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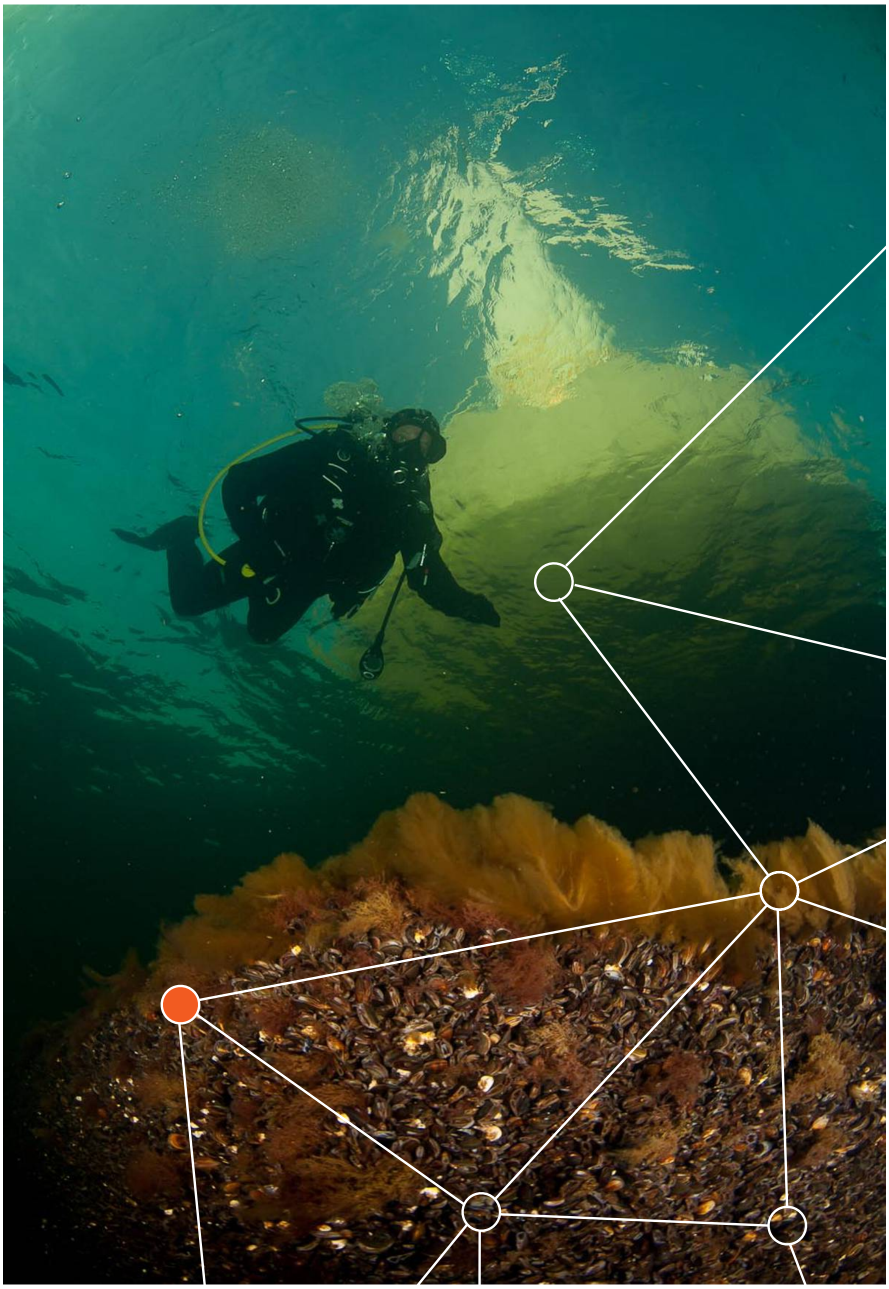

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Contents

1 Introduction

Each year across the ICES Area, approximately 100 million m^3 of sand and gravel are extracted from licensed areas of the seabed (as described in Chapter 2) as a source of aggregate for the construction industry, either to supplement land-based sources or as a source of material for coastal beach nourishment. As land-use constraints and resource exhaustion are tending to restrict the extraction of aggregate from terrestrial sources, attention continues to be 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 renourishment in the face of coastal erosion. However, the benefits of using marine sand and gravel must be balanced with the potentially significant environmental impacts. In recognition of this, the exploitation of marine resources is regulated in most ICES Member Countries by national and international mineral policies, subject to environmental safeguards.

Between 1998 and 2002 (ICES WGEXT annual reports), the amount of marine aggregate extraction was approximately 53 million m^3 $year^{-1}$ in ICES Member Countries, but this amount has nearly doubled in recent years. This rise reflects the increasing constraints on land-based extraction. Public attention to the effects of marine sand and gravel extraction both on the environment and on fisheries has grown in line with this expansion of effort. However, the resolution of issues related to these effects is more difficult in the marine environment than on land 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. Additional drivers emphasize the impacts of marine aggregate extraction 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 comprehensive protection of marine habitats (under the EU Habitats Directive) through international management initiatives under OSPAR, HELCOM, and the EU Marine Strategy Framework Directive (MSFD). The MSFD sets out 11 high-level descriptors with which to describe ”good environmental status”. Of particular relevance to the ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) are descriptors 6 (seafloor integrity) and 11 (introduction of energy, including underwater noise); however, descriptors 1 (biodiversity), 4 (foodwebs), and 7 (hydrographical conditions) also require consideration. OSPAR, HELCOM, and ICES are promoting transnational cooperation in developing the ecosystem-based marine management. National and international emphasis has been directed toward the development of ecosystem-based management, including evaluations of the scope for “cumulative” or “in-combination” impacts.

WGEXT was established in 1986 to increase 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 aims 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* (*CRR*) 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; Sutton and Boyd, 2009). One of the principal activities of WGEXT has been the identification and recommendation of future research needs. For example, *ICES Cooperative Research Report No. 297* (Sutton and Boyd, 2009) highlighted 15 key research themes, and in the intervening years, WGEXT has continued assuming the lead in reviewing ongoing research by monitoring progress on critical research needs. 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 and the monitoring and mitigation that is employed to assess and protect the marine ecosystem.

It is a role of the Working Group to review the amounts and impacts of aggregate extraction in relation to legal safeguards and to both national and international governance arrangements. It also provides detail on established legislative frameworks, as well as identifying the latest improvements for assessing risk at proposed extraction areas. This report presents a synthesis of information compiled over recent years and is based on previous *CRR*s and annual Working Group reports for the period 2005–2011. It is acknowledged that there are issues with consistency of presentation. However, this is as a result of the differing contributions provided by Member Countries to each annual report.

1.1 Objectives

The objectives of this report reflect those of WGEXT, namely to provide a review of:

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

1.2 Contributors

Thirteen authors from eight countries participated in the production of this report, with an additional fifteen members contributing data. A complete list of contributors is found in Annex 1. Particular acknowledgement is given to Rebecca Walker (Chapter 1), Mark Russell and Chris Dijkshoorn (Chapter 2), Ingemar Cato and Bryndis Robertsdottir (Chapter 3), Rebecca Walker, Annelies de Backer, Michel Desprez, and Marcel Rozemeijer (Chapter 4), Jan van Dalfsen, Lara Howe, and Rebecca Walker (Chapter 5), Ad Stolk (Chapter 6), and the editors Rebecca Walker and Henry Bokuniewicz. All material has been reviewed by WGEXT.

1.3 Recommendations

Recommendations from Section 4

- Create an ICES database, comprising all aggregate-related data. The database should include scientific research and environmental impact assessment (EIA) licensing and monitoring data.
- Ensure standardization of data across ICES Member Countries.
- Cumulative assessment guidance and a framework for assessment should be developed. This work may already be under development within another ICES or OSPAR WG; steps should be taken to investigate and align guidance as appropriate.

Recommendations from Section 5

- As extraction activities that are undertaken in an inappropriate way may cause significant harm to the marine and coastal environment, it is recommended that mitigation is examined by the WGEXT more systematically to describe current practices and identify options for the future. Consideration should also be given to whether research techniques should move away from the traditional Before–After Control–Impact (BACI) approach to one that is more hypothesis-driven to better enable extrapolation of results across extraction sites.
- It is recommended that further research be conducted that is aimed at assessing the opportunities for designing extraction sites to obtain a beneficial effect on the ecological functions of a dredging area.

Recommendations from Section 6

- ICES should bring forward to the EU the WGEXT interpretation of "good environmental status" (GES) descriptors 6 and 11.
- ICES Member Countries, where necessary, should discuss the implications of MSFD GES Descriptor 6 with their own administrations using the text provided by WGEXT.
- WGEXT should review the 2003 ICES Guidelines on Marine Aggregate Extraction, specifically in relation to GES descriptors under MSFD.

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

2.1 Extraction of marine sediments

This report only considers the extraction of marine sediment that is assessed and licensed for a specific purpose, whether for construction, beach replenishment, or fill purposes. Sand and gravel may also be generated as a byproduct of another activity, such as maintenance or capital dredging. In these instances, the sediment removed through these processes may be reused – the concept of beneficial use. Such dredging operations may not be controlled or managed in the same way as licence or borrow areas awarded specifically for the production of sediment; therefore, they are not considered in this report.

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 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 and Belgium), while others are primarily concerned with sands and gravels (e.g. the UK).

This chapter reviews the status of marine mineral 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 carbonate (shell) sands are also dredged in limited quantities and, where appropriate, these are also inventoried. 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 construction environment existing in all ICES Member Countries. The continual expansion and maintenance of this environment creates an annual demand equivalent to an output of 5.5 t of crushed rock, sand, and gravel *per capita* in Europe alone – a total demand of over 3000 million t. 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 sand and gravel, as resources become exhausted or subject to more limiting environmental constraint. On the other hand, countries such as Norway and Spain are looking to increase their output of crushed rock from large coastal quarries which could be exported to countries with a short-fall in "home-based" production. Some countries are providing suitable deep-water wharves near their markets to accommodate large bulk carriers.

Sustainable exploitation of marine resources is a well established basic principle in both international and national regulations, and constitutes a beneficial use of dredged materials arising from capital and maintenance dredging (as opposed to simple disposal). It is being encouraged through planning policy, differential taxation, and licence procedures. Careful planning of the use of dredged material from large-scale construction works has proven to be economically and ecologically acceptable and could reduce the pressure on land-based reserves, particularly of sand, as well as reducing the requirement to dispose of material at sea.

To be sustainable, finite marine resources must be used responsibly and appropriately. Over the last 15 years, there has been a significant increase in the use of secondary and recycled materials in an effort to reduce the pressures upon primary aggregate resources, including marine resources. Across Europe, secondary and recycled aggregates currently account for only ca. 6% of the total aggregate demand, although the Netherlands, Germany, and the UK in particular have led the field in this respect. However, there is a practical limit to the volumes of secondary and recycled materials available to be used. For example, in the UK, while the contribution of secondary and recycled materials is ca. 25% of total consumption (58 million t out of a total market demand of 206 million t in 2010), there is limited scope for further increases unless significantly greater use can be made of waste products from other extractive activities such as china clay and slate. As a result, on this basis, there is expected to be an ongoing need for primary-won aggregates to support construction. Marine sources represent one component of the wider portfolio of supply.

End-uses in which secondary and recycled materials can be employed are also limited. In concrete and concrete products, the end-uses generally require specific aggregates of high quality and, as such, there may be only limited potential for substitution, particularly for the sands required in product mixes. Use of poorer quality materials can also result in more cement being required for each project and, therefore, increased levels of carbon cost m^{-3} of concrete produced. However, specifications for construction fill to support major infrastructure projects are generally less stringent. There is, therefore, greater potential for substitution. However, the limiting factor in this instance is the availability of sufficient volumes of alternative materials and the ability to transport/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 was introduced in 2004 in order to unify and simplify the various existing national technical requirements. The objective has been to facilitate trade between all participating countries by standardizing the product descriptions and terminology for material producers, specifiers, and users alike. Standard specifications are in place for a range of end-uses, including concrete and mortar. These are particularly important for marine materials. Any product able to fulfil the requirements of the specification can be used, reinforcing the concept 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 cargo being equivalent to 250 20 t lorry loads, marine aggregate operations can offer significant advantages through their economies of scale. This means that large volumes can be economically transported from the licensed source over considerable distances (>150 km) to be delivered close to the market where they are required. There are also the wider benefits of reducing pressure on the road networks and the associated reductions in emissions and carbon cost per tonne delivered.

In the case of large-scale bulk fill or replenishment projects, it would not be economically feasible to undertake the projects without the use of marine dredged materials because of the huge volumes required to meet the construction schedule. In these instances, the concept of "fit for purpose" ensures that large volumes of high-end specification resources are not being used for a low-end use. It is common for material arising from navigation dredging (both maintenance and capital) to be used for these purposes rather than being simply disposed as waste, under the auspices of beneficial use.

The contribution of marine aggregates to ICES Member Countries forms one component of a much wider portfolio of supply options which meet the overall need for construction aggregates. Marine dredged material makes a significant contribution to overall construction aggregate supply requirements for a number of countries, in certain national regions, and for particular uses. They provide a major, sometimes predominant, source of supply. For example, the construction markets around the major points of landing, such as London (UK), New York (USA), Amsterdam (Netherlands), Antwerp (Belgium), and Dunkirk (France), very much depend on supplies of marine material. Marine materials also seem to be penetrating markets inland beyond the traditional coastal fringe to fill gaps in supply, via barges using inland waterways.

The role of marine sediments to support large-scale coast defence, beach nourishment, and major infrastructure projects (such as port developments) also appears to be playing a significant and arguably growing role across ICES Member Countries as nations respond to the challenges of climate change and support economic development.

2.2.1 Uses of marine sediments

Marine aggregates are an established construction aggregate resource, both technically and commercially. Modern technology and control systems ensure that all products are of a consistently high quality and, therefore, comparable in performance to 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 base, and other ground works; and (iii) coast protection in both recharge and coastal feeding. However, small quantities of marine sand are used in agriculture to improve soil structure and as cover for oil and gas pipelines. Marine sand and gravel are also being used to construct concrete gravity-base foundations used for offshore wind turbines.

Within ICES Member Countries, reliance on marine aggregate 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, often reflecting the original fluvio-glacial geological processes that created the deposits, in the case of coarse sand and gravel resources contained within palaeochannels, or, in the case of finer sands, the more recent hydrodynamic processes resulting from tide and wave action. In the North Sea basin, for example, sediments generally become finer from west to east, which is reflected in the extraction patterns from bordering countries. The UK extracts ca. 80% of the total gravel removed from the North Sea region (excluding sand) whilst the Netherlands extracts a similar percentage of sand.

2.2.2 Construction

Marine sand and gravel constitute very important raw materials for the construction industry, primarily for use as aggregates in the manufacture of concrete. Washed and graded marine sand and gravel are normally combined in the proportion of 50:50 in order to produce concrete and concrete products. Marine sand can also be used ”as dredged” in combination with crushed rock for the same purpose. The construction industry’s demand for coarse marine sand appears to be increasing because of the growing constraint on the availability of equivalent terrestrial resources.

Those national institutes responsible for the testing of construction material and specification have established that the use of marine sand and gravel is no less appropriate than the terrestrial equivalent. In certain cases, marine-sourced material can offer benefits through superior workability resulting from the more rounded nature of individual grains and clasts, and the lack of contamination from soft materials (fine sands, silts, and clays) compared to land-won resources.

Given the distribution of population 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 sand and gravel are used extensively in the UK for making concrete (>4.8 million m^3 in 2010 – equivalent to 23% of the total concreting aggregates consumed). Denmark and Iceland also use marine sand and gravel for concrete production, while other northern European countries use marine sand alongside imported crushed rock for the same purpose.

2.2.3 Construction fill and land reclamation

Marine dredged material has continued to be used for major construction fill and reclamation projects in the ICES Area, often associated with port developments.

In the Netherlands, marine sand has been used for a number of major landfill contracts. Although Dutch policy calls for more marine sand extraction, the volumes have been relatively stable. However, the quantities in 2009, 2010, and 2011 were higher because of a number of capital works projects, including Maasvlakte 2, Sand Motor, and the Weak Links projects programme.

For the expansion of the Rotterdam Harbour (Maasvlakte 2), an EIA for the extraction of 365 million m^3 of sand has been completed. The expansion, with an initial volume of 210 million m^3, was completed in 2013. This will be followed by a maintenance programme for the new coastline.

