OSPAR COMMISSION

Summary assessment of sand and gravel extraction in the OSPAR maritime area

Biodiversity Series

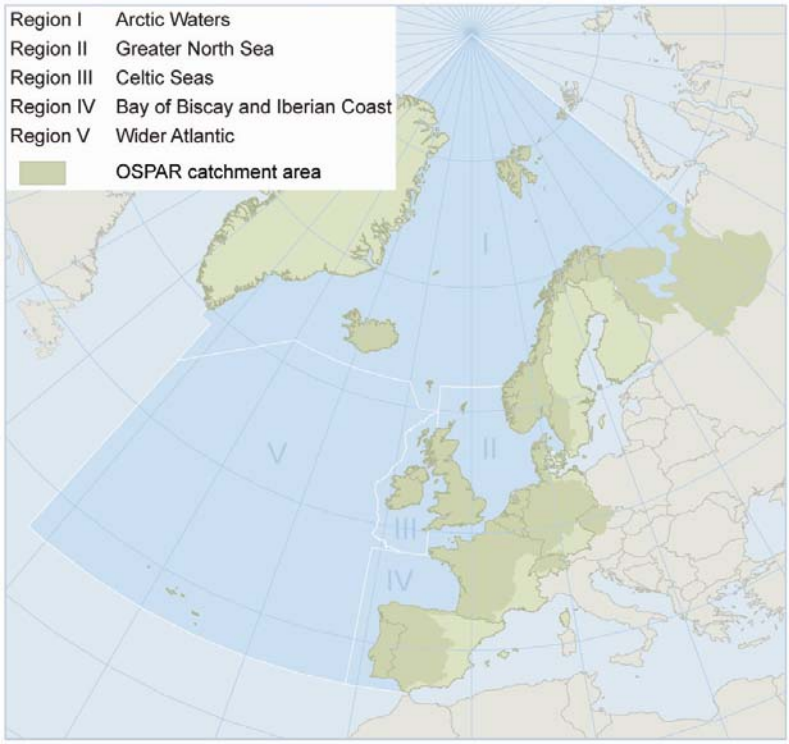
2009

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

Convention OSPAR

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris,
à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998.
La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.



The OSPAR maritime area and its five Regions

Acknowledgement

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Cover photo provided by Group De Cloedt

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Executive Summary

Sand and gravel extraction affects a significant area

Each year across the OSPAR area, around 50 – 60 million cubic metres of marine mineral deposits are extracted from the seabed for the construction industry or for beach nourishment. Gravel and sand (aggregates) are the principal materials extracted, but in some countries significant volumes of non-aggregate marine mineral resources such as maerl are also exploited.

Regulatory developments have focussed on minimising impacts

OSPAR has adopted ICES guidance on environmental impacts of aggregate extraction (OSPAR Agreement 2003-15). The regulatory imperative has been to promote the management of marine aggregate operations in order to minimise the footprint and potential resource conflict with other marine users. In all countries where significant aggregate extraction takes place, legislation has been adopted that takes into account the Habitats Directive (92/43/EEC). Specific mitigation and monitoring is routinely specified in consents for major extraction operations and some operations are subject to periodic or continual review.

Extraction activities may affect the marine system

The extraction of marine mineral deposits has profound effects on the seabed. It removes the substrate and associated organisms and may disrupt ecological services. Dredging may also result in changes to the nature and stability of sediments, increased turbidity, redistribution of fine particulates and the production of plumes of suspended material.

Ecological recovery depends on both the nature of the activity and the pre-existing conditions

Recolonisation of a dredged area may start to take place relatively rapidly, with restoration of biomass to pre-dredge levels anticipated to occur within two to four years if the activity is short-term. The seabed may take more than seven years to recover from intensive or protracted extraction operations.

Further efforts are needed to reduce pressure on the marine environment

The spatial extent of sand and gravel extraction is poorly understood. OSPAR Contracting Parties should supply comprehensive information to the ICES WGEXT relating to annual production rates, the area of seabed licensed and the area of seabed dredged. The use of electronic monitoring systems and a uniform reporting format by OSPAR Contracting Parties is recommended in this regard.

The effects of aggregate extraction are not fully understood. Further work is needed on impacts to fish, the smaller benthic fauna, on long-term recoverability of the seabed and the feasibility of seabed restoration. Where there is the potential for cumulative effects, a regional approach to development and assessment should be considered. This may require co-operation and co-ordination between Contracting Parties where a resource is on or near a national boundary.

Récapitulatif

L'extraction de sable et de gravier affecte une zone considérable

Chaque année dans la zone OSPAR, environ 50 à 60 millions de mètres cubes de gisements miniers marins sont extraits du fond marin aux fins de l'industrie de la construction ou du réapprovisionnement des plages. Les matériaux principaux que l'on extrait sont du gravier et du sable (agrégats) mais, dans certains pays, sont exploités des volumes importants de ressources minérales marines autres que des agrégats, telles que le maërl.

Les avancées réglementaires se sont focalisées sur la minimisation des impacts

OSPAR a adopté des orientations du CIEM sur les impacts environnementaux de l'extraction d'agrégats (Accord OSPAR 2003-15). L'impératif réglementaire vise la promotion de la gestion des opérations d'extraction des agrégats marins afin de minimiser l'empreinte et le conflit potentiel, dans ce domaine, avec d'autres usagers de la mer. Tous les pays qui pratiquent une extraction importante des agrégats ont adopté une législation qui tient compte de la Directive sur les habitats de l'UE. Les autorisations délivrées pour des opérations majeures d'extraction spécifient habituellement une mitigation et une surveillance spécifiques et certaines exploitations sont soumises à une revue périodique ou continue.

Les activités d'extraction risquent d'affecter le système marin

L'extraction des gisements miniers marins a d'importants effets sur le fond marin. Elle déplace le substrat et les organismes correspondants et risque de perturber les systèmes écologiques. Le dragage peut également entraîner des modifications de la nature et de la stabilité des sédiments, en augmentant la turbidité, en redistribuant les particules fines et en produisant des matières en suspension.

La récupération écologique dépend aussi bien de la nature de l'activité que des conditions préexistantes

La recolonisation d'une zone draguée peut se produire relativement rapidement et l'on prévoit que la biomasse atteindra les niveaux pré-dragage dans les deux à quatre ans qui suivent, si l'activité est de courte durée. Par contre, si les opérations d'extraction sont intensives ou prolongées, la récupération du fond marin risque de prendre plus de sept ans.

Il est nécessaire de faire des efforts supplémentaires pour réduire les pressions exercées sur le milieu marin

L'étendue spatiale de l'extraction du sable et du gravier est mal comprise. Les Parties contractantes OSPAR devraient communiquer au WGEXT du CIEM des informations exhaustives sur les taux annuels de production, la zone du fond marin autorisée et la zone du fond marin draguée. On recommande, à cet égard, aux Parties contractantes OSPAR d'utiliser des systèmes de surveillance électronique et un formulaire de notification uniforme.

On ne comprend pas pleinement les effets de l'extraction d'agrégats. Il convient donc de poursuivre les travaux relatifs aux impacts sur le poisson et la faune benthique de plus petite taille, à la récupération à long terme du fond marin et à la possibilité de récupération du fond marin. On devrait envisager une approche régionale pour le développement et l'évaluation dans le cas d'effets cumulatifs potentiels. Ceci demanderait coopération et coordination de la part des Parties contractantes lorsqu'une ressource se situe sur les limites nationales ou à proximité.

1. Introduction

This assessment presents an overview of the industry, the approaches to regulating it in OSPAR countries and the current understanding of the effects of aggregate extraction on the marine environment. It is based substantially on the most recent report of the International Council for the Exploration of the Sea (ICES) Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) (2009). This assessment has been prepared as part of a series of assessments of the impact of human activities on the marine environment of the OSPAR maritime area and its Regions under the 2003 OSPAR Joint Assessment and Monitoring Programme and as a contribution to the Quality Status Report 2010.

The ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) was established in 1986 with the stated aim of increasing knowledge of the impact of marine aggregate extraction on fisheries in particular and the marine environment in general. Since then, the WGEXT has widened its remit to further understanding of the impacts of marine sediment extraction on various components of the marine ecosystem. The WGEXT's Co-operative Research Reports have provided a synthesis of recent advances in our knowledge and understanding of ecosystem effects resulting from the extraction of marine sediments.

2. Concerns relating to sand and gravel extractions

Each year across the OSPAR area, around 50-60 million cubic metres of marine mineral deposits are extracted from the seabed from licensed areas as a source of material for the construction industry or for beach nourishment (see Figure 2.1). Gravel and sand (aggregates) are the principal materials extracted, but in some countries (for example France, Ireland) significant volumes of non-aggregate marine mineral resources such as maerl or shelly sands are also extracted (see Figure 2.2).

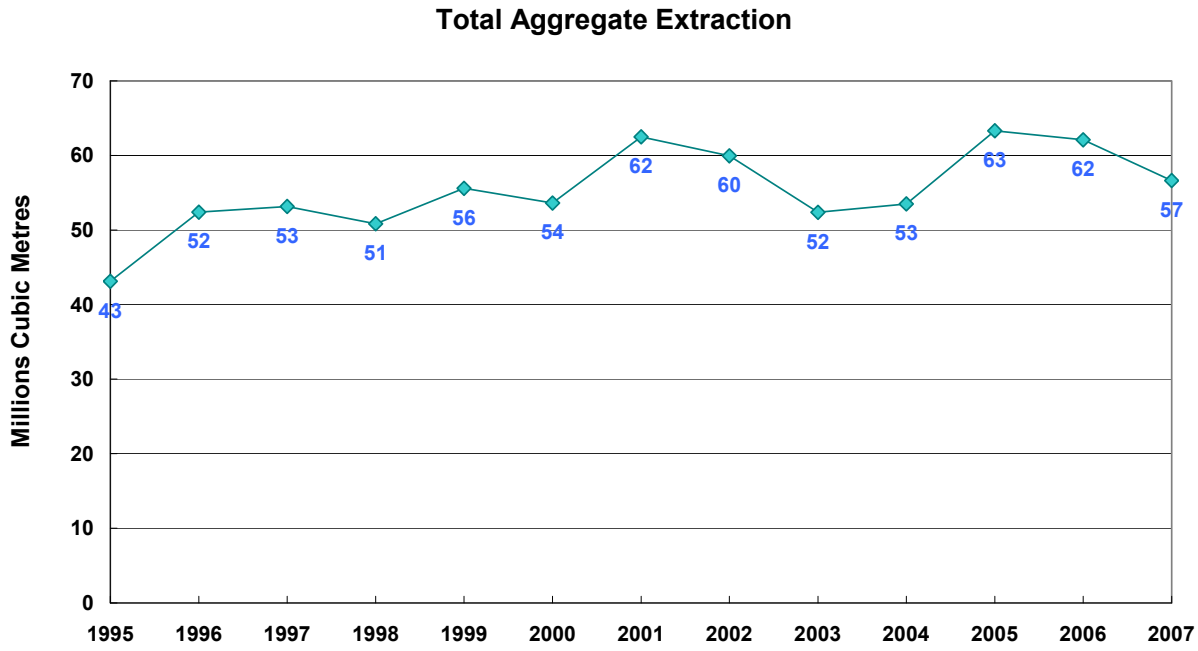

Figure 2.1: *Total aggregate extraction in the OSPAR Maritime Area*
Source: ICES, 2005, 2006, 2007, 2008, 2009. Note this only represents data reported to WGEXT and is thus an approximation.

The type and quantity of aggregate dredged in the OSPAR area varies according to location and end-use requirement (see Figure 2.2). By its very nature, dredging is a shallow water coastal activity, thus is most prevalent in Regions II, III and to a slightly lesser extent Region IV. Region II includes the Netherlands (the biggest producer by volume), and significant parts of the United Kingdom and France and Denmark (the next three biggest producers). The volume of sand and gravel extracted in Region II is estimated at approximately 80% of the overall volume extracted throughout the OSPAR area.

Demand for marine sand and gravel is likely to increase as a result of sea level rise.

Contracting Parties that may not themselves have a marine aggregates industry (for example Switzerland) may nonetheless be consumers of such products. Though beneficial re-use of alternative materials in the construction industry has increased over the last decade, demands for aggregates has also increased for a variety of uses, including construction, land reclamation and beach nourishment.

The extraction of marine mineral deposits has profound effects on the seabed as it essentially removes the substrate and any biota associated with it, thereby altering the ecological services of the dredged area. Dredging may also result in changes to the nature and stability of sediments, increased turbidity, redistribution of fine particulates and the production of plumes of suspended material.

Differences in the type of dredger employed as well as the nature of the receiving environment can influence the spatial scale of impact on the seabed and its fauna, both in terms of the direct effect of removal of sediments and the indirect effects of extraction associated with the deposition of re-suspended sediments.

While the total quantity of material extracted from the seabed has risen by approximately 30% over the last decade, available data suggest that the spatial extent of sand and gravel extraction in the OSPAR area is generally stable, as new concessions are progressively offset by relinquished acreage. However, the degree and speed of recovery of the seabed is a key concern as the medium and long term impacts of extraction activities persist after the activity has ceased. Many of the studies to date relate to the impacts of short-term dredging events. While these have proved useful in describing the processes leading to benthic re-establishment, further work is necessary to determine the validity of these findings in areas which have been exposed to long term industrial scale dredging operations. Most literature indicates that re-establishment of a community similar to that which existed prior to dredging can only be attained if the seabed topography and original sediment composition are restored.

Due to the distribution of marine sand and gravels, extraction activity tends to be focussed in discrete geographical locations dictated by the spatial extent of the resource. While a single dredging operation may result in an acceptable level of environmental impact, the potential for unacceptable impacts can increase significantly as a result of multiple dredging activities operating in close proximity to one another. Such cumulative impacts may also occur when aggregate extraction occurs close to another seabed activity, for example an offshore wind farm. The cumulative effect of aggregate extraction over time may also exacerbate the impact of individual extraction operations.

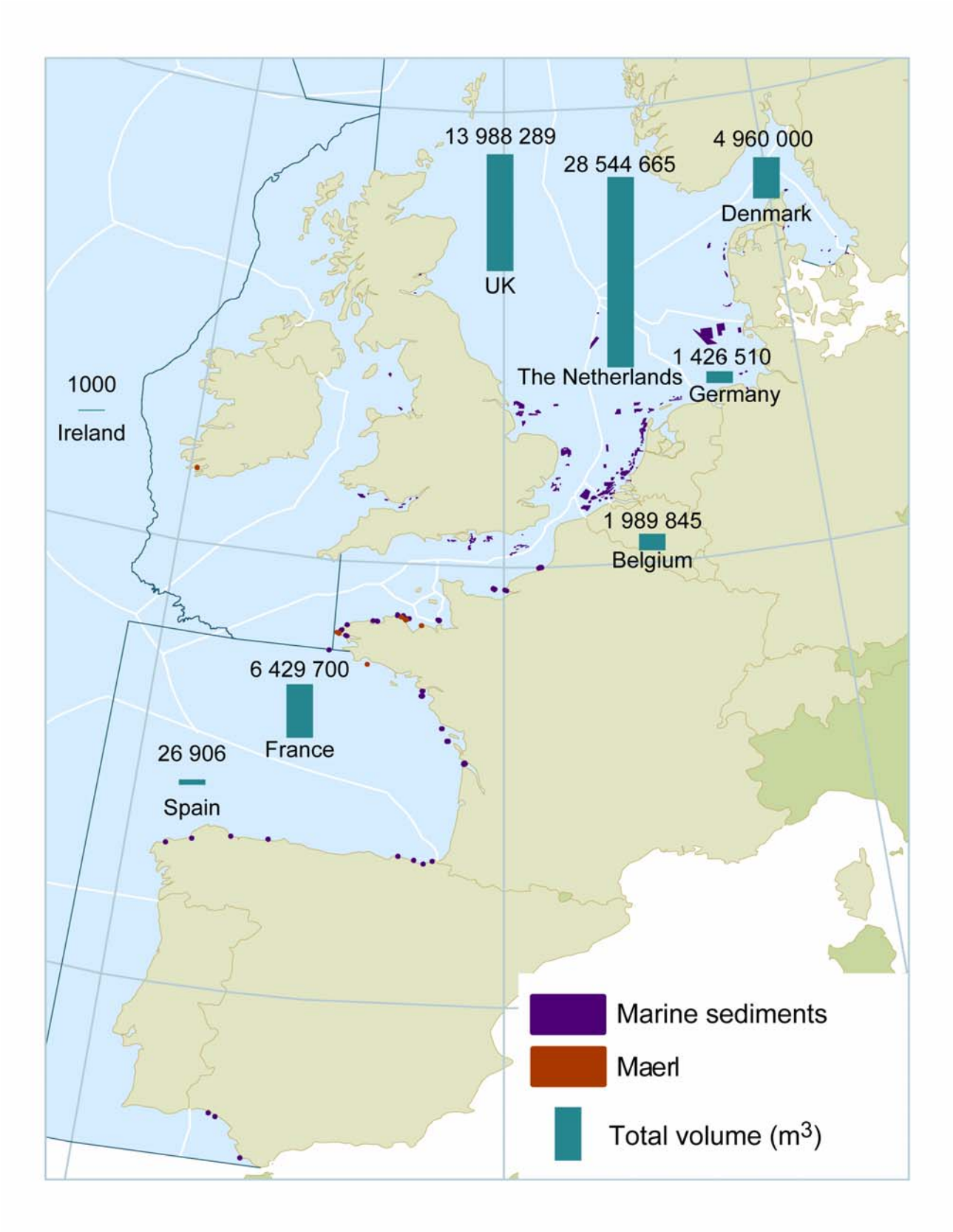

Figure 2.2: *Extraction sites for sand, gravel and maerl in the OSPAR maritime area and volumes extracted in 2007. Source ICES(2008) (volume)*

3. Management of aggregate extraction activities

3.1 Changes in aggregate extraction patterns and techniques

The environmental management of marine aggregate dredging has seen some significant advances over the past 10 years, partially in response to increased regulation and control as a result of ongoing development of the Environmental Impact Assessment Directive (85/337/EEC) and Habitats Directives (92/43/EEC). In addition, the industry itself has implemented some significant changes in the control of dredging operations in some OSPAR countries, linked both to improving resource management and reducing spatial conflicts with other marine users. This includes, for example, the increasingly widespread use of electronic 'black-box' monitoring devices (for example in Belgium, Denmark the Netherlands and the United Kingdom) that record detailed information on the spatial and temporal extent of extraction activities. This has obvious links to the development of wider marine spatial planning initiatives.

The move towards more spatially restricted (and therefore more intensive) levels of dredging activity raises an additional issue which requires investigation. While the total spatial footprint of the impact is reduced, the increased levels of intensity can affect the timescale for the recovery of the seabed. The availability of detailed black-box data to assess historical dredging activity will allow this issue to be examined in more detail.

3.2 Regulation and control

The regulatory imperative has been to promote the management of marine aggregate operations in order to minimise the footprint and potential resource conflict with other marine users (commercial fishing, navigation and the renewable energy industry). An increasing awareness of sustainability issues has informed this. The stricter regulation of aggregate extraction activities is exemplified by Spain, which has prohibited the use of marine sand and gravel for purposes other than beach nourishment.

In all countries where significant aggregate extraction takes place, legislation has been adopted that takes into account the EU Habitats Directive (92/43/EEC). ICES guidance on environmental impacts of aggregate extraction has been adopted by OSPAR (OSPAR, 2003) and has been implemented by most Member States through their national regulation or guidance. This guidance reflects the increasingly broad range of issues and key sensitivities.

In addition, specific mitigation and monitoring is routinely specified in consents for major extraction operations and some operations are subject to periodic or continual review. For example, the United Kingdom government has stipulated five yearly reviews on the licences granted in 2006 for Areas 463 – 465 in the English Channel. A recent Irish policy report has also recommended periodic reviews for aggregate extraction licences (Sutton *et al.,* 2008).

Substantial programmes to further understand the environmental consequences of aggregate extraction have been established in several OSPAR countries. Such initiatives are particularly important in understanding new areas of potential impact over and above the site specific effects of single operations. These include the potential for cumulative effects from multiple dredging activities in close proximity to one another, or the effects of aggregate dredging in conjunction with other activities, for example commercial fishing, capital dredging activities or offshore renewable energy.

Given the level of understanding available, the assessment of both temporal and spatial cumulative effects will continue to evolve. In both cases, the means to assess potential impacts and to establish their significance remains a key requirement, which can be best achieved by assessment at a regional scale. The Regional Environmental Assessment prepared by the industry in the United Kingdom sector of the Eastern English Channel represents one example of this approach.

3.3 Implementation

The regulation of sand and gravel dredging continues to evolve. The development of regional assessments has helped some OSPAR Contracting Parties that seek to implement marine spatial planning regimes (for example in the United Kingdom), but this is not replicated throughout the OSPAR maritime area. Spatial planning may prove an effective tool for balancing the requirements of extractive marine industries and fisheries with those of nature conservation, amenity and recreation. Such approaches are being adopted in several OSPAR countries such as the United Kingdom and Spain.

Comprehensive extraction data are not reported by all OSPAR Contracting Parties and data on the spatial extent of marine aggregate extraction by OSPAR Contracting Parties is variable. In the absence of such data, it is difficult to asses if regulation has resulted in improved protection of benthic habitats and species.

4. The principal effects of aggregate extraction

4.1 Benthic impacts

Loss of benthic habitats and species is the most obvious effect of aggregate extraction. Not only is there a direct loss of abundance, species diversity and biomass of the benthic community in the dredged area, but the effects of turbidity and resettlement of suspended material may cause similar (albeit lessened) effects over a wider area. (Kenny *et al.*, 1998; van Dalfsen *et al.*, 2000; Sardá *et al.*, 2000; van Dalfsen and Essink, 2001). Benthic impact is a key concern where dredging activities may impinge on habitats or species classified as threatened or in decline (such as maerl or *Sabellaria* reefs).

Changes to the nature and stability of sediments may lead to increased turbidity, redistribution of fine particulates and the production of plumes of suspended material. Such effects are not due solely to the mechanical disturbance of the seabed sediment by the drag-head. Outwash of material from spillways from the vessel hopper can generate a far greater quantity of suspended material. A further source of suspended material results from rejection of unwanted sediment fractions (termed sediment “screening”). The impact of plume fall-out from screening operations on the benthic fauna is complex. Current research suggests that the nature of the substrate is critical in determining the speed and extent of benthic recovery in such cases. The fauna inhabiting deposits of clean mobile sands tend to be adapted to naturally high levels of suspended sediments and are thus relatively resistant (Newell *et al.*, 2002; Cooper *et al.*, 2005). By contrast, sand may have a significant abrasive effect on encrusting epifauna in gravel habitats. A study of a gravel extraction site in the eastern English Channel (Desprez, 2000) has shown that the indirect impacts of sand deposition on macrobenthic fauna were as great as the direct effects of the extraction itself.

The estimated time required for recovery of the benthic fauna following marine aggregate extraction varies depending on the nature of the habitat and pre-existing fauna, the scale and duration of disturbance, hydrodynamics and associated bed load transport processes and the topography of the area. Several studies have suggested that recolonisation of a dredged area may start to take place relatively rapidly, with restoration of biomass to pre-dredge levels anticipated to occur within 2 – 4 years (van Dalfsen and Essink, 2001). However, such studies have focussed on dredging operations conducted over a relatively short time-scale, typically periods of up to one year. There is some disparity in the findings relating to the effects of long term aggregate extraction (*i.e.* over the life-time of a typical commercial extraction licence). These range from minimal disturbance following cessation of dredging to significant changes in community structure, persisting over many years. Some recent evidence from the United Kingdom part of the North Sea suggests that recovery periods can be prolonged *i.e.* >7 years especially where sites have been dredged repeatedly at high intensities (Cooper *et al.*, 2005).

4.2 Effects on the water column

The re-suspension of seabed material and the generation of turbidity plumes may also have impacts on the water column. In addition, reducing substances bound in the sediment (for example organic matter,

sulphides, ammonium) and heavy metals chelated to fine particles may be released to the water column. In sheltered non-tidal areas, where the content of these compounds in the sediment may be high, a critical reduction in dissolved oxygen concentrations may occur which may in turn adversely affect fish and benthos. Commercially dredged deposits have very low organic and clay mineral content. 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. Such impacts are of greater significance with respect to capital and maintenance dredging operations associated with harbour management or land reclamation and these are discussed in other other OSPAR publications related to JAMP assessments on dumping, dredging and land reclamation.(OSPAR, 2008 a,b, and OSPAR, 2009)

Turbidity plumes may affect the ability of diving birds and some fish species to forage, as well as damaging the gills of some fish and invertebrates. As with the chemical effects mentioned above, this is not a major concern in practice.

5. Conclusions and recommendations for future management of sand and gravel extraction

There remains a lack of knowledge on certain environmental impacts associated with aggregate extraction. Greater efforts to reduce the negative effects of mineral extraction will be required if sand and gravel extraction further increases as expected. Areas where several actions are recommended by ICES (see technical Annex), include fish, meiofauna, long-term recoverability of the seabed and the feasibility of seabed restoration. In addition, the extraction of maerl, which is listed by OSPAR as a declining habitat (OSPAR, 2008a) and negative effects of dredging on *Sabellaria spinulosa* reef, warrants further study to demonstrate the sustainability or otherwise of this practice.

All OSPAR Contracting Parties should strictly implement the ICES guidelines and supply comprehensive information about their marine aggregate industries to the ICES WGEXT; particularly information relating to annual production rates, the area of seabed licensed and the area of seabed dredged. The use of electronic monitoring systems and “black box” equipment is recommended in this regard. A uniform reporting format is recommended to facilitate inter-comparison. OSPAR maritime states are encouraged to implement seabed habitat mapping programmes to provide information to underpin licensing decisions and/or marine spatial planning initiatives.

Where multiple dredging operations are proposed in close proximity to one another, and where there is the potential for cumulative effects, a regional approach to development and assessment should be considered, for example by means of a regional environmental assessment. In some cases, where a resource is on or near a national boundary, this may require co-operation and co-ordination between Contracting Parties.

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Technical Supplement

Sand and gravel extraction in the OSPAR area

(Based on ICES WGEXT Cooperative Research Report)

ICES COOPERATIVE RESEARCH REPORT

Rapport des Recherches Collectives

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Effects of extraction of marine sediments on the marine environment 1998–2004

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Contents

1 Introduction

Each year across the ICES Area, approximately 53 million m^3 of sand and gravel are extracted from licensed areas of the seabed as a source of aggregate for the construction industry, either to supplement land-based sources or as a source of material for beach nourishment. Because planning constraints and resource exhaustion are tending to restrict the extraction of sand and gravel (aggregate) from terrestrial sources, attention is increasingly being focused on the importance of seabed resources to satisfy part of the demand for aggregates. The seabed is also recognized as the only viable source of material for beach recharge in coastal defence schemes. In recognition of this, the exploitation of marine resources is supported in most ICES Member Countries by national and international minerals policies, subject to environmental safeguards. The use of marine resources reduces the pressure to work land of agricultural importance or of environmental and hydrological value and, where materials can be landed close to the point of use, an additional benefit is that long-distance overland transport is avoided. However, the benefits of using marine sand and gravel must be balanced with the potentially significant environmental impacts.

The scale of marine aggregate extraction has increased in recent years. This rise reflects the increasing constraints on land-based extraction and the recognition that controlled dredging is sustainable in the foreseeable future. Interest by the general public in the effects of marine sand and gravel extraction on the environment and fisheries has grown in line with this expansion of effort. Issues such as the potential for conflict of interest between stakeholders in the resource and the efficacy of remedial measures during and after extraction are analogous to those arising from land-based activities. However, in the marine environment, their resolution is rendered more difficult because of the relative inaccessibility of sites, the general paucity of site-specific data on the structure and functional role of the habitat and biota associated with sand and gravel deposits, and problems in quantifying the performance of local fisheries. Further core drivers for understanding the impacts of marine aggregate extraction exist at the international level. In particular, there is an increasing focus on the conservation of marine biodiversity, following the Rio Earth Summit, and on the protection of marine habitats (under the EU Habitats Directive) of whole sea areas through international management initiatives under OSPAR, HELCOM, and the EU Marine Strategy Directive. OSPAR, HELCOM, and ICES are also promoting transnational cooperation in developing the ecosystem approach to marine management. Of particular relevance is the increasing emphasis in national and international fora on the development of more holistic (ecosystem-level) approaches to marine environmental management, including evaluations of the scope for "cumulative" or "in-combination" effects.

The ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) was established in 1986 with the stated aim of increasing knowledge of the impact of marine aggregate extraction, both on fisheries in particular and on the marine environment in general. Since then, WGEXT has widened its remit to include furthering the understanding of the impacts of marine sediment extraction on various components of the marine ecosystem. WGEXT also regularly contributes to the *ICES Cooperative Research Report* series; its efforts have provided a synthesis of recent advances in our knowledge and understanding of ecosystem effects resulting from the extraction of marine sediments (ICES, 1992, 2001). One of the principal activities of WGEXT has been the identification and recommendation of future research needs. For example, *ICES Cooperative Research Report No. 247* (ICES,

2001) highlighted 15 key research themes, and in the intervening years, WGEXT has taken a lead in reviewing ongoing research in order to monitor progress in meeting the identified need. This report, therefore, presents the latest synthesis of recent research on the effects of marine sediment extraction.

This report also provides a synthesis of state-of-the-art approaches to understanding the effects of the extraction of marine sediments. Keeping abreast of developments, particularly those relating to the role of remote acoustic techniques in resource mapping programmes, is one of WGEXT's main concerns. Coverage of this topic in the current report was, therefore, considered important, particularly because the production of high-resolution biotope maps of the seabed, using data derived from a combination of conventional acoustic and visual techniques, is increasingly employed in environmental assessments of marine sediment extraction sites.

Recognizing the role of this working group in reviewing the impacts of aggregate extraction in relation to legal safeguards and national and international governance arrangements, this report presents a synthesis of information compiled over recent years. Finally, in addition to providing detail on established legislative frameworks, this report also identifies the latest developments in approaches to assessing risk at proposed extraction areas.

1.1 Objectives

The objectives of this report reflect those of WGEXT, namely 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.

1.2 Contributors

At least 15 authors from as many countries participated in the production of this report or contributed data. A complete list of contributors can be found in Annex 1. Particular acknowledgement is given to Siân Boyd and Gerry Sutton (Section 1), Mark Russell (Section 2), Ingemar Cato (Section 3), Siân Boyd, Kris Hostens, Jochen Krause, and Manfred Zeiler (Section 4), and Ad Stolk and David Carlin (Section 5). All material has been reviewed by WGEXT.

2 Review of the quantity, quality, location, and uses of marine sediments extracted

2.1 Extraction of marine sediment

Extraction of marine sediment in the ICES Area can be related to two distinct operations. The first concerns sediment generated by an extraction activity that is assessed and licensed for a specific purpose, whether for construction, replenishment, or reclamation purposes. The second concerns marine sediment generated as a by-product of another activity, such as maintenance or capital dredging. The sediment removed through such activities may be reused (the concept of beneficial use). Under these circumstances, the dredging operation may not be controlled or managed in the same way as it would be in licensed or borrow areas awarded specifically for the production of sediment. This report only considers the extraction of marine sediment that is assessed and licensed for a specific purpose.

The nature of the sediments being dredged by ICES Member Countries varies according to the availability of the natural sediment resources offshore and the national/international market demand for these materials. The principal markets for marine dredged sediments vary between ICES Member Countries, but in general terms, these can be broadly characterized as construction aggregates, construction fill/land reclamation, and beach replenishment/coastal protection. As a consequence of the variations in resource availability and market demand, some national operations are concerned primarily with sand (e.g. the Netherlands), whereas others are primarily concerned with gravels (e.g. the UK).

This section reviews the status of marine sediment extraction in the ICES Area. Although the dredging of marine sediments is dominated by sand and gravel (aggregates), other non-aggregate materials, such as maerl and glacial till, are also dredged in limited quantities and, where appropriate, these are also detailed. Short descriptions of the national activity in each ICES Member Country are provided, and national production statistics are presented in Annex 2.

Changes and developments in the end uses of marine dredged sediments in the ICES Area are reviewed, including the nature of the resources being targeted, the management of marine sediment resources, the dredging industry, and the dredging technologies that are employed.

2.2 Sustainable use of aggregate resources

Aggregates are an essential part of the modern built environment, which exists in all ICES Member Countries. The continual development and maintenance of this environment creates an annual demand (based on output) equivalent to 7.8 t of crushed rock, sand, and gravel per head of population in Europe alone – a total demand of over 3000 million t every year. This is met from a variety of sources, ranging from primary crushed rock, sand, and gravel (including marine) to secondary and recycled materials.

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, and this could be

exported to countries with a shortfall in home-based production. Some countries, such as the UK, are looking to provide suitable deep-water wharves near their larger markets to accommodate large bulk-carriers.

Sustainable exploitation of marine resources is well established as a basic principle in both national and international regulations, and beneficial use of dredged materials arising from capital and maintenance dredging is being encouraged through planning policy, differential taxation, and licence procedures. In the Netherlands and Denmark, most of the material dredged for navigational purposes is being used for construction fill; in Denmark, glacial till and limestone are also being used for land reclamation. In some areas, sand from capital and navigational dredging is of high quality and can be used for making concrete. Careful planning of the use of dredged material from large-scale construction projects has proven to be economically and ecologically acceptable, and could reduce the pressure on land-based reserves, particularly of sand, as well as reducing the requirement to dispose of material at sea.

As part of the sustainable exploitation of marine resources, it is a fundamental issue that these finite resources be used responsibly and appropriately. Over the past ten years, there has been a significant increase in the use of secondary and recycled materials in an effort to reduce the pressures on primary aggregate resources, including marine resources. The Netherlands, Germany, and the UK, in particular, have led the field in this respect. However, there is a limit to the volumes of secondary and recycled materials available, for example, in the UK. Although the contribution of secondary and recycled materials is ca. 23% of total consumption, there is limited scope for further increases in the use of most alternatives to primary aggregates, unless significantly greater use can be made of other waste products, such as those from the production of china clay. On this basis, there is expected to be a continuing demand for primary-won aggregates to support construction, of which marine sources represent one component.

There are also limits to the end uses in which secondary and recycled materials can be employed. In concrete and concrete products, the end uses generally require high-quality materials; as such, there is only limited potential for substitution. However, for bulk fill, the specifications are generally less stringent. There is, therefore, greater potential for substitution; the limiting factor in this instance is the availability of sufficient volumes of alternative materials and the ability to transport and deliver them economically. The concept of "fit-for-purpose" is, therefore, particularly important.

Under the EU Construction Products Directive, a set of European standards for construction aggregates has been introduced in order to unify and simplify the various existing national technical requirements. In turn, this is expected to facilitate trade between all participating countries by standardizing the product descriptions and terminology for the producers, specifiers, and users of materials alike. Standard specifications have now been established for a range of end uses, including concrete and mortar, which rely particularly on marine material. Any product able to fulfil the requirements of the specification can therefore be used, reinforcing the idea of fit-for-purpose.

The sustainability arguments surrounding aggregate supply also need to consider wider issues beyond the finite nature of the resources. Aggregates are a low-cost, bulk material and are therefore very sensitive to transport costs. By road, the cost of materials can double for every 50 km travelled. With a typical 5000 t (3000 m^3) cargo being equivalent to 250 lorry loads of 20 t (12 m^3), the marine aggregate industry offers significant advantages through economies of scale. This means that large vol-

umes can be transported economically from the source over large distances (>150 km) and be delivered close to the point of demand. There are also the wider benefits of relieving pressure on the road networks and the associated reduction in emissions.

Large-scale bulk-fill or replenishment schemes involve huge volumes over long timescales, and it would not be economically feasible to undertake such projects without the use of marine dredged materials. In these instances, the concept of fit-for-purpose is important to ensure that large volumes of high-end specification resources are not being used for a low-end purpose. It is common for material arising from navigation dredging (both maintenance and capital) to be used for such purposes, rather than merely being disposed of, under the auspices of beneficial use.

The contribution of marine aggregates to ICES Member Countries forms one component of the overall need for aggregates (e.g. 20% of the total demand for sand and gravel in the UK). Marine dredged materials contribute significantly to overall demands by a number of countries and, in certain areas and for certain uses, they are a major/predominant source of supply. The British, American, Dutch, Belgian, and French markets around the major points of landing, such as the Thames, New York, Amsterdam, Antwerp, Dunkirk, and Flushing, depend heavily on supplies of marine material. Additionally, in ICES Member Countries, beach nourishment and land reclamation/construction fill accounts for more than 20 million m^3 of marine material per annum.

2.2.1 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 therefore comparable in performance with land-based alternatives. This is reinforced by the introduction of common European standards.

There are three main uses for marine aggregates: (i) construction – mainly for making concrete; (ii) land reclamation, infilling of docks, road bases, and other ground works (construction fill); and (iii) coastal protection – both recharge and coastal feeding. Small quantities of marine sand are used in agriculture to improve soil structure and as cover for 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 uneven. In the North Sea basin, for example, sediments generally become finer from west to east, which is reflected in the extraction patterns of the countries bordering it. The UK extracts approximately 80% of the total gravel removed from the North Sea region (excluding sand), whereas the Netherlands extracts a similar percentage of sand.

2.2.2 Construction

Marine sand and gravel constitute an important raw material for the construction industry, primarily for use as aggregates in the manufacture of concrete for building purposes. Washed and graded marine sand and gravel are normally combined in the proportion of 50:50 to produce concrete and concrete products. Marine sand can also be used "as dredged" in combination with crushed rock for the same purpose.

Research carried out by national institutes responsible for the testing and specification of construction material has established that the use of marine sand and gravel is

no less appropriate than the terrestrial equivalent, and marine-sourced material has the benefit of superior workability and lack of contamination from soft materials compared with land-won sand and gravel.

Given the distribution of populations within ICES Member Countries along both the coastal fringe and the major river systems extending inland, 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 transport of large quantities of land materials by road.

Marine aggregates (sand and gravel) are used extensively in the UK (more than 8 million m^3 in 2003) 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.

2.2.3 Construction fill and land reclamation

Marine dredged material continues to be used for a number of major construction fill and reclamation projects in the ICES Area.

In the Netherlands, marine sand has been used for a number of major contracts – mainly for landfill. Although Dutch policy is for more marine sand extraction, the volumes are more or less stable. However, the quantities in 2001 and 2002 were higher because of large infrastructure projects on land.

There have been no major reclamation projects in the Netherlands in recent years. The licence granted for 20 million m^3 of marine sand extraction for the enlargement of the Port of Flushing has not yet been used as a result of unresolved issues associated with the environmental impact assessment (EIA). For the sand extraction of the enlargement of the Port of Rotterdam, an EIA for 300 million m^3 sand is in progress. The enlargement began in 2008.

In Denmark, a major enlargement of the harbour of Århus required more than 8 million m^3 of sand dredged from two areas in the Århus Bight between 1998 and 2000. In 2005, an additional 4.8 million m^3 was dredged from the same two areas for further enlargement of the harbour. The construction of an artificial island and beach (the Amager Beach Resort, near Copenhagen) required more than 1 million m^3 of sand dredged from Kriegers Flak and two areas off the east coast of Sjælland.

In Denmark, small volumes of glacial till arising from capital dredging projects continue to be used for fill.

In Estonia, 3.5 million m^3 of sand were dredged for reclamation at the Port of Muuga (Tallinn), and 500 000 m^3 was used for the capping of an atomic waste facility.

In the UK, significant volumes of marine sand and gravel have been used to support various port developments. In 2001, 480 000 m^3 was used in Belfast harbour, Northern Ireland, and between 2003 and 2004, 1.17 million m^3 was used at the Port of Felixstowe, England.

2.2.4 Coastal protection

Soft engineering approaches to prevent coastal erosion and protect coastal communities from inundation by the sea are now well established. Material for beach recharge schemes generally 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. However, given the pres-

sures of exploiting an essentially finite resource, more effort is being made to employ sand and gravel resources that are readily available rather than being controlled by the need for a particular specification.

Besides beach replenishment, where sand and gravel is deposited directly on the beach, a new technique, termed *coastal feeding*, is being employed. Material is deposited into the sediment transport regime upstream of the natural processes that are feeding the coastline. The additional sand is incorporated into the overall flux of available sediment, thereby increasing the amount of sediment that can be transported into the foreshore and beach systems through natural processes.

In the Netherlands, beach nourishment to protect the national coastline has been used since 1950. In 1990, the Dutch Parliament adopted a policy to stop further structural coastal recession, which has meant that the coastline has to be maintained at its 1990 position. Every year, the status of the Dutch coastline is measured and compared with the 1990 reference standard. An annual sand nourishment programme maintains the baseline coastline, and losses of dune and beach sand are compensated with marine sand. Since 2001, more than 10 million m^3 of sand annually have been used for coastal feeding and beach nourishment.

In the UK, coastal frontages along the east coast of England (Lincolnshire, Norfolk, and Essex), the south coast of England (Kent, East Sussex, West Sussex, and Dorset), and southwest England (Somerset) have been subject to coastal protection or replenishment works since 1996. The annual volumes supplied have varied considerably – ranging from 3.58 million m^3 in 1997 to 147 000 m^3 in 2001 – partly as a result of changes to funding priority. In the US, most beach nourishment works have taken place on the Inner Shelf (< 3 nautical miles/5.6 km) under state jurisdiction, and since the 1920s, more than 500 million m^3 have been placed at more than 200 locations. As sand resources suitable for nourishment become depleted in state waters, Outer Continental Shelf (> 3 nautical miles/5.6 km) resources under federal jurisdiction are increasingly being considered, with more than 18 million m^3 being dredged since 1995.

Poland, Spain, Germany, and Denmark have also undertaken significant coast protection works, including one-off projects and ongoing maintenance commitments.

Most ICES Member Countries continue to use marine sediments for beach replenishment. With the predicted alterations in sea level resulting from climate change, marine dredged sediments can be expected to play an increasing role in coast protection across the ICES Area as the 21st century progresses.

2.2.5 Other uses

For many years, calcareous seaweed (maerl) has been used to improve structure and replenish minerals in soil, as well as for animal feed, additives, and biopharmaceutical products. In France, the production of maerl and shelly sand has begun to decrease slightly, with 358 000 m^3 dredged in 2004 compared with 470 000 m^3 in 2002, and in Ireland, only small quantities of maerl (7000 m^3) are extracted each year. In the UK, dredging of maerl has ceased in recent years.

In the Netherlands, more than 200 000 m^3 of shell and shell fragments have been extracted from the Western Scheldt, the North Sea, and the Wadden Sea each year between 1993 and 2003, although production decreased in 2004.

2.3 Marine aggregate resources

The distribution of marine sand and gravel resources across ICES Member Countries is uneven, and it is reflected in the extent to which resources are exploited by individual states. As on land, the distribution of resources is dictated by the geological origins of the source material and the physical processes that have eroded, transported, sorted, and deposited them.

What constitutes a potential resource also varies widely between ICES Member Countries. Almost all states have significant volumes of sand and/or gravel off their coastlines, but without a market, they will not be exploited. This is often directly related to the availability of alternative sources of construction material, normally from terrestrial sources. However, either the absence of suitable resources or a constraint on remaining resources (e.g. through prior development or increasing environmental restrictions) can lead to alternative sources – including marine resources – being exploited to fulfil the necessary demand.

Over the past 20 years, the social and environmental pressures on historical terrestrial sources of sand and gravel have been increasing; indeed, this was one of the major factors leading to the establishment of many national marine aggregate industries. However, similar pressures (the protection of habitats and species, competition with other offshore activities, including fisheries and windfarms) are now well established in the marine environment. This has meant that historical extraction in shallow waters (< 30 m) and relatively close to shore is coming under increased pressure from a range of interests. Furthermore, the development of new resources, either to replace exhausted licensed areas or to develop the industry further, has become increasingly complex.

These pressures on existing nearshore marine resources mean that alternative sources of sand and gravel are being examined in order to maintain the contribution that marine aggregates make to the construction industry. In English and French waters, new large-scale resources have been identified and are being investigated in the Eastern English Channel. With water depths greater than 50 m, this location raises technical challenges for the operation of aggregate dredgers. The new location also brings a number of new environmental issues under consideration, such as the nature of the impact on a stable gravel seabed removed from the relative dynamism of wave and storm action, and the associated implications for recoverability. The implications of farfield impacts arising from the introduction of sands (through overspill, screening, or release from the dredged seabed) into a sediment transport regime with a relatively limited flux need to be examined. Other deep-water resources are being investigated in the Outer Bristol Channel off the coast of south Wales.

On the Dutch continental shelf, investigations are continuing into the extraction of coarser sediments located beneath the finer modern Holocene sediments. Production would require the removal and disposal of significant volumes of overburden material, the implications of which are currently being considered.

On the Atlantic coast of the US, as Inner Shelf (< 3 nautical miles/5.6 km) sand resources for beach nourishment become more scarce, increased attention is being paid to the availability of resources located on the Outer Shelf (> 3 nautical miles/5.6 km).

In both Belgium and Denmark, the potential for beneficial use of dredged material associated with capital and maintenance dredging activity is being investigated for either fill or beach-feeding/nourishment schemes. Similar approaches are already in place in the Netherlands and the UK to ensure that best use is made of the material

available and that high-quality resources are not necessarily employed for low-grade end uses.

In the current regulatory and policy climate, it is necessary to go significantly beyond simply assessing the site-specific impacts of marine sand and gravel extraction. The distribution of commonly targeted marine sand and gravels is such that extraction activity tends to be focused in discrete geographical locations dictated by the spatial extent of the resource. Whereas a single dredging operation may result in an acceptable level of environmental impact, the potential for unacceptable impacts can increase significantly as a result of multiple dredging activities operating near each other, creating a "cumulative" or "in-combination" effect.

As the coastal zones of Member States become ever more congested, with competition for space on sea surface and seabed at various temporal and spatial scales, it is now necessary to consider the additive in-combination effects of other activities that interact with the seabed and are taking place near the dredging operations, such as capital dredging, windfarm development and operation, and commercial fishing. By the same token, these other activities taking place in the marine environment must now consider aggregate dredging.

For both the cumulative and in-combination effects, the means to assess potential impacts and establish their significance remains a key requirement that can only be achieved by assessment at a regional scale. The Regional Environmental Assessment, prepared by the industry in the English sector of the Eastern English Channel, represents one example of this approach.

One key to understanding the effects of marine aggregate dredging is increasing our knowledge of the geological resource being targeted and the sediment processes taking place in and around the extraction area. Understanding these processes is particularly important, because it is the sediment transport processes that will dictate the nature and extent of impacts from extraction activities outside the immediate dredging site, and which will drive the recovery processes once extraction has ceased. The development of positioning and survey technologies, and the collection of data at higher resolutions, has afforded industry a better understanding of the scale, extent, orientation, internal configuration, and composition of marine aggregate resources. In combination with this, the use of high-resolution sidescan sonar and multibeam systems has permitted seabed sediment transport processes to be more accurately defined. This, in turn, has allowed extraction plans to be designed that take account of both resource management and environmental implications, and allows the establishment of appropriate mitigation and monitoring measures.

2.4 Review of ICES Member Country activity

Tables containing summary statistics for individual ICES Member Countries are presented in Annex 2.

2.4.1 Belgium

Most of the sand dredged from the Belgian continental shelf is not of very good quality (100–200 μm), and it is mainly used in the construction industry as fill, or in tarmac, cement, or concrete. Better quality sand (250 μm) is dredged from Kwintebank and the eastern side of Thorntonbank (see Table A2.1).

2.4.2 Canada

No commercial extraction of marine aggregates has taken place in Canada in recent years, although industry is pursuing some interests on Canada's west coast. Research projects on marine aggregates, including a number of technical and environmental assessments, have been undertaken since 1998 (e.g. in the Bay of Fundy), but so far, no permission for the extraction of marine sediments has been granted (see Table A2.2).

2.4.3 Denmark

The extraction of marine aggregates in Denmark accounts for 10–20% of the total production of aggregates. Extraction of aggregates for construction has remained more or less stable between 1998 and 2004. In contrast, the extraction of sand fill for land reclamation depends on construction activities and has exhibited large variations over the years. Major projects requiring fill material have been infrastructural projects, harbour enlargements, and artificial islands.

The production of sand for beach nourishment on the west coast of Jutland has markedly increased from 40 000 m^3 in 1980 to about 3 million m^3 annually. Extraction is expected to remain at this level in the coming years.

Beneficial use of sand from maintenance and capital dredging represents an important contribution to the supply of materials for coastal protection, construction, and fill. Between 10 and 15% of the total marine extraction of sand comes from these sources (see Table A2.3).

2.4.4 Estonia

In Estonia, extraction of sand and gravel takes place primarily in the Gulf of Finland. In 2003 and 2004, 4.3 million m^3 of sand and gravel were dredged from three different areas (see Table A2.4).

2.4.5 Finland

Sand and gravel extraction from Finnish coastal areas was negligible until 2004. The harbour of Helsinki and the Forest and Park Service have permission to extract 11 million m^3 of marine aggregate off Helsinki until 2011. Extraction commenced in 2004, with a total of 1.6 million m^3 dredged, and continued in 2005 with 2.388 million m^3 (see Table A2.5).

2.4.6 France

Extraction of marine aggregates represents only a small part (1%) of the total national production. The amount of marine aggregates extracted has remained stable in recent years and is about 3 million m^3 $year^{-1}$. Extraction is restricted to a limited number of dredging areas in Normandy, Brittany, and along the Atlantic coast.

France has a limited extraction of non-aggregates, primarily maerl and shelly sand, of ca. 300 000–400 000 m^3 $year^{-1}$ (see Table A2.6).

2.4.7 Germany

In Germany, extraction of marine aggregates takes place in both the Baltic and the North seas.

The extraction of aggregates in the Baltic Sea for both beach recharge and construction has taken place for a number of years in designated dredging areas along the

coast and on the Adler Ground. In recent years, the exploitation has been stable or decreased slightly. Most of the aggregates are used for beach recharge. No new licences have been granted recently.

A limited number of licences for extraction are granted in the North Sea, mainly for reclamation projects, and more recently for the extraction of coarse construction aggregates for the local and international market (see Table A2.7).

2.4.8 Ireland

No commercial extraction of marine aggregates has taken place in Ireland for a number of years. Continuing extraction of maerl takes place, with a licence permitting 6000 m^3 $year^{-1}$ to be extracted from Bantry Bay (see Table A2.8).

2.4.9 The Netherlands

The annual average extraction of marine aggregates since 1996 is ca. 23.5 million m^3. As a result of major land-based infrastructure projects during 2001 and 2002, production increased to about 35 million m^3 $year^{-1}$. Approximately 50% of the average amount of commercially extracted aggregates is used for construction fill purposes on land. A small proportion of this is used for construction aggregate. The remaining 50% is used for beach nourishment. Since 1990, the Ministry of Transport, Public Works and Water Management introduced a regular coastal defence policy, which provides a national beach nourishment programme. As a result, the annual quantities dredged have increased. Annual production has also increased as a result of undertaking sand nourishment works on the foreshore instead of on the beach itself. Small volumes of marine aggregates continue to be supplied from the extraction areas in the southern part of the Dutch sector of the North Sea to Belgium for use as construction fill and in the construction industry (see Table A2.9).

2.4.10 Norway

Only very small quantities of marine aggregates for fill and construction have been extracted in Norway over the years as a consequence of the availability of and access to land-based resources. The amount of marine aggregates extracted annually is less than 1% of the national production (see Table A2.10).

2.4.11 Poland

Marine aggregates, primarily for beach recharge, have been extracted in Poland for many years, but minor quantities of sand and gravel for construction have also been produced from a few areas (see Table A2.11).

2.4.12 Spain

Beach nourishment is the only end use for which extraction of marine sand from the Spanish continental shelf is permitted.

Between 1990 and 2005, more than 15 million m^3 of marine sediment was dredged for this purpose along the North Atlantic Spanish coast, including the Canary Islands (see Table A2.12).

2.4.13 Sweden

No marine aggregates have been dredged in Sweden since 1993 (see Table A2.13).

2.4.14 United Kingdom

Marine sand and gravel production continues to make an important regional contribution to the construction aggregate requirements of the UK, particularly in England and Wales, where approximately 20% of the sand and gravel supply comes from marine sources.

Annual marine production off the coast of England and Wales amounts to approximately 13.25 million m^3 $year^{-1}$, with London and the south coast of England receiving 6 million m^3, equivalent to one third of the region's overall construction aggregate requirement. Although the aggregate is used in general construction, specific projects have included the high-speed Channel Tunnel Rail Link between London and Folkestone and the new Terminal 5 at Heathrow Airport. Smaller volumes of sand and gravel are landed in the northeast of England (the rivers Humber, Tyne, and Tees), whereas marine sand remains a regionally important source of fine construction aggregate (sand) supply in the Bristol Channel and the Irish Sea.

A significant proportion of the UK production (3.6–4.2 million m^3 $year^{-1}$) continues to be exported to northern France, Belgium, and the Netherlands for use as coarse construction aggregate. This is in the absence of any significant volumes of coarse aggregate being present on the eastern shelf of the southern North Sea.

Beach replenishment and construction fill remain important end uses of UK production, with annual volumes ranging from 3.58 million m^3 in 1997 to 147 000 m^3 in 2001. Coastal frontages along the east coast of England (Lincolnshire, Norfolk, and Essex), the south coast of England (Kent, East Sussex, West Sussex, and Dorset), and southwest England (Somerset) have been subject to coastal protection or replenishment works since 1996. The annual volumes supplied have varied considerably, partly as a result of changes to funding priority, with investment being diverted to inland flood protection projects.

In future, the construction and infrastructure development requirements for the 2012 Olympic Games to be hosted in London are likely to generate additional demand for construction aggregates, some of which will be met by marine supplies.

Original production figures for the UK were originally provided in tonnes. These have been converted to cubic metres (m^3) for ease of comparison with other national reports. Conversions are based on 1.66 t m^{-3} (see Table A2.14).

2.4.15 United States

Commercial marine aggregate operations

The US currently has two commercial marine aggregate dredging operations, although neither is actually offshore. Since 1985, Amboy Aggregates of South Amboy, New Jersey, has held a licence to dredge aggregates from the Ambrose Channel, the entrance to New York Harbour. Amboy produced an average of 1.225 million m^3 $year^{-1}$ of sand and gravel until 2003, when production increased to 1.59 million m^3, and then to 1.89 million m^3 in 2004. The company uses the MV "Sandy Hook", a 4500 million m^3 capacity hopper dredge, and is the largest supplier of aggregates to the New York City area. Amboy made a request several years ago to obtain the commercial rights to a large sand and gravel deposit located in federal waters offshore of northern New Jersey. However, public opposition to the project precluded the US Minerals Management Service from pursuing a competitive lease sale for access to the deposits.

The other operation is on Lake Erie and has processing facilities in Erie, Pennsylvania. It is owned by the Oglebay Norton Company and produces about 306 000 m^3 of concrete and mortar aggregates annually, using a trailing suction hopper dredger. The predecessor of this company, Erie Sand and Gravel Company, began dredging in Lake Erie in the early 1900s.

Marine sand for beach nourishment

Inner Shelf (state jurisdiction)

Most beach dredging operations have taken place in state waters within the 3 nautical mile/5.6 km territorial jurisdiction. Beach nourishment is the preferred method of coastal protection in the US, mainly because it preserves the aesthetic and recreational values of protected beaches by replicating the protective characteristics of natural beach and dune systems. The US has more than 200 nourished areas and, since the 1920s, has placed ca. 500 million m^3 of sediments on its beaches. Most of the nourishments on the US Pacific coast consisted of the use of beneficial sediments (opportunity nourishments), whereas on the east coast, nourishments were triggered by the need for shore protection from storms and hurricanes.

Outer Continental Shelf (federal jurisdiction)

As sand resources available in state waters for coastal and beach restoration and replenishment become scarce, the federal Outer Continental Shelf (OCS) increasingly represents a viable source of material for beach restoration purposes. These resources are under the jurisdiction of the Minerals Management Service (MMS), a bureau within the US Department of the Interior. To facilitate the leasing of these resources, Congress enacted Public Law 103–426 in October 1994, which amended the Outer Continental Shelf Land Act to provide the Secretary of the Interior with new authority to negotiate agreements and issue leases for the use of federal sand, gravel, or shell resources for public-works-related projects.

Sand has been dredged from the OCS (3 nautical miles/5.6 km and beyond) since 1995, when 917 520 m^3 were placed on a beach in Jacksonville, Florida. Since then, approximately 18.3 million m^3 have been dredged from the OCS for beach nourishment. This material has been used to nourish beaches on the coasts of the following states:

- Maryland (Assateague Island)
- Virginia (Sandbridge Beach)
- Virginia (Dam Neck Naval Facility)
- Florida (Brevard County beaches)
- Florida (Patrick Air Force Base)
- Florida (Duval County/Jacksonville Beach)
- Louisiana (Holly Beach)
- South Carolina (Surfside Beach).

The original US production figures were provided in tons and cubic yards. These have been converted to cubic metres (m^3) for ease of comparison with other national reports. Tons were initially converted to metric tonnes, and thence to cubic metres, based on 1.66 t m^{-3} (see Table A2.15).

2.4.16 Other ICES Member Countries

No national reports were received from Iceland, Latvia, Lithuania, Portugal, and Russia.

2.5 Operational management of aggregate dredging activities

The management and control of aggregate dredging activities has continued to evolve in the ICES Area. This can be partly linked to the continuing development of environmental policy and regulation at both regional and national scales. At the same time, the marine aggregate industry, on its own initiative, has been introducing responsible management practices on a voluntary basis.

The regulatory imperative has been to ensure the effective management of marine aggregate operations, both planned and ongoing, in order to minimize the impact to the environment (benthos, fisheries, and habitats) and to other marine stakeholders (commercial fishing, navigation, and the renewable energy industry). The ICES guidance on environmental impacts reflects the range of issues that now must be taken into account, together with potential key sensitivities, (see Annex 3). The current consenting systems within ICES Member Countries largely reflect these common themes.

The requirement for site-specific mitigation and monitoring associated with modern dredging consents has also evolved significantly (see Section 5). This ensures that the potential for impacts is reduced as far as possible and that the predicted impacts are monitored comprehensively to ensure that they fall within predicted values. If not, consents can be modified or even withdrawn. Many aggregate dredging operations are now subject to continual review throughout their predicted lifetimes. Additionally, new areas of potential impact have had to be considered over and above site-specific effects. These include the potential for in-combination effects from multiple dredging activities that are near each other and the effects of aggregate dredging in conjunction with other activities, such as commercial fishing, capital dredging activities, and offshore renewable energy. Given the level of understanding available, the assessment of both cumulative (temporal) and in-combination effects will continue to evolve.

From a production perspective, companies need to ensure that they maximize the aggregate resources to which they have access. To achieve this, there has been a considerable increase in the understanding of site-specific resources (in terms of the quality of equipment, positioning, and data) and how they can be used to help mitigate potential impacts and manage production operations. This, in turn, has allowed operators to delineate the commercially viable resources and to identify production zones over time in order to work resources more effectively. With regulatory requirements to minimize the extent of area dredged and to work areas to economic exhaustion before moving to a new area, the ability to manage activity at this scale is crucial. The use of computer-based plotting systems on board dredgers, interfaced with reliable and accurate GPS positioning, means that dredging operations can be focused into defined lanes, often 50–100 m wide.

A significant influence has been the interaction of the marine aggregate industry with other marine users and particularly the developing interest in marine spatial planning. Although the total area of seabed licensed for marine aggregate extraction can be quite large (e.g. 1257 km^2 in the UK in 2004), the area of seabed actually dredged in any one year will be significantly smaller (135 km^2). By being able to demonstrate this, and by disseminating information on both the licensed area and the total extent of the area being dredged, the potential for adverse interaction with other sectors can

be significantly reduced. In the UK, a voluntary initiative has been established by the industry and The Crown Estate to provide updated regional information on dredging activities every six months. This information is made available directly to the fishing industry and more widely on the Internet.

2.5.1 Electronic monitoring systems (EMS)

The use of black-box monitoring systems on board aggregate dredging vessels is now common practice among those ICES Member Countries who are the principal producers of marine aggregate, including Belgium (Figure 2.5.1), the Netherlands (Figure 2.5.3), Spain, Germany, and the UK. For example, in the UK, there are more than ten years of detailed records of dredging activity, covering more than 300 000 ha and 30 million individual dredging records. In Denmark, dredging activities have been reported in detail since 1990. This information, in turn, has provided unparalleled levels of information on the scale, extent, and intensity of dredging operations, providing benefits to both regulators and operators.

