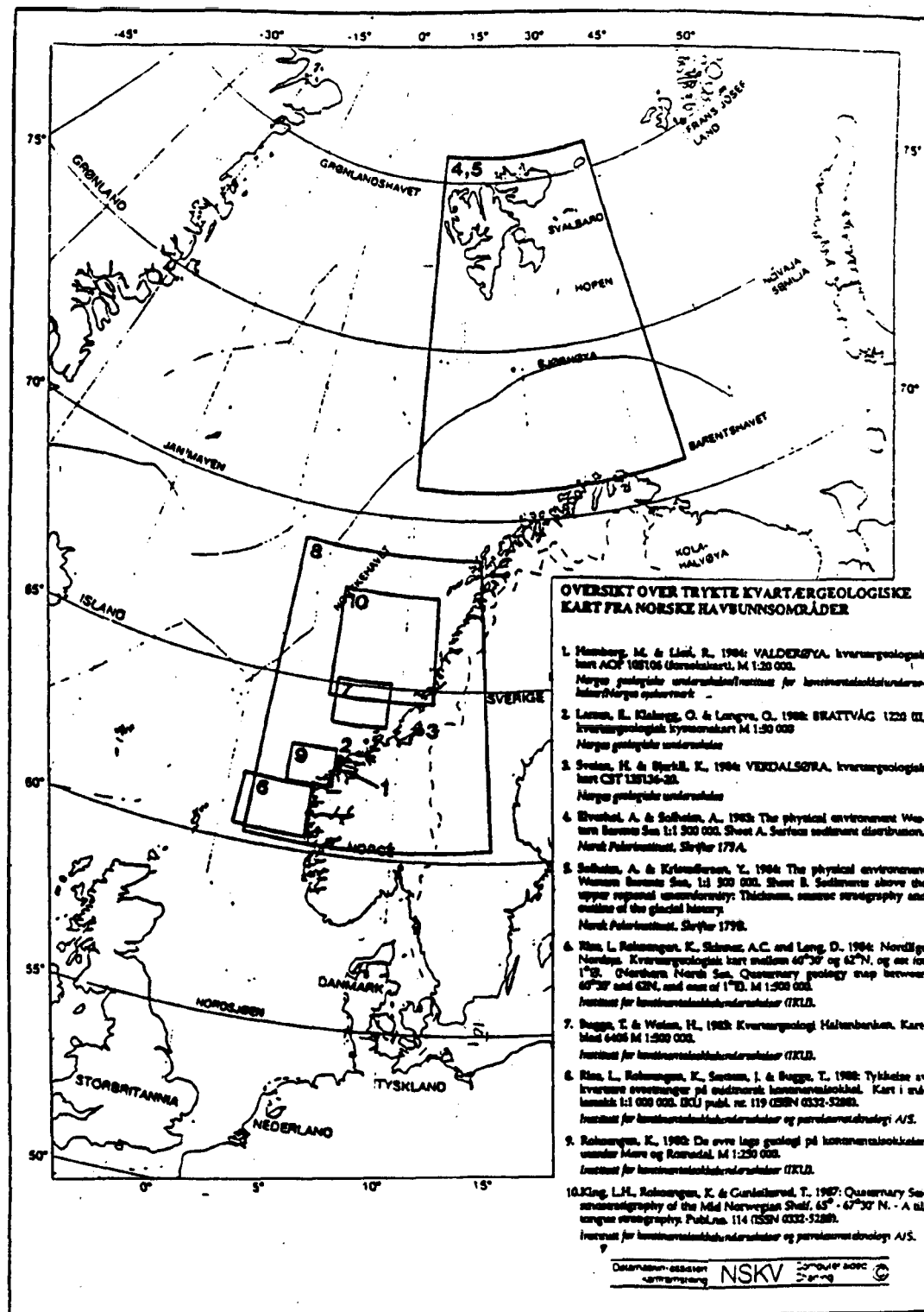


Figure 5.9. Published Quaternary Maps of the Norwegian Continental Shelf.



5.13 Norway

Staff: The Marine Group of the Norwegian Geological Survey consists of around ten people largely involved in geological mapping and related matters. Of these, six persons are scientists.

Equipment: The NGU has a small (55 feet), sandwich-constructed research vessel, operated by three persons in coastal waters. For offshore surveys, larger ships are hired.

The marine mapping programme uses a suite of equipment including:

- high-resolution seismics including airguns, Topas, boomer with recording and data processing facilities;
- grabs, gravity and vibrocores.

Budget: Annual budget is 6–8 million NOK.

Mapping: Seabed sediment maps are published by the Geological Survey of Norway (NGU) at different scales, ranging from 1:20,000 to 1:1,000,000 and show the distribution of the superficial Quaternary sediments according to character and genesis. The maps are published from the different areas where the work is concentrated rather than in the ordinary map series. From the Skagerrak area, a series of maps providing information on seabed sediments and the Quaternary succession is available in digital format. The maps are also published in a NGU report. A seabed sediment map at 1:250,000 scale covering the eastern North Sea Plateau and parts of the south-western slope of the Norwegian Trench has been produced. The map is based on the interpretation of side-scan sonar data, seismic profiles, and shallow core data.

The NGU has published a series of maps of the carbonate sand resources along the western coast of Norway. The maps are published in NGU reports, mostly at a 1:20,000 scale.

Published maps: See the map of Norway (Figure 5.9) with the list of references.

Information and Ordering: Geological Survey of Norway, Division of Marine Geology, Box 3006, N-7002 Trondheim, Norway. Tel: +47 73 904011, Fax +47 73 921620.

5.14 Poland

Organisation and staff: The Polish Geological Institute belongs to the Ministry of Environmental Protection, Natural Resources and Forestry and performs many functions of a national geological survey. The institute is involved in the exploration of the geological structure of Poland and in the evaluation of mineral resources, the evaluation of ground water reserves and quality, as well as investigations of pollution of the lithosphere.

The institute is also responsible for geological mapping of the country. The Polish Geological Institute, with its headquarters in Warsaw, has six regional branch offices.

The branch office of Marine Geology is located in Gdansk and is responsible for the mapping of the Polish Exclusive Economic Zone of the Baltic Sea, the eastern part of the Polish coast, and the northern part of Poland. The main theme of the Marine Geology branch's activities is geological and geochemical mapping, notably of the sea floor, and detailed geological, geomorphological, geodynamic, and ecological investigations of the coastal zone. The branch office has a permanent staff of 38 persons (26 post-graduate geologists with different specialisations, eight technicians, and four administrative staff).

Within the branch office of Marine Geology is a regional section of the Central Geological Archives which collects and manages offshore and coastal zone data and investigation results as well as data on mineral resources including raw materials.

Equipment: Equipment used for mapping by the Polish Geological Institute includes:

- positioning systems: DECCA, Syledis, differential GPS;
- grabs: Van Veen and Petersen;
- 6-m vibro and gravity corers;
- Niemistö and Kajak corers;
- EG & G Boomer;
- Sub-bottom profiler and side-scan sonar;
- Echosounders.

Mapping: The Geological Map of the Baltic Sea Bottom, 1:200,000 (published: 1989–1994)

The Polish EEZ (30,532 km²) was mapped between 1976 and 1990 at a scale of 1:200,000. See the map in Figures 5.10 and 5.11. During 1976–1990 there were carried out about 30,000 km of echosounding profiles and about 7,000 km of shallow seismic (EG&G Boomer) lines; 6051 samples of seabed deposits and 827 cores were taken, and 23 boreholes down to 30 m were made.

The results are presented on twelve map sheets including explanatory booklets in Polish showing the seabed sediments (1:200,000) according to a modified Shepard 1954 classification, developed additionally for sands and with a bathymetric background with 5-m isobaths, geological cross-sections and core profiles, and thematic maps on geomorphology, lithodynamics, sediments 1 m below the seabed, and mineral resources at the scale of 1:500,000. Legends are bilingual: Polish and English.

Figure 5.10. Sand and gravel resources in the Polish Exclusive Economic Zone.

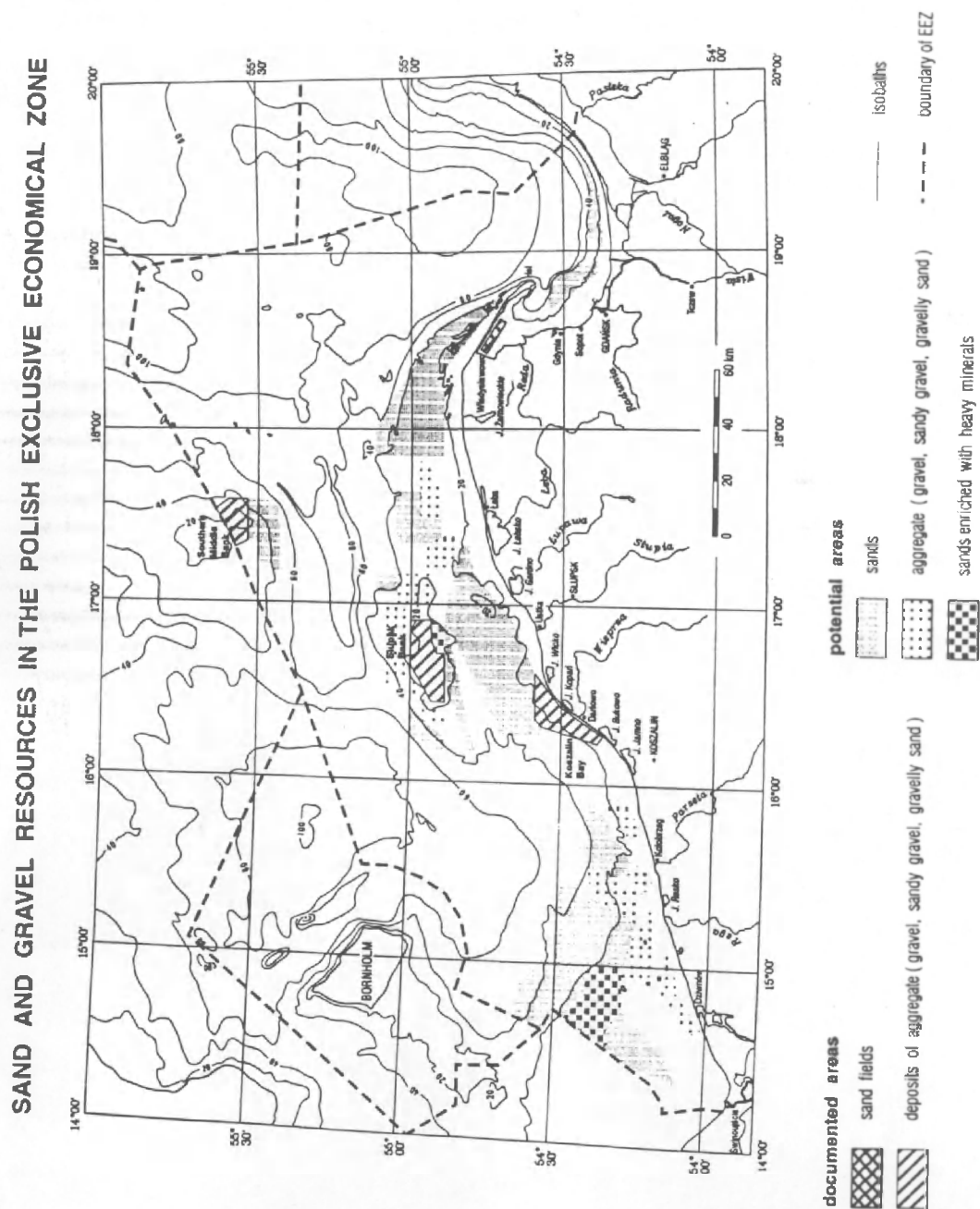
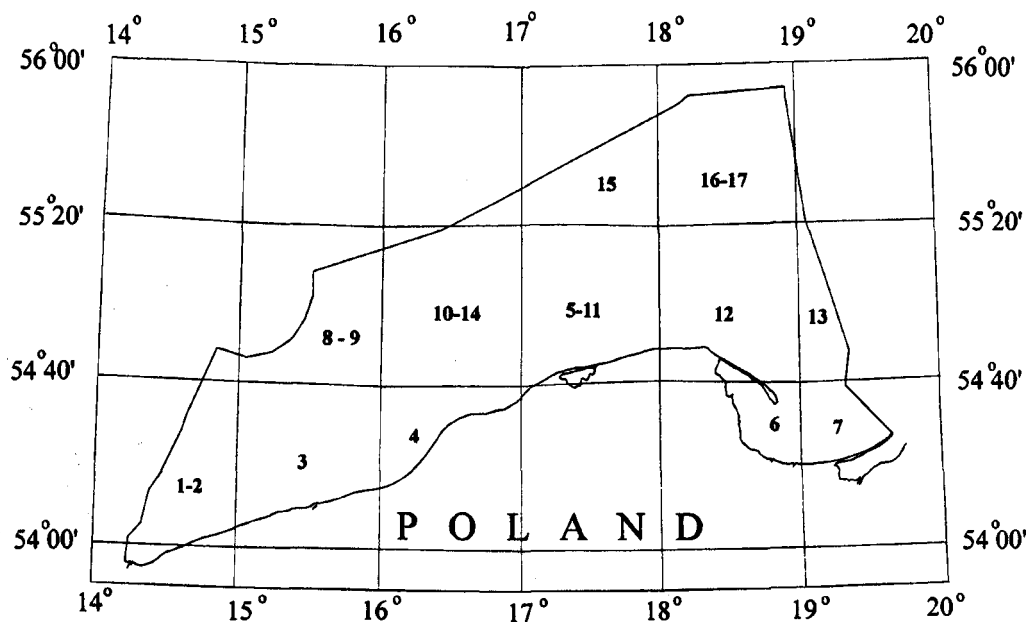