In Denmark, the continued expansion of Århus Harbour required 4.8 million m^3 of sand to be dredged from licensed areas in the Århus Bight during 2005. The third phase of the harbour development is expected to require a further 11 million m^3 of sand. Small volumes of glacial till arising from capital dredging projects continue to be used for fill.

In Finland, the expansion of Helsinki Harbour required 4.57 million m^3 of marine sand and gravel to be dredged between 2005 and 2006. There has been no extraction since, although the licence was renewed in 2010 for a further 5 million m^3.

In Germany, the Jade Weser port project created demand for marine sand and gravel resources, which peaked in 2009.

In Sweden, the planned expansion of the port of Trelleborg in southern Sweden will also see an estimated 1.33 million m^3 removed to deepen the port area and reclaim new land.

In the UK, significant volumes of marine sand and gravel have been used to support several major infrastructure development projects, including the extension of Ronaldsway Airport on the Isle of Man (0.32 million m^3 in 2009/2010) and the development of Felixstowe Harbour (2.17 million m^3 in 2009/2010).

2.2.4 Coastal protection

Soft engineering approaches to prevent coastal erosion and protect coastal communities from inundation from the sea are now well established. Material for beach recharge schemes has to meet tight specifications in terms of grading. Size ranges 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 pressures of exploiting an essentially finite resource, more effort is being made for the beneficial reuse of sand and gravel resources from, for example, those arising from other capital and maintenance dredging processes, rather than being controlled by the need for a particular specification.

As well as beach replenishment, where sand and gravel is deposited directly onto the beach, a new technique has been "coastal feeding". Material is deposited into the sediment transport regime upstream of the natural processes that are feeding the coastline. The additional sand is then incorporated into the overall flux of sediment available, therefore increasing the availability of sediment to be transported into the foreshore and beach systems through natural processes. An example of coastal feeding at work is the Sand Motor[1] project in the Netherlands. This project is part of the Building with Nature programme (further information is provided in Chapter 5) and involved placing 21.5 million m^3 of sand on the Dutch coastline to protect the shoreline from erosion. The sand was shaped into a hook, and natural processes were allowed to disperse the sediment along the coast creating new ecological habitat for nature as well as recreational areas. If the project is successful, further sand replenishment schemes along this part of the coastline will not be required for the next 20 years.

In Belgium, recent studies have shown that one-third of the Belgian coastline is not sufficiently protected against severe storm events. Therefore, an Integrated Master Plan for Coastal Safety has been introduced which forms the basis for the development of the seafront along the Belgian coast in the short, medium, and long term (up to 2050), with safety against flooding as its main objective. The implementation phase of the Master Plan is planned to take place between 2011 and 2015, for which >20 million m^3 sand is needed to raise and broaden the beaches and dunes and maintain them until the year 2050. For these nourishment works, sand will be extracted in the new licensed areas on the Hinderbanks.

Along the Netherlands coast, beach nourishments have taken place since 1950. In 1990, the ministry in charge adopted a policy to stop any 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 2005, >10

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[1] http://www.dezandmotor.nl/en-GB/.

million m^3 has been used annually for coastal feeding and beach nourishment, including a peak of 30.9 million m^3 in 2009.

In Spain, extraction from marine aggregate resources in Spanish waters is only permitted if the sediment removed is to be used for beach replenishment. Sand extraction takes place from Atlantic Spanish waters and at the Canary Islands for use as beach nourishment, with the principle objective being to improve the amenity value of beaches. Between 1990 and 2011, >10.5 million m^3 of sand has been removed from Atlantic Spanish waters for this purpose.

In Sweden, the Ystad Municipality in southern Sweden was licensed in 2011 to extract a total of 0.34 million m^3 of sand from an area 6 km off the coast over a 10-year period. In 2011, 0.095 million m^3 of sand was removed in support of beach nourishment works in the Ystad Sandskog and Loderups Strandbad areas. The beaches at these locations are important for tourism, but are retreating through a combination of isostatic sinking and sea-level rise.

In the UK, coastal frontages along the eastern coast of England (Northumberland, Lincolnshire, Norfolk, and Essex) and along the southern coast of England (Kent, East Sussex, West Sussex, and Dorset) have been subject to coast protection or replenishment works since 2005. The annual volumes supplied have varied considerably from 0.65 million m^3 in 2010 to 2.99 million m^3 in 2009, partly as a result of changes to funding priority, with investment being diverted to inland flood protection projects.

Denmark, Germany, Lithuania, Poland, Portugal, and the USA are also actively engaged in beach renourishment projects. Most ICES Member Countries, therefore, continue to make use of marine sediments for beach replenishment. With the predicted changes in sea level and an increase in the number of extreme weather events resulting from climate change, marine dredged sediments can be expected to play an increasingly important role in coastal protection across the ICES Area as the 21st century advances.

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 shell sand has remained relatively stable between 2005 and 2011 at ca. 0.49 million m^3. However, it should be noted that maerl extraction will be prohibited in France after 2013.

In southwestern Iceland, marine shell sands are used locally in the manufacture of cement. Extraction has decreased from 0.158 million m^3 in 2007 to 0.04 million m^3 in 2011. Extraction of maerl in northwestern Iceland (Arnarfjordur) commenced from a single licensed area in 2005 following an EIA that was started in 2002. A total of 0.014 million m^3 was extracted in the first year, increasing to 0.054 million m^3 in 2010. Since 2009, further areas of maerl resource are now also being investigated in the same region, although no further licences have been issued to date.

In the Netherlands, >0.24 million m^3 of marine shell were extracted from the Western Scheldt, the North Sea, and the Wadden Sea each year between 1993 and 2011, although licensed volumes and production have decreased since 2004.

2.3 Marine aggregate resources

Marine sand and gravel resources are unevenly distributed across ICES Member Countries. As a result, resources are exploited to varying extents by individual states. Just as on land, the distribution of resources is dictated by the geological origins of the source material and the physical processes which have eroded, transported, sorted, and deposited them.

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

Over the past 25 years, the social and environmental pressures on traditional land-based sources of sand and gravel have been increasing. Indeed, this was one of the major factors for many national marine aggregate industries being established. However, similar pressures (the protection of habitats and species, competition with other offshore activities and uses, including fisheries and wind farms) 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 growing pressure from a range of interests. Furthermore, the development of new resources to either replace exhausted licence areas or to allow the industry to respond to new market demands has become increasingly complex.

The pressures on existing nearshore marine resources, coupled with a need to replace resources that are reaching the end of their economic life, 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, extensive new resources have been identified and continue to be developed in the eastern English Channel in water depths >50 m. Within English waters, extraction commenced in 2005 after the issue of licences had followed a detailed EIA process. The new setting brings a number of new environmental issues to be considered through assessment, mitigation, and monitoring; for example, 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. Also, the implications of far-field impacts arising from the introduction of sands through either overspill, screening, or release from the dredged seabed into a sediment transport regime with a relatively limited flux must be addressed. Other deep-water resources are being developed in the outer Bristol Channel off the coast of southern 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 fine grained sediment. The borrow pits resulting from the Maasvlakte 2 project have potentially exposed some of this coarser sediment, and there are interests in trials to examine whether this material is suitable for other uses.

In both Belgium and Denmark, the potential for beneficial use of dredged material associated with capital and maintenance dredging activity continue to be considered for either fill or for beach feeding/nourishment schemes. Similar approaches are already in place in the Netherlands, the US, 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. Due to the distribution of marine sand and gravels that are commonly targeted, extraction activity tends to be focused 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, creating a ″cumulative″ effect.

As the coastal zones of Member Countries become ever more congested, with competition for space on sea surface and seabed at temporal and spatial scales, there is now also a requirement to consider the additive ″in-combination″ effects of other activities that interact with the seabed (for example, capital dredging, wind-farm development and operation, and commercial fishing) taking place in proximity to the extracting operations. By the same token, the other activities taking place in the marine environment must take account of aggregate extraction.

The growing complexity of marine activities and their associated assessment and management has seen the development of a European Marine Strategy Framework Directive (MSFD) to move towards ecosystem-based management of European seas at a regional sea scale. The Directive requires EU Member States to take measures to achieve or maintain good environmental status (GES) for their seas by 2020. GES involves protecting the marine environment, preventing its deterioration, and restoring it where practical, while using marine resources sustainably. The Directive is very wide-ranging and sets out eleven descriptors of GES relating to biological diversity, invasive species, commercially exploited fish and shellfish populations, foodwebs, human-induced eutrophication, seafloor integrity, hydrographical conditions, concentrations of contaminants, contaminants in fish and other seafood, litter, and noise. Measures must also be developed to achieve the desired GES outcomes. Individual marine dredging operations are likely to see limited direct impacts from the Directive. However, the wider implications arising from the cumulative impact of marine aggregate activities alongside the equivalent impacts from renewable energy, oil and gas, and fishing mean that the precise implications for the future assessment and management remain uncertain.

In the case of both the cumulative and in-combination effects associated with marine aggregate extraction, the means to assess potential impacts and to establish their significance remains a key requirement of the regulatory process. In many cases, the assessment of these effects can only really be achieved at a regional scale. The Marine Aggregate Regional Environmental Assessment (MAREA) approach, developed by the UK industry in the English sector of the eastern English Channel, represents one example of this approach. The MAREA approach has now been extended by the UK industry to four other regions: the Isle of Wight, the outer Thames Estuary, the Anglian, and the Humber, in support of a programme of licence renewals.

Understanding the effects of marine aggregate dredging requires knowledge of the geological resource being targeted and the sediment processes occurring in and around the extraction area. The latter are particularly important, because sediment transport processes will dictate the nature and extent of impacts from extraction activities outside the immediate dredging site. These processes will also drive the recovery processes of the site once extraction has ceased. Modern positioning and survey technologies and the ability to acquire data at higher resolutions has allowed the industry to better understand 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 have permitted seabed sediment transport processes to be more accurately defined. As a result, extraction plans can be designed to take account of both resource management and environmental implications and allow 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

The annual production of marine aggregates in Belgium is ca. 2 million m^3, with an increase in 2011 to 3.5 million m^3. A total of 80% of production is for industrial purposes and ca. 20% is used in support of beach nourishment. All sand dredged from the Belgian continental shelf is taken from the licensed areas that correspond to major sand bank features, and the majority of sand is dredged from the crest of these features. About 70–80% of all marine sand is extracted from only one licensed area (Zone 2; Figure 2.1). Since 2005, a second area (Zone 1) has captured up to 25% of overall extraction. Extraction is carefully monitored to prevent excessive deepening and to maintain the quality of the dredged product. Management has resulted in some parts of licence areas being closed as pre-determined depth limits (5 m) were reached, because sand quality was compromised as a result of adjacent dredge spoil disposal activity, or because of allocation as a reference area for scientific purposes.

To sustain the availability of high quality sand and because of the Integrated Master Plan for Coastal Safety from the Flemish Region, new resource areas have been investigated farther offshore in the Hinderbanks. Four new licensed areas were designated on the Hinderbanks over December 2010 and January 2011. The new areas are currently only in use by the Flemish Region for beach nourishment purposes; no industrial extraction is taking place yet (Figure 2.1).

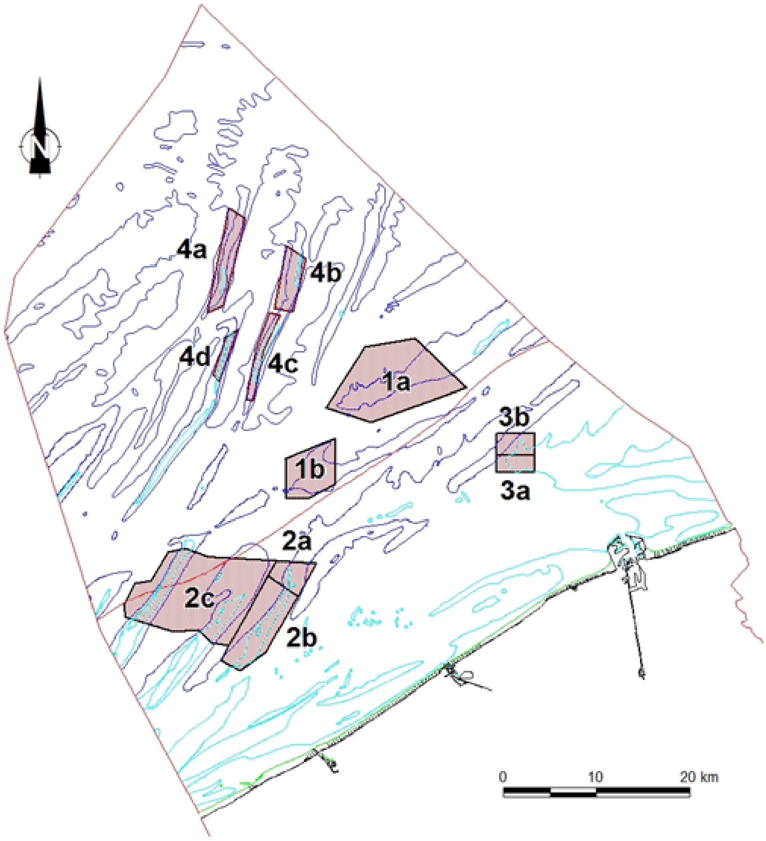


Figure 2.1. Map of permitted exploitation areas for sand and gravel on the Belgian continental shelf as defined in the Royal Decree of 1 September 2004 (last adapted in 2010) and the Ministerial Decree of 24 December 2010 (for exploitation zones 4a–d).

2.4.2 Canada

There has been no marine aggregate production since 1992.

2.4.3 Denmark

The extraction of marine aggregates in Denmark accounts for 10–20% of the total Danish production of aggregates. Since 2005, the extraction of aggregates for construction has remained more or less stable. The production of sand for beach nourishment at the western coast of Jutland, which started in the 1980s, has also remained stable over the last six years at ca. 2 million m^3 $year^{-1}$.

The amount of sand extracted for land reclamation depends on construction activities, which vary from year to year. The most significant amounts were extracted during 2005, where the continuing extension of Århus Harbour resulted in 4.8 million m^3 of marine sand being dredged from licensed areas in the Århus Bight. The third phase of the harbour development is expected to require a further 11 million m^3 of sand.

Between 10 and 15% of the total marine extraction of sand comes from maintenance and capital dredging. This sand continues to be used beneficially and represents an important contribution to the supply of materials for coastal protection, construction, and fill.

2.4.4 Estonia

In Estonia, extraction of sand and gravel primarily takes place within the Gulf of Finland in and around the Tallin and Ihasalu Bay.

Between 2008 and 2010, >1.8 million m³ of sand and gravel was dredged from licence areas in this region. Construction sand accounted for 1 million m³ of the total volume (Figure 2.2).

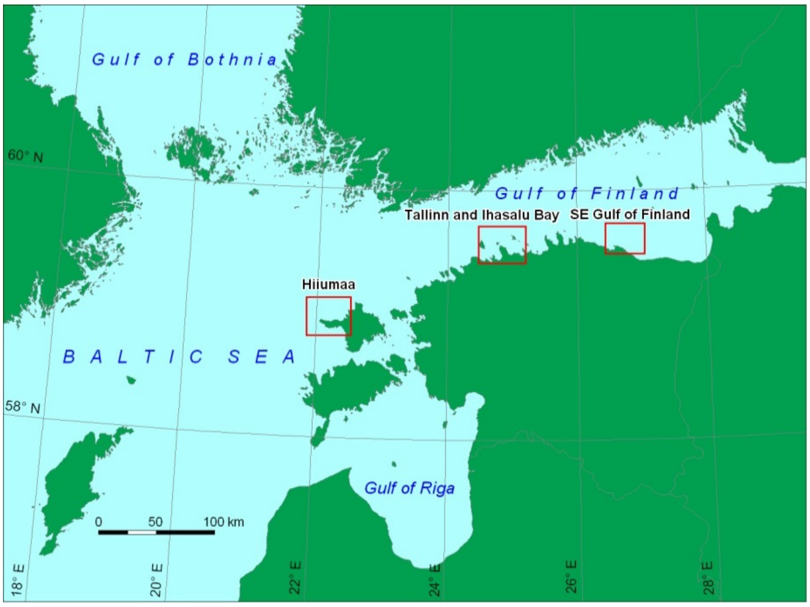


Figure 2.2. Overview map showing the Gulf of Finland and the extraction site

2.4.5 Finland

Sand and gravel extraction from Finnish coastal areas was negligible until 2004, when Helsinki Harbour was permitted to extract 11 million m³ of sediment until 2011. In 2004, 1.6 million m³ was extracted, 2.38 million m³ was extracted in 2005, and 2.19 million m³ was extracted in 2006, the majority of which was used as fill for the new Helsinki–Vuosaari Harbour. There has been no extraction since 2006, although the licence was renewed in 2010 for an additional 5 million m³.