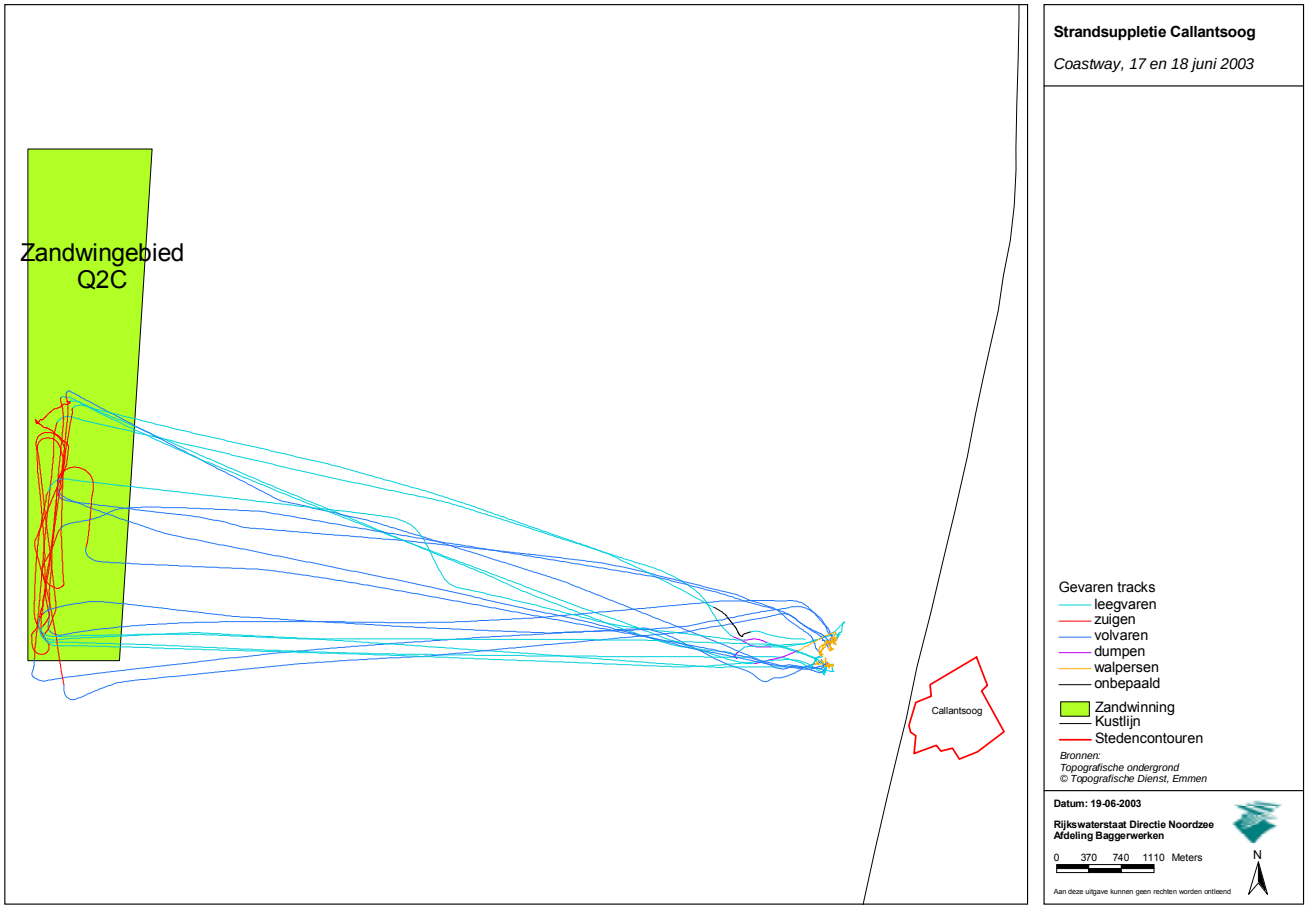

Figure 2.5.1. An example of a Belgian black-box monitoring trackplot.

In the UK, the advent of EMS data (Figure 2.5.2), and in particular the annual summaries of activity, has allowed the industry and landlord (The Crown Estate) to produce annual reports detailing the area of seabed licensed and dredged. Analysis of EMS data allows the annual extent and intensity of dredging activity based on dredging hours to be recorded in individual 50 m x 50 m grid cells (Figure 2.5.4).

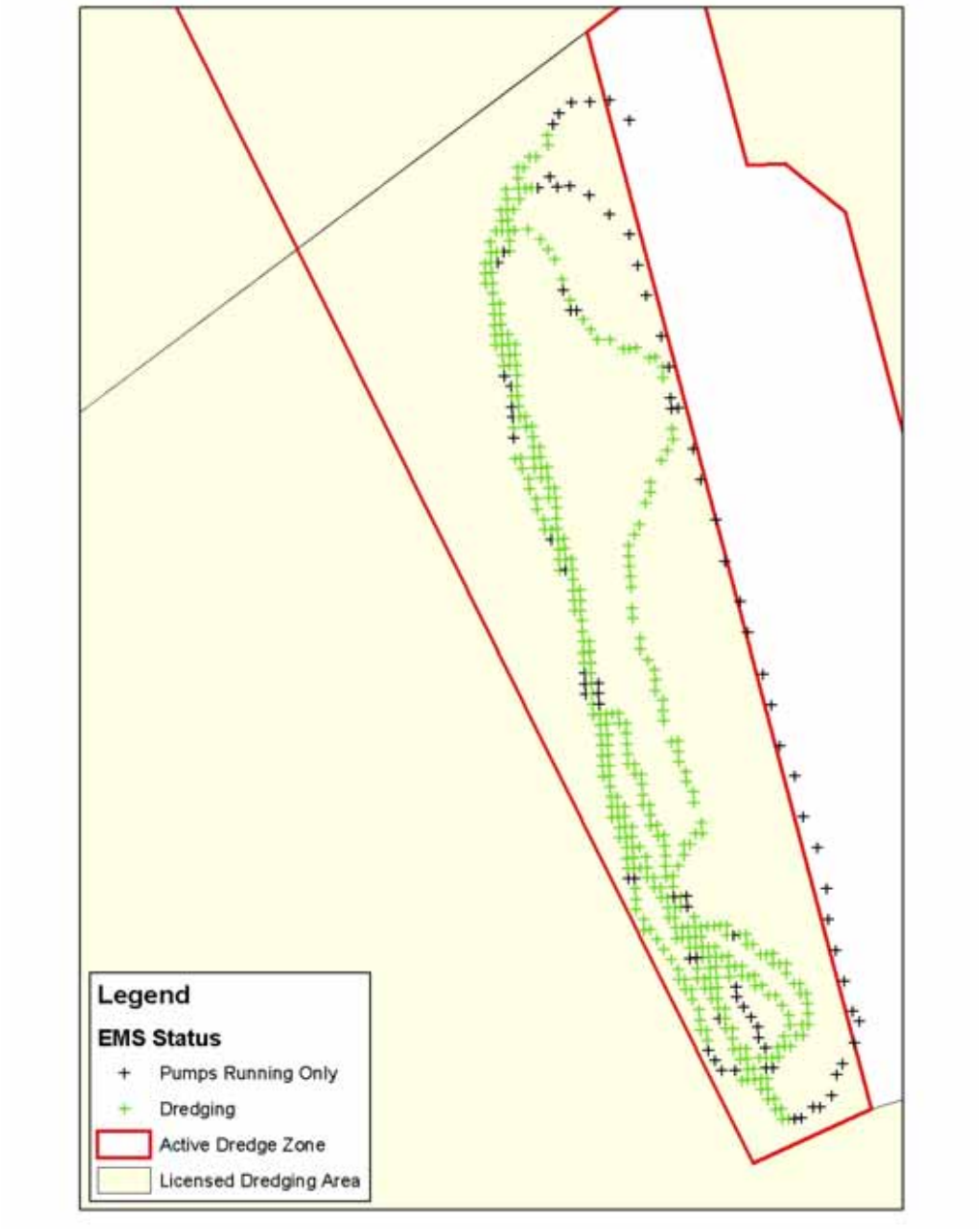

Figure 2.5.2. An example of a UK EMS trackplot.

This information, in turn, has become a guide to the industry's overall environmental performance. In particular, the annual reviews highlight the significant regional differences in dredging patterns, reflecting the geological setting of the resources being targeted. Sheet deposits of sand and gravel off the east coast of England reveal extensive dredging activity over a wide area, whereas the discrete palaeo-valley infills and terrace deposits off the south coast require a more focused approach to operations, with intensive activity over a restricted area. This is a practical demonstration of how the industry is using geological understanding of the resources being dredged in order to control and manage extraction operations.

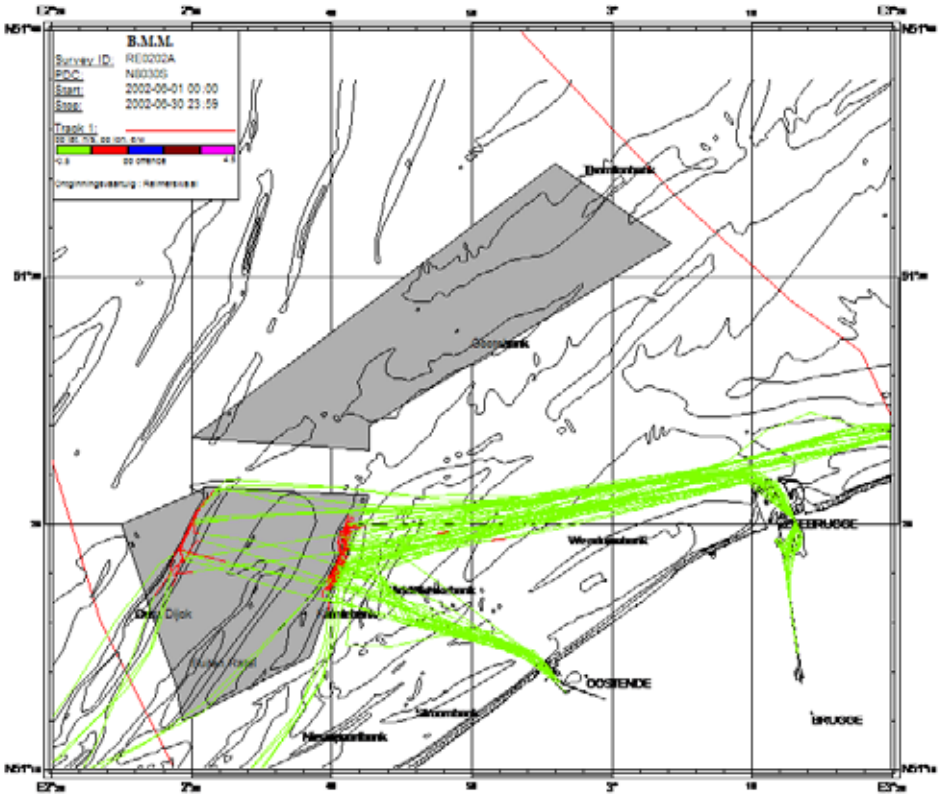

Figure 2.5.3. An example of a Dutch black-box monitoring trackplot.

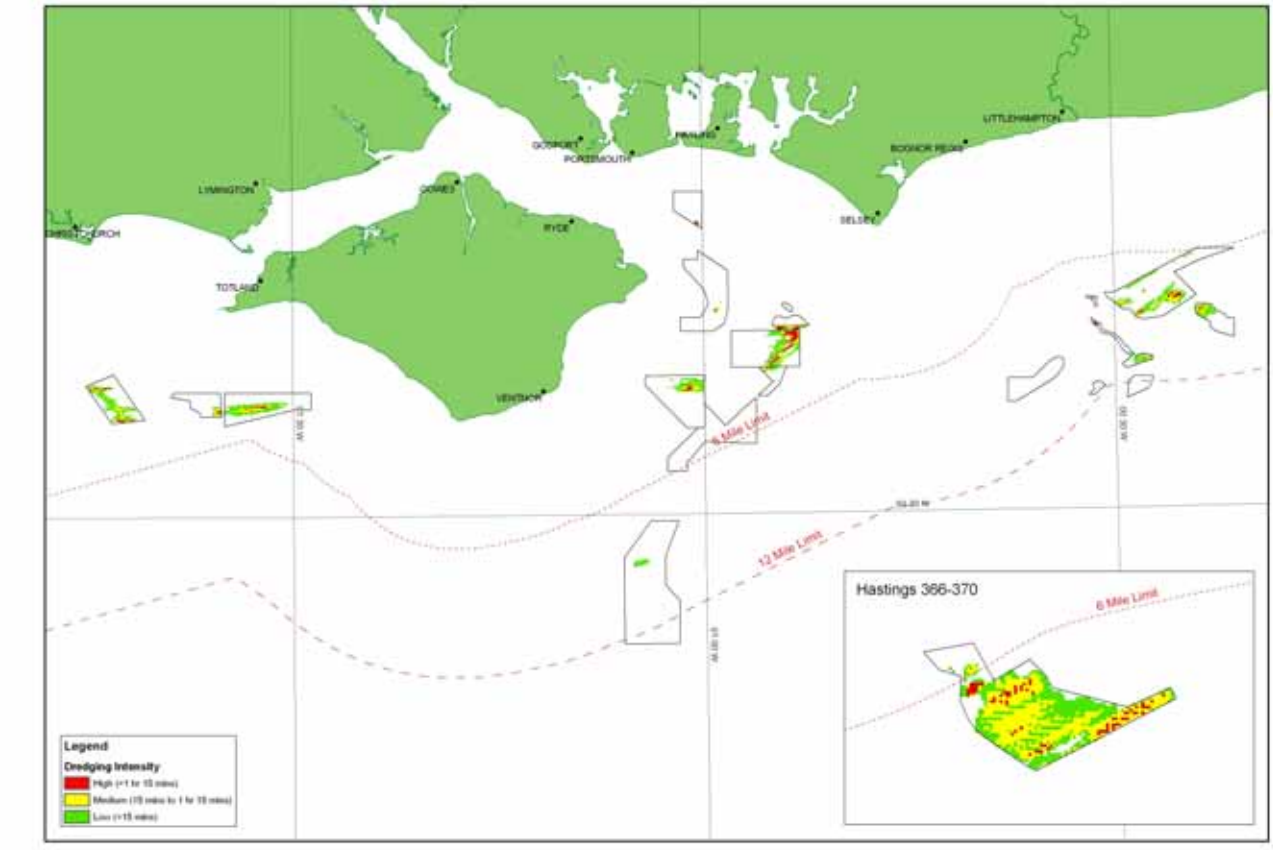

Figure 2.5.4. An example of a UK analysis of dredging activity from EMS data.

The availability of accurate, detailed EMS data over a number of years has allowed further analysis to be undertaken that has relevance to both regulators and industry. Although information on the extent of dredging activities is reported annually, it is possible, by combining this information, to consider the cumulative footprint (the total extent of dredging activity) over a period of time. The UK has begun this exercise (Figure 2.5.5) and has found that, over a five-year period, the total area dredged by the marine aggregate industry totalled 380 km^2, compared with annual totals ranging from 220 km^2 to 149 km^2. This information is particularly relevant to research and monitoring when attempting to relate observed environmental impact or recovery to the timing and intensity of actual dredging operations (see Section 5).

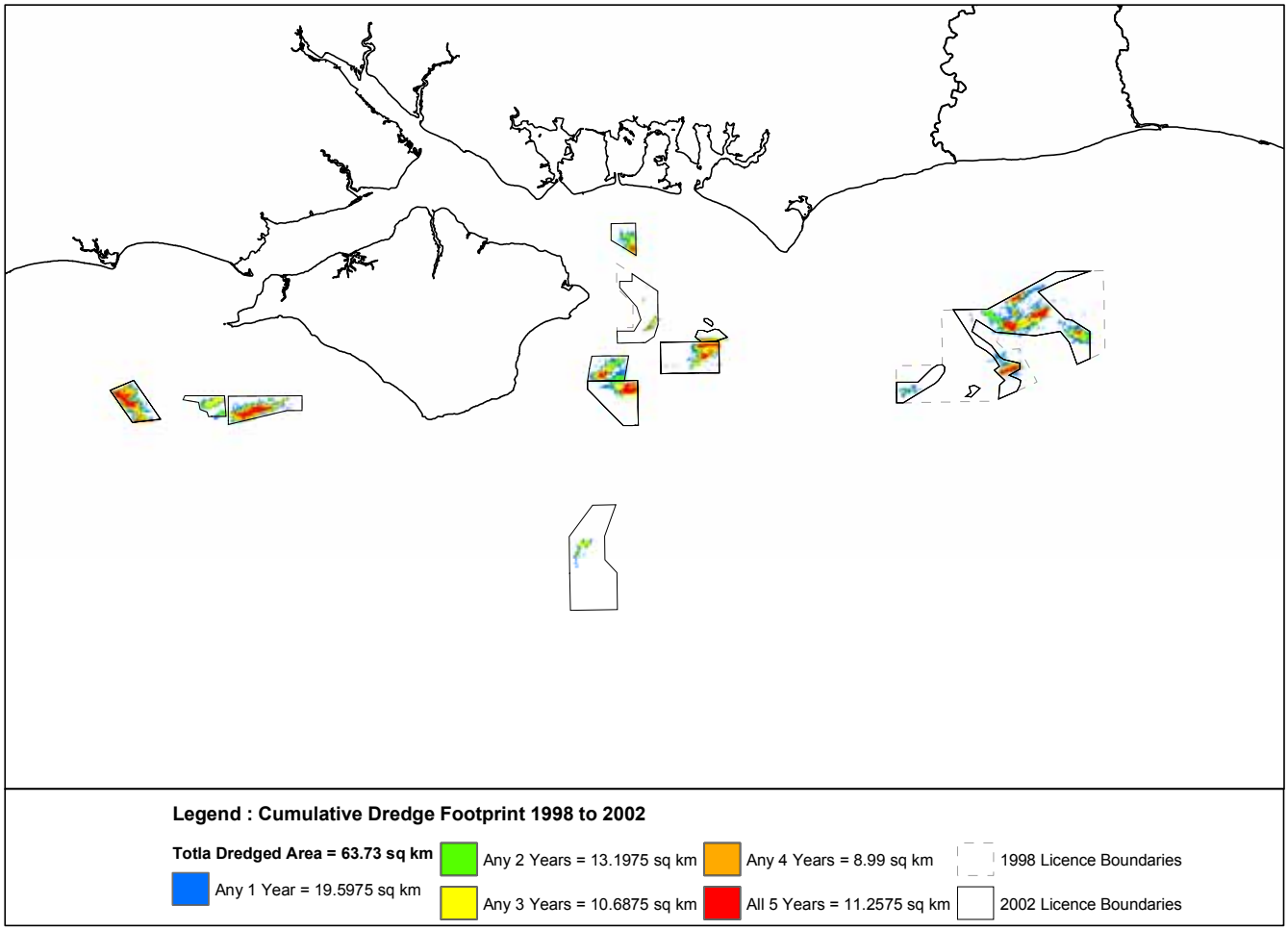

Figure 2.5.5. An example of a UK cumulative analysis of dredging activity from EMS data, 1998–2002. This demonstrates the extent and intensity of activity, based on dredging hours recorded in individual 50 m × 50 m grid cells. Over the period of the review, 47 km^2 of new licence area was permitted and 180 km^2 was relinquished, resulting in the total area licensed for marine aggregate extraction to fall from 332 km^2 in 1998 to 198 km^2 in 2002. Over the same period, the total area of seabed dredged in the region was 63.7 km^2.

Analyses of the dredging activities in Denmark, which has a larger proportion of stationary dredging (see Section 2.6 for further explanation) than the UK, have demonstrated that, over a five-year period, only 3–5% of the total dredging area of 900 km^2 has actually been dredged (Figure 2.5.6).

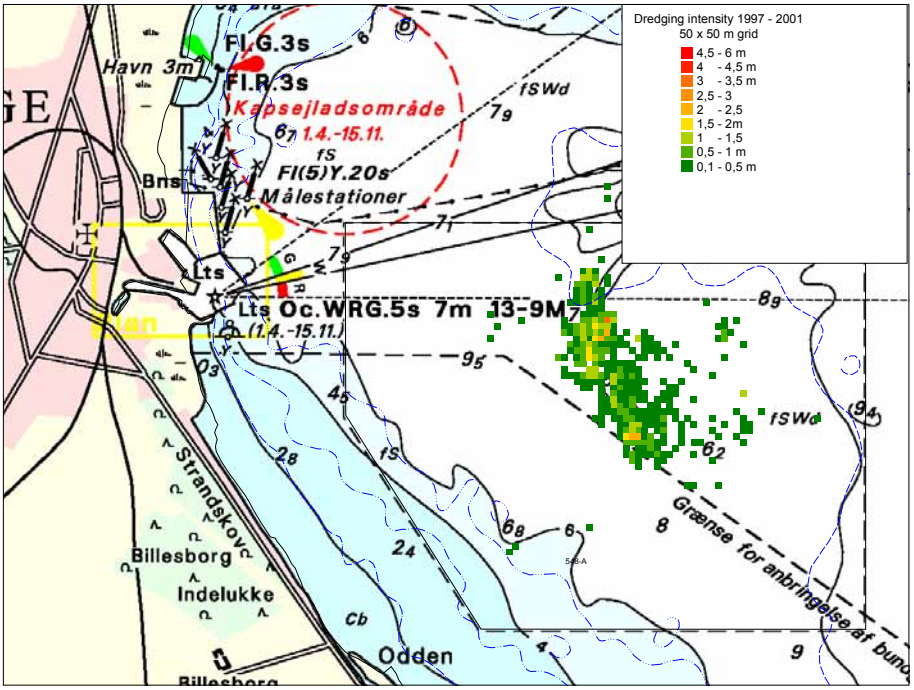

Figure 2.5.6. An example of a Danish regional analysis of dredging intensity in Køge Bugt. The size of the permitted area is 13 km². The figure shows how much has been removed in the period 1997–2001. The active dredge area is 0.8 km². On average, the area was dredged five times a week during 2001, and the active dredge area was less than 0.5 km². The area has been one of the most intensely dredged areas in Denmark. The active dredge area in 2004 was 0.05 km².

The evolution of the management of marine aggregate dredging activities has seen some significant advances over the past ten years. Although the pressures of environmental regulation and control have continued to increase, particularly as a result of the EU Environmental Impact Assessment and Habitats Directives, some of the greatest changes in management and control of dredging operations have come from the industry. These are linked not only to improving resource management but also to reducing spatial conflicts with other marine users. This has obvious links to the development of wider marine spatial planning initiatives.

However, the move towards more spatially restricted and, therefore, more intensive levels of dredging activity raises an additional issue requiring investigation. Although the total spatial footprint of the impact is reduced, the increased levels of intensity can affect the time-scale for the recovery of the environment. The availability of detailed black-box data to assess historical dredging activity will allow this issue to be examined in more detail.

2.6 Dredging technology

The trailer suction hopper dredger remains the principle method of extracting marine aggregates within the ICES Area, although static suction hopper dredgers are also employed (Figure 2.6.1). This is a proven technology, routinely employed in both maintenance and capital dredging operations. Although the general principles are similar (a centrifugal pump lifting a mixture of sediment and water from the seabed via a dredge pipe into a storage hopper) however, there are two major factors unique to dredgers that only extract aggregate for construction purposes.

Figure 2.6.1. A typical construction-aggregate trailer suction hopper dredger, the MV "Sand Falcon". The vessel has a cargo capacity of 5000 m^3 and has both screening towers and a bucket wheel self-discharge system.

First, besides loading "as-dredged" or "all-in", many aggregate dredging vessels can process the dredged sediment during loading operations through a process termed *screening*. This is particularly useful where the *in situ* composition of the seabed sediments falls outside that required for construction or beach replenishment. During the screening process, the sediment–water mix is passed over a mesh screen before it enters the cargo hopper. A proportion of the water and finer sediment falls through the screens and is returned to the sea, while the coarser sediment is retained in the hopper. This process can also be reversed to allow only sand to be loaded. Two main techniques are generally employed: either (i) a centrally located box screen system, or (ii) a more complex and efficient series of screening towers. The screening process returns a significantly greater volume of sediment to the water column during loading operations, increasing the potential for "farfield" impacts resulting from the settlement of the sediment plume. As such, the environmental implications of this activity need to be very carefully considered during the consenting process. However, screening does allow the more marginal resources to be worked efficiently, thereby reducing the need for new dredging sites, and allows the industry to deliver cargoes to specification.

The second factor concerns the manner of unloading (Figure 2.6.2). Most capital and maintenance dredgers are able to discharge material either through doors in the bottom of the hopper or by pumping out the material (wet discharge). This is particularly important for beach-nourishment projects (Figure 2.6.3). However, most purpose-built construction-aggregate dredgers are designed to self-discharge a dry cargo. This requires the dredged material retained in the hopper to be dewatered before unloading. There are a number of discharge techniques, including grab cranes, scraper buckets, and bucket wheels, for unloading the cargo directly onto the wharf for immediate use.

Figure 2.6.2. A typical construction-aggregate trailer suction hopper dredger, the MV "Orisant", discharging at the quay in the harbour of Bruges, Belgium.

Figure 2.6.3. A typical construction-aggregate trailer suction hopper dredger, the MV "Mellina", supplying sand for beach nourishment at the coast of Ameland, the Netherlands.

To increase dredging flexibility, some modern trailer suction hopper dredgers are being designed to carry out static dredging operations. This is particularly useful where more localized, thicker sand and gravel deposits are being targeted. Vessels are also being designed with pump-ashore facilities to perform beach-replenishment operations and, in certain cases, limited capital or maintenance dredging work. The identification and development of new resources located in deeper water (e.g. in the Eastern English Channel and the Outer Bristol Channel) are driving the development of marine aggregate technology. Whereas sand and gravel resources were previously dredged in maximum water depths of 35–40 m, the new resource areas have water depths of 50–60 m. A few aggregate dredgers can work at these depths; the others will have to be modified, with longer dredge pipes and the addition of pipe-mounted dredge pumps.

There is an increasing requirement to ensure that resources of marine sand and gravel are managed and exploited in an effective and sustainable manner. The cross-over between high-tech capital and maintenance operations and the aggregate sector is a natural development as the industry seeks to improve operational efficiency and minimize environmental impact, and these developments can be expected to continue in future. Two areas in particular are evolving. The first concerns the ability of aggregate dredgers to operate effectively within tightly controlled lanes, defined either for resource management or as environmental mitigation. To do this effectively, vessels must have the navigational capability and the necessary power and manoeuvrability. The second concerns the dredging process itself. Increasingly, it is a requirement to work licensed reserves to economic exhaustion before moving to new areas. Operators, therefore, need to maximize their ability to extract sand and gravel reserves within defined areas through carefully controlled dredge-management plans, while at the same time minimizing environmental impacts. This requires knowledge and understanding of the geological context of the aggregate resource being targeted. However, the control and management of the dredging process itself is equally important if licensed resources are to be maximized.

2.7 Summary

1. The number of ICES Member Countries reporting on the use of marine sediments (noted in *ICES Cooperative Research Report No. 247*; ICES, 2001) has continued to expand, with sand and gravel dominating production. The UK remains the main producer of sand and gravel for the manufacture of concrete, whereas the Netherlands produces and uses the largest quantity of sand.
2. The construction industry's demand for marine sand and gravel has remained fairly stable. Beach nourishment and fill for construction purposes and land reclamation remain important, arising particularly from the beneficial use of maintenance and capital dredging. The extent to which sediment produced by maintenance and capital dredging is reused varies widely between countries, depending on the quality of sediment and the potential existing end-use opportunities.
3. Commercially viable sand and gravel reserves are unevenly distributed among ICES Member Countries. Although most states have significant volumes of sand and/or gravel off their coastlines, they are unlikely to be exploited without a market. This is often directly related to the availability of alternative sources of construction material.

4. The requirement for sustainable use of marine sand and gravel reserves is now a well-established principle at both national and international scales, and it is reflected in national policies and regulations.
5. A number of the new resources of sand and gravel have been identified in deeper water (40–60 m), for example, in the Eastern English Channel and the Outer Bristol Channel (Wales). In order to exploit these new resources, many existing dredging vessels will need to be modified in order to operate effectively. Further resource mapping is expected to lead to the identification of substantial new resources.
6. There remains no realistic alternative to the use of marine aggregate material for most beach recharge and major coastal reclamation schemes. The beneficial use of navigational dredging continues to be used for these purposes and significantly reduces the need to work licensed resources.
7. There have been continual improvements in the provision and analysis of detailed dredging monitoring data alongside improvements in the accuracy and resolution of resource information. This has allowed dredging activity to be more tightly controlled, with resulting benefits through minimized environmental impact and interference with other marine activities.
8. Communication and awareness of detailed dredging activity has increased, which is particularly useful for regulatory authorities, as well as other marine users. This data also has significant value in supporting and informing research on the extent and effects of dredging.
9. The move towards more spatially restricted, and therefore more intensive, levels of dredging activity raises unresolved issues. Although the total spatial footprint of the impact is reduced, the increased levels of intensity affect the time-scale for the recovery of the environment. The availability of black-box data to assess historical dredging activity will assist in examining this issue.

3 Seabed sediment (resource) mapping programmes of ICES Member Countries

3.1 Introduction

This section presents an outline of the philosophy, schemes, methods, and results of various geological (sub)seabed mapping programmes that may provide insight into the occurrence of aggregate resources or, more commonly, indications suggesting the possible presence of those resources.

A reliable picture of aggregate resources requires very detailed surveying and sampling, which are usually done only when aggregate extraction schemes are being considered. However, indications of the presence of such aggregate resources may be obtained by other simpler and cheaper means, of which the most widely used are offshore geological reconnaissance mapping and more detailed seabed sediment mapping.

The various mapping programmes and mapping results for ICES Member Countries have been summarized and are presented in this section in alphabetical order. The level of detail available for each country varies because aggregate resource mapping, seabed sediment mapping, and geological reconnaissance mapping are accorded different priorities in each member country. Factors that influence this include population density, intensity of industrial activities, presence of coastal defence schemes and land reclamation projects, public awareness of the environmental effects of aggregate extraction onshore, and, not unimportantly, the level of budget that states, governmental organizations, and industry are willing or able to invest in these mapping programmes. Also, the roles and responsibilities of government and industry may vary in ICES Member Countries; for example, in several countries, aggregate resource mapping and assessment is done by industry, whereas in many others, it is a governmental matter.

The present state of seabed mapping in ICES Member Countries indicates that some countries have a fairly detailed overview of what is available in their part of the continental shelf and for what purpose surficial materials may be used. This means that these countries can start to formulate aggregate and environmental policies that have some basis in reality. Most countries have not yet reached this situation, and so, in this sense, their policies are based more on assumption than fact.

Reconnaissance mapping of the seabed sediments forms the framework in which to delineate marine sand and gravel resources, and provides strategic information for short- and long-term planning and best-practice use of these resources in the marine environment. Detailed resource mapping is required to obtain reliable information about the volume, quality, and composition of the seabed resources, and thereby to establish their economic viability.

Detailed surface sediment maps and habitat maps, including information on seabed sedimentary dynamic processes and morphology, form the basis for the assessment of the physical and biological impact of marine construction projects and aggregate extraction, and for its subsequent monitoring during and after the activity in question.

The summary descriptions of activities in each country also include a list of organizations from which data and information relevant to aggregate resource mapping may be obtained. Additional information may be found through EU-Seased, a recently

(1998–2004) established searchable Internet meta-database of seabed samples and hydroacoustic measurements (seismics, sidescan sonar, multibeam, etc.) held at European geological surveys and other European institutions (available online at http://www.eu-seased.net/welcome_flash.html).

This database provides a means by which civil servants, scientists, engineers, and other parties interested in the seabed can quickly find out what seabed samples and hydroacoustic measurements have been recovered and where they are stored, thereby promoting secondary usage of this important raw data resource. The database only lists metadata; access to the samples, the hydroacoustic raw data, and any related accessory datasets must be negotiated by the requester with the repository where the information is stored. It is an important source of information about potential aggregate resources, as well as for scientific research, decision-making in government, and management in the commercial sector. Information not provided in the Annex may be found via the EU-Seased meta-database and its links.

3.2 Belgium

National organizations responsible for seabed mapping

Geological Survey of Belgium (GSB), Jennerstraat 13, 1000 Brussels, Belgium. Contact: C. Baeteman: tel: +32 2 788 76 26; fax: +32 2 647 73 59; e-mail: cecile.baeteman @naturalsciences.be.

FPS Economy, Fund for Sand Extraction, Koning Albert-II laan, 1000 Brussels, Belgium. Contact: M. Roche: tel: +32 2 206 40 31; fax: +32 2 206 57 52; e-mail: Marc.Roche @mineco.fgov.be.

Management Unit of the North Sea Mathematical Models (MUMM), Gulledelle 100, 1200 Brussels, Belgium. Contact: B. Lauwaert: tel: +32 2 773 21 20; fax: +32 2 770 69 72; e-mail: B.Lauwaert@mum.ac.be.

Ministry of the Flemish Community, Administratie Waterwegen en Zeewezen (AWZ), Vrijhavenstraat 3, 8400 Oostende, Belgium. Contact: G. Dumon: tel: +32 59 55 42 11; e-mail: guido.dumon@lin.vlaanderen.be.

Renard Centre for Marine Geology (RCMG), Ghent University, Krijgslaan S8, 9000 Ghent, Belgium. Contact: J-P. Henriet: tel: +32 9 264 45 85; fax: +32 2 264 49 67; e-mail: JeanPierre.Henriet@Ugent.be.

Types of seabed maps

The GSB no longer has any proper mapping programmes. In the past, a dense boring grid with vibrocores was sampled in a zone about 10 km off the coast. Very few data are available farther offshore. Eleven deep, mechanically cored borings have been carried out at depths of 25–80 m, covering the entire Quaternary sequence into the Tertiary deposits.

Several geological maps and primary datasets are available from the GSB (www.naturalsciences.br/geology/). Printed maps, with descriptions in Dutch and English, can be ordered from the GSB (bgd@natuurwetenschappen.be), the Geological Society of the Netherlands, and the British Geological Survey.

1:250 000 maps

Balson, P. S., Laban, C., Schuttenhelm, R., Paepe, R., and Baeteman, C. 1991. Ostend: sheet 51°N 02°E. Seabed sediments and Holocene geology. 1:250 000 series. British Geological Survey, Geological Society of the Netherlands, and Belgian Geological Survey.

Balson, P. S., Laban, C., Schuttenhelm, R., Paepe, R., and Baeteman, C. 1992. Ostend: sheet 51°N 02°E. Quaternary geology. 1:250 000 series. British Geological Survey, Geological Society of the Netherlands, and Belgian Geological Survey.

For pre-Quaternary geology, see the Netherlands (Section 3.11) or the UK (Section 3.17).

Other maps

The Fund for Sand Extraction conducts regular multibeam surveys to study the impact of sand (and gravel) exploitation. Resource maps and databases on multibeam data and dredging activities are available online at http://www.mineco.fgov.be). An example is shown in Figure 3.2.1.

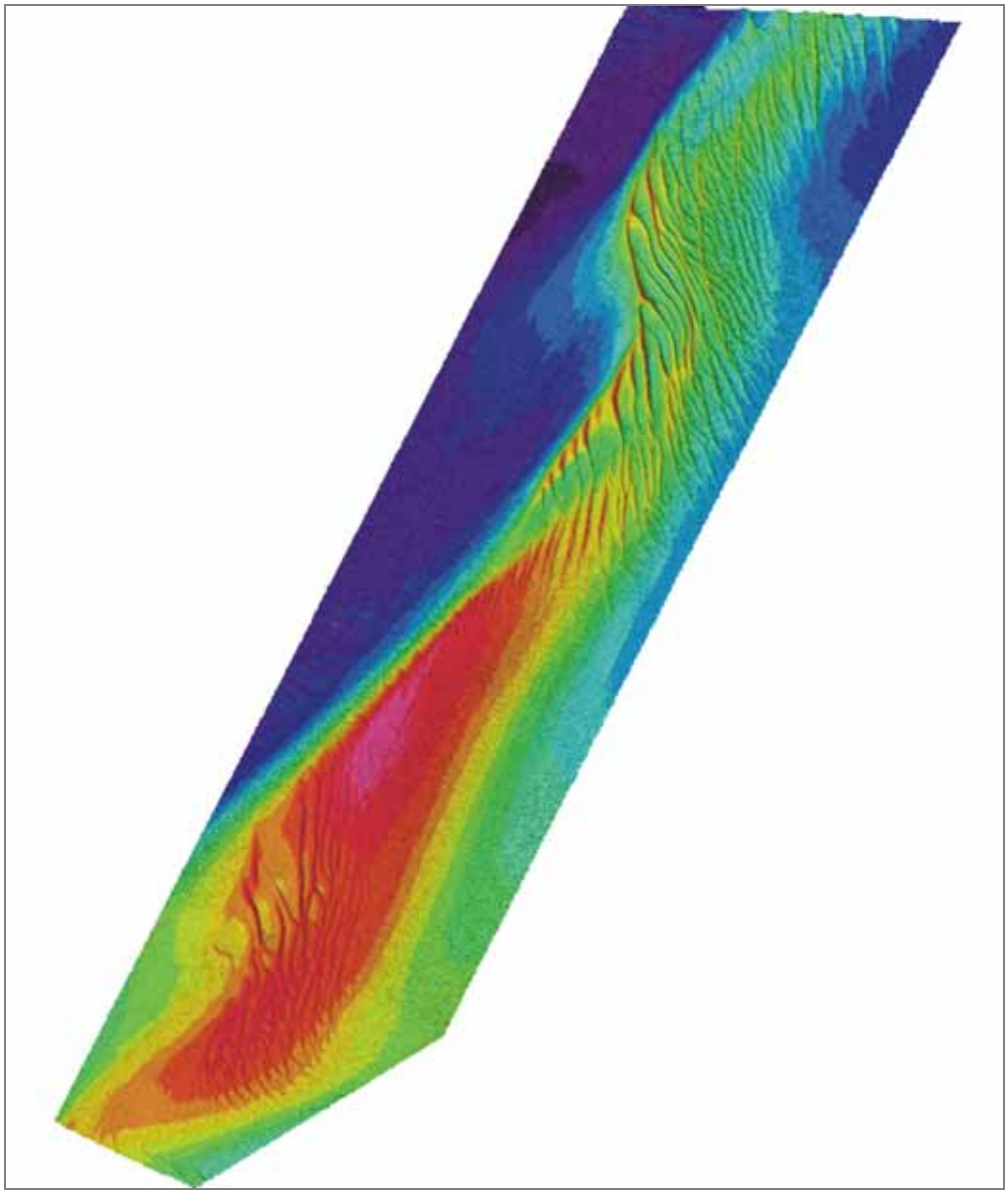

Figure 3.2.1. Map of Kwintebank, based on multibeam data Source: Fund for Sand Extraction.

The Management Unit of the North Sea Mathematical Models (MUMM) regularly produces resource maps, maps on licensed areas, and data on dredging activities, including EMS black-box data and hydrodynamic data (www.mumm.ac.be).

The Ministry of the Flemish Community regularly updates bathymetric datasets covering the entire Belgian continental shelf. The verified data serve as input to marine landscape work. An example is given in Figure 3.2.2. Multibeam data on the dredge dumping sites off the Belgian coast are also available online at http://www.awz.be.

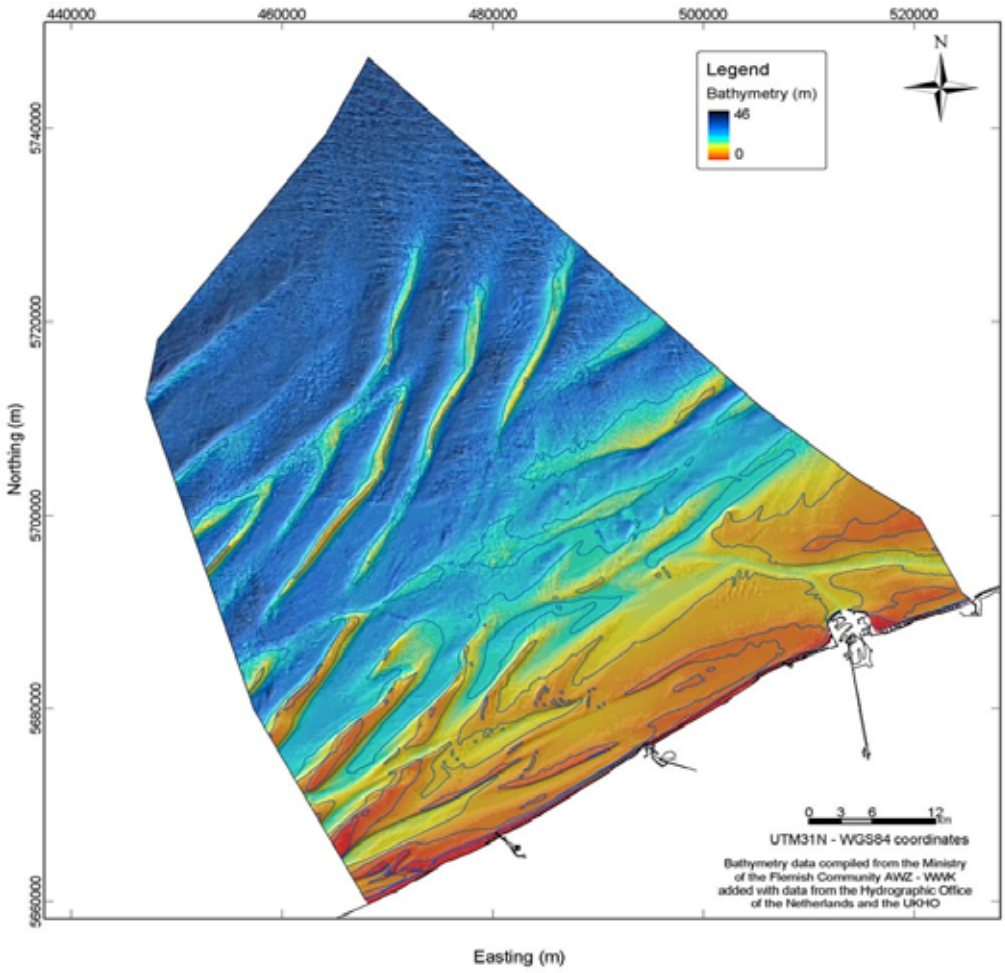

Figure 3.2.2. A new holistic bathymetry digital terrain model covering the Belgian continental shelf, based on a statistical analysis of bathymetrical datasets from the Belgian, Dutch, and English hydrographic offices. Taken from the Marebasse project (van Lancker *et al.*, 2005).

In recent years, a variety of projects have been carried out by the RCMG (University of Ghent) to map the seabed of the Belgian continental shelf. Primary datasets, as well as geological, sedimentological, morphological, and resource maps, are available online at http://www.rcmg.ugent.be. This work was primarily founded and led by the Marebasse project (van Lancker *et al.*, 2005; available online at http://users.ugent.be/~vvlancke/Marebasse/).

Bedform, surficial sediments, and habitat maps were created by this project. An example is shown in Figure 3.2.3.

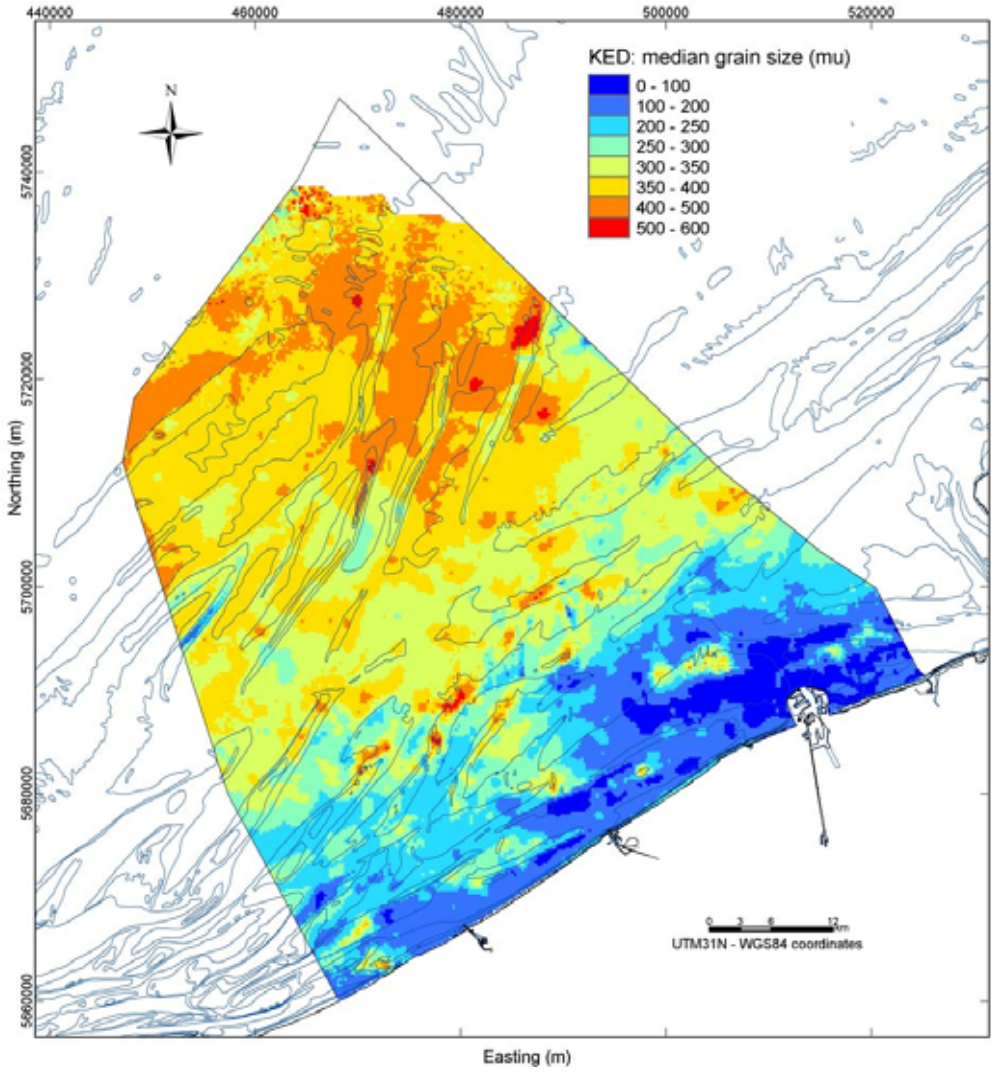

Figure 3.2.3. A spatial distribution map of the median grain size, based on the sedisurf@database (hosted by Ghent University, RCMG) and interpolated using the geostatistical method Kriging with external drift (KED). Caution is needed for the sediment distribution at the northern extremity of the Bligh Bank and the Fairy Bank, owing to a lack of samples (circles). Taken from the Marebasse project (van Lancker *et al.*, 2005).

Data on Tertiary geology can be found in de Batist and Henriet (1995).

MESH, a three-year, international marine habitat mapping programme, began in spring 2004. A consortium of 12 partners across Belgium, the UK, Ireland, the Netherlands, and France was funded by the EU Interreg IIIB. The MESH partnership covers all five countries in the Interreg (IIIB) northwestern European area, drawing together scientific and technical habitat-mapping skills, expertise in data collation and its management, and proven practical experience in the use of seabed habitat maps for environmental management within national regulatory frameworks. MESH aims to produce seabed habitat maps for northwest Europe (see MESH study area) and to develop international standards and protocols for seabed mapping studies.

The end products of the MESH programme will be a meta-database of mapping studies, a web-delivered geographic information system (GIS) demonstrating the habitat maps, guidance for marine habitat mapping, including protocols and standards, a

report describing case histories of habitat mapping, a stakeholder database, and an international conference with published proceedings.

The MESH project website (http://www.searchmesh.net) presents an excellent overview.

Survey equipment

Several multipurpose vessels are used for seabed mapping. Bathymetrical, geological, hydrological, and resource information is collected with equipment held by the institutes mentioned above.

Vibrocores, van Veen, and Hamon grabs, mechanically cored borings, sidescan sonar, sparker (150 Hz–1 kHz), singlebeam, multibeam, and video equipment are used. The Simrad 1002S multibeam echosounder is mounted on the RV "Belgica". ArcView, Mapinfo, and ArcGIS are used to visualize the data. For details, see the websites and papers and reports mentioned above.

Data holders

Data are held by the GSB; Fund for Sand Extraction; MUMM: Ministry of the Flemish Community; and RCMG. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

FPS Economy, Fund for Sand Extraction. For contact information, see the section National organizations responsible for seabed mapping, above.

3.3 Canada

National organization responsible for seabed mapping

Geological Survey of Canada (GSC), Geoscience for Oceans Management Programme, Bedford Institute of Oceanography, PO Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada. Contact: Dick Pickrill, Programme Manager: tel: +1 902 426 5387; fax: +1 902 426 6186; e-mail: dpickril@nrcan.gc.ca.

Mapping programme

In 2002, Natural Resources Canada (NRCan) initiated the Geoscience for Ocean Management programme (GOM) to deliver the geoscience knowledge to support ocean management in Canada (https://gom.nrcan.gc.ca). Underpinning the GOM programme is a systematic approach to seabed mapping. One of the first objectives of the programme was to develop a seabed mapping strategy. After two years of stakeholder and in-house discussion, the map standards and scales were established, culminating in the approval of a new marine map series within the GSC. The map series provides a conduit to publish the new multibeam-based bathymetric data and sets the framework for seamless mapping of Canada's onshore and offshore lands. GOM products will be the first new A-Series marine maps to be delivered from NRCan for more than 25 years.

Maps are being produced at scales of 1:50 000 and 1:100 000, plus larger scale maps (e.g. 1:5000) for specific local studies. Within the map series, there are four standard sheets: multibeam bathymetry, backscatter, interpreted geology, and benthic habitat. Where appropriate, special maps, such as geohazards, will also be produced. Maps will be available digitally and in hard copy. Mapping has been an integral component

of geoscience research projects, and all projects have incorporated mined legacy data into new map products and companion reports. Maps are supported by digital, reliable, quality-controlled datasets that include bathymetry, seismics, seabed samples, cores, and seabed photographs.

The first phase of the programme was completed in March 2006 and focused on priority areas that have multiple land-use issues or where large-scale projects require extensive multidisciplinary knowledge. A geographical balance was reached, with projects in Canada's three oceans. More than 100 map sheets are planned from this phase. The second three years of the GOM programme was approved in March 2006. The federal budget of 2005 provided additional funding through Canada's Ocean Action Plan to accelerate the mapping activities.

Areas surveyed and scheduled for map production include:

- Straits of Georgia and Juan de Fuca, British Columbia
- Coastal Queen Charlotte Island and sponge reef complexes in the Queen Charlotte Basin
- Estuary of the Gulf of St Lawrence
- Placentia Bay, Newfoundland
- Outer shelf and continental slope, Nova Scotia
- Bras d'Or lakes, Nova Scotia

During the second phase of the GOM programme, surveys were extended to the Bay of Fundy.

Survey equipment

A full suite of hydrographic and geological/geophysical survey equipment is operated from the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia, and the Institute of Ocean Sciences (IOS) in Sydney, British Columbia. Three regional Canadian Hydrographic Service offices provide additional survey capacity. Simrad multibeam systems are the principal hydrographic tool, with five launch-based systems and three ship-based systems being operated across the country. Interferometric sidecar sonar is used in shallow water. Seismic equipment ranges from high-frequency piezo-electric sources to airguns. All ship-based hydrographic surveys routinely collect 3.5 kHz seismic reflection data. Towed video, high-resolution photography, along with bottom sampling, are used to ground-truth the acoustic data.

Data holders

Data are held by the GSC at BIO and IOS. For contact information, see the section National organization responsible for seabed mapping, above. Aggregate resource data are not archived separately.

3.4 Denmark

National organizations responsible for seabed mapping

Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen K, Denmark. Contacts: Jørgen O. Leth and Jørn Bo Jensen: tel: +45 38 14 29 05; fax: +45 38 14 20 50; e-mail: jol@geus.dk.

Danish National Forest and Nature Agency (NFNA), Haraldsgade 53, DK-2100 Copenhagen Ø, Denmark. Contact: Poul Erik Nielsen: tel: +45 39 47 20 00; fax: +45 39 27 98 99; e-mail: PEN@sns.dk.

Mapping programme

There have been no proper mapping programmes since 1990. However, several individual mapping projects have been carried out in cooperation with other government institutions and private enterprises. Recently, the focus has been on habitat mapping and the mapping of marine aggregates suitable for sustainable use.

Past mapping programmes

The results of the previous mapping programme for raw materials were published in a series of reports from the NFNA between 1979 and 1990. The reports include sediment maps and distribution maps of raw materials, generally using a scale of 1:100 000. During 1990–2000, GEUS published a series of geological maps used partly for the evaluation of raw materials in specific areas. Maps can be ordered from GEUS. A national specification of the available mapped resources has been reported to the NFNA by GEUS (1997).

Survey equipment

Equipment used for seismic/acoustic mapping includes single-channel sparker and boomer, Chirp, and X-Star systems with a vertical resolution of 0.1 –1 m. In addition, sidescan sonar and multibeam sonar have been used since 2005.

Equipment used for sampling includes vibrocore (6 m), grab samples.

Data holders

GEUS is the main data holder of aggregate resource survey data. The availability of some data is limited, because of confidentiality. For contact information, see the section National organizations responsible for seabed mapping, above.

National standards

National standards for Denmark can be found in Larsen *et al.* (1995).

3.5 Estonia

National organization responsible for seabed mapping

Geological Survey of Estonia (EGK), Tallinn, Estonia. Contact: S. Suuroja: tel: +372 67 20090; fax: +372 67 20091; e-mail: s.suuroja@egk.ee.

Types of seabed maps

Approximately 6% (ca. 2000 km^2) of all Estonian territorial waters (35 000 km^2) have been geologically mapped in detail (scale 1:50 000), and approximately 90% have been mapped to a medium scale (1:200 000), giving a total of 96%. Three main types of seabed geological maps have been compiled: bottom sediments, Quaternary deposits, and bedrock. Areas mapped to date are listed below. The shallow offshore area will be mapped in detail (scale 1:50 000) during the base geological mapping programme.

Printed maps with a description in English, as well as digital maps and data, can be ordered from the EGK (e-mail: egk@egk.ee). For further contact information, see the section National organization responsible for seabed mapping, above.

1:200 000 maps

Geological maps and databases at a scale of 1:200 000 are based mainly on continuous seismic profiling (dense grid of runlines: ca. 2 km) and gravity core sampling (density of sampling stations: ca. 2 km). These maps exist mainly in the form of manuscripts, but published maps are available for part of the Gulf of Riga. Digital versions of these maps do not exist. All basic information about these maps is stored in various manuscript databases.

Published maps (1:200 000)

Baraškovs, A., Talpas, A., and Kask, J. 1997. Landscape-ecological map of the Gulf of Riga. Scale 1:200 000. (Includes explanatory note.) Geological Survey of Latvia. Geological Survey of Estonia. Riga.

Juskevics, V., and Talpas, A. 1997. Map of the Quaternary deposits of the Gulf of Riga. Scale 1:200 000. (Includes explanatory note.) Geological Survey of Latvia. Geological Survey of Estonia. Riga.

Seredenko, R., Zaitsev, V., Talpas, A., and Suuroja, S. 1997. Bedrock map of the Gulf of Riga. Scale 1:200 000. (Includes explanatory note.) Geological Survey of Latvia. Geological Survey of Estonia. Riga.

Stribrinš, O., and Väling, P. 1996. Bottom sediments of the Gulf of Riga. Scale 1:200 000. (Includes explanatory note.) Geological Survey of Latvia. Geological Survey of Estonia. Riga.

Unpublished maps (1:200 000)

Malkov, B., Dulin, E., Kiipli, T., and Talpas, A. 1983. The geological mapping of shelf area in Baltic Sea in Estonian territorial waters. Scale 1:200 000. (Recognizable mapping in 1981–1983; in Russian). Geological Survey of Estonia, Tallinn.

Malkov, B., Kiipli, T., Rennel, G., Tammik, P., Dulin, J. 1986. The regional geological and geophysical investigations of shelf area in Baltic Sea in Estonian territorial waters. Scale 1:200 000. (in Russian.) Geological Survey of Estonia, Tallinn.

Talpas, A., Kivisilla, J., Kõrvel, V., Mardla, A., Petersell, V., Popova, L., Rennel, G., *et al*. 1989. Regional geological and geophysical investigations in Gulf of Finland (eastern part). Scale 1:200 000. Geological Survey of Estonia, Tallinn.

1:50 000 seabed sediment maps

This type of map (bottom sediments, Quaternary deposits) was compiled for four sheets surrounding the submarine Neugrund meteorite crater area off northwest Estonia (Gulf of Riga). The maps are based on a dense grid of seismic continuous profiling and sidescan sonar measurements; gravity coring and sampling of submarine bedrock outcrops by diving was used as well. The map contains the same information as the 1:200 000 maps.

1:50 000 digital maps

Suuroja, K., Suuroja, S., and Talpas, A. 1999. The investigations of seabed between islands Pakri and Osmussaar. Scale 1:50 000. (Three maps – bottom sediments, Quaternary deposits, bedrock – with explanatory note in Estonian and English summary. Known and assumed marine sand and gravel resources in Estonia.

The most important known mineral resources on the Estonian continental shelf are sand and gravel deposits. These are exploited commercially by the Port of Tallinn (Muuga) around the islands of Prangli and Naissaar. Sand and gravel from these deposits is of poor quality and is used as fill material. Exploitation has occurred else-

where in the Gulf of Tallinn and in small areas around Sillamäe (Gulf of Finland) and the western Estonian archipelago.

Survey equipment

The EGK has no survey vessel and no special survey equipment.

Data holders

Data are held by the EGK. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

Analyses for the EGK are carried out by contracted accredited laboratories.

3.6 Finland

National organization responsible for seabed mapping

Geological Survey of Finland (GTK), PO Box 96, FI-02151 Espoo, Finland. Contact: J. Rantataro: tel: +358 20 550 11; fax: +358 20 550 12; e-mail: jyrki.rantataro@gtk.fi.

Types of seabed maps

Finnish territorial waters have been mapped in detail (scale 1:100 000/1:50 000) in inshore areas of the Gulf of Finland and in the easternmost part of the Archipelago Sea, as well as in some sites in the Gulf of Bothnia. An overview of the mapped areas is shown in Figure 3.2.4. Reconnaissance mapping of the Exclusive Economic Zone (EEZ) waters commenced in 2006.

Printed maps, with descriptions and English summary, can be ordered from the GTK (e-mail: julkaisumyynti@gtk.fi; for further contact information, see the section National organization responsible for seabed mapping, above).

1:100 00/1:50 000 seabed sediments and Quaternary stratigraphy maps/databases

These maps show the distribution of the predominant sediment in the uppermost tens of centimetres of the seabed, according to character and genesis. The maps are accompanied by a separate description, including the sediment stratigraphy down to the bedrock surface of selected geological sections from the same area, as well as bottom photos, diagrams, etc. The map area shows the distribution of pre-Quaternary rocks, till, glaciofluvial deposits, postglacial and glacial clays, sampling/coring sites, tracklines, etc. The maps are projected in Gauss–Krüger with the Finnish KKJ grid net and the longitude and latitude system in WGS84.

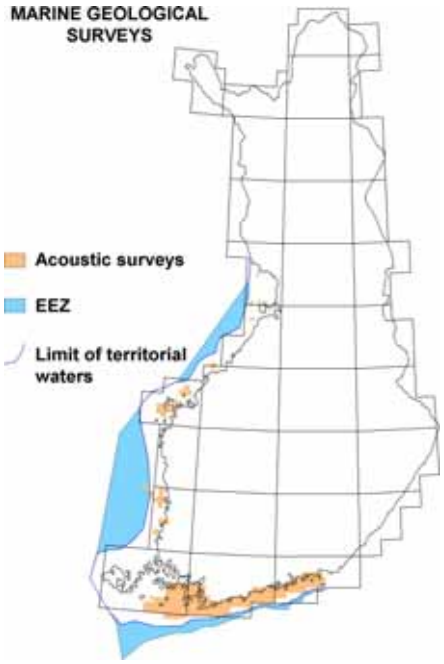

Figure 3.2.4. Map of the GTK acoustic–seismic surveys showing coverage of mapped areas within Finnish territorial waters and EEZ at scales of 1:100 000 or 1:50 000.

Since 1986, this kind of mapping has been based on the simultaneous use of single-channel, seismic survey with boomer-type sound source, and echosounding (28/30 kHz) with sidescan sonar. The grids of tracklines are generally spaced at 500 m, and sampling/coring was used for checking and/or for guidance of interpretation.

Printed maps and digital versions of maps may have any form, format, and content. All basic information from 1989 onward is stored in various databases. The GTK should be contacted for information and availability. Detailed information of the aggregate resources within the mapped area is available on request to GTK.

Published maps (1:100 000/1:50 000)

GTK. 1991. Geological map of Finland, Sea floor deposit, Kotka-Pyhtää-Vehkalahti. Scale 1:100 000. Report of Investigation No. 109.

GTK. 1991. Marine geological map, surficial sediments, Inkoo-Espoo-Helsinki-Sipoo. Scale 1:50 000. Helsingin seutukaavaliiton julkaisuja (Uusimaa Regional Council) C31. (Four maps.)

GTK. 1991. Sea floor sand and gravel investigations in Gullkrona Fjärden, The Archipelago Sea, 1989. Varsinais-Suomen Seutukaavaliitto (Regional Council of Southwest Finland), 1990. Two maps.

Other types of marine geological maps and information

Bargel, T., Huttunen, T., Johansson, P., Lagerbäck, R., Mäkinen, K., Nenonen, K., Olsen, L., *et al*. 1999. Maps of Quaternary geology in central Fennoscandia: sheet 1: Quaternary deposits. Scale 1:1 000 000. Geological Survey of Finland, Espoo.

Ignatius, H., Kukkonen, E., and Winterhalter, B. 1980. Pohjanlahden kvartäärikerrostumat. Summary: The Quaternary deposits of the Gulf of Bothnia. Appendices: marine geological maps of the Gulf of Bothnian Sea and the Bothnian Bay. Scale 1:100 000. Geological Survey of Finland, Report of Investigation No. 45.

Koistinen, T. (Ed.) 1994. Precambrian basement of the Gulf of Finland and surrounding area. Scale 1:1 000 000. Geological Survey of Finland, Espoo.

Known and assumed marine sand and gravel resources

The most important known mineral resources on the Finnish continental shelf (EEZ) are sand and gravel deposits. Until now, these have been the only non-living natural resources to be exploited commercially in Finnish waters. Exploitation has been undertaken on a small scale and has been concentrated in areas offshore of Helsinki and Pyhtää in the Gulf of Finland.

Marine sand extraction amounted to about 100 000–200 000 t year^{-1}, but has been sporadic, with occasional cessations lasting more than a year. Sand and gravel was used generally as fill material.