Figure 5.11. Map of the Polish EEZ showing coverage of published marine geological maps.



Map of the Polish EEZ of the Baltic Sea showing coverage of published marine geological maps 1:200 000

sheets	authors
1-2 - Szczecin - Dziwnów	<i>Jurowska Z. , Kramarska R. (1990)</i>
3 - Kołobrzeg	<i>Uścińowicz Sz. (1989)</i>
4 - Koszalin	<i>Michałowska M. , Pikles R. (1990)</i>
5-11 - Łeba - Słupsk	<i>Uścińowicz Sz. , Zachowicz J. (1991)</i>
6 - Gdańsk	<i>Uścińowicz Sz. , Zachowicz J. (1993)</i>
7 - Elbląg	<i>Uścińowicz Sz. , Zachowicz J. (1993)</i>
8-9 - Ronne - Nekso	<i>Uścińowicz Sz. , Zachowicz J. (1993)</i>
10-14 - Ławica Słupska - Ławica Słupska-N	<i>Kramarska R. (1991)</i>
12 - Puck	<i>Pikles R. , Jurowska Z. (1994)</i>
13 - Głębia Gdańska	<i>Uścińowicz Sz. , Zachowicz J. (1993)</i>
15 - Południowa Ławica Środkowa	<i>Pikles R. (1992)</i>
16-17 - Basen Gotlandzki - Próg Gotlandzko-Gdański	<i>Pikles R. (1993)</i>

Geochemical Atlas of the Southern Baltic, 1:500,000
(published: 1994)

During 1991–1993 cores of bottom sediments were taken at 368 stations in a regular grid (10 × 10 km), covering the 30,532 km² of the Polish Exclusive Economic Zone.

The samples were analysed for grain size distribution, TOC, and various elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mn, Ni, P, Pb, S, Sr, V, Zn). The rate of sedimentation was determined in six cores using the ²¹⁰Pb method.

Element distribution in the 0–1 cm surface layer and vertical distribution in selected cores are presented in printed maps. The resulting atlas consists of nineteen colour maps (documentation map plus eighteen mono-element maps printed on a background of bathymetry and sediment granulometry) and an explanatory booklet (Polish and English).

Geological Atlas of the Southern Baltic, 1:500,000
(published: 1995)

The objective of this work was to summarise the existing knowledge about the geological structure of the southern Baltic and about the evolution of this part of the Baltic Basin.

The Atlas contains 34 colour-printed plates (with Polish and English explanations), explanatory text in both Polish and English, and a list of references. Among others the plates show the bathymetry, and the geological structure from the surface of the crystalline basement to the present-day seabed sediments and include an offshore raw materials map. These maps are accompanied by a geological cross-section and profiles of selected boreholes.

Geochemical Atlas of the Vistula Lagoon, 1:150,000
(published: 1996)

During 1994 the Polish part of the Vistula Lagoon (328 km²) was geologically and geochemically mapped by sampling stations within a regular grid of 2 × 2 km.

The geochemical atlas presents maps of the vertical distribution of 24 elements and various ratio maps together with a documentary map, a bathymetric map with 1 m isobaths, a map of bottom sediments following Shepard's (1954) classification, as well as an explanatory text in both Polish and English.

Detailed geological - geodynamical map of the coastal zone (in progress)

The aim of this project is to determine the geological background of the coastal zone evolution. The first stage of the project started in 1993 and was finished in 1997, and covers the coastal zone (1 km inland and 1.5 km offshore) between Dziwnów and Sarbinowo (about 80 km in the western part of the Polish coast) and between Łeba and Gdynia (ca. 100 km in central-eastern part of the Polish coast).

The investigations will determine the Quaternary geological structure—lithology, origin and age of deposits both inland and on the seabed, bathymetry, coastal erosion hazards, land use, land cover, water quality, soils, forests, protected areas, etc. The base topographic map is at a scale of 1:10,000. The second stage of this project, covering the rest of the Polish coast, was started in 1999 and is due to be completed in 2003.

Geological Map of the Baltic Sea Bottom (pre-Quaternary deposits)

The project started in 1996. The aim of the map is to identify the pre-Quaternary deposits up to ca. 300–600 m below the sea bottom in the Polish EEZ. This has involved some 6,000–7,000 km of seismic profiles with multichannel equipment and reinterpretation of previously carried out geological investigations of the deeper structure of the southern Baltic area.

Maps will be produced at a scale of 1:500,000, presenting general lithology, stratigraphy, tectonics and relief of the top of pre-Quaternary formations, as well as geological cross-sections.

Resource mapping: During the past thirty years, geological prospecting and reconnaissance surveys carried out by the Branch of Marine Geology of the Polish Geological Institute has resulted in locating concentrations of various mineral products of the seabed of the Polish part of the Baltic Sea. In some cases they are of potential economic significance. Natural aggregates, i.e., gravel, sandy gravel and gravelly sand, which form deposits on the seabed are the most thoroughly investigated mineral resources in the southern Baltic. To date, three deposits have been documented: the "Slupsk Bank" deposit, the "Southern Middle Bank" deposit and the "Koszalin Bay" deposit. The results are presented in various reports.

Information and ordering: Further information and maps are available at the Polish Geological Institute, (c/o Branch Director) Branch of Marine Geology, Kosciarska 5, 80328 Gdansk, Poland. Tel: +48 58 554 3134; Fax: +48 58 554 2910; e-mail: jzachowicz@pgi.gda.pl.

5.15 Portugal

No data are available.

5.16 Russia (Kaliningrad and St. Petersburg regions)

See Lithuania for multi-national maps of the Baltic seabed. See Section 2 for detailed information on sand and gravel resources. No further information is available.

5.17 Spain

No recent information is available. The map in Figure 5.12 shows the seabed sediment maps completed by 1992.

5.18 Sweden

The Geological Survey of Sweden (SGU), Division of Marine Geology, has a permanent staff of twelve persons (seven marine geologists, one computer-system engineer, two sea captains, two chiefs) and an annual budget of about 11.8 million SEK in 1997 (including the capital costs of the survey vessel). As a consequence of a government decision in 1988 the rate of mapping has increased, so the Swedish EEZ will be mapped at a scale of 1:100,000 by the year 2060, i.e., one map per year. The marine geological mapping programme also contains a special geochemical sub-programme concentrating on natural and anthropogenic substances (about 60 inorganic elements and about 50 organic micropollutants are studied). In 1998 the geochemical database comprised more than 50,000 analyses.

Equipment: The SGU has a twin-hull, sandwich-constructed survey vessel, S/V "Ocean Surveyor", of 509 brt, 38 m long and 12 m wide. The vessel has six 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;
- sector scanning sonar;
- doppler current meter;
- satellite navigator, DGPS, Syledis positioning systems including survey computer;
- seven work-stations and 14 PCs;
- shallow seismic system (boomer, sparker, sleeve gun);
- 50, 100, 500 kHz and 100 kHz chirp side-scan sonars;
- 3.5/7 kHz and 8 kHz chirp pingers;
- echosounders;
- CTD-sonde including processing software;
- vibro-hammer corer (6 m);
- piston corers (3/6 m);
- gemini corer and gravity corers including sub-sampling devices;
- grabs;
- underwater video, sea-floor camera;
- radiometer including processing software.

Map content: Maps are published by the Geological Survey of Sweden (SGU) at a scale of 1:100,000 and show the distribution of the surficial Quaternary deposits according to character and genesis. Each map sheet covers an area of 2500 km² and is accompanied by a subsidiary map at the same scale showing the stratigraphy of selected geological sections of the mapped area. These two maps are accompanied by a description including photos, diagrams, and thematic maps. These maps are produced mainly at a scale of 1:200,000 and show, within the map area, the distribution of pre-Quaternary rocks, till, glaciofluvial deposits, sand volumes, thickness of postglacial and glacial clays, about 60 inorganic elements and about 50 organic micropollutants of environmental interest, coring sites, surface sample sites, and tracklines. The maps are projected in Gauss with both the Swedish grid net 2.5c°W, 1938 and the longitude and latitude system (Swedish datum).

Published maps: Currently Sweden has mapped 14 % of the Swedish EEZ (see maps in Figures 5.13 and 5.14). The results are published in five maps from the Sound at a scale of 1:50,000 (SGU Rapport och Meddelanden, no. 13), three maps from the northern Gotland area in the Baltic Sea (SGU Serie Am, nos. 1–3) and three maps from the Kattegat (SGU Serie Am, nos. 4–6) at a scale of 1:100,000. The Stockholm Archipelago will now be mapped in five sheets. The first were published in 1998 (SGU Serie Am, no. 7). Field work has been completed within two map areas in the southwestern Baltic Sea south of Scania and covering parts of the Arkona Basin and the Bornholm Strait.

An outline map of the solid geology of the Swedish EEZ at a scale of 1:1,000,000 (SGU Rapport och Meddelanden, no. 47) was published in 1986. In cooperation with the National Forest and Nature Agency of Denmark and the Geological Survey of Denmark, a map at a scale of 1:500,000 showing the bottom sediments around Denmark and western Sweden was published in 1992 (SGU Serie Ba, no. 48). In the National Atlas of Sweden, outline sedimentary and bedrock maps at a scale of 1:2,500,000 over the Baltic Sea, the Kattegat and the Skagerrak were published in 1992 (volume "Sea and Coast") and 1994 (volume "Geology"). Within the framework of a joint Lithuanian-Swedish project (GEOBALT), two maps at a scale of 1:500,000 showing the bathymetry and the seabed sediments of the central Baltic Sea, respectively, were published at the end of 1998 (SGU Serie Ba, no. 54). The maps are also available in a CD-ROM version.