A number of new licence areas for marine sand are currently being developed or are going through the licensing process. These licence areas are in various locations around the eastern Bay of Finland and in the Bay of Bothnia.

2.4.6 France

Only 2% of the total national production in France is supplied by marine aggregates. Production is focused entirely on use for construction, with no material used for coastal defence or construction fill (except for an unknown quantity extracted by regional authorities for beach nourishment, who are not required to report these extractions). Extraction is restricted to 10–15 licensed areas in Normandy, Brittany, and along the Atlantic coast, where the maximum permitted extraction for all licence areas totals ca. 7 million m³ year^{-1}.

France also permits up to 0.5 million m³ annually of non-aggregate extraction, primarily for maerl and shell sand, along the Atlantic coast. However, maerl extraction will be prohibited after 2013 (Figure 2.3).

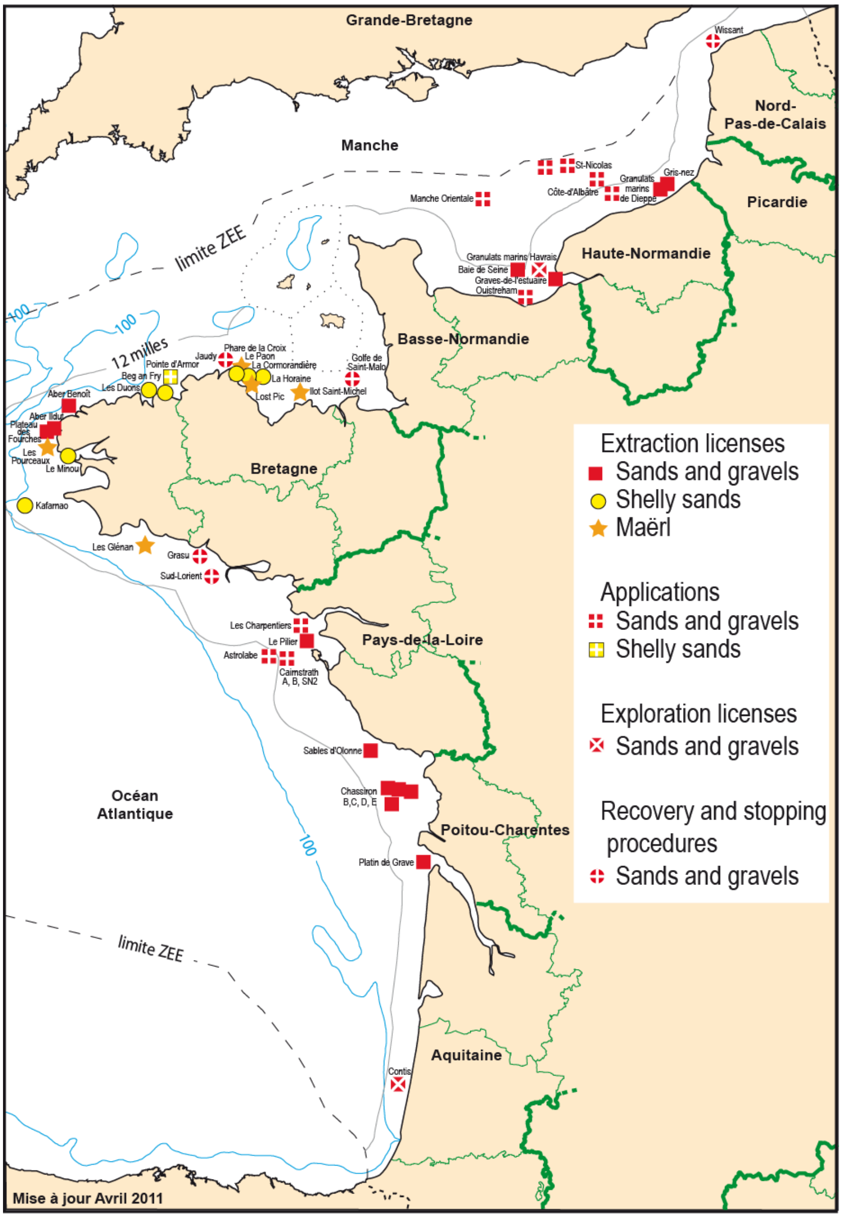


Figure 2.3. Extraction licences in France.

2.4.7 Germany

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

In the Baltic, extraction of aggregates for beach nourishment and for construction has taken place in designated dredging areas along the coast and on the Adler Ground. Over the last decade, the majority of aggregates dredged have been used for beach nourishment; however, since 2010, the demand for construction aggregates has significantly increased from 0.21 million m^3 in 2009 to 1.5 million m^3 in 2010.

A limited number of licences for extraction have been permitted in the North Sea mainly for construction, land reclamation, and coastal defence projects. The most significant of these has been the Jade Weser port project, for which demand peaked in 2009, with a total of 19.05 million m^3 being extracted for construction and fill purposes.

2.4.8 Greenland and the Faroes

No information to report.

2.4.9 Iceland

Production statistics are provided by the Icelandic National Energy Authority (NEA). Marine sand and gravel is mainly extracted from southwestern Iceland (Faxafloi Bay), with extraction declining from a peak of 1.41 million m^3 in 2004 to 0.126 million m^3 in 2010, largely as a consequence of the economic downturn. The licence areas in southwestern Iceland were renewed for a period of 10 years following the completion of an EIA between 2005 and 2009.

Shell sand, used locally in the production of cement, has been extracted from Faxafloi Bay since 1958. Between 2000 and 2010, the annual volume of carbonate (shell) sands extracted peaked at 0.16 million m^3 in 2007, but declined to 0.04 million m^3 in 2010.

Extraction of maerl in northwestern Iceland (Arnarfjordur) commenced in 2005 following an EIA that was started in 2002. Maerl is extracted from a single licence area, and a total of 0.014 million m^3 was extracted in the first year, increasing to 0.054 million m^3 in 2010. The majority of the production is exported. Since 2009, additional areas of maerl resource are now being investigated in the same region, although no further licences have been issued to date.

2.4.10 Ireland

No commercial extraction of marine aggregates has taken place in Ireland since 2001.

The extraction of maerl was licensed in Bantry Bay. Up to 6250 m^3 $year^{-1}$ was licensed to be extracted until 2006. Since 2006, there has been no reported extraction.

2.4.11 Latvia

No information on production has been reported to date. Potential marine aggregate resources have been identified, although these will require further investigation.

2.4.12 Lithuania

During 2010 and 2011, >0.2 million m^3 of marine aggregate has been dredged from Juodkrante for use in support of beach nourishment at Palanga.

2.4.13 The Netherlands

Marine sand extraction continues for coastal protection, land-based infrastructure projects, and industrial aggregates. Annual production is ca. 25 million m^3 $year^{-1}$, with one-half used for coastal protection.

All the sand is extracted from different sites in the North Sea seawards of the 20 m depth contour. In addition, individual capital projects have resulted in increased demands for marine sand; for example, the land reclamation works at Maasvlakte 2 (2009–2013) and the Sand Motor (2011), with volumes of 210 and 21.5 million m^3, respectively.

The former Ministry of Transport, Public Works and Water Management introduced a regular coastal defence policy in 1990. The policy established a national beach nourishment programme. The identification of "weak links" along the Netherlands coast is part of the safety programme for the defence of the Dutch coastline in the face of climate change and expected sea level rise. "Weak links" were identified at ten locations along the Netherlands coast, and these will be strengthened in the period up to 2015 (Figure 2.4).

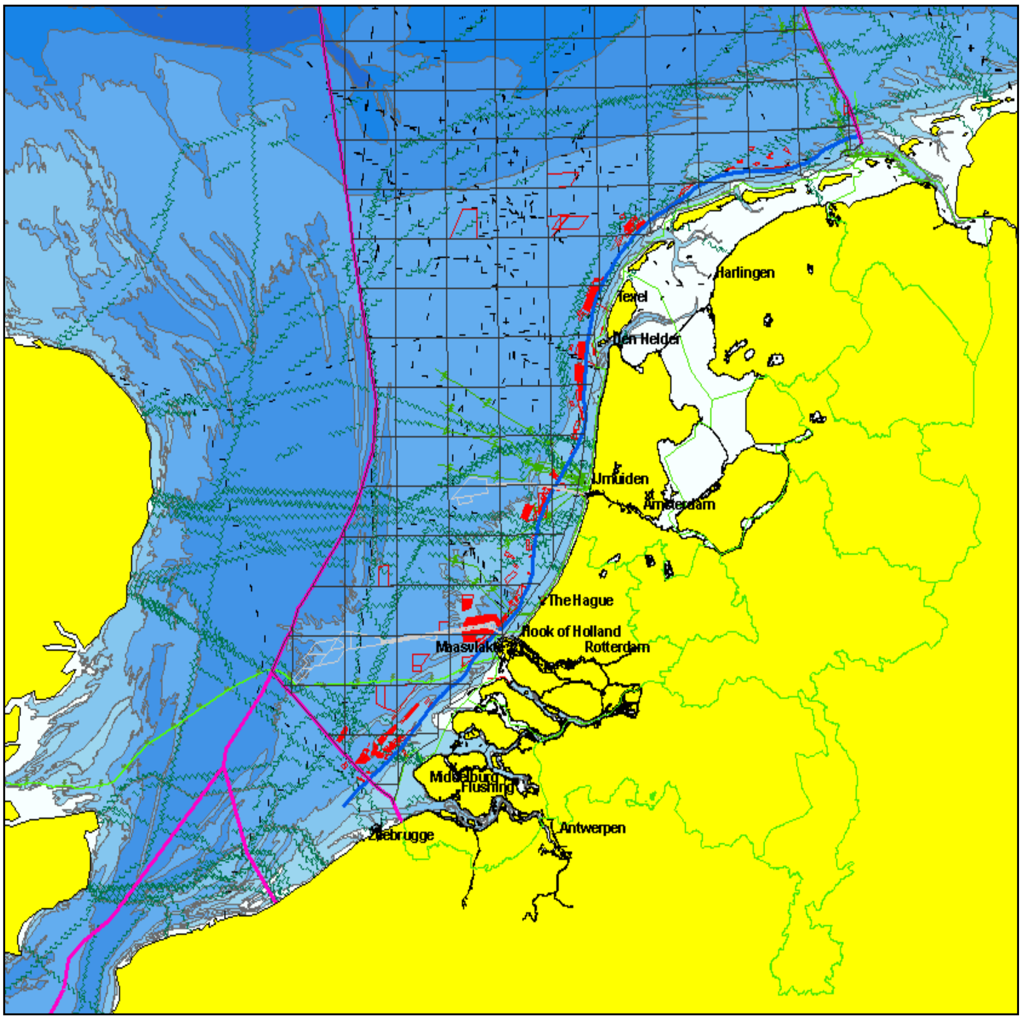


Figure 2.4. Licensed sand extraction areas 2010.

A significant proportion of Dutch production (2–3 million m^3) continues to be exported to Belgium for use as coarse sand for construction fill and to be used in the construction industry.

In addition to sand extraction, there is continued shell extraction in the Wadden Sea, Western Scheldt, Voordelta, and other parts of the North Sea. Extraction takes place seawards of the 5 m depth contour, with an annual production ca. 0.25 million m^3.

2.4.14 Norway

There are unsubstantiated reports of very limited sand and gravel extraction (estimated to be a few thousand m^3 $year^{-1}$) taking place from deltas in northern Norway over several years.

Carbonate (shell) sand extraction has also occurred in small areas between the outermost islands and skerries of the western coast of Norway. The volume extracted is estimated to be a few thousand m^3 $year^{-1}$. This activity is controlled by the counties (fylke). There is no central reporting.

2.4.15 Poland

Marine aggregates, primarily for beach renourishment, have been extracted from Polish waters for many years.

2.4.16 Portugal

In the Madeira and Azores archipelagos, it has become common practice for marine sand and gravel to be extracted for use as construction aggregate since the late 1990s. In this location, the largest annual extraction was 0.197 million m^3 removed during 2004 and 0.126 million m^3 removed in 2011.

Marine sand and gravel extraction from the mainland continental shelf of Portugal for construction purposes is prohibited, although extraction of marine aggregate resources for beach nourishment has taken place in the south-central and southern continental shelf between 2006 and 2011. During this period, annual volumes extracted ranged from between 0.37 and 1.25 million m^3 $year^{-1}$.

2.4.17 Russia

No information to report.

2.4.18 Spain

Extraction from marine aggregate resources in Spanish waters is only permitted if the sediment removed is to be used for beach replenishment. Marine sand extraction takes place in Atlantic Spanish waters and at the Canary Islands for use as beach nourishment in order to improve the amenity value of beaches. Between 1990 and 2011, >10.5 million m^3 of sand was extracted from Atlantic Spanish waters for this purpose.

2.4.19 Sweden

Marine aggregate extraction was not permitted in Sweden between 1998 and 2007. The last permitted extraction was in connection with the building of the Øresund Link between Sweden and Denmark, with the material dredged used to construct an artificial island south of Saltholm. The total extraction from the Flint shipping channel was 2.5 million m^3.

Since 2007, there has been more interest in marine aggregate extraction for beach nourishment, also to support the development of an offshore wind farm. In the latter case sand and till was dredged to prepare the seabed prior to turbine installation at Lillgrund in 2007, with the sediment used for fill in Malmö Harbour. The planned expansion of the port of Trelleborg in southern Sweden will also require dredging of an estimated 1.33 million m^3 to deepen the port and reclaim new land.

During 2011, the Ystad municipality in southern Sweden was licensed to extract a total of 0.34 million m^3 of sand from an area 6 km off the coast over a 10-year period. A total of 95 562 m^3 of sand was removed during 2011 and used for beach nourishment works along the Ystad Sandskog and Loderups Strandbad coasts. The beaches at these locations are important for tourism, but are retreating through a combination of isostatic sinking and sea-level rise.

2.4.20 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 ca. 20% of the sand and gravel supply comes from marine sources.

Annual marine production off the coast of England and Wales amounts to ca. 12.7 million m^3 $year^{-1}$. London and the southern coast of England receives around 5.78 million m^3 of this material, equivalent to one-third of the region's overall construction aggregate demand. Specific projects include the 2012 Olympic Park and the Crossrail train link joining east and west London. Smaller volumes of sand and gravel are landed in the northeastern part of England along the Humber, Tyne, and Tees rivers, while marine sand remains a regionally important source of fine construction aggregate supply in the Bristol Channel and the Irish Sea.

A significant proportion of the UK production (3.46–4 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 contract fill remains an important end-use of UK production. Annual volumes ranged from 0.56 million m^3 in 2010 to 2.59 million m^3 in 2009. Coastal frontages along the eastern coast of England (Northumberland, Lincolnshire, Norfolk, and Essex) and along the southern coast of England (Kent, East Sussex, West Sussex, and Dorset) have been subject to coastal protection or replenishment works since 2005. 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 addition, marine aggregate resources have also been used to support several major infrastructure development projects, including the extension of Ronaldsway Airport on the Isle of Man (0.32 million m^3 in 2009/2010) and the development of Felixstowe Harbour (1.88 million m^3 in 2009/2010).

2.4.21 United States

Amboy Aggregates of South Amboy, New Jersey has held a licence to dredge aggregates since 1985 from the Ambrose Channel, the entrance to New York Harbour, supplying aggregates to the New York City area. Dredged sand is often mixed with crushed rock at a shoreside facility.

Between 2007 and 2011, sand extracted from navigation channels in New York Harbour was used as capping material, as part of the restoration of a former offshore disposal site known as the Historic Area Remediation Site (HARS), located 22 km outside of the harbour.

Small volumes of rock removed as part of the deepening of navigation channels into New York Harbour between 2008 and 2010 were used to construct fishing reefs offshore.

The vast majority of dredging operations for beach renourishment have taken place within the 3-mile jurisdiction of the individual states. 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 Federal Outer Continental Shelf (OCS) represents a potentially viable source of sand for beach renourishment. From 2011, these resources have fallen under the jurisdiction of the Marine Minerals Program within the Bureau of Ocean Energy Management (BOEM), a bureau within the US Department of the Interior.

Outside the ICES Area, sand has been dredged from the Outer Continental Shelf (three nautical miles and beyond) since 1995, when 1.2 million $yards^3$ were placed on a Jacksonville, Florida beach. To date, the Marine Minerals Program within the BOEM (and its predecessor agencies) have conveyed rights to about 58 million yards^3 of OCS sand for 31 coastal restoration projects in five states (Florida, Virginia, Maryland, South Carolina, and Louisiana). These projects have resulted in the restoration of 180 miles of the nation's coastline, protecting billions of dollars of infrastructure as well as important ecological habitat.