Survey equipment

The GTK has a new twin-hull, aluminium-constructed survey vessel, SV "Geomari", of 75 grt, 20 m length, 7.5 m width, and 0.9 m draft. The vessel has winches, L-frame, moon pool, sediment laboratory, and a special survey room for data collection and processing. The vessel is equipped with a differential global positioning system (D-GPS) navigator. Geological information is collected with shallow seismic systems (boomer, airgun); sidescan sonar systems (100 kHz, 500 kHz, and 100/500 kHz); 5 kHz pinger; 28 kHz echosounder; and various sampling and corer devices, including vibro-hammer corer (6 m), piston corer (6 m), Gemax-corer (0.5 m, including subsampling devices), boxcorer (0.6 m), and underwater camera.

Data holders

Data are held by the GTK. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

Analyses for GTK are mainly carried out through in-house accredited laboratories or by contracted accredited laboratories.

3.7 France

National organization responsible for seabed mapping

Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Z.I. Pointe du Diable, B.P. 70, 29280 Plouzané. Contact: Claudes Augris: tel: +33 2 98224242; e-mail: Claudes.Augris@ifremer.fr.

Mapping programme

IFREMER is in charge of offshore mapping, and its staff includes two geologists whose work involves the continental shelf. It cooperates with the Bureau de Recherches Géologiques et Minières (BRGM), which is in charge of onshore geological mapping, to integrate IFREMER marine data into coastal maps published by BRGM.

Future mapping programmes

Mapping of the French Exclusive Economic Zone (EEZ), both of continental France and its overseas territories, is planned 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.

Published maps

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Alluvial Mining. 1972. Report on the AMdril sampling survey undertaken on the continental shelf off the northern coast of France, Part Two: la baie de Seine. Contrat CNEXO 1972/548.

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Augris, C. and Berthou, P. 1990. Les gisements de maërl en Bretagne. Rapport, 27 cartes et annexes.

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Augris, C., Blanchard, M., Berthou, P. 1986. Étude d'un site d'exploitation de maërl au Nord des îles de Glénan (Finistère). Rapport, 7 cartes.

Augris, C., Blanchard, M., Bonnot-Courtois, C., and Houlgatte, E. 2005. Carte des formations superficielles sous-marines entre le cap Fréhel et Saint-Malo. (Map of surface deposits between Cape Fréhel and Saint-Malo.) Scale 1:20 000. Editions Quae, Versailles. IFREMER.

Augris, C., Bonnot-Courtois, C., Maze, J-P., le Vot, M., Crusson, A., Simplet, L., Blanchard, M., *et al.* 2007. Carte des formations superficielles du domaine marin côtier de l'anse de Paimpol à Saint-Malo (Côtes d'Armor–Ille-et-Vilaine). (Map of surface formations of the coastal marine area of Paimpol Cove at Saint-Malo (Côtes d'Armor–Ille et Vilaine).) Scale 1:50 000. Editions Quae, Versailles. IFREMER + Cemagref, Cirad, and Inra.

Augris, C., Bonnot-Courtois, C., Mazé, J-P., le Vot, M., Crusson, A., Simplet, L., Blanchard, M., *et al.* 2006. Carte des formations superficielles du domaine marin côtier de l'anse de Paimpol à Saint-Malo (Côtes d'Armor – Ille-et-Vilaine). (Map of surface formations of the coastal marine area of Paimpol Cove at Saint-Malo (Côtes d'Armor – Ille et Vilaine).) Scale 1:50 000. Editions Quae, Versailles. IFREMER + Cemagref, Cirad, and Inra.

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Laboratoire des Ponts et Chaussées de Lille. 1969. Étude géotechnique de sédiments de la Manche. Contrat CNEXO P.V. 4817/0.

Laboratoire Pont et Chaussées de Saint-Brieuc. 1975. Recherche de granulats marins au Sud de la Bretagne. Dossier 44.4.1.235.

Laboratoire Pont et Chaussées de Saint-Brieuc. 1977. Pertuis charentais. Rapport technique "granulats marins". Dossier 44.7.1.019.

Lesueur, P., Klingebiel, A. 1986. Carte des sédiments superficiels du plateau continental du Golfe de Gascogne, partie septentrionale (échelle 1:500 000). Bureau de Recherches Géologiques et Minières (BRGM), Institut Français de Recherche pour l'Exploitation de la Mer (Ifremer).

Musée Océanographique de Monaco. 1971. Recherches lithosismiques sur les sables du plateau continental du cap Couronne au cap Martin. Contrat CNEXO 1971/320.

Musée Océanographique de Monaco. 1971. Sables et graviers entre l'embouchure du Rhône et la frontière italienne. Contrat CNEXO 1972/471.

Robert, J-P., Ville, P. 1971. Carte géologique et structurale de la marge continentale française : Boulogne-sur-mer/Rouen au 1:250 000. Feuilles 0-50, 0-49, CNEXO and BRGM.

Serete Etudes. 1972. Exploitation des sables et graviers d'origine marine pour l'approvisionnement de la région parisienne à l'horizon 1985. Contrat CNEXO 1972.

Serete Etudes. 1974. Exploitation des sables et graviers d'origine marine pour l'approvisionnement de la région Bretagne. Contrat CNEXO 1974.

Université de NANTES. 1974. Le dessalement des sables marins par lavage par aspersion. Contrat CNEXO 74/953.

Vaslet, D., Larsonneur, C., Auffret, J-P. 1978. Les sédiments superficiels de la Manche au 1:500 000 et notice explicative. Carte géologique de la marge continentale Française. Bureau de Recherches Géologiques et Minières (BRGM), Centre National pour l'Exploitation des Océans (CNEXO). 17 pp.

Further information is available online at

http://wwz.ifremer.fr/drogm/ressources_minerales/materiaux_marins

IFREMER publications can be ordered from: Editions QUAE, c/o Inra RD 10, 78026 Versailles Cedex, Versailles, France; tel: +33 1 30833416; fax: +33 1 30 833449.

BRGM publications may be ordered from BRGM. For contact information, see the section National organization responsible for seabed mapping, above.

Survey 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 for operation in the Atlantic/Channel and one for operation in the Mediterranean. A further five similar vessels are run by the universities.

Relevant types of IFREMER equipment include very high resolution seismics, differential global positioning systems (D-GPS), sidescan sonars, multibeam for shelf, various corers, and grabs.

3.8 Ireland

National organizations responsible for seabed mapping

Geological Survey of Ireland (GSI), Beggar's Bush, Haddington Road, Dublin 4, Ireland; tel: +353 1 678 2864; fax: +353 1 678 2579; e-mail: Koen.Verbruggen@gsi.ie.

Marine Institute (MI), Marine Institute Headquarters, Rinville, Oranmore, Co. Galway, Ireland: tel: +353 9 138 7200; fax: +353 9 138 7201; e-mail: institute.mail@marine.ie; vessel chartering and surveying enquiries: rv@marine.ie; website: http://www.marine.ie.

Requests for data

Marine Data Online (http://www.marinedataonline.ie/) is an online service that provides access to marine data and projects in Ireland. A summary of the content, the currency, and format is given for each entry, conforming to the ISO19115 standard for geographic metadata.

Third-level organizations active in seabed mapping

Coastal and Marine Resources Centre, University College Cork, Haulbowline Naval Base, Cobh, Co. Cork. Contact: Gerry Sutton: tel: +353 21 470 3113; e-mail: Gerry.sutton@ucc.ie.

Department of Earth and Ocean Sciences, National University of Ireland, Galway, Ireland. Contact: Paul Ryan: tel: +353 9 149 2194; fax: +353 9 149 4533; e-mail: paul.ryan@nuigalway.ie.

Mapping programme

In 1999, the Irish Government allocated €32 million to fund the Irish National Seabed Survey (INSS) project, which was designed to map Ireland's offshore area. The GSI, in partnership with the MI, manages the project. In the last six years, more than 520 000 km^2 of the Irish Exclusive Economic Zone (EEZ) has been surveyed. During the lifetime of the project, which is now the largest mapping initiative in the world, several vessels and aircraft have been involved.

In 2006, an extension of the INSS–INFOMAR (Integrated Mapping for the Sustainable Development of Ireland's Marine Resource) began to extend mapping work into the inshore zone around Ireland, focusing on 26 priority bays and three coastal areas. Carried out in partnership by the MI and the GSI, it represents the second phase of the groundbreaking INSS, which has already mapped 87% of the offshore areas of Ireland's 89 000 km^2 marine territory.

Ireland's territorial seabed extends more than 600 nautical miles/1111 km into the Atlantic Ocean, into waters more than 4500 m deep. For full details, see the large-scale map in Figure 3.2.5. For surveying purposes, the territorial seabed has been divided by contour into three distinct zones: 0–50 m contour (Zone 1); 50–200 m contour (Zone 2), and 200–4500 m contour (Zone 3).

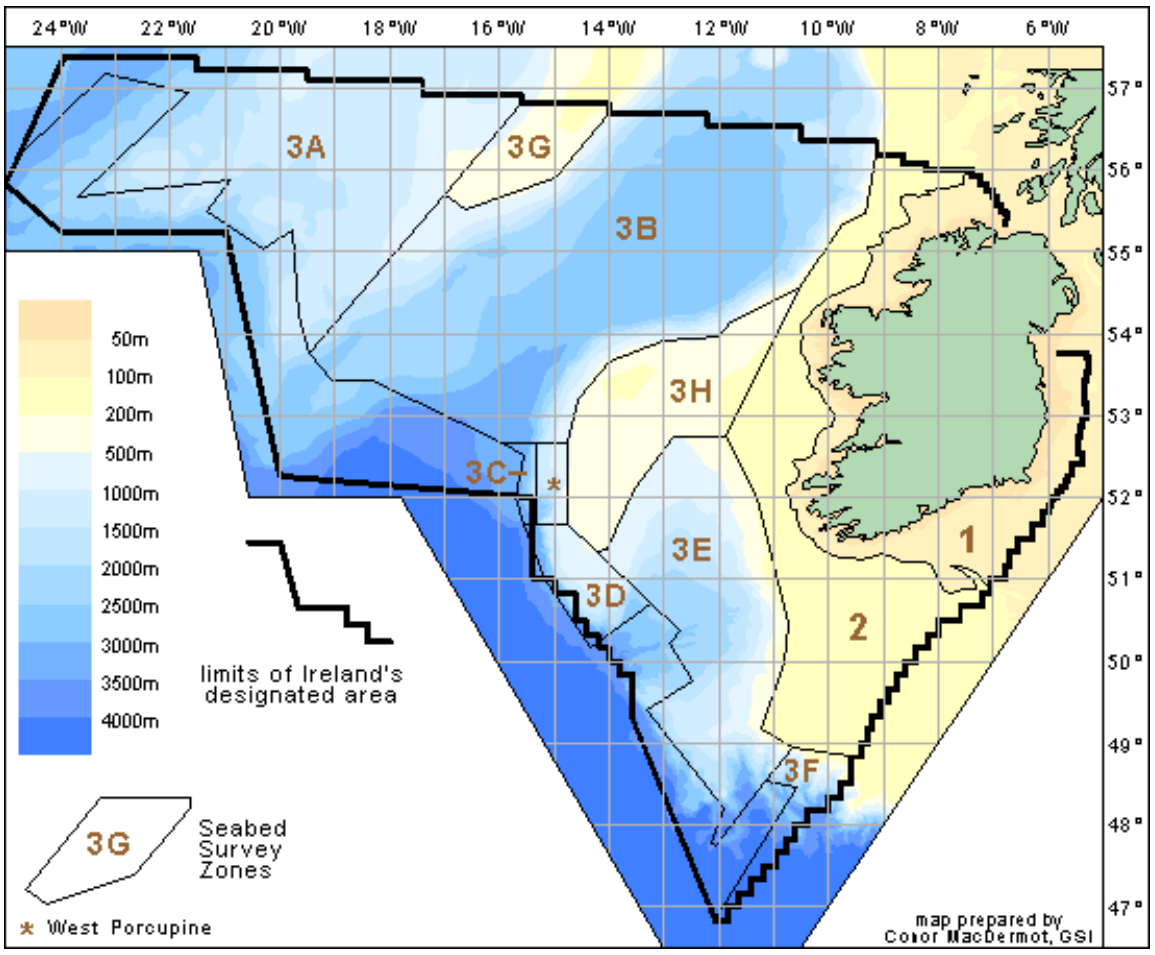

Figure 3.2.5. Map showing the Irish EEZ and the seabed survey zones surveyed by the Irish National Seabed Survey (INSS).

Past mapping programmes

The GSI has been involved in seabed mapping since the mid-1970s. Mapping was undertaken mainly in discrete areas or for topic-specific survey cruises. The GSI also collaborated closely with the British Geological Survey in data acquisition and interpretation, and in the production of the 1:250 000 scale seabed sediment sheets that cover a portion of Irish waters (east coast and eastern parts of the north and south coasts, Malin, Isle of Man, Anglesey, Cardigan Bay, and Nymph Bank).

Types of seabed maps

The primary deliverable from the INSS survey is a multibeam sonar dataset that will serve as a reference for future marine research, navigation charts, policy, protection, and industrial initiatives. A comprehensive series of bathymetric, geological, magnetic, and gravity charts have been produced. They are 2° longitude × 1° latitude map sheets at a scale of 1:250 000. Further scales are available for shallower waters (e.g. 1:60 000 and 1:30 000: Figures 15–18). They provide an accurate basis, both for further research and for additional maps customized to the needs of the various end-users.

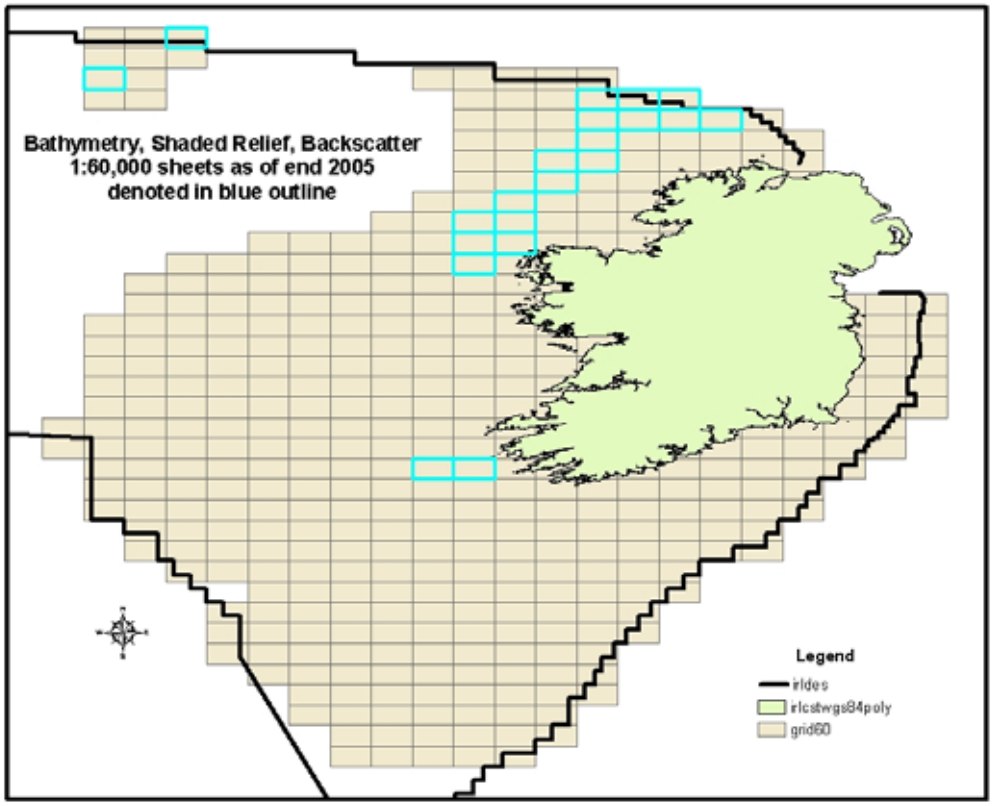

Figure 3.2.6. Irish bathymetric and backscatter maps produced at a scale of 1:60 000.

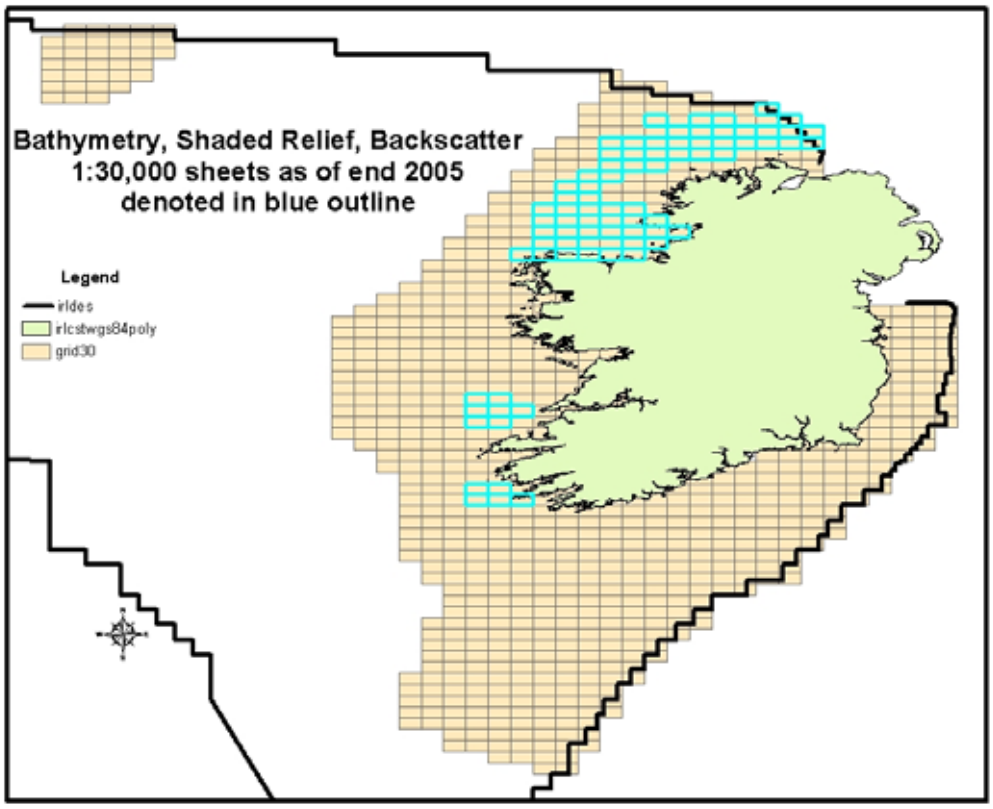

Figure 3.2.7. Irish bathymetric and backscatter maps produced at a scale of 1:30 000.

Products are available in both paper and digital format, and in as flexible a manner as possible, in order to accommodate the needs of all kinds of customer groups. GSI is happy to deal with specific customer requests and will consider entering into data-exchange arrangements. Applicants must complete a one-page, data-access request form in order to provide basic information about requirements, deliverables, etc. A web-mapping interface allows access to further detailed information on mapping coverage and products. Further information is available online at: http://193.178.1.182/website/gsi_multi/viewer.htm.

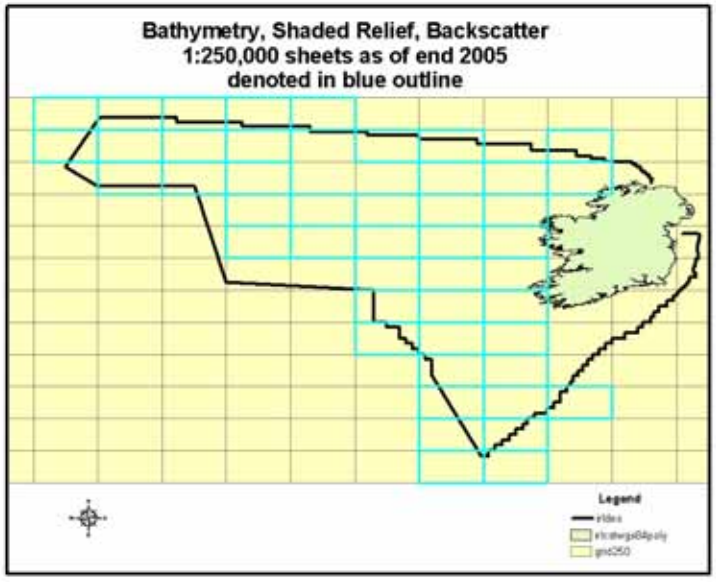

Figure 3.2.8. Irish bathymetric and backscatter maps produced at a scale of 1:250 000.

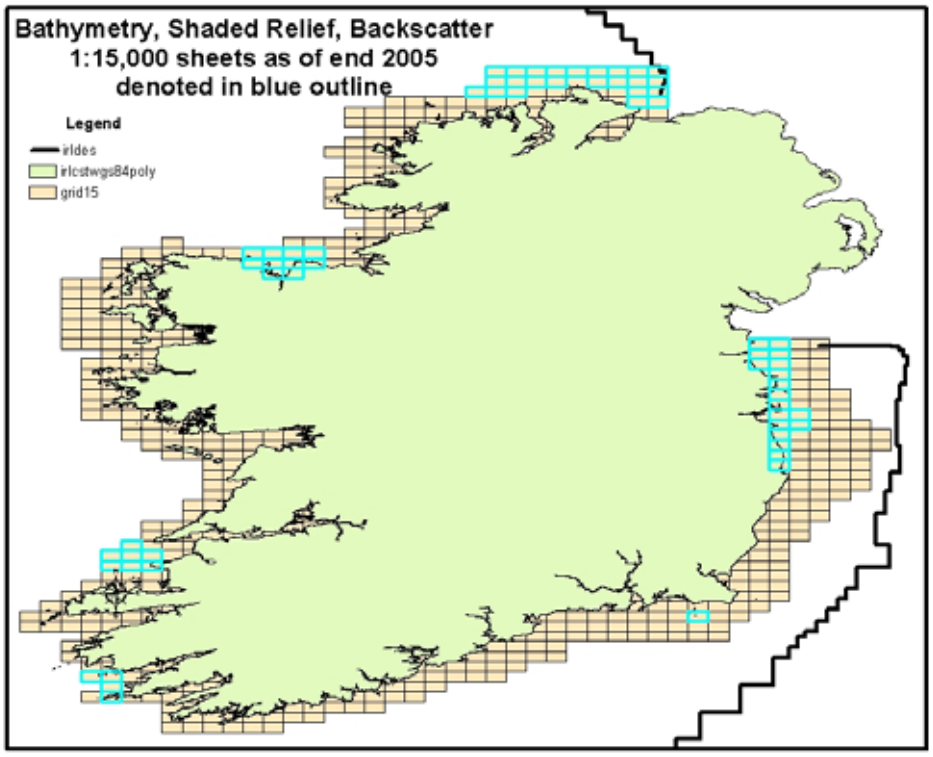

Figure 3.2.9. Irish bathymetric and backscatter maps produced at a scale of 1:15 000.

The Coastal and Marine Resources Centre also holds a range of resource-relevant digital and analog geophysical data and reports from work performed between 1998 and 2005. Further details can be obtained from the centre (for contact information, see the section National organizations responsible for seabed mapping, above). Data from the Irish Sea Marine Aggregates Initiative (IMAGIN) became available during late 2007.

Other publications

Other research, detailed below, has examined many facets of the potential for development of Irish offshore marine aggregates.

Sutton, G. D. 2002. Irish offshore aggregate resources: context, appraisal, and geographic information system (GIS) as a resource mapping tool. Unpublished MSc thesis. National University of Ireland, Cork.

Sutton, G. D., and Wheeler, A. J. 1999. Reconnaissance Assessment of Coastal Seabed Sand and Gravel Resources in the Form of Seabed Mapping and Quantification. GIS and digital data archive.

Sutton, G. D., Wheeler, A. J., and O'Leary, E. 2001. An assessment of the current status and RTDI requirements in respect of the development of Irish seabed resources. Report to the Marine Institute. Coastal Resources Centre, University College, Cork. 242 pp.

Sutton, G. D., Wheeler, A. J., Devoy, R. J., and Gault, J. 2002. Reconnaissance quantification of aggregate resources on the south coast of Ireland. Unpublished report.

Wheeler, A. J., Walshe, J., and Sutton, G. D. 2000. Geological Appraisal of the Kish, Burford, Bray and Fraser Banks, Outer Dublin Bay Area. Marine Institute, Marine Resource Series No. 13. 35 pp.

Wheeler, A. J., Walshe, J., and Sutton, G. D. 2001. Seabed mapping and seabed processes in the Kish, Burford, Bray, and Frazer Banks area, southwestern Irish Sea. Irish Geography, 34: 194–211.

Survey equipment

The INSS is primarily a multibeam sonar survey of an area of 525 000 km^2. This acoustic technique provides detailed bathymetry data and information about the nature of the seabed and its overlying sediment. Magnetic and gravity techniques help to evaluate the nature and structure of the deeper geology. Other survey techniques are also being used to acquire additional primary datasets, including:

- multifrequency, single-beam echosounding;
- sub-bottom profiling (shallow seismic);
- water column measurements of salinity, conductivity, temperature, and speed-of-sound profiles;
- seabed ground-truthing: sediment sampling and video footage;
- sidescan sonar;
- two-dimensional seismic data collection.

Ancillary data are being collected on an opportunistic basis, and secondary projects could be initiated to research a wide range of marine topics, such as:

- **Atmospheric studies**. Automated samplers and analysers operated with minimal on-board assistance could be installed on vessels for meteorology, radiation, or air quality.

- **Air/air–sea interface biological studies**. At specific times of the year, space could be made available for the conduct of seabird and cetacean surveys.
- **Water column studies**. The spatial and temporal biological, chemical, and physical parameters could be analysed.
- **Geological/seabed discrimination**. Seismic, sidescan sonar, or acoustic data have been collected within the boundaries of the main seabed survey. The collection of seabed samples would be an invaluable asset for a variety of research proposals.
- **Benthic ecology**. The biodiversity, chemistry, bottom currents, sediment transport, and composition could be studied using grabs and corers or cameras.

Data holders

The GSI holds a limited quantity of older resource-relevant archival data in the form of paper geophysical records and some magnetic tapes from research and mapping cruises up to the mid-/late 1990s. For further details, see the section National organizations responsible for seabed mapping, above.

National standards

Currently, Ireland has no specific standards for marine aggregates because no extraction, other than for maerl or limited national interest projects, takes place. Analyses are undertaken by third-level institutions and accredited laboratories.

3.9 Latvia

National organization responsible for seabed mapping

Latvian Environment, Geology, and Meteorology Agency (LEGMA), Maskavas Str. 165, Riga, Latvia. Contact: Georgijs Konshins or Inara Nulle: e-mail: konshin@vgd.gov.lv or inara.nulle@vgd.gov.lv.

LEGMA is a state institution under the supervision of the Ministry of Environment. It was established 1 January 2005, uniting three institutions: the Latvian Environmental Agency, the Latvian Hydrometeorological Agency, and the State Geological Survey of Latvia.

The main activities of LEGMA are the collection and processing of environmental information, environmental monitoring, the dissemination of information about the state of the environment, ensuring the rational use and geological supervision of subsoil, and the implementation of state policy in the spheres of geology, meteorology, climatology, hydrology, air quality, and transboundary air pollution. During the implementation of its tasks, LEGMA cooperates with national and international environmental protection, research, and other institutions, and participates in different local and regional projects.

The main activities of LEGMA in the sphere of geology are the supervision of geological operations and coordination of the use of subsoil; approval of state mineral reserves; licensing of the use of subsoil; collection, storage, and dissemination of relevant geological information; and different geological, geophysical, and geo-ecological investigations.

The geology of the Latvian territorial waters and Exclusive Economic Zone (EEZ) has been mapped in detail (scale 1:200 000) and in a reconnaissance scale (1:500 000, 1:1 000 000).

Types of seabed maps

Unpublished geological maps (1: 200 000)

During 1984–1991, a programme of geological mapping was carried out in Latvian territorial waters at a scale of 1:200 000. Sheets for areas 0-34-XXIV, 0-34-XXX, 0-35-XXIX, and 0-35-XXV, incorporating most of the Gulf of Riga, were compiled in full. Sheets for areas 0-34-XXII and 0-34-XXIII were partly covered (Figure 3.2.10). There was no mapping in the areas of Sheets 0-34-XXVIII and 0-34-XXXIV. In the area of Sheet 0-34-XXXIII, specialized marine geotechnical mapping was conducted.

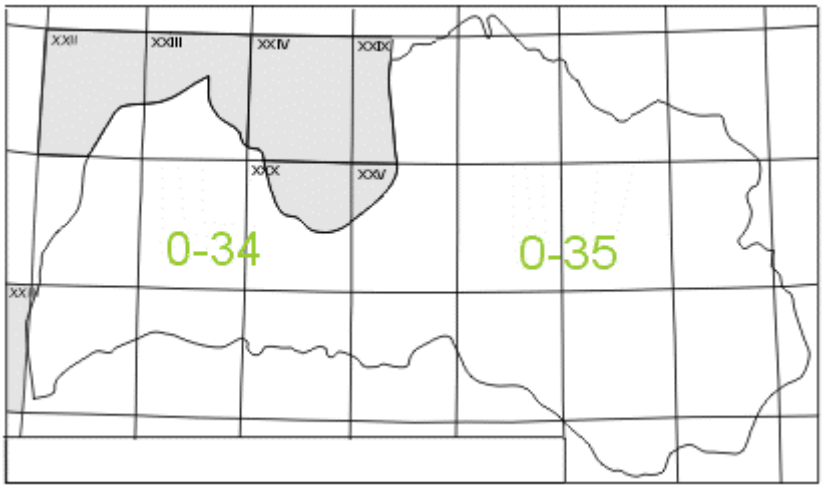

Figure 3.2.10. Scheme of the Baltic Sea, showing coverage of unpublished map areas within the Latvian territorial waters at a scale of 1:200 000.

During offshore mapping, continuous seismo-acoustic profiling, sidescan sonar investigations, echosounding, vibrocoring from vessel, and sampling using a bottom grab were used. As a result of mapping, a set of maps was prepared, including bottom sediment, Quaternary deposits, bedrock, mineral resources, geomorphology, landscape–ecology, pre-Quaternary relief, and other features. The maps were not published and are stored in the geological archives of LEGMA.

Report on experimental geological mapping: sheets 0-34-XXX and 0-35-XXV (offshore part). State Geological Fund, Reg. No. 10543. 1987. Department of Geology, Riga. 1987. (In Russian)

Report on geological mapping: sheets 0-34-XXIV and 0-35-XIX and XXV (offshore part). State Geological Fund, Reg. No. 10888. 1992. Department of Geology, Riga. 1992. (In Russian)

Information report on geological mapping: sheets 0-34-XXII and 0-34-XXIII (offshore part). State Geological Fund, Reg. No. 11041. 1993. Department of Geology, Riga. 1993. (In Russian)

Published maps (1: 200 000)

In 1997, in cooperation with the Geological Survey of Estonia (ETK), maps at a scale of 1:200 000 were published for the Gulf of Riga, including a map of bottom sedi-

ments, landscape–ecological maps, and maps of pre-Quaternary and Quaternary deposits (see Figure 3.2.11). Each is accompanied by an explanatory note in English; the legends are in Latvian, Estonian, and English. These maps can be used for the solution of important economic problems, particularly those related to shipping and fisheries.

Map of bottom sediments (1 : 200 000)

The map of the bottom sediments of the Gulf of Riga (see below) is based on products of geological mapping (1984–1992) and generalized results of earlier studies, as well as data from other institutions. 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 descriptions of the grain size of the bottom sediments, their mineralogical and chemical composition, physical–mechanical properties, geochemical characteristics, etc., based on data from more than 4700 stations.

Stiebriņsh, O., and Valigs, P. 1996. Bottom sediments of the Gulf of Riga. Scale 1:200 000. Geological Survey of Latvia. Geological Survey of Estonia. Riga. 54 pp.

Landscape–ecological map (1 : 200 000)

The landscape–ecological map of the Gulf of Riga is based on the products of geological mapping (1984–1992) and the results of the investigations of zoobenthos and hydrochemical conditions (temperature, salinity, and oxygen content) in the near-bottom layer of water, carried out at the Institute of Biology of the Latvian Academy of Sciences. The map shows the distribution of the landscapes and their generic relationship with bottom sediments. In addition, the map shows the distribution of pollution in the bottom sediments (scale 1:1 000 000) by six components: organic C, Pb, Cu, Zn, Cd, and Hg. The explanatory note includes descriptions of the landscapes, an evaluation of the pollution of bottom sediments, and an estimate of the prospects for use of the basin in the national economy.

Barashkovs, V., Talpas, A., and Kasks, J. 1997. Landscape–ecological map of the Gulf of Riga. Scale 1:200 000. Geological Survey of Latvia. Geological Survey of Estonia. Riga.

Barashkovs, V., Talpas, A., and Kasks, J. 1997. Map of occurrence of organic matter and heavy metals in the Gulf of Riga. Scale 1:1 000 000. Geological Survey of Latvia. Geological Survey. Riga.

Maps of pre-Quaternary and Quaternary deposits (1:200 000)

In 1995, it was decided to start the preparation of new geological maps of Latvian onshore and offshore areas, which would provide up-to-date geological and related information suited to current requirements (Figure 3.2.11). The maps are based on an accurate topographic base: the Latvian Coordinate System (LKS-92). Each map is accompanied by descriptions of the geological structure in Latvian and short explanatory notes in English.

Geological maps of pre-Quaternary and Quaternary deposits at a scale of 1:200 000, several auxiliary maps at a scale of 1:500 000, and descriptions of the geological structure provide information about the rocks in the area, conditions of their occurrence, minerals, relief structure, and modern geological processes. Digital versions of these maps may have any form, format, and content, and can be printed on demand/request. All basic information is stored in various databases. Printed maps,

with descriptions and English summary, as well as digital maps and data, can be ordered from LEGMA.

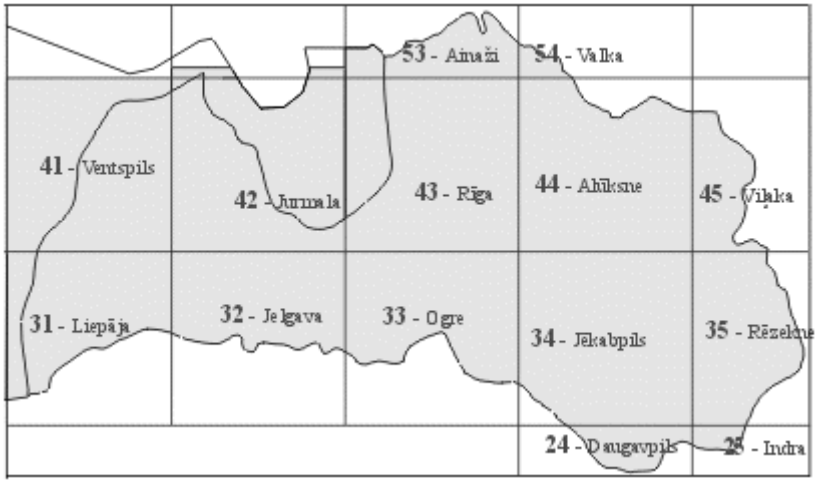

Figure 3.2.11. Scheme of the Baltic Sea, showing coverage of the latest published geological map areas in the Gulf of Riga.

Geological Map of Latvia. Quaternary deposits. Ventspils: sheet 41. Scale 1:200 000. Inset maps (scale 1:500 000): map of minerals, map of nature zones, and map of pre-Quaternary surface relief. State Geological Survey, Riga, 1998. Available as hard copy and in digital format. ISBN 9984-9299-2-2. (Names in Latvian, legends in Latvian and English)

Geological Map of Latvia. Quaternary deposits. Liepaja: sheet 31. Scale 1:200 000. Inset maps (scale 1:500 000): map of minerals, map of nature zones, and map of pre-Quaternary surface relief. State Geological Survey, Riga, 1998. Available as hard copy and in digital format. ISBN 9984-9130-8-2. (Names in Latvian, legends in Latvian and English)

Geological Map of Latvia. Quaternary deposits. Jurmala: sheet 42. Scale 1:200 000. Inset maps (scale 1:500 000): map of minerals, map of nature zones, and map of pre-Quaternary surface relief. State Geological Survey, Riga, 1999. Available as hard copy and in digital format. ISBN 9984-9299-3-0. (Names in Latvian, legends in Latvian and English)

Geological Map of Latvia. Quaternary deposits. Riga: sheet 43, and Ainazhi: sheet 53. Scale 1:200 000. Inset maps (scale 1:500 000): map of minerals, map of nature zones, and map of pre-Quaternary surface relief. State Geological Survey, Riga, 1999. Available as hard copy and in digital format. ISBN 9984-9299-6-5. (Names in Latvian, legends in Latvian and English)

Jushkevichs, V., Stiebrinsh, O., and Talpas, A. 1997. Map of the Quaternary deposits of the Gulf of Riga. Scale 1:200 000. Geological Survey of Latvia and Geological Survey of Estonia. Riga.

Published reconnaissance maps, scale (1:500 000, 1:1 000 000)

Within the framework of a joint 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 in 1998 (Gelumbauskaité; Repecka and Cato) and, accompanied by a subsidiary description, in 1999 (Gelumbauskaité *et al.*).

Gelumbauskaité, L-Z. 1998. Bathymetric map of the Central Baltic in the scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54.

Gelumbauskaité, L-Z., Grigelis, A., Cato, I., Repecka, M., and Kjellin, B. (Eds). 1999. Bottom topography and sediment maps of the Central Baltic Sea. 1:1 000 000. A short description. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54. 24 pp.

Repecka, M., and Cato, I. (Eds). 1998. Bottom sedimentary map of the Central Baltic Sea. Scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54.

Seredenko, R., Zaitsev, V., Talpas, A., and Suuroja, S. 1997. Bedrock map of the Gulf of Riga, scale 1: 200 000. Geological Survey of Latvia. Geological Survey of Estonia. Riga.

Other types of marine geological maps and information

A special map showing the lithology, geochemistry, and morphology of the shore zone (Figure 3.2.12) was published in 1998.

Ulsts, V., and Bulgakova, L. 1998. General lithological and geomorphologic map of Latvia shore zone – Baltic Sea and Gulf of Riga. Scale 1:200 000. State Geological Survey of Latvia, Riga.

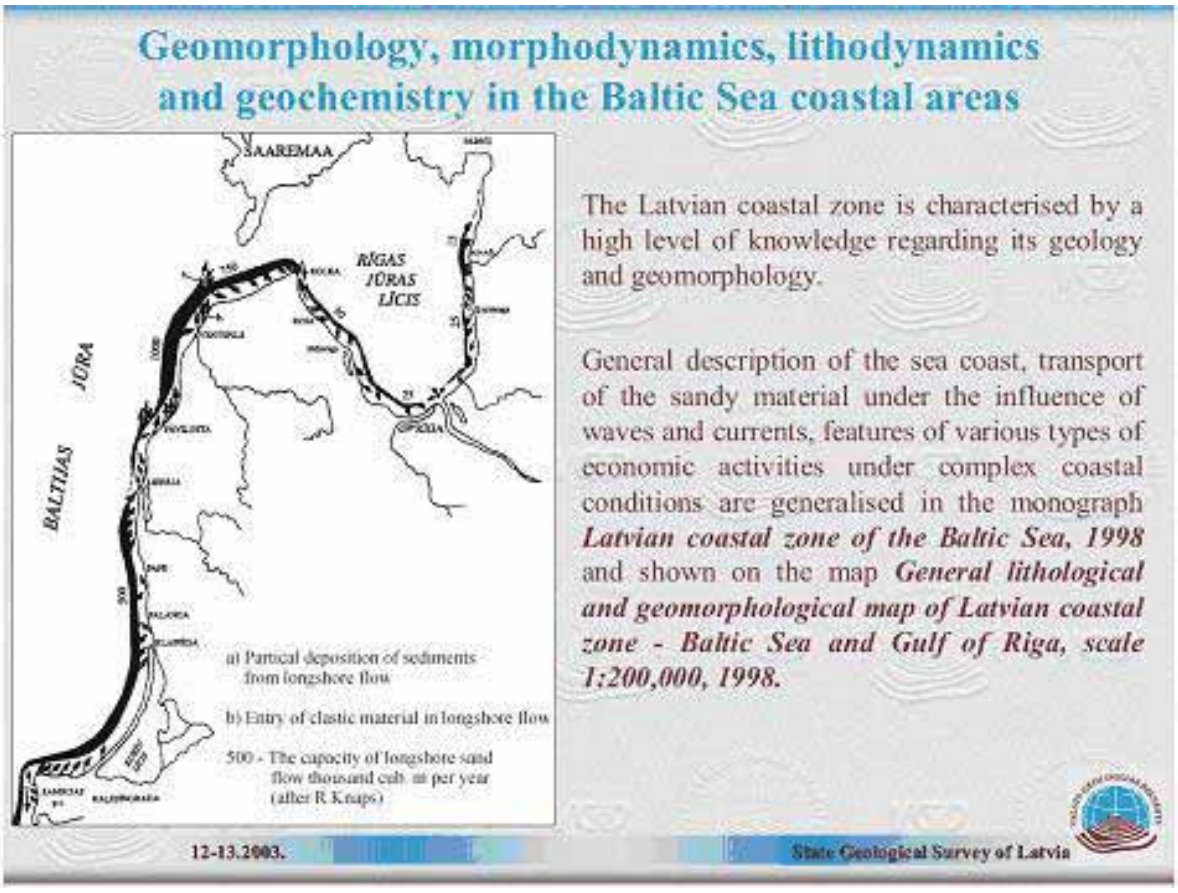

Figure 3.2.12. Maps showing the lithology, geochemistry, and morphology of the Latvian shore zone, continued.

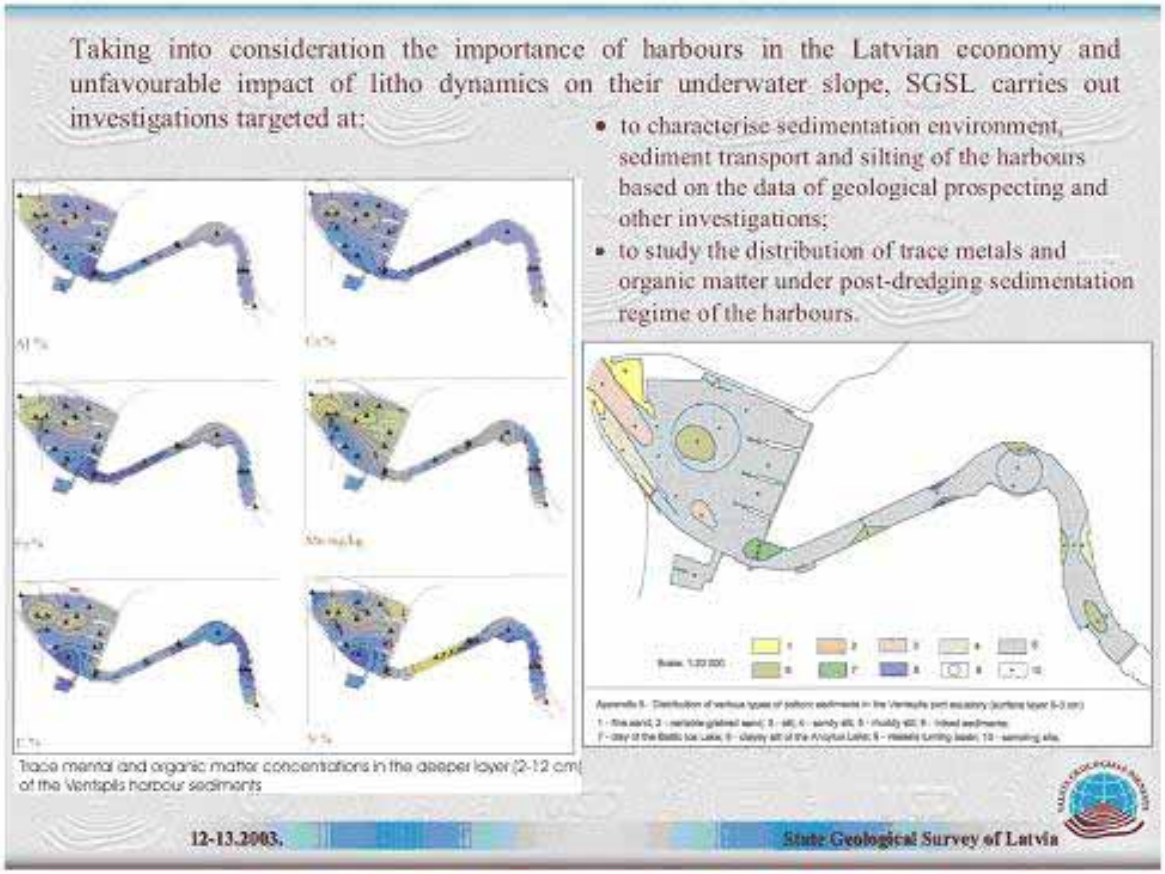

Figure 3.2.12 continued. Maps showing the lithology, geochemistry, and morphology of the Latvian shore zone.

Known and assumed marine sand and gravel resources in Latvia

During 1975–1992, in the coastal zone of the Gulf of Riga and the Baltic Sea proper, in the area from Cape Ovishi to Pavilosta, prospecting and exploration for construction sand, sand–gravel mix, and titanium–zirconium placers took place (Figure 3.2.13). The operations incorporated the coastal zone to a depth of 30 m. A forecast of the impact of the mining on the condition of the coast and benthos was made.

Several areas of sand were discovered on the western and southern coastal slopes of the Gulf of Riga. These areas are not large and the sand layer is thin, so there are unlikely to be any plans for sand extraction in the Gulf of Riga in the near future. It is also necessary to preserve this area as a fish spawning ground.

Survey equipment

LEGMA has no research vessels or specialized equipment for marine geological and geophysical investigations. If funds were available, it might be possible to charter geotechnical vessels and hire sampling and seismic acoustic equipment from specialized Latvian geotechnical companies. However, LEGMA possesses several computer systems and equipment for in-house processing of seismic and log data. LEGMA also has experience in the preparation of digital maps.

Data holders

The State Geological Fund of LEGMA is the holder of most of the data on bottom sediments and exploration for sand-gravel deposits. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

LEGMA holds the standards, developed in the former USSR during 1980–1990, for conducting marine geophysical, geotechnical, and ecological investigations. The existing map-preparation standards are used for this purpose.

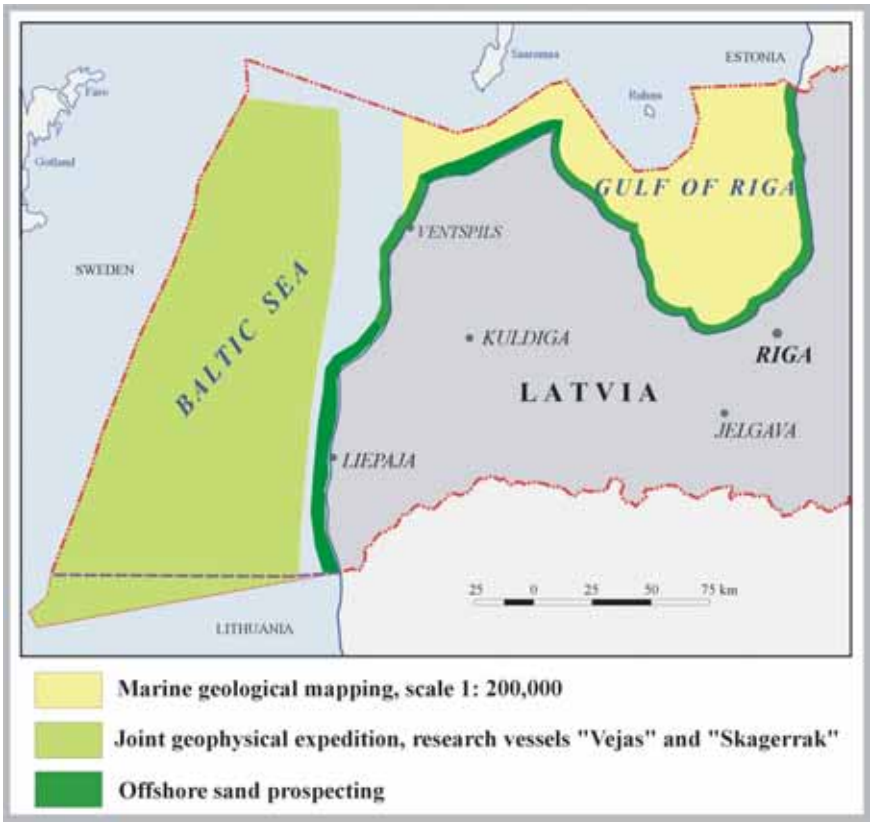

Figure 3.2.13. Scheme of the area showing coverage of sand and gravel resources within Latvian territorial waters.

3.10 Lithuania

National organization responsible for seabed mapping

Geological Survey of Lithuania (LGT) and Lithuanian Institute of Geology and Geography (LIGG), LT-03223 Vilnius, Sevcenkos Str. 13, Lithuania. Contacts: L. Z. Gelumbauskaite and A. Grigelis: tel: +370 5 210 47 15; fax: +370 5 21 36 408; e-mail: leonora@geo.lt or grigelis@geo.lt.

Types of seabed maps

1:50 000 detail geological maps

Lithuanian territorial waters and Exclusive Economic Zone (EEZ; about 9000 km^2) have been mapped in detail (scale 1:50 000), giving a total coverage of 3280 km^2 (36%). In addition, 100 % of the Lithuanian part of the Curonian Lagoon (426 $km^{2)}$ was mapped in 1998–1999 by field survey. Detailed maps (1:50 000) are archived in

the LGT and LIGG. No printed detailed maps are available. Detailed mapping was cancelled in 2000 because of a lack of financial resources.

1:500 000 Baltic Sea geological regional maps

Three geological maps (pre-Quaternary geology, Quaternary geology, and geomorphology) at a regional scale (1:500 000) cover 100% of Lithuanian territorial waters and EEZ. These were compiled in 1992, forming part of the complete Baltic Sea map coverage and including data from previously existing geological–geophysical surveys from the Soviet era. Details of all available geophysical investigations, sampling, borehole, and laboratories from 1980 onwards have been included. No digital database was compiled. The maps resulted from multiyear studies and provided a background for comprehensive research of both general geological structure and environmental conditions of the entire Baltic Sea. Maps at a regional scale (1:500 000), with description in Russian and an English summary, (1992), can be ordered from LIGG (for contact information, see the section National organization responsible for seabed mapping, above).

1:500 000 Central Baltic Sea regional maps

Two digital geological maps (bottom topography and bottom sediments) of the Central Baltic Sea at a regional scale 1:500 000 were compiled in 1998. The documents (maps and explanatory notes in English) were completed from relevant and new information collected by the states around the Baltic Sea. The maps were compiled in ArcInfo format in a Graphic Information System (GIS) database and issued in analog format on two sheets (also available on CD-ROM). These maps and description can be ordered from LIGG (for contact information, see the section National organization responsible for seabed mapping, above) or from the Geological Survey of Sweden.

Published maps (1:500 000) and legends

Gelumbauskaite, L-Z. (Ed). 1998. Bathymetric map of the Central Baltic Sea. Scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54. Vilnius-Uppsala.

Grigelis, A. (Ed). 1991. Geology and geomorphology of the Baltic Sea. Explanatory note of the geological maps. Scale 1:500 000. A monograph. Lithuanian Geological Institute. Nedra, Leningrad. 420 pp.

Grigelis, A. (Ed). 1992. Geological map of the Baltic Sea bottom and adjacent land areas. Scale 1:500 000. Lithuanian Geological Institute, Vilnius.

Litvin, V. M., and Gelumbauskaite, Z. A. (Eds). 1992. Geomorphological map of the Baltic Sea bottom and adjacent land areas. Scale 1:500 000. Lithuanian Geological Institute, Vilnius.

Repecka, M., and Cato, I. (Eds). 1998. Bottom sedimentary map of the Central Baltic Sea. Scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54. Vilnius-Uppsala.

Repecka, M., and Spiridonov, M. A. (Eds). 1992. Geological map of the Quaternary deposits of the Baltic Sea bottom and adjacent land areas. Scale 1:500 000. Lithuanian Geological Institute, Vilnius.

1:50 000 seabed sediment maps

The state marine geological mapping at a scale of 1:50 000 covered Lithuanian territorial waters from shore to 20°30'E in 1993–2000. Two sectors were mapped: (i) Klaipeda – Sventoji area (1630 km^2) in 1993–1996; and (ii) Nida–Klaipeda area

(1650 km²) in 1998–2000. The mapping data were collected on a dense grid of sampling and coring with shallow seismic and sidescan sonar measurements. The maps have not been published, and data are stored in the archives of LIGG. Aggregate resources within the mapped area were discovered. The data are available on request to LIGG.

Unpublished maps (1:50 000)

Repecka, M., Grigelis, A., Gelumbauskaite, Z., Simkevicius, P., Radzevicus, R., and Monkevicius, A. 1997. State marine geological mapping at a scale 1:50 000 in Klaipeda – Sventoji sector. Geological Survey of Lithuania and Lithuanian Geological Institute, Vilnius (manuscript; five maps).

Other types of marine geological maps and information

Within the framework of a joint Lithuanian–Swedish project (GEOBALT), two maps at a scale of 1:500 000 showing the bathymetry (Gelumbauskaité, 1998, see below) and the seabed sediments (Repecka and Cato, 1998, see below) of the Central Baltic Sea, respectively, were published in 1998, accompanied by a subsidiary description (Gelumbauskaité *et al.*, 1999, see below). The maps are also available on CD-ROM.

Gelumbauskaite, L-Z. (Ed). 1998. Bathymetric map of the Central Baltic Sea. Scale 1:500,000. LGT Series of Marine Geological Maps No. 1., Sveriges Geologiska Undersökning Series Ba No. 54. Vilnius-Uppsala.

Gelumbauskaité, L-Z., Grigelis, A., Cato, I., Repecka, M., and Kjellin, B. (Eds). 1999. Bottom topography and sediment maps of the Central Baltic Sea. A short description. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54. 24 pp.

Repecka, M., and Cato, I. (Eds). 1998. Bottom sediment map of the Central Baltic Sea. Scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54.

Known and assumed marine sand and gravel resources in Lithuania

Known mineral resources in Lithuanian territorial waters, mapped in the Klaipeda–Sventoji sector (1993–1996), are sand and gravel deposits. Gravels cover an area of 290 km² in water depths of 12–37 m. As the thickness does not exceed 1 m, this resource has little potential. It is possible that gravel deposits occur in the area of the submerged coastline of the Littorina Sea. Seabed sands cover a total area of 537 km², of which 96 km² (5.9%) is in shallow waters (depth 8–10 m). The thickness of this layer is unknown. It can be assumed that marine sand and gravel deposits in Lithuanian territorial waters offer little potential for exploitation because of their poor quality and the unstable open-sea conditions.

The remainder of the Lithuanian EEZ has not been explored for sand and gravel deposits.

Survey equipment

The LIGG has no survey vessel; mapping surveys were carried out under contract by RV "Vejas" (1100 grt, Klaipeda, Lithuania); RV "Doctor Lubecki" (300 grt, Gdańsk, Poland); and, in lagoon waters, by RV "Peilboot Ludwig" (7.8 m length, 2.5 m width, Kiel, Germany). The vessels are equipped with satellite navigator system, GPS or D-GPS, devices for sediment data collection, and seismo-acoustic and scanning sonar systems, including survey computers.

Geological and geophysical information is collected using shallow seismic systems (100/1000 Hz and 10 kHz airgun; 0.3–22 kHz boomer in lagoon), echosounder (28 kHz Furuno II; 210 kHz Deso 14; 200 kHz Simrad in lagoon), sub-bottom profiler (3.5 kHz OreTech 3010-S; 20–10 kHz X-Star), sidescan sonar systems (105 + 15 kHz Katran-3M, 105 + 15 kHz; 307 kHz Wesmar SHD700SS; 100 and 325 kHz EdgeTech DF1000, in lagoon), CTD-sond, and sampling and corer devices (4–6 m gravity corer; 1.1 m Niemisto corer; 0.8 m small gravity corer in lagoon waters; grab Ocean-25; van Veen grab; 0.2 m^2 boxcorer).

Data holders

Data are held by the LGT and the LIGG. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

Contracted laboratories carry out the analyses of LIGG.

3.11 The Netherlands

National organization responsible for seabed mapping

Netherlands Institute of Applied Geoscience TNO (TNO-NITG), PO Box 80015, 3508 TA Utrecht, the Netherlands. Contact: Cees Laban: tel: +31 302 564 551; fax: +31 302 564 855; e-mail cees.laban@tno.nl.

Mapping programmes

Active mapping programmes

The present mapping programme for the Dutch part of the North Sea (Netherlands Continental Plateau, or NCP; about 50 000 km^2) covers the entire NCP. The data are collected by the Royal Dutch Navy Hydrographic Office and comprise detailed digital bathymetric maps of parts of the Dutch sector, sidescan sonar images, and grab samples. Every ten years, the entire sector is surveyed by the Hydrographic Office. Additional data are collected from commercial companies and the Ministry of Public Works, North Sea Directorate. The maps are only available in digital formats or printouts.

The following maps are available:

- detailed bathymetry;
- seabed sediments;
- folk population classification map;
- Holocene formations at seabed;
- thickness of the Holocene deposits;
- depth to the top of the Pleistocene;
- lithostratigraphy of the top of the Pleistocene.

Printouts or digital formats, with a legend in English, can be ordered from the NITG. For contact information, see the section National organization responsible for seabed mapping, above.

Past mapping programmes

Most of the Dutch sector of the North Sea has been mapped at a scale of 1:250 000 (reconnaissance mapping programme; see Figure 3.2.14). Each sheet consists of three maps: (i) seabed sediments and Holocene geology, (ii) Quaternary geology, and (iii) pre-Quaternary geology. Printed maps are available. The last sheet over Terschelling Bank is only available in digital form.

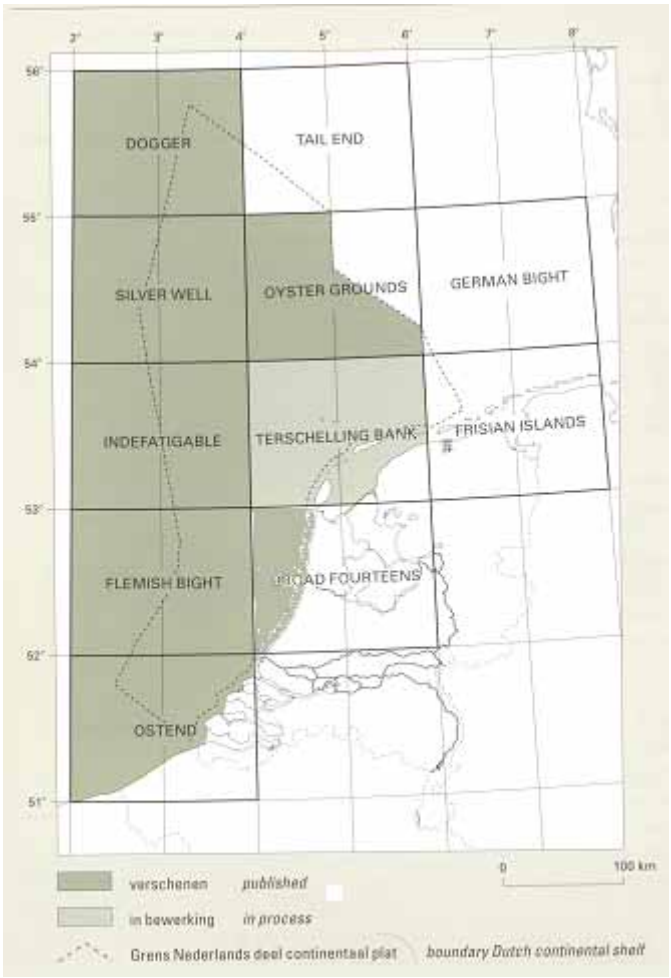

Figure 3.2.14. The available printed maps of the 1:250 000 series (Terschelling Bank series, Rabsbank, and Buitenbanken in printed and digital form, and Broad Fourteens only in digital form).

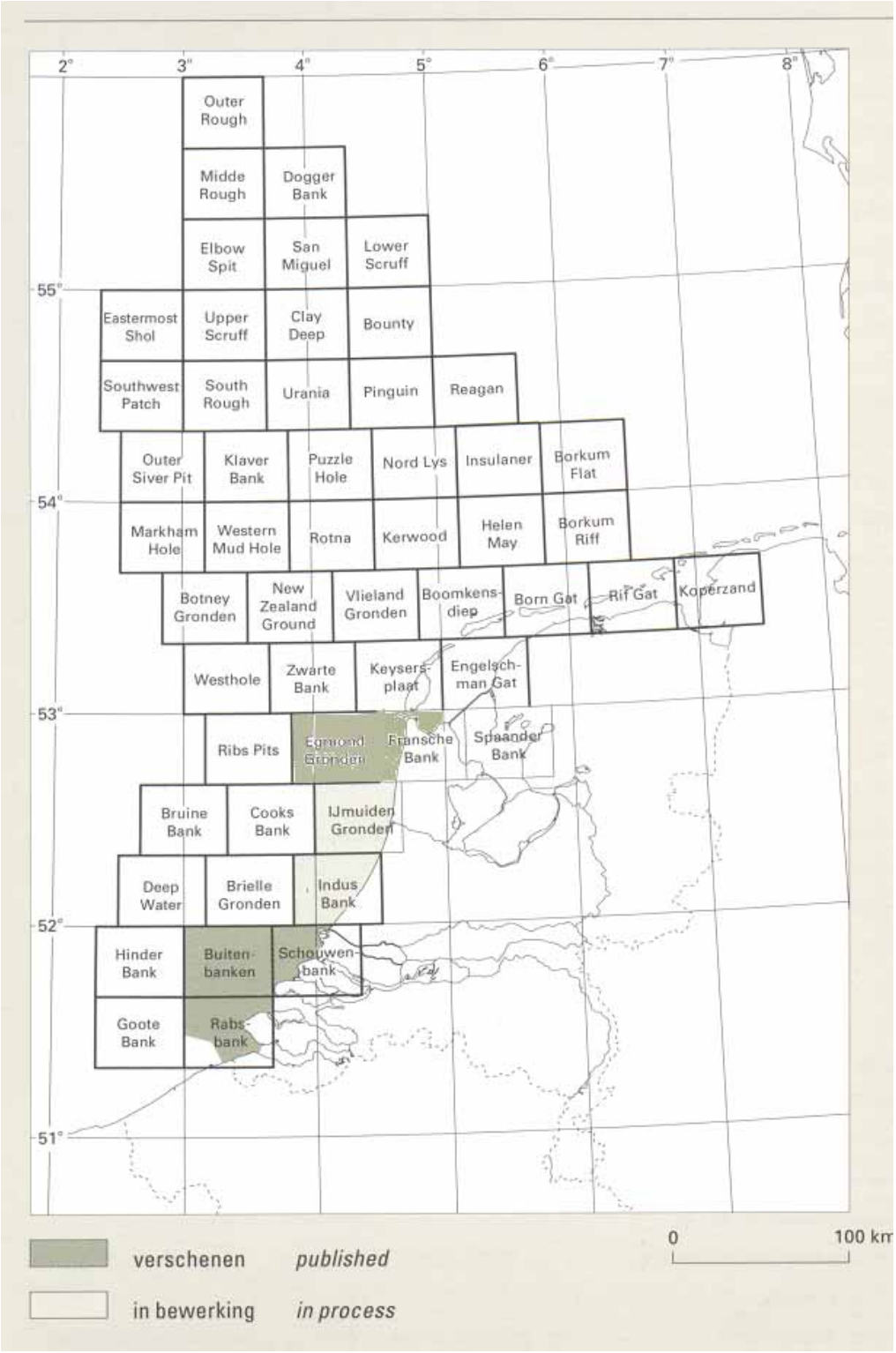

Figure 3.2.15. The available maps of the 1:100 000 printed format. The remaining maps are in digital format.