Ordering: Maps, with description and English summary, can be ordered from: Geological Survey of Sweden, Box 670, S-751 28 Uppsala, Sweden. Tel. +46 18 179 000, Fax +46 18 179 210, E-mail: kundservice@sgu.se.

[illegible]

Figure 5.13. Map of the Swedish Continental Shelf showing coverage of published marine geological maps.

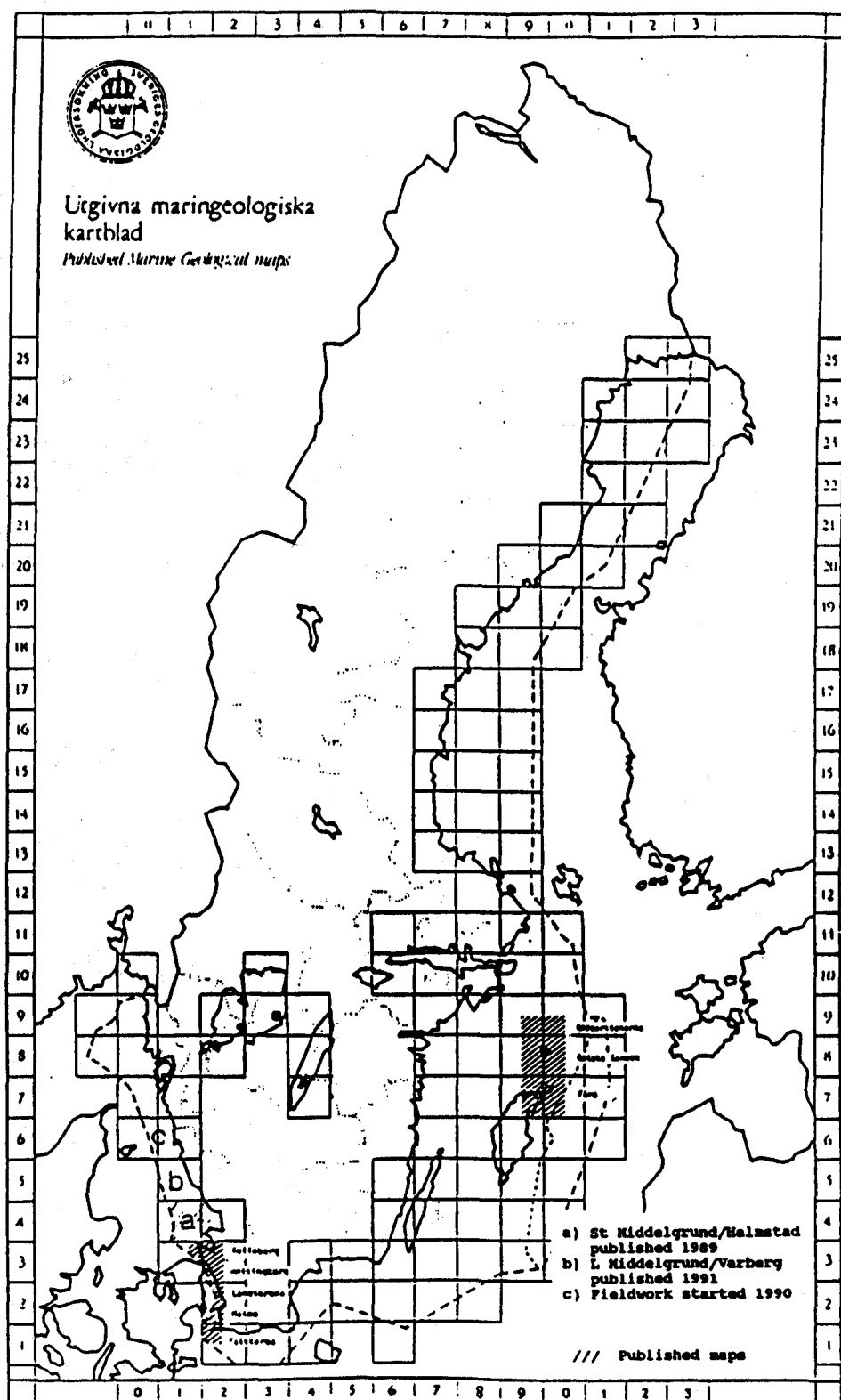
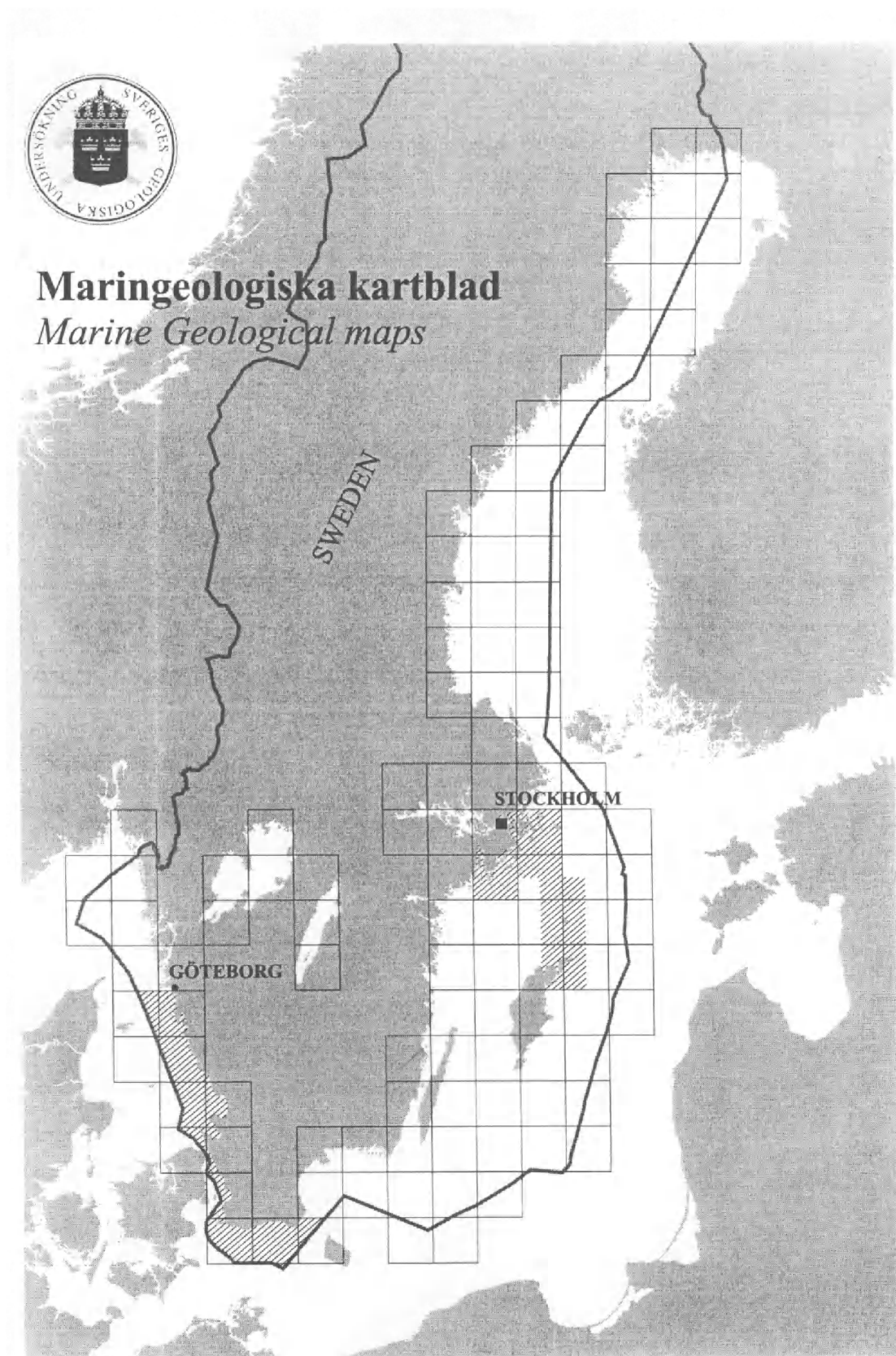


Figure 5.14. Map of the Swedish Continental Shelf showing coverage of published marine geological maps.



Information: Geological Survey of Sweden, Division of Marine Geology, Box 670, S-751 28 Uppsala, Sweden. Tel. +46 18 179 000, Fax +46 18 179 420, e-mail: icato@sgu.se.

5.19 United Kingdom

Staff: The BGS Marine and Coastal Geology Groups consist of around forty people largely involved in geological mapping and related matters. The marine aggregates programme involves a small number of people for specific projects and contracts.

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.

Seabed sediment maps: BGS began mapping the UK continental shelf in 1966. See the map in Figure 5.15. 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. There are 342 maps 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. The regional mapping programme was completed in 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 1:1,000,000 giving details of sediment parameters and calcium carbonate contents.

In addition to the 1:250,000 series, the seabed sediment maps are summarised on two sheets covering, respectively, the northern and southern UK shelf areas, at

a scale of 1:1,000,000 and are described in a summary report.

BGS has also produced a series of eleven offshore geological reports giving a general account of the geology of the UK sector of the northwestern European continental shelf.

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

The maps and reports 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 (0)131 667 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, was a series of desk studies covering most offshore areas of the UK continental shelf. The first of these studies, covering the southern North Sea area, 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 appraisal of resources and the geological interpretation 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 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.

Desk studies have been carried out and published on the Southern North Sea (1986), the South Coast (1988), the East Coast (1991), and the Irish Sea (1992). See the map in Figure 5.16. A further report on the Bristol Channel area is also available and a confidential report covering the Thames Estuary area has been produced for the Crown Estate.

Resource surveys have been undertaken from Great Yarmouth to Southwold, East Anglia (1988), from the Isle of Wight to Beachy Head (1989), and in the Humber region (1992). The resource survey reports describe the distribution of resources and the geological controls which determine their quality and quantity.

Figure 5.15. Areas of recent data collection, offshore UK.