2.5 Management of aggregate dredging activities

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

Effective management of marine aggregate operations, both planned and ongoing, requires minimizing the impact to benthos, fish, and habitats and to other marine stakeholders, such as commercial fishing, navigation, and the renewable energy industry. The ICES guidance on environmental impacts reflects the range of issues that now have to be taken into account, together with potential key sensitivities. The current consenting systems within Member Countries generally reflect these common themes.

The requirement for site-specific mitigation and monitoring associated with modern dredging permits has also evolved significantly. Examples of mitigation include restricting the area of seabed that can be dredged and the use of exclusion zones to protect sensitive features, while the potential effects of dredging on seabed bathymetry, habitats, and benthic communities can be subject to routine monitoring. This ensures that the potential for impacts is reduced as much as possible, and that the predicted impacts are monitored comprehensively to ensure that the observed effects are consistent with those predicted through the EIA process. If not, permits can be modified or even withdrawn. Many aggregate dredging operations are now subject to continual review throughout their predicted lifetimes. In addition, 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 in close proximity to one another, and 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 cumulative, temporal, and in-combination effects will continue to evolve.

Effective and sustainable production requires operators to ensure that they maximize their accessible aggregate resources. In order to achieve this, there has been a considerable increase in the understanding of site-specific resources in terms of the quality of equipment, accuracy of positioning, and environmental data. Improved information helps to better mitigate potential impacts and to 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 exploit resources more effectively. Regulatory requirements tend to minimize the extent of area dredged and to work areas to economic exhaustion before moving to a new area; as a result, the ability to manage extraction to this scale is critical. The use of real-time, on-board plotting systems, interfaced with reliable and accurate GPS positioning, allows modern dredging operations to be confined to well-defined lanes, often only 100 m wide.

The marine aggregate industry has the potential to interact with a range of other marine users through its operations; therefore, the development of marine spatial planning is of great interest. While the total area of seabed licensed for marine aggregate extraction can be quite large, the area of seabed actually dredged in any year will usually be significantly smaller. In the UK, for example, although 1274 km^2 are licensed, only 114 km^2 are actually dredged in a given year based on 2011 data. The potential for adverse interaction with other sectors can be significantly reduced by disseminating information on both the licensed area and the total extent of the area being dredged. In the UK, a voluntary initiative has been established by the industry and The Crown Estate (the mineral owner) to provide updated regional information on aggregate extraction 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

The evolution of management of marine aggregate dredging activities has seen some significant advances over the past 15 years. Environmental regulation and control have continued to increase, with the European controls particularly influenced by Directives from the European Commission, for example, the EIA (85/337/EEC) and Habitats (92/43/EEC) Directives. Some of the greatest changes in management and control of dredging operations have come from the industry themselves. These are not only linked to improving resource management, but also reducing spatial conflicts with other marine users. This has obvious links to the development of wider marine spatial planning initiatives.

The use of ”black box” electronic monitoring systems (EMSs) onboard aggregate dredging vessels is now common practice among those ICES Member Countries who are the principal producers of marine aggregate, including Belgium, Denmark, the Netherlands, Spain, Germany, and the UK. Examples from this data are shown in Figures 2.1–2.4. The examples of Belgium and UK demonstrate that EMS information is particularly relevant to research and monitoring when attempting to relate observed environmental impact or recovery to the spatial extent, timing, and intensity of actual dredging operations.

In Belgium, the data derived from the EMS has proven its importance to monitoring the impact of dredging by allowing a quantitative analysis of the extracted volumes removed over time (Figure 2.7). As the EMS is not equipped with sensors to record the load of dredged materials in real-time, a method has been developed by the Belgian authorities to estimate the extracted volume of a trailing suction hopper dredger within a certain timeframe. This calculation is further improved and crosschecked by linking the EMS data with the extraction register which is the officially declared volume for each cargo dredged. The reliability of the estimation of the extracted volumes from EMS data can be evaluated by comparing the values of annual total volumes estimated from the EMS data with the annual total volumes calculated independently from the extraction registers. A mean deviation of 3% is observed between the two datasets. This low deviation confirms the validity of the assumptions used as a basis for calculating the extracted volumes from EMS data. The results for the period 2003–2010 confirm a near-perfect correlation between extracted volumes and bathymetric change determined by multibeam monitoring surveys. All bathymetric changes across licensed areas can be explained by documented extractions and, in closed areas, no recovery of the morphology has taken place.

In the UK, the advent of EMS data and, in particular, the annual summaries of activity has allowed the industry and The Crown Estate to produce annual reports detailing the area of seabed licensed and dredged (Figures 2.5 and 2.6). This information in turn has become a guide to the industry’s overall environmental performance. 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 eastern coast of England show extensive dredging activity over a wide area, while the discrete palaeovalley and terrace deposits off the southern coast require a more focused approach to operations, with intensive activity over a considerably smaller area. This is a practical demonstration of how the industry is using geological understanding of the resources being exploited to control and manage extraction operations.

The availability of accurate detailed EMS data over a number of years has allowed further analysis to be undertaken, which has relevance to both regulators and industry. While information on the extent of dredging activities is reported annually, by combining this information, it is possible to consider the cumulative footprint, i.e. the total extent of dredging activity over longer periods of time. The UK has found that over a 10-year period, the total area of seabed dredged between 1998 and 2007 amounted to 463.71 km^2, of which 54.52 km^2 (11.76%) is no longer licensed. Over the same period, the area of new seabed dredged annually reduced from 75.44 km^2 in 1999, which was 34% of the total licensed area, to 11.79 km^2 in 2007 or 8.76% of the total licensed area. Over the 10-year period from 1998 to 2007, the average area of new seabed dredged each year was 26.79 km^2. However, during the most recent five-year period (2003–2007), this figure had reduced to 16.73 km^2 year^{-1}.

The move to more spatially restricted and, therefore, more intensive levels of dredging activity raises an additional issue requiring investigation. While 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 detailed black-box data to assess historical dredging activity will allow this to be examined in more detail.

Figure 2.5. An example of the Dutch monitoring and registering system (MARS), which shows track plots of different hopper dredgers within licence areas during extraction for the Sand Motor project (21.5 million m^3).

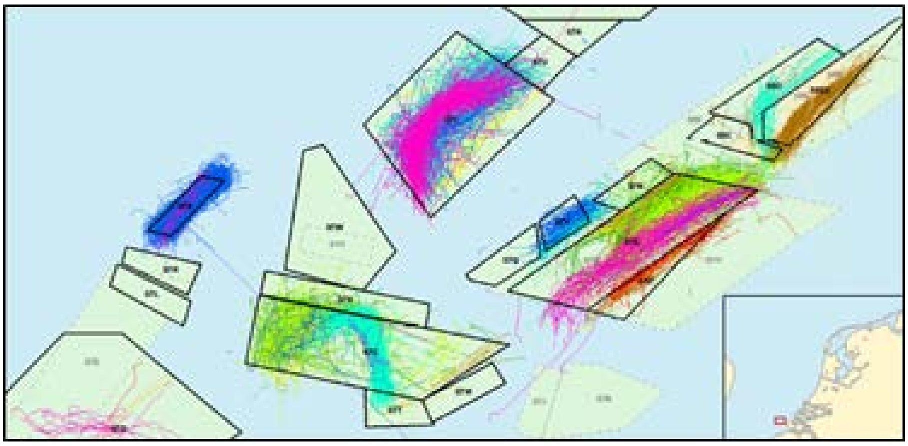


Figure 2.6. An example of the Dutch monitoring system (EMS black boxes), which shows recorded track plots of different hopper dredgers during sand extraction from licensed areas in the south-eastern North Sea.

Figure 2.7. An example of a track plot derived from the UK electronic monitoring system. The position and status of the vessel (pump on/dredging) is recorded every 30 seconds while dredging is taking place, using a combination of GPS and sensors associated with the dredge gear.

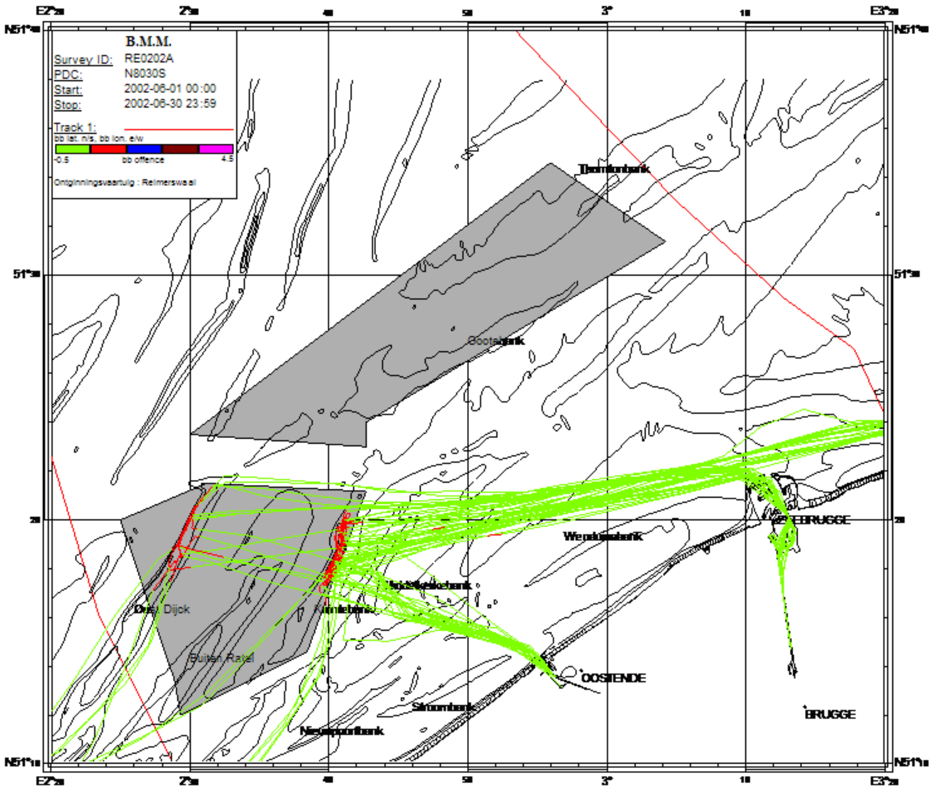


Figure 2.8. An example of track plots derived from the Belgian electronic monitoring system.

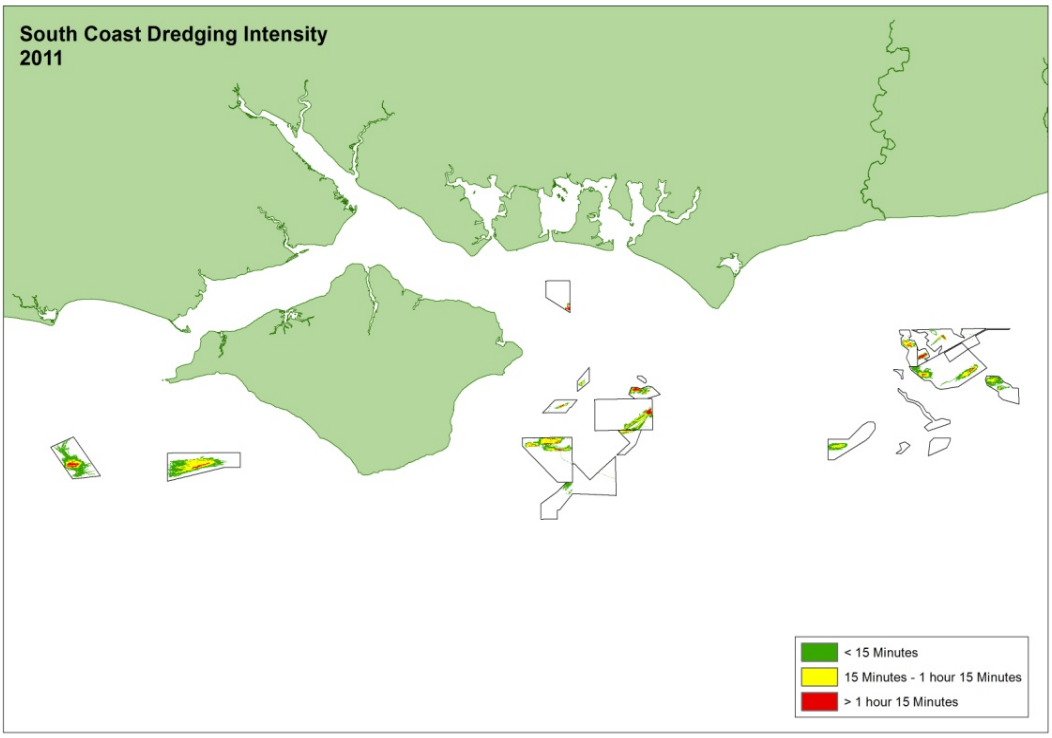


Figure 2.9. An example of EMS data from the UK presented at a regional scale. This shows the area dredged analysis for marine aggregate production licence areas off the southern coast of England during 2011. The extent and intensity of extraction activity is based on dredging hours recorded in individual 50 x 50 m grid cells. The total area licensed for marine aggregate extraction in the region in 2011 was 148.4 km^2, of which 26.02 km^2 was dredged. The total production from these licence areas during this period was 2.45 million m^3.

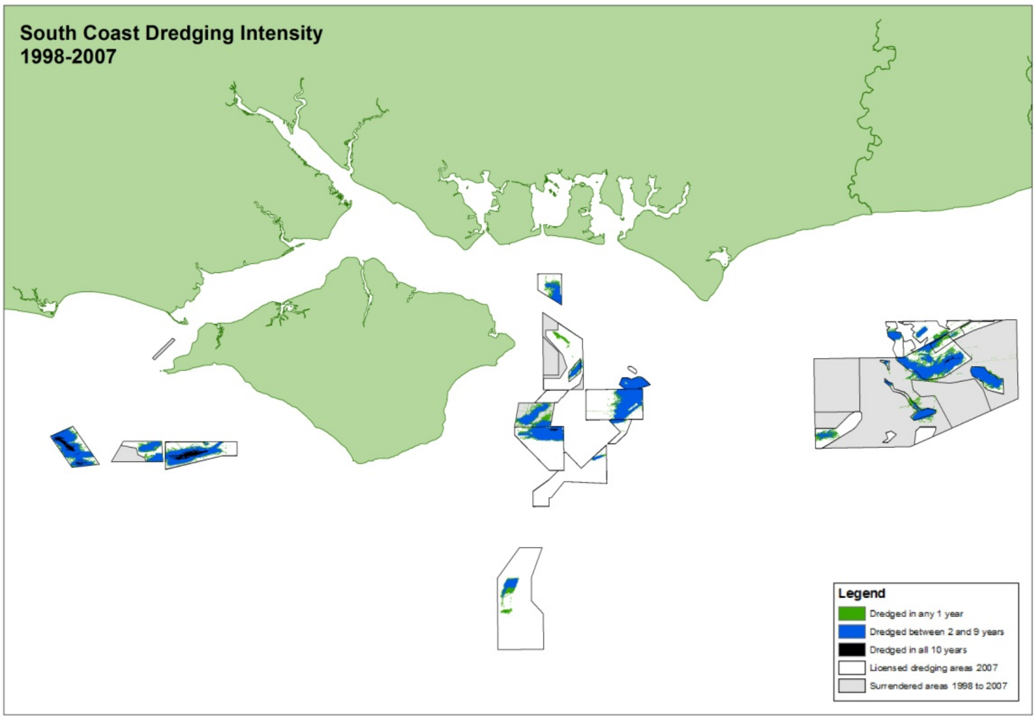


Figure 2.10. An example of EMS data from the UK presented at a regional scale. The analysis presents the cumulative area dredged footprint for production licence areas off the southern coast of England over a 10-year period (1998–2007) from the extent and intensity of dredging activity based on dredging hours recorded in individual 50 x 50 m grid cells. Over the period of the cumulative analysis, 81.57 km^2 of new licence area was permitted, while 180 km^2 was relinquished, resulting in the total area licensed decreasing by a net 98.48 km^2. Over the same period, the total cumulative area of seabed dredged in the region was 78.21 km^2, from which 28 million m^3 of marine sand and gravel was extracted. The area of new seabed dredged annually reduced from 10.86 km^2 in 1999 (31.29% of the total area dredged in the year) to 1.95 km^2 in 2007 (7.41%).