The coastal zone of the southern part of the Dutch sector has been mapped at a scale of 1:100 000 (Figure 3.2.15). Two maps have been printed (Rabsbank and Buitenbanken); the remaining maps, which are only available in digital form, show the lithology of the upper 2 m, the thickness of the Holocene deposits, depth to the top of the Pleistocene, and the lithostratigraphy of the top of the Pleistocene.

Printouts or digital formats, with a legend in English, can be ordered from the NITG. For contact information, see the section National organization responsible for seabed mapping, above.

Types of seabed maps

Published maps (1:250 000 series)

Balson, P. S., Laban, C., Schüttenhelm, R. T. E., Paepe, R., and Baeteman, C. 1991. Ostend: sheet 52°N/02°E. Seabed sediments and Holocene geology. 1:250 000 series. British Geological Survey, Geological Survey of the Netherlands, and Belgian Geological Survey.

Balson, P. S., Laban, C., Frantsen, P. J., Parker, N., Henriet, J. P., de Batist, M., and Mostaert F. 1991. Ostend: sheet 52°N/02°E. Solid geology. 1:250 000 series. British Geological Survey, Geological Survey of the Netherlands, and Belgian Geological Survey.

Cameron, T. D. J., Laban, C., and Schüttenhelm, R. T. E. 1984. Flemish Bight: sheet 52°N/02°E. Quaternary geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Cameron, T. D. J., Laban, C., and Schüttenhelm, R. T. E. 1984. Flemish Bight: sheet 52°N/02°E. Seabed sediments and Holocene geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Cameron, T. D. J., Grimshaw, S., Hall, D., Laban, C., Mesdag, C. S., Parker, N., and Schüttenhelm, R. T. E. 1984. Flemish Bight: sheet 52°N/02°E. Solid geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Cameron, T. D. J., Laban, C., and Schüttenhelm, R. T. E. 1986. Indefatigable: sheet 53°N/02°E. Quaternary geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Cameron, T. D. J., Bulat, J., Parker, N., Frantsen, P., Laban, C., and Schüttenhelm, R. T. E. 1987. Indefatigable: sheet 53°N/02°E. Solid geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Harrison, D. J., Laban, C., and R. T. E. Schüttenhelm. 1987. Indefatigable: sheet 53°N/02°E. Seabed sediments, and Holocene geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Jeffery, D. H., Laban, C., and Schüttenhelm, R. T. E. 1988. Silver Well: sheet 54°N/02°E. Seabed sediments and Holocene geology, 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Jeffery, D. H., Frantsen, P., Laban, C., and Schüttenhelm, R. T. E. 1989. Silver Well: sheet 54°N/02°E. Quaternary geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Jeffery, D. H., Graham, C., Wright, S., Laban, C., and. Schüttenhelm, R. T. E. 1990. Dogger: sheet 55°N/02°E. Seabed sediments and Holocene geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Jeffery, D. H., Laban, C., Mesdag, C. S., and Schüttenhelm, R. T. E. 1991. Dogger: sheet 55°N/02°E. Quaternary geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Laban, C., Schüttenhelm, R. T. E., Balson, P. S., Baeteman, C., and Paepe, R. 1992. Ostend: sheet 51N/02E Quaternary geology. 1:250 000 series. British Geological Survey and Geological Survey of the Netherlands.

Laban, C., van der Klugt, P. C. M., and Frantsen, P. J. 1995. Oyster Grounds: sheet 54°N/04°E. Seabed sediments and Holocene geology. 1:250 000 series. Geological Survey of the Netherlands.

Published maps (1:100 000 series)

Ebbing, J. H. J., Frantsen, P. J., Nederlof, H. P., and Laban, C. 1994. Sheet Rabsbank. 1:100 000. series. Geological Survey of the Netherlands.

Kok, P. T. J., Zonneveld, P. C., and Laban, C. 1996. Sheet Buitenbanken. 1:100 000 series. Geological Survey of the Netherlands.

Other types of published maps

de Gans, W., Laban, C., and Rijsdijk, K. F. 1993. General map top Pleistocene deposits in the Netherlands and in the Netherlands sector of the North Sea. Scale 1:1 000 000. Geological Survey of the Netherlands.

Survey equipment

Data acquisition has been carried out with single-channel seismics (EG&G X-star model SB512), multichannel seismics (12- or 18-channel receivers), sleevegun 10 in^3 sound source, and sidescan sonar (Hydrographic Office). Sampling has been done with Hamon grab (superficial sediments), hydraulic vibro-corer, Geodoff MKII counterflush/airlift (1 m penetration), and Roflush counterflush/airlift (15–25 m penetration).

Main data holders

All data of the Dutch subsoil (shallow and deep) data are stored at the NITG in the National Databank DINO (Data and Information Dutch Subsoil). The following data are currently available in digital form:

- Basic data:
  - borehole information.
- Mining data:
  - exploration and survey data;
  - production and storage data.
- Data visualization:
  - three-dimensional atlas of the deep subsurface.
- TNO standards:
  - lithostratigraphic nomenclature of the shallow subsoil;
  - stratigraphic nomenclature of the deep subsurface;
  - oil and gas maps of the Netherlands.

National standards regarding aggregates, their study, and use

The Netherlands Standardization Institute (NNI) has issued a national standard to ensure that the composition of loose (unconsolidated) deposits is described in an unambiguous manner: NEN5104 Sediment Classification. This standardization greatly improves the efficiency for comparing geological data. Therefore, TNO-NITG uses this standard as the basis for its descriptions of drilling samples according to the Standard Description Method for Boreholes (SBB). The oldest boring recorded in DINO dates from 1834, and new borehole descriptions are added every day. All borings in the database of the Dutch subsurface have been labelled with a quality code.

Sediment classification NEN 5104

In 1989, the NNI published a sediment classification standard (NEN 5104 *Classificatie van onverharde grondmonsters*). This document defines the nomenclature for lithological description of drilling samples for all unconsolidated deposits. The starting point for the classification is the division of the sample into fractions, one comprising organic matter and four others, based on particle size (Table 3.2.1).

Table 3.2.1. Classification of sediment samples into fractions based on particle size.

Particle size	Name of fraction
<2 µm	lutum (clay)
>2 µm – <63 µm	silt
>63 µm – < 2 mm	sand
>2 mm – <63 mm	gravel (including shells)
>63 mm – <200 mm	cobble
>200 mm – <630 mm	boulders
>630 mm	blocks

The weight percentages of the fractions in a sample are plotted in a series of three triangular graphs. According to NEN5104, five lithologies exist: gravel, peat, sand, clay, and loam. These are subdivided on the basis of admixtures.

More information about this classification system can be found at http://www.nen.nl/normshop; however, an NEN subscription is required in order to download the standards.

Standard description method for boreholes (SBB)

The NEN 5104 Sediment Classification system only covers a small portion of sample characteristics, albeit the most essential ones. In addition, a method has been drawn up for defining other important data: the *Standaard Boor Beschrijvingsmethode* (SBB; standard description method for boreholes). This method provides standards for all the general data (metadata) necessary for describing a borehole and the lithological data from the penetrated layers.

Borehole descriptions that have been made on basis of the NEN5104 sediment classification and the SBB can be added to the DINO boreholes database. Descriptions can be entered digitally in the freeware program BORIS. After sending the descriptions to TNO-NITG by e-mail, the information can be added to DINO after an extensive quality check.

Data can be ordered at http://dinoloket.nitg.tno.nl/.

3.12 Norway

National organization responsible for seabed mapping

Geological Survey of Norway (NGU), NO-7491 Trondheim, Norway. Contact: R. Bøe: tel: +47 73 90 40 00; fax: +47 73 92 16 20; e-mail: reidulv.boe@ngu.no.

Types of seabed maps

No map series in a specific scale has been published for Norwegian waters. However, several different maps covering various seabed themes have been published. The

most well mapped area is the Skagerrak, including the northeastern parts of the North Sea off southwest Norway, where a series of maps has been produced covering bedrock geology, Quaternary geology, thickness maps, Holocene sedimentation, etc. No gravel extraction has taken place on this part of the Norwegian shelf. An overview of the Norwegian shelf (see Figure 3.2.16), with various maps, is available online at http://www.mareano.no.

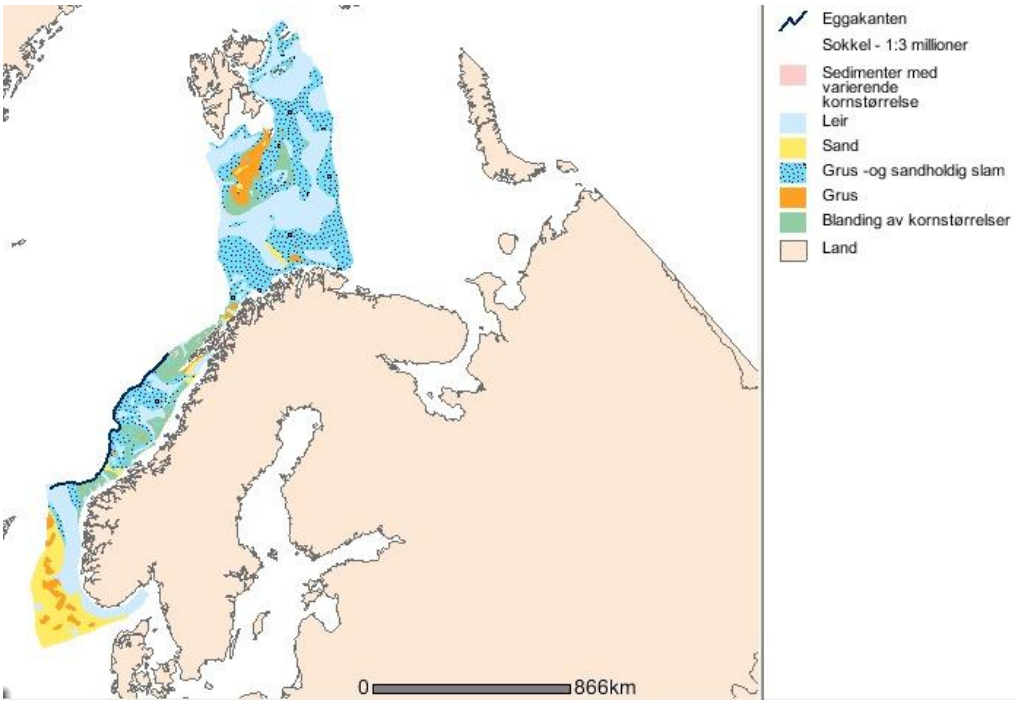

Figure 3.2.16. Overview map of the Norwegian shelf showing the distribution of different sediment types. Blue = clay, yellow = sand, blue with spots = mud with gravel and sand, orange = gravel, and green = varying grain sizes.

A seabed-mapping programme is being carried out in the Oslo fjord area. The programme will provide complete multibeam bathymetric coverage (including backscatter), including high-resolution seismic data (TOPAS) and sediment samples from the seabed.

A large mapping programme for the northern parts of the Norwegian shelf has been proposed (Lofoten–Barents Sea). This programme (Mareano 2006–2010; http://www.mareano.no) will serve a multitude of users. It will include the production of multibeam bathymetry, as well as geological interpretative products of sediment distribution, habitats, seabed dynamics, and hazards.

Marine sand and gravel resources in Norway

Submarine gravels have generally not been exploited along the Norwegian coast or in the fjords. However, carbonate sand and gravels have been exploited mainly for use as agricultural fertilizers. The NGU has mapped these resources in several counties along the south and west Norwegian coasts.

Survey equipment

The NGU has a small survey vessel (RV "Seisma") with a length of 18 m. Equipment for depth measurements is an interferometric Sonar (Geoswath 250 kHz or 125 kHz, full coverage 0–200 m depth). Seismic equipment includes a Geopulse boomer, TO-

PAS (parametric sonar), and sleeveguns (15–40 in^3). The vessel is equipped with various sampling devices, such as gravity corer, multicorer, and grabs.

Data holders

Data are held by the NGU. For contact information, see the section National organization responsible for seabed mapping, above.

3.13 Poland

National organization responsible for seabed mapping

Polish Geological Institute (PGI), Branch of Marine Geology, Koscierska 5 st., 80–328 Gdańsk, Poland. Contact: S. Uscinowicz: tel: +48 58 554 31 34; fax: +48 58 554 29 10 ext 233; e-mail: szymon.uscinowicz@pgi.gov.pl.

Types of seabed maps

The Polish Republic's maritime areas include internal waters (part of the Gulf of Gdańsk, with Puck Bay, Puck Lagoon, and the Vistula Lagoon, as well as the Szczecin Lagoon), the territorial waters (extending to 12 nautical miles/22.2 km), and the Exclusive Economic Zone (EEZ). Poland shares Baltic Sea borders with Germany, Denmark, Sweden, and Russia. The Polish Republic's maritime areas (excluding the Szczecin Lagoon) cover 30 533 km^2, 100% of which has been mapped in detail for shallow geology (scale 1:200 000) and pre-Quaternary formation (scale 1:500 000). An overview of the mapped areas is shown in Figure 3.2.17. The Gulf of Gdańsk area was mapped in detail in 2008 at scales of 1:50 000 and 1:100 000.

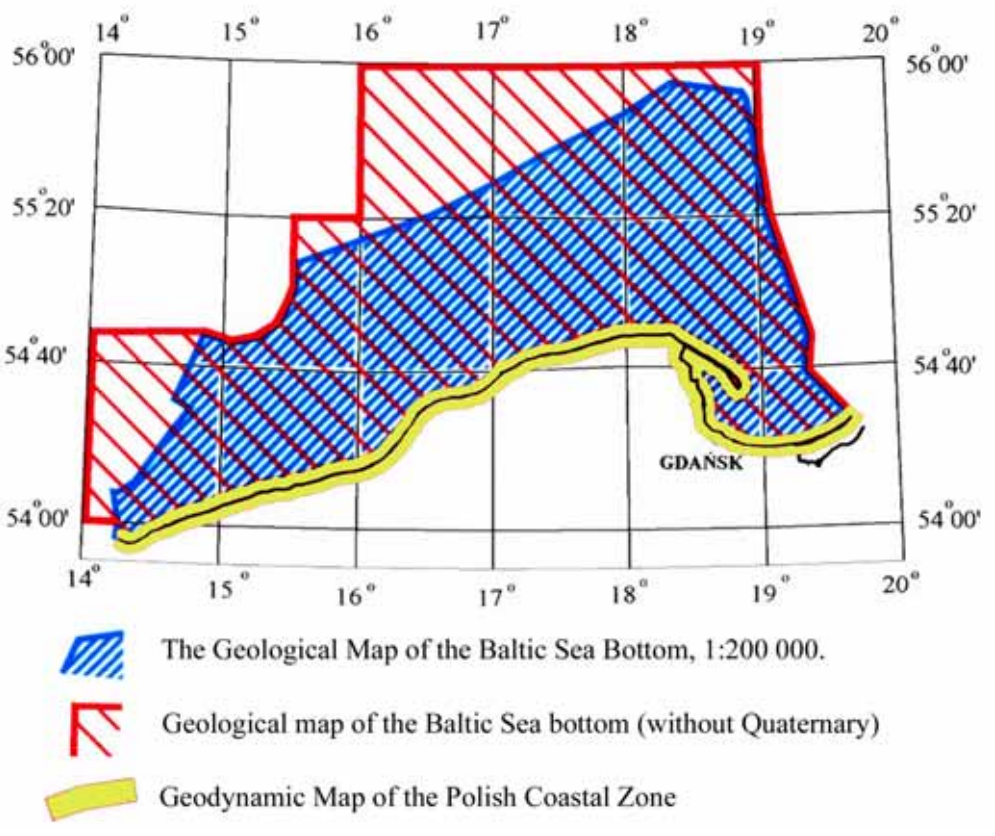

Figure 3.2.17. Map showing coverage of mapped areas within the Polish maritime areas (territorial waters and EEZ) in scales of 1:500 000, 1:200 000, and 1:10 000, respectively.

Printed maps, with legends in Polish and English, and description only in Polish, as well as digital maps and data, can be ordered from the PGI, Branch of Marine Geology. For contact information, see the section National organization responsible for seabed mapping, above.

Published maps (1:500 000) – geological map of the Baltic Sea bottom (without Quaternary)

The objective was to obtain a picture of the direct substratum of the Quaternary in the southern Baltic region, and also to determine the structural relationships between the sub-Cainozoic layers and the deep geological structure (previously well investigated for hydrocarbons), and the structural conditions of regional development during the Quaternary period.

The area of investigations, for which geological maps have been developed, includes the Polish EEZ of the Baltic (up to 12 nautical miles/22.2 km from Bornholm), part of the Danish sector (east of Christiansø Island), the adjoining German sector (up to the 14° meridian), and part of the Swedish sector (up to latitude 55°).

The basis for the map is geophysical investigations, using the high-resolution reflective seismic method. For the measurements, the seismic system belonging to the Netherlands Institute of Applied Geosciences was used. The source of seismic waves was a Texas Instruments 10 in^3 sleevegun (pressure 125 bars, frequency 30–640 Hz, excitation interval 12.5 m). For reception of the signal, a Prakla Seismos 12-channel streamer (12.5 m distance between the hydrophones) was used. The data were recorded using the MGS Marine Data Acquisition System. Recording time was 1.0 s, and the sampling step was 0.5 s.

During three research surveys, about 4500 km of seismic profiles were taken. The arrangement of profiles in the SE–NW and SW–NE directions in the western part of the survey area, and in the meridional and latitudinal directions in the central and eastern part, was fitted to the system of the main structural units.

The recorded seismic data were processed and interpreted at the PGI, using Landmark Graphics Corporation software. In the interpretation process, correlations were made with the results of deep reflection seismics and seismo-acoustics and with data from boreholes.

The final result of the investigations is a 1:500 000 map showing outcrops of geological layers on the sub-Quaternary surface, the relief of this surface, and the main elements of tectonics of the area. Also, geological cross sections down to 800 m and an explanatory text in Polish and English are provided. The information layers of the map are also prepared in digital form in GIS, allowing printouts at a scale of 1:200 000.

Published maps (1:200 000) – geological map of the Baltic Sea bottom

During 1976–1990, 30 000 km of echosounding profiles and ca. 5000 km of shallow seismic lines were collected. Also, 6051 samples of surficial sediment and 827 cores were taken and 23 boreholes were made. Standard investigations in the laboratory were done, including 8850 analyses of grain size distributions, ca. 3570 contents of heavy minerals, and ca. 2150 compositions of heavy minerals. Also ^{14}C, TL, pollen, and diatomological analyses were carried out.

Results of cruises and laboratory work are presented on 12 sheets, which include bottom sediments 1:200 000, geological cross sections, geological profiles, and maps at 1:500 000 showing geomorphology, lithodynamics, sediment 1 m below the seabed,

and mineral resources (legends are in Polish and English). There is also an explanatory booklet for each sheet of the map (only in Polish). Results of cruises and laboratory work are stored in a computer database (FoxPro); only echograms and shallow seismics records are in hard copies. Maps of bottom sediments at 1:200 000 are also available in GIS ArcInfo format.

Published maps (1:10 000) – Geodynamic geodynamic map of the Polish Coastal Zone

A total of 520 km of the Polish coast has been mapped and prepared in GIS format. This includes elements of geology, geodynamics, and evaluation of hydrogeological conditions, engineering geology, and resource geology. Geological cross sections are included on the each map sheet. The 64 sheets of this map cover the entire Polish coast; 33 sheets are available in ArcGIS format and the remainder will be digitized in the near future.

The map was based on a large number of field measurements, including: mapping, boring (inland and offshore), seismo-acoustic, sidescan sonar and micro-seismic, laboratory analyses (grain size, petrography, heavy mineral composition and quantity, $CaCO_3$ content), biostratigraphic analyses, and also ^{14}C and TL age determinations. In the map, geological, geodynamic, geosozologic assessment, hydrogeological, engineering geology, and mineral resource elements have been presented. Geological transects have also been plotted. Analysis of geodynamic conditions has demonstrated that processes of marine erosion have intensified not only along cliff coasts, but also along spits and lowland sections.

Work on the map of the Polish coastal zone was undertaken between 1995 and 2003. The entire Polish coastline was mapped in 2005 to monitor rates of erosion/deposition.

Geochemical atlas of the southern Baltic

During 1991–1993, cores of bottom sediments were taken at 368 stations in regular grid (10 km × 10 km). Muddy deposits from the top 0–6 cm layer were sliced into 1 cm samples, and deposits from the 6–20 cm layer into 2 cm samples; samples of sands were taken from the top 0–5 cm layer. All samples were placed in airtight plastic boxes, frozen, and stored at −20 °C. Granulometric analyses were carried out on 498 samples, and 924 samples were subjected to chemical investigations comprising the determination of total organic C, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mn, Ni, P, Pb, S, Sr, V, and Zn for <2 mm fraction, which was separated using a nylon sieve. For six selected cores, the rate of sedimentation was determined using the ^{210}Pb method. All analyses were done in the Central Chemical Laboratory of the PGI, and the correctness of the analytical methods was checked by analysing international reference samples and through interlaboratory comparisons carried out at Warsaw University and the Institute of Oceanology of the Polish Academy of Sciences.

Results of analyses and measurements were stored in a FoxPro database. The distribution of elements in the 0–1 cm layer and the vertical distribution in selected cores are presented in printed form in 18 monoelement geochemical maps over a bathymetric and granulometric background, which are available in PC ArcInfo format.

Geochemical atlas of the Vistula Lagoon (1:150 000)

During June and July 1994, samples of bottom sediments were taken at 100 sampling stations in a regular grid (2 km × 2 km). The 20 cm long cores of muddy deposits were

sliced into 2 cm samples; samples of sands were taken from the top 0–5 cm layer. All samples were placed in airtight plastic boxes, frozen, and stored at −20°C.

Granulometric analyses were undertaken for 100 surficial samples, and 110 chemical investigations were carried out in order to determine total organic C, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mg, Mn, N, Ni, P, Pb, S, Sr, Ti, V, and Zn for <2 mm fraction, which was separated using a nylon sieve.

Results of investigations are presented in an atlas containing maps of documentary, bathymetry, bottom sediments in Sheppard's (1954) classification, 24 monoelement maps with vertical distributions of elements in selected cores (on inserts) and maps of As/Al, Cd/Al, Cr/Al, Cu/Al, Hg/Al, Ni/Al, Pb/Al, Zn/Al ratios, as well as explanatory text in Polish and English.

Results of analyses are stored in a FoxPro database; maps were digitized (PC ArcInfo) and prepared for printing using ArcInfo as well as Corel Draw software.

Known and assumed marine sand and gravel resources in Poland

Recognized resources of gravel, sandy gravel, and gravelly sand

During the past 30 years, geological prospecting and reconnaissance surveys carried out by the Branch of Marine Geology of the PGI have successfully located concentrations of various mineral products on the Polish Baltic seabed. In some cases, these are of potential economic significance. Natural seabed aggregates (i.e. gravel, sandy gravel, and gravelly sand) are the most thoroughly investigated mineral resources in the southern Baltic. Three main deposits have been documented to date.

The "Słupsk Bank" deposit lies at a depth of 16–20 m. The deposit comprises eight fields of aggregate within sandy deposits in the middle and eastern part of the Bank, or on a washed-out surface of till (in the western part of the Bank). The areas of the fields range from 0.8 km^2 to 10.5 km^2 and totalling about 31.0 km^2. The thickness of the deposit layer is between 0.3 m and 2.0 m, with an average of about 1.0 m. The average content of grains with a diameter <2 mm fraction (sand) is 64%. Geologically documented resources are 64.5 million t.

The "Southern Middle Bank" deposit lies at a depth of 16–30 m. The aggregate occurs in the form of irregular patches of varying thickness resting on sandy substratum and, in the southwestern part, on till. Nine deposit fields have been documented, with areas ranging from 0.53 km^2 to 16.9 km^2 (totalling about 26.0 km^2). The thickness of the deposit layer is between 0.3 m and 5.0 m, with an average of 0.92 m. The average content of grains with a diameter <2 mm fraction (sand) is 56.3%. Geologically documented resources are 57.1 million t.

The "Koszalin Bay" deposit is in the shallow-water zone at a depth of 10–25 m. Seventeen deposit fields occur in the form of isolated patches lying on a sandy substratum or, in the southwestern part, on till. The area of the fields ranges between 0.3 km^2 and 3.6 km^2 (totalling about 21.0 km^2). The thickness of the deposit layer is between 0.3 m and 1.8 m, with an average of 0.9 m. The average content of grains with diameter <2 mm fraction (sand) is 60.1%. Geologically documented resources are 37.7 million t.

Sand resources for beach nourishment

Sand resources have been recognized in six deposit areas: four in the open sea, one in Puck Lagoon, and one in Vistula Lagoon. Between 1991 and 1998, five areas of sands for beach nourishment were documented: four in the open seabed and one large area in Puck Lagoon.

1) The first area, documented in 1991, is located northeast of Jastarnia, off the Hel Peninsula, at a distance of 2.5–4 km from shore and a depth of 14–20 m. The area consists of two fields of medium sands, with available resources for exploitation of 3 496 750 m^3.

2) The second area, documented in 1992, is located northeast of Cape Rozewie and north of Władysławowo, about 4–10 km from shore and at a depth of 15–20 m. The area consists of 11 250 000 m^3 of medium and coarse sand.

3) The third area, documented in 1996, is located east of Władysławowo, 3–5 km from shore and at a depth of 14–18 m. Like the first area, it consists of two fields of medium sands, with total resources of 103 000 m^3.

4) The fourth area, documented in 1998, is located 7 km north of Dziwnow (western part of Polish EEZ) at a depth of 9.5–12.0 m. The deposit field, with an area of 0.96 km^2, contains ca. 1 700 000 m^3 of medium sands for beach nourishment.

5) In the fifth area, Puck Lagoon, seven fields of sands were recognized, all located about 0.6–2.5 km from shore at a depth of 1–3 m. The northwestern part of the lagoon contains four fields of fine sand totalling ca. 12 000 000 m^3. The fifth field contains ca. 3 500 000 m^3 of fine sand mixed with medium sand. The sixth and seventh fields, which occur on the submerged barrier forming the southeast margin of Puck Lagoon, contain medium sand totalling ca. 3 000 000 m^3. All are suitable for beach nourishment and land reclamation.

Potential sand and gravel resources

Gravel

Apart from the deposits with proven resources, described above, the Polish EEZ is host to other promising regions with aggregate accumulations. The most promising areas are on the northern and northwestern slopes of the Słupsk Bank, with several smaller fields lying in the Pomeranian Bay and in the shallow-water area between Dziwnów and Kołobrzeg. There are also a few prospective fields in the area north of Łeba.

Sand enriched with heavy minerals

Accumulations of sand enriched with heavy minerals have been well investigated on Odra Bank. In this area, the highest concentrations of heavy minerals occur at the seabed surface in the form of small isolated fields or elongated belts. The layer with a high, heavy-mineral content rarely exceeds 40 cm (mostly 15–20 cm) and is composed of 0.2–1.0 cm thick laminae alternately rich and poor in heavy minerals. As a rule, the enriched sand contains over 80% fine sand (0.25–0.063 mm fraction) and is well to very well sorted. As a result of surveys on the northern and northeastern parts of Odra Bank, nine deposit fields of 9.0 km^2 total area have been located and investigated. The average thickness of the deposit layers is 0.55 m, and the average

heavy-mineral content is 4.64% by weight. More than 7.0 million t of sand are enriched with heavy minerals, which include about 0.5 million t of garnet, zircon, rutile, ilmenite, magnetite, monazite, and others.

Two prospective areas with heavy minerals have also been found on Słupsk Bank. On this bank is found fine sand with a high heavy-mineral content adjacent to the natural aggregate fields. Percentages of heavy minerals vary from 0.75 to 45.0% by weight. The mean percentage of heavy minerals is 13.1% for the first field and 3.1% for the second. According to preliminary assessments, the average contents of the respective sands are: ilmenite, 40 kg t^{-1} and 12 kg t^{-1}; zircon, rutile, and monazite, ca. 3.5 kg t^{-1} and 2.5 kg t^{-1}; and garnet, 3.0 kg t^{-1} and 9.5 kg t^{-1}.

Sands for beach nourishment and other purposes

Areas of medium- and coarse-grained sand accumulations are expected in the shallow-water zone (between 10 and 30 m depth) north of Jarosławiec and Sutra and northwest of Łebsko Lake (on Czołpino Shoal), northeast of Łeba, northwest and northeast of Rozewie, and in the Gulf of Gdańsk. Preliminary evaluation of the areas of medium- and coarse-sand areas in the Rozewie region, which could be used for nourishment of the Hel Peninsula beaches, is about 240 km^2. Thickness of the sand layer is between 1 m and 5 m. The areas of fine-sand accumulation with the greatest potential are in the Pomeranian Bay and on Odra Bank. Such areas also occur in the Ustka and Łeba regions northwest of Rozewie and in the Gulf of Gdańsk. Because of their chemical composition and physical properties, fine sands may be used for industrial applications. The best quality are the well-sorted, fine sands of Odra Bank, which can be used as raw material for the steel (moulding) and glass industries and as construction sands.

Large amounts of sand for land reclamation and construction of dams and embankments are known and dredged in the coastal zone of Vistula Lagoon.

Survey equipment

The PGI possesses sampling equipment and software for seismic sampling data processing, as well as software for data storage, visualization, and presentation. Various sampling and corer devices include vibro-hammer corer (6 m), piston corer (3 m/6 m), Niemisto corer (1 m), Gemini corer (1 m), Oscorer (1 m), van Veen type grabs, and heavy boxcorer (0.6 m). Geological information is collected in Visual FoxPro system and ArcGIS.

Data holders

Data are held by the PGI Branch of Marine Geology. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

Analyses for the PGI are carried out by in-house and contracted accredited laboratories.

3.14 Portugal

National organization responsible for seabed mapping

Marine Geology Department of the National Institute for Engineering Technology and Innovation (INETI), Estrada da Portela, Apartado 7586, 2720-866 Alfragide, Portugal. Contact:

Fátima Abrantes: tel: +351 214 705 535; fax: +351 214 719 018; e-mail: fatima.abrantes@ineti.pt.

Types of seabed maps

Portuguese territorial waters have been geologically mapped at scales of 1:1 000 000, 1:500 000, and 1:200 000.

Printed maps can be ordered from INETI (tel: +351 214 705 474; fax: +351 214 720 203; e-mail: paula.serrano@ineti.pt.) For contact information, see the section National organization responsible for seabed mapping, above.

Continental shelf map (1:1 000 000)

This map from 1978 is a compilation of information extracted from several projects carried out by the University of Rennes, University of Paris, Instituto Hidrográfico, Serviço de Fomento Mineiro, and SHELL Prospex Portuguesa.

The published map (1:1 000 000) is currently only available in digital format.

Marine geological map (1:500 000)

The fifth edition was published in 1992. Geological information for the immersed area (including the continental shelf and part of the continental slope) was obtained from the interpretation of seismic lines obtained from different sources, including GLORIA sidescan sonar mosaics, analysis of bottom rocks, and geological results from hydrocarbon exploration. The published map (1:500 000) is available in both digital and printed formats.

Marine geological maps (1:200 000)

The immersed area forms part of four of eight sheets that cover Portugal at a scale of 1:200 000. Three of these four sheets have been published. The geological information of the immersed area was obtained from the same sources described above (see Marine geological map (1:500 000)).

Published maps (1:200 000)

These are currently only available in printed format. They include:

- Geological Map of Portugal. AREA: sheet 1. Scale 1:200 000. 1992.
- Geological Map of Portugal. AREA: sheet 7. Scale 1:200 000. 1984.
- Geological Map of Portugal. AREA: sheet 8. Scale 1:200 000. 1992.

Potential marine sand and gravel resources in Portugal

Several projects were undertaken in the 1980s, during which Dias *et al.* (1980, 1981, 1987) and Dias and Nittrouer (1984) described and identified several non-consolidated deposit areas along the Portuguese shelf. Characterization (compositional and textural), together with geographic proximity, makes these deposits very promising for future explorations.

Survey equipment

Geological information is collected using seismic systems (Chirp sonar, boomer, and sparker) and sampling devices (van Veen dredge, boxcorer, and multicorer).

Data holders

Data are held by the Marine Geology Department of INETI. For contact information, see the section National organization responsible for seabed mapping, above.

3.15 Spain

National organizations responsible for seabed mapping

Instituto Geológico y Minero de España (IGME), c/o Rios Rosa 23, Madrid-28003, Spain. Contact: José Ramón de Andrés: tel: +34 91 7287229; fax: +34 91 7287202; e-mail: jr.deandres@igme.es.

Instituto Español de Oceanografía (IEO), c/o Corazón de María 8, Madrid-28002, Spain. Contact (ESPACE project): José Luis Sanz: tel: +34 91 3473733; fax: +34 91 4135597; e-mail: josel.sanz@md.ieo.es.

Resource mapping

Directorate General of Coasts (DGC), Division for the Protection of the Marine Environment, Environment Ministry, Pza San Juan de la Cruz s/n, 28071–Madrid. Contact: José L. Buceta (Technical Advisor): tel: +34 91 5976652; fax: +34 91 5976902; e-mail: JBuceta@mma.es.

Types of seabed maps

Continental margin maps

The Spanish continental margins have been geologically mapped since 1980 (FOMAR Program, scale 1:200 000). The marine sheets are edited by the IGME in the series "Geological mapping of the Spanish continental margin and adjacent zones, scale 1:200 000". Each marine sheet contains the following seabed information: morphostructural map (scale 1:200 000), geological map (scale 1:200 000), two sedimentological maps (scale 1:400 000, textural distribution of surface sediments, texture/carbonate ratio of surface sediments). They also include an explanatory document (in Spanish) with addenda maps, such as sampling/coring sites and geophysical tracks.

The marine sheets can be ordered from the IGME. For contact information, see the section National organizations responsible for seabed mapping, above.

Published maps

Seven maps of the Western Mediterranean Sea and one from Cadiz (Atlantic Ocean) have been published.

EEZ maps

Oceanographic investigation of the Spanish Exclusive Economic Zone (EEZ) began in 1995. Data collection surveys are carried out by several institutions: the Navy Hydrographic Institute (IHM), the Royal Institute and Observatory of the Navy (ROA), the IEO, and the IGME. The areas along the Atlantic Ocean covered to date include the Canary Islands (Atlantic Ocean) and Galicia (northwest Spain, Atlantic Ocean). The survey equipment used includes multibeam sounders, parametric sounder, 3.5 kHz marine gravimeter, and proton magnetometer. To date, 26 maps have been published, including bathymetric and geomagnetic charts (edited and published by IEO and IHM), as well as free-air and Bouguer anomaly maps (edited and published by ROA).

The EEZ data can be ordered from the IEO, Avenida de Brasil 31, Madrid-28020. Published data can be obtained from the IGME. For contact information, see the section National organizations responsible for seabed mapping, above.

Seabed information prior to 1980

Before 1980, several seabed sedimentological studies were completed, but marine geological mapping was not the target. There are no published maps.

Mapping programmes

Sand and gravel resources mapping

Marine sand and gravel deposits within Spanish territorial waters have not been commercially exploited, and very little information is available. Only local uses of shallow sand/gravel deposits are documented.

Nevertheless, the Spanish Ministry of Environment, the agency responsible for integrated coastal-zone management, uses marine sand deposits for beach nourishment as a strategy for achieving conservation and sustainable multiple use of the coastal zones, thus increasing the tourism potential of such zones. Specialized shallow-water (less than 40 m depth) prospecting for sand deposits is carried out by private consulting companies contracted to the Ministry, which has an annual budget to plan and execute survey programmes. Resource mapping is not a priority for the IGME. Available marine sheets offer two sedimentological maps (scale 1:400 000), which include the general distribution of surface sediments along the continental shelf and part of the upper slope. The grid of sampling stations is rather sparse as it covers the entire shelf area, so the sand and gravel zones are only roughly delimited.

Although reconnaissance mapping and exploitation are carried out under the auspices of the Ministry of Environment, no information is published directly. Information can be requested from the IGME.

From the late 1980s to 1994, the DGC carried out a comprehensive geophysical survey, covering depths of 10–40 m around the Spanish coast. The main objective of this research was to locate and assess sand resources in marine reservoirs that were capable of being exploited by means of the conventional dredging equipment existing at that time and used for beach nourishment. The areas investigated were along the North Atlantic coast of Spain (Figure 3.2.18), and the south coast of Spain (Figure 3.2.19; only Huelva and Cadiz provinces are included in the OSPAR–ICES Area). The areas investigated in the Canary Islands (included in the ICES Area, but not within the scope of OSPAR) are shown in Figure 3.2.20.

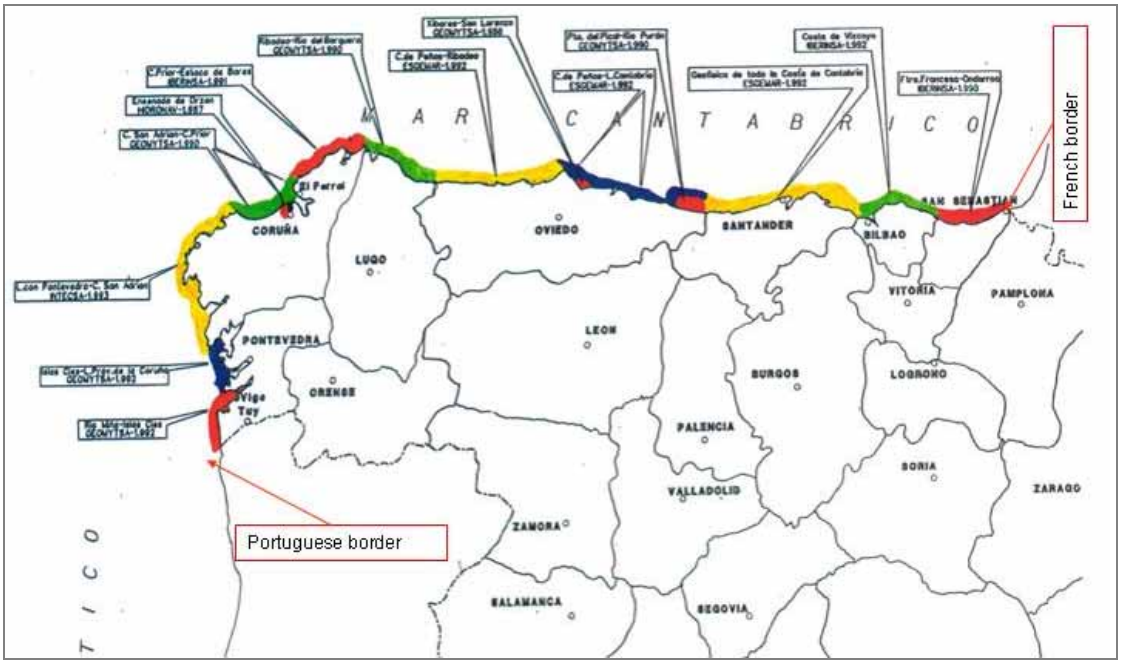

Figure 3.2.18. Map showing the different areas mapped with respect to sand and gravel resources along the North Atlantic Spanish coast.

In the first phase, the work consisted of charting bathymetric and seismic profiles, and gathering and analysing surface sediment samples from the seabed. In this way, information has been collected about the thickness and physical characteristics of non-consolidated sediment layers.

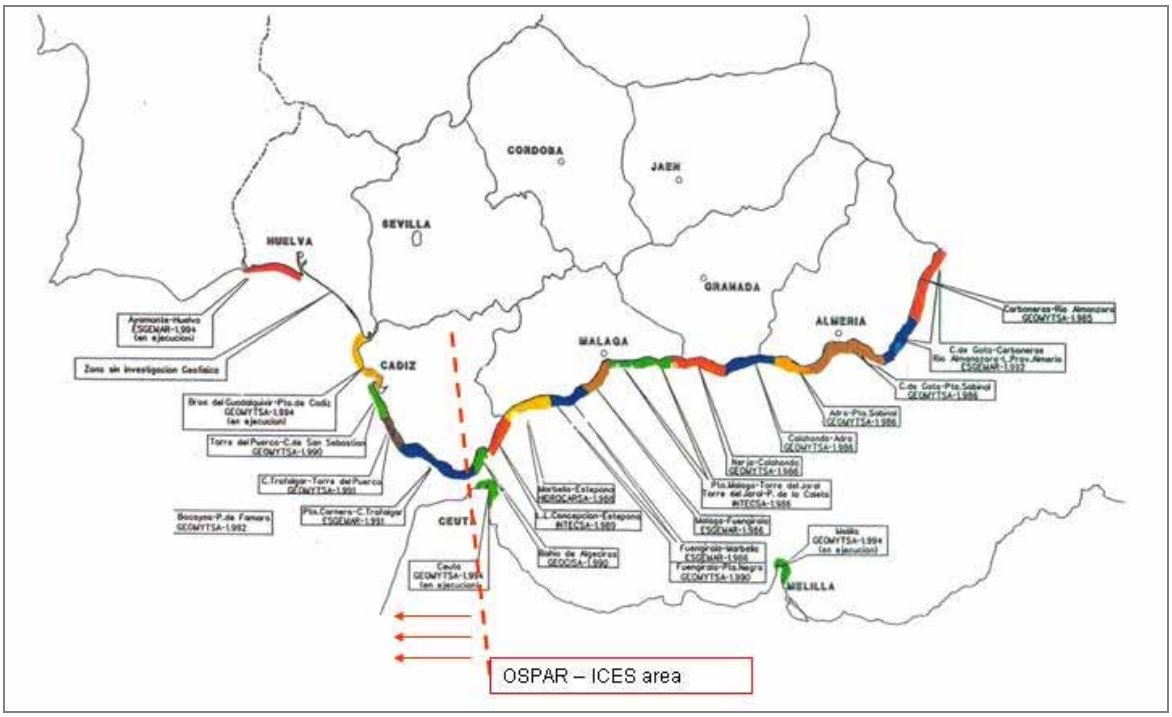

Figure 3.2.19. Map showing the areas mapped with respect to sand and gravel resources along the south coast of Spain (only Huelva and Cadiz provinces are included in the OSPAR–ICES Area).

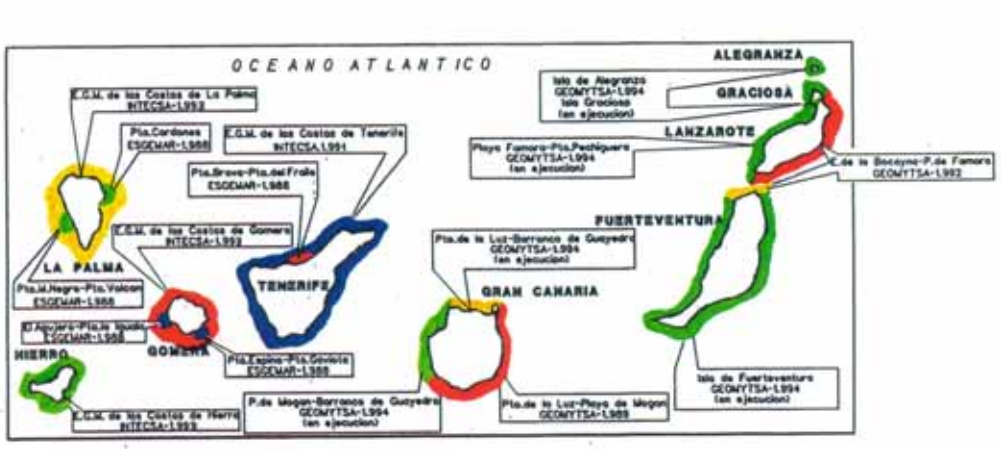

Figure 3.2.20. Map showing the areas mapped with respect to sand and gravel resources in the Canary Islands (included in the ICES Area, but not within the scope of OSPAR).

A second phase was conducted in the most promising areas, and vibrocore samples were collected. Unmodified sediment cores with a length of 6–8 m were extracted, permitting the exact definition of the existing material. Samples were analysed for granulometric and mineralogical characteristics, and for the presence of pollutants (e.g. heavy metals, organic compounds, microbiology) in order to obtain a complete characterization of these sands.

Between 2004 and 2005, this information was digitalized and vectorized and has since been included in a thematic Geographical Information System by the DGC.

Coastal ecocartography

In 2001, the DGC launched a second comprehensive project known as "Coastal Ecocartography" in order to take into account the increasing pressures on the coastal areas, caused primarily by the tourism industry. This work was carried out in order to generate a better understanding of the characteristics of the coastal ecosystems and how they function.

The Ecocartography project started in the Canary Islands and represents a long, continuous process of fieldwork by a large interdisciplinary team. The study takes into consideration all aspects necessary for the complete categorization of the coastal area. The scope of the study is the coastal public domain, including the terrestrial littoral area and the marine environment to a depth of 50 m.

Some of the more notable field tasks are listed below.

- Description of the physical environment, including:
  - bathymetry of the continental shelf using multibeam sounder;
  - topography of beaches and coastal area;
  - coastal dynamics and general circulation of currents;
  - underwater geomorphology using sidescan sonar;
  - colour aerial photography and digital orthophotography of the coastal area.
- Description of the biotic environment, including:
  - bionomic characterization using video transects, direct inspections by scientific diving, and taxonomy determinations of sediment samples;

- detailed study and description of coastal biological communities, both marine and terrestrial;
- landscape characterization.

Fieldwork results were analysed before being compiled into a GIS designed to allow queries, analyses, and diagnoses combining all the themes considered in the physical and biological studies. Examples of the presentation of information retrieved from these geophysical investigations are shown in Figure 3.2.21.

All of the Canary Islands have been mapped to date. The work on Gran Canaria and Lanzarote, followed by La Palma, was completed in 2005. The regional government then completed a similar initiative for Tenerife Island. Lastly, work on the remaining Canary Islands (El Hierro, La Gomera, and Fuerteventura) was finished in 2006. New ecocartography projects are currently underway in the Mediterranean (Málaga).

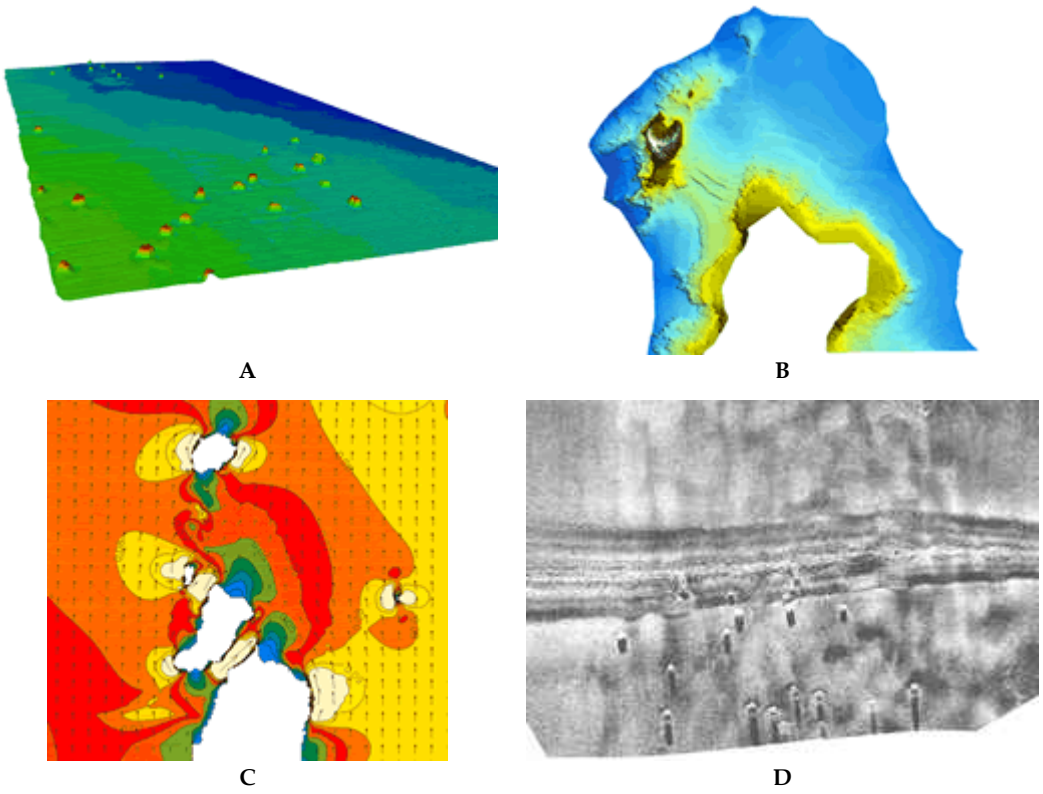

Figure 3.2.21. Various types of thematic information retrieved from the Coastal Ecocartography project. A. Detailed bathymetry; artificial reefs; multibeam sound. B. General bathymetry of the seabed; multibeam sound. C. Measurement of currents and tides; modelling of currents. D. Geomorphology of the seabed; sidescan sonar.

ESPACE project

The ESPACE (Study of the Spanish Continental Shelf) project started in 1999 with the aim of obtaining detailed and quality information about bathymetry (according to the International Hydrographic Organization parameters) and a comprehensive cartography of the seabed. The latter includes information about benthic bionomy and seabed quality and morphology (e.g. rocks, granulometric distribution, seagrass or algae meadows, obstacles), which is obtained through high-resolution geophysical techniques, such as multibeam sounder (EM 3000) and parametric sounder (TOPAS PS 40), complemented by ground-truthing techniques (Shipeck and van Veen grabs, photo, and underwater TV). The project is an initiative of the Spanish General Fisher-

ies Secretariat, Ministry of Agriculture and Fisheries, under the scientific direction of the IEO.

The ESPACE project has defined methodologies and work standards in order to obtain results that are comparable in time and space:

> **Organization of data and information into basic information units (BIUs)**. A BIU consists of 1′ of latitude per 1′ of longitude. Each BIU is identified by the coordinates of the lower left corner.
>
> **Standards for data acquisition**. *Geophysical survey*: multibeam data acquisition with coverage overlapping in the order of 10 %; TOPAS profiles ("Chirp" mode) parallel with the coast at 1.5–2 km intervals and perpendicular to the coast at 4 km intervals.
>
> *Sampling survey*: sediment samples at intervals of about 5 km^2; submarine photo and videotape transects perpendicular to the coast at intervals of 5–8 km and from a depth of 25 m to the coast.
>
> **Standards for data processing**. Each BUI is processed separately. The results are bathymetry (from grids of 5 m × 5 m cell size) and backscatter. The results are incorporated into a GIS.

The project, which is carried out by a multidisciplinary cartographic team, consists of an annual campaign to classify the bathymetric and physical and biological characteristics of the seabed of a certain area from the coastline to the continental shelf border at ca. 100–200 m depth. The Spanish coast has been divided into 186 map sheets at a scale of 1:50 000. This cartographic series also shows the characteristics of Quaternary deposits on land. The system of reference is WGS84 and projection UTM. Each sheet presents three series:

- **Series A**. Descriptive of the marine environment (scale 1:50 000; Figure 3.2.22):
  - **Marine areas**. bathymetry (2 m equidistant isobaths); textural classification of seabed and seagrass meadows.
  - **On land**. topographic contours at 100 m intervals; Quaternary deposits classified by sedimentary environment, beaches, rivers, administrative limits, lighthouses, highways, and urban nuclei.
- **Series B**. Management of the marine environment (scale 1:50 000):
  - **Marine areas**. bathymetry (5 m isobaths), aggregated textural classification of seabed, main scarps, seagrass meadow classification, fishing areas, marine reserves, community interest sites, artificial reefs, baselines, anthropogenic elements (pipelines, cables, others), and charts signals of navigation traffic.
  - **On land**. topographic contours at 100 m intervals; Quaternary deposits classified by lithology, beaches, rivers, highway, and urban nucleus.
- **Serial C**. Models and geomorphology (three maps, scale 1:100 000; Figure 3.2.23):
  - Marine geomorphology, model of illumination or 2.5-dimensional, slopes map and four figures of three-dimensional view (land and sea).

Each year, six to eight sheets are completed, which is the equivalent of a medium-size province. Until now, mapping has been completed for the southern Mediterranean coast, and cartography in the ICES Area has started in the Canary Islands

(Hierro Island). After a temporary halt, caused by administrative problems, the project was resumed in 2006 along the north coast of Spain. Examples of thematic maps are given in Figures 31 and 32.

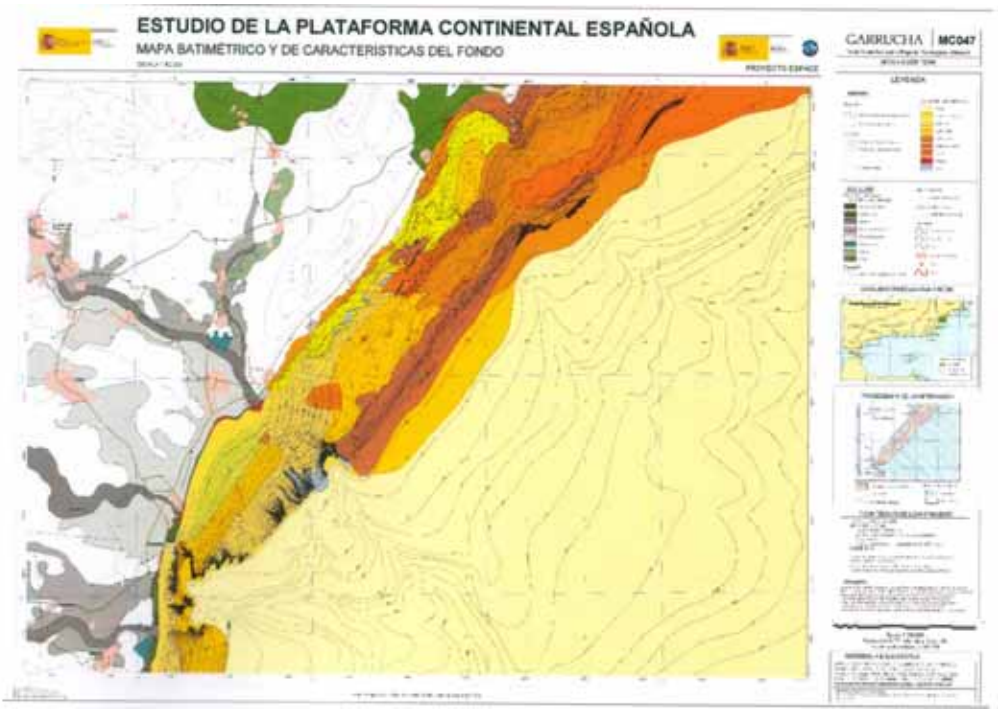

Figure 3.2.22. Example of thematic maps (Series A) produced within the framework of the ESPACE (Study of the Spanish Continental Shelf) project.

This cartography is intended to allow better coastal and marine management, and to facilitate decision-making regarding the exploitation/conservation of living marine resources, designation of marine reserves, marine sediment extraction, location of artificial reefs and other infrastructure, the conservation of species and habitats and cultural heritage.

The marine sheets can be ordered from the IEO, Departamento de Publicaciones, Avenida de Brasil 31, Madrid-28020. Contact: José Luis Sanz: tel: +34 91 3473733; fax: +34 91 4135597; e-mail: josel.sanz@md.ieo.es.

Published maps include nine sheets (each of the Western Mediterranean Sea). A further 19 maps (Mediterranean Sea) are being processed.

Details (in Spanish) of the ESPACE project as well as edited sheets are available online at:

http://www.ieo.es/ESPACE/proyectoESPACE.htm.

Other mapping programmes

Some Autonomous Communities have also developed seabed cartographies within their jurisdictions (e.g. País Vasco, Andalucía, and Canarias).

The work being carried out in País Vasco is similar to the Coastal Ecocartography project and is enclosed within a project of the Autonomous Government developed by the AZTI Foundation. In this project, a comprehensive study of the seabed characteristics at depths between 0 and 100 m began in 2005 and was concluded in 2007. Multibeam sidescan sonar and high-definition seismic surveys were undertaken. In

2005, 40 % of the seabed area was surveyed with multibeam at water depths between 0 and 50 m , together with ground-truthing techniques (sediment samples, video and photo images, and scuba-diving inspections). Benthic populations and the presence of organic and inorganic pollutants were also analysed. Orthophotography and LiDAR topographic data were used to characterize the coastal interface and intertidal region.

Figure 3.2.23. Example of thematic maps (Series C) produced within the framework of the ESPACE (Study of the Spanish Continental Shelf) project.

Webmap service

Between 1998 and 2004, the IEO has been gathering and synthesizing information published on Spanish marine areas and incorporating it into a GIS.

A Webmap Service has been operative since June 2007, with information (multisource) on bathymetry, sedimentary textural distribution, rock areas, artificial reefs, marine reserves, marine protected areas (zones proposed by WWF), indicators of habitats, baselines, and other information that is currently being defined.

The next objective is to increase the fields of information and to develop a Webmap Server.

Survey equipment

Geophysical surveys employ monochannel continuous-reflection seismic equipment: sparker, Uniboom, TOPAS, echosounder, multibeam, sidescan sonar systems, 3.5 kHz sub-bottom profiler, marine gravimeter and magnetometer (within the EEZ); airgun and multichannel continuous-reflection seismic equipment are used occasionally.

Sampling surveys typically employ Shipeck grabs, van Veen grabs (or similar), gravity corers, rock corers, vibrocorers, and underwater cameras.

Data holders

Data are held by the Ministry of Environment. For contact information, see Directorate General of Coasts listed in the section National organizations responsible for seabed mapping, above.

National standards

Analyses for IGME are carried out by contracted accredited laboratories.

3.16 Sweden

National organization responsible for seabed mapping

Geological Survey of Sweden (SGU), PO Box 670, SE-751 28 Uppsala, Sweden. Contacts: I. Cato: tel: +46 18 17 90 00; fax: +46 18 17 92 10; e-mail: ingemar.cato@sgu.se or Anders Elhammer: e-mail: anders.elhammer@sgu.se.

Types of seabed maps

Approximately 17% of Swedish territorial waters and Exclusive Economic Zone (EEZ), totalling 156 000 km^2 in area, has been geologically mapped in detail (scale 1:100 000), and 59% has been mapped to a reconnaissance scale (1:500 000) for a total of 76%. An overview map showing the areas mapped is given in Figure 3.2.24. Reconnaissance mapping of the remaining part was finished in 2008.

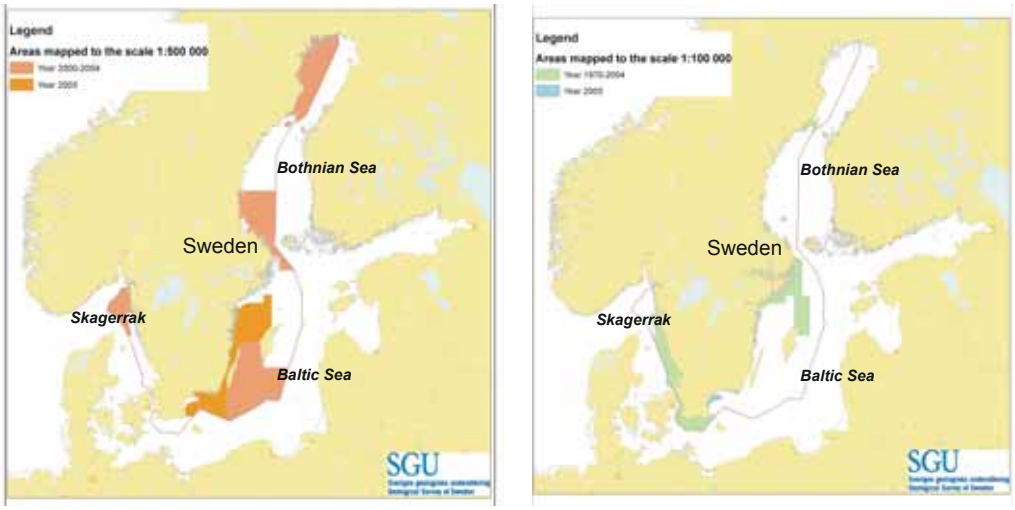

Figure 3.2.24. Map of the Skagerrak and Baltic Sea showing the coverage in 2006 of mapped areas within Swedish territorial waters and the EEZ at scales of 1:500 000 (reconnaissance mapping, left) and 1:100 000 (detailed mapping, right).