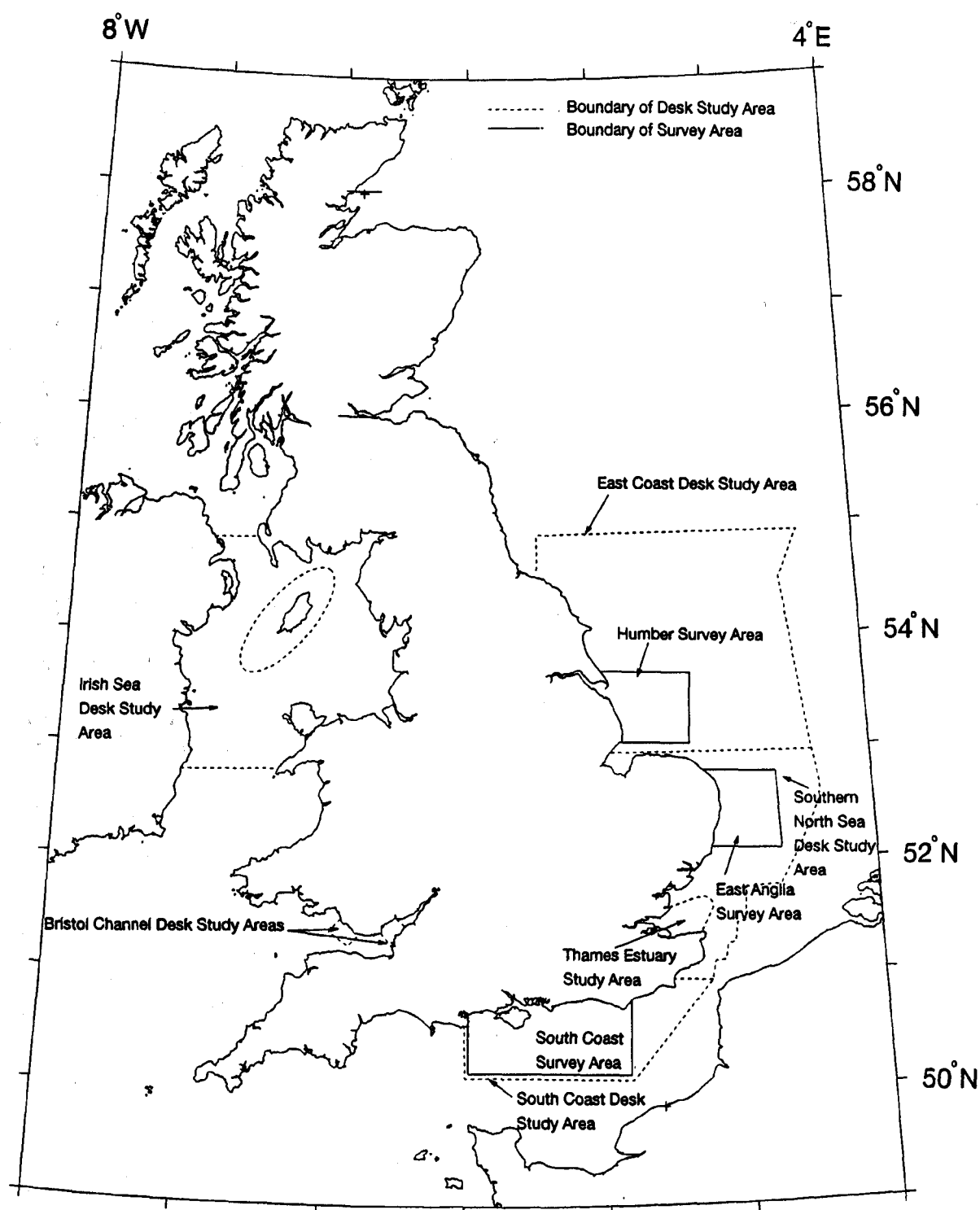
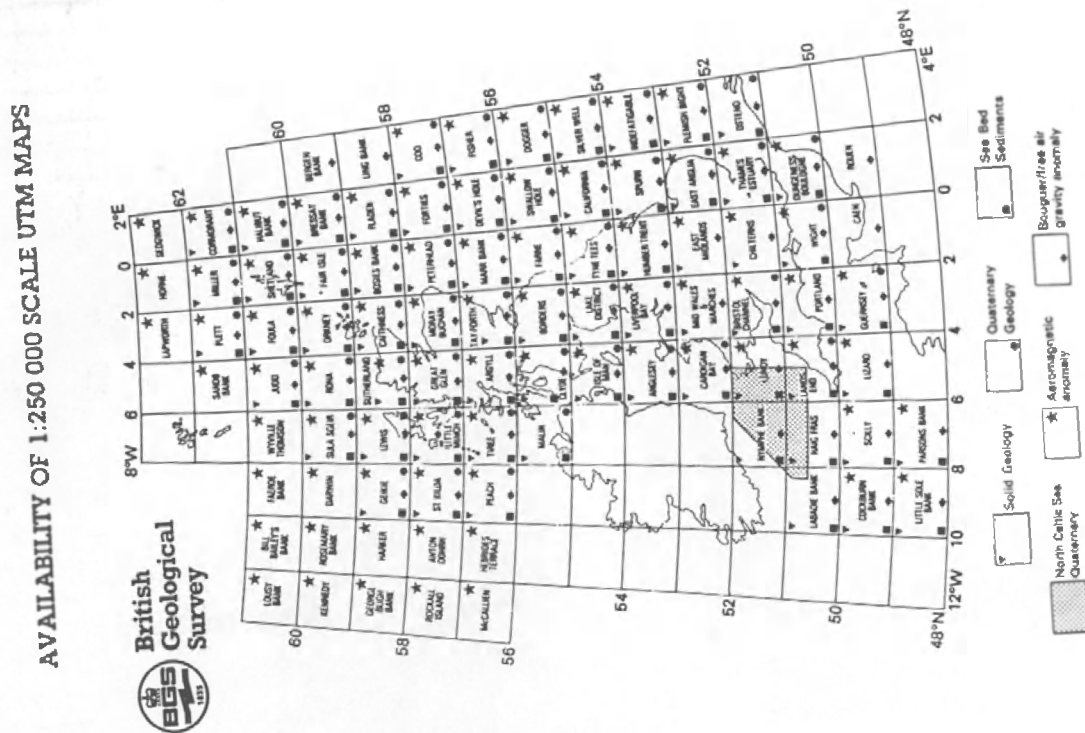
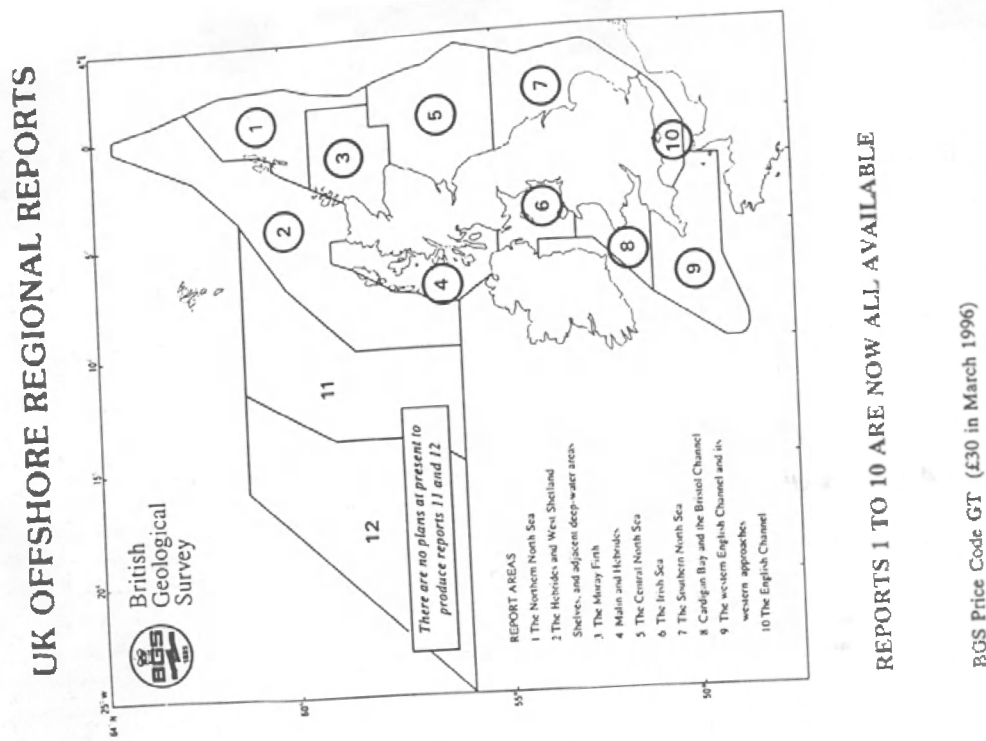


Figure 5.16. Map of the UK showing coverage of published marine geological maps.



The reports are accompanied by colour-printed maps at the 1:100,000 scale or 1:250,000 scale showing: Bathymetry; Geophysical lines and sample stations; Seabed sediments and bedforms; Thickness of superficial sediments; Seismostratigraphy; Thickness of palaeovalley sediments; Geological map; Potential aggregate resources.

In addition to the marine aggregate resource appraisal programme, BGS has undertaken a further desk study to determine volume estimates of offshore sand and gravel, averaged over 4×4 km grid squares, for areas shown on the map. The data are included in a report prepared for the UK Construction Industry Research and Information Association, CIRIA (Humphreys *et al.*, 1996).

Offshore data collection continues in selected areas under a number of research projects and commercial contracts. Areas of data collection recently undertaken by BGS are shown in the map.

Ordering: BGS offshore geological maps are available from:

Sales Desk, British Geological Survey, Keyworth, Nottingham NG12 5GG, Tel: +44 (0)115 936 3241

Sales Desk, British Geological Survey, Murchison House, Edinburgh EH9 3LA, Tel: +44 (0)131 667 1000

BGS Information Office (Orders), Geological Museum, Exhibition Road, London SW7 2DE, Tel: +44 (0)171 589 4090

London Map Centre, (Ordnance Survey Agent), 22–24 Canon Street, London SW1H 0QU, Tel: +44 (0)171 222 2466

Thomas Nelson and Son, (Ordnance Survey Agent), 51 York Place, Edinburgh EH1 3JD, Tel: +44 (0)131 557 3011

Geological Museum, Bookshop (Counter Sales), Exhibition Road, London SW7 2DE, Tel: +44 (0)171 589 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, Tel: +44 (0)171 210 4377

BGS marine aggregate survey reports and maps are available from the British Geological Survey (address above). The reports are priced at publication costs (approximately £130 per report).

CIRIA reports are available from:

CIRIA, 6 Storey's Gate, Westminster, London SW1P 3AU.

5.20 United States

Staff: There is at present no comprehensive effort at offshore mapping of sand and gravel resources. The mapping effort is largely but not completely limited to the re-analysis and integration of existing data and samples. Further information is not available.

Equipment: Not applicable for historical surveys, as outlined above. Otherwise no information is available.

Budget: No information is available.

Published maps: Sand and gravel maps have been published at a scale of 1:1,000,000 by Mineral Management Service, MMS (Amato, R., 1994. Sand and gravel maps of the Atlantic continental shelf with explanatory text, OCS monograph MMS 93–0037, US Department of the Interior, Office of International Activities and Marine Minerals, 35 pp. plus four maps). Within the CONMAP Programme intended to remap the entire Atlantic Coast and the coast of the Gulf of Mexico at a scale of 1:1,000,000, only the map of the New England shelf has been published.

Resource mapping: Recent resource and habitat mapping activities concentrated on Georges Bank (USGS and NOAA), Massachusetts Bay (USGS), and parts of the Northeast coast (US Fish and Wildlife Services). Three states, Maryland, Delaware and New Jersey, are collecting information to search for offshore borrow sites for beach renourishment. As part of the MMS Programme, 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); a series of maps is in preparation.

Public information: The US Geological Survey sediment texture database can be accessed on the World Wide Web at site oracle.er.usgs.gov/sediment. The US Geological Survey has side-scan mosaics for selected areas of interest. (These were not necessarily undertaken for the purpose of sand and gravel mapping.) Sites were in Boston Harbor, Stellwagen Bank (Massachusetts), Georges Bank, New York Bight, Little Egg Inlet (New Jersey), Wrightsville Beach (North Carolina), and the Gray's Reef National Marine Sanctuary (Georgia). These can be reviewed on the WWW site kaler.usgs.gov/surveys/usmap.html.