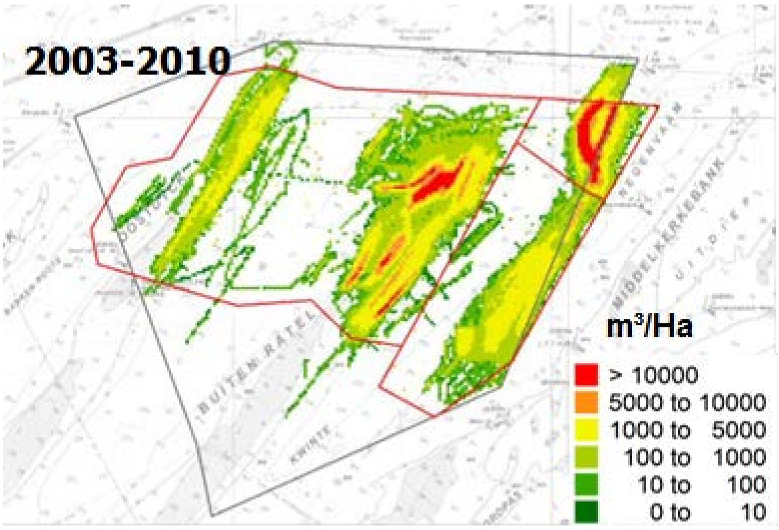


Figure 2.11. An example of Belgian EMS data cumulative analysis showing the volume extracted per unit area (m^3 ha^{-1}) over the period 2003–2010.

2.6 Dredging technology

The trailer suction hopper dredger (TSHD) remains the principal method of marine aggregate extraction within the ICES Area, although static suction hopper dredgers are also employed, particularly in Denmark. TSHDs have also been routinely employed in both maintenance and capital dredging operations. These dredgers use a centrifugal pump to lift a sediment–water mixture from the seabed through a pipe into a storage hopper. However, marine aggregate extraction technology can often have two unique characteristics.

First, as well as loading ″as-dredged″ or ″all-in″, many aggregate dredging vessels have the ability to process the dredged sediment while loading operations are underway. This process is referred to as "screening" and is particularly useful where the *in situ* composition of the seabed sediments falls outside that required for construction or beach replenishment. Screening, therefore, allows more marginal resources to be worked efficiently, thereby reducing the need for new dredging sites, and enables the industry to deliver cargoes to specification.

When screening, 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, allowing only sand to be loaded. Two main techniques are generally employed. A centrally located box screen system can be used or, alternatively, a more complex and efficient series of screening towers might be employed. The screening process returns a significant volume of sediment to the water column during loading operations. This increases the potential for ″far-field″ impacts resulting from the suspension and subsequent settlement of the sediment plume. As a result, the environmental implications of this activity have to be very carefully considered through the permitting process.

The second factor which distinguishes marine aggregate dredging is the manner of unloading. Most capital and maintenance dredgers will be able to discharge material via doors in the bottom of the hopper or by pumping out the material as "wet discharge". However, aggregate dredgers are usually designed to self-discharge a dry cargo, requiring the excavated aggregate retained in the hopper to be dewatered before unloading. Grab cranes, scraper buckets, or bucket wheels may be employed to unload the cargo directly onto the wharf for immediate use.

To increase dredging flexibility, modern trailer suction hopper dredgers are being designed with a capability to undertake static dredging operations. Static dredging operations are appropriate when exploiting localized, thick sand-and-gravel deposits. In addition, modern vessels can be capable of pumping aggregate directly ashore for beach replenishment or, in limited cases, capital or maintenance dredging.

To an increasing extent, the goal of management is to ensure that resources of marine sand and gravel are exploited in an effective and sustainable manner. The crossover in high-tech capital and maintenance operations and the aggregate sector is a natural development as industry seeks to improve operational efficiency and minimize environmental impact. These developments can be expected to continue in the future. Two specific areas are rapidly evolving. The first is the ability of aggregate dredgers to operate effectively within the tightly controlled lanes needed either for resource management or as environmental mitigation. To do this effectively, vessels need to have the navigational capability and the necessary power and manoeuvrability. The second concerns the dredging process itself. It is now generally required that the industry work licensed reserves to economic exhaustion before moving on to new areas. Operators, therefore, need to maximize their ability to extract sand and gravel within well-defined areas. Extraction management plans must be carefully controlled while minimizing environmental impacts at the same time. This requires more knowledge and better 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

- The number of ICES Member Countries reporting on the use of marine aggregates noted in the *ICES Cooperative Research Report No. 297* (Sutton and Boyd, 2009) has continued to expand. The UK remains the main producer of aggregates for the manufacture of concrete, whilst the Netherlands produces and uses the largest quantity of sand.
- The construction industry's requirement for marine sand and gravel has remained relatively stable, as a proportion of the overall contribution to construction aggregate demand, although there is some evidence of an increasing demand for coarse sand. However, the global economic downturn has resulted in an overall reduction in construction aggregate demand which is reflected in some Member Country annual statistics.
- Beach nourishment and fill for construction purposes and land reclamation remain important. There is some evidence of a growing demand for marine sediments to support both responses to climate change and to support large capital infrastructure projects, particularly port developments. Associated with this trend has been the use of borrow pits – areas licensed to provide large volumes of marine sediment over a relatively short time-period to support a specific capital project. The scale of sediment removed and the period over which the extraction takes place results in different challenges for impact assessment, mitigation, and monitoring.
- Commercially viable sand and gravel reserves are not evenly distributed among ICES Member Countries. While most countries have significant volumes of sand and/or gravel off their coastlines, without a potential market, they are unlikely to be exploited. Often, this is directly related to the availability of alternative sources of construction material or the local demands created by the need to protect the coast or support infrastructure projects.
- The requirement for sustainable use of marine sand and gravel reserves is now a well established principle at both international and national scales, and reflected in national policies and regulations.
- 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.
- There continues to be improvements made in the provision and analysis of detailed dredging monitoring data, as well as improvements in the accuracy and resolution of resource information. This has allowed dredging activity to be more tightly controlled, with resulting benefits in minimizing environmental impacts and interference with other marine activities.

The focus on more spatially restricted and, therefore, more intensive levels of dredging activity continue to raise issues. While the total spatial footprint of the impact is reduced, the increased levels of intensity affect the time-scale for the recovery of the environment (Chapter 4, Section 4.7). The availability of black-box data to assess historical dredging activity continues to assist in examining this issue.

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

3.1 Introduction

The aim of this section is to present an outline of the philosophy, schemes, methods, and results of various geological seabed and subseabed mapping programmes that provide indications suggesting the possible presence of aggregate resources. A reliable picture of aggregate resources requires detailed surveying and sampling. These are usually only done when aggregate extraction schemes are being actively considered. However, indications of the presence of such aggregate resources may be obtained by other simpler and cheaper means. The most widely used techniques are offshore geological reconnaissance mapping and seabed sediment mapping. Seabed sediment mapping delineates the sediment types found on the surface of the seabed. This is usually done by directly collecting samples, but may include the sonar signature, specifically the backscatter, on the seabed. Reconnaissance mapping of the seabed sediments forms the framework for delineation of 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 on the volume, quality, and composition of the seabed resources, and thereby to establish their economic viability.

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 given 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 the industry, whereas in many others, it is a governmental matter.

The EU Marine Strategy Framework Directive has singled out European seabed sediment mapping as a priority issue. Detailed surface sediment maps and habitat maps, including information on seabed sedimentary dynamic processes and morphology, are crucial as a 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 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 seabed sediments may be used. These countries can start to formulate rational aggregate and environmental policies. Most countries, however, have not yet reached this level of understanding, and so, in this sense, policy decisions may rely more on assumptions than facts.

3.2 Review of ICES Member Country seabed mapping

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 metadatabase 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 for anyone to quickly find the locations of existing seabed samples and hydroacoustic measurements. The database only lists metadata; access to the raw data, the hydroacoustic records, and any related accessory datasets must be negotiated by the requester and the repository where the information is stored. This metadatabase is an important source of information not only about potential aggregate resources, but also for scientific research, decision-making in government, and management in the commercial sector. Information not provided may be found via the EU-SEASED metadatabase and its links.

The European Marine Observation and Data Network (EMODnet) Geology Project started in 2009 as a consortium of the national geological survey organizations of the UK, Ireland, France, and Belgium. The consortium brought together datasets according to the "Preparatory Actions for European Marine Observation and Data Network Tendering Specification", namely all available seabed sediments, including rate of accumulation or sedimentation; seabed geology (including age, lithology, and origin); geological boundaries and faults; rate of coastal erosion and sedimentation; geological events and event probabilities (to include information on submarine landslides, volcanic activity, earthquake epicentres); seismic profiles; minerals (including aggregates, oil, and gas). Additional information, such as the mapping authority and contact information, was provided by the Netherlands, Germany, Denmark, Norway, Sweden, Finland, Estonia, Latvia, Lithuania, and Poland. Within EMODnet-Geology, data compiled by the project partners and additional datasets that are publicly available were compiled in maps on a scale of 1:1 million (http://www.emodnet-geology.eu/).

EMODnet-Geology is available online using the multilingual OneGeology-Europe portal developed in the OneGeology-Europe (1GE) project (http://www.onegeology-europe.org/). Existing metadata have been stored on the EU-SEASED website developed under the EC-funded Geo-Seas project, which ended in January 2013 (http://www.geo-seas.eu/). These results, for example, have been used for EUSeaMap, a European-wide broad-scale habitat modeling initiative (http://jncc.defra.gov.uk). The areas covered within Phase 1 of EMODnet are the Baltic Sea, greater North Sea, and Celtic Sea according to the boundaries shown in Figure 3.1. Phase 2 is planned to follow in 2013–2015 and will cover the remaining areas in the figure.

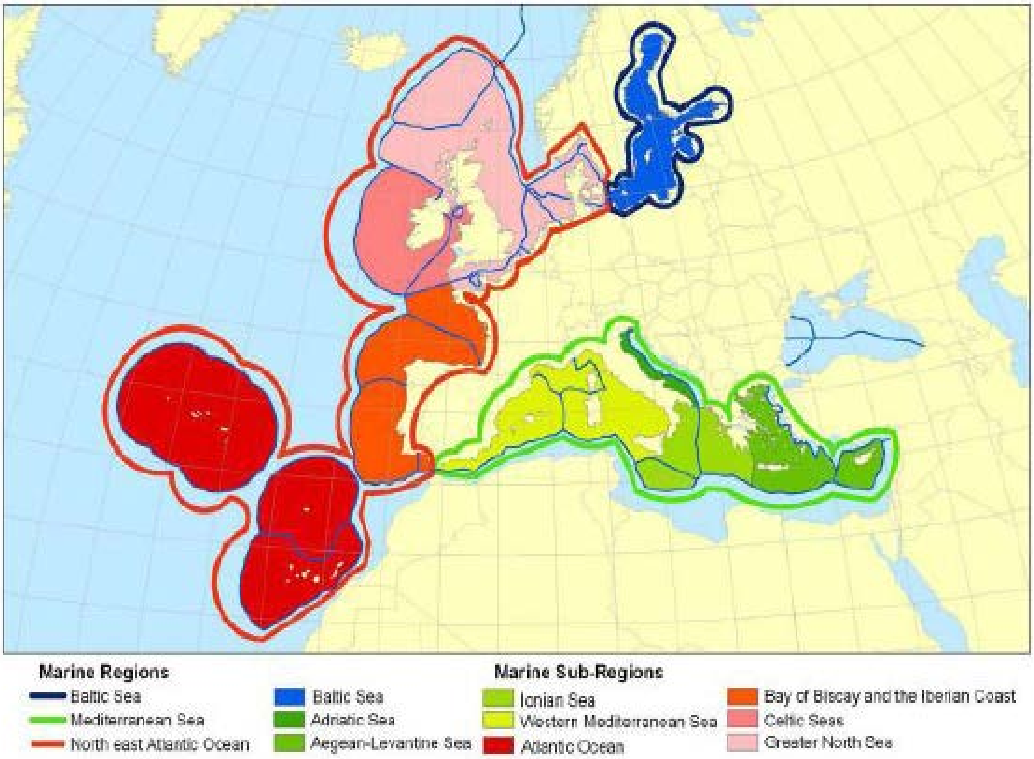


Figure 3.1. Marine regions and subregions as defined by the Marine Strategy Framework Directive.

3.2.1 Belgium

The national organizations active in the field of seabed mapping are:

- Geological Survey of Belgium (GSB), Jennerstraat 13, 1000 Brussels, Belgium. Contact person: Dr C. Baeteman; tel: +32 2 788 76 26; fax: +32 2 647 73 59; e-mail: cecile.baeteman@naturalsciences.be.
- Federal Public Service Economy – Continental Shelf (Fund for Sand Extraction), Koning Albert-II laan 16, 1000 Brussels, Belgium. Contact person: Dr M. Roche; tel: +32 2 277 77 47; fax: +32 2 277 54 01; e-mail: Marc.Roche@economie.fgov.be.
- Operational Directorate Natural Environment (OD Nature), Management Unit of the North Sea Mathematical Models (MUMM), Gulledelle, 100, 1200 Brussels, Belgium. Contact person: V. Van Lancker; tel: +32 2 773 21 29; fax: +32 2 770 69 72; e-mail: v.vanlancker@mumm.ac.be.
- Maritieme Dienst Kust – Coastal Division. Flemish Hydrography. Vrijhavenstraat 3, 8400 Oostende, Belgium. Contact person: Mr G. Dumon; tel: +32 59 55 42; e-mail: kust@vlaanderen.be, www.vlaamsehydrografie.be, www.afdelingkust.be.
- Renard Centre for Marine Geology (RCMG), Gent University, Krijgslaan S8, 9000 Gent, Belgium. Contact person: Prof. M. De Batist; tel: +32 9 264 45 87; fax: +32 2 264 49 67; e-mail: Marc.debatist@Ugent.be.

The Geological Survey of Belgium (GSB) no longer has any official systematic mapping programmes. In the past, a dense grid of vibrocores was taken within about 10 km off the coast. Farther offshore, 11 deep mechanical corings were taken at depths between 25 and 80 m covering the entire Quaternary sequence into the Tertiary deposits. Geological maps and primary datasets are available from GSB (www.naturalsciences.be/geology/). Printed maps on a scale of 1:250 000, with descriptions in Dutch and English can be ordered from the Geological Survey of Belgium (bgd@natuurwetenschappen.be), the Netherlands, and the UK (Balson *et al.*, 1991, 1992). For the pre-Quaternary geology, see the Netherlands or the UK.

The Continental Shelf Fund, that is, the Federal Public Service Economy, conducts regular multibeam surveys to study the impact of sand and gravel exploitation. Resource and seabed maps and databases on multibeam data as well as dredging activity are available (http://economie.fgov.be). An overview of the available multibeam data is given in Figure 3.2, and an example of the different maps for two concession zones is given in Figure 3.3 (a, b, and c).

TheOD Nature of the Management Unit of the North Sea Mathematical Models (MUMM) regularly updates maps on licensed areas and dredging activities, including EMS "black-box" data (www.mumm.ac.be). The Belgian Marine Data Centre hosts standardized data on oceanographic parameters. Data are added in the framework of the EU-Geo-Seas project (http://www.geo-seas.eu/) on sediments, geology, and geophysical parameters. Furthermore, hydrodynamic and sediment transport models are further developed and used to estimate impacts related to marine aggregate extraction.

Seabed and pre-Quaternary sediments were mapped in the EMODnet–Geology project on a scale of 1:1 million (http://www.emodnet-geology.eu/) and contributed to the OneGeology data portal (http://www.onegeology-europe.org). These data can be downloaded. More detailed mapping (< 1:250 000) was done in response to the European Marine Strategy Framework Directive (MSFD) (Van Lancker and van Heteren, 2012). In the Belgian Science Policy project QUEST4D (Van Lancker *et al.*, 2012), new seabed sediments data grids were produced, as well as detailed habitat maps. Ecosystem changes over the past 100 years are described.