Printed maps, with a description and English summary, as well as digital maps and data, can be ordered from the SGU (e-mail: kundservice@sgu.se). For further contact information, see the section National organization responsible for seabed mapping, above.

1:500 000 geological reconnaissance maps/databases

These types of maps/databases contain the same information as the 1:100 000 maps described below. The difference is the lack of total coverage with sidescan sonar, the less-dense grid of runlines (about 10–15 km cc), and fewer sampling/coring stations,

which form the basis of the final map. However, the resolution of data collection along the run lines is the same as for the 1:100 000 maps.

Digital versions of these maps may have any form, format, and content and can be printed on demand/request. All basic information is stored in various databases. The investigations for this type of reconnaissance maps/databases began in 2000 and were completed in 2008.

Published maps (1:500 000)

Maps of this type are currently only available as print-on-demand.

1:100 000 seabed sediments and Quaternary stratigraphy maps/databases

These maps show the distribution of the predominant sediment in the topmost 50 cm of the seabed according to character and genesis. Each map sheet is accompanied by a subsidiary map at the same scale, showing the sediment stratigraphy down to the bedrock surface of selected geological sections from the same area. These two maps are accompanied by a description (separate or on the reverse of the map), including bottom photographs, diagrams, and thematic maps at a scale of 1:250 000. Features shown within the map area include the distribution of pre-Quaternary rocks, till, glaciofluvial deposits, sand volumes, thickness of postglacial and glacial clay, about 60 inorganic elements and about 50 organic micropollutants of environmental interest, land upheaval, sampling/coring sites, tracklines, etc. The maps are projected in Gauss with both the Swedish grid net 2.5°W (1938), and the longitude and latitude system in WGS84 (see example in Figure 3.2.25).

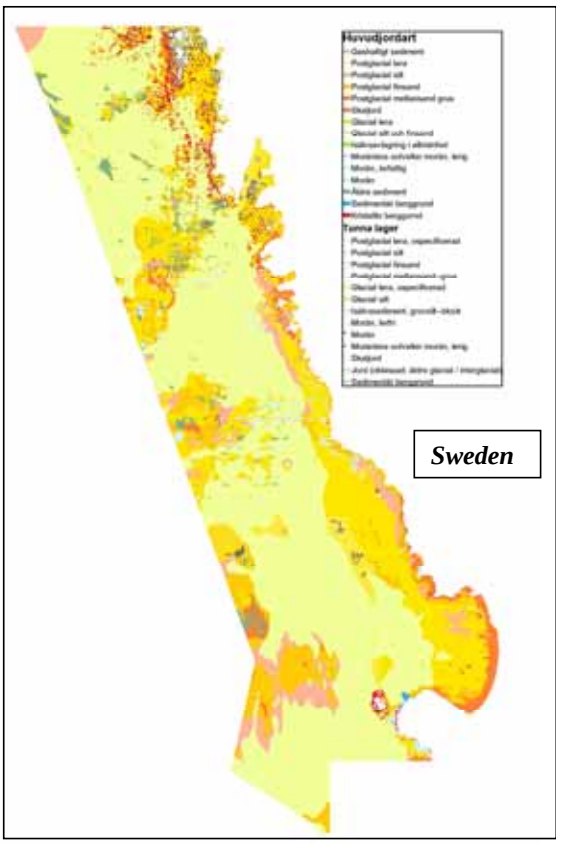

Figure 3.2.25. Example of a Swedish seabed map at a scale of 1:100 000 showing the distribution of various sediments within the Swedish EEZ of the Kattegat.

Since 1996, this kind of mapping has been based on almost full coverage with sidescan sonar (conventional or Chirp type).

Digital versions of these maps may have any form, format, and content and can also be printed on demand/request. All basic information from 1990 onward is stored in various databases. The SGU can be contacted for information and availability.

Published maps (1:100 000)

SGU. 1987. The Marine Geological Map: Gotska Sandön. Scale 1:100 000. Sveriges Geologiska Undersökning Series Am No. 1.

SGU. 1987. The Marine Geological Map: Fårö. Scale 1:100 000. Sveriges Geologiska Undersökning Series Am No. 2.

SGU. 1987. The Marine Geological Map: Kopparstenarna. Scale 1:100 000. Sveriges Geologiska Undersökning Series Am No. 3.

SGU. 1989. The Marine Geological Map: Stora Middelgrund-Halmstad. Scale 1:100 000. Sveriges Geologiska Undersökning Series Am No. 4.

SGU. 1992. The Marine Geological Map: Lilla Middelgrund-Varberg. Scale 1:100 000. Sveriges Geologiska Undersökning Series Am No. 5.

SGU. 1992. Bottom sediments around Denmark and western Sweden. Scale 1:500 000. Sveriges Geologiska Undersökning Series Ba No. 48.

SGU. 1997. The Marine Geological Map: Vinga-Kungsbacka. Scale 1:100 000. Sveriges Geologiska Undersökning Series Am No. 6.

SGU. 1998. Bottom sediment map of the Central Baltic Sea. Scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54.

SGU. 2005. The Marine Geological Map 9I: Landsortdjupet-Nynäshamn. Scale 1:100 000. Seabed sediments. Sveriges Geologiska Undersökning Series K No. 3:1.

SGU. 2005. The Marine Geological Map 9I: Landsortdjupet-Nynäshamn. Scale 1:100 000. Geological sections. Sveriges Geologiska Undersökning Series K No. 3:2.

1:50 000 seabed sediment maps

These maps cover the Swedish part of the Sound area (Öresund) between Denmark and Sweden. The maps are based on a dense grid of sampling, coring, and some shallow seismic and sidescan sonar measurements. The content of the maps is very much the same as the information presented in the 1:100 000 scale maps (see above). The maps of Öresund have also been compiled to 1:100 000 scale (see above), with a new legend.

Detailed information on the aggregate resources within the mapped area is available on request to the SGU. For contact information, see the section National organization responsible for seabed mapping, above.

Published maps (1:50 000)

Hörnsten, Å. 1979. Marine geological map of the Sound. Scale 1:50 000. Sveriges Geologiska Undersökning Rapporter och Meddelanden No. 13. (Five maps.)

Other types of marine geological maps and information

An outline map of the solid geology of Swedish territorial waters and EEZ at a scale of 1:1 000 000 was published in 1986 (Ahlberg, 1986; see below). In cooperation with the National Forest and Nature Agency of Denmark (NFNA) and the Geological Sur-

veys of Denmark and Greenland (GEUS), a map at scale 1:500 000 showing the bottom sediments around Denmark and western Sweden was published in 1992 (Kuijpers *et al.*, 1992; see below). 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 (Cato *et al.*, 1992; see below) and 1994 (Cato and Kjellin, 1994; see below).

Within the framework of a joint Lithuanian–Swedish project (GEOBALT), two maps at a scale of 1:500 000, showing the bathymetry (Gelumbauskaité, 1998; see below) and the seabed sediments (Repecka and Cato, 1998; see below) of the central Baltic Sea respectively, were published in 1998, accompanied by a subsidiary description (Gelumbauskaité *et al.*, 1999; see below). The maps are also available on a CD-ROM version.

Published maps and information

Ahlberg, P. 1986. Den svenska kontinentalsockelns berggrund. Scale 1:1 000 000. Sveriges Geologiska Undersökning Rapporter och Meddelanden No. 47. 100 pp. (Map + description).

Cato, I., and Kjellin, B. 1992. Mineral resources. *In* Sea and Coast, pp. 120–121. Ed. by B. Sjöberg. National Atlas of Sweden, Bd. 7. Bokförlaget Bra Böcker.

Cato, I., and Kjellin, B. 1994. Quaternary deposits on the seabed. *In* Geology, pp. 150–153. Ed. by C. Fredén. National Atlas of Sweden, Bd. 12. Bokförlaget Bra Böcker.

Cato, I., Kjellin, B., and Nordberg, K., 1992. Bottoms and sediments. *In* Sea and Coast, pp. 16–25. Ed. by B. Sjöberg. National Atlas of Sweden, Bd. 7. Bokförlaget Bra Böcker.

Gelumbauskaite, L-Z. (Ed). 1998. Bathymetric map of the Central Baltic Sea. Scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54. Vilnius-Uppsala.

Gelumbauskaité, L-Z., Grigelis, A., Cato, I., Repecka, M., and Kjellin, B. (Eds). 1999. Bottom topography and sediment maps of the central Baltic Sea. A short description. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Undersökning Series Ba No. 54. 24 pp.

Kuijpers, A., Nielsen, P-E., Larsen, B., Cato, I., Kjellin, B., Jensen, J. B., Leth, J. O., *et al.* 1992. Bottom sediments around Denmark and Western Sweden. Scale 1:500 000. Sveriges Geologiska Udersökning Series Ba No. 48.

Repecka, M., and Cato, I. (Eds). 1998. Bottom sedimentary map of the Central Baltic Sea. Scale 1:500 000. LGT Series of Marine Geological Maps No. 1. Sveriges Geologiska Udersökning Series Ba No. 54.

Known and assumed marine sand and gravel resources in Sweden

The most important known mineral resources on the Swedish continental shelf or EEZ are the sand and gravel deposits. Until now, these are the only non-living natural resources that have been exploited commercially in Swedish waters. Exploitation has been undertaken on a small scale and has been concentrated in certain areas in the Kattegat, the Sound, east of Fårö Island (northern Gotland), and in the Luleå Archipelago.

Marine sand extraction totalled approximately 70 000 m^3, or about 100 000 t $year^{-1}$, which represents 1% of the total extraction in Sweden during the period 1998-2004. Sand and gravel of poorer quality were used as fill material, whereas deposits of high quality (e.g. with high silica content and low iron content) were used for the manufacture of cement, glass and glassfibre, and within the ceramics industry.

Recently, an overview of the marine sand and gravel deposits within Swedish territorial waters and EEZ was published (Cato, 2004). The paper presents estimated volumes of investigated resources and a historical record of sand and gravel extraction in marine areas of Sweden.

Survey equipment

The SGU operates a twin-hull, sandwich-constructed survey vessel, SV "Ocean Surveyor", of 514 grt, 38 m length, and 12 m width. The vessel has six winches, an A-frame; moonpool, sediment laboratory equipped with an X-ray sediment scanner (ITRAX) and a gamma-spectrograph; and a special survey room for data collecting and processing. The vessel is also equipped with a dynamic positioning system (DP); a hydroacoustic positioning reference system (HPR); satellite navigator; differential global positioning system (D-GPS); Syledis positioning system, including survey computers; sector scanning sonar; and Doppler log.

Geological information is collected using shallow seismic systems (boomer, sparker, sleevegun), sidescan sonar systems (50 kHz, 100 kHz, 500 kHz, and 100/500 kHz Chirp), 3.5/7 kHz and 8 kHz Chirp pingers, echosounders, and CTD-sonde, and various corers and sampling devices: vibro-hammer corer (6 m); piston corer (3 m/6 m); Gemini corer (1 m); gravity corers (1 m/0.4 m), including subsampling devices; grabs (OPB); boxcorer (0.6 m); underwater camera; and radiometer.

Data holders

Data are held by the SGU. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

Analyses for SGU are carried out by contracted accredited laboratories.

3.17 United Kingdom

National organization responsible for seabed mapping

British Geological Survey (BGS), Marine, Coastal and Hydrocarbons Programme, Murchison House, West Mains Road, Edinburgh, EH9 3LA, Scotland, UK. Contact: Robert Gatliff: tel: +44 131 667 1000; fax: +44 131 668 4140; e-mail: rwga@bgs.ac.uk; website: http://www.bgs.ac.uk.

Types of seabed maps

1:250 000 maps

The BGS has mapped most of the UK continental shelf and deep-water areas west of the UK. During the 1970s and 1980s, a regional mapping programme led to the production of a series of 1:250 000 scale maps of seabed sediments, Quaternary geology, and solid geology. An overview of the areas mapped is shown in Figure 3.2.26. Since the end of the regional programme, BGS has continued to map areas of the UK seabed, both independently and in collaboration with other organizations, including the oil and gas industries. Some map sheets have been revised, based on new data. The 1:250 000 series maps and 1:1 million compilations are available as paper copies. Digital maps of seabed sediments (DigSBS250) and bathymetric data (DigBath250) are available. BGS products can be purchased online at http://www.bgs.ac.uk/Shopping/home.html, or by writing to the BGS Central Enquir-

ies Desk, British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham, NG12 5GG, UK: tel: +44 115 936 3143; fax: +44 115 936 3276; e-mail: Enquiries@bgs.ac.uk.

The BGS marine programme was reorganized in April 2005 to merge with the coastal and hydrocarbon resources activities within the organization. The new Marine, Coastal, and Hydrocarbons Programme will focus on the completion of unmapped areas of the UK seabed and offshore data acquisition using sub-bottom seismic profiling, sidescan sonar, and sampling/coring, as well as multibeam echosounder data.

Other types of marine geological maps and information

The BGS holds a wide range of offshore geological data, both in databases and in the BGS Offshore GIS. These include palaeontological, geotechnical, aeromagnetic, gravity, and geochemical data. For example, the BGS holds geochemical data for approximately 9000 seabed samples; analytical data for up to 38 elements are included in the database and have been interpreted in an offshore geochemical atlas.

Known and assumed marine sand and gravel resources in the UK

Marine aggregates contribute 21% of the sand and gravel needs of England and Wales, including 33% of southeast England's sand and gravel requirements and 90% of the sand needed in south Wales. The industry employs 2500 people on British-registered vessels and on land. Extraction of marine aggregates affects less than 1% of the UK seabed (0.8%); most extraction takes place between 10 m and 35 m water depth. Since 1955, a total of ca. 500 million t of aggregates has been dredged from the seabed.

The Crown Estate owns the mineral rights to the seabed around the UK, and issues commercial licences to explore and extract sand and gravel. However, an exploration licence is only issued if permission to dredge is given by the Department of Environment, Transport and the Regions (DETR) in England, the National Assembly for Wales, or the Scottish Parliament. The British Marine Aggregate Producers Association (BMAPA) is one of the constituent bodies of the Quarry Products Association, the trade association for the aggregate, asphalt, and ready-mixed concrete industries in the UK.

Contacts

The Crown Estate, 16 Carlton House Terrace, London, SW1Y 5AH, UK: tel: +44 020 7210 4377; fax: +44 020 7930 8187; http://www.thecrownestate.co.uk/home.htm.

British Marine Aggregate Producers Association, Gillingham House, 38–44 Gillingham Street, London SW1V 1HU, UK: tel: +44 020 7963 8000; fax: +44 020 7963 8001; e-mail: bmapa@qpa.org; website: http://www.bmapa.org/.

Survey equipment

Regional surveys of the UK seabed acquired geological data using a range of shallow seismic systems (deep-tow and surface-tow boomer, sparker, airgun, watergun) sidescan sonar systems, pingers, and echosounders. Samples and cores were collected mainly using Shipeck grabs, gravity cores, vibrocores, and rock drills, as well as boreholes acquired by wireline drilling. Underwater videos were used from submersibles in a few locations.

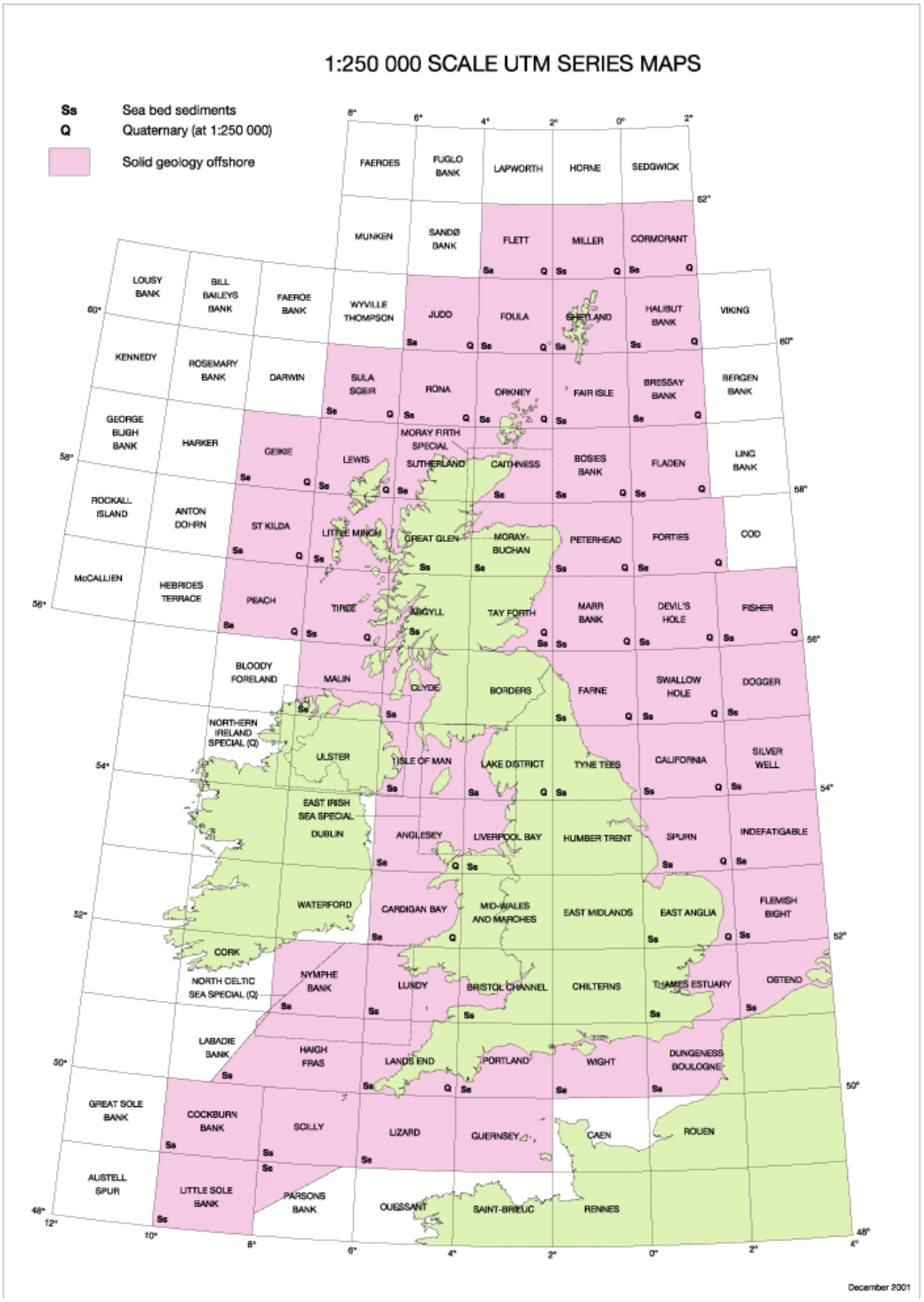

Figure 3.2.26. BGS-published maps of offshore geology at 1:250 000 scale.

The BGS does not own any research vessels; however, as a component body of the Natural Environment Research Council (NERC), the survey has access to the NERC research fleet. Details of the NERC ships are available online at http://www.researchshipunit.com/.

3.18 United States

National organization responsible for seabed mapping

United States Geological Survey (USGS), Coastal and Marine Geology Program, Woods Hole Science Center, 384 Woods Hole Road, Quissett Campus, Woods Hole, MA 02543–1598, USA. Contact: Nancy Soderberg (archivist): tel: +1 508 548 8700 or 508 457 2200; e-mail: nsoderberg@usgs.gov.

The USGS Woods Hole Science Center's Information Archives is responsible for maintaining and updating inventories of all pertinent data and other information. Examples of such information include cruise data, map collections, publications, and the Gosnold Reading Room Periodicals.

Types of seabed maps

In the ICES Area of the northeast coast of the US, recent mapping products of the USGS Coastal and Marine Geology Program include bathymetry, sediment type, sonar mosaics, and some core and sub-bottom data (as specified below).

In addition, a complete collection of maps, fact sheets, Open File reports, abstracts, and other publications relating to the research of the USGS, Woods Hole, MA, from 1962 to the present, are available online.

These marine maps are available online at:

http://coastalmap.marine.usgs.gov/regional/contusa/eastcoast/index.html.

The entire USGS publication list may be found at:

http://woodshole.er.usgs.gov/operations/ia/index.html

or by contacting Donna Newman (e-mail: dnewman@usgs.gov) at the USGS, Woods Hole Science Center.

Published map products

These products are available online and accessible at variable scales. The site's interactive ArcIMS map server displays a variety of data layers.

US SEABED: Atlantic Coast offshore surficial sediment data

The database includes information about seabed sediment texture, composition, and colour; biota and biological effects on the seabed; rocky areas and seabed hardness; seabed features, such as ripples; seabed acoustic properties; sediment geochemical analyses; and sediment geotechnical analyses. The map of data distribution and database is available online at http://coastalmap.marine.usgs.gov/ArcIms/website/usa/eastcoast/ecst_usseabed_2005/viewer.htm.

A subset of these data for the Gulf of Maine, available online at http://coastalmap.marine.usgs.gov/ArcIMS/website/usa/eastcoast/gome/overview/viewer.htm, provides an overview of USGS research activities and GIS data compiled from various sources for the Gulf of Maine. Data layers include surficial samples and bathymetry contours.

The US Atlantic east coast site, available online at http://coastalmap.marine.usgs.gov/ArcIms/website/usa/eastcoast/atlanticcoast/viewer.htm, is an interactive mapping site that includes an index to 21 GLORIA sidescan sonar mosaics collected and processed by the USGS in 1987. Additional data layers contain coastal vulnerability index to future sea-level rise, bottom photographs, surficial samples, and sedimentary environment for the entire East coast.

Regional data off the coast of Massachusetts (Cape Cod and Massachusetts Bay) is available online at http://coastalmap.marine.usgs.gov/ArcIMS/website/usa/eastcoast/gome/cape_cod/viewer.htm. As described on-site:

> This mapping site combines data from a number of individual publications that include high-resolution mapping of the seabed off Massachusetts, coastal vulnerability of the National Seashore Park, and bedrock cores acquired from recent drilling in western Cape Cod. The highlights of the map server include well-site information that provides links to the bedrock photograph locations and attribute of cores collected from recent drilling in western Cape Cod, Massachusetts, and location and links to seabed bottom photographs acquired from various field activities surrounding the area. Additional data layers include a geologic interpretation of Cape Cod and the Islands (Martha's Vineyard and Nantucket), town boundaries, village names, and roads.

Mapping of the continental shelf seaward of the New York–New Jersey Metropolitan Area, which includes the New York Bight and southern Long Island coast, is presented as a regional synthesis of the seabed geomorphology; seabed sedimentary lithotypes, the occurrence of Cretaceous strata and Quaternary deposits; and the region's geological history. Data include surficial samples and a sidescan sonar mosaic. Links are provided to directly examine the seismic records. An example is shown in Figure 3.2.27. These data are available online at http://coastalmap.marine.usgs.gov/ArcIMS/website/usa/eastcoast/midatl/ny_bight/viewer.htm.

Data maps specifically from Long Island Sound (New York and Connecticut) are available online at http://coastalmap.marine.usgs.gov/ArcIms/website/usa/eastcoast/mid-atl/lis/viewer.htm.

High-resolution sidescan sonar mosaics, bathymetry contours, and core information are displayed. Links are also provided directly to seismic data profiles and interpreted GIS data layers.

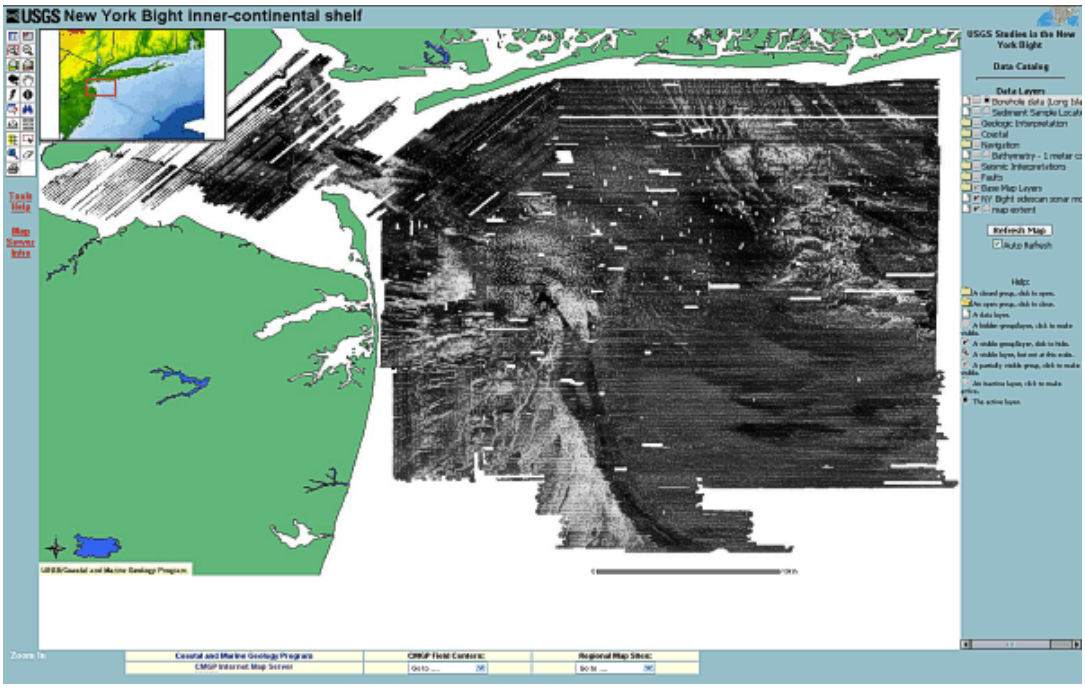

Figure 3.2.27. Sidescan sonar mosaic from the New York Bight.

Other types of information

Physical oceanographic data (current velocity, temperature, pressure, conductivity, and light transmission) from tripods, including beam attenuation, collected for various special projects in the region, are available online at http://stellwagen.er.usgs.gov/.

Data are available in the raw sample interval, hourly averaged, and low-pass filtered. Details can be obtained from Fran Lightsom (e-mail: flightsom@usgs.gov), Woods Hole Science Center, USGS.

Known and assumed marine sand and gravel resources in the northeast US

Glacial sands cover much of the shelf off the northeast US, but the resource is most abundant and most utilized south of Long Island, New York. One commercial aggregate company has been operating there for many years, recovering about 1 million m^3 $year^{-1}$ for use in local construction activity. A comparable, but variable, amount of marine sand is used for beach nourishment.

Survey equipment

A wide variety of equipment has been used in the collection of the data discussed above. These include both single-beam and interferometric sonar, and Chirp subbottom profilers, as well as sparkers, airguns, and boomers. A description of the range of equipment used by the USGS Coastal and Marine Geology Program is available online at http://woodshole.er.usgs.gov/technology.html.

Data holders

Data are held by the USGS, Coastal and Marine Geology Program. For contact information, see the section National organization responsible for seabed mapping, above.

National standards

Procedures and standards used in the generation of these data are reported in "USGS east-coast sediment analysis: Procedures, database and georeferenced displays. US Geological Survey Open-File Report 00–358". This report is available online at http://pubs.usgs.gov/of/2000/of00–358/.

4 Effects of extraction activities on the marine ecosystem

4.1 Introduction

Each year across the ICES Area, ca. 53 million m^3 of sand and gravel are extracted from licensed areas of the seabed as aggregate for the construction industry, to supplement land-based sources, or as a source of material for beach nourishment (Singleton, 2001; see also Section 2). Planning constraints tend to restrict the extraction of sand and gravel (aggregate) from terrestrial sources, and the capacity of seabed resources to satisfy part of the demand for aggregates is being realized. The seabed is also acknowledged as the only viable source of material for beach recharge in coastal defence schemes. Therefore, the exploitation of marine resources is supported in most ICES Member Countries by national and international mineral policies, subject to environmental safeguards (see Section 5). The use of marine resources reduces the pressure to work agriculturally, environmentally, or hydrologically valuable land, and where materials can be landed close to the point of use, the additional benefit of avoiding long-distance overland transport can be realized. However, the benefits of using marine sand and gravel need to be balanced with potential significant environmental impacts.

The scale of marine aggregate extraction activity has increased in recent years (see Section 2). This rise reflects increasing constraints on land-based extraction and the acknowledgement that controlled dredging is sustainable for the foreseeable future. Increasing interest by the general public in the effects of marine sand and gravel extraction on the environment and fisheries has grown in line with this expanded effort. Issues, such as possible conflicts of interest between stakeholders in the resource and the efficacy of remedial measures during and after extraction, are analogous to land-based activities. However, in the marine environment, their resolution is rendered more difficult because of the relative inaccessibility of sites, the general paucity of site-specific data on the structure and functional role of the habitat and biota associated with sand and gravel deposits, and problems in quantifying the performance of local fisheries. Further core drivers for understanding the impacts of marine aggregate extraction exist at the international level. In particular, following the Rio Earth Summit, there has been an increasing tendency to conserve marine biodiversity and (under the EU Habitats Directive) protect marine habitats of whole sea areas, through international management initiatives under OSPAR, HELCOM, and through the developing EU Marine Strategy Directive. OSPAR, HELCOM, and ICES are also promoting transnational cooperation in developing the ecosystem approach to marine management.

Awareness of the impacts of sand and gravel dredging, particularly in relation to the coast, goes back at least a century. However, interest in the environmental impacts of sand and gravel extraction dates back some 50 years and became more significant in the 1960s (see Shelton and Rolfe, 1972; Dickson and Lee, 1972; Millner *et al*., 1977; de Groot, 1979b). Initially, concern focused on the potential impacts on the benthic macrofauna and consequential effects on fish resources and commercial fisheries. This interest has expanded over the years to include most components of the marine ecosystem.

The environmental impacts of dredging have been well documented, with general reviews of the topic provided by de Groot (1979a, 1979b, 1986), ICES (1992, 2001), Newell *et al*. (1998), and van Rijn *et al*. (2005). From these reviews, it is clear that most studies have been concerned with impacts from maintenance dredging and beach

recharging projects. However, there is now a significant body of literature on the environmental impacts of marine sand and gravel extraction on the marine ecosystem.

This section begins with an account of the physical, biological, and chemical effects of marine aggregate extraction. It is followed by a review of a number of case studies that have examined the environmental consequences of marine sand and gravel extraction. It includes studies of both the benthic fauna and fish and shellfish populations. Finally, in addition to providing a summary of past research, this section also identifies state-of-the-art approaches to assessing the impacts of marine aggregate extraction. These are likely to evolve further, in line with the outcome of ongoing research and development (see http://sandpit.wldelft.nl, http://www.marinealsf.org.uk and http://www.azti.es/eumarsand/eumarsand.htm).

4.2 Nature of physical effects

Marine sand and gravel is dredged within ICES Member Countries by means of static suction hopper dredgers, cutter suction dredgers, and, more typically, by trailer suction hopper dredgers. Cutter suction dredgers are only used in shallow water in connection with temporary storage areas. Trailer suction hopper dredgers extract the deposit by backward suction through one or two pipes while the ship is underway, thereby forming shallow linear furrows on the seabed, approximately 1–3 m wide and generally 0.2–0.3 m deep (Kenny and Rees, 1994). The new generation of trailer suction hopper dredgers have a cargo capacity of >30 000 m^3. Repeated dredging by trailer suction hopper dredgers can lower substantially the seabed across a wide area, which is related to the frequency of dredging and level of dredging intensity (Norden Andersen *et al*., 1992).

The most efficient method of sand and gravel extraction is by static suction hopper dredger. This method is employed in areas where the deposit is spatially restricted or locally thick (e.g. Central English Channel and German sector of the North Sea). In such cases, the vessels dredge by anchoring or remaining stationary over the deposit and, by forward suction through a pipe, create deep, crater-like pits or saucer-shaped depressions, typically 4–25 m deep, with slopes of ~5° and up to 200 m in diameter. However, its application is restricted to inshore locations or well-protected offshore areas because such operations are vulnerable to rough weather conditions. Static suction hopper dredging is employed offshore in the UK and Germany for gravel extraction but in some countries, such as Belgium, it is not permitted. New dredging technology is being developed, but is still not fully operational, for example, fluidization and sand-bypassing systems, and the punaise system, a submerged deep suction dredger (van Rijn *et al*., 2005).

4.2.1 Alteration of topography

The length of time that trailer-dredged furrows or depressions, created by static dredging, remain as distinctive features on the seabed depends on the excavated substrate (sand or gravel) and on the ability of tidal currents or wave action to erode crests or transport sediments into them (Millner *et al*., 1977; van der Veer *et al*., 1985; Diesing *et al*., 2006). Observations, largely from studies conducted in sandy gravel sediments, reveal that the morphological behaviour of dredged tracks and pits varies significantly. In an area exposed to long-period waves, dredge tracks 0.3–0.5 m deep, in a gravelly substrate at a depth of 38 m, were found to disappear completely within eight months (van Moorsel, 1993, 1994). In contrast, at an experimental dredged gravel site off Norfolk, UK, in 25 m of water, dredge tracks appeared to have been completely eroded well within three years of the cessation of dredging (Kenny and

Rees, 1994, 1996; Kenny *et al*., 1998). Erosion of dredge tracks in areas of moderate wave exposure and tidal currents have been observed to take from three to more than seven years in gravelly sediments (Limpenny *et al*., 2002; Boyd *et al*., 2003a, 2005; Cooper *et al*., 2005). In the latter case, however, infill resulted mainly from sand in transport.

Typical time-scales for the regeneration of dredge furrows in sandy substrates are in the range of months. For example, sidescan sonar surveys demonstrated that furrows created by trailer suction dredging at 8–10 m of water depth in the Graal–Müritz area in the German Baltic Sea, which was dominated by marine fine-to-medium sands, refilled within months (Diesing *et al*., 2006). A similar finding was obtained after the analysis of multibeam data of trailer dredge tracks in medium sands on Kwintebank in the Belgian North Sea. Furrows in fine sands in water depths between 14 and 21 m in the Tromper Wiek area in the German Baltic Sea, however, are still visible more than ten years after their creation. Indeed, the time-scales required for regeneration in this area have been assessed to be in the order of decades (Diesing *et al*., 2006).

Dredged depressions or pits created by static dredging have also been reported to remain as recognizable seabed features for several years. Dickson and Lee (1972) concluded that, at a location off Hastings in the Eastern English Channel, UK (Shelton and Rolfe, 1972), many years, perhaps decades, would be required for the dredged gravel seabed to revert to its pre-dredging condition. Similarly, extraction pits of 5–50 m in diameter and up to 7 m deep in sandy gravels in the German Baltic Sea do not refill completely, but remain relatively stable for at least several years (Diesing *et al*., 2006).

Van der Veer *et al*. (1985) studied the recovery of several sandpits in the estuarine Dutch Wadden Sea. Sand extraction took place in areas with very different hydrographic regimes, namely on tidal flats and in shallow and deep tidal channels with low and high tidal current velocities, respectively. The time taken for infilling of the sandpits below the low-water mark in the tidal streams varied between one and three years, whereas infilling of pits on the tidal flats took more than 15 years.

In summary, the rate of infill of pits varies in relation to water depth, from rapid (a matter of months) in shallow water to very slow (decades) in deeper water. In some cases, pits have been observed to migrate slowly in the direction of the dominant current. Hoogewoning and Boers (2001) and Boers (2005a) reviewed the morphological behaviour of different pits, trenches, and channels excavated in sandy sediments on the Dutch continental shelf. The morphological behaviour of sandpits has also been intensively investigated through process-oriented modelling (van Rijn *et al*., 2005). Such reviews have found that the sedimentation of material in extraction pits depends on a number of factors:

- sediment transport (mud, silt, and sand) carried by the approaching flow to the pit, which depends on flow rate as well as wave and sediment properties;
- the trapping efficiency of the pit, which depends on pit dimensions, orientation, and sediment characteristics.

Further detailed information on the rates of sedimentation and behaviour of sandpits can be found in Boers (2005a), van Rijn *et al*. (2005), and Roos (2004).

4.2.2 Impact on the hydrodynamics

Before beginning marine sand and gravel extraction, potential changes in local waves and current patterns that may result from the dredging operations are usually assessed. Changes in wave heights and current direction after dredging can result in localized changes in erosional and depositional patterns (nearfield effects), and possibly even in shoreline changes (farfield effects), as a result of alterations to alongshore transport rates close to the coast. This was the subject of a four-year study in the US and a four-year European study (SANDPIT), and is, therefore, only briefly considered here (see van Rijn *et al*., 2005). Typically, assessments involve numerical modelling studies of waves, tide-induced and wind-induced currents, sediment transport patterns, and related morphological changes in the local area near the extraction site, as well as consideration of the potential impact of dredging on the shoreline (van Rijn *et al*., 2005).

Van Rijn *et al*. (2005) demonstrated that, for dredged sandpits, changes to the local current pattern depend on:

- pit dimensions (length, width, depth);
- angle between the main pit axis and the direction of the approaching current;
- strength of the local current;
- bathymetry of the local area (shoals around pit).

It was also found that, in general and in relative terms, the dimensions of dredged pits are so small that the deepened area has little influence on the macroscale current pattern. Furthermore, it was concluded that, in most cases, the current pattern would only be changed in the direct vicinity of the dredged area.

4.2.3 Substrate alteration

The removal of a significant thickness of sediment by trailer or static suction dredging can cause a localized drop in current strength associated with the increase in water depth. This reduced strength of the bottom currents can cause the deposition of fine sediments within the dredged depressions. Certain dredging practices can also contribute to the fining or coarsening of sediments over time. For example, the aggregate extraction industry in the UK and Germany carries out screening activities in order to meet the specific sand and gravel requirements of the construction industry (Krause, 2002). Vessels are equipped with either static screen boxes or screening towers, and the composition of the dredged aggregate is altered by passing the water and aggregate mix over a mesh screen. Assuming that the intention is to increase the gravel content, a proportion of the finer material and water will pass through the screen and be returned to the sea by means of a reject chute. Hitchcock and Drucker (1996) and Newell *et al*. (1998) estimated that, during a typical loading of a dredged cargo at some extraction areas in the UK, up to 1.6–1.7 times the total cargo is discharged into the surrounding water column as a consequence of the screening process. Clearly, estimates such as these are site-specific and will vary in relation to the grain size of seabed sediments, the grading required for the cargo, and the efficiency of the dredger. Over time, the progressive removal of the original sandy gravel or coarse sands, and their replacement by finer sandier sediment fractions through screening activities, may result in a gradual fining of the sediment within the extraction areas. However, in some instances, this increase in fine sand may be temporary because of the reworking capabilities of tides and waves.

Changes in sediment composition as a result of dredging are well documented (Dickson and Lee, 1972; Shelton and Rolfe, 1972; Kaplan *et al*., 1975; van der Veer *et al*., 1985; Kenny and Rees, 1994, 1996; Kenny *et al*., 1998; Desprez, 2000; Boyd *et al*., 2003b, 2005). Such changes range from minor alterations to the surficial granulometry (McCauley *et al*., 1977; Pointer and Kennedy, 1984) to an increase in the proportion of sands (Desprez, 2000; van Dalfsen *et al*., 2000; Boyd *et al*., 2005) or silt (van der Veer *et al*., 1985; Byrnes *et al*., 2004a), or to an increase in gravel as a result of the exposure of coarser sediments (Kenny *et al*., 1998). As infill of dredged depressions or tracks depends typically on the mobilization of fine sediments by tidal currents, this can result in a change in sediment composition from coarse sands and gravels to gravelly sands (van der Veer *et al*., 1985; Boyd *et al*., 2005). For example, sandy material discharged by dredgers in the Tromper Wiek area in the Baltic Sea is frequently remobilized, especially during late winter and early spring, and contributes to the refilling of dredged gravel pits (Klein, 2003; Diesing *et al*., *2006*). In contrast, silty material, consisting of 63% fines, infills sandpits on the tidal flats of the estuarine Dutch Wadden Sea (van der Veer *et al*., 1985). Long-term consequences of sediment extraction caused by alteration of substrate have been observed in relatively steep bathymetric depressions on account of an increase in silt and clay following dredging (Byrnes *et al*., 2004a). Similarly, silty material settling in a deep depression associated with a borrow site located 3.6 km offshore of Coney Island, New York, resulted in an alteration of an infaunal assemblage, which has persisted for nearly a decade (Byrnes *et al*., 2004a).

4.2.4 Impacts on the coast

Extraction of sediment from offshore borrow sites can result in modifications to physical processes at and adjacent to the extraction site and in the nearshore zone. The rate of extraction and total quantity of material removed is particularly relevant to the physical impact on the coastline of marine aggregate dredging (Byrnes *et al*., 2004b). At present, the impacts of deep extraction pits on the coast can only be roughly estimated from the available data gathered from existing extraction pits in the coastal waters of the US, Japan, the UK, and the Netherlands (van Rijn *et al*., 2005). Again, this topic has been the subject of an extensive review by van Rijn *et al*. (2005) and is, therefore, only briefly considered here.

Four zones are distinguished in relation to their location on the shoreface, and the impact of a pit in each zone is summarized below.

1) **Pit located at the foot of the beachface (−2 to −5 m depth contour)**. Inexpensive method of sediment removal off sheltered coasts (mild wave regimes; small littoral drift); infill from beachside and from seaside (annual infill rate is not more than ca. 3% of initial pit volume; infill rates are between 5 and 15 $m^3 m^{-1}$ $year^{-1}$, depending on wave climate; time-scale for refilling is 20–30 years); local recirculation of sand; no new extraction sand is added to beach system in case the extracted sand is used for beach replenishment.
2) **Pit located in the upper shoreface zone (−5 to −15 m depth contour)**. Relatively strong impact on inshore wave climate as a result of modified refraction and diffraction effects; relatively strong modification of gradients of littoral drift in lee of pit, resulting in significant shoreline changes (growth of beach salients); relatively rapid infill of extraction pit with sediments from landside (beach zone); annual infill rates up to 20% of initial pit volume in shallow water (filling time-scale is 5–10 years); local recirculation

of sediment; no new extraction sand is added to nearshore system in case the extracted sand is used for beach replenishment.

3) **Pit in middle shoreface zone (–15 to –25 m depth contour)**. Negligible impact on nearshore wave climate; negligible effect on nearshore littoral drift; no measurable shoreline changes; new extraction sand is added to nearshore morphological system (in cases of nourishment); infill of extraction pit is mainly from landside, with sediments eroded from upper shoreface by near-bed offshore-directed currents during storm events; annual infill rate is about 1% of initial pit volume (filling time-scale is 100 years); trapping of fine sediments in pits (negative ecological effect); particle-tracer studies show small but measurable transport rates, mainly ascribable to storm waves; long-term deficit of sand for upper shoreface.

4) **Pit in lower shoreface zone (below –25 m depth contour)**. No impact on nearshore wave climate; no effect on nearshore littoral drift; no measurable shoreline changes; new extraction sand is added to nearshore morphological system (nourishment); minor infill of sand in extraction pit; only during super-storms; trapping of fine sediments in pits (negative ecological effect); particle-tracer studies show minor bed-level variations (to the order of 0.03 m over winter) during storms.

4.2.5 Impact of turbidity on water column

Dredging activity can also lead to the production of plumes of suspended material. This material may result from the mechanical disturbance of the seabed by the draghead. However, the outwash of material from spillways from the vessel hopper can generate a far greater quantity of suspended material. Another source of suspended material is the sediment fractions rejected by screening activities (in order to deliver to shore a more desirable mix of sand and gravel). Suspended sediments arising from the last two processes have been termed "surface plumes". Their spatial extent and excursion depend on the sediment particle size, total quantity of material suspended, velocity of discharge, and the local hydrodynamics (Hitchcock and Drucker, 1996). Recent studies show that coarse particles (i.e. up to sand-size) settle within 300–600 m of the point source of discharge, depending on water depth (Newell *et al.*, 2004), whereas fine, silt-sized particles can be detected at a distance of up to 3.5 km; this residual signature may be attributed to organic matter derived from fragmented benthos discharged during the dredging process.

Large increases in suspended solid concentrations tend to be short-lived and localized, that is, close to the operating dredger. Turbid plumes with low concentrations can cover much larger areas over extended periods (several days instead of several hours), especially when dredging occurs simultaneously in adjacent extraction areas (Wallingford, 2002). Now, new dredger plants are also able to reject water and fine sediments under the vessel, thereby limiting the extent of the excursion of sediment plumes and leading to a rapid deposition of very fine sands and silts in the dredging area itself.

4.3 Nature of chemical effects

During dredging, reducing substances bound in the sediment (e.g. organic matter, sulphides, ammonium) and heavy metals chelated to fine particles may be released into the water column. In sheltered, non-tidal areas, where the content of these compounds in the sediment may be high, the oxygen level in the seawater may be lowered to concentrations that are critical to fish and benthos. In addition, in situations

such as exist in the Baltic Sea, an anoxic zone underlying the commercial deposits can be exposed by static suction hopper dredging. However, it should be emphasized that the chemical effects of aggregate dredging are likely to be minor on account of the very low organic and clay mineral content of most commercial aggregate deposits in tidal environments. 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 are only of short duration, which further limit any chemical impact. Effects on the environment from the dredger's ship-related operations (e.g. antifouling paints) may be more important, albeit still of minor consequence, than the release of harmful substances from the sediment.

4.4 Nature of the effects on the marine benthos

4.4.1 Direct effects

As the extraction of marine sand and gravel has its primary impact at the seabed, assessment of the effects of this activity has conventionally targeted bottom substrata and the associated benthic fauna (Millner *et al*., 1977; Desprez, 2000; van Dalfsen *et al*., 2000). Available evidence indicates that dredging causes an initial reduction in the abundance, species diversity, and biomass of the benthic community (Kenny *et al*., 1998; Sardá *et al*., 2000; van Dalfsen *et al*., 2000; van Dalfsen and Essink, 2001; Newell *et al*., 2002). Historically, the scientific study of coarser substrata has presented a significant challenge, largely on account of the difficulties of obtaining reliable quantitative samples (Eleftheriou and Holme, 1984). As a consequence, information on the nature and distribution of benthic assemblages, and on their wider role in the marine ecosystem, is considerably more limited than in areas of soft sediments.

Differences in the type of dredger employed, as well as the nature of the receiving environment, can influence the spatial scale of impact on the benthic fauna in terms of both the direct effect of removal of sediments and the indirect effects of extraction associated with the deposition of suspended sediments.

4.4.2 Indirect effects

The significance of sedimentation from plume fallout or screening operations on the benthic fauna, and its effect on the rate of recolonization, is receiving increasing attention (Pointer and Kennedy, 1984; Desprez, 2000; Newell *et al*., 2002; Boyd and Rees, 2003; Robinson *et al*., 2005). One study of a fine-sediment site in Moreton Bay, Australia, demonstrated enhanced abundance of benthic invertebrates adjacent to dredged subtidal sandbanks, which may have been linked to sedimentation of plume material (Pointer and Kennedy, 1984). Increased sedimentation and resuspension caused by dredging in deposits of clean, mobile sands are generally thought to be of less concern, because the fauna inhabiting such areas tend to be adapted to naturally high levels of suspended sediment resulting from wave and tidal current action (Millner *et al*., 1977; Newell *et al*., 2002; Cooper *et al*., 2005). Effects of sediment deposition and resuspension may be more significant in gravelly habitats dominated by encrusting epifaunal taxa because of the abrasive impacts of suspended sediments (Desprez, 2000; Boyd and Rees, 2003). This effect was highlighted in a study of a gravel extraction site in the Eastern English Channel, where the indirect effects of sand discharged from the dredger were as great as the direct effects of extraction on macrobenthic species (Desprez, 2000). At this location, effects beyond the extraction site were manifested by a reduced complement of species, lower densities, and a significantly reduced biomass, compared with nearby locations. More recently, Newell

et al. (2002, 2004) and Robinson *et al*. (2005) found evidence that the impacts of dredging extend beyond the margins of licensed extraction sites in the UK in terms of the suppression of benthic biomass, suggesting that this resulted from impacts associated with the remobilization of sediments introduced by screening activities.

4.4.3 Recolonization of extraction sites

Most studies that have considered the effects of marine aggregate extraction on benthic fauna have concentrated on establishing the rates and processes of macrobenthic recolonization upon cessation of dredging (Cressard, 1975; van Moorsel, 1993, 1994; Kenny *et al*., 1998; Desprez, 2000; Sardá *et al*., 2000; van Dalfsen *et al*., 2000; van Dalfsen and Essink, 2001; Krause, 2002; Boyd *et al*., 2003b, 2004, 2005; Cooper *et al*., 2005). The time estimated for "recovery" of the benthic fauna following marine aggregate extraction can vary depending on the nature of the habitat, the scale and duration of disturbance, the intensity of dredging, hydrodynamics and associated bed-load transport processes, the topography of the area, and the degree of similarity of the habitat to that which existed prior to dredging (for a review, see Newell *et al*., 1998).

Van Dalfsen *et al*. (2000) suggested that recolonization of a dredged area by polychaete worms occurred within 5–10 months of the cessation of dredging in a site located in the North Sea, with restoration of biomass to pre-dredge levels anticipated to occur within 2–4 years. Such studies have been mainly concerned with the effects of dredging operations conducted over a relatively short time-scale, such as up to one year (Kenny *et al*., 1998; Sardá *et al*., 2000; van Dalfsen *et al*., 2000; van Dalfsen and Essink, 2001). Thus, by their nature, these studies did not address the effects of dredging over the lifetime of a typical commercial extraction licence. However, zoning of extraction activity in Dieppe recently provided an example of such short-term recolonization by opportunistic polychaete worms, with densities up to ten times higher than in the reference area. Assessments of "recovery" usually involve an examination of a number of community parameters, such as abundance, numbers of species, diversity, and biomass, prior to disturbance and subsequently at various intervals (Bonsdorff, 1983; Kenny *et al*., 1998; Desprez, 2000). Typically, biomass dominants and age structures tend to take longer to return to pre-dredging levels than other community attributes (Rees, 1987; Kenny *et al*., 1998; van Dalfsen *et al*., 2000; Newell *et al*., 2002; Vanaverbeke *et al*., 2003).

A number of studies have addressed the consequences of long-term dredging operations on the recolonization of biota and the effects of dredging on the composition of sediments following cessation (Desprez, 2000; Newell *et al*., 2002; Boyd *et al*., 2003b, 2004, 2005; Cooper *et al*., 2005; Robinson *et al*., 2005; Diesing *et al*., 2006). There is some disparity in the findings of these studies, ranging from minimal effects of disturbance following cessation of dredging (Robinson *et al*., 2005) to significant changes in community structure persisting over many years (Desprez, 2000; Boyd *et al*., 2003b, 2004, 2005; Cooper *et al*., 2005). Recent evidence suggests that recovery periods can be prolonged (i.e. more than seven years), especially when sites have been dredged repeatedly at high levels of intensity (Boyd *et al*., 2003b, 2004, 2005; Cooper *et al*., 2005). Nevertheless, even at sites where the long-term effects of dredging have been observed, recent evidence suggests that some recovery can occur if sands are transported away from the site of extraction (Cooper *et al*., 2005). The period for recovery, therefore, appears to depend not only on the intensity of dredging activity, but also on the type of macrofaunal assemblage present and the hydrodynamics of the site (Boyd *et al*., 2004).

4.4.4 Models on the effects of disturbance and recovery of benthic assemblages

One consequence of the limited availability of literature concerning the effects on the benthos of commercial aggregate extraction is the difficulty it creates for the establishment of "models" that are firmly grounded in empirical data. A further difficulty in generalizing about the effects of commercial aggregate extraction is the variability of both the dredging history and the dredging practices to which different sites have been exposed, i.e. a typology of dredging disturbance does not exist. Consequently, when developing conceptual models, generalizations about the effects of aggregate extraction must be qualified by the nature of dredging activity and the conditions under which extraction activity occurs. Recently, Boyd *et al*. (2005) modified two models of response to account for the two most commonly encountered scenarios following marine aggregate extraction in the UK:

- sites where the substratum has changed from a sandy gravel to a gravelly sand;
- sites where the substratum has remained unchanged.

In the first scenario, it was hypothesized that the colonizing fauna would reflect a change to the substrata through a shift in the proportions of sandy vs. gravelly fauna (Desprez, 2000). Accompanying this, it was suggested that there would be a net decline in biomass. This model of response is schematically portrayed in Figure 4.3.1.A. A similar model of response could account for changes at some sand extraction sites where the seabed substrata have changed from coarse to fine sand (Sardá *et al*., 2000; van Dalfsen *et al*., 2000).

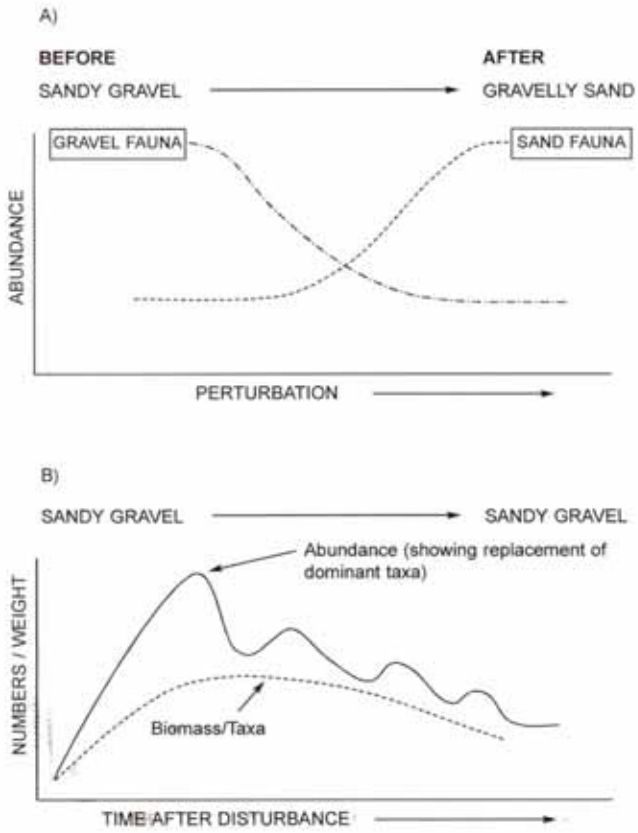

Figure 4.3.1. Top: A simplified diagram of changes in the proportions of gravelly fauna in response to a change in sediment type as a consequence of marine aggregate extraction. Bottom: A simplified model of changes in the benthos after the cessation of marine aggregate extraction.

In the second scenario, sediments present at the seabed following the cessation of marine aggregate extraction are similar to those that existed prior to disturbance, namely sandy gravels (Figure 4.3.1.B). From the available data on the effects of marine gravel extraction (Kenny and Rees, 1994, 1996; Kenny *et al*., 1998; Newell *et al*., 1998; Boyd *et al*., 2004), it is reasonable to postulate that the fauna recolonizing such sites will follow classical successional dynamics (Grassle and Sanders, 1973). Although such simplified models require further validation and/or refinement, they provide a useful framework for evaluating the outcome of post-cessation recolonization studies and recovery rates, and eventually could provide a reliable predictive capability.

Table 4.3.1. Summary of recent studies on the different aspects of environmental impacts of dredging by country. Several case studies are described more in detail. The case studies are introduced by a description of the studied extraction sites, including geographic position, sediment type and topography, tidal range, biotope description, and extraction specifications.

	Nature of physical effects				Nature of chemical effects	Nature of biological effects		
Country	Water column	Substrate	Bottom topography	Coastline stability		Meiobenthos	Macrobenthos	Fish
Belgium		Degrendele *et al.* (2002a); Bonne and Vincx (2003)	Degrendele *et al.* (2002b)	Degrendele *et al.* (2002a)	Leermaekers (2004); Spirlet (2004)	Bonne and Vincx (2003); Vanaverbeke *et al.* (2003, 2006)	Bonne *et al.* (2003); Moulaert *et al.* (2006a); this report	Hostens and Moulaert (2006)
Finland	Vatanen and Niinimäki (2005)				Vatanen and Niinimäki (2005)		Oulasvirta *et al.* (1987)	
France	du Gardin (2002)						Desprez (2000)	This report
Germany	Harf *et al.* (2004); Ziervogel and Bohling (2003; Baltic Sea, on dredge material disposal)			Diesing *et al.* (2006; North Sea and Baltic Sea); Krause (2002)			Krause (2002)	
The Netherlands							van Dalfsen *et al.* (2000); van der Veer *et al.* (1985)	
UK	John *et al.* (2000)	Kenny *et al.* (1998); Boyd *et al.* (2003b); Newell *et al.* (2002); Boyd *et al.* (2005)	Limpenny *et al.* (2002)	James and Limpenny (2002)			Boyd *et al.* (2003b); Newell *et al.* (2002); Boyd *et al.* (2005); Robinson *et al.* (2005)	Rogers and Nicholson (2002)

4.5 Case studies on the environmental effects of marine sand and gravel extraction

4.5.1 Belgium

On the Belgian continental shelf, Kwintebank is the most intensively exploited extraction area, mainly because of its location close to the coast and the suitability of the grain size of the sand for construction purposes. In the late 1970s, about 310 000 m^3 of sand were extracted annually from Kwintebank. This increased to approximately 1 360 000 m^3 $year^{-1}$ in the late 1990s and 1 700 000 m^3 in 2001 (source: Fund for Sand Extraction).

Impact on the sedimentology and geomorphology

Kwintebank is an elongated, linear subtidal sandbank about 25 km long, 3 km wide, and rising above the surrounding seabed to about 10 m in the north and up to 20 m in the south. The mean water depth varies between 6 m in the central part to over 20 m at the northern and southern edges (Lanckneus *et al*., 1992). Kwintebank belongs to the Flemish Banks, a group of linear subtidal sandbanks situated west of Oostende between the 6 and 12 nautical mile zones (11.12 and 22.2 km zones) off the Belgian coast. These sandbanks are oriented southwest–northeast and display a transverse asymmetry, with a steeper western slope as a result of the strong impact of the dominating flood stream. Flanks and the summit of the banks are covered with various types of bedforms, especially at their northern edges, where the energy of waves and currents is greater (Stolck, 1993; Lanckneus *et al*., 1994). The extensive sandwave area in the northern part changes into a flat plateau towards the south. These morphological characteristics correspond to a decreasing median grain size from north to south, as described in general for the Flemish Banks (Lanckneus, 1989; Trentesaux *et al*., 1994). The Flemish Banks are separated by swales that dip to the northeast, with those of the Kwinte dipping to the northwest of Kwintebank and those of the Negenvaam to the southeast.

Since marine sediment extraction off the Belgian continental shelf began in 1976, several studies have been conducted to monitor the impact of dredging. Early investigations by Ghent University included the collection of seismic data and vibrocore samples of Kwintebank, Buitenratel, and Oostdyck in order to describe the geological origins and internal structure of the sandbanks. Several sedimentological and geomorphologic surveys have been performed by the same institute to investigate whether sediment changes are natural or a consequence of sand extraction. In addition, bathymetric data are regularly updated, and specific profiles across Kwintebank, Buitenratel, Oostdyck, and Gootebank have been collected since the beginning of extraction until 1998, using a singlebeam echosounder. Sidescan data have also been collected since 1994 to study the morphodynamics on Kwintebank and Gootebank.

Since 1999, the Fund for Sand Extraction has used a Simrad 1002S multibeam echosounder to study the geomorphology of the extraction areas on Kwintebank compared with a nearby reference zone on Middelkerke Bank. From black-box data, it was calculated that more than 95% of the sand extraction on Kwintebank was concentrated at the centre and the northwestern tip of the sandbank in the late 1990s. The intensive exploitation during several decades led to the formation of a depression in both zones. In 2000, a depression of 5 m was detected in the central part of Kwintebank. Analysis of older data revealed that this central depression did not exist prior to 1993, but rapidly expanded from 1994 to 1997, after which its development slowed.

Between 1999 and 2003, the central depression deepened by 0.8 m, whereas the reference zone on Middelkerke Bank demonstrated a natural deepening of only 0.2 m. Since 15 February 2003, the central depression has been closed for sand extraction to allow geomorphologic rehabilitation of the area. In 2005, there was still no evidence of the restoration, but a spread of fine homogeneous sand has been observed within the depression since cessation of dredging activities.

In the northern part of Kwintebank, which is also subject to intensive sand extraction, a continuous loss of volume has been noted since 1987. The multibeam surveys in this area demonstrated a deepening of 0.4 m from 1999 to 2003. In addition, no consistent sedimentological changes have been observed.

Benthic responses to dredging on Kwintebank

Since 1978, Kwintebank has been subject to several benthic research programmes, mainly undertaken by Ghent University–Marine Biology and ILVO-Fisheries. The benthic components that are being investigated are meiobenthos (harpacticoid copepods and nematodes), macrobenthos, epibenthos, and demersal fish.

Impact of dredging on harpacticoid copepods

In 1997, harpacticoid copepods were sampled with a Reineck boxcorer at ten stations on Kwintebank and at two stations in the swales at both sides of Kwintebank (Bonne and Vincx, 2003). Density, diversity, and community structure were analysed in relation to sediment characteristics and sand extraction intensity, and compared with data from 1978 (Willems *et al*., 1982), that is, before the start of intensive sand extraction. Sand extraction intensity on and around the sampling stations was calculated based on 1.5 million black-box records from Belgian and Dutch vessels. Differences in dredging pressure were established by comparing the mean number of disturbances per month (= number of days during which dredging occurred), the mean duration of one disturbance (= number of minutes dredged per extraction), the mean total volume of sand extracted per month, and the thickness of the sediment layer removed each year in the defined areas.

Despite sand extraction, harpacticoid density and species richness were found to be high on Kwintebank, although the values were lower in 1997 than in 1978. Based on the recent dataset, an apparent correlation was noted between the occurrence of erosion and extraction areas and the distribution of the harpacticoid communities. In the zone between the northern and the central depression (where sand exploitation is less intensive), the harpacticoid community was remarkably similar to that found in 1978, before intensive extraction had taken place.