Information and ordering: US Geological Survey – NOAA Joint Office for Mapping and Research, 915 National Center, Mail Stop 195, Reston, Virginia 22092, USA; or Minerals Management Service, Atrium Parkway Building, 381 Eldon Street, Herdon, Virginia 22070, USA.

5.21 Conclusions and recommendations

The mapping programmes and mapping results mentioned above show that seabed sediment and surficial resource mapping is accorded different importance in the

ICES Member Countries. Factors that seem to play a role include population density, intensity of industrial activities, the presence or absence of coastal defence schemes and land reclamation projects, the public awareness for the environmental effects of aggregate extraction onshore and, not unimportantly, budgets that states and governmental organisations are willing or able to invest in these mapping programmes.

The present state of seabed mapping in ICES Member Countries indicates that some countries do have an overview of what is in their part of the seabed and for what purpose surficial materials can be used. This means that those countries can start to formulate aggregate and environmental policies that have some basis in reality. Most countries have not reached this situation yet, so their policies in this sense are only based on assumptions and not on facts.

From an international point of view, it is unfortunate that some ICES countries have stopped funding or have curtailed seabed sediment mapping and have only incomplete and insufficient map series and data sets that are becoming more and more inadequate in relation to coverage of the sea floor and outdated in the sense of requirements. Economic and environmental considerations would support further funding and research. Therefore, the following conclusions and recommendations can be made:

Conclusions

- 1) Large parts of the shelf areas of ICES Member Countries remain essentially unmapped.
- 2) Reconnaissance mapping has proceeded and continues to proceed at a variable rate in the ICES Member Countries.
- 3) Mapping programmes in several ICES Member Countries contain primarily geological information and lack information on physical, compositional, and biological resource parameters.
- 4) Resolution of the seabed data is often inadequate over large areas for present requirements. Reliance on grab sample data for much reconnaissance survey work means that there is a general knowledge of only the topmost 20 cm of seabed, while current and future extraction techniques enable extraction down to several metres or tens of metres depending on the technique.

Recommendations

- 1) Without reconnaissance geological maps there is no framework for understanding the extent of benthic habitats and fisheries, which are not limited by international borders. WGEXT recommends that there should be an aim to attain 100 % reconnaissance coverage at adequate resolution of the EEZ of ICES Member Countries.
- 2) Those countries without advanced reconnaissance survey coverage should be encouraged to speed up

their survey programmes to meet the needs of the international community (in the sense of Agenda 21) for common knowledge of the sea floor.

- 3) For a sustainable and balanced future use of seabed resources, it is essential that there be improved collection of data on physical and compositional sediment parameters and related ecosystems.
- 4) Future survey work should also aim to include more detailed geological and environmental information from the sediment cover down to at least a critical depth of sediment corresponding to current and planned dredging practice to provide a more accurate picture of resources.

6 DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

This section sets out the conclusions drawn by members of WGEXT based on studies and information reviewed since the completion of its previous *Cooperative Research Report* No. 182 (ICES, 1992). Since that time considerable research and detailed investigations have been conducted with regard to the mapping of the resource and of the environmental effects of extraction operations. In particular, much work has been directed at investigating the recolonisation of dredged areas and the nature of alterations to the benthos caused by extraction operations. Based on such investigations and reviews of research, WGEXT has recommended a "Code of Practice for the Commercial Extraction of Marine Sediments" and "Guidelines for Fisheries Consultations" (ICES, 1992, Annex 1). These have been widely adopted, and in this report WGEXT has set out "Guidelines for the Preparation of an Environmental Impact Assessment" (Section 4.2, above). Many of the research questions identified in the previous *Cooperative Research Report* (ICES, 1992) have been answered (if not in full, at least in part) by the most recent research projects reviewed in the preceding sections. While our understanding of the environmental effects of extraction operations has improved considerably as a result, there are still important areas for future research. At the end of this section, we record our recommendations for further research. Importantly, these do not suggest concern over lack of knowledge, but rather they are an attempt to provide a focus that will enable a better understanding to be applied when future extraction operations are considered.

Extraction activities, uses, and related issues

1. The number of ICES Member Countries reporting on the use of marine aggregates has increased since 1992, especially those bordering the Baltic Sea. The UK remains the main producer of aggregates for the manufacture of concrete, whilst the Netherlands produces and uses the largest quantity of sand. Since 1992, further reserves of sand and gravel have been reported in both the Baltic Sea and the North Sea.

2. Beach nourishment and fill for construction purposes and land reclamation account for much of the increased quantities extracted. Use for concreting has remained fairly static.

3. Sand and gravel reserves are not evenly distributed. The reserves of coarse marine aggregates must be considered as finite and this applies also to sand reserves in the Baltic Sea. Fine sand reserves in the North Sea and adjacent areas are abundant.

4. Improvements in dredging technology and the ready availability of more accurate and reliable navigation systems such as Differential Global Positioning Systems enables more efficient recovery and effective management of resources.

5. Most countries reported increasing concerns about the extraction of aggregate from the land and the sea. The sustainable use and strategic management of finite reserves is seen as a key issue for the future.

6. There are no realistic alternatives to the use of marine aggregate material for most beach recharge and major coastal reclamation schemes. Strategic planning for these is essential for the future supply of suitable materials.

Effects of extraction activities on the marine ecosystem

Sedimentology/morphology

1. Aggregate extraction alters the topography of the seabed. In some cases, such changes to the seabed topography can interfere with fishing activities. In other cases, particularly in high energy environments, individual extraction tracks or furrows quickly disappear.

2. The persistence of dredged pits and furrows is dependent on both the natural sediment dynamics and the “intensity” of the dredging operation.

3. An important condition for the establishment of a biological community comparable to the pre-dredged state is that the seabed exhibits the same physical characteristics as existed originally (i.e., before dredging). That natural variation will occur in the benthic community must also be taken into account in assessing “recovery” to the pre-dredged state.

4. When the dredged area differs in its physical characteristics from the pre-dredged conditions, biological communities will establish but will differ from the pre-dredged community.

Hydrodynamics

1. A change in hydrodynamic conditions may result from dredging operations that significantly alter the seabed topography, for example, deep pits will lead to long-term changes in bottom sediments and most critically to oxygen depletion. These conditions, when extreme, will inhibit macrobenthic recolonisation.

2. Extraction operations in shallow coastal areas may alter wave conditions and/or disrupt the supply of sediment to the coast and in extreme cases may affect shoreline integrity.

3. Aggregates extraction will cause an increase in suspended sediment in the immediate vicinity of extraction and this will, to a lesser or greater extent, have an impact on the flora and fauna.

Biological effects

1. Aggregate extraction causes a localised and immediate loss of macrobenthic fauna and flora.

2. Normally, in areas that have previously been dredged by trailer-hopper methods, macrobenthic recolonisation proceeds rapidly, with opportunistic species dominating in the initial stages.

3. The time taken to establish a macrobenthic community comparable to that of the pre-dredged state will depend on the structure of the community and its natural variability. For example, a community dominated by long-lived and large individuals will take longer to achieve a state which is comparable to the pre-dredged condition, compared to a community dominated by short-lived opportunistic species.

4. The removal of the benthos and/or alteration of the substrate may consequently affect any associated shellfish and finfish resources.

Management of extraction activities

1. All countries mentioned in this report have laws and/or policies regulating the extraction of marine sediments. Most require that considerable attention is paid to environmental and fishery concerns prior to the issue of a license, and use mechanisms to control dredging activities, for example, by imposing conditions on licenses.

2. Environmental Impact Assessments (EIAs) are not always a statutory requirement. It is evident, however, that most countries now require EIAs at either a strategic or site-specific level or both. These enable decisions to be taken on whether it is acceptable to allow dredging and, if so, to identify means of minimising the degree of disturbance. EU Member States are required to implement the “Directive on the assessment of the effects of certain public and private projects on the environment” (85/337/EC) and give effect to its amendment (97/11/EC) by 14 March 1999. It is at the discretion of individual Member States to define fixed criteria and/or threshold values for marine sediment extraction projects to require an EIA.

3. Many countries have also developed rigorous requirements for monitoring extraction operations. Electronic monitoring systems (EMS) and/or black boxes are now widely used to track the movements of dredgers and to ensure that dredging only occurs within licensed

areas (see Section 5). There is also an increasing use of monitoring programmes to assess the effects of dredging on the physical and biological environment. These usually require studies to be undertaken before, during, and after dredging operations. Data collected from such studies provide an important information base. They enable decisions to be taken on the appropriateness of existing conditions on specific licensed areas, and contribute to a broader understanding of marine processes.

4. Guidelines for the preparation of an EIA have been produced by WGEXT and are set out in this report (see Section 4.2, above). They represent current best practice and are based on the practical experience of members of WGEXT.

Resource mapping

1. The mapping programmes and mapping results mentioned above show that seabed sediment and surficial resource mapping is accorded different importance in various ICES Member Countries. Factors that play a role include population density, intensity of industrial activities, the presence or absence of coastal defence schemes and land reclamation projects, the public awareness for the environmental effects of aggregate extraction onshore, and budgets that states and governmental organisations are willing or able to invest in these mapping programmes.

2. The present state of seabed mapping in ICES countries indicates that some countries do have an overview of what is in their part of the seabed and for what purpose surficial materials can be used. This means that those countries can start to formulate aggregate and environmental policies that have some basis in reality. Most countries have not reached this situation yet, so their policies in this sense are only based on assumptions and not on facts.

3. From an international point of view, it is unfortunate that some ICES countries have stopped funding or have curtailed seabed sediment mapping, and have only incomplete and insufficient map series and data sets that are becoming more and more inadequate in relation to coverage of the sea floor and outdated in the sense of requirements. Economic and environmental considerations would support further funding and research.

4. In summary:

- Large parts of the ICES shelf areas remain essentially unmapped.
- Reconnaissance mapping has proceeded and continues to proceed at a variable rate in the ICES Member Countries.
- Mapping programmes in several ICES Member Countries contain primarily geological information

but lack information on physical, compositional, and biological resource parameters.

- Resolution of the seabed data is often inadequate over large areas for present requirements.
- Reliance on grab sample data for much reconnaissance survey work means that there is a general knowledge of only the topmost 20 cm of the seabed, while current and future extraction techniques enable extraction down several metres or tens of metres depending on the technique.

RECOMMENDATIONS

1. ICES Member Countries should be encouraged to supply information about their marine aggregate industries to WGEXT.

2. The dredging industry should continue to improve dredging technology and the (sustainable) management of these valuable sand and gravel reserves.

3. Given the wide range of extraction operations in Northern European and Atlantic waters, and the enormous diversity of seabed habitats, WGEXT recommends that the specific requirements for any particular extraction operation be determined on a case-by-case basis.

4. WGEXT recognises the use of EMS and black boxes as a valuable management tool, and their wider use by ICES countries is recommended.

5. It is also recommended that, wherever possible, data and the management experience of the regulatory authorities be made widely available to facilitate the continued development of best practice.

6. Reconnaissance geological maps (and associated resource maps) provide a framework for understanding not only the extent of marine sediment resources, but also benthic habitats and fisheries, which are not limited by international borders. WGEXT recommends that there be an aim to attain 100 % reconnaissance coverage at adequate resolution of the ICES Member Countries' marine jurisdictional zones (EEZs and continental shelf).

7. Work aimed at characterising the composition of overspill and amounts discharged by the variety of dredgers presently operating would be of particular value in future environmental impact assessments. Similarly, further assessment of plume effects on the benthos in areas adjacent to extraction operations would provide useful inputs to such environmental assessments.