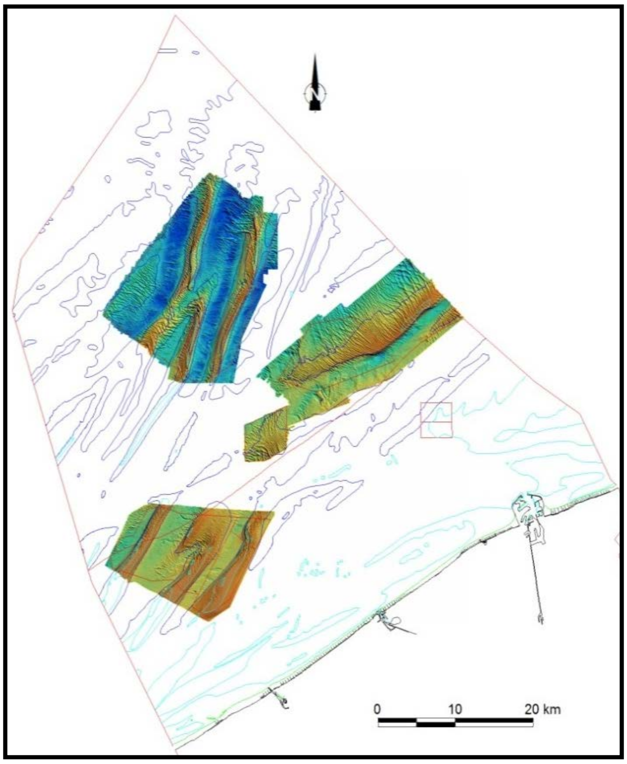


Figure 3.2. Aggregate extraction areas and coverage of the available multibeam data of the Belgium Continental shelf.

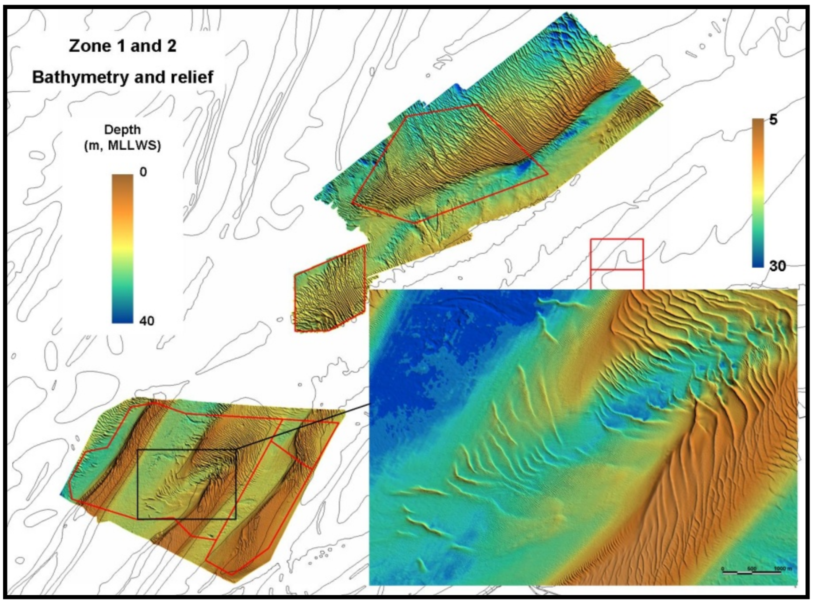


Figure 3.3a. Bathymetry and relief map of two concession zones.

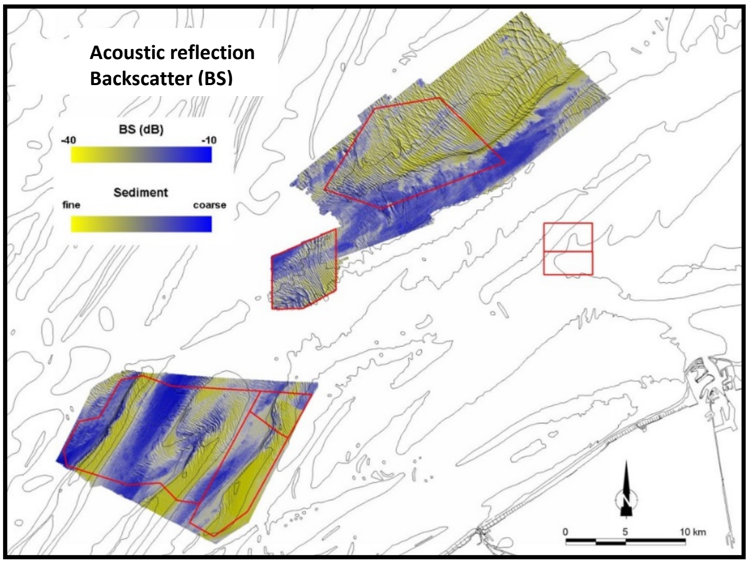


Figure 3.3b. Backscatter and seabed of two concession zones.

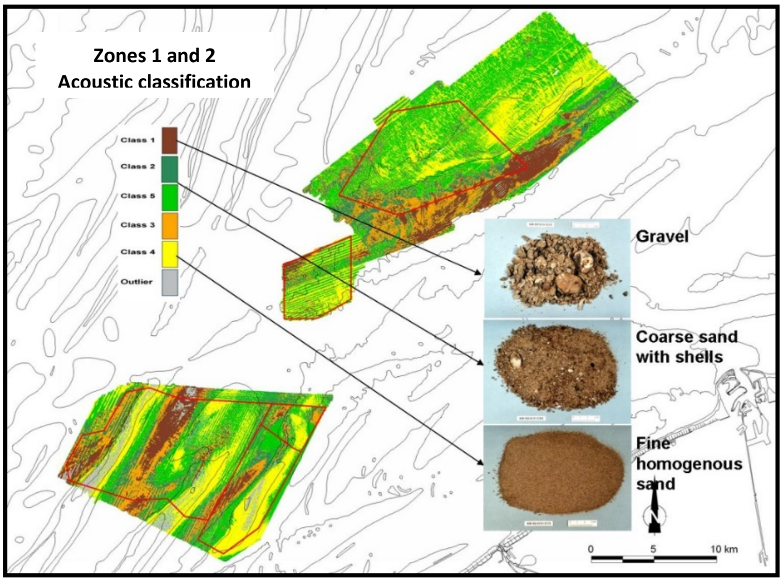


Figure 3.3c. Seabed classification maps of two concession zones.

The Flemish Hydrography regularly updates bathymetric datasets covering the whole Belgian Continental Shelf (www.vlaamsehydrografie.be). Data were provided to EMODnet-Hydrography (EU-DG MARE) for a comprehensive bathymetric map of the North Sea at a resolution of 0.25 arc-minutes (http://www.emodnet-hydrography.eu).

The Ghent University, Renard Centre of Marine Geology (RCMG) hosts an extensive seismic database covering the entire Belgian part of the North Sea. A synthesis is provided in Le Bot *et al.* (2003). Mathys (2009) reinvestigated data on the Quaternary, with new acquisition of data. All data of good quality were scanned making use of the SEISCANEX infrastructure.

Surficial seabed information of the entire Belgian part of the North Sea (sediments, morphology) and local resource maps have been compiled on a DVD, which is freely available (GIS@SEA DVD – Van Lancker *et al.*, 2007). Verfaillie *et al.* (2006) describes in detail the statistical approaches for sediment mapping in shallow shelf seas.

All metadata on the mapping of habitats can be consulted on the data portal of MESH (Mapping European Seabed Habitats, EU-InterregIIIb, (www.searchmesh.net). From a compilation of the data, a first comprehensive seabed habitat map for northwestern Europe was produced. For Belgian waters, additional landscape maps were produced (Verfaillie *et al.*, 2009), as well as habitat suitability maps of the major macrobenthic communities (Degraer *et al.*, 2008a).

A variety of multipurpose vessels are used for seabed mapping. Bathymetrical, geological, hydrological, and resource information is collected with equipment held by the different institutes mentioned above. Vibrocores, Van Veen, and Hamon grabs, mechanically drilled cores, sidescan sonar, Sparker (150 Hz to 1 KHz), single-beam, multibeam, and video equipment are used. Simrad 1002S and Simrad 3002D multibeam echosounders are installed onboard the national oceanographic vessel RV "Belgica". Arcview, Mapinfo, and ArcGIS are used to visualize the data. For details, see the different websites and papers/reports mentioned above. All data are held by the Geological Survey of Belgium (GSB), Fund for Sand Extraction, Operational Directorate Nature Management Unit of the North Sea Mathematical Models, MDK Coastal Division and Ghent University, Renard Centre for Marine Geology (RCMG). Addresses and contact persons are provided above.

Each of the national contact points adheres to international standards. Within the framework of the EU-FP7 Geo-Seas, a pan-European data infrastructure project on geological and geophysical data management, primary datasets on cores, sediments, and multibeam acquisition are standardized using similar metadata structures, common vocabularies, and similar output formats (http://www.geo-seas.eu/).

3.2.2 Canada

The national organization responsible for seabed mapping is:

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

There is no update to the Canadian mapping information because no information has been received by WGEXT since 2006.

3.2.3 Denmark

The organizations responsible for seabed mapping in Denmark are:

- Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK 1350 Copenhagen K. Contact person: Dr Jørgen O. Leth / Dr Jørn Bo Jensen; tel: +45 38 14 29 00; fax: +45 38 14 20 50; e-mail: jol@geus.dk or jbj@geus.dk.
- Danish Nature Agency, Haraldsgade 53, DK-2100 Copenhagen Ø. Contact person: Joachim Raben-Levetzau; tel: +45 72 54 30 00; e-mail: jorab@sns.dk.

No systematic mapping programmes are taking place in Denmark, but mapping projects for sand and gravel have been carried out, governed by the Danish Nature Agency. Furthermore, the Danish Coastal Authority has programmes for mapping sand resources for beach nourishment. Recently, projects for mapping marine habitats and marine aggregates have also been done by the Geological Survey of Denmark and Greenland (GEUS) and the Danish Nature Agency. General mapping using seismic and coring equipment was performed in the North Sea with a focus on the Jutland

Bank region. In total, 6000 km seismic lines, 60 vibrocores, and 100 grab samples were taken (see Figures 3.4 and 3.5).

Seabed and pre-Quaternary sediments were mapped in the EMODnet-Geology project on a scale of 1:1 million (http://www.emodnet-geology.eu/) and further contributed to the One-Geology data portal (http://www.onegeology-europe.org) from where data can be downloaded.

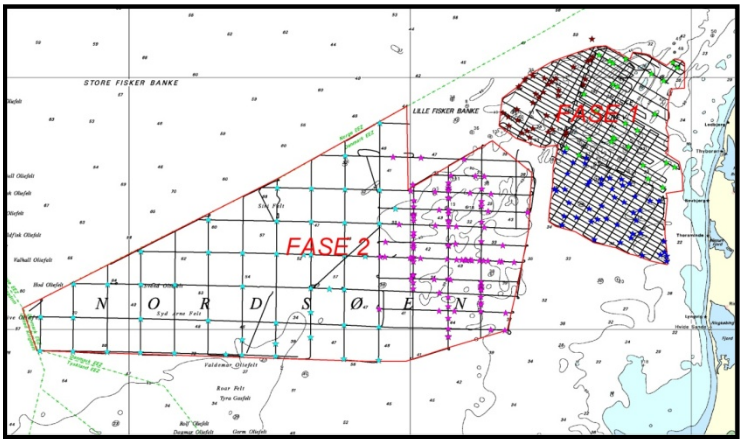


Figure 3.4. Overview of survey lines and sample point acquired by GEUS in 2010 for the Danish Nature Agency. From Nicolaisen (2010).

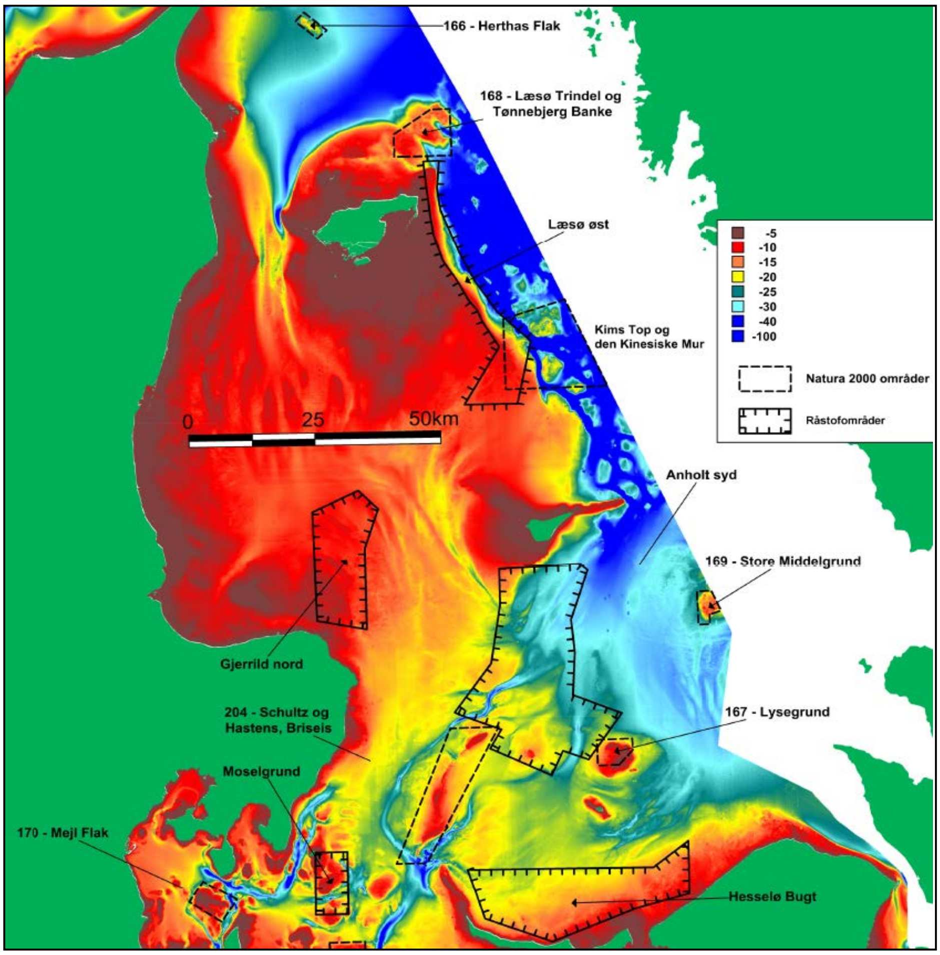


Figure 3.5. Bathymetric overview of Kattegat with indications of Natura 2000 and aggregate survey areas surveyed in 2011. From Anon. (2011).

Between 1990 and 2000, GEUS published a series of geological maps applicable to the evaluation of marine aggregates. Maps can be ordered from GEUS. A national specification of the available mapped resources has been reported to the Danish Forest and Nature Agency (GEUS, 1997).

Commercial survey vessels have been used for seabed mapping. Seismic/acoustic mapping has been done with a single channel sparker (300 to 3 kHz), chirp (1–10 kHz), sidescan sonars (100 and 400 kHz), and single-beam and multibeam echosounder (Simrad 3002D). Direct sampling was done with 6 m vibrocores and Van Veen grab samplers.

GEUS is custodian of marine data including sand and gravel resource surveys. The marine geophysical data are kept by GEUS in a database named "MARTA". Metadata is available at http://www.geus.dk/UK/data-maps/Pages/default.aspx. Confidentiality issues limit the availability of some data. Sediment data (cores and grab samples) are available from GEUS Jupiter database: http://www.geus.dk/UK/data-maps/jupiter/Pages/default.aspx.

Primary data on cores, sediments, and multibeam acquisition are standardized according to the framework of the EU-FP7 Geo-Seas, a pan-European data infrastructure project on geological and geophysical data management. They use similar metadata structures, common vocabularies, and similar output formats http://www.geo-seas.eu/.

3.2.4 Estonia

The national organization responsible for seabed mapping is:

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

Systematic investigations directly related to the seabed research of Estonia's territorial waters were launched in 1973 when the Institute of Geology of the Estonian Academy of Sciences purchased RV "Joldia". More detailed mapping of the uppermost part of the seabed was carried out in Pärnu, Narva, and Tallinn bays and the Sea of Straits, Väinameri (Lutt, 1985). Additional investigations were focused on the sediment transport processes occurring in Matsalu Bay (Lutt and Kask, 1980) and along the shore. Between 1980 and 1985, the Institute of Oceanology of the Academy of Sciences of the USSR collected ca. 500 rock samples from underwater escarpments.

Systematic seabed geological mapping started in 1981 when the respective programme was compiled at the Geological Survey and the RV "Marina" was purchased. As a result, seabed maps of the Estonian shelf were compiled, first at a scale of 1:500 000, later at 1:200 000, supplemented with exploratory research. This mapping covered most of the Estonian territorial waters. The All-Union Geological Institute (VSEGEI) carried out additional mapping of the eastern Gulf of Finland (east of the Aseri settlement). These data are still stored at VSEGEI (in spite of repeated attempts and former agreements, we have failed to obtain these materials). The first set of maps includes maps of bottom deposits, Quaternary deposits, bedrock geology, and seabed topography.