In contrast, from 1978 to 1997, a separate (impoverished) community had developed in the intensively exploited northern part of the sandbank. Also, in the central depression, a separate and impoverished community was found during the period 1978–1997, induced by a change in sediment characteristics, from coarse sands in the 1970s to fine sands in the 1990s. This altered sediment composition is probably the result of a local accretion of fine sediments, caused by overflow and changed current patterns in the depression. To the southern border of the depression, the harpacticoid community was similar to that in the swale stations, being characterized by very low density and diversity, although the sediment composition of this station was still more similar to the richer stations on top of the sandbank. A significantly higher density of juveniles was found in both intensively exploited areas and may be a direct response of the harpacticoid fauna to sand extraction. The abundance of large epi-

and endobenthic species has decreased over time, and the species composition has altered in favour of small interstitial species, which reproduce more frequently and are able to burrow deeper into the sediment.

In the southern part of Kwintebank, which is characterized by low sand extraction intensity and no important erosion trends, the harpacticoid community structure at the outset and after 20 years was still comparable and hence stable in time.

Impact of dredging on nematodes – the use of biomass and size spectra

In traditional benthic ecological research, communities are described by structural variables such as density, species composition, and diversity indices. Nematode studies are not routinely employed in monitoring studies because of (i) the relatively large amount of time (and money) that is required, compared with macrobenthic studies; and (ii) the specialized taxonomic skills needed, to identify of nematode species. An alternative method involves the study of functional attributes of communities, for example, the biomass distribution of the community relative to the size of the organisms. This method requires little taxonomic expertise and, therefore, may simplify the description and comparison of benthic communities.

Nematode biomass spectra (NBS) have been constructed for undisturbed sandbanks (Gootebank and Noordhinder) and a sand extraction site on Kwintebank (Vanaverbeke *et al*., 2003). Regression slopes of the cumulative NBS were not significantly different, indicating that no differences can be found among biomass spectra from different localities. However, differences between the sites were also assessed by comparing the peaks in nematode size spectra (NSS). This measure was demonstrated to be a useful indicator of change caused by sand extraction. It was suggested that a shift towards smaller nematode species might be a direct consequence of sand extraction, because smaller species can be more resilient to sediment removal, resuspension, and changes in overlying water currents. Smaller organisms are often associated with frequently disturbed habitats (Newell *et al*., 1998). They are characterized as early colonizers because of their rapid growth and early reproduction.

Impact of dredging and cessation of dredging on macrobenthos

The Belgian continental shelf is characterized by a large variety of benthic communities with fluctuating densities and diversities. Highest densities are encountered close to the coast and offshore in the swales between the sandbanks (Wittoeck *et al*., 2005; Moulaert *et al*., 2007).

In a recent study by Ghent University, macrobenthos data from 144 samples on Kwintebank, the slope, and the adjacent swales were compared (Bonne *et al*., 2003). These data were taken from three different research projects covering the late 1970s, mid-1990s, and 2001, but no samples were available for the intervening periods. For the macrobenthos, three communities could be distinguished: a bank community, covering the whole sandbank from north to south; a slope community; and a swale community. In the centre of the Negenvaam and the southern part of the Kwinte swale, an *Abra alba –Mysella bidentata* community occurs, which shifts to a transitional species association between the *Nephtys cirrosa* and the *Abra alba–Mysella bidentata* communities (as defined in van Hoey *et al*., 2004) on the slope of Kwintebank.

The macrobenthos community on the sandbank was characterized by low density and diversity, typical for mobile sands and reflecting the situation on other sandbanks of the Belgian continental shelf. No significant change was detected between the 1970s and the 1990s. There was also no increase in the biotic coefficient (Borja *et*

al., 2000), although sand extraction intensity has increased since the late 1970s. Differences within the bank community only reflected a small year-to-year variability, and in the data for the 1990s, no clear spatial differences in overall density, diversity, or biotic coefficient (Muxika *et al*., 2005) could be detected between areas of high and low sand extraction intensity, as was demonstrated for the harpacticoid copepod communities. On a temporal scale, the bivalve species *Spisula* had disappeared from the intensively exploited areas in the 1990s, and the abundance of the polychaete *Ophelia limacina* clearly decreased from the 1970s to the 1990s, which could be attributed to sand extraction activities.

Several studies have demonstrated that it is difficult to detect long-term changes in macrobenthos, mainly because of the impoverished nature of this ecosystem component on Kwintebank, the large niche width of the community, and the extent to which macrobenthos species are adapted to high levels of sediment disturbance in these dynamic systems. Furthermore, data interpretation is usually hampered by the lack of baseline information, in this case, prior to sand extraction activities.

To gain insight into the possible restoration of benthic life in the central depression of Kwintebank after closure of the area in February 2003, one Spanish and three Belgian institutes were involved in the multidisciplinary project SPEEK (Study of Post-Extraction Ecological effects in Kwintebank sand dredging area), in which data on the meio- and macrobenthos were supported by geological data. Only the results from the study by ILVO-Fisheries on the macrobenthic component are summarized below (Moulaert *et al*., 2006a).

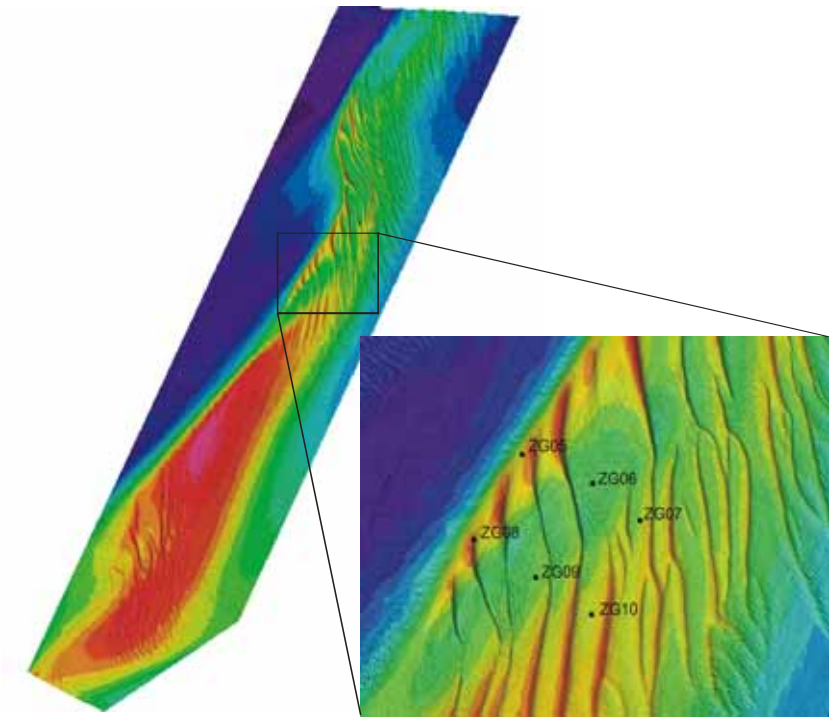

Figure 4.4.1. Location of the SPEEK macrobenthos sampling locations in the central depression on Kwintebank.

Six locations in the central depression of Kwintebank (Figure 4.4.1) were sampled seven times between 2003 and 2005 (sampling was continued until 2008). Three other locations on Kwintebank were used as reference areas. The data revealed that, one month after cessation of the extraction activities (early 2003), density, number of spe-

cies, and species diversity in the central depression were lower than subsequent periods. For this period, the values were also lower than the reference zones south of the depression and in the northern part of Kwintebank, where low levels of dredging activity occurred. In the most central part of the depression only, the amphipod *Urothöe brevicornis* and the carnivorous bristleworm *Nephtys cirrosa* were already present in larger numbers in March 2003.

A positive trend was found from 2003 to 2004 as density and diversity increased in all sampling locations in the central depression of Kwintebank (Figure 4.4.2). Consequently, the data for the central depression became more similar to those from the surrounding reference stations, where there was no or only limited dredging activity. Low densities were recorded in 2004 and 2005 in the third reference station, situated in the recently highly exploited area in the northern part of Kwintebank; these were similar to the low values obtained shortly after cessation of dredging activities in the central depression. This seems to indicate that the positive trend in density and diversity of the macrobenthos in the central depression can be related to the cessation of dredging activity in that area.

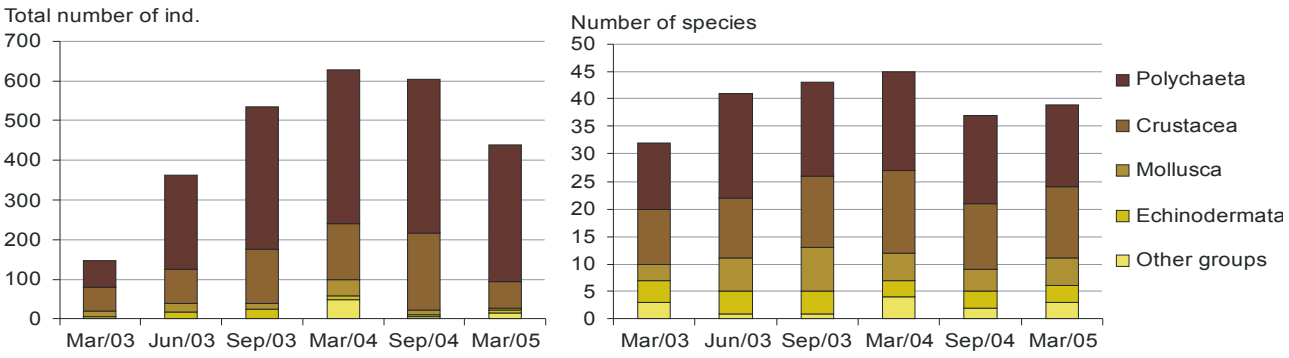

Figure 4.4.2. Average density and number of species for the macrobenthos in the central depression of Kwintebank during the period 2003–2005.

The amphipod *Urothöe brevicornis* and the polychaetes *Hesionura elongata*, *Polygordius appendiculatus*, *Spiophanes bombyx*, *Scoloplos armiger*, and *Nephtys cirrosa* (both juvenile and adult individuals), were the most important species from autumn 2003 onwards. Using multivariate analyses, a small change in community composition was found, related to an increased density of polychaetes over the entire sampling period. Also, the ratio between adult and juvenile *Nephtys cirrosa* individuals changed slightly over the sampling period in favour of the adults, which might also indicate that "recovery" of the macrobenthic community has begun. However, because of a lack of baseline data, it remains unclear whether this macrobenthic community matches the "original" or has evolved into a new, stable community.

In general, it can be concluded that the impoverished macrobenthic community found in the central depression of Kwintebank in early 2003, immediately after the cessation of extraction, evolved in less than one year into a community more characteristic for a typical sandbank area on the Belgian continental shelf.

4.5.2 Finland

Itä-Tonttu sand extraction area

Sand extraction in the Itä-Tonttu area, off Helsinki, in the Gulf of Finland, commenced in 2004 when 1.6 million m^3 of sand were extracted. The effects of sand ex-

traction were studied by measuring the turbidity and sedimentation levels, algal vegetation, and through consultations with professional fishers (Vatanen and Niinimäki, 2005). Previous investigations of the macrofauna, Baltic herring and white fish, juvenile fish larvae, and concentrations of tributyl tin (TBT) and polychlorinated biephenyls (PCBs) in fish tissues have been conducted in the Helsinki port area (see Niinimäki *et al*., 2004). The investigations were repeated in 2005, following sand extraction.

Turbidity measurements were taken during sand dredging, using three methods: vertical lines, surface mapping, and continuous-measurement instruments. Increases in turbidity in the dredging area resulting from sand dredging were considered to be minor. Only slight increases in turbidity (<10 NTU) were observed within surface waters a few hundred metres from the point of dredging. The highest recorded level of turbidity was 14 NTU. However, during one month of monitoring, the levels did not exceed 10 NTU, except for a period of less than two hours. In the deeper water layer close to the seabed, at 20–30 m water depth, a slight enhancement in light attenuation (5 NTU) was occasionally observed 2 km from the dredging point. Increases in sedimentation caused by dredging were considered to be low near the sand-dredging areas (0.9–3.5 g m^{-2} d^{-1}). Higher values for turbidity in surface waters were measured from the ship en route to the unloading area at the port. This was caused by overspill of material from the sand transportation barges. Furthermore, the turbidity of both surface waters and the water–sediment interface was high after the barge was emptied.

The spawning success of Baltic herring (*Clupea harengus*) and the nature of vegetation in the spawning areas were also studied from 1989 to 2003 in the eastern side, off Helsinki. The nearest herring spawning grounds are situated about 4 km from the licensed sand-dredging area. Further studies of the spawning grounds were carried out in 2005, following sand dredging. TBT and PCB concentrations in fish tissue were also examined from fish collected from the port area. TBT concentrations were found to be high, but did not exceed the WHO limits for human consumption. Low concentrations of PCBs were also recorded. An assessment of the catch rates of herring and salmon caught using trapnets near the sand-dredging area was conducted in consultation with local fishers between 1991 and 2004. Catches declined over this period. This is typical of conditions across the Gulf of Finland and is attributed to the effects of eutrophication. The fishers also reported that turbidity and noise caused by the autumn 2004 dredging activity adversely affected the autumn whitefish fishery.

Macrobenthic samples were collected from the area in 1997, 1998, and 2003. The sampling stations in the sand-dredging area were located at a water depth of 26–47 m and were characterized by species typical of soft sediments, such as *Macoma balthica*, *Monoporeia affinis*, *Saduria entomon*, the oligochaete *Tubifex costatus*, and the polychaete *Marenzelleria viridis*. The investigations were repeated in 2005, following sand extraction.

4.5.3 France

The Dieppe recolonization study

The extraction site 3 nautical miles/5.6 km off Dieppe, in the Eastern English Channel, is less than 2 km^2 and located at a depth of 10–15 m. Extraction at this site commenced in 1980 and continued at a high rate (ca. 0.4–0.8 million t $year^{-1}$) until 1985, when the level of extraction declined, stabilizing at ca. 0.1 million t $year^{-1}$ in 1992 (Desprez and Duhamel, 1993). Monitoring studies carried out between 1986 and 1993

indicated that the fauna within the extraction site was extremely variable, with only five out of a total of 45 species being encountered regularly (Desprez, 1995). Dredging in the western part of the site ceased in 1994 (ICES, 2001). This provided an opportunity to study the recolonization of the seabed in the aftermath of dredging, and surveys were conducted in 1996, 1997, and 2001, i.e. one, two, and six years after extraction (Desprez, 1995, 2000; ICES, 2001). In total, nine stations were sampled within, and in the vicinity of, the former dredging site, using a van Veen grab. The rationale behind the sampling design was as follows: (i) five stations were located within the extraction site and were monitored from 1993 onwards; (ii) two reference stations were selected in 1986 in order to track natural fluctuations in benthic populations; and (iii) two stations located on the southern and northern edges of the extraction site were sampled in 1996 and 1997 to quantify impacts associated with the transport of fines from overspill.

The topography within the extraction site was found to be extremely disturbed, with large furrows up to 5 m deep, separated by crests of coarse sediment composed predominantly of pebbles. Dredged furrows were also found to be partially infilled with sand, presumed to be partly the result of fine sands discharged with the overflow and also the result of the trapping of bed-load sediments. Particle-size analysis revealed that sediments within the dredged area typically had a bimodal distribution, with a dominant gravel fraction and a fine sand fraction. Similarly, sediments collected from reference areas also had a bimodal distribution, but with a dominant coarse sand component. In contrast, stations considered to be affected by the deposition of plume material were largely dominated by fine sands.

Biological monitoring at this site some 16 months after cessation demonstrated that densities and biomass had reached 56 and 35% of the reference values, respectively. Numbers of taxa found within the extraction site were also indistinguishable from reference values. Further evidence of restoration was indicated by a survey 28 months after cessation, when levels of biomass reached 75% of the reference values. However, densities within the site were still substantially reduced compared with background levels.

In the western part of the extraction site, where mobile coarse sands were intruding, the community was dominated by several species common to the reference area, such as the echinoderm *Echinocyamus pusillus* and the polychaetes *Polycirrus medusa*, *Notomastus latericeus*, and *Syllis* sp. In contrast, the eastern part of the site was characterized by gravels and fine sands, and dominated by the sessile polychaete *Pomatoceros triqueter* and hydroids. Motile epibenthic crustaceans, such as *Pisidia longicornis* and *Galathea intermedia*, were also found, and were accompanied by taxa most often associated with fine sands, such as the amphipods *Urothöe elegans* and *Cheirocratus sundevalli*, and the polychaetes *Spiophanes bombyx* and *Nephtys cirrosa*. In the area affected by plume fallout, the sediment was found to consist of clean, fine sands and was characterized by the polychaetes *Spiophanes bombyx*, *Nephtys cirrosa*, and *Ophelia limacina*, the bivalve *Tellina pygmaea*, and the amphipod *Urothöe brevicornis*. Interestingly, 28 months after dredging, Desprez (1997, 2000) was able to distinguish a gradient of increasing effect running through the extraction site from west to east.

The preliminary findings from this study highlighted the importance of tidal currents to the restoration process, by providing a source of larval recruits. The latest investigation of the site in 2004 indicated that recovery of the seabed was achieved in the western part of the former dredging site mainly through larval recruitment. However, recovery was not evident at the eastern part for several possible reasons.

- a higher maximal dredging intensity before 1994
- temporary dredging after 1994
- impact of oversanding from a new dredging site located close to the northern border (i.e. a cumulative impact)

This investigation also revealed that densities of benthic organisms were up to ten times higher in the former extraction site than in the reference zones. These elevated densities were mainly caused by enhanced numbers of the polychaete *Pomatoceros triqueter* (78–84%) and the decapod *Pisidia longicornis* (7–9%).

The abundance and diet of fish species at the Dieppe extraction site

Monthly fishing campaigns started in July 2004, with a local fishing boat, using a bottom trawl with a wide vertical opening. The main aim was to collect benthic and demersal fish species within and in the vicinity of the Dieppe extraction site and to analyse the stomach contents in relation to the availability of benthic fauna. Stomachs were removed from the dominant fish species (i.e. plaice, skate, gurnards, red mullet, sea bream, and cod) for analysis of benthic prey.

Plaice were found to be less abundant in the extraction area than in the reference area and were also concentrated in the eastern part of the deposition area. Prey species of plaice were typical of fine and coarse sands (63% bivalves, 28% crabs).

Similarly, skate were less abundant in the dredging area and did not appear to favour the deposition area. Prey items of skate included species characteristic of sands (35% shrimps, 16% mysids) as well as the ubiquitous crabs (32%). Interestingly, dominant species within the dredging area were found to constitute very little of the overall diet of skate.

Gurnards also appear to avoid the deposition area, and no species from this area were found in their stomachs. Although scarce in the dredging area, the diet of gurnards appeared to consist of epifaunal prey items (49%), decapods (18%), and species associated with the coarse sands from the reference areas (16%).

In contrast, cod were absent from the sandy (reference and deposition) areas, and no prey items from these sectors were identified. Cod are regularly fished, albeit caught in low densities, within the dredging area. Stomach contents analysis confirmed that this area is their preferred feeding ground.

Red mullet were found in similar densities within the recolonization and reference areas, but were found in smaller numbers in the dredging and the deposition areas. The stomach contents of this species reflected the sediment composition of each area, but red mullet also demonstrated a clear preference for prey items typical of the muddy heterogeneous sediments within the dredging tracks. Of all the species encountered, red mullet was the most abundant and frequently sampled in all the areas. It was, therefore, viewed as an excellent indicator of conditions within and in the vicinity of the extraction site.

Complementary surveys of fish populations within the region provided additional information, beyond that obtained from grab surveys, about the status of the extraction site in terms of the range and relative abundance of species present and their functional significance to other components of the ecosystem.

Table 4.4.1. Relative scores of the impact on fish species in the different areas of the study site, based on relative abundance of the fish species and their preference for certain prey items encountered.

Impact/Area	Skate	Plaice	Red mullet	Gurnard	Cod	Sea bream	Global impact
Cumulative effects	−1	−1	0	−1.5	−3	−2	−8.5
Deposition	+ 0.5	+2	−0.5	−1.5	−3	−3	−5.5
Dredging	−3	−1.5	0	0	0	+1	−3.5
Fallow	−2.5	−3	−1	−0.5	+3	+3	−1
Recolonization	−2	−4	0	+2	+3	+4	+
Global index*	−8	−7.5	−1.5	−1.5	0	+3	

*** Presence index + trophic index**

The following general conclusions can be drawn from this study (Table 4.4.1).

- Plaice and skate are the two fish species most adversely affected by dredging activity. In contrast, plaice appeared to prosper in the sandy sediments located with the deposition area.
- Red mullet is not significantly affected by dredging, because this species is able to adapt its diet to all "newly" created habitats produced by dredging.
- Gurnards in this region are not affected by dredging because any adverse effects of dredging associated with the deposition of sandy material are offset by a positive response to conditions at the recolonization area.
- Black sea bream (and cod) are absent from sandy reference and deposition areas; they are attracted to dredging areas by the abundance of opportunistic benthic species recolonizing pebbles as soon as activity has ceased.

4.5.4 Germany

North Sea studies

Westerland II is located approximately 7 km west off Sylt, with an overall area of 14.5 km^2 and a water depth of ca. 14 m. Since 1984, coarse sands have been extracted from this site for beach nourishment. The total extraction volume from this site until 2003 was 23.9 million m^3. The sand resource is characterized as Tertiary kaolin sand and is covered by a relatively thin veneer of Holocene and Pleistocene fine-to-medium sands. Static suction hopper dredgers have been employed at this site, resulting in the creation of several pits, typically up to 10 m deep, with slopes of 3–5°, and up to 2000 m in diameter.

Single-beam bathymetric datasets collected between 1988 and 2001 were used for morphometric analyses. The results revealed that only 10% of the volume extracted from the pits is refilled. Infill material consists initially of sand arising from slope instabilities. Over time, mainly soft mud accumulates in the pits, changing the sediment composition substantially. However, there was no evidence that the refilling processes of these pits had a detectable influence on the bathymetry and morphology of the surrounding seabed. Rates of sediment transport were estimated according to the formulae given by van Rijn and Walstra (2002) and ranged between 60 and 80 m^3 m^{-1} $year^{-1}$. Owing to their steep slopes, the pits of Westerland II act as efficient sediment traps for fine-grained (<63 μm) material. This material is derived from suspended particulate matter from the River Elbe, as confirmed by their similar spectra of organic pollutants.

The extraction site near the island of Pellworm is located in the North Frisian Wadden Sea (tidal flats) in very shallow waters (0.9–2 m). In 1994, ca. 290 000 m^3 of material were extracted for dike construction, using a static suction hopper dredger. The resulting pit had a maximum depth of 13.5 m, with slopes up to 21.5°. Within six and a half years, 95% of the pit was refilled. Sediment cores also revealed that the refill material was of the same sedimentological composition as the surrounding material on the tidal flats (Zeiler *et al*., 2004).

Western Baltic Sea studies

The Baltic Sea is one of the largest perennial brackish seas. The large freshwater inflow of many rivers, precipitation exceeding evaporation, and the restricted inflow of marine waters are the main factors responsible for the brackish character of the Baltic Sea. The western Baltic Sea also has no significant tidal regime. Circulation of water masses is only wind-driven, and there are no permanent currents. The environmental impact of marine aggregate extraction in this area can be very different from those in other, tidal settings.

Graal–Müritz

Graal–Müritz 1 is located approximately 20 km northeast of Rostock–Warnemünde and has an overall area of 8.2 km^2. The water depths range between 7 and 12 m. Since 1998, Holocene sands have been extracted by trailer suction dredgers for beach nourishment. The thickness of the sand resource varies between 0 and 4 m. Approximately 292 000 m^3 of material was extracted in November/December 1999 and 341 000 m^3 during September/November 2000, resulting in three depressions up to 1 m deep.

Sidescan sonar surveys confirmed the erosion of dredge tracks after a period of two years. This rapid recovery was attributed to the availability of mobile sands, sufficient hydrodynamic forces in the shallow waters, and the more benign nature of trailer suction hopper dredging. Mass balance calculations indicated that 50% of the material was refilled within the first year. During the subsequent year, however, 50% of the refill volume was exported, and so the net refill volume was approximately 25%. Thus, it was evident that the refilling process in such shallow waters was not linear (Zeiler *et al*., 2004).

Tromper Wiek

Extensive studies have also been conducted in the gravel extraction sites of Tromper Wiek, a semi-closed bay at the eastern part of the island of Rügen. These sites (Tromper Wiek 1 and 3) are in water depths of between 9 and 15 m, and close to a sand extraction site (Tromper Wiek Ost) in slightly deeper waters (14–21 m). The geology of Tromper Wiek is dominated by gravelly sands and reworked lag sediments of Pleistocene till covered by sands in water depths of >15 m. The coarse sediments (cobbles and boulders) are covered by mussel beds (*Mytilus*). These sites have been used since the 1980s, but information on the amounts of material extracted prior to 1989 is not available. Dredging commenced in the northeastern part of Tromper Wiek 1 and then progressed towards the southwestern part of the adjacent licensed area of Tromper Wiek 3.

Gravel extraction in these licensed areas is performed using static suction hopper dredgers, with sands returned to the seabed as overspill. Numerous pits of up to 6 m deep and approximately 30 m in diameter were observed within both licensed areas.

Only 10–30% of the volume extracted was refilled with sands, mud, and mussel shells. A substantial amount of refill material was generated during the screening process. Sands deposited around the pits were found to coarsen over time as the finer fraction (<350 μm) was mobilized by wave action and accumulated within the pits. Muddy refill material was also observed during the deployment of an acoustic Doppler current profiler (ADCP). As a qualitative indicator of suspended particular matter, a time-series of echo intensities clearly demonstrated that the hydrodynamic forces were able to remobilize muddy material at the bottom of the pits and export fine-grained refill material (Klein, 2003). After two years, stable conditions appeared to have been established in the relinquished sectors of the extraction sites. However, the complete refilling of the pits is considered unlikely, given the very low sediment availability in the bay.

The extraction furrows created by trailer suction hopper dredgers at the sand extraction site of Tromper Wiek Ost have been observed to be fairly stable. For example, dredge tracks from 1989 have been observed from sidescan sonar images more than ten years after their creation. Furthermore, the distinctive acoustic backscatter signatures of the dredge tracks suggest that the refill material is finer grained than the material on the surrounding seabed. Interestingly, there was no evidence that screening of sediments within the gravel extraction sites in shallow waters had any impact on the refilling processes of Tromper Wiek Ost (Diesing *et al*., 2006; Kubicki *et al*., 2007).

Physical refilling processes

The Federal Maritime and Hydrographic Agency (Bundesamt für Seeschiffahrt und Hydrographie) and the Institute of Geosciences (University of Kiel) conducted a collaborative three-year study to assess the physical refilling processes of four different extraction sites in the North Sea and the Baltic Sea (Zeiler *et al*., 2004). The objectives of the programme were to investigate the physical processes of refilling, their timescales, and the spatial extent of the affected seabed. A variety of sites were selected for study, representing the different physical manifestations on the seabed resulting from extraction using the different dredging techniques. Sites were also located at various distances from the coastline. The results confirm differences in the refilling processes of extraction sites, depending on sediment availability, hydrodynamic forces, and type of extraction (static or trailing suction). Although the >10 m pits in the offshore area of the North Sea and the 5 m pits in the Bight of Tromper Wiek (Baltic Sea) refilled only partly, the 10 m pit in the North Frisian Wadden Sea was observed to be almost completely infilled. This disparity in the findings was attributed to the site in the Wadden Sea having a permanent import of particulate matter via a trough, which had a connection to the tidal inlet even during low water levels. Infill material at this site was found to be almost identical with local sediments. In contrast, the pits in the open North Sea and Tromper Wiek are refilled by episodic input of sandy material from the slope instabilities, bed-load transport, and deposition of screened sands (Tromper Wiek). Owing to their steep slopes, these pits act as efficient mud traps. The long-term refilling of the pits of Tromper Wiek and the shallow depressions off Fischland–Darss (Baltic Sea) are interrupted by erosion of infill material. Despite their short distance from the shore, all sites are located outside the alongshore sediment-transport belts, which are restricted in both sea areas to a relatively small zone seaward of the coastline.

Wustrow

This study site is situated less than 1 nautical mile/1.85 km offshore of the coast near Wustrow, Germany. The area belongs to the Darss Sill, a shoal separating the Belt Sea from the Baltic proper. Freshwater surplus from the Baltic proper leads to an outflow of low-saline surface water through the Belt Sea, Kattegat, and Skagerrak into the North Sea. This is compensated by an infrequent inflow of water masses with higher salinities beneath the outflow. Thus, different water masses meet in the area. Salinity is usually higher (>10) in the western than in the eastern part of Darss Sill (~7). Prior to extraction, an investigation characterized the area as being approximately 1 100 000 m^2, with a mean depth of sand deposits of 1.9 m and a mean water depth of 11–13 m. The mean sediment grain size of sands was 210–250 μm.

During October/November 1997, 320 261 m^3 of medium sands were dredged from the extraction field Wustrow II. Extraction was undertaken using a trailer suction hopper dredger. Alterations to the seabed topography and morphology were measured using an echosounder and sidescan sonar. Oxygen concentration, salinity, and temperature of the water column were measured using specific sensors associated with a CTD. Sediment core samples were collected for the analysis of various abiotic parameters, and to characterize the macrobenthic community, using a van Veen grab and by scuba divers (Krause, 2002). The aim of this part of the study was to monitor the physical and chemical modifications to the sediments and water column, and to document any consequent changes to the macrofauna.

There were significant changes to the seabed within the dredged box, although these were locally heterogeneous. The general deepening of the dredged area in relation to the surrounding seabed also influenced the local water column. Although the water column above the control area demonstrated no, or only minor, stratification after dredging, there was a clear stratified zone in the water column above the dredged site.

An examination of sidescan sonar records revealed that, six months after dredging, at least 68% (970 000 m^2) of the licensed dredged box was disturbed by at least one dredge furrow. Four months later, substantial recovery of the area was observed, with only 41% (580 000 m^2) of the extraction field containing one or more furrows (Figure 4.4.3).

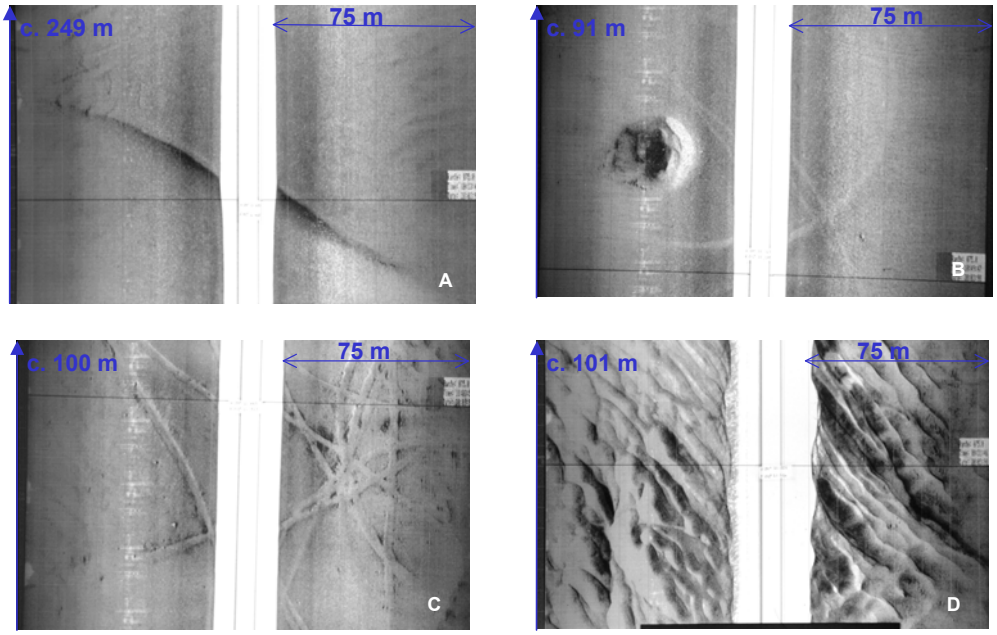

Figure 4.4.3. Four representative examples of seabed topography four months after dredging in the extraction area: A) from the control area; B) a hole outside the extraction site of 15 m diameter and 3 m deep; C) dredge furrows in the upper part of the extraction site approximately 2 m wide and 0.3 –1.0 m deep; and D) multiple-dredged building channels up to 5 m wide and 3 m deep. (Sidescan sonar images courtesy of M. Diesing and K. Schwarzer, University of Kiel, Germany, FK Littorina).

Within the main dredged area, 1% (210 000 m²) of the total area was intensely and permanently disturbed by more than 25 dredge furrows per 100 × 100 m square grid. However, this calculation does not take account of the additional dredged area (approximately 680 000 m²) found outside the extraction box. Sediments from the impact area were substantially different following dredging. Fine sands (mean $\phi = 2.7$) enriched in organic content (mean C_{org} <1.2%) replaced the medium sands (mean $\phi = 1.8$) of low organic content (mean C_{org} <0.2%) in the upper sediment layers. Comparison of the impact sediment gradients revealed that, six months after dredging, only the upper few centimetres of sediment were organically enriched, whereas ten months after dredging, a layer of muddy sediment several decimetres thick was present. Four months after cessation of dredging, field measurements of sediment cores indicated that oxygen penetrated significantly deeper into the sediment of the control area than into that of the impact area.

In summary, the results show that most of the dredged seabed recovered within one year of dredging. However, a smaller section of the licensed area was severely changed by an overall deepening of up to 6 m, resulting from multiple dredge furrows. During the following year, measurements revealed a shift to finer grain size, higher organic content, reduced oxygen saturation, and thinned redox potential discontinuity (RPD) layers, as well as the movement of chemically reduced layers close to the seabed surface. Ten months after dredging, oxygen depletion zones were found in the most heavily affected part of the dredge box.

These changes were attributed to the morphological changes to the seabed caused by dredging activity. In particular, the dredged furrows were considered to be behaving as sediment traps. These physical impacts had a significant but short-term effect on the common non-sensitive species of the macrozoobenthos community. As expected,

the effects were severe for the species known to be sensitive to seabed disturbance. Such species had not recolonized one year after dredging.

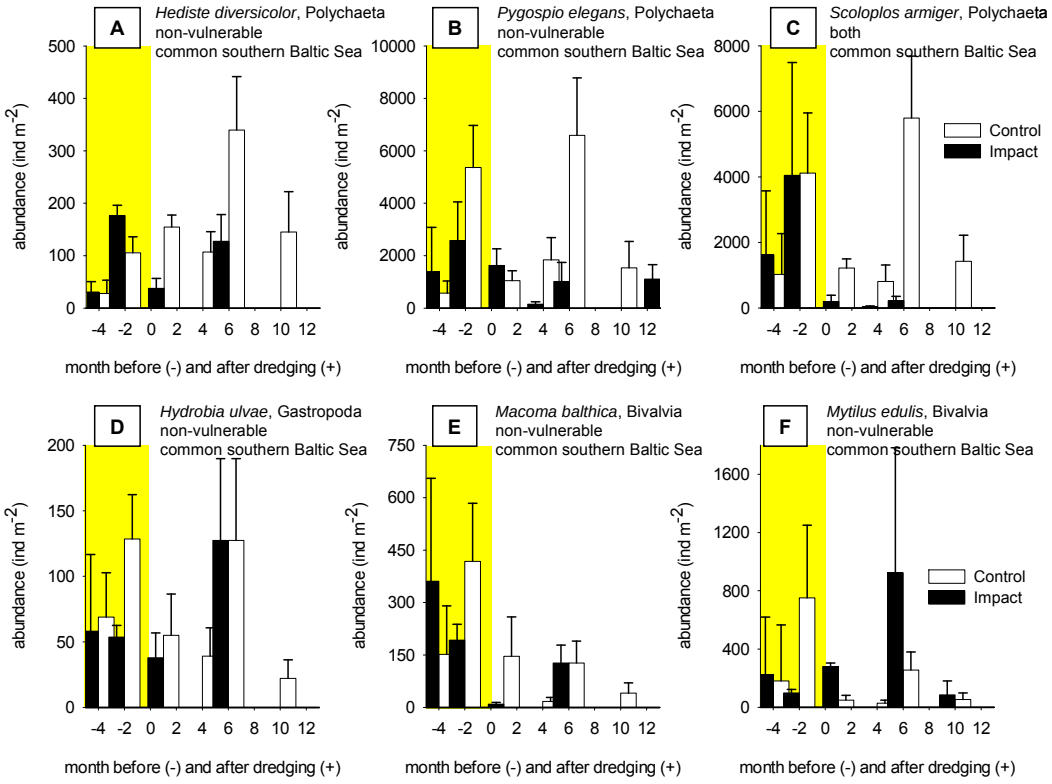

Figure 4.4.4. Mean abundance of the six most frequently occurring species in control and impact area before (–) and after dredging (+). Sampling before dredging is indicated by a yellow box. Error bars indicate standard deviation.

An analysis of the abundance of the six most frequently occurring species in control and impact areas before and after dredging was conducted and compared with the known abundance of regional indicator species. All common and non-vulnerable species were recorded after dredging in the impact site, indicating fast recovery rates. However, for most of them, with the exception of *Mytilus edulis,* a decline in abundance was recorded one month after dredging. Figure 4.4.4 illustrates this result for *Hydrobia ulvae*, *Macoma balthica,* and *Mytilus edulis*. In contrast, "sensitive" species vanished almost completely at the impact site after dredging, except for a few small individuals of the bivalve *Mya arenaria.* However, they were sampled regularly only at the control site (Figure 4.4.5). Examples for the "sensitive" species are the differences in abundance of *Bathyporeia pilosa* and *Travisia forbesii*. Some individuals of *T. forbesii* were collected in the impact site one month after dredging, but none were collected thereafter (Krause *et al*., 2007).

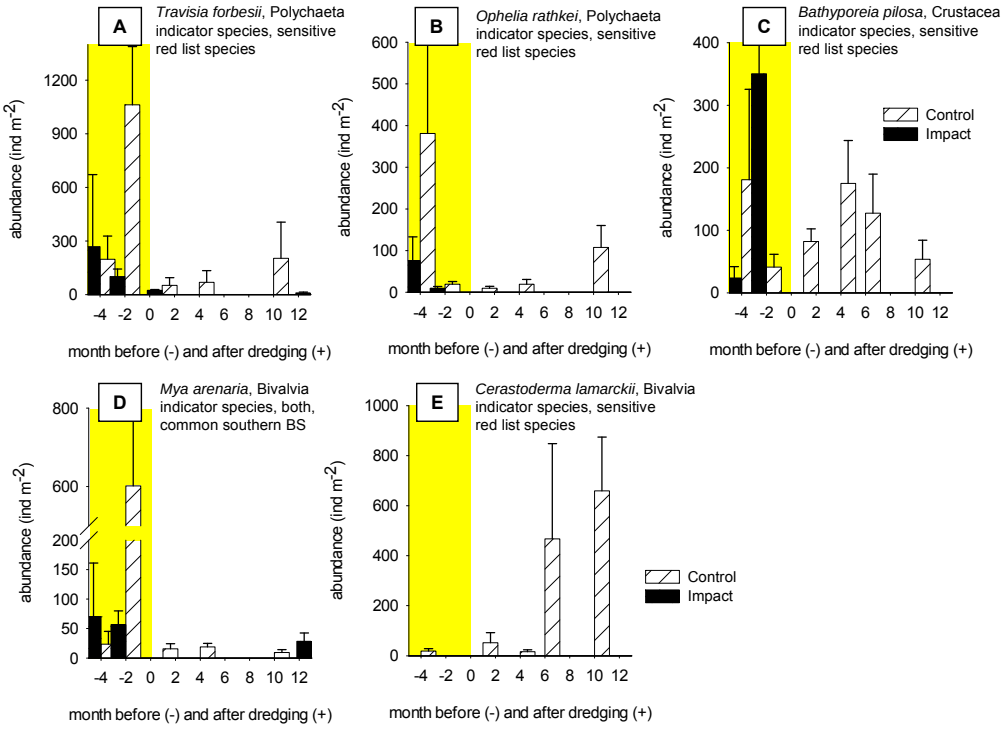

Figure 4.4.5. Mean abundance of five sensitive composition indicator species in control and impact area before (–) and after dredging (+). Sampling before dredging is indicated by a yellow box. Error bars indicate standard deviation.

4.5.5 The Netherlands

Klaverbank

Klaverbank is a relatively small area (30 km^2) in the southern North Sea, which has been identified as a potential source of gravel for the construction industry (van Moorsel, 1994). An experimental study was initiated in this area in 1989 to investigate the effects of marine gravel extraction on the benthic macrofauna (van Moorsel, 1993, 1994). A baseline study was conducted prior to the extraction of 336 000 m^3 of gravel. Sampling was then conducted in autumn, two months after dredging, to investigate the impact of gravel extraction on the geomorphology and ecology of Klaverbank. The sampling design consisted of a transect of stations running within the extraction site and reference stations located nearby. Samples were collected using a Hamon grab for the assessment of macrofauna and analysis of particle size before, immediately after, and then annually for the first two years following extraction.

Both the numbers of species and their densities were reduced substantially following dredging, by 30 and 72%, respectively. In addition, biomass was reduced by 80%, which was attributed to the removal of large bivalve species, particularly *Arctica islandica* and *Dosinia exoleta*. Eight months after dredging, the seabed morphology had changed markedly, with the disappearance of dredge tracks, which was attributed to bed-load transport of sediments by winter storms. Interestingly, dredging did not cause a change in the gravel content of sediments at this site, suggesting infill of dredge tracks was not the result of sand in transport (Kenny *et al.*, 1998). Total number of species and densities were restored within eight months following dredging, although biomass remained lower than pre-dredging levels, even two years after dredging. In 2002, a further survey was carried out to investigate the natural variabil-

ity of the area and to assess the long-term (more than ten years) effects of experimental gravel dredging (van Moorsel, 2003). Effects of aggregate extraction conducted in 1989 were no longer perceptible in 2002. Large molluscs that had been significantly affected by dredging two years after extraction were found to have substantially recovered.

In 2003, after instigating an EIA to assess the impacts of marine sand and gravel extraction from Klaverbank, the Dutch government decided not to allow dredging in this area. Available information concerning this application to dredge was published, along with underlying reports on the geology and biota of the area. This study concluded that it was possible to extract sand and gravel from the area without long-term consequences to the benthic fauna, providing that a surficial layer of material remains on the seabed post-dredging. Nevertheless, future extraction is considered unlikely in Klaverbank given that the area has been identified as an important site of nature conservation (van Moorsel, 2003).

PUTMOR project

The Rijkswaterstaat North Sea Directorate, in cooperation with the Netherlands National Institute for Coastal and Marine Management, initiated the PUTMOR (pit morphology) project in 1999. The study site consisted of an extraction pit at the Lowered Dumping Site near the Hook of Holland. The pit was located at a water depth of 23 m and had an overall volume of 4.5 million m^3, with dimensions of 1300 × 500 m and an extraction depth varying between 5 and 12 m. Over a six-month period, measurements of morphology, sediment particle size, current velocity, water level, turbidity, salinity, temperature, and oxygen concentration were undertaken. These measurements were carried out using both frame-mounted and ship-borne instruments within and outside the pit. The aim of the investigation was to examine the impacts of a deep extraction pit on ecological and physical parameters and user functions. After initial surveys, research focused on physical parameters rather than the recovery of benthic fauna. The study indicated that both the depth and design of the pit are important influences on tidal currents. Furthermore, the study demonstrated that there was no risk of oxygen depletion in a pit of this size in this area (Boers, 2005b). Current velocity measurements taken inside and outside the pit were also used to validate the outputs from hydrodynamic models.

4.5.6 United Kingdom

Recolonization of disused extraction sites

A number of studies have been undertaken in the UK to assess the status of the seabed substrata and associated benthic fauna within and outside areas where dredging had ceased, and to conduct follow-up sampling to monitor progress towards full recolonization (Boyd *et al*., 2003b, 2004, 2005; Cooper *et al*., 2005). The main objectives of one large programme were to understand the rate at which the seabed recovers, to identify measures to enhance the potential for the rehabilitation of dredged areas, and to investigate whether or not different historical levels of dredging intensity affect the subsequent rate and nature of benthic recolonization following cessation of marine aggregate extraction.

Sites were first identified as being representative of some of the extraction areas/habitats around the English coastline, and then selected on the basis of the variety of time intervals that had elapsed since cessation of dredging. Comprehensive time-series investigations of the sediments and benthic macrofauna were conducted at sta-

tions corresponding to different degrees of dredging intensity. Two of the sites are located in the North Sea: one offshore of Felixstowe in the outer Thames region (Area 222) and the other offshore from the Humber estuary (Area 408). Both these extraction areas were isolated from the possible impacts of dredging from other licensed areas. In addition, two extraction areas within the Eastern English Channel were targeted for study, both located on Hastings Shingle Bank (Hastings Areas X and Y). The Hastings sites were selected on the basis that both contained similar deposits and biological habitats, but each was exposed to different dredging regimes in terms of the frequency and intensity of extraction operations (with the potential to impose different degrees of impact on the areas).

Information from the electronic monitoring system (EMS) was used to precisely target locations of varying dredging intensity during the design of seabed surveys. Areas of the seabed subjected to high and lower levels of dredging intensity were sampled alongside reference locations. The reference sites were located well outside the likely influences of dredging operations and were chosen because they were representative of conditions in the wider environment. Sidescan sonar surveys indicate that, after the cessation of extraction, the physical effects (i.e. presence of weathered dredge tracks) can be detected for at least three years at Hastings Area Y, seven years at Hastings X, four years at Area 408, and ten years at Area 222.

In general, sediments collected from areas previously exposed to high levels of dredging intensity tended to contain proportionally more sand and less gravel than other sampled sediments. There was also evidence of greater patchiness in the substrata within the surveyed extraction sites. This variability among replicate samples was also evident in some of the biological samples from dredged locations, which was considered to be an identifiable symptom of perturbed conditions. The absence of comprehensive baseline data for each of the extraction areas precludes definitively attributing cause-and-effect relationships. Despite this, evidence from this study suggests that the fauna remains in a perturbed state in areas previously subjected to "high" levels of dredging intensity: at least three years at Hastings Area Y, four years at Area 408, and seven years at Area 222. Deposits exposed to lower levels of dredging intensity at Area 222 and Hastings Area X were found to be almost indistinguishable from the surrounding sediments in terms of species variety and population densities of macrobenthic invertebrates within a period of six to seven years after cessation.

Precautionary fishery monitoring related to aggregate extraction

Any assessment of the effects of marine aggregate extraction on the marine environment must include the fish resources and commercial fisheries in the vicinity of the licence application. During the scoping and environmental impact assessment of the application, key issues related to the life-cycle stages of fish and shellfish, or the commercial exploitation of these species, will be noted. Sufficient information for these species must be gathered to describe the spatial distribution and timing of migrations, spawning events, etc., and to indicate the times and locations where conflicts could arise with the aggregate industry. Detailed knowledge of the local patterns and seasonality of commercial fisheries and shellfisheries must also be available to highlight the most sensitive areas and seasons where displacement of fishing activity may be most serious.

The data available from this part of the assessment process must be sufficient to allow the regulator to judge whether or not mitigation is required before the licence to

dredge is granted. Mitigation measures can involve a zoning plan to minimize the extent of dredging activity, restrictions on annual tonnage removed, area exclusions to protect sensitive parts of the seabed, such as spawning grounds, seasonal restrictions on dredging activity, or limitations on the level of screening to reduce the concentrations of resuspended sediments. Under some circumstances, it may be necessary to refuse a licence in order to protect particularly vulnerable features. Licensing is normally accompanied by a monitoring programme to confirm that the mitigation measure or measures selected have been effective and that no adverse effects will result from a licence.

It is important to note that such monitoring activities are not designed as experimental programmes to investigate the effects of aggregate extraction on fish and shellfish populations. Monitoring or low-level surveillance programmes merely provide time-series data, which need to be investigated more fully if they show undesirable or rapid changes in slope. Such follow-up investigations must be hypothesis-based and must consider the full range of physical factors known to influence the distribution and relative abundance of marine fish and shellfish populations. These studies are not usual, however, and decisions often rely on evaluation of data from monitoring programmes that may not have been designed with high levels of statistical rigour.

This section reports briefly on a case study from the south coast of England concerning the establishment of a protocol for assessing the effects on fish catches of a seasonal restriction on dredging (Rogers and Nicholson, 2002). It demonstrates how fish monitoring is most effective when underpinned by a decision-making procedure related to meaningful scientific outcomes. There are considerable benefits if this procedure can be agreed before licensing and monitoring begins. The decisions that follow are precautionary and lead to adequate levels of sampling, unambiguous conclusions, and an agreed basis for decisions between both industries.

Background of the study in the south coast of England

When considering applications for marine dredging, particularly those in areas that are important for fish spawning, migration routes, or as nursery and overwintering grounds, it is UK government policy to adopt a precautionary approach (DETR, 2001). The UK Marine Minerals Guidance Note 2 (DETR, 2001) states:

> **§41**. Where necessary, conditions will be imposed to restrict dredging activities to particular times of the year or states of the tide, in order to allow access by fishermen, or avoid disturbance of fisheries, at critical times of the year. The effectiveness of such restrictions will be carefully considered where permissions are periodically reviewed after five and ten years.
>
> **§56**. To ensure that the monitoring programme is cost-effective, it is essential that it has clearly defined objectives derived from the potential impacts predicted by the EIA. The results should be reviewed at regular intervals against the stated objectives and the exercise should then be continued, revised, or terminated depending on the findings.

Trends in sole (*Solea solea*) catches at an aggregate licence at Hastings were assessed to provide a monitoring programme that conforms to these precautionary ideals. The effectiveness of the programme was reviewed at regular intervals to confirm that the mitigation measure was achieving its intended purpose.

The fixed-net fishery for sole inshore of Hastings Shingle Bank has traditionally been one of the most important UK fisheries in the Eastern English Channel, but catches

have declined since the late 1980s. The occurrence of regionally important deposits of aggregate at Hastings Shingle Bank has led fishers to believe that the decline in catches is related to this activity, although comparison of fish landings and extraction rates of aggregate had not demonstrated any direct relationship. A monitoring programme that compared catches at traditional fishing grounds and at a nearby control site provided no evidence of a spatial difference. Analysis of trends in commercial landings at Hastings and ports east and west suggested, however, that only Hastings and one neighbouring port, Eastbourne, had undergone a consistent decline in catches.

Although there is no evidence that dredging at Hastings is directly responsible for the decline in sole catches, the continuing decline in landings at Hastings, but not at similar ports in the area, was a concern, and suggested a precautionary approach. As a result, a seasonal restriction on dredging was imposed during the spring spawning period (mid-February to the end of April), on the assumption that aggregate removal might be impeding the onshore migration of fish.

The purpose of such a mitigation measure is to improve catches, preferably to the pre-dredging catch level. However, if the catches of sole remain the same or continue their steady decline after the dredging restriction has been implemented, the fishers may argue for an extension of the restriction, on the assumption that the original restriction has not yet been effective. On the other hand, the aggregate industry will want the restriction removed on the grounds that it has been ineffective. If catches increase, the fishers will assume that the restriction has been effective, and so they may argue for it to be sustained, because the inverse relationship between dredging and catches has been demonstrated. In this case, the aggregate industry could argue for the restriction to be lifted, because catches have improved and the restriction is now unnecessary. Such disputes could be avoided if the basis for future decisions was identified and agreed before the restriction and the monitoring begin. At its simplest, this agreement on clear monitoring objectives and an appropriate level of sampling may only be possible at a scientific level. However, the benefits would be even greater if such agreements included policy-makers, and if future decisions were agreed by both the fishing and dredging industries.

A precautionary approach

If there is no significant difference between the pre-dredging fish catch and catches after the dredging restriction has been applied, there are two possible explanations: either there was no effect to be seen or there was an effect but the test had insufficient statistical power, perhaps because the frequency of fish sampling or the extent of replication were inadequate. These hypotheses are unprecautionary because the burden of proof is on the fishers, who have to establish that their catches are less than they should be. A more precautionary approach would be to reverse these hypotheses and agree an acceptable level of impact. The null hypothesis is then that the impact is worse than this agreed level. If a small (e.g. 20%) reduction in pre-dredging catches is acceptable, then the monitoring programme has to show that the catches are significantly better than this, that is, they fall within zone A of Figure 4.4.6 (Rogers and Nicholson, 2002).

To test whether or not the control measures have failed to improve the catch, the procedure is reversed. In this case, an acceptable minimum recovery rate in catch rates is agreed (e.g. >20%); if, at some future date, recovery is significantly less than 20%,

then it can be concluded that the restriction has had no effect (i.e. fell in Zone C of Figure 4.4.6).

Actions or decisions must now be associated with these hypotheses. For example, catch rates falling within Zone A (fishery recovered) suggest that the dredging restriction has been effective and should be maintained, but monitoring should eventually be reduced to a watch-dog level as a safeguard against further reduction. Catch rates that consistently fall within Zone B suggest that the fishery is recovering and that monitoring should continue. In Zone C (no recovery), the dredging restriction has had no effect and other mitigation measures should be evaluated. To test these hypotheses, a statistically designed monitoring programme will be needed, with a corresponding set of statistical tests of significance.

Such a monitoring protocol was at Hastings in 2002 to assess the trend in the ratio of sole catches at Hastings to those at nearby ports. A full description of the methods used to define the upper and lower thresholds used in the assessment are provided in Rogers and Nicholson (2002). Although it is too early to evaluate the success of this precautionary approach to monitoring the sole population at Hastings, the following hypothetical example illustrates the procedure. In this case, the minimum and maximum annual fish catch ratios calculated from the most recent five years have been chosen as the evaluation criteria. Thus, a dataset that generates data points in Zone B (Figure 4.4.7, Example 1) will suggest that monitoring should continue at Hastings, because the effectiveness of the mitigation measure will not have been confirmed. In contrast, the trend patterns illustrated in Figure 4.4.7 indicate that the restriction was either successful (Example 2) or had had no effect (Example 3).

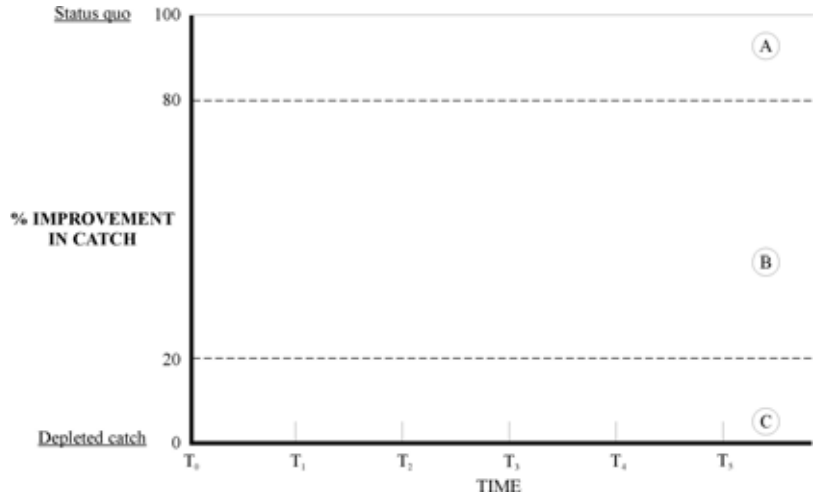

Figure 4.4.6. Schematic figure showing a method of evaluating a precautionary monitoring scheme. If a certain reduction from a previously favourable catch (*status quo*) is acceptable, then the monitoring programme must show that the catch is significantly better than this (i.e. in Zone A). To test whether or not the management measures have failed to improve the current catch, the procedure is reversed. If, at some future date, the catch is significantly less than the agreed level of worthwhile improvement, then it can be concluded that the ban has had no effect (i.e. in Zone C). Catches in Zone B suggest that there may be an improvement.

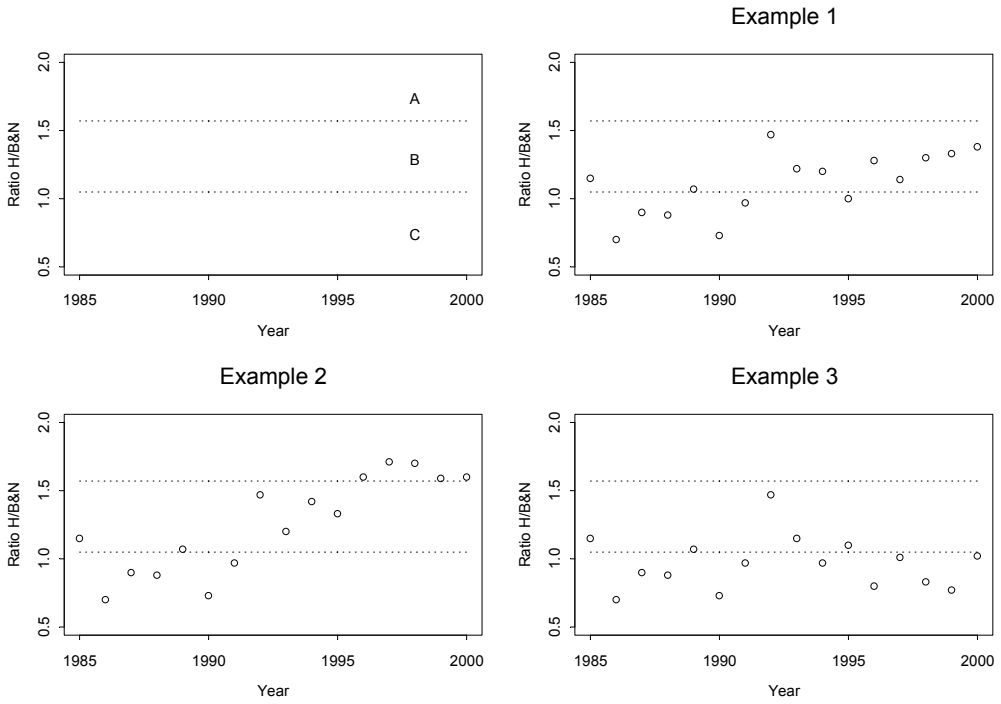

Figure 4.4.7. Three examples of possible scenarios showing how different patterns of monitoring results lead to different decisions.

Discussion of the precautionary study in Hastings

Although a five-year ratio of catches has been used at Hastings, many other statistical procedures could be adopted, such as the use of average or median catches, and for a longer or shorter duration. Some procedures are more stringent than others, and their selection should be based on local monitoring conditions and management priorities. Whatever measure is chosen, the short-term precautionary objective for sole catch rates at Hastings is to apply a restriction on dredging in the hope that the fishery can regain relative parity with catch rates at nearby ports. The statistical procedure has been chosen to reflect this objective, but has been extended to provide a test of an additional outcome – that the restriction has had no effect. Also, although the procedure is simple to apply, deciding on the values that separate the three zones (see Figure 4.4.6), namely for an acceptable reduction in the historical pre-dredge catch and for an unacceptably small increase in the current catch, may be difficult.

However, these issues are mostly about the choice of procedure. The essential difference with this approach is that it makes these choices explicit and reverses the burden of proof from merely demonstrating an impact (unprecautionary) to demonstrating an acceptable level of impact (precautionary).

Catch rates of edible crab on Hastings Shingle Bank

Background of the crab study in relation to gravel dredging

The fishery for the edible crab (*Cancer pagurus*) around Shingle Bank off Hastings, in the Eastern English Channel, was pioneered in the 1980s and now produces 50–100 t of crabs annually. Following a positive Government View, gravel dredging began in a licensed extraction area on Shingle Bank in 1989, and has continued to the present day through subsequent licence renewals in 1996 and 2001. The principal crab fisher in the area contends that dredging on Shingle Bank threatens his livelihood. He ar-

gues that sediment plumes emanating from the dredging or the dredger spillways are transported by the local tidal ellipse towards his crab pots, which are set south and east of Shingle Bank. His contention is that these sediment plumes smother his pots and adversely affect his catch rates. In view of these concerns, the dredging licence was issued on condition that a monitoring programme be carried out by the licence holder in order to identify any changes in the catch rate of crabs following the onset of dredging and to evaluate whether or not those changes could be linked to dredging activity. In this report, we summarize the data on crab catch rates collected and analysed as part of the monitoring programme, and discuss what further data are required before we can evaluate fully whether or not gravel dredging has had any impact on local crab stocks. The full results of the analysis of crab data can be found in Bannister (2004).

Data on catch rates of crabs

The fisher's contentions about the impact of dredging on crab catches were investigated through a major analysis using two data sources. First, the fisher's personal logbooks, which contain daily records of crab catches, with detailed positional information, were analysed to identify any changes in catch rates covering the pre- and post-dredging periods. Second, as a condition of the renewal of the dredging licence in 1996, the dredging companies were required to finance the independent monitoring of crab catches in the Shingle Bank area using "sentinel" strings of crab pots set and hauled during the main autumn season. The sentinel strings were fished by the local fisher, but catch data were recorded on a pot-by-pot basis by environmental consultants on board the vessel. The two sets of data were analysed at varying spatial scales to test the general hypothesis that, if the fisher's contentions were correct, the catch rates of crabs in pots fished in areas likely to be influenced by settlement of sediment plumes would be lower than those in areas well away from the dredging operation.