8. Assessments of environmental impacts should take into account any demonstrable concerns over loss of biodiversity in the marine environment.

9. The effects of aggregate extraction on marine macrophytes requires further investigation, particularly

in the Baltic Sea area and other relevant shallow coastal waters.

10. Where sediment extraction operations require extraction to greater sediment depths, far more attention needs to be given to the mitigation of environmental impacts in the design of such operations and associated dredging sites. Sloping sides, giving gradual depth reduction, may avoid such areas becoming traps for fine sediments and stratification of enclosed water.

11. Meiofaunal effects have been less well studied; this will require quantitative sampling of meiofaunal assemblages, which in turn depends on the further development of quantitative meiofauna sampling techniques.

12. Long-term investigations of the recovery of the benthos should be undertaken to determine in particular:

- a) restoration of the structure and function of the biological community;
- b) variation in macrobenthic assemblages between infilled dredged furrows and unexploited peaks, from the start of dredging operations through to longer-term recovery;
- c) any persistent changes to benthic communities measured in terms of biomass, number of taxa, and abundance within the natural spatial and temporal variability of the pre-dredged environment.

13. Biotope (i.e., habitat and associated communities) investigations into "undisturbed" sediments (in areas where dredging is not occurring) may cast further light on natural spatial and temporal variability.

14. The cumulative environmental effects of multiple extraction operations is worthy of further investigation. Such studies should seek to distinguish cumulative impacts from sediment outfall plumes, potential for cumulative loss of habitat, and cumulative impacts on fish stocks, their distribution and associated fishing and spawning/nursery grounds.

15. Some theoretical work and field investigations have been conducted on the effects of extraction operations on fisheries. Future investigations on the effects at higher trophic levels will benefit significantly from the knowledge and understanding gained from studies of the effects on the marine benthos and water column. Future research should seek to evaluate effects on commercial fish populations and their distributions, but should not ignore other fishes which may be more vulnerable to commercial extraction operations even where they are of slight or no commercial value.

7 REFERENCES

Agassiz, A. 1888. Three cruises of the United States coast and geodetic survey steamer "Blake". Vol 1.

Bulletin Mus. Com. Zool. Harvard College, Cambridge, 14. 314 pp.

Arlt, G., and Krause, J. Chr. 1997. Oekologische Bedeutung der Kies- und Sandgebiete der deutschen Ostseeküste für das Makrozoobenthos mit besonderer Berücksichtigung der "Roten-Liste-Arten". Unveroeff. Bericht Bundesamt für Naturschutz.

Boesch, D. F., and Rosenberg, R. 1981. Response to stress in marine benthic communities. John Wiley & Sons, Chichester, pp. 179–198.

Bonsdorff, E. 1983. Recovery potential of macrozoobenthos from dredging in shallow brackish waters. *Oceanologica Acta* (Special Volume), Dec. 1983, pp. 27–32.

Buchanan, J. B. 1993. Evidence of benthic-pelagic coupling at a station off the Northumberland coast. *Journal of Marine Biology and Ecology*, 172: 1–10.

Cabioch, L. 1968. Contribution à la connaissance des peuplements benthiques de la Manche Occidentale. *Cahiers de Biologie Marine*, 9: 493–720.

Cohen, E., Grosslein, M., Sissenwine, M., and Steimle, F. 1980. A comparison of energy flow on Georges Bank and in the North Sea. ICES CM 1980/L:64, 13 pp. (mimeo).

Collins, K. J., and Mallinson, J. J. 1983. Sublittoral survey from Selsey Bill to the east Solent. Report to the NCC. 24 pp.

Collins, K. J., and Mallinson, J. J. 1989. Marine flora and fauna off Bembridge, Isle of Wight. Report to the NCC. 17 pp.

Connor, D. 1995. Methods for studying hard bottom substrates. In Report of the Benthos Ecology Working Group, ICES CM 1995/L:3, pp. 71–76.

Crisp, D. J., and Barnes, H. 1954. The orientation and distribution of barnacles at settlement with particular reference to surface contour. *Journal of Animal Ecology*, 23: 179–196.

Daan, N., Bromley, P. J., Hislop, J. R. H., and Nielsen, N. A. 1990. Ecology of North Sea fish. *Netherlands Journal of Sea Research*, 26(2–4): 343–386.

Davoult, D. 1990. Biofacies et structure trophique du peuplement des cailloutis du Pas de Calais (France). *Oceanologica Acta*, 13(3): 335–348.

Davoult, D., and Richard, A. 1990. Experimental study of the recruitment of the sessile community on the pebbly sea-bed in the Dover strait. *Cahiers de Biologie Marine*, 31: 181–199.

- Davoult, D., Dewarumez, J.-M., Prygiel, J., and Richard, A. 1988. Benthic communities map of the French part of the North Sea. *Etudes et Cartographie*, Lille, France.
- DCA & VKI. 1997. RIACON Risk Analysis of Coastal Nourishment Techniques. The Danish Coastal Authority in cooperation with the VKI.
- de Groot, S. J. 1979. The potential environmental impact of marine gravel extraction in the North Sea. *Ocean Management*, 5: 233–249.
- de Groot, S. J. 1986. Marine sand and gravel extraction on the North Atlantic and its potential environmental impact, with emphasis on the North Sea. *Ocean Management*, 10: 21–36.
- Desprez, M. 1992. Bilan de dix années de suivi de l'impact biosédimentaire de l'extraction de graves marins au large de Dieppe. Comparaison avec d'autres sites. Rapport GEMEL. St. Valéry-sur-Somme.
- Desprez, M., and Duhamel, S. 1993. Comparison of impact of gravel extraction on geomorphology, sediment and macrofauna in two areas: Klaverbank (NL) and Dieppe (F). In Report of the Working Group on the Effects of Extraction of Marine Sediments. ICES CM 1993/E:7.
- Desprez, M. 1995. Biological and sedimentological impact of a marine aggregate extraction site (Dieppe) along the French coast of the English Channel. Preliminary results on post-dredging recolonization. ICES CM 1995/E:5, pp. 73–79.
- Desprez, M. 1996. Etude des sédiments superficiels et de la macrofaune benthique dans le secteur de l'ancienne souille expérimentale du CNEXO. Rapport GEMEL. 26 pp.
- Desprez, M. 1997. Suivi biologique et sédimentaire de la recolonisation d'un site d'extraction de graves marins au large de Dieppe. Rapport GEMEL: 22 pp. + figures et annexes.
- Dewarumez, J.-M., Davoult, D., Sanvicente Anorve, L. E., and Frontier, S. 1992. Is the "muddy heterogeneous sediment assemblage" an ecotone between the pebbles community and the *Abra alba* community in the Southern Bight of the North Sea? *Netherlands Journal of Sea Research*, 30: 229–238.
- Dickson, R., and Lee, A. 1972. Study of effects of marine gravel extraction on the topography of the sea bed. ICES CM 1972/E:25, 19 pp. (mimeo).
- DMU. 1997. Spredning og sedimentation af partikulært materiale under råstofindvindig ved Læsø Trindel (Spreading and sedimentation of particles during dredging on Læsø Trindel). NERI, National Environmental Research Institute, Denmark.
- Eden, R. A. 1975. North Sea environmental geology in relation to pipelines and structures. *Oceanol. Inf.*, 75: 302–309.
- Essink, K. 1998. RIACON. Risk analysis of Coastal Nourishment Techniques. Final Evaluation Report. Report RIKZ-97.031. National Institute for Coastal and Marine Management/RIKZ, Haren, The Netherlands, 42 pp.
- Ford, E. 1923. Animal communities of the level sea-bottom in the water adjacent to Plymouth. *Journal of the Marine Biological Association of the UK*, 13: 164–224.
- Forster, G. R. 1953. A new dredge for collecting burrowing animals. *Journal of the Marine Biological Association of the UK*, 32: 193–198.
- Gayman, W. 1978. Offshore dredging study: environmental ecological report. *Ocean Management*, 4: 51–104.
- Gosselck, F., Lange, D., and Michelchen, N. 1996. Auswirkungen auf das Ökosystem Ostsee durch den Abbau von Kies und Kiessanden vor der Küste von Mecklenburg-Vorpommern (Effects of the extraction of gravel and gravely sands from the coastal shelf of Mecklenburg-Vorpommern on the Baltic Sea ecosystem). Study on behalf of the Agency for Environment and Nature, Mecklenburg-Vorpommern. 95 pp.
- Gray, J. S. 1974. Animal-sediment relationships. *Oceanography and Marine Biology Annual Review*, 12: 223–261.
- Greening, J., and Kenny, A. J. 1996. The macrofauna inhabiting marine gravels off the UK. Crown Estate Commission, London; and Centre for Environment, Fisheries and Aquaculture Science, Burnham-on-Crouch, UK. 30 pp.
- Hall, S. J., Basford, D. J., and Robertson, M. R. 1991. The impact of hydraulic dredging for razor claims *Ensis* sp. on an infaunal community. *Netherlands Journal of Sea Research*, 27(1) pp 119–125.
- Hall, S. J. 1994. Physical disturbance and marine benthic communities: life in unconsolidated sediments. *Oceanography and Marine Biology Annual Review*, 32: pp 179–239.
- Hammond, R. 1963. A preliminary report on the marine fauna of the North Norfolk coast. *Trans. Norf. Norwich Nat. Soc.*, 20(1): 2–31.
- Hily, C. 1983. Macrozoobenthic recolonization after dredging in a sandy mud area of the Bay of Brest enriched by organic matter. *Oceanologica Acta* (Special Vol.), Dec. 1983, pp.113–120.
- Hitchcock, D. R., and Drucker, B. R., 1996. Investigation of benthic and surface plumes associated with