Coverage of the central Gulf of Finland included predominately seismic sounding as well as gravity cores and grab samples. On some small islands of the Gulf of Finland (Põhja-Uhtju, Väike-Tütarsaar, Vaindloo), drill holes penetrating into the crystalline rocks were undertaken.

The results include the following maps on:

- seabed topography,

- bedrock geological,
- Quaternary deposits,
- geomorphology,
- bedrock topography,
- mineral deposits,
- lithology of the topmost part of bottom deposits,
- geochemical data,
- geophysical investigations,
- drill holes and sampling points.

The seabed geological investigations continue to be undertaken at the Geological Survey of Estonia. Geological maps of the Estonian part of the Gulf of Riga were compiled in 1993. In 1994, the western Gulf of Finland was mapped, including nearly 4000 km of seismoacoustic soundings and 3884 bottom sediment stations on the small islands of Aegna, Koipse, and Rammu; drill holes reached the crystalline basement. In addition, in cooperation with VSEGEI, engineering–geological investigations were carried out within Tallinn Bay.

Seismoacoustic soundings were carried out mainly by a profilograph operating at frequencies up to 450 Hz. In addition, high-frequency acoustic profilograph (24 kHz) and echosounder data were used. Seismoacoustic methods were, in some cases, able to penetrate down to the surface of the crystalline basement. Bottom sediments were sampled by gravity cores up to 18 m long, grab samples, and sometimes by vibrocores. Drill cores of 14 m were obtained by this method. At 1:200 000, the resolution was 2 km. In 1991–1992, seismoacoustic sounding at 250–500 Hz and 4 kHz and magnetometry was completed by RV "Livonia" in the central Baltic Sea, within Estonian territorial waters and economic zone. Data are stored in digital databases at the Depository of Manuscript Works along with interpretive reports and the metadata.

Geological mapping of Estonian territorial waters and exclusive economic zone (EEZ) is done at a scale of 1:500 000 and 1:200 000 (Figure 3.6).

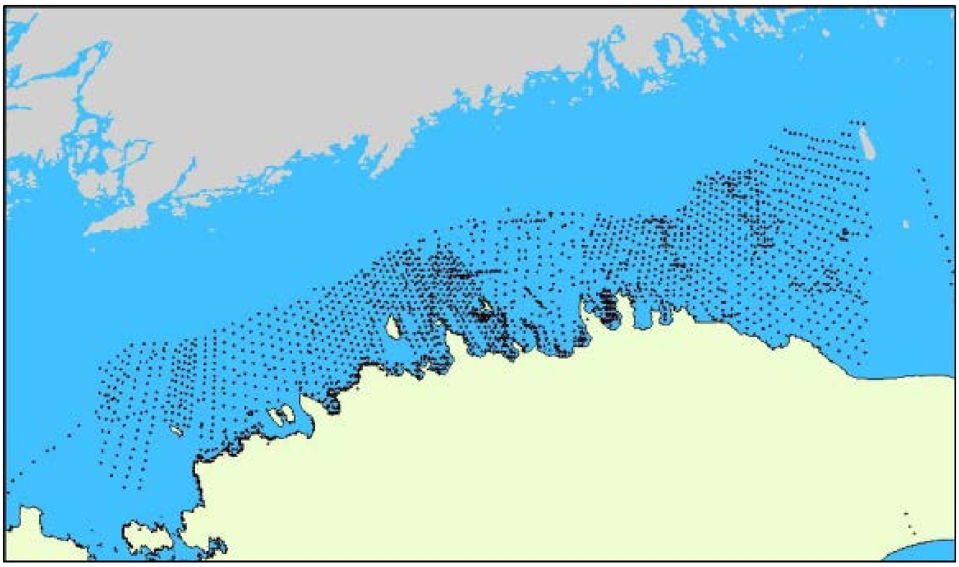


Figure 3.6. Geological mapping of the shelf carried out by EGK in 1981–1992.

New impetus in seabed geological investigations occurred in 1995 when large-scale geological mapping discovered a possible meteor impact structure in northeastern Estonia near Nuegrund Bank. Several international expeditions were carried out between 1996 and 2012.

Currently, seabed geological mapping is under the auspices of the state geological base mapping programme of Estonia. The complex digital mapping at a scale of 1:50 000 includes the seabed (Figure 3.7). Printed or digital maps and data can be ordered from the Geological Survey of Estonia, Tallinn, Estonia; tel: +372 67 20090; fax: +372 76 20091; e-mail: egk@egk.ee. The most recent, specific, geological maps in Estonian territorial waters and EEZ, at a scale of 1:50 000, are the geological seabed investigations of the Estonian shelf on the map sheets of Kohtla-Järve, Sillamäe, and Narva (2008) and the geological seabed investigations of the Estonian shelf on the map sheet of Pakri (2012).

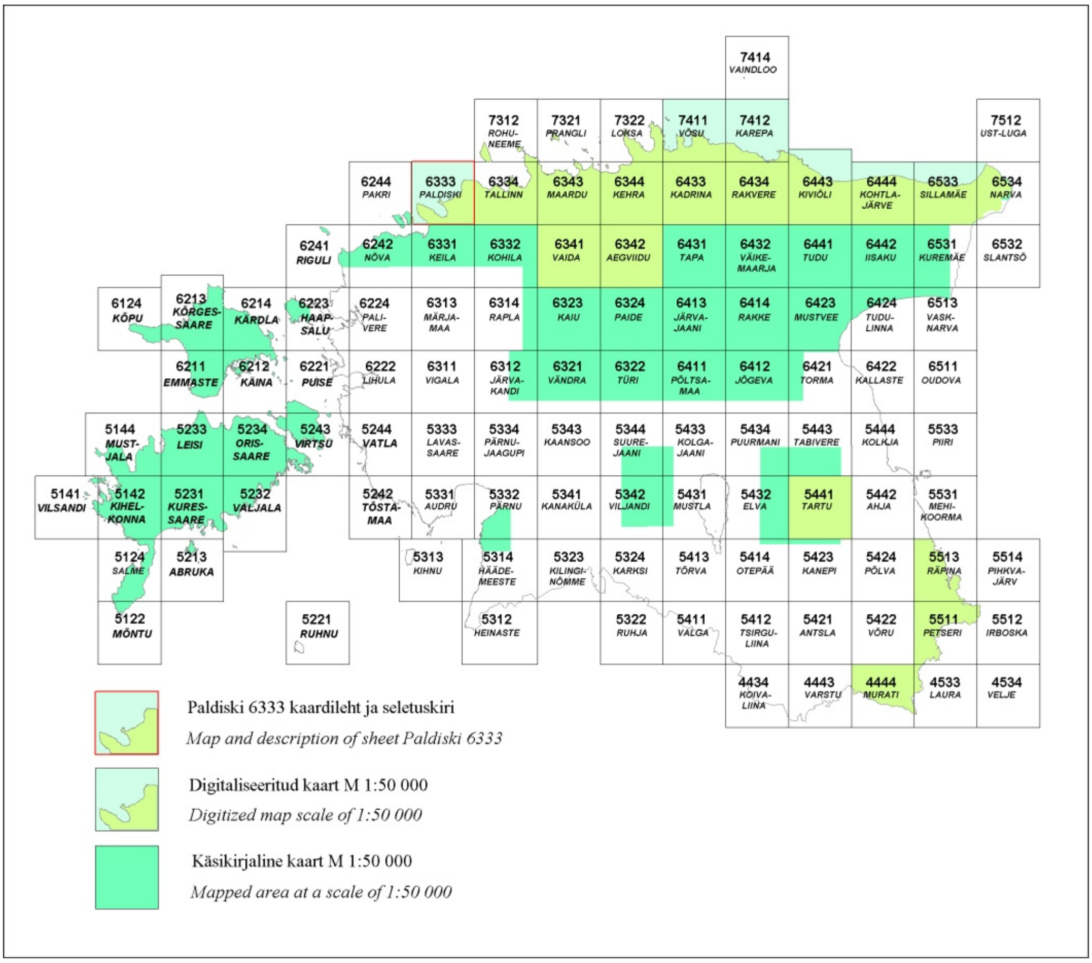


Figure 3.7. The map sheets of the state geological base mapping programme at a scale of 1:50 000.

Seabed and pre-Quaternary sediments were mapped in the EMODnet-Geology project on a scale of 1:1 million (http://www.emodnet-geology.eu/) and further contributed to the One-Geology data portal (http://www.onegeology-europe.org) from where data can be downloaded.

West of Hiiumaa Island, in Tallinn, Muuga, and Ihasalu Bay and the southwestern part of the Gulf of Finland, >90 million m^3 of sand have been found since the 1990s (Figures 3.8–3.11). Sand deposits overlie postglacial clay in deeper areas and glacial till in shallower regions. Aggregate deposits at the foot of bedrock escarpments and on the slopes of glacial deposits are usually found at water depths of < 25 m. Demand has always been controlled by building activities. The annual amount of sand used in Estonia was ca. 7.5 million m^3 in 1975–1990, ca. 0.9 million m^3 in 1990–1995, and ca. 3 million m^3 in 2006 (Raudsep, 2008). The need for sand has increased in connection with the construction of new large harbours such as Sillamäe and the extension of the Muuga and Paldiski harbours.

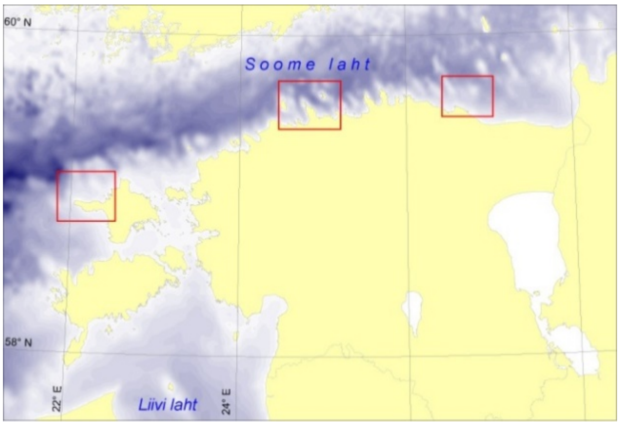


Figure 3.8. Regions of sand distribution on the Estonian shelf. From left to right, the indicated areas (red squares) are Muuga, the Tallinn area, and the Gulf of Finland.

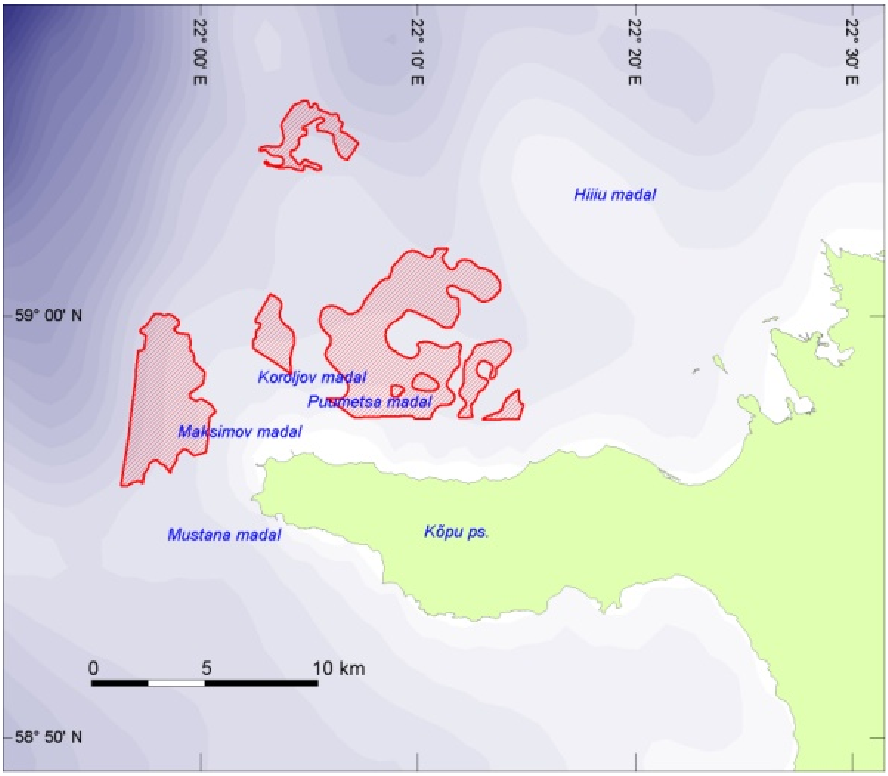


Figure 3.9. Sand deposits (red areas) at Hiiumaa Island.

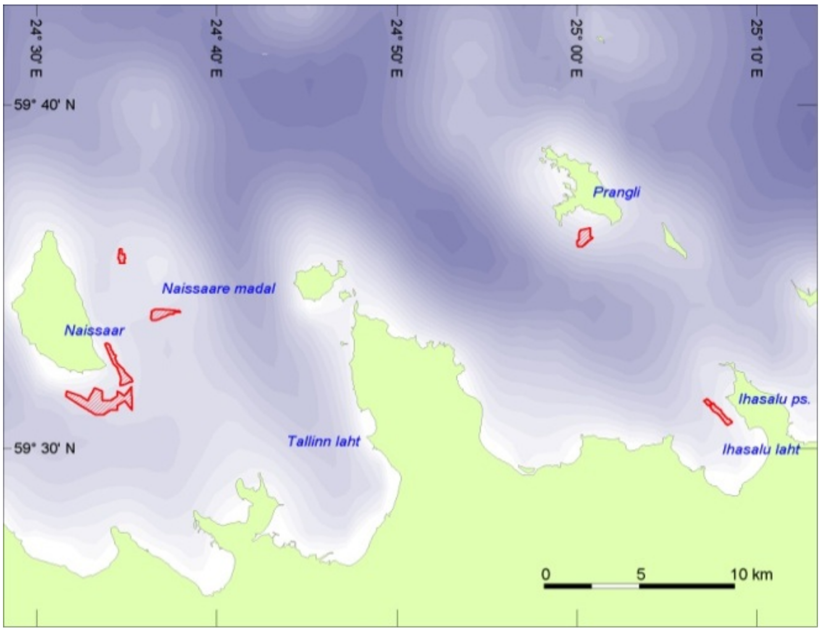


Figure 3.10. Sand deposits (red areas) in the Tallinn area.

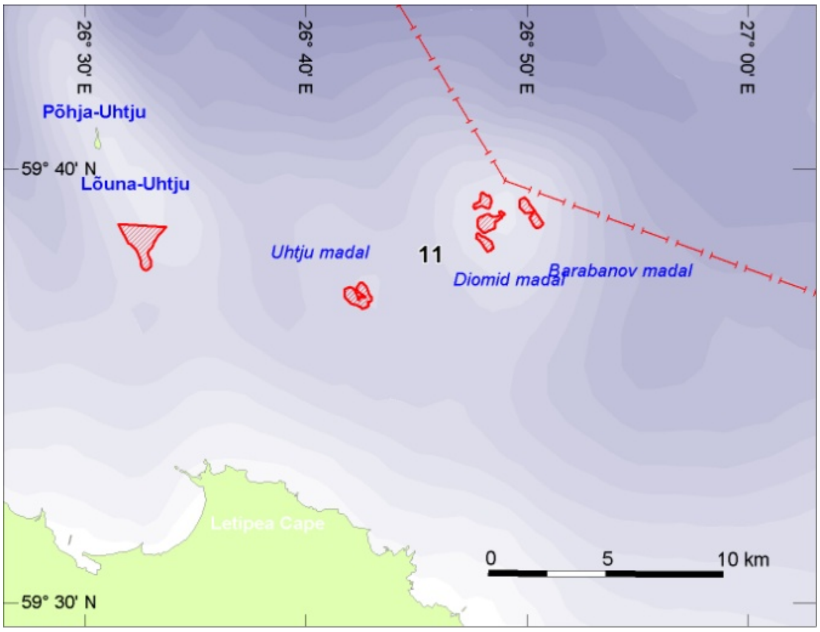


Figure 3.11. Sand deposits (red areas) in the southern part of the Gulf of Finland.

Research vessels from the Estonian Maritime Museum, Tallinn Technical University, and the Estonian Maritime Agency are used for coring and geophysical research, with a low-frequency echosounder (pinger with frequency 24 kHz), seismoacoustic devices (boomer with operational frequency 1.6 kHz and subbottom profiler with frequency range of 0.4–12 kHz), and a dual-frequency sidescan sonar. Bottom sampling is carried out with Van Veen grab samplers and vibrocores.