Results of data analysis

Prior to analysis, the catch rate data from the fisher's commercial strings of pots were grouped into areas determined by the approximate northeast–southwest movement of the sediment plume on the prevailing tide and the seasonal westward movement of the crabs along the southern slope of Shingle Bank. In particular, catch rates of crabs from strings fished in downstream "treatment" areas potentially at risk from transported sediment south and southeast of the dredging area (Areas A and B) were compared with catch rates from an upstream "control" area (C) northwest of Shingle Bank unlikely to be affected by sediment from dredging. Good-quality data from these commercial strings of pots were available for 1985–2003. Analysis demonstrated that, following the onset of dredging in 1989, there had been a sudden drop in catch rates in all three areas in 1991, but the decline in catch rate was greater in treatment areas A and B than in control area C. There was no overall downward trend in catch rates of crabs either before or after 1991, when this "step change" was observed. More detailed comparison of the catch rates from strings of pots closer to (inner strings) and farther out from (outer strings) the southern slope of Shingle Bank in areas A and B demonstrated that catch rates from the inner strings had declined compared with catch rates from the outer strings. This change in relative catch rates was generated by a stable catch rate in the outer strings, but a gradual and progressive decline in catch rate in the inner strings.

Analysis of the catch data from the fisher's commercial pots provides some support for the hypothesis that catch rates of crabs had declined close to the dredging area on Shingle Bank. However, the observation that catch rates also declined in the control area, albeit to a lesser extent, indicates that other factors, in addition to dredging, may be driving the observed change in crab catch rates.

Three strings of sentinel pots were fished: two across the crab migration path south-east and east of Shingle Bank and a "control" string farther south. Although catch rates averaged at the string level were generally higher in the southern area farthest from the dredging site, analysis of the catches on a pot-by-pot basis demonstrated no clear evidence of lower catch rates in pots closest to Shingle Bank at the northern end of the strings. Therefore, no measurable effect was found that might be attributable to the settlement of the sediment plume from the dredging operation.

Discussion of the catch rates of crabs in relation to gravel dredging

Although the data analysis demonstrated a clear stepwise decline in catch rates of crabs following the onset of dredging, the results were somewhat equivocal. Analysis of the fisher's commercial catches demonstrated clearly that catch rates in strings of pots close to the dredging site were lower than catch rates in strings farther from the dredging site, supporting the hypothesis that settlement from the sediment plume on the fishing grounds had caused a reduction in catch rates of crabs. In contrast, there was no clear evidence from the analysis of the catch rates from the sentinel strings that catch rates were lower closer to the dredging site.

The analysis was complicated by the fact that fishing effort had increased significantly from 1991/1992 onwards (i.e. 2–3 years after the onset of dredging), particularly in the area east of Shingle Bank; this area is thought to be the source of the crabs, which exhibit seasonal migrations westwards across the main fishing grounds. Taken at face value, the commercial data show that catch rates of crabs were lower following the increased fishing effort in 1991/1992 than in the period prior to the onset of dredging (1985–1989). This raises the possibility that the observed decline in catch rates of crabs may be caused by increased fishing effort, either in addition to, or in place of, the potential effect of dredging.

Interpretation of the observed step change in catch rates of crabs in relation to these two potential causes – onset of dredging and increased fishing effort – is complicated. There is no doubt that there has been an abrupt drop in catches, but its timing did not fit well with either the onset of dredging or the increase in fishing effort. There is a significant time-lag between the onset of dredging and the observed decline in catch rates, whereas the increase in fishing effort appears to occur after the step change in catch rates. This lack of synchronization of observed effect with potential causes suggests that there may be other factors driving the observed changes in catch rates of crabs, a hypothesis supported by the observation that the step change in catch rates in 1991 was observed in both treatment and control areas.

Conclusions and implications for monitoring programmes

Some general conclusions can be drawn from this case study, which may have implications for other monitoring programmes concerned with the potential impact of dredging on commercial fisheries. First, the Shingle Bank crab-monitoring programme demonstrates that unequivocal results will not necessarily be obtained, even with long time-series of good-quality fisheries data. Second, the analysis of crab catch-rate data, on its own, cannot provide a definitive statement or proof about

cause, because the data do not inherently contain causal information. Conclusions about cause and effect, therefore, rest on interpretations of whether the crab fishery changes are what would be expected if the cause was either sediment transport or some other factor, such as fishing effort. This report highlights how difficult it is to reach scientifically firm conclusions in this context. What is required is either more scientific data from the field about sediment transport or more information about alternative biological or mechanical hypotheses, including, for example, the possibility of some cause farther east at whatever location is the actual source of the crab migration that feeds Shingle Bank each autumn. Logger pots have been used in attempts to link the occurrence of sediment pulses in the vicinity of crab pots to the local pattern of dredging activity at Shingle Bank, but no convincing answer was obtained.

This study highlights the need to ensure that monitoring studies on catch rates in fisheries are carried out in conjunction with physical, benthic, and other monitoring programmes that can identify the likely mechanisms through which dredging operations can potentially affect catch rates in commercial fisheries. It is essential that the purpose of any fishery-monitoring programme is made clear before it is implemented. Without concurrent physical and benthic monitoring, the monitoring of catch rates in commercial fisheries will not provide answers to questions about the potential impacts of dredging operations. In these circumstances, the monitoring programme becomes a surveillance exercise, which simply identifies changes in commercial catch rates without evaluating the causes of those changes. It is important, therefore, to differentiate between the differing capabilities of the various forms of monitoring programmes at their outset.

4.5.7 European projects

RIACON project (the Netherlands, Denmark, Germany, Belgium, and Spain)

The RIACON (Risk Analysis of Coastal Nourishment Techniques) project involved an investigation of the responses of benthic assemblages at sites in Denmark (Torsminde), Germany (Norderney), the Netherlands (Terschelling), Belgium (de Haan), and Spain (Costa Daurada). Recolonization following sand extraction with a suction trailer dredger was studied (Essink, 1997; Sardá *et al.*, 2000; van Dalfsen *et al.*, 2000; van Dalfsen and Essink, 2001). In each case, a baseline survey was conducted prior to the commencement of dredging. The sediment composition of the North Sea borrow sites varied little after extraction, although there was a slight reduction in the organic content of sediments at the Terschelling site. In contrast, sediments at the extraction site at Costa Daurada had changed considerably after extraction, with a 5–20 cm layer of fine sediment overlying material similar in composition to the original substrate.

A reduction in abundance and biomass was observed at the North Sea sites. Post-dredging monitoring also revealed a rapid increase in the abundance of the opportunistic polychaetes *Spio filicornis*, *Capitella capitata*, and *Spiophanes bombyx* within the first year. However, two and half years after sand extraction at the Terschelling site, the biomass and age composition of longer living species, such as the bivalve *Donax vittatus* and the heart urchin *Echinocardium cordatum*, had not returned to pre-extraction levels (van Dalfsen and Essink, 2001). Similarly, at the Mediterranean borrow site, there was a significant increase in the abundance of the opportunistic polychaetes *Capitella capitata* and *Malacoceros* sp. Van Dalfsen and Essink (2001) concluded from these investigations that the response of benthic assemblages to aggregate ex-

traction was related to the site-specific differences in hydrodynamics and the associated sediment transport regimes.

EUMARSAND project

The EUMARSAND project (European Marine Sand and Gravel Resources: Evaluation and Environmental Impact of Extraction) was a Research Training Network funded by the European Commission within the fifth Framework Programme "Improving the Human Research Potential and the Socio-economic Knowledge Base", and was conducted over a four-year period up to January 2006 (Bonne *et al.*, 2006). Young European researchers were trained at nine institutes in eight countries in the interdisciplinary research approaches needed for resource prospecting and the environmental impact assessment of marine aggregate extraction using state-of-the-art knowledge and instrumentation.

The objectives of EUMARSAND comprised the estimation of usage, assessment of resource availability, and comparison of the compatibility of the different national licensing/regulatory regimes within the present European environmental legislation and international conventions.

With regard to the field studies, two sites were investigated: one along the tidal Belgian coast and one in the non-tidal Baltic Sea. In the southern North Sea, the centre of a tidal sandbank (Kwintebank) was selected for investigation. This area of seabed has been intensively extracted since the 1970s, resulting in a central depression within which sand extraction has been suspended for three years. In the Baltic Sea, gravel and sand extraction areas were investigated in the German Tromper Wiek area. These sites have been subjected to different aggregate extraction techniques, namely trailer and static suction hopper dredging, respectively.

Both study sites have been surveyed using state-of-the-art geophysical/geological techniques and instrumentation (acoustic data from seismic profiles; multibeam and sidescan sonar surveys; ground-truthing sediment samples from vibrocores, box-cores, and van Veen grabs; video imagery). The physical impacts of the extraction activity on the seabed have also been assessed using hydrodynamic, sediment-dynamic, and morphodynamic modelling, calibrated/validated by high-quality *in situ* measurements (bottom- and hull-mounted acoustic Doppler current profiler (ADCP), ACDP S4, autonomous benthic landers). Ecological impacts have been investigated for Kwintebank, and the physical effects on the adjacent coastline were assessed for the Baltic Sea area between Warnemünde and Darss.

Main conclusions for the Kwintebank study area in the North Sea

Sedimentological and biological sampling indicated that the central depression, in which sand extraction is very clearly distinguished from its sandbank surroundings, does not show any geomorphologic or sedimentological restoration after the cessation of extraction. Furthermore, the area in the central depression tends to behave as a swale, not as a sandbank feature. These results further suggest that the sandbank environment should not be considered as an infinite resource of renewable sand deposits. The central depression has been excavated almost down to a deeper and coarser deposit layer. This was ascertained from seismic profiles of Kwintebank. It is still uncertain whether or not sediment resources exist that could be transported from the surrounding area to substitute for the extracted sediments over the longer term. Hence, it has been suggested that this dynamic sandbank system should be considered as a relict sediment source. These findings have opened the debate whether

dredging activity should be concentrated in one area, leading to exceeding the environment's carrying capacity or should be more diffusely distributed across a greater number of areas with limitations on the extraction intensity.

Main conclusions for Tromper Wiek and Warnemünde–Darss study areas in the Baltic Sea

The bed of the gravel extraction pits were found to be covered by sand arising from on-board screening of the fine material during the dredging process. The pits did not refill completely, but remained relatively stable for at least several years, based on evidence from sidescan sonar imagery. At the sand extraction site, the comparison of the multibeam bathymetry before and after sand extraction demonstrated an infill of 25% of the sand extraction furrows in the first three years after extraction. Higher suspended sediment concentration was observed inside the pits as a result of advection of fine sediment towards the pit, in which it was retained. In the long term, fine sand was found to be preferentially trapped. This may reduce the overall sediment budget towards the coast and enhance erosion. Further investigations of the sediment balance in the pits, based on the long-term, wave-climate information prevailing in the area, would assist with the development of guidelines for gravel extraction in the area, in terms of water depth for extraction and the dimension of the pits.

The coastal impact of sand extraction was also investigated in the area between Warnemünde and Darss. Because of the extensive shore protection structures, it was difficult to distinguish between natural and artificial coastal change, and no direct relationship was found between changes in the coastline and the bathymetry. The alterations in bathymetry over a 20-year period are very subtle, but sufficient to produce significant changes in sediment transport potential at the coast. There is little input of sediment into the system, so if an increasing amount of sand is extracted for industrial use, and leaves the system, it may have a negative effect on the total sand budget and consequently on the coast.

Detailed information on the methodology and field surveys is available online at http://www.azti.es/eumarsand/.

4.6 Summary of Case Studies

From studies of dredged sites (Cressard, 1975; Kenny and Rees, 1994, 1996; Kenny *et al.*, 1998; Newell *et al.*, 1998; Desprez, 2000; van Dalfsen *et al.*, 2000; Krause, 2002; Boyd *et al.*, 2003b) and from observations following defaunation caused by storm disturbance (Eagle, 1973, 1975; Rees *et al.*, 1977), a general pattern of recolonization is emerging (see also ICES, 2001). The first stage involves the settlement of a few opportunistic species able to take advantage of the dredged and sometimes unstable sediments (Hily, 1983; Kenny and Rees, 1994, 1996; Kenny *et al.*, 1998; van Dalfsen *et al.*, 2000; van Dalfsen and Essink, 2001). Recolonization can be either by adults or larvae from the surrounding area if the disturbed area is similar to the original substrata (Cressard, 1975), or by larvae from more distant sources if the sediment is markedly different (Santos and Simon, 1980; Hily, 1983; Desprez, 2000). These species can substantially increase the overall abundance and numbers of species during the early stages of post-dredging recolonization (Hily, 1983; Lopéz-Jamar and Mejuto, 1988; Kenny and Rees, 1994, 1996; Kenny *et al.*, 1998; Desprez, 2000; van Dalfsen *et al.*, 2000).

A second phase is characterized by reduced community biomass, which can persist for a number of years (Kenny and Rees, 1994, 1996; Kenny *et al.*, 1998; Desprez, 2000; van Moorsel, 2003). There is a natural expectation that biomass will remain reduced,

while new colonizers "grow on" to a maturity comparable with the pre-dredging age–size profile (Rees, 1987; van Dalfsen and Essink, 2001). Evidence from the case studies above suggests that the reduced biomass values may be caused by increased sediment (mainly sand) transport, which scours the epibenthos. Paradoxically, it is this sandy sediment that is also responsible for the infilling of dredge tracks (Kenny *et al.*, 1998; ICES, 2001; Limpenny *et al.*, 2002; Diesing *et al., 2006*) and, in the longer term, promotes physical stability.

Over time, it may be expected that, at some sites, the bed-load transport will approach the pre-dredged equilibrium, allowing the restoration of community biomass (Kenny *et al.*, 1998). A similar model of response has been represented schematically by Hily (1983) and includes a further stage in which opportunists are replaced by a greater number of species. It was suggested that this replacement is the result of increasing levels of interspecific competition. However, this model was based on observations following the dredging of a sandy mud (Hily, 1983). Further evidence is required to establish whether or not such oscillations occur in more stable gravel habitats during the later stages of succession.

Many of the field studies reported above, and those in the literature, are the result of investigations on the impacts of short-term dredging events. These have proven useful in determining the rates and processes leading to benthic re-establishment following aggregate extraction. From such studies and from studies undertaken at sites exploited for commercial interests, a general pattern of response to marine aggregate extraction is emerging. This needs to be tested to establish its general validity in all environments, particularly in areas that have been exposed to industrial-scale dredging operations over many years. From such work, it is clear that re-establishment of a community similar to that which existed prior to dredging can only be attained if the topography and original sediment composition are restored (for a contrary view, see Seiderer and Newell, 1999). Should physical stability of the sediments not be attained, however, it is hypothesized that communities will remain at an early developmental stage.

5 Aggregate resource management policy, legislative frameworks, and risk assessment

5.1 Review of developments in national authorization, administrative framework and procedures, and approaches to environmental impact assessment

5.1.1 Introduction

The main objectives of this section are to:

- show the development of EU and OSPAR regulations and review the regulating regime and environmental impact assessment (EIA) approaches during previous years (1998–2004);
- show the differences in approach in several countries without being prescriptive as to a preferred option;
- emphasize that countries are free to organize this in their own way, but must be transparent about their regulations, both to the industry and to non-governmental organizations (NGOs);
- identify general trends, both in regulations and in EIA approaches.

The information presented in this section is based on a compilation of information drawn from the annual reports of the ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) for the period 1998–2004.

5.1.2 Belgium

The exploration and exploitation of sand and gravel in certain areas on the Belgian continental shelf is regulated by the law of 13 June 1969, amended by the law of 20 January 1999 and the law of 22 April 1999. Two implementing Royal Decrees (RDs) were published in the Belgian State Bulletin (BSB 07.10.2004).

- RD of 1 September 2004 (BSB 07.10.2004), regarding conditions, geographic limits, and procedures for granting licences; the "Procedure decree"
- RD of 1 September 2004 (BSB 07.10.2004), regarding rules for environmental impact assessment (EIA)

An application must be sent to the Minister of Economic Affairs. At the same time, the environmental impact report (EIR) must be sent to the Management Unit of the North Sea Mathematical Models (MUMM), which has to prepare an environmental assessment for the minister responsible for the marine environment. The application will not proceed without positive advice from this minister.

The decree for an EIA foresees the possibility that an integrated EIA can be produced. This is possible because the extraction zones in Belgium are defined by royal decree, and all permit holders have access to these zones. An integrated EIR is valid for three years and can be used by all permit holders, who have to renew their permit during that time. A new applicant cannot make use of this EIR and will have to provide the missing information identified by the administration that reviewed the EIR and is responsible for the EIA.

An Advisory Committee has been installed to ensure coordination between the administrators involved with the management of the exploration and the exploitation of

the continental shelf. A specific task of this committee is to evaluate a three-year review report in the light of continuing research.

Figures 45 and 46 show flowcharts of the procedures for granting licences and the regulation of the EIA.

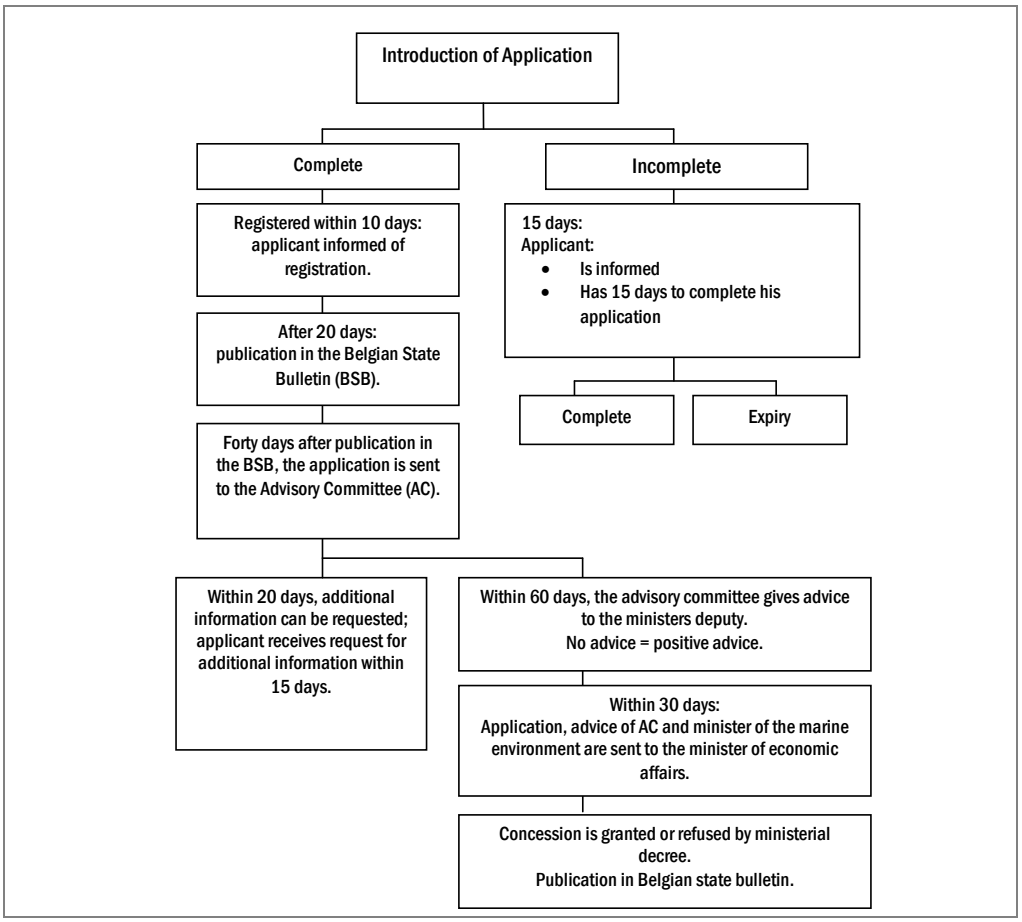

Figure 5.1.1. Flowchart showing the new application procedure in Belgium.

In the procedure decree, three control zones are defined, each divided into sectors for which a concession can be issued. The accessibility for the control zones is defined as follows.

- Sectors 1a, 2c, and 3a are open for exploitation all year.
- Sector 1b is only open for exploitation during March, April, and May.
- Sectors 2a and 2b are open for exploitation for alternate periods of three years. Thus, when the Advisory Committee, which was established by RD of 12 August 2000 (BSB 27.09.00) opened Sector 2a from 15 March 2005, Sector 2b was closed for exploitation.
- Sector 3b is closed for exploitation as long as the sector is still being used as a dumping site for dredged material.

In addition to the control zones, there is an exploration zone, defined as Zone 4. The locations of the zones and sectors are shown in Figure 5.1.3.

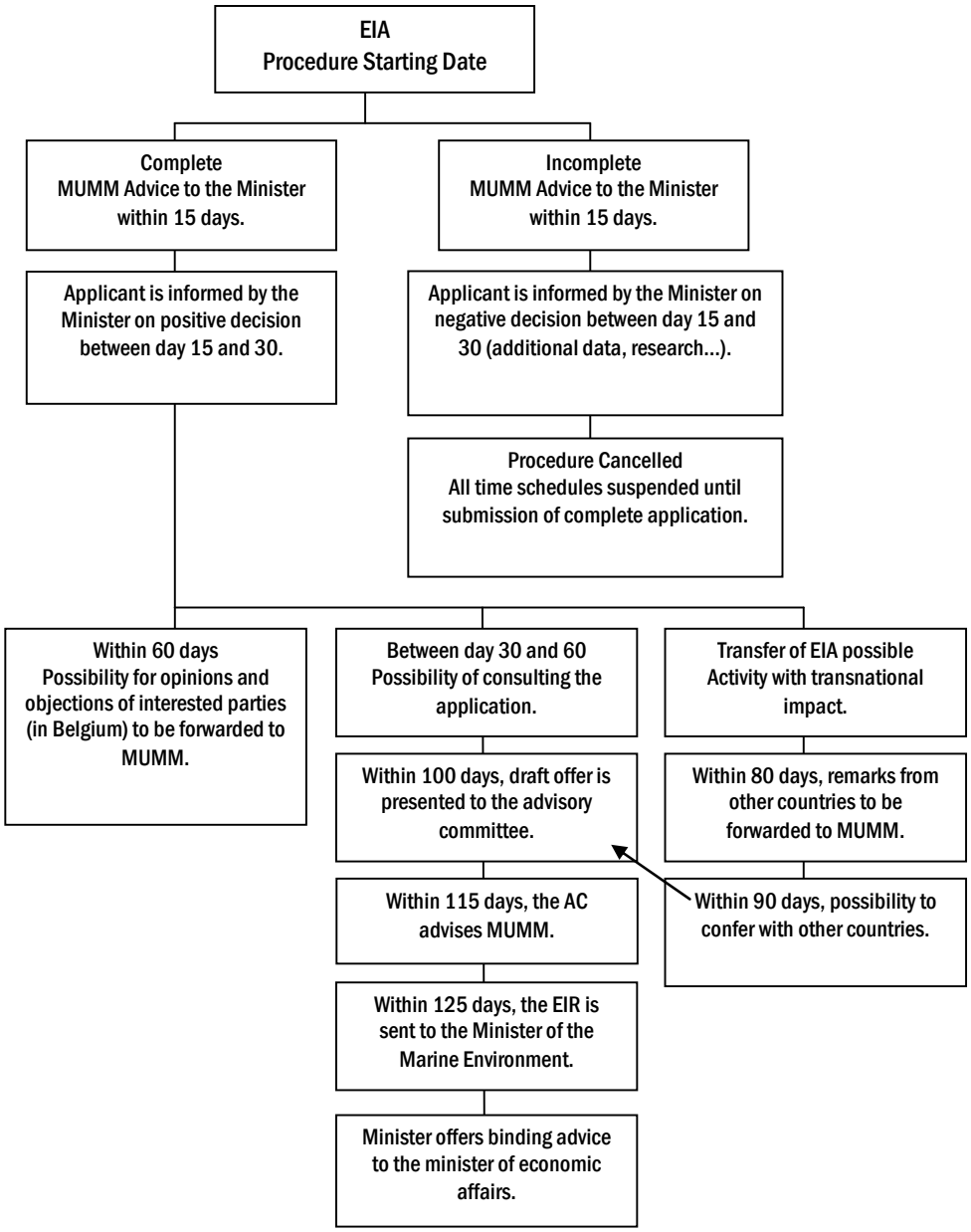

Figure 5.1.2. Flowchart showing the new EIA procedure in Belgium.

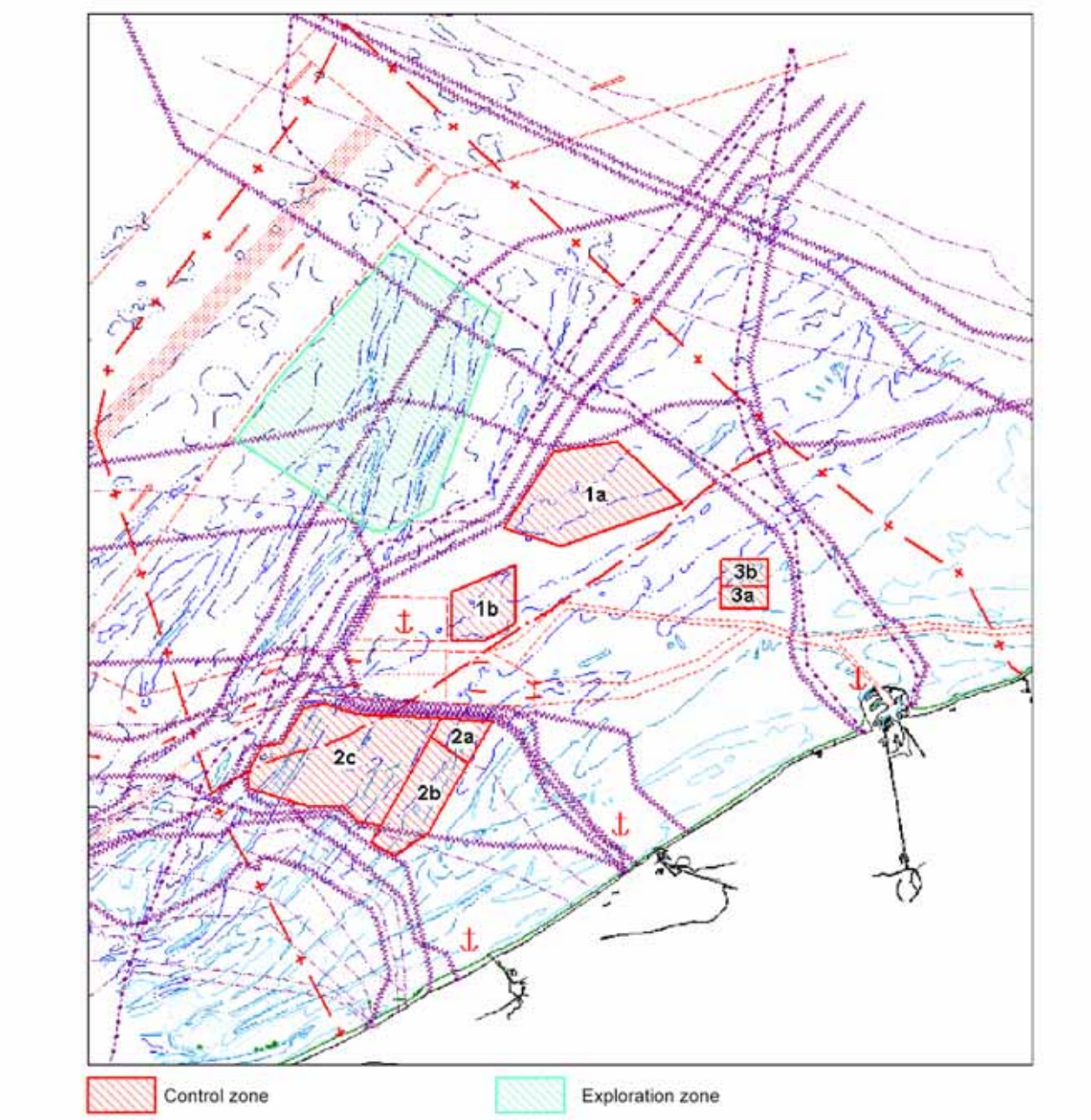

Figure 5.1.3. Map showing new marine sediment extraction zones on the Belgian continental shelf.

5.1.3 Canada

Canada proclaimed the Oceans Act in 1997, which, in domestic law, recognizes Canada's jurisdiction over its maritime zones. It establishes the authorities and responsibilities required to support Canada's new ocean management regime. Under this Act, the Department of Fisheries and Oceans (DFO) leads the development and implementation of Canada's Ocean Strategy (COS), with the cooperation and collaboration of the 23 federal departments and agencies with ocean-related responsibilities. Based on three principles – precautionary approach, sustainable development, and integrated management – COS was destined to become a coordinated policy and decision-making process for ocean management.

The Oceans Act has established a new approach to the management of Canada's oceans based on an ecosystem approach, and calls for consideration of the impacts of all human activities on the respective ecosystem. The Policy and Operational Framework for Integrated Management (IM) recognizes that management objectives and planning practices must reflect the fact that ecosystems nest within other ecosystems, and it proposes that IM will extend from scales of Large Ocean Management Areas (LOMAs) to Coastal Community Planning Areas, with a range of connected and nested structures providing options for regional scales of response within this spectrum.

The Oceans Act integrates all activities, and the maintenance of ecosystem health becomes paramount in decision-making. Special areas, termed marine protected areas (MPA) are given protection in the act. Overall, the objective has been to strike a balance between the maintenance of sustainable marine ecosystems and the development of marine resources. The Oceans Act provides the context within which existing and future activities in, or affecting, marine ecosystems will occur. An offshore minerals industry has been identified as an emerging new oceans technology industry.

5.1.4 Denmark

In Denmark, the National Forest and Nature Agency is responsible for the administration of marine aggregate extraction in territorial waters and on the continental shelf under the Raw Materials Act.

A new Raw Materials Act came into force on 1 January 1997 (Consolidated Act No. 569 of 30 June 1997). Since this date, all new dredging activities must take place in permitted areas. A ten-year transitional period is allowed for dredging in 117 temporary areas.

New dredging areas are subjected to a Government View procedure, including public and private involvement. The applicant is requested to provide sufficient documentation about the volume and quality of the resources in the area and to carry out an EIA (Executive Order No. 1167 of 16 December 1996). Permits are granted for a period of up to ten years.

On 1 January 2003, a minor change in the Raw Materials Act was made, making it possible to extract materials other than sand and gravel in international protected areas and at water depths less than 6 m. The amendment includes extraction of other resources (e.g. shells) within the same administrative framework as the extraction of sand and gravel. The administration of extraction in international protected areas and in water depths less than 6 m is very restrictive and is only permitted when a valuable resource can be extracted without deleterious effect on the local environment.

In addition to permits for dredging in specific areas, dredgers must have authorization to dredge in Danish waters. In order to maintain sustainable and environmentally justifiable dredging activity, the total tonnage of the dredging fleet is to be held at the current level.

Extraction activities, which can be assumed to have a significant impact on the environment, may be permitted only on the basis of an assessment of the environmental consequences in accordance with EU Council Directive 85/337/EEC. The procedure is laid down in Executive Order No. 126 of 4 March 1999. Dredging of more than 1 million m^3 $year^{-1}$, or 5 million m^3 in total for a specific project or in a single area is always subject to this procedure.

The Danish Government has implemented the Århus Convention of 1998 on Access to Information, Public Participation in Environmental Decision-making and Access to Justice in Environmental Matters in the administration of marine extraction (Executive Order No. 835 of 4 September 2000). This Executive Order gives the public wider access for complaints about decisions made by the authorities in accordance with the Raw Materials Act.

The process of converting the temporary dredging area granted from 1997, in accordance with the new Act, began in 2002. The first permissions were given in 2004. It was expected that up to 80 areas would be evaluated and receive permission before 2007.

5.1.5 Estonia

In 2003, an EIA was executed under Estonian law for the extraction of 1 300 000 m^3 sand from the Gulf of Finland in the Estonian Exclusive Economic Zone (EEZ). The sand was intended for construction purposes. The EIA was undertaken by the Geological Survey of Estonia and the Estonian Marine Institute at the University of Tartu. The EIA was aimed at understanding the possible impacts on the marine ecosystem, including benthic communities, fish, fisheries, seabirds, and seals. Coastal impacts and impacts on seabed morphology were also determined. The EIA also detailed the monitoring programmes needed during and after the extraction.

5.1.6 Finland

Metsähallitus (Administration of Forests) was formerly responsible for the administration of land and sea areas owned by the state. Metsähallitus became a state-owned company in 1994, and the company transferred its business operations on soil resources to the Morenia Company in March 2006. Morenia sells the licences for marine sand extraction in territorial waters.

The Water Rights Court, according to the Water Act (19.5.1961/264), grants permits for the extraction of marine sediments.

The Act on Environmental Impact Assessment Procedures (468/1994) and the decree (792/1994) on 1 September 1994 put into effect the EU Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment. The Act was amended on 1 April 1999 to implement the changes required by EU Council Directive 97/11/EC, and a new decree (268/1999) was given in the same context. An EIA is now required if the working area is larger than 25 ha or the amount of extracted material is greater than 200 000 m^3.

Finland signed the 1998 Århus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters on 1 September 2004. In 2005, the Finnish Government submitted a new proposal to change the act and decree on EIA procedures to implement the Convention and EU Council Directive 2003/35/EC.

5.1.7 France

Since 1997, the extraction of calcareous and siliceous aggregates has been regulated by the Ministry of Industry.

Several applications are required to obtain a mining permit, state permission for dredging and, finally, an authorization to commence mining work. The procedures

are complex because of the succession of consultations and public inquiries at different phases of a project, and the investigations may take several years to complete.

Therefore, the Council of State and the Mining Mineral Council are seeking to reorganize the administration and to adapt monitoring and policy techniques to allow state decisions to become more transparent.

A remodelling of Ordinance 80-470 from 1980 was submitted to the Council of State in 2006. One of the main objectives is to reduce the length of the administrative procedure, which currently takes about two years, by combining the first of the two procedures:

- obtaining a licence (up to 18 months);
- obtaining dredging permission (six months).

It is proposed that only one application will be required to obtain the mining permit, state permission for dredging, and the authorization to begin the mining work. This application will include an impact study completed at the beginning of the investigation. The required preliminary studies and monitoring measures will be detailed in the new decree.

It is also proposed that a joint coordinated assessment of the consolidated application take place. This will include a single consultation of the administrative services concerned, which will cover all aspects of the application and occur only once during the assessment period. There will also be only one public inquiry, instead of two successive inquiries, regarding the different applications.

Local dialogue commissions, including all services and concerned parties, have been set up. These will include representatives from the different user groups, especially fishers. In addition, a monitoring committee will be set up by the prefect.

To encourage the identification of new extraction areas, state authorization will deliver, free of charge, exclusive research licences and preliminary prospecting authorizations if the volume of materials removed is less than 10 000 m^3.

5.1.8 Germany

Sediment extraction is covered by the federal Mining Law, the Mining Regulation for the Continental Shelf, and the Regulation for the Environmental Impact Assessment of Mining Projects.

The Mining Law and its amendments require descriptions of the impact on the coastal (and island) stability and fisheries. It also states that extraction cannot be permitted when impact on plants and animals exceeds the acceptable limit. In addition, the Mining Regulation covers activities that have a particular impact on the seabed and fisheries. These are described in detail in the Requirements for the Aspects of Fisheries and Ecology in the Guidelines of the Regional Mines Inspectorate.

North Sea

The organizations responsible for administering procedures relating to the extraction of marine minerals are the Bergamt Meppen and the Federal Waterways and Shipping Authorities for the Territorial Seas (12-nautical-mile zone); and the Oberbergamt Claustal–Zellerfeld and the Federal Maritime and Hydrographic Agency for the EEZ.

For the German part of the North Sea under the authority of the Oberbergamt (Regional Mines Inspectorate) in Claustal–Zellerfeld, the inspectorate introduced a guideline for obtaining permission for sediment extraction.

Baltic Sea

The organizations responsible for administering procedures relating to the extraction of marine minerals are the Bergamt Stralsund and the Federal Waterways and Shipping Authorities for the Territorial Seas (12 nautical mile zone); and the Bergamt Stralsund and the Federal Maritime and Hydrographic Agency for the EEZ.

For the Baltic Sea, HELCOM Recommendation 19/1 "Marine Sediment Extraction in the Baltic Sea" is used.

Germany introduced development planning into the EEZ by law on 20 July 2004. The ministry in charge is the Federal Ministry of Traffic, Building, and Housing. The Federal Maritime and Hydrographic Agency supports the ministry in setting up the objectives for planning, as well as the development plan itself, and performing the strategic EIAs.

The State Regional Planning Departments of Lower Saxony, Schleswig-Holstein, and Mecklenburg-Vorpommern establish development plans for their own territorial waters.

These activities are embedded in the implementation of the national strategy for integrated coastal-zone management. With respect to sand and gravel extraction, needs and impacts will be considered to identify suitable and/or potential areas in offshore waters.

5.1.9 Ireland

Coastal and marine environments are managed by means of sectoral legislation covering issues such as fishing, water quality, and coastal protection. There is little coherency between terrestrial planning (above mean high-water mark), foreshore planning (below mean high-water mark), and marine spatial planning.

However, within the current legislative and regulatory framework, there are a number of legislative bodies that have a significant bearing on potential marine aggregate extraction in Irish waters. These key regulatory mechanisms include the Foreshore Acts, and the Environmental Impact Assessment (EIA) Directive and Strategic Environment Assessment Directives (see below).

Foreshore Acts

The Foreshore Acts of 1933–1998 comprise three Acts.

- Foreshore Act 1933, No. 12
- Foreshore (Amendment) Act 1992, No. 17
- Fisheries and Foreshore (Amendment) Act 1998, No. 54

These acts require that a lease or licence be obtained from the Minister for Communications, Marine, and Natural Resources for undertaking any work or placing structures or material on, or for the occupation of or removal of material from, state-owned foreshore, which represents the greater part of the foreshore. The foreshore is the seabed and shore below the line of high water of ordinary or medium tides and extends outwards to the limit of 12 nautical miles (about 22.24 km).

Under these acts, leases are granted for the erection of long-term structures (e.g. piers, marinas, bridges, roads, car parks), and licences are granted for other work (e.g. laying submarine pipelines and cables) and purposes (e.g. aquaculture). Leases and licences are granted subject to the payment of fees, and the term of any lease cannot exceed 99 years.

A Foreshore Lease includes all minerals on or in the demised foreshore to a depth of 30 ft (10 m) from the surface of such foreshore, together with the right to get and take such minerals, but no such lease shall extend to or include any mines or minerals more than 30 ft (10 m) below the surface of the demised foreshore.

Environmental impact assessment directives

Certain developments on the state-owned foreshore are subject to the European Communities (Environmental Impact Assessment) Regulations, 1989–1999. These regulations require the preparation of an EIA, which must be provided to the consultative organizations specified in the Foreshore (Environmental Impact Assessment) Regulations 1990 (SI No. 220/1990). As set out in the European Communities (Environmental Impact Assessment) Regulations 1999 (SI No. 93/1999), an EIA must be provided in cases involving extraction of stone, gravel, sand, or clay by marine dredging (other than maintenance dredging) where the area involved is greater than 5 ha or, for fluvial dredging (other than maintenance dredging), where the length of river involved is greater than 500 m.

The Irish Department of Communications Marine and Natural Resources (DCMNR) has indicated that it looks forward to reviewing the output of the IMAGIN project as a key input in the development of Irish policy for the exploitation of marine aggregates resources from the Irish Sea. In this context, the DCMNR anticipate that the process of policy development is likely to be completed within a period of two years after the closure date of the IMAGIN project in February 2007.

5.1.10 The Netherlands

Extraction of marine sediment is based on the Sediment Extraction Law (amended 1997). Licences are given by the Ministry of Transport, Public Works, and Water Management, the Directorate-General of Public Works and Water Management, and the North Sea Directorate.

In July 2004, a new policy on the extraction of marine sediments was formalized by the Dutch Government in the Second Regional Extraction Plan for the North Sea. The main difference from former policy was the distinction made between small-scale extractions (<10 million m^3 per licence) and large-scale extractions (>10 million m^3 per licence). For small-scale extractions, the maximum extraction depth was set at a depth of 2 m. For large-scale extractions, an extraction depth of more than 2 m was allowable if the EIA indicated that this would be the preferred option.

From 2003 onwards, an EIA has to be produced when an extraction exceeds an area of 500 ha (EEZ) or 100 ha (territorial sea) and/or exceeds a volume of 10 million m^3. The "ICES Guidelines for the Management of Marine Sediment Extraction" (ICES, 2003) are used for EIAs. The landward limit for extraction of marine sediments is the established NAP 20 m depth contour, which is a simplification of the actual NAP 20 m depth contour. The depth contour is defined by the NAP (Dutch Ordnance Level ~ Mean Sea Level). There are some exceptions to this, such as extraction in access channels to harbours. Seaward of the established NAP 20 m depth contour, extraction is allowed in principle.

The National Policy Document on the Extraction of Shells has been re-evaluated and partially revised for a second time. The main differences from the former policy are the definition of new quotas for the extraction of shells in certain areas, some redefinition of areas, and a simplification of the way in which quotas are defined, in order to avoid unnecessary limitations on the extraction industry.

In 2005, a new national Spatial Planning Policy Document was formalized. The Netherlands sector of the North Sea is recognized within this document, and the extraction of sand for landfill from the North Sea is highlighted as a matter of national interest. The regulations of the Second Regional Extraction Plan for the North Sea are confirmed by this document. They are also confirmed by the Integrated Management Plan for the North Sea 2015 (formalized in 2005), which also states that, in the event of a spatial conflict between windfarms and sediment extraction seaward of the 12-nautical-mile zone, windfarms will have priority.

5.1.11 Norway

The issue of permits based on the Act on the Continental Shelf 1963, regarding the extraction of sand and gravel (both siliclastic and biogenic) from national waters, is delegated by the Department of Industry and Energy to local authorities (county administrations).

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

5.1.12 Poland

Permits are given by the Licence Bureau of the Ministry of Environment under the Polish Geological and Mining Law (1994; supplements 1996, 2001). For geological and mining surveillance, the District Mining Office is the administrator.

For licences for reconnaissance and exploration, the following documents are required.

- application from the investor to the Ministry of Environment
- description of project of geological (exploratory) work
- environmental impact assessment (EIA) of the exploration
- criteria of resources balance (proposed by the investor and approved by the Ministry of Environment)

For an exploitation licence, the following documents are needed.

- geological documentation of resources (approved by the Ministry of Environment)
- EIA of the exploitation
- delimitation of mining territory and premises (approved by the District Mining Office)
- plan of resources field development and detailed plan of exploitation (approved by the Ministry of Environment)
- annual balance of resources
- quarterly report on exploitation

The fee for exploitation depends on the quarterly volume of exploited raw material.

5.1.13 Spain

The extraction of marine sediments in Spanish waters is regulated by the following legislation.

- Shores Act (22/1988, 28 July) and Royal Decree 1471/1999, 1 December, which further develops its regulations
- Royal Legislative Decree 1302/1986, 28 June, on Environmental Impact Assessment (developed through Royal Decree 1131/1988, 30 September), amended by Act 6/2001, 8 May, which transposed EU Directive 97/11/EEC to the Spanish legislation
- State Ports and Merchant Navy Act (Act 27/1992, 24 November, modified by Act 48/2003, 26 November, concerning the Economic System and Service Supply in Ports of General Interest), which only regulates dredging activities in harbours

In Spain, jurisdiction over the Coastal Public Domain belongs to the State Administration, namely the Directorate General of Coasts. This institution, through its peripheral services (Services and Demarcations of Coasts, one in each Spanish littoral province), is responsible for authorizing any marine sediment extraction, with the exception of navigational dredging.

According to Article 63.2 of the Shores Act, marine sediment exploitation is only allowed for beach nourishment, and is always prohibited for construction purposes.

The Shores Act also makes it mandatory to carry out an environmental assessment for all sediment extractions in order to examine its effects on the Coastal Public Domain before it can be authorized. When sediment extraction exceeds 3 million m^3, it is necessary to undertake a regulated environmental impact assessment procedure, according to EU Directive 97/11/EEC, transposed to the Spanish legal system by Act 6/2001. Regional legislation regarding EIA is also applicable to these projects, and in instances of conflict with national law, maximum protection measures prevail. In the OSPAR area, Andalucía establishes the same legal stipulations for sediment exploitation, that is, a regulated EIA procedure for extractions over 3 million m^3 and an environmental assessment for smaller projects. Galicia and Cantabria have established a mandatory EIA for all sediment exploitation activities, including marine aggregate extraction. Finally, the Pais Vasco EIA Act does not specifically mention marine sand extraction, but establishes a mandatory and regulated EIA procedure for all conservation and regeneration activities in the Coastal Public Domain category; this would include sand extraction for beach nourishment, the only marine sediment exploitation permitted in Spain.

Furthermore, in accordance with the EU Habitats Directive, transposed to the Spanish legislation by Royal Decree 1997/1995 of 7 December, a stricter and more detailed evaluation of extraction activities is carried out in, or in the vicinity of, proposed Special Areas of Conservation (Sites of Community Importance, or Special Areas of Conservation for Birds) in order to prevent any alteration to their natural integrity. Moreover, in protected areas designated by regional governments, management plans regulate all activities and often rule out all marine sediment exploitation.

Before any sand or gravel extraction can be authorized, it is also mandatory to consult with environmental authorities (under the auspices of the Autonomous Communities), the navigation authority (Merchant Navy), and the fishery authorities (this jurisdiction belongs to the Autonomous Communities in internal waters, and to the State Administration, through the Agriculture and Fisheries Ministry in exterior wa-

ters). Also, a comprehensive environmental monitoring is carried out in large extraction areas.

In 2005, following the OSPAR 2003-15 recommendation that all Member Countries should adhere to "ICES Guidelines for the Management of Marine Sediment Extraction" (ICES, 2003), these guidelines were translated into Spanish and distributed to all relevant authorities in Spain.

In addition, the Spanish authorities, in order to improve the execution of pre-extraction studies of sand deposits, have published a "Methodology Guide for the Development of Environmental Impact Studies of Sand Extraction for Beach Nourishment" (José L. Buceta Miller, 2004, CEDEX).

Harbour dredging, including materials destined to fill port structures, is not considered to be mineral exploitation and is therefore regulated by the State Ports Act. However, it is important to mention that, when the product of navigational dredging is sand, it is customarily used for beach replenishment if the sediment fulfils the established quality criteria. In this case, it is considered a beneficial use of dredged material and not a sand extraction operation.

Finally, it is important to emphasize that the only authority with power over marine sediment extraction is the Directorate General of Coasts; therefore, this institution is in charge of all data collection regarding this issue.

5.1.14 Sweden

The Geological Survey of Sweden is responsible for the administration and licensing of the extraction of marine aggregates. Licensing in the Exclusive Economic Zone (EEZ) beyond the territorial limit is the responsibility of the government. Since 1 July 1992, the Swedish Act of the Continental Shelf has required development of an environmental impact assessment (EIA) in connection with any application for extraction of marine sediments and for larger construction work in the marine environment.

5.1.15 United Kingdom

Applications for new aggregate dredging areas are currently considered under the Interim Government View (GV) procedures introduced in 1998. The interim procedures reflect many of the provisions that were introduced with the new regulations in 2006, although they do not have statutory force.

Applications for a GV should be made to the Office of the Deputy Prime Minister (ODPM) or the National Assembly for Wales (NAW), as appropriate. In reaching its decision, the ODPM/NAW will consider all information submitted with the application, including reports on the environmental effects of the proposed dredging, all comments received in response to consultation with interested parties, and comments received following advertisement of the application.

Applicants for dredging licences are therefore already required to undertake an environmental impact assessment (EIA), which must include a coastal impact study and an assessment of the effects of the proposal on the marine environment, fisheries, and other legitimate users of the sea.

In 2002, the ODPM published "Guidance on the Extraction by Dredging of Sand, Gravel and Other Materials from the English Seabed". This provides policy guidance on marine aggregate dredging and will support the new statutory procedures.

In 2004, the NAW published its Interim Marine Aggregate Dredging Plan (IMADP). This policy attempts to relate regional sensitivities associated with coastal processes in the Bristol Channel. Additionally, the policy also refers to nature conservation and fishery interests in the region. The plan defines preferred areas for marine sand extraction to be developed in future.

The preparation of draft regulations by the ODPM to bring marine aggregate extraction under statutory control in England and Northern Ireland continues. The regulations will be consistent with the requirements of the EU EIA and Habitats Directives and will be compatible with Human Rights legislation. Scotland and Wales are producing their own regulations and guidance. Guidance on the application procedures for authorization to dredge (a Dredging Permission) in English waters is also being prepared. Separate guidance notes will be issued for dredging in Welsh, Scottish, and Northern Irish waters. The draft regulations and guidance for England came into force at the end of 2006.

The UK Government is also developing policy in a range of areas that will lead to new legislation affecting the way human activities are managed in the marine environment; this is to be accomplished through a Marine and Coastal Access Bill. The final outcome will introduce a new framework for the seas, based on marine spatial planning, that balances conservation, energy, and resource needs.

The purpose is to improve the delivery of policies relating to marine activities operating in coastal and offshore waters, and to marine natural resource protection, in particular by providing an integrated approach to sustainable management, enhancement, and use of the marine natural environment.

As a first stage in the development of this initiative, a consultation document was launched on 29 March 2006 that outlined the development of policy options according to five main themes.

1) The management of marine fisheries
2) Planning the marine environment through the creation of a new system of marine spatial planning
3) Licensing marine activities to include options for streamlining the UK Government's regulation of marine activities
4) Improving marine nature conservation to include new mechanisms for the conservation of marine ecosystems and biodiversity, including protected areas for important species and habitats
5) Considering the need for a new marine management organization

The Bill completed its committee stage on 21 April 2009.

In terms of the linkages with marine aggregate extraction, the outcome of the themes dealing with planning, licensing, and delivery (marine management organization) can be expected to influence the future management and control of the activity. In 2002, the Centre for Environment, Fisheries and Aquacultural Science (CEFAS) published guidelines for the conduct of benthic studies at aggregate dredging sites. These guidelines were produced to facilitate consistency of approaches among consultants employed by the industry when carrying out baseline and monitoring surveys and to foster compatibility between ongoing regulatory monitoring activity and related research.

5.1.16 United States

The Outer Continental Shelf Act 1983 (amended 1994) allows the leasing of areas of the shelf for sand and gravel extraction. In 1999, the Minerals Management Service and the US Army Corps of Engineers, which has responsibility for many beach replenishment projects, developed a Memorandum of Understanding for the coordination and cooperation of the two agencies involved in sand resources on the outer continental shelf. One issue that affects the extraction of marine sand and gravel is in the Sustainable Fisheries Act (1996), which has required the National Marine Fisheries Service to define essential habitats for various commercial species. All federal agencies must consult the National Marine Fisheries Service on any action that may adversely affect essential fish habitats.

The Minerals Management Service has decided not to proceed with the designation and leasing of offshore areas for marine aggregate mining, although the exploitation designation and use of offshore borrow areas for beach nourishment continue on the strength of public benefits by beach restoration.

5.2 Risk assessment

5.2.1 Introduction

Approaches to risk assessment in connection with the extraction of marine sediments and its possible effects on the marine ecosystem are still far from mature, and although approaches vary considerably among ICES Member Countries, the most advanced can still be regarded as partial risk assessment. Thus, the completeness and utility of these approaches need to be examined in detail, and conclusions need to be drawn as to the benefits or shortcomings of these methods of risk assessment, together with comparisons with methods used in other sectors. This type of detailed analysis is considered to be beyond the scope of the current report and will be treated in depth in subsequent reports.

In some other marine industries, risk-assessment procedures are well developed and utilize the latest probability-based theories and procedures. However, it is important to understand that absolute levels of risk are usually extremely difficult to establish, owing to the high levels of uncertainty in the input parameters and the limitations of the modelling. The most beneficial use of risk-assessment procedures is, in the comparison of the risks associated with specific activities and alternatives.

Given the general lack of scientific knowledge regarding cause-and-effect relationships in potential impacts on the marine environment, the severity of many of the perceived detailed impacts needs to be assessed in a subjective manner. Hence, the degree of resolution in such assessments is necessarily coarse, and usually involves the opinions of a number of experts. This leads to coarse banding of risks, for example, into high, medium, or low categories, perhaps with intermediate bands in an attempt to increase the resolution. However, these processes are applied equally to the likelihood of the impact occurring and the severity of the consequences in order to produce a risk matrix. There are usually many overall uncertainties in these approaches.

More systematic and quantified approaches used elsewhere (e.g. in the offshore oil and gas industry) utilize advanced techniques, such as Bayesian probability networks (BPN). Although such techniques often still require subjective stakeholder input, they produce quantified analyses of the identified risks. BPNs are best used in a wider appraisal of risks to identify the optimal practical solution (given that sediment ex-

traction is needed to satisfy market demand and, where practised, is in accord with government policies). The solution identified by such techniques will balance the technical, safety, and environmental costs against economic costs, thus permitting sensitivity analyses of the consequences of alternative approaches. BPN techniques require an identification of unacceptable or "failure" conditions (e.g. a degree of environmental impact), but will clearly identify the probability of this being avoided.

The aim of the Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) was to further examine BPNs and other approaches to risk assessment, and to report its conclusions to ICES in 2007. Summaries of some national approaches are given below.

Hazard assessment is another area where procedures for evaluating risk are well developed, e.g. the PEC/PNEC (predicted environmental concentration/predicted no-effect concentration) risk-assessment technique applied in the Netherlands.

The WGEXT observed that the setting of threshold values, or EcoQOs (ecological quality objectives), was one approach to judging the acceptability of environmental risks arising from anthropogenic activities. However, the difficulty of deriving EcoQOs in environments where sediment extraction is ongoing was noted. In particular, it was observed that the derivation of scientifically robust EcoQOs for ecological parameters was problematic on account of the absence of any long time-series datasets for deriving and then testing the behaviour of potential measures. Despite such obvious difficulties, it was noted that there are increasing numbers of examples where threshold levels have been set in order to protect the marine environment from the adverse consequences of marine sediment extraction. An illustration of this approach is provided by the Øresund Fixed Link, in which targets for vulnerable receptors (e.g. eelgrass and bird species) and overspill material were established during its construction. In this instance, monitoring programmes were instigated to ensure that the agreed threshold levels were not exceeded. In the UK, the monitoring of sole at Hastings is another example of a scheme where acceptable limits for a vulnerable receptor were set.

Geographical information system (GIS) techniques were also suggested as a tool for undertaking spatial and temporal analysis of complex datasets, which could be modified to include risk-assessment models.

It has been observed that more informal risk assessments were often carried out by permitting authorities when arriving at decisions on extraction applications, which may take into account political aspects of the extraction operations.

5.2.2 Techniques for environmental risk assessment

The identification of risk is of paramount importance for the regulation of marine aggregate extraction activities, both in the determination of consent to dredge and in the identification of areas where monitoring and/or mitigation may be required. Many different techniques can be used. This section presents a summary review of several techniques and a discussion on the utility of Graphic Information System (GIS) tools in facilitating processes that can contribute greatly to the assessment and management of risks associated with the extraction of marine aggregates.

Risk-assessment protocol in the UK

Assessment of the environmental impacts of marine aggregate extraction and other human activities in the UK (England and Wales) is the responsibility of the Depart-

ment of Environment, Food and Rural Affairs (DEFRA), through their agency, the Centre for Environment, Fisheries and Aquaculture Science (CEFAS). Environmental impact assessments (EIA) produced in support of these applications tend to be reviewed as a single activity, in isolation from others that may have been considered previously or reviewed by different members of staff within the organization. Although each EIA is thoroughly evaluated in terms of its site-specific impact, it is often difficult to apply standardized criteria consistently to every application; this suggests that evaluation may be a subjective process, with different personnel and/or different local issues influencing the quality and outcome of the evaluation. To consider this issue in more detail, a research project, funded by DEFRA (Rogers and Carlin, 2002), was carried out, the main aim of which was to develop a standard protocol for the assessment of the effects of aggregate extraction on commercial fisheries and fish resources. The purpose of this was to ensure that, from year to year, and throughout English and Welsh coastal waters, a standardized methodology was adopted for licence assessment.

The approach taken in the project was based on a formalized risk-assessment process. The protocol that was developed formally documents the review by CEFAS of EIAs submitted in support of aggregate extraction applications in relation to the potential impacts of the activity on fish resources and commercial fishery activity. The main benefit of this approach is that each potential impact is evaluated against each aspect of the biological resource, and the outcome is a consistent assessment of each application. It also ensures that the approach to assessment is standardized between regions and over time. This protocol was set out in a two-page template (Figure 5.2.1) and allowed the opportunity for summary comment explaining the major issues and justification of each evaluation; thus, it provides a permanent record for subsequent review in terms of both improving consistency in the provision of advice and providing an evidence-based approach for the training of new reviewers.

The protocol developed is based on a formal risk-assessment process which takes account of the potential sensitivity of a resource (a fixed value associated with the generic impact of aggregate extraction on that resource) and the actual vulnerability of the resource in a site-specific context (this value varies depending on the site-specific nature of the individual application under review). For each application under review, the following elements of the application were considered against a suite of environmental impacts (as outlined in the matrix shown in Figure 5.2.1): Temporal and Spatial Scale of the Operation, Method of Aggregate Extraction, Plume Effects, and Cumulative Effects.

Based on a review of scientific literature, the content of the EIAs produced in support of aggregate extraction applications previously submitted, and the advice provided by CEFAS on these applications, the potential sensitivity values for each environmental impact were ranked on a scale of Very High, High, Moderate, and Low. Actual vulnerability was allocated to the same scale, although the allocation of values for individual applications is determined on a site-specific basis (i.e. a decision is made as to whether the actual vulnerability of the site is expected to be Very High, High, Moderate, or Low in relation to the potential sensitivity for that particular incident). The combination of the potential sensitivity and actual vulnerability values produced a risk value for the particular impact, and was ranked using a scale of High, High/Medium, Medium, Medium/Low, Low, and Near Zero. The combination of all risk values also allowed an overall risk value for that specific application to be made (see the risk matrix in Figure 5.2.1) and allows the reviewer to determine

whether the application is likely to pose a significant environmental risk to fish and fish resources.

In preparing the template and considering the procedure that should be adopted during review, a number of issues became apparent. First, although the completed templates appear to be finalized, there are opportunities for revision as consultations with the dredging industry and further technical notes provide greater detail on some issues, and suggestions for mitigation resolve more serious concerns. In general, the assessments completed in this report reflect views at an early stage in the review process. They are, therefore, working documents that highlight areas where improvements need to be made, and they should not necessarily be considered to represent the actual scale of impact of the final licence.

Second, this formal process obliges the reviewer to assess the potential impacts of a dredging operation individually. This has the benefit of placing no explicit emphasis on any one part of the ecosystem, and helps to prevent the unfair focus of assessment on a specific issue, such as the displacement of commercial fisheries. However, there is a danger that such a formal process, with its clear outcome, may suggest that the conclusions of the review have a sound scientific basis. Decision-making in the absence of detailed scientific advice has been an inevitable part of this review and assessment process, but this formal approach makes these shortcomings even more obvious. This has been especially apparent when evaluating the potential scale of the impact of sediment plumes on the benthic fish and invertebrate community, where it is often necessary to assume that sedentary filter-feeders will be uniformly highly vulnerable to siltation, and that the presence of screening activity in a highly diverse benthic community will always result in an environmental impact of high risk. There is an opportunity in the review process to modify an actual vulnerability rating if, for example, quantities of sediment are low or if mitigation measures are to be put in place that will minimize an otherwise major impact. The text boxes associated with the protocol are an important place to record these issues and can be referred to at a later date to assess the degree of variance in the overall assessment.

The other topic, which, so far, is largely unsupported by scientific research, is the cumulative or in-combination impacts on the structure of the benthic community of several dredge applications within a region. With no knowledge of the precise zone of influence of each application or current licence, and no understanding of the consequences of each impact, it is impossible to assess the total impact on a community. Furthermore, there is insufficient understanding of the proportion of a habitat or community that must remain unimpacted in order to ensure its sustainability. The cumulative effects of multiple licences in a region are also of concern to coastal communities and are an important topic. Local fishers, in particular, express anxiety about the consequences of multiple dredge licences in relation to unimpeded access to local fish and shellfish stocks. To some extent, this perception is based on poor communications between the dredging industry and the local fishery representatives: although suitable zoning schemes are put in place, they are not sufficiently advertised, and damage to strings of pots and set-nets can still occasionally occur. These practical issues, related to the cumulative effects of dredging activities, can often be resolved at well-attended regional liaison groups. It is more difficult, however, to understand the implications for mobile fish and shellfish populations, which are indirectly affected by the removal of seabed that is used for spawning, nursery grounds, or overwintering by shellfish.

So far, consideration of cumulative effects has focused only on dredging activities; however, in principle, it is necessary to include all other potentially damaging activities in the marine environment. When combined with the seasonal and spatial variability of fish resources and the regional changes in the importance of different stocks, the review process develops into a complex multivariate approach. Progress in the use of GISs to store and manipulate large quantities of data suggests that this is a valuable opportunity to advance our knowledge of broad-scale environmental impacts and to develop this in a marine spatial-planning context. In particular, the use of a GIS allows potential impacts of human activity to be placed in a regional context. This will be fundamental when considering the need for a more strategic view of licensing the activities of the marine aggregate industry.

Finally, it has become apparent during the preparation of this protocol that there is considerable variability of the quality of EIAs produced in support of licence applications. This can hinder the simple comparison of activities, which may be described in different units or where some topics, such as commercial fishing activities, are described in different levels of detail. Although such problems can be rectified in later technical reports that review and update EIAs, it would seem sensible to devise detailed guidelines that describe the data to be provided and the most suitable method of presentation. A number of current initiatives have resulted in guidelines for offshore industries (i.e. offshore windfarms: "Guidance Note for Environmental Impact Assessment in Respect of the Food and Environmental Protection Act (FEPA), and Coast Protection Act (CPA) requirements", (CEFAS, 2004); "Guidance on seismic operations for the offshore industries", (Joint Nature Conservation Committee/JNCC, unpublished), and there are continuing discussions within the OSPAR Biodiversity Committee as to whether formal guidelines on sand and gravel extraction are required. In view of this international interest in moving towards standardization of the impact assessment process, the protocol within this project was made available to environmental consultants and dredging companies involved in impact assessment, and this is actively used by these organizations. Work within CEFAS also continues to expand the scope of this protocol to include other aspects of the marine environment impacted by marine aggregate extraction (e.g. benthic communities and coastal processes). This work has particular value in the current climate of marine aggregate extraction in English and Welsh waters as we move towards a regional approach to the evaluation of the impact of aggregate extraction and dredging.