- marine aggregates mining in the United Kingdom. *Oceanology International* 96. The Global Ocean—towards operational oceanography. Conference Proceedings, vol. 2.
- Holme, N. A. 1949. A new bottom sampler. *Journal of Marine Biologist Association UK*, 28: 323–332.
- Holme, N. A. 1953. The biomass of the bottom fauna in the English Channel off Plymouth. *Journal of the Marine Biological Association of the UK*, 32: 1–49.
- Holme, N. A. 1961. The bottom fauna of the English Channel. *Journal of the Marine Biological Association of the UK*, 41: 397–461.
- Holme, N. A. 1966. The bottom fauna of the English Channel: II. *Journal of the Marine Biological Association of the UK*, 46: 401–493.
- Holme, N. A., and MacIntyre, A. D. (Eds.) 1984. *Methods for the study of marine benthos*. Blackwell Scientific Publications, Oxford, pp. 165–166.
- Holme, N. A., and Wilson, J. B. 1985. Faunas associated with longitudinal furrows and sand ribbons in a tide-swept area in the English Channel. *Journal of the Marine Biological Association of the UK*, 65: 1051–1072.
- Hurme, A.K., and Pullen, E. J. 1988. Biological effects of marine sand mining and fill placement for beach replenishment: lessons for other uses. *Marine Mining*, 7: 123–136.
- ICES. 1992. Effects of Extraction of Marine Sediments on Fisheries. Cooperative Research Report No. 182. International Council for the Exploration of the Sea, Copenhagen.
- Johnson, R. O., and Nelson, W. G. 1985. Biological effects of dredging in an offshore borrow area. *Florida Scientist*, 48(3): 166–187.
- Johnston, S. A. 1981. Estuarine dredge and fill activities: a review of impacts. *Environmental Management*, (5): 427–440.
- Jones, S. G., and Candy, S. 1981. Effects of dredging on the macrobenthic infauna of Botany Bay. *Australian Journal of Marine and Freshwater Research*, 32: 379–398.
- Jones, R. 1984. Some observations on energy transfer through the North Sea and Georges Bank food webs. *Rapports et Procès-Verbaux des Réunions—Conseil International pour l'Exploration de la Mer*, 183: 204–217.
- Kaplan, E. H., Welker, J. R., Kraus, M. G., and McCourt, S. 1975. Some factors affecting the colonisation of a dredged channel. *Marine Biology*, 32: 193–204.
- Kenny, A. J., and Rees, H. L. 1994. The effects of marine gravel extraction on the macrobenthos: early post-dredging recolonisation. *Marine Pollution Bulletin*, 28(7): 442–447.
- Kenny, A. J., and Rees, H. L. 1996. The effects of marine gravel extraction on the macrobenthos: Results 2 years post-dredging. *Marine Pollution Bulletin*, 32(8/9): 615–622.
- Kenny, A. J., Rees, H. L., and Lees, R. G. 1991. An inter-regional comparison of gravel assemblages off the English east and south coasts: Preliminary Results. ICES CM 1991/E:27, 15 pp. (mimeo).
- Kranck, K., and Milligan, T. G. 1989. Effect of a major dredging program on the sedimentary environment of Miramichi Bay, New Brunswick. *Canadian Technical Report of Hydrography and Ocean Sciences*, 112. 65 pp.
- Krause, J. Chr., Nordheim, H.V., and Gosselck, F. 1996. Auswirkungen submariner Kiesgewinnung auf die benthische Makrofauna in der Ostsee vor Mecklenburg-Vorpommern. (Effects of submarine gravel extraction on benthic fauna in the Baltic Sea off Mecklenburg-Vorpommern). *German Journal of Hydrography, Supplement 6*: 189–199.
- Lees, R. G., Rees, H. L., Lambert, M. A., Rowlatt, S. M., and Limpenny, D. S. 1990. Benthic Studies in Relation to Dredging Activity off the Isle of Wight, Southern England. ICES CM 1990/E:15. 19 pp. (mimeo).
- Leuchs, H., Anlauf, A., and Nehring, S. 1996. Baggern und Verklappen im Küstenbereich. Auswirkungen auf das Makrozoobenthos. Bundesanstalt für Gewässerkunde. BfG-Mitteilungen 11, 111 pp. Koblenz, Germany.
- Mare, M. F. 1942. A study of a marine benthic community with special reference to the micro-organisms. *Journal of the Marine Biological Association of the UK*, 25: 517–554.
- Maurer, D., Keck, R. T., Tinsman, J. C., and Leathem, W. A. 1981a. Vertical migration and mortality of benthos in dredged material—part I: mollusca. *Marine Environmental Research*, 4: 299–319.
- Maurer, D., Keck, R. T., Tinsman, J. C., and Leathem, W. A. 1981b. Vertical migration and mortality of benthos in dredged material—part II: crustacea. *Marine Environmental Research*, 5: 301–317.
- Mackie, A. S. Y., Oliver, P. G., and Rees, E. I. S. 1995. Biomôr 1 - benthic biodiversity in the southern Irish Sea. *Studies in Marine Biodiversity and Systematics from the National Museum of Wales. BIOMOR Reports*, 1, 263 pp.

- May, R. M. 1975. Patterns of species abundance and diversity. *In* Ecology and evolution of communities, pp. 81–120. Ed. by M.L. Cody and J.M. Diamond. Belknap Press, Cambridge, Massachusetts.
- McCauley, J. E., Parr, R. A., and Hancock, D. R. 1977. Benthic infauna and maintenance dredging: a case study. *Water Research*, 11: 233–242.
- McFarland, V. A., and Peddicord, R. K. 1980. Lethality of a suspended clay to a diverse selection of marine and estuarine macrofauna. *Archives of Environmental Contamination and Toxicology*, 9: 733–741.
- 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 CM 1977/E:48, 11 pp. (mimeo).
- Moore, P. G. 1977. Inorganic particulate suspensions in the sea and their effects on marine animals. *Oceanog. Mar. Biol.*, 15: 225–364.
- Moran, P. J. 1991. The effects of dredging on the larval settlement and community development of fouling organisms in Port Kembla Harbour, Australia. *Water Research*, 25(9): 1151–1155.
- Newcombe, C. P., and MacDonald, D. D. 1991. Effect of suspended sediments on aquatic ecosystems. *North American Journal of Fisheries Management*, 11: 72–82.
- Nielsen, P.E. 1996. Spildmålinger ved Læsø Trindel (Spill measurements on Læsø Trindel), Proveindsamling og analyseresultater. National Forest and Nature Agency, Denmark.
- Nielsen, P.E. 1997. Sediment Spill and Sedimentation in connection with Dredging and Construction Work in Marine Environments. Report submitted to the ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem, Copenhagen, 1997.
- Nunny, R. S., and Cillingworth, P. C. H. 1986. Marine dredging for sand and gravel. HMSO, London, 191 pp.
- Oele, E. 1978. Sand and gravel from shallow seas. *Geol. Mijnbouw*, 57: 45–54.
- Øresundskonsortiet, 1998a. Investigation of the Impacts on the Marine Environment Caused by a Fixed Link across the Øresund. Sand Extraction at Kriegers Flak in 1997 and the Impact on the Benthic Fauna 1996–1997. Technical Report, Øresundskonsortiet, 1998.
- Øresundskonsortiet, 1998b. The Øresund Link. Assessment of the Impact on the Marine Environment of the Øresund Link, Update, March 1998.
- Osman, R. W. 1977. The establishment and development of a marine epifaunal community. *Ecol. Monogr.*, 47: 37–63.
- Pagliai, A. M. B., Varriale, A. M. C., Crema, R., Galletti, M. C., and Zunarelli, R. V. 1985. Environmental impact of extensive dredging in a coastal marine area. *Marine Pollution Bulletin*, 16(12): 483–488.
- Pennekamp, J. G. S., and Quaak, M. P. 1990. Impact on the environment of turbidity caused by dredging. *Terra et Aqua*, 42: 10–20.
- Peterson, C. G. J. 1914. Valuation of the sea, II. The animal communities of the sea bottom and their importance for marine zoogeography. Report of the Danish Biological Station, 21:1–44.
- Pianka, E. R. 1970. On *r*- and *K*-selection. *Am. Nat.*, 104: 592–597.
- Poiner, I. R., and Kennedy, R. 1984. Complex patterns of change in the macrobenthos of a large sand bank following dredging. *Marine Biology*, 78(3): 335–351.
- Rees, E. I. S., Nicolaidou, A., and Laskaraidou, P. 1977. The effects of storms on the dynamics of shallow water benthic associations. *In* Biology of benthic organisms, pp. 465–474. Ed. by B.F. Keegan, P.O. O'Ceidigh, and P.J.S. Boaden. Pergamon Press, Oxford.
- Rees, H. L. 1987. A survey of the benthic infauna inhabiting gravel deposits off Hastings, southern England. ICES CM 1987/L:19, 19 pp. (mimeo).
- Regier, M. 1995. Auswirkungen der Entnahme von Spuelsand aus dem Meeresboden im Bereich des Lister Tiefs/Salzsand – Meeresbiologische Untersuchungen. Institut für Hydrobiologie und Fischereiwissenschaften, Universität Hamburg (Amt für Wasserwirtschaft Husum), 36 pp.
- Rodriguez, S. R., Ojeda, F. P., and Inestrosa, N. C. 1993. Settlement of benthic invertebrates. *Marine Ecological Progress Series*, 97: 193–207.
- Rhoads, D. C., and Boyer, L. F. 1982. Effects of marine benthos on physical properties of sediments. A successional perspective. *In* Animal-sediment relations, pp. 3–51. Ed. by P.L. McCall, and M.J.S. Tevesz. Plenum Press, New York.
- Roberts, C. D. 1979. The colonial behaviour of *Modiolus modiolus* (L.) and its ecological significance. *In* Biology and systematics of colonial organisms, pp. 255–256. Ed. by G. Larwood and B. B. Rosen. Academic Press, London.

- Sips, H. J. J., and Waardenburg, H. W. 1989. The macrobenthic community of gravel deposits in the Dutch part of the North Sea (Klaverbank), ecological impact of gravel extraction. Bureau Waardenburg bv., Culemborg, the Netherlands, p. 73.
- Shelton, R. G. J., and Rolfe, M. S. 1972. The biological implications of aggregate extraction: recent studies in the English Channel. ICES CM 1972/E:26, 12 pp. (mimeo).
- Sissenwine, M. P., Cohen, E. B., and Grosslein, M. D. 1984. Structure of the Georges Bank ecosystem. Rapports et Procès-Verbaux des Réunions—Conseil International pour l'Exploration de la Mer. 183: 243–254.
- Smith, W., and McIntyre, A. D. 1954. A spring loaded bottom sampler. Journal of the Marine Biological Association of the UK, 33: 257–264.
- Sothoran, I. S., Foster-Smith, R. L., and Davies, J. 1997. Mapping of marine benthic habitats using image processing techniques within a Raster-based geographic information system. Estuarine, Coastal and Shelf Science, 44 (Supplement A): 25–31.
- Steven, G. A. 1952. Nets. How to make, mend and preserve them. Routledge and Kegan Paul, London, 128 pp.
- Stebbing, A. R. D. 1971. The epizoic fauna of *Flustra foliacea* (Bryozoa). Journal of the Marine Biological Association of the UK, 51: 283–300.
- Steele, J. H. 1974. The structure of marine ecosystems. Blackwell Scientific Publications, Oxford. 127 pp.
- Storebælt. 1997. Environmental Programme. Biological Monitoring. Environmental Programme Project Report, April 1997.
- Sullivan, B. K., Doering, P. H., Oviatt, C. A., Keller, A. A., and Frithsen, J. B. 1991. Interactions with the benthos alter pelagic food web structure in coastal waters. Canadian Journal of Fisheries and Aquatic Science, 48: 2276–2284.
- Taylor, J. J., and Saloman, C. H. 1968. Some effects of dredging and coastal development in Boca Gega Bay, Florida. Fishery Bulletin Fish and Wildlife Service, U.S., 67: 213–241.
- Turner, S. J., and Todd, C. D. 1991. The effects of *Gibbula cineraria* (L.), *Nucella lapillus* (L.) and *Asterias rubens* L. on developing epifaunal assemblages. Journal of Experimental Marine Biology and Ecology, 154: 191–213.
- van Dalssen, J. A., and Essink, K. 1997. RIACON. Risk analysis of coastal nourishment techniques. National Evaluation Report (The Netherlands). Report RIKZ-97.022, National Institute for Coastal and Marine Management/RIKZ, Haren, the Netherlands, 98 pp.
- van der Veer, H. W., Bergman, M. J. N., and Beukema, J. J. 1985. Dredging activities in the Dutch Wadden Sea: effects on macrobenthic infauna. Netherlands Journal of Sea Research, 19(2): 183–190.
- van Dolah, R. F., Calder, D. R., and Knott, D. M. 1984. Effects of dredging and open-water disposal on benthic macroinvertebrates in a South Carolina estuary. Estuaries, 7(1): 28–37.
- van Moorsel, G. W. N. M., and Waardenburg, H. W. 1990. Impact of gravel extraction on geomorphology and the macrobenthic community of the Klaverbank (North Sea) in 1989. Bureau Waardenburg bv, Culemborg, the Netherlands, 75 pp.
- van Moorsel, G. W. N. M., and Waardenburg, H. W. 1991. Short-term recovery of geomorphology and macrobenthos of the Klaverbank (North Sea) after gravel extraction. Bureau Waardenburg bv, Culemborg, the Netherlands, 90 pp.
- van Moorsel, G. W. N. M. 1993. Long-term recovery of geomorphology and population development of large molluscs after gravel extraction at the Klaverbank, (North Sea). Bureau Waardenburg bv, Culemborg, the Netherlands, 41 pp.
- van Moorsel, G. W. N. M. 1994. The Klaverbank (North Sea), Geomorphology, macrobenthic ecology and the effect of gravel extraction. Report no. 94.24, Bureau Waardenburg bv, Culemborg, the Netherlands.
- Warwick, R. M., and Davies, J. R. 1977. The distribution of sublittoral macrofauna communities in the Bristol Channel in relation to the substrate. Estuarine Coastal and Marine Science, 5: 267–288.
- Warwick, R. M., and Uncles, R. J. 1980. Distribution of benthic macrofauna associations in the Bristol Channel in relation to tidal stress. Marine Ecology Progress Series, 3: 97–103.
- Young, C. M., and Chia, F. 1987. Abundance and distribution of pelagic larvae as influenced by predation, behaviour, and hydrographic factors. In Reproduction of marine invertebrates: IX. General aspects: seeking unity in diversity. pp. 385–463. Ed. by A.C. Giese, J.S. Pearse, and V.B. Pearse. Blackwell Scientific Publications, California.
- Zeitzschel, B. 1980. Sediment-water interactions in nutrient dynamics. In Marine benthic dynamics, pp. 195–218. Ed. by K.R. Tenore, and B.C. Coull. Belle W. Baruch. Symposium Marine Science 11, University of South Carolina Press, Columbia.