The utility of the risk-assessment protocol developed as part of this research project lends itself to other areas of the marine advisory work currently undertaken by CEFAS. CEFAS currently advises DEFRA on a number of human impacts, including applications for maintenance and capital dredging, and for marine and coastal construction work (including offshore windfarms), made under the CPA and FEPA. There is clear scope for adjusting this protocol to take into account the environmental impacts associated with these other human impacts. As a result, CEFAS is considering ways of incorporating this process into these other areas of advisory work.

Aggregate Dredging Licence Application: Evaluation Protocol

Applicant Name:	**SOUTH COAST SHIPPING LTD**		
Licence Name:	**ST CATHERINES**		
Licence Number:	**AREA 407**	**Advice Ref:**	A2.46

1. Temporal and Spatial Scale of the Operation	
	Brief Remarks
Benthic Fish Community	Diverse benthic community with abundant structural fauna (incl. Sabellaria) and an important source of food and shelter for crab (edible and spider) cuttlefish, and other resources for bass and bream. Direct uptake of fauna will lead to reduced abundances of these species in the area. Removal rate (1m t per yr) is average.
Fisheries Resources: breeding / spawning grounds	Most important spawning species appear to be bass and lobster. Limited impacts of the scale of the operation on these species.
Fisheries Resources: nursery grounds	Thought to be an important settlement area for crab and lobster.
Fisheries Resources: over-wintering grounds	No evidence that the site is used for overwintering by crab.
Fisheries Resources: migratory routes	Pre-adult female crab, bream, flatfish and pelagics species may pass through the site during seasonal spawning migrations, although the extent of their use of the site is unknown.
Fisheries Resources: direct mortality	Egg-bearing lobster likley to be impacted by direct uptake to moderate extent - no evidence of edible crab spawning at the site.
Commercial Fishery: reduction of income	Unlikely that dredging will seriously affect the alleged 10 bass boats at the site. Some potential impact on the lobster resource - apparently exploited by 4 potting vessels.
Commercial Fishery: displacement of vessels	No evidnece that the site forms important part of local fisheries. Some boats visit the site on a seasonal basis, but no evidence that this is the only site in the region which provides the resources which they target.

2. Method of Aggregate Extraction	
	Brief Remarks
Benthic Fish Community	Use of static and mobile dredgers has the potential to change seabed topography and thus adversely affect settlement and distribution of important prey species. Lobster resource in unlikely to be adversely affected by changes in demersal assemblage per se, and bass also likely to find alternative feeding grounds.
Fisheries Resources: breeding / spawning grounds	Limited potential for noise disturbance or impact of changes in seabed topography, to adversely affect spawning fish and shellfish resources.
Fisheries Resources: nursery grounds	Not an important nursery for flatfish, some juvenile crab may be affected to a moderate extend by localised disturbance.
Fisheries Resources: over-wintering grounds	No known edible crab overwintering areas specific to the application area.
Fisheries Resources: migratory routes	No migration routes specific tot he application area.
Commercial Fishery: reduction of income	Potential reduction in income of the fisheries by 10% (p. 8), but this thought to be unlikely, and evidence for consistent fisheries, and accurate fisheries values from the region, is poor.

3. Plume Effects	
	Brief Remarks
Benthic Fish Community	A diverse benthic fauna which will be adversely affected by sediment plumes during screening.
Fisheries Resources: breeding / spawning grounds	Some moderate likelihood of impact on lobster resource of sedimentation from plumes at the site and in the immediate vicinity.
Fisheries Resources: nursery grounds	Juvenile shellfish may be afected by plume during screening.
Fisheries Resources: over-wintering grounds	No known crab overwintering areas specific to the application.
Fisheries Resources: migratory routes	Migration routes (if they occur here) are not likely to be impacted by plumes.
Commercial Fishery: reduction of income	Some potential for lobster populations to be deterred from the locality by short-term sediment impacts and longer-term changes to pyhsical substrate.

4. Cumulative Effects	
	Brief Remarks
Benthic Fish Community	High density of human activities in region east of the IoW to the north, so some potential for broad-scale changes to assemblages, but very little evidence to supoprt the threat of serious impact. Results of A0903 needed to inform this topic before valid decisions can be made.
Fisheries Resources: breeding / spawning grounds	Combined impacts on shellfisheries in the IoW region have the potential to be significant, but no evidence of stock declines
Fisheries Resources: nursery grounds	Limited potential for combined effects of juvenile shellfish in the IoW region.
Fisheries Resources: over-wintering grounds	No evidence of crab overwintering here.
Fisheries Resources: migratory routes	No evidence of cumulative effects on migration routes in the IoW region.
Commercial Fishery: reduction of income	Potential for the combined effects on shellfish resources of the east IoW licences to adversely affect the populations of crab and lobster, but the supporting science to justify this is Very Weak.
Commercial Fishery: displacement of vessels	Can be argued that vessels displaced fro St Catherines 407 could also be adversely affected by restrictions on access to other nearby grounds from aggregate licences.

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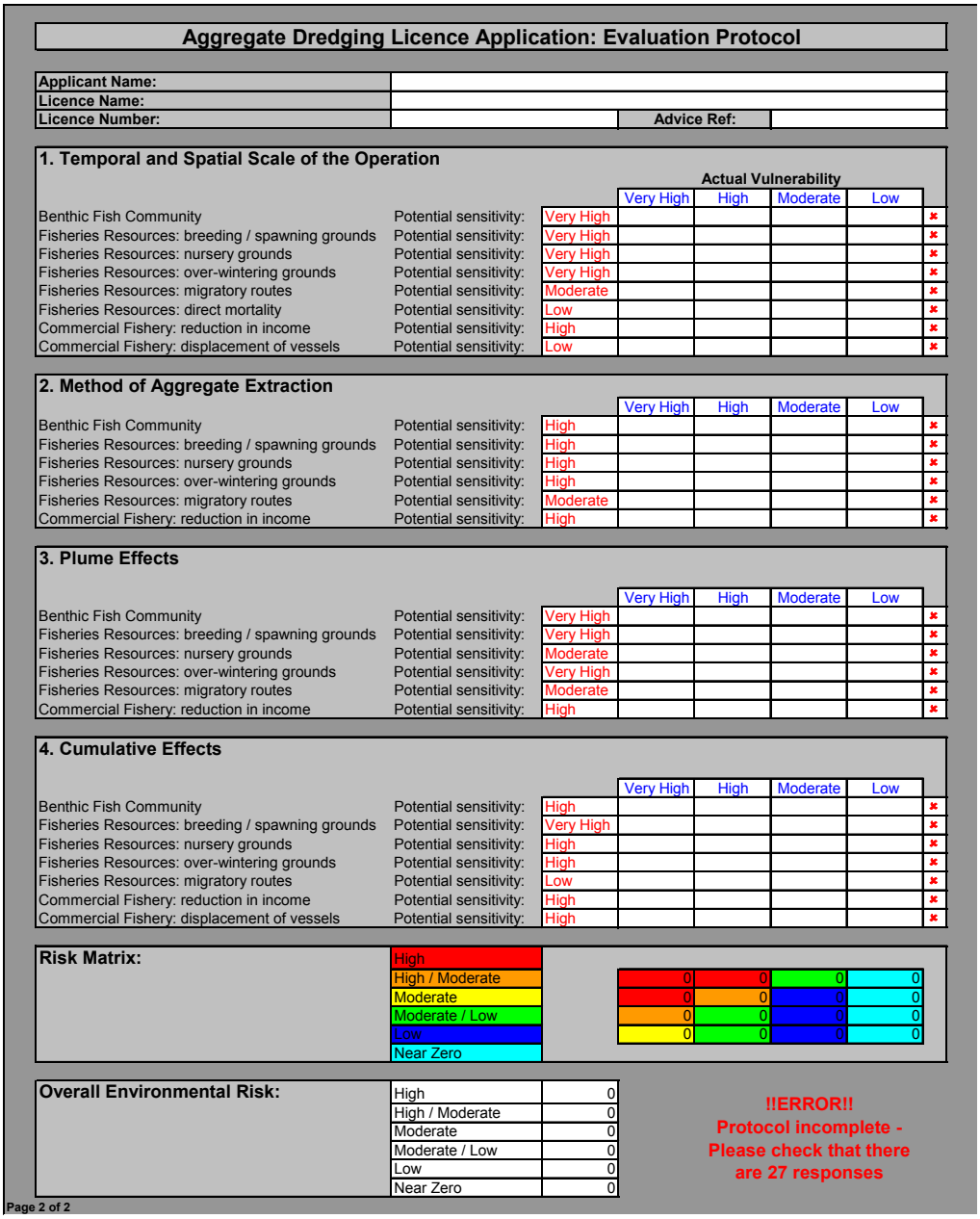
Figure 5.2.1. Protocol record template (continued).



Aggregate Dredging Licence Application: Evaluation Protocol

Applicant Name:	
Licence Name:	
Licence Number:	**Advice Ref:**

1. Temporal and Spatial Scale of the Operation

			Actual Vulnerability				
			Very High	High	Moderate	Low	
Benthic Fish Community	Potential sensitivity:	Very High					✖
Fisheries Resources: breeding / spawning grounds	Potential sensitivity:	Very High					✖
Fisheries Resources: nursery grounds	Potential sensitivity:	Very High					✖
Fisheries Resources: over-wintering grounds	Potential sensitivity:	Very High					✖
Fisheries Resources: migratory routes	Potential sensitivity:	Moderate					✖
Fisheries Resources: direct mortality	Potential sensitivity:	Low					✖
Commercial Fishery: reduction in income	Potential sensitivity:	High					✖
Commercial Fishery: displacement of vessels	Potential sensitivity:	Low					✖

2. Method of Aggregate Extraction

			Very High	High	Moderate	Low	
Benthic Fish Community	Potential sensitivity:	High					✖
Fisheries Resources: breeding / spawning grounds	Potential sensitivity:	High					✖
Fisheries Resources: nursery grounds	Potential sensitivity:	High					✖
Fisheries Resources: over-wintering grounds	Potential sensitivity:	High					✖
Fisheries Resources: migratory routes	Potential sensitivity:	Moderate					✖
Commercial Fishery: reduction in income	Potential sensitivity:	High					✖

3. Plume Effects

			Very High	High	Moderate	Low	
Benthic Fish Community	Potential sensitivity:	Very High					✖
Fisheries Resources: breeding / spawning grounds	Potential sensitivity:	Very High					✖
Fisheries Resources: nursery grounds	Potential sensitivity:	Moderate					✖
Fisheries Resources: over-wintering grounds	Potential sensitivity:	Very High					✖
Fisheries Resources: migratory routes	Potential sensitivity:	Moderate					✖
Commercial Fishery: reduction in income	Potential sensitivity:	High					✖

4. Cumulative Effects

			Very High	High	Moderate	Low	
Benthic Fish Community	Potential sensitivity:	High					✖
Fisheries Resources: breeding / spawning grounds	Potential sensitivity:	Very High					✖
Fisheries Resources: nursery grounds	Potential sensitivity:	High					✖
Fisheries Resources: over-wintering grounds	Potential sensitivity:	High					✖
Fisheries Resources: migratory routes	Potential sensitivity:	Low					✖
Commercial Fishery: reduction in income	Potential sensitivity:	High					✖
Commercial Fishery: displacement of vessels	Potential sensitivity:	High					✖

Risk Matrix:

High	0	0	0	0
High / Moderate	0	0	0	0
Moderate	0	0	0	0
Moderate / Low	0	0	0	0
Low				
Near Zero				

Overall Environmental Risk:

High	0
High / Moderate	0
Moderate	0
Moderate / Low	0
Low	0
Near Zero	0

!!ERROR!!
Protocol incomplete - Please check that there are 27 responses

Page 2 of 2

Figure 5.2.1 continued. Protocol record template.

The PEC/PNEC approach in risk analyses of dredging activities

Environmental risk assessment is aimed at identifying potential environmentally harmful effects of an activity. Furthermore, it facilitates the selection of mitigating measures and quantifies the environmental benefit of implementing these measures.

The basis of risk assessment is a comparison of the exposure (disturbance) of an ecosystem (or part of it) to certain stressors (e.g. chemical substances) related to an activity with its sensitivity to this stressor. This principle is used in many countries for the evaluation of the environmental risk of toxicants by using standardized evaluation schemes. The same methodology can also be applied to assess the risks of non-chemical, non-toxic stressors, which affect the ecological status of water bodies or sediments (e.g. those caused by dredging activities).

A risk-assessment method commonly applied in the oil and gas industry is the PEC/PNEC approach:

- PEC = predicted environmental concentration;
- PNEC = predicted no-effect concentration.

The PEC/PNEC approach was especially developed for the evaluation of chemical substances and is included in several guidelines for risk assessment. The principles of the method are described in the EU Technical Guidance Document (EU-TGD; EEC, 2003). This approach has been adopted by OSPAR for the evaluation of toxic stress.

The major potential environmental impacts of dredging are related to: (i) the removal of sediment, including its inhabitants; (ii) an increase in turbidity; (iii) rapid deposition of fine material; (iv) changes in hydrodynamics; (v) oxygen depletion; (vii) changes in sediment composition, resulting either from increased sedimentation or from the exposure of different types of sediment caused by the removal of superficial material. These potential impacts are similar to the impacts from oil-well drilling, resulting in plumes with suspended clays and deposition of fine particles and drill cuttings.

In this note, the PEC/PNEC approach is discussed as a promising tool in evaluating the potential impacts of dredging activities. Recent studies that are seeking to establish threshold values and risk-assessment approaches for non-toxic sediment stressors related to drilling discharges, such as burial of organisms, sediment changes, and oxygen depletion, could serve as a basis for this. Strictly speaking, the terms PEC and PNEC should not be used for non-toxic stressors, because these terms refer to a certain concentration. These terms could be replaced by exposure, level or change, and threshold.

PEC/PNEC ratio

The PEC/PNEC ratio gives an indication of the likelihood of the occurrence of adverse effects as a result of exposure to a specific chemical or stressor. However, it does not provide a quantification of the environmental risk and cannot directly be compared with other PEC/PNEC ratios from other stressors. However, PEC/PNEC ratios can be translated into a probabilistic risk measure: the potentially affected fraction (PAF) of a species. The PAF, which indicates the probability of a randomly selected species being exposed above its threshold, can be estimated on the basis of empirically estimated variation in sensitivity among marine biota expressed in a species sensitivity distribution (SSD). This distribution describes the average sensitivity of species towards stressors and the variation in sensitivity among different species. The main assumption on the use of SSDs in risk assessment is that the distribution, which is based on a selection of species (for which data are available), is representative for the species in the field. When different PAF values are derived as a result of exposure to different stressors, a combined PAF can be calculated to estimate the potential impact of all stressors combined. As a cut-off criterion, the exposure of marine organisms to several stressors in their aquatic environment is considered acceptable if no more than 5% of the marine species are at risk, corresponding to a combined PAF of 5%.

Discussion

In order to address the application of the PEC/PNEC approach as a risk-analysis methodology for the dredging industry, the following issues should be addressed:

i) identification of suitable criteria for the selection of the main stressors, such as habitat change, burial, and oxygen depletion effects;

ii) collection of no-effect "concentrations"/disturbance levels, depending on life strategies, tolerances, and habitats for different species;

iii) evaluation of the relative importance of potential risks related to stressors in the water column ascribable to dredging plumes (e.g. increased suspension, oxygen depletion) and potential impacts to the sediment as a result of sedimentation (alterations in the sediment quality and structure, burial, and oxygen depletion).

To do this requires a broad inventory of effect data that describe the specific impacts of these factors on a group of organisms that are representative of different habitats or ecosystems.

A distinction must be drawn between the direct effects of turbidity in the water phase and subsequent sedimentation on and in the seabed, as well as habitat changes caused by sediment alterations, and possible chemical changes of the sediment. Each of these effects has a particular impact on different species or life stages, necessitating a broad-scale review of the impacts on individual species.

In addition, dredging may have indirect or secondary effects that cause stress to benthic communities, such as oxygen depletion and high sulphide concentrations. Therefore, a distinction must also be made between these effects, and descriptions need to be provided of their impacts on several main species groups, including algae (phytoplankton), zooplankton, macrobenthos, fish, and larger vertebrates (birds and mammals). The availability of practical, independent empirical data describing the impacts of these factors is very limited, which suggests that it may be necessary to use extrapolation techniques. Examples of different extrapolation techniques are given in risk-assessment guidelines for chemical substances based on small datasets (as described in the literature).

The challenge in using the PEC/PNEC approach for assessing the risk of dredging will be to overcome the limited availability of specific information. Another challenge will be to define thresholds for the acceptability or unacceptability of impacts on the ecosystem in relation to the most sensitive endpoints at the species level.

With the PEC/PNEC approach in place, cost-effective risk-mitigation measures can be defined in order to optimize the environmental performance of the dredging activity. However, as the PEC/PNEC approach is generic and conservative, it will only indicate the potential impacts to the environment. In order to check whether or not environmental impacts actually occur (and, if so, to what extent), a dedicated monitoring plan can be tailored to the activity, based on the results of the risk assessment.

GIS and marine environmental risk assessment: supporting the management of marine aggregate extraction

Introduction

In order to appreciate the power and value of GISs as tools to support risk assessment and the management of marine aggregate extraction, the following quotation from Dawn Wright is informative (Wright and Bartlett, 2000):

To minimize risk, both to human health and property, as well as to the natural environment, various types of information from different sources are needed quickly for further processing, analysis, and interpretation, both in a regulatory as well as in a

risk management framework. People in government and industry, responsible for planning, managing, and regulating hazardous operations and substances need tools that bring to bear the best available science and information. Advanced information technology can help to provide this information in a timely and directly useful format.

A GIS is a computer-based system to input, store, manipulate, analyse, and output spatially referenced data and is composed of software, hardware, and liveware (humans).

The availability of affordable computers, as well as new technologies, such as expert systems, interactive modelling, and high-resolution, dynamic computer graphics, now make it possible to build powerful, accessible, and easy-to-use information and decision-support systems for risk assessment and risk communication. A GIS populated with the right data and models can help in the organization, interpretation, and communication of ecological information in an efficient and effective manner.

Although the GIS is now a widely adopted, semi-mature technology, for which terrestrial applications are particularly well developed, the complex multidimensional nature of the marine domain poses particular GIS challenges. These continue to be addressed through R&D on a continuing basis. Limitations to progress include the need for the development of a common language of practice for marine conservation GIS: distinctions still present challenges (e.g. definitions of habitat, differing ways of representing and analysing benthic terrain, measures of benthic complexity, rugosity, and position indices). In short, many of these challenges have, at their root, complexities that stem from the variety of extant ontologies (conceptions of reality and the relationships between them). The development of common marine ontologies remains a major goal of the marine GIS and geomatics science communities. Also of fundamental importance in marine GIS is the requirement to ensure that the datasets, once captured, developed, or otherwise acquired, are stored and structured in a consistent and organized way. In this regard, there has been considerable incentive, and some progress has been made towards the development of data models that cater to the specific requirements of marine data. These have facilitated the construction of marine GIS databases that provide a structured framework to support more efficient and more powerful GIS tools. An example is the Arc Marine data model, which is achieving considerable recognition worldwide. It should be recognized that this model works well in conjunction with the product family of ESRI (one of the leading commercial GIS producers), but it is also available for implementation using generic or open source software solutions (Breman, 2002).

Handling complexity in spatial and temporal representation

The need for temporally dynamic analytical models is a great challenge when it comes to representing marine processes in space and time (NRC, 2004). This will require fundamental adaptation of core GIS processes and assumptions (e.g. with respect to embedding hydrodynamic models in a GIS environment). However, this is very much in line with the main trend of advances, which is geared to answering the more specific questions of policy-makers and managers. Furthermore, many current statistical approaches were originally designed for static analyses; however, some new approaches are being borrowed and adapted from geocomputation, including diffusion modelling, time-series regression, cellular automata and network extensions, differential equation modelling, and spatial evolutionary algorithms.

Practical purposes and applications of GIS

GIS tools are most often used in a supporting role to facilitate risk-management tasks associated with resource management within various national and EU legislative frameworks. The trend in development is away from localized, often-bespoke systems. The increasingly widespread adoption of common interoperability standards is allowing individual dispersed systems to intercommunicate, thereby vastly increasing utility and encouraging the sharing and reuse of information between regulatory agencies, government, industry, and academia. Web-based GISs are rapidly evolving in tandem with constant advancements in web technologies and protocols (e.g. HTML, GML, KML, UML, XML, Java). Unfortunately, in some countries, issues associated with data ownership and restrictive licensing policies still curb its rate of expansion and adoption, presenting a fundamental challenge that has yet to be overcome.

Increasingly, marine GISs are being customized with specialized interfaces and integrated tools that allow them to function with spatial intelligence, that is, to perform complex queries between many different types or classes of objects and arrive at conclusions that can assist directly in determining and visualizing complex interactions by following predetermined or newly analysed patterns or systems of rules. Figure 5.2.2 outlines the typical elements of a system capable of handling environmental risk-management applications (Naresh, 2003).

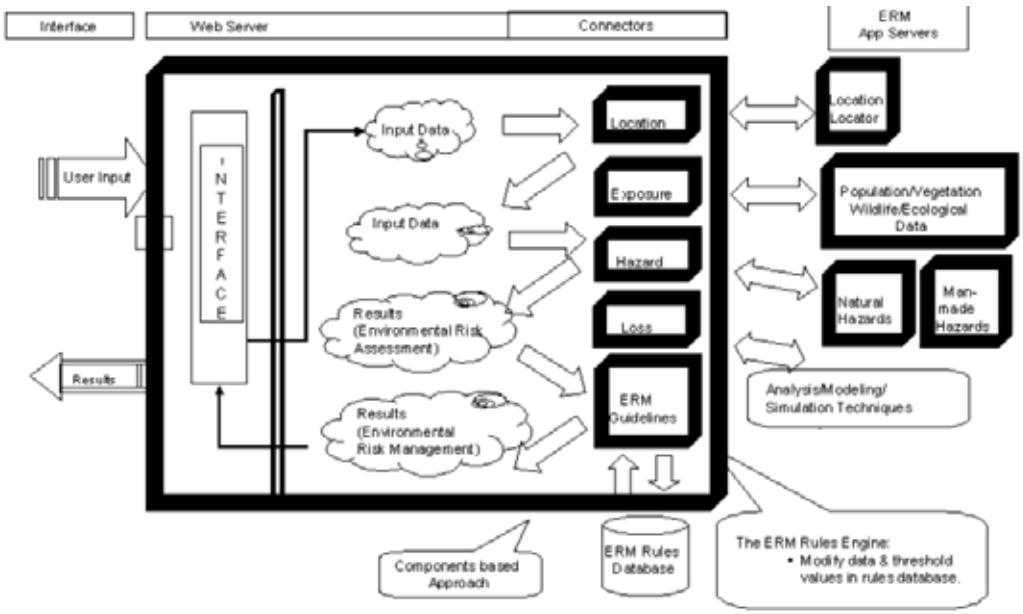


Figure 5.2.2. A typical architecture for a components-based environmental risk-management application. Source: Naresh (2003).

Conclusion

The basic elements and issues involved in the development of frameworks for GIS software applications for use in environmental risk management have been described. The use of GIS-software-based ERM (Enterprise Risk Management) applications has immense advantages, and it is being increasingly adopted by a wide variety of people in the marine domain. Although GIS is widely used by both regulatory authorities and industry, sophisticated applications specific to the management of environmental risk associated with marine aggregates are still at an early stage of

development, and no clear examples of such a system were encountered during this research. Technological advances and the ready availability of low-cost, high-power, desktop, Intranet or Internet environments are supporting the development of ERM systems in an efficient and timely manner. The use of component-based architectures is now allowing complex systems to be modelled with multiple and scalable components; however, the use of expert opinion remains a very important factor in the success of such knowledge-based systems. Results obtained from spatial and analytical modelling tools for environmental risk assessment have a variety of uses (e.g. for comparative, or relative, risk analysis; cost–benefit analysis; scenario analysis; probabilistic analysis; decision matrix; sensitivity analysis). GIS-based software applications will increasingly serve as powerful tools for the assessment and management of effective environmental risk because of their capacity to rapidly and accurately display and analyse huge volumes of spatial and non-spatial environmental data (including hazards and exposure).

5.3 Conclusions

The nature of the sediments being dredged by ICES Member Countries varies, depending on the availability of the natural sediment resources offshore and the national/international market requirement for these materials. The principal markets for marine dredged sediments vary between Member Countries, but in general, they can be broadly identified as construction aggregates, construction fill/land reclamation, and beach replenishment/coastal protection. As a consequence of the variations in resource availability and market demand, some national operations are concerned primarily with sand, whereas others are primarily concerned with gravel.

The use of marine sediments within ICES Member Countries varies greatly, depending to a large extent on the availability of alternative sources of material and of suitable marine sediments within national boundaries.

5.3.1 Resource mapping

There is increasing demand on marine space and resources across ICES shelf sea areas, partly because of the expansion of some maritime industries and also because of newer developments, such as offshore windfarms. These changes in marine use mean that conflicts can arise between different activities. Marine seabed maps provide important information to assist in resolving conflicts arising from multiple uses of the seabed, and they are also an essential underpinning for the sustainable management of offshore resources.

It is evident that, within ICES Member Countries, there is a growing movement towards seabed and resource mapping programmes, driven by several forward-looking and horizon-scanning exercises that have recognized the need to underpin spatial planning and the sustainable use of seabed resources. Developments in survey methods, such as the use of acoustic techniques for accurate discrimination of sediment type, are also proceeding rapidly. This rapid pace of developments in the field of resource mapping, driven by continuous improvements in acoustic techniques (e.g. sidescan sonar, multibeam bathymetry, and acoustic ground-discrimination systems), has radically altered approaches to the assessment of anthropogenic impacts on the seabed. In addition, their extensive use in wide-scale reconnaissance surveys (e.g. in a resource or conservation context) means that they are increasingly being employed by a growing number of ICES Member Countries as part of strategic national seabed mapping programmes. However, large parts of the ICES shelf sea area remain unmapped. Yet, this baseline information is essential to the strategic management of

offshore resources and for the assessment of the broad-scale vulnerability of habitats and species to sand and gravel extraction. Such information is also becoming essential to the identification of potential environmental constraints (e.g. the location of fish spawning areas, sensitive and important species and habitats, archaeological features), allowing sustainable informed development. It is therefore important that seabed-mapping programmes continue to be supported to simultaneously address the needs of governments and marine stakeholders by mapping prioritized areas of the seabed in a strategic manner.

5.3.2 Environmental effects

Awareness of the impacts of sand and gravel dredging, particularly on the coast, spans at least a century. However, interest in the potential environmental impacts of sand and gravel extraction dates back some 50 years, and became a significant issue from the 1960s onwards. Initial concerns focused on the potential impacts on benthic macrofauna and the consequential effects on fish resources and commercial fisheries. This interest has expanded over the years to include most components of the marine ecosystem.

Research has demonstrated that sand and gravel extraction can have a number of environmental effects on the seabed, including the removal of sediment and the resident fauna, changes to the nature and stability of sediments accompanying the exposure of underlying strata, increased turbidity, and the redistribution of fine particulates. Typically, this activity is assessed by ICES Member Countries not only from the standpoint of effects on the benthic fauna during and after the extraction event, but also in terms of its effects on the wider resource, including dependent fish/shellfish populations and associated fisheries, coastal processes, and other legitimate interests, such as conservation and recreation. These issues are addressed as part of an environmental impact assessment (EIA) or by conducting targeted research.

Dredging can also lead to the production of plumes of suspended material. This material can arise from the mechanical disturbance of the seabed sediment by the draghead. However, the outwash of material from the spillways of the vessel hopper can generate a far greater quantity of suspended material. A further source of suspended material is the sediment fractions rejected during screening activities.

An increasing number of studies has concentrated on establishing the rates and processes of macrobenthic recolonization upon cessation of dredging. These studies typically indicate that marine sediment extraction causes an initial reduction in the abundance, species diversity, and biomass of the benthic community. Available evidence from such investigations, carried out in a variety of environmental conditions, suggests that substantial progress towards seabed "recovery" could be expected within two to three years of cessation of dredging in highly dynamic environments, although this period can be greater in areas that are dredged repeatedly or where the seabed has been significantly altered.

5.3.3 Management of marine aggregate extraction operations

Not all countries have the same approach to the legislation and regulation of marine aggregate extraction, and it is inadvisable to prescriptively formulate a preferred option. However, while countries are free to organize their own legislation and regulation, it is important that they are transparent about their regulations, both to the industry and to NGOs.

The general trend in legislation and regulation is increasingly to take environmental issues into account in a formal way. The obligation to follow EIA procedures and to include EU directives in the management of marine aggregate extraction is operationalized.

Some countries have an overall marine legislation under which marine aggregate extraction is regulated. However, most countries have national laws on extraction, although it is often regulated by regional authorities.

Regarding the considerations required for regulation, risk assessment is a promising instrument, but in connection with the extraction of marine sediments and the possible effects on the environment, it is still far from mature.

5.4 Recommendations

The Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) recommends the continued use of the "ICES Guidelines for the Management of Marine Sediment Extraction" (ICES, 2003) by national administrations within domestic consenting regimes for marine aggregate extraction.

1) ICES Member Countries and OSPAR contracting parties should continue to supply information about their marine aggregate industries to WGEXT, particularly information relating to annual production rates, the area of seabed licensed, and the area of seabed dredged.

2) WGEXT recommends that information on the design, implementation, and use of the results of monitoring programmes associated with aggregate extraction activities are shared with the working group so that best practice can be determined.

3) The dredging industry should continue to improve dredging technology and management practices in order to ensure the sustainable development and use of these valuable, but finite sand and gravel resources.

4) Use of electronic monitoring systems and black-box monitoring equipment for surveillance of dredging operations in ICES Member Countries is recommended. The analysis of the data from these systems has continued to evolve, significantly improving their value as a management tool.

5) Where multiple dredging operations are proposed in proximity to each other, and where the potential exists for cumulative or in-combination effects, a regional approach to development and assessment should be considered, for example, by means of a regional environmental assessment.

6) Given the wide range of extraction operations in northern European and Atlantic waters, and the large diversity of seabed habitats, WGEXT continues to recommend that the specific requirements for any particular extraction operation be determined on a case-by-case basis, taking into account information from regional environmental assessments, as appropriate.

7) Wherever possible, data and environmental management experience of the regulatory authorities and dredging industry should proactively be made widely available to facilitate the continued development of best practice. Issues such as currency, completeness, and facilitated access should be addressed, for example, by means of web-enabled spatial databases and user-friendly GIS interfaces.

8) The aim should be to increase the spatial coverage and resolution of seabed maps and to encourage the adoption of common standards and practices.

9) WGEXT encourages ICES Member Countries to undertake programmes of habitat mapping, in order to provide information to underpin licensing decisions and/or marine spatial planning initiatives in relation to the extractions of marine sediment. Such information will also be useful for sustainable management of the marine environment and the identification of features important to nature conservation.

10) There is a need for fundamental research into the effects of marine aggregate extraction on meiofaunal populations. Development of new taxonomic keys and further development of quantitative meiofaunal sampling methods for gravel substrates is required in order to permit quantitative sampling of meiofaunal assemblages in and around marine sediment extraction sites. Such research will be required to inform any future decisions about whether to include meiofaunal assessment in monitoring programmes associated with marine aggregate extraction activities.

11) Some preliminary research has been conducted on the effects of extraction operations on fish resources and their trophic interactions with other components of the ecosystem. Future investigations should seek to develop an understanding of the effects of marine aggregate extraction activities on both commercial and sensitive fish species in relation to changes in marine habitats. Such investigations should seek to apply the relevance of such research to a wide range of environmental conditions and dredging strategies.

12) WGEXT recommends further efforts to develop approaches to risk assessment in connection with the extraction of marine sediments and the possible effects on the marine ecosystem. The completeness and utility of existing approaches needs to be examined in detail, together with comparisons with risk-assessment methods employed in other sectors, such as the oil and gas industries.

13) A large number of studies have now been undertaken to determine the environmental effects of marine aggregate extraction across ICES Member Countries. WGEXT emphasizes the need to establish the significance of such effects compared with natural fluctuations in the marine environment (including climate change) and changes caused by other anthropogenic activity. Such an appraisal of the concept of environmental significance in relation to stakeholder perception is long overdue and needs to include an assessment of socio-economic factors.

14) Long-term investigations (over several years) on the recovery of fish resources and benthos should be undertaken to determine, in particular: (i) natural recovery of the structure and function of the biological community, and (ii) any persistent and long-term changes to fish resources and benthic community parameters within the context of natural, spatial, and temporal variability of reference environments.

15) There is a need for further research to assess the feasibility and cost-effectiveness of restoring sensitive marine habitats in areas where adverse, persistent, and long-term effects of marine aggregate extraction are evident.

Work to identify suitable indicators of the impacts of marine sand and gravel extraction should continue. Such indicators will need to satisfy the criteria as far as possible (see *ICES Cooperative Research Report No. 273*; ICES, 2005), as well as attempting to achieve EcoQOs, including those already proposed by OSPAR.

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Annex 2 Summary by country of annual marine aggregate extraction statistics

No national reports were received from Iceland, Latvia, Lithuania, Portugal, and Russia.

Table A2.1. Belgium: extraction figures presented in m^3.

Year	Total marine aggregate extraction
1988	584 759
1989	963 709
1990	957 908
1991	1 448 116
1992	1 232 773
1993	1 448 413
1994	1 602 040
1995	1 669 488
1996	1 443 669
1997	3 893 302*
1998	1 392 901
1999	1 685 170
2000	1 900 974
2001	1 911 057
2002	1 619 216
2003	1 653 804
2004	1 551 000
2005	1 364 165

*** Higher production is a result of sand dredged for a pipeline fill.**

Table A2.2. Canada: extraction figures presented in m^3.

Year	Total marine aggregate production
1992	325 000

No marine aggregate production since 1992.

Table A2.3. Denmark: extraction figures presented in m³.

Year	Reclamation (sand)	Beach nourishment (sand)	Construction aggregates (sand and gravel)	Total marine aggregate production (sand and gravel)
1978	1 612 006	0	2 972 213	4 584 219
1979	2 510 836	0	2 482 667	4 993 503
1980	1 021 980	40 000	2 483 524	3 545 504
1981	993 639	60 000	1 668 265	2 721 904
1982	1 800 431	60 000	1 415 239	3 275 670
1983	1 491 575	260 000	1 992 087	3 743 662
1984	1 203 477	120 000	1 266 284	2 589 761
1985	813 045	250 000	1 556 818	2 619 863
1986	1 330 300	330 000	1 540 505	3 200 805
1987	3 494 459	480 000	1 650 747	5 625 206
1988	1 346 910	740 000	1 479 058	3 565 968
1989	4 201 802	860 000	2 613 926	7 675 728
1990	2 575 535	1 360 000	1 806 230	5 741 765
1991	2 385 591	1 610 000	2 402 360	6 397 951
1992	478 284	1 880 000	2 020 899	4 379 183
1993	545 997	1 550 000	2 227 621	4 323 618
1994	639 030	1 930 000	2 605 012	5 174 042
1995	700 421	2 120 000	2 485 793	5 306 214
1996	1 364 540	2 780 000	2 177 277	6 321 817
1997	836 215	3 010 000	2 556 679	6 402 894
1998	1 013 347	3 600 000	2 048 338	6 661 685
1999	7 327 152	2 600 000	2 108 396	12 035 548
2000	2 522 076	2 500 000	2 094 267	7 116 343
2001	726 389	2 540 000	2 146 821	5 413 210
2002	625 071	2 800 000	2 149 142	5 574 213
2003	1 263 704	2 800 000	2 122 155	6 185 859
2004	1 860 000	2 600 000	2 000 000	6 460 000
2005	3 010 000	5 710 000	2 330 000	11 050 000

Table A2.4. Estonia: extraction figures presented in m³.

Year	Reclamation
2003/04	4 256 000

No data available before/after 2003/04.

Table A2.5. Finland: extraction figures presented in m^3.

Year	Total marine aggregate extraction
1992	< 500 000
1993	< 500 000
1994	< 500 000
1995	< 500 000
1996	< 500 000
1997	0
1998	0
1999	0
2000	0
2001	0
2002	0
2003	0
2004	1 600 000
2005	2 388 000

Table A2.6. France (Atlantic/English Channel coast): extraction figures presented in m^3.

Year	Marine aggregate extraction	Non-aggregate (maerl/shelly sands)
1991	2 000 000	n/d
1992	1 900 000	n/d
1993	1 900 000	n/d
1994	2 500 000	n/d
1995	2 500 000	n/d
1996	2 300 000	n/d
1997	2 600 000	n/d
1998	2 600 000	n/d
1999	2 600 000	n/d
2000	3 777 600	467 000
2001	4 003 000	464 000
2002	5 110 000	476 000
2003	5 235 000	475 000
2004	5 735 000	470 500
2005	6 072 000	472 000

Table A2.7. Germany: extraction figures presented in m^3.

Year	Baltic Sea marine aggregate extraction		North Sea marine aggregate extraction	
	Construction	Beach replenishment	Construction	Beach Replenishment
1991	158 889	702 512	0	0
1992	198 000	123 400	0	0
1993	177 983	666 247	0	0
1994	211 818	521 806	782 961	0
1995	595 592	184 238	0	0
1996	710 110	1 505 394	0	0
1997	315 396	2 026 119	0	691 609
1998	2 569 039	814 438	0	0
1999	341 323	821 069	0	441 019
2000	102 306	1 389 896	0	1 046 077
2001	108 452	810 329	0	501 875
2002	151 645	57 790	0	509 186
2003	389 711	1 493 729	89 968	603 043
2004	0	0	146 961	626 448
2005	358 292	0	115 571	723 581

Conversion: tonnes converted to cubic metres using a standard conversion of 1.8 t m^{-3} for construction aggregate and 1.6 t m^{-3} for beach replenishment.

Table A2.8. Ireland: extraction figures presented in m^3.

Year	Beach recharge (sand/gravel)	Construction fill	Maerl
1995	0	0	3 850
1996	0	1 000 000	3 850
1997	0	0	3 850
1998	0	0	5 770
1999	0	0	0
2000	51 267	0	6 150
2001	183 500	0	8 460
2002	0	0	7 690
2003	0	0	7 690
2004	0	0	7 690
2005	0	0	7 168

Table A2.9. The Netherlands: extraction figures presented in m³.

Year	Reclamation/ construction fill	Beach nourishment	Construction aggregate	Total
1974	2 787 962	0	n/d	2 787 962
1975	1 530 791	700 098	n/d	2 230 889
1976	1902409	0	n/d	1 902 409
1977	157 130	600 000	n/d	757 130
1978	2 701 560	651 908	n/d	3 353 468
1979	2 709 703	0	n/d	2 709 703
1980	2 864 907	0	n/d	2 864 907
1981	2 372 337	0	n/d	2 372 337
1982	1 456 748	0	n/d	1 456 748
1983	2 121 576	0	n/d	2 252 118
1984	2 658 174	0	n/d	2 666 949
1985	2 487 257	230 000	n/d	2 724 057
1986	1 955 491	0	n/d	1 955 491
1987	4 346 131	0	n/d	4 346 131
1988	6 681 717	272 499	n/d	6 954 216
1989	8 426 896	0	n/d	8 426 896
1990	6 769 671	6 587 093	n/d	13 356 764
1991	6 355 088	6 414 597	n/d	12 769 685
1992	6 022 125	8 647 832	n/d	14 795 025
1993	3 379 965	9 539 251	n/d	13 019 441
1994	8 469 145	4 913 201	171 927	13 554273
1995	11 015 235	5 421 145	396 019	16 832 471
1996	15 442 511	7 653 186	53 936	23 149 633
1997	13 332 594	7 918 664	138 839	22 751 152
1998	14 818 241	7 415 687	272 660	22 506 588
1999	15 986 046	6 198 921	211 819	22 396 786
2000	17 323 360	7 568 785	527 697	25 419 842
2001	22 598 125	13 142 950	704 549	36 445 624
2002	16 395 461	16 179 309	1 262 844	33 837 614
2003	12 223 337	10 460 271	1 204 329	23 887 937
2004	11 759 676	10 625 337	1 204 833	23 589 846
2005	12 775 098	14 124 734	1 857 841	28 757 673

Table A2.10. Norway: extraction figures presented in m³.

Year	Carbonate sand	Total aggregates
1992	n/d	0
1993	n/d	100 000 – 150 000
1994	n/d	100 000
1995	n/d	100 000 – 150 000
1996	n/d	155 000
1997	n/d	100 000 – 150 000
1998	n/d	n/d
1999	n/d	n/d
2000	n/d	n/d
2001	n/d	n/d
2002	n/d	n/d
2003	115 000	115 000
2004	n/d	n/d
2005	n/d	n/d

Table A2.11. Poland: extraction figures presented in m^3.

Year	Recharge/fill	Construction aggregate	Total
1990	1 046 358	0	1 046 358
1991	766 450	0	766 450
1992	817 056	54 400	871 456
1993	974 798	0	974 798
1994	251 410	6400	257 810
1995	280 720	0	280 720
1996	134 000	0	134 000
1997	247 310	3200	250 510
1998	88 870	0	88 870
1999	375 860	73 000	448 860
2000	241 000	280 000	521 000
2001	100 253	86 500	186 753
2002	365 000	167 144	532 144
2003	n/d	n/d	n/d
2004	n/d	n/d	n/d
2005	n/d	n/d	n/d

Table A2.12. Spain (Atlantic coast, including Canary Islands): extraction figures presented in m^3.

Year	Beach nourishment
1990	82 030
1991	663 797
1992	1 315 433
1993	2 186 176
1994	2 752 974
1995	415 834
1996	1 477 981
1997	1 667 668
1998	1 408 231
1999	492 000
2000	410 000
2001	298 295
2002	83 500
2003	1 191 016
2004	792 660
2005	48 662

Table A2.13. Sweden: extraction figures presented in m^3.

Year	Marine silica sand (glass production)
1990	171 770
1991	116 797
1992	52 739
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0 *
1999	0

Year	Marine silica sand (glass production)
2000	0
2001	0
2002	0
2003	0
2004	0
2005	0

*** In 1998, 2 500 000 m ^{3} of chalk were dredged for fill as part of the Øresund Link Project.**

Table A2.14. United Kingdom: extraction figures presented in m^3.

Year	Reclamation/fill (sand and gravel)	Beach nourishment (sand and gravel)	Construction aggregates (sand and gravel)	Total marine aggregate production
1992	605 802	169 800	11 609 339	12 384 941
1993	151 015	344 809	10 820 955	11 316 779
1994	207 866	567 057	12 525 835	13 300 758
1995	1 523 973	1 589 963	12 622 664	15 736 601
1996	764 062	3 585 722	11 682 491	16 032 275
1997	552 137	2 409 746	12 023 965	14 985 848
1998	225 947	1 217 058	12 332 043	13 775 048
1999	294 869	1 372 946	14 264 311	15 932 126
2000	128 597	1 300 647	12 460 446	13 889 690
2001	822 910	147 760	12 741 575	13 712 245
2002	281 148	618 435	12 313 480	13 213 062
2003	556 488	719 839	12 112 872	13 389 199
2004	156 202	916 634	11 908 342	12 981 178
2005	0	921 984	11 859 724	12 781 708

Conversion: tonnes converted to cubic metres using a standard conversion of 1.66 t m^{-3}.

Table A2.15. United States (Atlantic seaboard).

Year	Construction aggregate (metric t)	Beach Recharge (m^3)
1990	200 000	16 350 000
1991	800 000	7 115 000
1992	800 000	12 320 000
1993	1 500 000	11 900 000
1994	1 700 000	9 350 000
1995	1 400 000	13 400 000
1996	1 400 000	13 200 000
1997	1 400 000	11 400 000
1998	1 300 000	6 000 000
1999	1 300 000	8 600 000
2000	1 100 000	15 800 000
2001	1 300 000	19 700 000
2002	1 100 000	9 600 000
2003	1 400 000	12 600 000
2004	1 600 000	4 500 000
2005	1 400 000	5 751 000

Conversion: tons converted to metric tonnes, and thence to cubic metres using a standard conversion of 1.66 t m^{-3}.

Annex 3 ICES guidelines for the management of marine sediment extraction [1]

Introduction

In many countries, sand and gravel[2] 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 of environmental and hydrological value, and where materials can be landed close to the point of use, there can be the additional benefit of avoiding long-distance, overland transport. Marine dredged sand and gravel is also increasingly used in flood and coastal defence, fill, 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 with the potential negative impacts of aggregate dredging. Aggregate dredging activity, if not carefully controlled, can cause significant damage to the seabed and its associated biota, to commercial fisheries, and to adjacent coastlines, as well as creating conflict with other users of the sea. In addition, current knowledge of the resource indicates that, although there are extensive supplies of some types of marine sand, there appear to be more limited resources of gravel suitable, for example, to meet current concrete specifications and for beach nourishment.

Against the background of utilizing a finite resource, together with its associated environmental impacts, it is recommended that regulators develop and work within a strategic framework that 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, while ensuring that there are adequate supplies to meet the demands of society;
- encouraging their efficient use (and, where appropriate, reuse), minimizing wastage, and avoiding the use of higher quality materials where lower grade materials would suffice;
- ensuring that methods of extraction minimize the adverse effects on the environment and preserve the overall quality of the environment once extraction has ceased;
- encouraging an ecosystem approach to the management of extraction activities and the identification of areas suitable for extraction;
- protecting sensitive areas and important habitats (such as marine conservation areas) and industries (including fisheries), and the interests of other legitimate uses of the sea;

[1] These guidelines do not relate to navigational dredging (i.e. maintenance or capital dredging).

[2] It is recognized that other materials are also extracted from the seabed, such as stone, shell, and maerl, and the same considerations should apply to them.

- preventing unnecessary sterilization of mineral resources by other forms of development.

The implementation of these principles requires knowledge of the resource and an understanding of the potential impacts of its extraction and the extent to which rehabilitation of the seabed is likely to take place. The production of an environmental statement, developed along the lines suggested below, 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 usually be allowed.

It should also be recognized that improvements in technology may allow exploitation of marine sediments from areas of the seabed that are not currently commercially viable, whereas development of technical specifications for concrete, etc. may, in future, allow lower quality materials to be used for a wider range of applications. In the shorter term, continuation of programmes of resource mapping may also identify additional sources of coarser aggregates.

Scope

It is recognized that sand and gravel extraction, if undertaken in an inappropriate way, may cause significant harm to the marine and coastal environment. There are a number of international and regional initiatives that should be taken into account when developing national frameworks and guidelines. These include the Convention on Biological Diversity (CBD), EU Directives (particularly those on Birds, Habitats, Environmental Impact Assessment [EIA], and Strategic Environmental Assessment [SEA] – once implemented), and other regional conventions and agreements, in particular the OSPAR and Helsinki Conventions, and the initiatives pursued under them. This subject, for example, was recently included in the Action Plan of Annex V to the 1992 OSPAR Convention on the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area as a human activity requiring assessment. It is also recognized that certain ecologically sensitive areas may not be designated under international, European, or national rules, but nonetheless require particular consideration within the assessment procedures described in these Guidelines.

Administrative framework

It is recommended that countries have an appropriate framework for the management of sand and gravel extraction, and that they define and implement their own administrative framework with due regard to these guidelines. There should be a designated regulatory authority to:

- issue authorization after full consideration of the potential environmental effects;
- be responsible for compliance monitoring;
- develop the framework for monitoring;
- enforce conditions.

Environmental impact assessment

The extraction of sand and gravel from the seabed can have significant physical and biological effects on the marine and coastal environments. The significance and extent

of the environmental effects will depend on a range of factors, including: the location of the extraction area; the nature of the surface and underlying sediment; coastal processes; the design, method, rate, amount, and intensity of extraction; and the sensitivity of habitats and assorted biodiversity, fisheries, and other uses in the locality. These factors are considered in more detail below. Particular consideration should be given to sites designated under international, European, national, and local legislation in order to avoid unacceptable disturbance or deterioration of these areas for the habitats, species, and other designated features.

To allow the organization(s) responsible for authorizing extraction to evaluate the nature and scale of the effects and to decide whether or not a proposal can proceed, an adequate assessment of the environmental effects needs to be carried out. It is important, for example, to determine whether the application is likely to have an effect on the coastline or an impact on fisheries and the marine environment.

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 in all cases before an extraction is authorized. For EU Member States, the extraction of minerals from the seabed falls within Annex II of the EU Directive on the Assessment of the Effects of Certain Public and Private Projects on the Environment (85/337/EEC; also known as the EIA Directive). As an Annex II activity, an EIA is required if the Member State considers it necessary. It is at the discretion of the individual EU Member States to define the criteria and/or threshold values that need to be met to require an EIA. This Directive was amended in March 1997 by Directive 97/11/EC, which obliged Member States to transpose the requirements of the Directive into national legislation by March 1999.

It is recommended that the approach adopted within the EU be followed. Member States should, therefore, set their own thresholds for deciding whether and when an EIA is required, but an EIA should always be undertaken when extraction is proposed in areas designated under international, European, or national rules, and in other ecologically sensitive areas. For NATURA 2000 sites, Article 6 of the EU Habitats Directive contains special requirements in this respect.

Where an EIA is considered appropriate, the level of detail required to identify the potential impacts on the environment should be carefully considered and identified on a site-specific basis. 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 should take account of the potential for any cumulative impacts. In such cases, consideration should be given to the need for a strategic environmental assessment.

Consultation is central to the EIA process. The framework for the content of the EIA should be established by early consultation with the regulatory authority, statutory consultees, and other interested parties. Where there are potential transboundary issues, it is important to undertake consultation with the other countries likely to be affected, and the relevant competent authorities are encouraged to establish procedures for effective communication.

As a general guide, the topics considered below will probably need to be addressed.

Description of the physical setting

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

- the bathymetry and topography of the general area;
- the distance from the nearest coastlines;
- the geological history of the deposit;
- the source of the material;
- type of material;
- sediment particle size distribution;
- extent and volume of the deposit;
- the stability and/or natural mobility of the deposit;
- thickness of the deposit and evenness over the proposed extraction area;
- the nature of the underlying deposit and any overburden;
- local hydrography, including tidal and residual water movements;
- wind and wave characteristics;
- average number of storm days each year;
- estimate of bed-load sediment transport (quantity, grain size, direction);
- topography of the seabed, including occurrence of bedforms;
- existence of contaminated sediments and their chemical characteristics;
- natural (background) suspended sediment load under both tidal currents and wave action.

Description of the biological setting

The biological setting of the proposed extraction site and adjacent areas should be described in terms of:

- the flora and fauna within the area likely to be affected by aggregate dredging (e.g. pelagic and benthic community structure), 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, overwintering grounds for ovigerous crustaceans, and known routes of migration;
- trophic relationships (e.g. between the benthos and demersal fish populations by stomach content investigations);
- the 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, UNEP "Man and the Biosphere" reserves, World Heritage sites, marine protected areas (MPAs), marine nature reserves, special protection areas (EU Birds Directive), or special areas of conservation (EU Habitats Directive)).

Description of the proposed aggregate dredging activity

Where appropriate, the assessment should include information on:

- the total volume to be extracted;

- proposed maximum annual extraction rates and dredging intensity;
- expected lifetime of the resource and proposed duration of aggregate dredging;
- aggregate dredging equipment to be used;
- spatial design and configuration of aggregate dredging (i.e. the maximum depth of deposit removal, the shape and area of resulting depression; ICES, 2003);
- substrate composition on cessation of aggregate dredging;
- proposals to phase (zone) operations;
- whether on-board screening (i.e. rejection of fine or coarse fractions) will be carried out;
- number of dredgers operating at a given time;
- routes to be taken by aggregate dredgers to and from the proposed extraction area;
- time required for aggregate dredgers to complete loading;
- number of days each year on which aggregate dredging will occur;
- whether aggregate dredging will be restricted to particular times of the year or parts of the tidal cycle;
- direction of aggregate dredging (e.g. with or across tide).

It may also be appropriate, if known, to include details of the following:

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

Information required for physical impact assessment

To assess the physical impacts, the following should be considered:

- implications of extraction for coastal and offshore processes, including possible effects on beach draw-down, changes to sediment supply and transport pathways, changes to wave and tidal climate;
- changes to the seabed topography and sediment type;
- exposure of different substrates;
- changes to the behaviour of bedforms within the extraction and adjacent areas;
- potential risk of release of contaminants by aggregate dredging and exposure of potentially toxic natural substances;
- transport and settlement of fine sediment disturbed by the aggregate dredging equipment on the seabed or originating from hopper overflow or on-board processing, and its impact on normal and maximum suspended load;
- the effects on water quality, mainly through increases in the amount of fine material in suspension;

- implications for local water circulation resulting from removal or creation of topographic features on the seabed;
- the time-scale for potential physical "recovery" of the seabed.

Information required for biological impact assessment

To assess the biological impact, the following information should be considered:

- changes to the benthic community structure and to any ecologically sensitive species or habitats that may be particularly vulnerable to extraction operations;
- effects of aggregate dredging on pelagic biota;
- effects on the fishery and shellfishery resources, including spawning areas, with particular regard to benthic spawning fish, nursery areas, overwintering grounds for ovigerous crustaceans, and known routes of migration;
- effects on trophic relationships (e.g. between the benthos and demersal fish populations);
- effects on sites designated under local, national, or international regulations (see above);
- predicted rate and mode of recolonization, taking into account initial community structure, natural temporal changes, local hydrodynamics, and any predicted change of sediment type;
- effects on marine flora and fauna, including seabirds and mammals (ICES, 2003);
- effects on the ecology of boulder fields/stone reefs.

Interference with other legitimate uses of the sea

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

- commercial fisheries;
- shipping and navigation lanes;
- military exclusion zones;
- offshore oil and gas activities;
- engineering uses of the seabed (e.g. adjacent extraction activities and undersea cables and pipelines, including associated safety and exclusion zones);
- areas designated for the disposal of dredged or other materials;
- location in relation to existing or proposed aggregate extraction areas;
- location of wrecks and war-graves in the area and general vicinity;
- windfarms;
- areas of heritage, nature conservation, archaeological, and geological importance;
- recreational uses;
- general planning policies for the area (international, national, and local);
- any other legitimate use of the sea.

Evaluation of impacts

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. Consideration should also be given to the assessment of the potential for cumulative impacts on the marine environment. In this context, cumulative impacts may result from aggregate dredging at a single site over time or from dredging at multiple sites in the same vicinity, possibly in combination with effects from other human activities (e.g. fishing and disposal of harbour dredgings). It is recommended that a risk assessment be undertaken. This should include consideration of worst-case scenarios and indicate uncertainties and assumptions used in their evaluation.

The environmental consequences should be summarized 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 allow assessment of its suitability for the particular modelling exercise.

Mitigation measures

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

- the selection of aggregate dredging equipment and timing of aggregate dredging operations to limit impact upon the biota (e.g. birds, benthic communities, any particularly sensitive species and habitats, and fish resources);
- modification of the depth and design of aggregate dredging operations to limit changes to hydrodynamics and sediment transport, and to minimize the effects on fishing;
- spatial and temporal zoning of the area to be authorized for extraction or scheduling extraction to protect sensitive fisheries or to respect access to traditional fisheries;
- preventing on-board screening or minimizing material passing through spillways when outside the dredging area in order to reduce the spread of the sediment plume;
- agreeing exclusion areas to provide refuges for important habitats or species, or other sensitive areas.

Evaluation of the potential impacts of the aggregate dredging proposal, once any mitigating measures have been taken into account, should allow 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 aggregate dredging proceeds. The EIA should form the basis for the monitoring plan.

Authorization issue

Once an aggregate extraction operation is approved, an authorization should be issued in advance (which may take the form of a permit, licence, or other form of regulatory approval). In granting an authorization, the immediate impact of aggregate extraction occurring within the boundaries of the extraction site, such as alterations to

the local physical and biological environment, is accepted by the regulatory authority. Notwithstanding these consequences, the conditions under which an authorization for aggregate extraction is issued should be such that environmental change beyond the boundaries of the extraction site is as far below the limits of allowable environmental change as practicable. The operation should be authorized subject to conditions that further ensure that environmental disturbance and detriment are minimized.

The authorization is an important tool for managing aggregate extraction and should contain the terms and conditions under which aggregate extraction may take place, as well as providing a framework for assessing and ensuring compliance.

Authorization conditions should be drafted in plain and unambiguous language and should be designed to ensure that:

- the material is only extracted from within the selected extraction site;
- any mitigation requirements are complied with;
- any monitoring requirements are fulfilled and the results reported to the regulatory authority.

Monitoring compliance with conditions attached to the authorization

Monitoring compliance with conditions attached to the authorization is an essential requirement for the effective control of marine aggregate extraction. This has been achieved in several ways (e.g. an electronic monitoring system or black box).

The information provided will allow the regulatory authority to monitor the activities of aggregate dredging vessels to ensure compliance with particular conditions in the authorization. The information collected and stored will depend on the requirements of the individual authorities and the regulatory regime under which the permission is granted (e.g. the EIA, Habitats, and Birds Directives of the EU).

The minimum requirements for the monitoring system should include:

- automatic recording of the date, time, and position of all aggregate dredging activity;
- recording of position to within a minimum of 100 m in latitude and longitude, or other agreed coordinates, using a satellite-based navigation system;
- an appropriate level of security; and
- a frequency of recording of position appropriate to the status of the vessel, i.e. less frequent when the vessel is in harbour or in transit to the aggregate dredging area (e.g. every 30 min), and more frequent when dredging (e.g. every 30 s).

The above are considered to be reasonable minimum requirements to allow the regulatory authority to monitor the operation of the authorization in accordance with any conditions attached. Individual countries may require additional information for compliance monitoring at their own discretion.

The records can also be used by the aggregate dredging company to improve utilization of the resources. The information is also an essential input into the design and development of appropriate environmental monitoring programmes and research into the physical and biological effects of aggregate dredging, including combined/cumulative impacts (see Evaluation of impacts, above).

Environmental monitoring

Sand and gravel extraction inevitably disturbs the marine environment. The extent of the disturbance and its environmental significance will depend on a number of factors. In many cases, it will be impossible to predict fully the environmental effects at the outset, and a programme of monitoring may be needed to demonstrate the validity of the EIA's predictions, the effectiveness of any conditions imposed on the authorization, and, therefore, the absence of unacceptable impacts on the marine environment.

The level of monitoring should depend on the relative importance and sensitivity of the surrounding area. Monitoring requirements should be site-specific and, wherever possible, be based on the findings of the EIA. To be cost-effective, monitoring programmes should have clearly defined objectives derived from the impact hypothesis developed during the EIA process. The results should be reviewed at regular intervals against the stated objectives, and the monitoring exercise should then be continued, revised, or even terminated. It is also important that the baseline and subsequent monitoring surveys take account of natural variability. This can be achieved by comparing the physical and biological status of the areas of interest with suitable reference sites located away from the influence of the aggregate dredging effects and other anthropogenic disturbance. Suitable locations should be identified as part of the EIA's impact hypothesis.

A monitoring programme may include assessment of a number of effects. When developing the programme, a number of questions should be addressed, including:

- What are the environmental concerns that the monitoring programme seeks to address?
- What measurements are necessary to identify the significance of a particular effect?
- What are the most appropriate locations at which to take samples or observations for assessment?
- How many measurements are required to produce a statistically sound programme?
- What is the appropriate frequency and duration of monitoring?

The regulatory authority is encouraged to take account of relevant research information in the design and modification of monitoring programmes. The spatial extent of sampling should take account of the area designated for extraction and the areas outside that may be affected. In some cases, it may be appropriate to monitor more distant locations if there is some question about a predicted nil effect. The frequency and duration of monitoring may depend on the scale of the extraction activities and the anticipated period of consequential environmental changes, which may extend beyond the cessation of extraction activities.

Information gained from field monitoring (or related research studies) should be used to amend or revoke the authorization or refine the basis on which the aggregate extraction operation is assessed and managed. As more information on the effects of marine aggregate dredging becomes available and a better understanding of impacts is gained, it may be possible to revise the extent of the monitoring. It is, therefore, in the interest of all concerned that monitoring data be made widely available. Reports should detail the measurements made, results obtained, their interpretation, and how these data relate to the monitoring objectives.

Reporting framework

It is recommended that the national statistics on aggregate dredging activity continue to be collated annually by the ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT).

Definitions

In these Guidelines, the term "marine sediment extraction" refers to the extraction of marine sands and gravels (or "aggregates") from the seabed for use in the construction industry (where they often directly replace materials extracted from land-based sources) and in flood and coastal defence, beach replenishment, fill, and land reclamation projects.

It is recognized that other materials are also extracted from the seabed, such as stone, shell materials, and maerl, and similar considerations to those set out in the Guidelines should also apply to them. The Guidelines do not apply to navigational dredging (e.g. maintenance or capital dredging operations).

In these Guidelines, the term "authorization" is used in preference to "permit" or "licence" and is intended to replace both terms. The legal regime under which marine extraction operations are authorized and regulated differs from country to country, and the terms "permit" and "licence" may have a specific connotation within national legal regimes and also under rules of international law. The term "authorization" is therefore used to mean any use of permits, licences, or other forms of regulatory approval.

The ecosystem approach will be elaborated by further work in both OSPAR and ICES. The following definition has been used elsewhere: "the comprehensive integrated management of human activities based on best available scientific knowledge of the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity".

Revision of Guidelines

WGEXT will continue to review any new information, conclusions, and understandings from scientific research projects and any reports from countries on their experiences with the implementation of the Guidelines, and, where appropriate, will revise the Guidelines accordingly.

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