ANNEX A

STANDARD OPERATING PROCEDURES: SAMPLING AND ANALYSIS OF THE MACROBENTHIC FAUNA FROM GRAVEL SEDIMENTS

Background

Research in a number of ICES Member Countries has been investigating the biological and physical impacts of commercial marine aggregate dredging on the sea-bed. As an ongoing element of this research, quantitative macrobenthic sampling methods, appropriate for use on gravel sediments, have been developed. For gravel sediments, most samplers (typically grabs and corers deployed from research vessels) are incapable of taking samples of gravel sediments. An investigation into the effects of marine aggregate extraction on the Klaverbank in the Dutch sector of the North Sea (Sips and Waardenburg, 1989) reported that a Hamon grab proved to be an effective quantitative coarse sediment sampler. Consequently, in 1991 MAFF constructed a Hamon grab based upon an original design provided by the Dutch Geological Survey (Oele, 1978) and have deployed this successfully now in several studies.

Field sampling

The Hamon grab is routinely deployed to obtain samples of commercial coarse aggregate sediments. The device samples a surface area of about 0.25 m². Once the Hamon grab has reached the seabed, the first 5 m of warp are slowly hauled-in so as to maximise the grab's sampling efficiency. The grab is then hauled to the surface at a normal rate. Once the grab is recovered, it is lowered onto a supportive frame, which allows a sample box (two 60 litre plastic fish bins) to be placed under the grab's sample bucket. The sediment is then slowly released into the bins, after which an estimate of the sample volume can be made. This is achieved using a sediment depth measurer and a precalculated conversion factor which allows the depth of sediment measured in one of the sample bins to be converted to a volumetric unit. Samples with a depth of less than 3 cm (depth measured in a 60-litre grey or red fish bin), i.e., about 10 litres of sediment, are discarded and a repeat sample is taken. In routine grid-type surveys of an area, where only one sample of the benthos is required at each station, a minimum of three grab deployments will be made, before a station is abandoned. Once an acceptable sample has been taken, a 500 cm³ sub-sample is taken for laboratory particle size analysis. A basic description of the sediment type (e.g., "muddy", "sandy gravel") is entered in the logbook.

The contents of the sample bin are then transferred to a purpose-built benthos sieving table. The total sample is initially washed (under gentle hose pressure) over a removable 5 mm square mesh screen. Larger individual animals and all encrusting fauna present on shell and gravel are removed. Any sediment remaining on the 5

mm screen (with no attached fauna) may be discarded. The nature of the coarse material, including the presence of any artefacts, will be routinely recorded. Fauna collected on the 5 mm mesh are transferred to plastic bottles or buckets (depending on the sample size). A mixture of 7 % formaldehyde in sea water, buffered with sodium acetate trihydrate, is added as a fixative and samples are labelled both inside and outside using permanent markers for future reference and storage purposes. "Rose Bengal", a vital stain, is also routinely added to the fixative prior to its use.

The finer sediment fraction is sieved over a 1 mm or 0.5 mm polyester mesh screen, the choice depending on the objectives of the investigation. The fine sieve frequently becomes blocked with sediment. In such cases, care is taken to ensure that no loss of animals occurs as a result of overflow. The sieve is removed from beneath the outlet pipe of the benthos sorting table and replaced by another. Accumulations of sediment on the mesh can usually be removed by gentle "puddling" in a large plastic bin with sea water. The sediment retained is then transferred to plastic buckets, which are then fixed and labelled as above.

Laboratory analysis

Initial sample processing 5 mm fraction

Samples are located in an outside store. Following the transfer of a sample to the laboratory, it is opened in a fume cupboard and then emptied over a 1 mm brass sieve, in order to filter off the fixative. The sample is then washed for a few minutes with fresh water so as to remove any further fixative. The sample is then transferred to a white plastic sorting tray that has been marked, with permanent pen, into twelve equally sized rectangles. In samples where taxa are present in large densities or which encrust a large proportion of the sediment, a sub-sample is taken. In these cases, about one third of the sample, by area, is removed and all individual and colonial taxa are extracted. The remaining sample is then sorted for any other individual or colonial benthos. Animals removed are placed in a petri-dish containing a preservative (70 % methanol GPR, 20 % fresh water, 10 % glycerol) for counting, identification, and weighing at a later stage.

This procedure is conducted under an air extractor hood if there is significant formaldehyde retention by larger organisms.

Initial sample processing 1 mm fraction

Following the transfer of a sample to the laboratory, it is opened in a fume cupboard and then emptied over a 1 mm brass sieve, or a mesh size corresponding to that used during sample collection in the field, in order to filter off the fixative. A small quantity of the sample (about 1 litre) is then transferred to a large bucket (about 10 litres) which is then topped up with fresh water in order to facilitate the separation of the smaller and less dense animals. The water is then poured over the sieve after which the process of decanting is repeated several times until no further benthos is extracted. The sediment retained in the bucket is then removed and kept separately for later sorting. The whole process is repeated until all of the sample has been processed. The material retained on the sieve is carefully back-washed into petri-dishes containing a preservative (as above).

Identification and enumeration

Easily recognisable species are simultaneously identified and enumerated, using digital counters for the more common occurrences. Problematic species are kept to one side and later identified to species level as far as possible using the standard taxonomic keys which are held in the laboratory (see Rees *et al.*, 1989). In the case of broken specimens, only heads are counted. Colonial species such as hydroids and bryozoans are initially recorded on a presence/absence basis, but are later quantified by weighing.

Having been identified, whole specimens and fragments of each species are transferred to numbered glass vials (one for each species) for subsequent biomass determination.

Biomass determination

The animals from the numbered glass vials are transferred onto white blotting paper to remove excess liquid.

They are then placed on a Sartorius 5 figure balance with attached printer, which records the weight and species number. Weighed specimens are then placed into a labelled sample jar with preservative for permanent storage.

The blotted wet weights (including shells, tests and gut contents) are then converted to ash-free dry weights using cited conversion factors (see Eleftheriou and Basford, 1989).

References

- Eleftheriou, A., and Basford, D. J. 1989. The macrobenthic infauna of the offshore northern North Sea. *Journal of the Marine Biological Association of the United Kingdom*, 69: 123–143.
- Elliott, J. M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. *Freshwater Biol. Assoc.*, Ambleside, 25: 144.
- Oele, E. 1978. Sand and gravel from shallow seas. *Geol. Mijnbouw*, 57: 45–54.
- Rees, H. L., Moore, D. C., Pearson, T. H., Elliott, M., Service, M., Pomfret, J., and Johnson, D. 1989. Procedures for the monitoring of marine benthic communities at UK sewage sludge disposal sites. Dept. Agriculture and Fisheries for Scotland, Scottish Fisheries Information Pamphlet No. 18, p. 79.
- Sips, H. J. J., and Waardenburg, H. W. 1989. The macrobenthic community of gravel deposits in the Dutch part of the North Sea (Klaverbank), ecological impact of gravel extraction. Bureau Waardenburg bv., Culemborg, the Netherlands, p. 73.

ANNEX B

CONTRIBUTORS TO THE REPORT

The following people supplied data and information or contributed to the writing and preparation of this report. A special acknowledgement must be given to the section editors. The report was started at the WGEXT annual meeting in Stromness in 1996, continued throughout 1997 and finalised at the Working Group's annual meeting in Haarlem in 1998.

Dr Claude Augris, IFREMER, France

Professor Henry Bokuniewicz, State University of New York, USA

Dr Siân Boyd, CEFAS Burnham Laboratory, UK

Dr Ingemar Cato, Geological Survey of Sweden

Jan van Dalssen, National Institute for Coastal and Marine Management, The Netherlands

Dr Michel Desprez, GEMEL, France

Chris Dijkshoorn, Directorate of Public Works and Water Management, North Sea Directorate, The Netherlands

Dr Karel Essink, National Institute for Coastal and Marine Management, The Netherlands

Dr Gordon Fader, Geological Survey of Canada

Dr Bas de Groot, Netherlands Institute for Fisheries Research, The Netherlands (Chair: 1975–1998)

Dr David Harrison, British Geological Survey, UK

Stig Helmig National Forest and Nature Agency, Denmark

Christof Herrmann, Agency for Environment and Nature, Germany

Hans Hillewaert, Sea Fisheries Department, Belgium

Bernard Humphreys, British Geological Survey, UK

Dr Raymond Keary, Geological Survey of Ireland

Dr Andrew Kenny, ABP Research and Consultancy Ltd, UK (Rapporteur 1999 – and Section Editor)

Jochen Christian Krause, BfN-INA, Germany

Dr Cees Laban, Netherlands Institute of Applied Geoscience, TNO, The Netherlands

Brigitte Lauwaert, Ministry of the Environment, Belgium

Dr Heiko Leuchs, Federal Institute of Hydrology, Germany

Andrew Morrison, formerly Crown Estate, UK

Dr Tony Murray, Crown Estate, UK (Section Editor)

Dr Poul Erik Nielsen, National Forest and Nature Agency, Denmark

Dr Dag Ottesen, Geological Survey of Norway

Richard Pearson, ARC Marine Ltd, UK

Dr Ruud Schüttenhelm, Netherlands Institute of Applied Geoscience, TNO, The Netherlands (Section Editor)

Dr Jonathan Side, Heriot-Watt University, Scotland, UK (Rapporteur 1996–1998, Chair: 1999–present, and Section Editor)

Dr Tom Simpson, Department of the Environment, Transport and the Regions, UK (Section Editor)

Ad Stolk, Directorate of Public Works and Water Management, North Sea Directorate, The Netherlands

Dr Szymon Uscinowicz, Polish Geological Institute, Poland

Dr Joanna Zachowicz, Polish Geological Institute, Poland

Dr Manfred Zeiler, Federal Maritime and Hydrographic Agency, Germany