The Geological Survey of Estonia (EGK) is the custodian of these data. Analyses of EGK are carried out by contracted accredited laboratories.

3.2.5 Finland

The national organization responsible for seabed mapping is:

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

Finnish territorial waters have been mapped at a scale of 1:100 000/1:50 000/1:20 000 in the Gulf of Finland, eastern Archipelago Sea, and in some parts of the Bothnian Sea. Some maps are also available for the EEZ. An overview of the mapped areas is shown in Figure 3.12. Printed maps and/or electronic versions (ArcGIS shape) can be ordered from the Geological Survey of Finland (GTK), PO Box 96, FI-02151 Espoo, Finland. Contact: tel: +358 20 550 11; fax: +358 20 550 12; e-mail: publication.sales@gtk.fi.

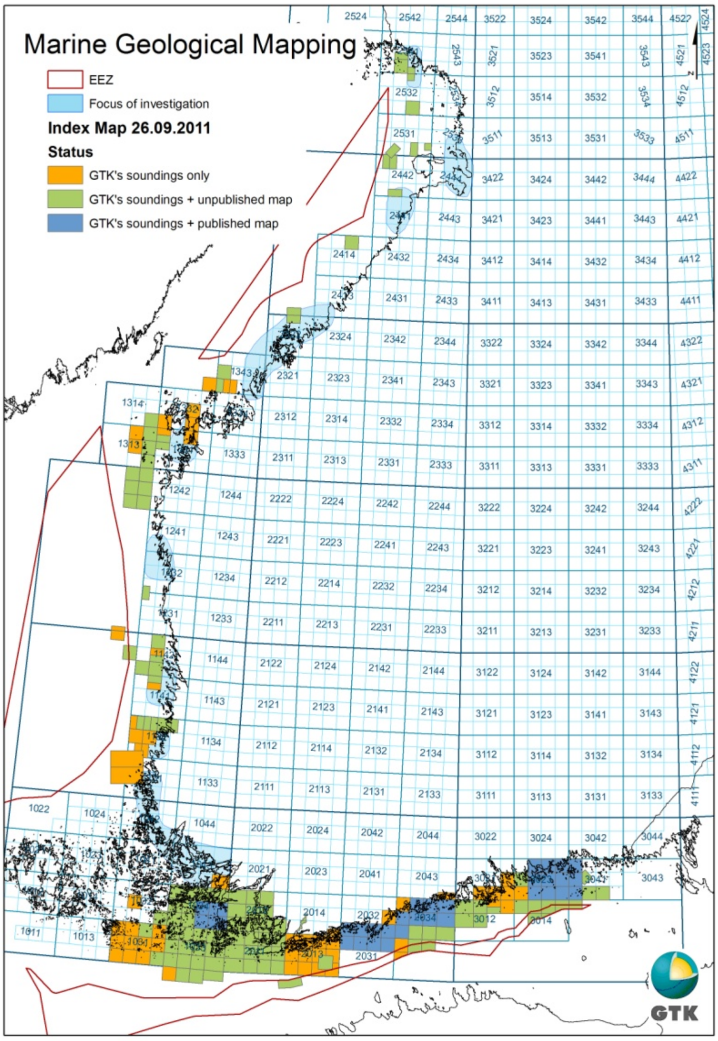


Figure 3.12. Map of the GTK's acoustic-seismic surveys showing coverage of mapped areas within Finnish territorial waters and EEZ at scales of 1:100 000, 1:50 000, or 1:20 000.

Since 1986, mapping has been based on the simultaneous use of a single-channel seismic survey with a boomer-type sound source, echosounding (28/30 kHz), and sidescan sonar. In 2006, chirp and multibeam were added to the system. The survey line spacing has generally been 500 m. Grab samples and coring are used for verification and interpretation.

Data from 1989 are stored in various databases. Printed maps and digital versions of maps may have any form, format, or content. Contact GTK for information and availability. Detailed information of the aggregate resources within the mapped area is available on request from GTK. Permission from the Defence Command is required for any marine inventory data to be distributed in Finland, according to the Territorial Surveillance Act of 2000. To apply for the permit, contact GTK.

No maps of marine geology have been published since 2005, but unpublished, ready-to-use maps are available. See index map (Figure 3.12.).

Seabed and pre-Quaternary sediments were mapped in the EMODnet-Geology project at a scale of 1:1 million (http://www.emodnet-geology.eu/) and further contributed to the OneGeology data portal (http://www.onegeology-europe.org) from where data can be downloaded.

The most important known mineral resources in Finnish territorial waters or EEZ are the sand and gravel deposits, and these are the only non-living natural resources that have been exploited commercially in Finnish waters to date. Exploitation has been concentrated in areas off Helsinki and Pyhtää in the Gulf of Finland.

GTK has a twin-hull, aluminium survey vessel SV "Geomari" to accomplish this work (Figure 3.13).

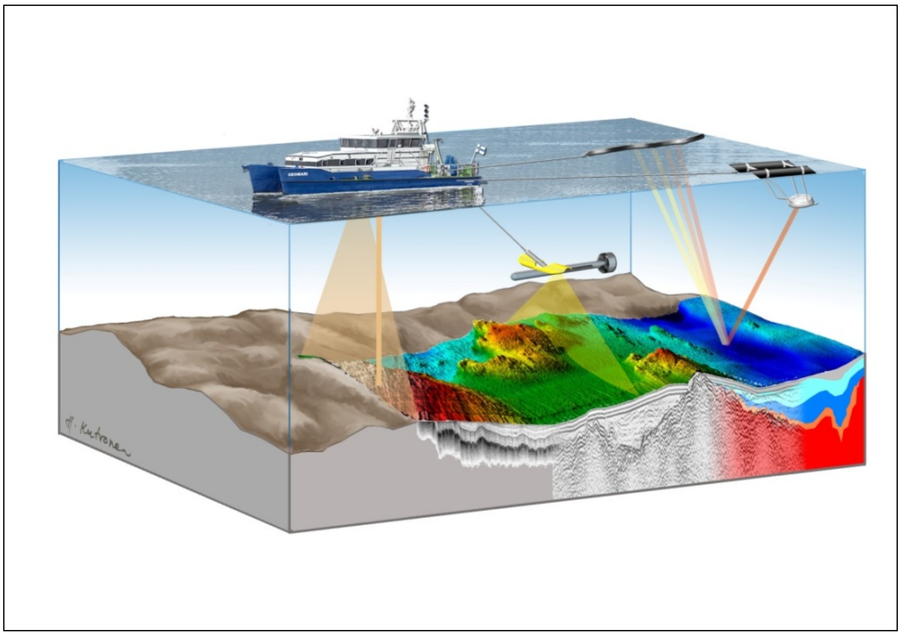


Figure 3.13. Thematic picture of acoustic-seismic survey equipment used on SV "Geomari".

The vessel has winches, an L-frame, moon-pool, sediment laboratory, and laboratory for data collection and processing. Geological information is collected with multibeam, shallow seismic systems, sidescan sonar, chirp, and pinger. This vessel is 20 m in length, 7.6 m in width, a draught of 0.9 m, gross tonnage of 75 t, and can cruise at 20 knots. It is equipped with water-jet propulsion, dynamic positioning, and has a power capacity of 1044 kW.

Survey equipment also includes various grab samplers and corers, including a vibrohammer corer, piston corer, box corer, Van Veen grab, gemax corer including subsampling devices, and an underwater camera. GTK also has a smaller RV "Gridi" equipped with a similar array of equipment.

The Geological Survey of Finland (GTK) is the custodian of these data. Analyses of GTK's sediment samples are carried out under contract with accredited laboratories, very often Labtium Oy, which is the former laboratory of GTK, privatized in 2007.

3.2.6 France

National organizations responsible for seabed mapping are:

- Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Z.I. Pointe du Diable, BP 70, 29280 Plouzané, France. Contact persons: Claude Augris; tel: +33 2 98224242; e-mail: Claude.Augris@ifremer.fr, and Laure Simplet; e-mail: laure.simplet@ifremer.fr.
- Service Hydrographique et Océanographique de la Marine (SHOM), CS 92 803-29 228 BREST Cedex 2, France.
- Bureau de Recherches Géologiques et Minières (BRGM), 3 avenue Claude Guillemin, BP 36009, 45060 Orléans Cedex 2, France. Contact persons: Isabelle Thinon: tel: +33 2 38643345; e-mail: i.thinon@brgm.fr, and Fabien Paquet: e-mail: f.paquet@brgm.fr.

IFREMER is in charge of mapping offshore aggregates and publishing atlases of coastal areas dealing with seabed type, morpho-sedimentary, geology, sediment thickness, and bedrock morphology. IFREMER is also involved in mapping the continental shelf, slope, and abyssal plain.

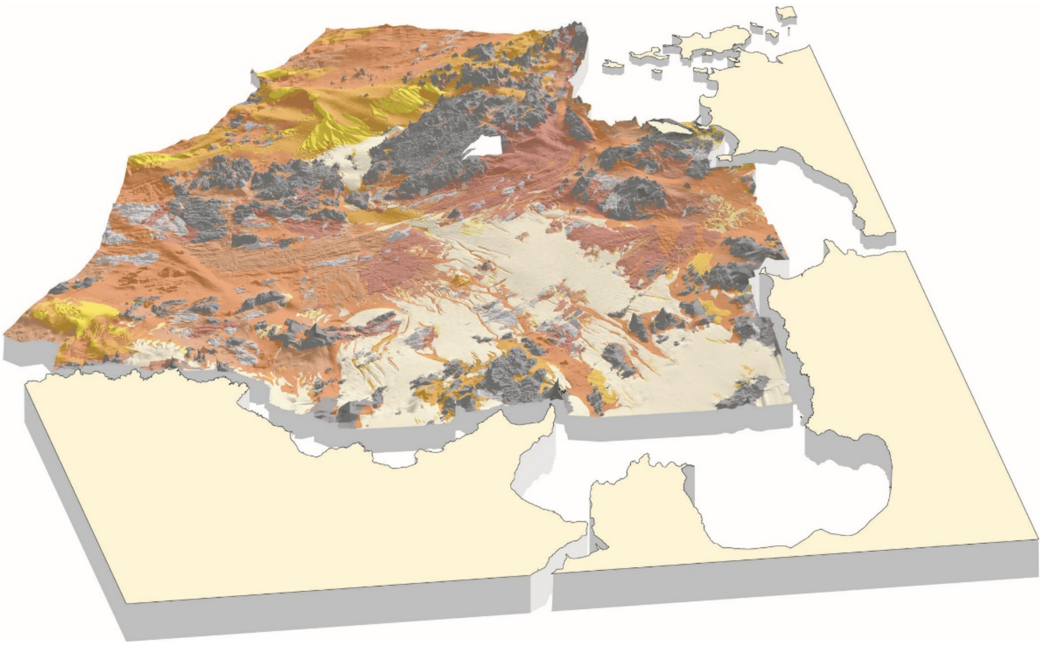


Figure 3.14. 3D view of the seabed sedimentology of the Bay of Lannion (Augris *et al.*, 2011).

The REBENT project collects data relating to seabed habitats and associated benthic biocenosis along the coasts, offering scientists, marine managers, and the general public access to information that may improve their knowledge of current resources as well as detect spatiotemporal evolutions (Figures 3.14 and 3.15). All French territorial waters are expected to be encompassed by the project, but tidal zones and coastal waters are priority areas, in compliance with the Water Framework Directive. Maps are available at: http://www.rebent.org/cartographie/index.php.

Mapping is planned for the French EEZ (Extraplac project), covering both continental France and its overseas territories. Cruises devoted to EEZ exploration have been carried out, and six bathymetric charts at a scale of 1:250 000 are being produced between the mainland and Corsica, and in the Gulf of Biscay and French Guiana.

The French Naval Hydrographic and Oceanographic Service (SHOM) is in charge of bathymetric surveys dedicated to marine safety. Their nautical charts and seabed sedimentological charts ("G" type maps) cover the area between five and 15 nautical miles from the coast (Figure 3.16) at various scales (typically 1:50 000). These are compiled from existing data, for example, derived from tallow lead samples that cover 95% of the continental shelf, grab samples, cores, sidescan sonar, multibeam reflectivity, and aerial photography, in collaboration with universities.

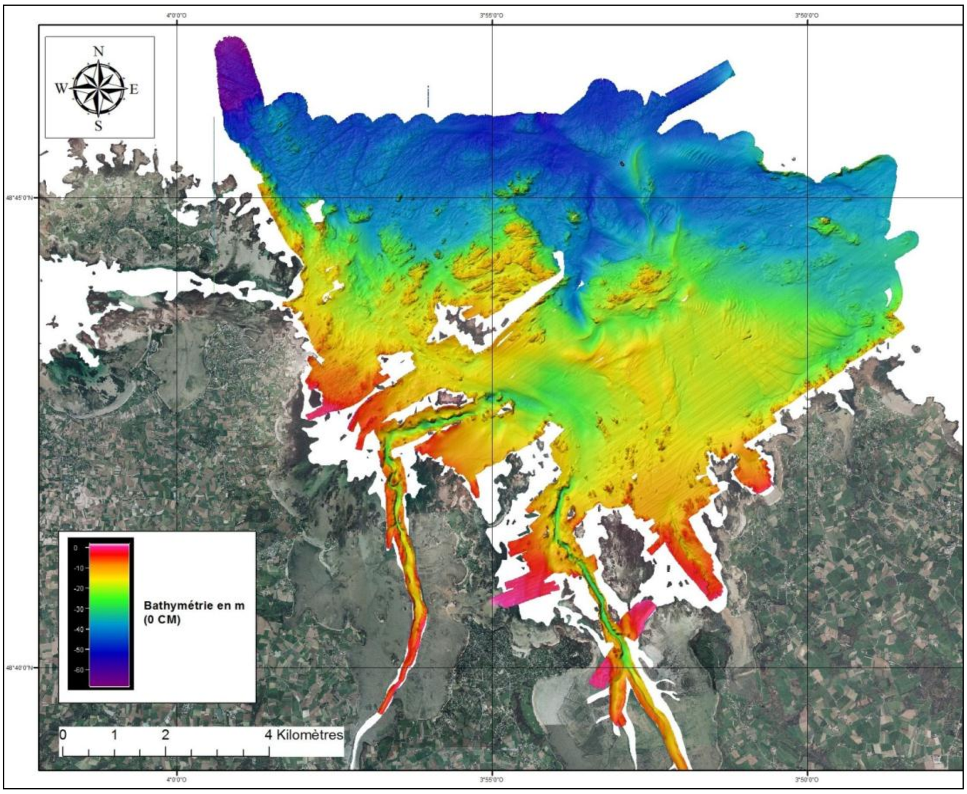


Figure 3.15. Morphological map of the seabed of the Bay of Morlaix.

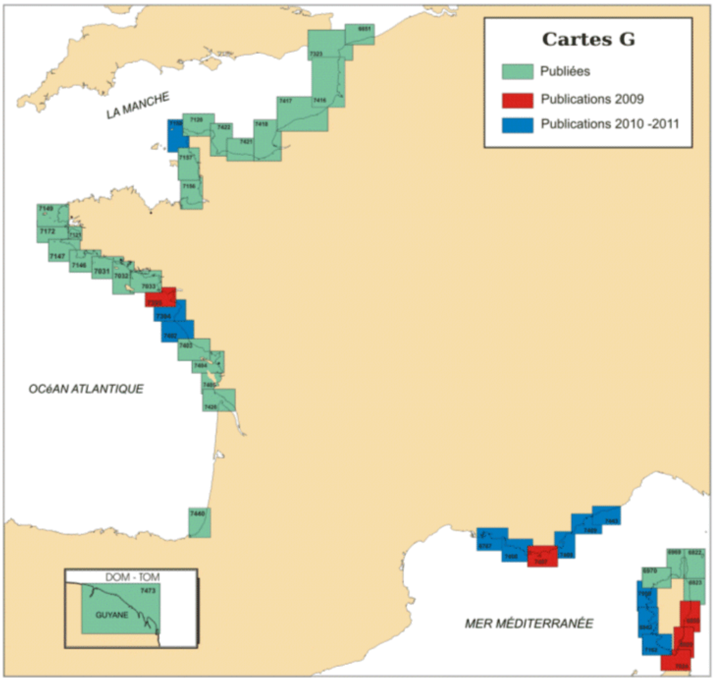


Figure 3.16. "G maps" prepared for SHOM.

BRGM (French Geological Survey) is in charge of the offshore geological ("hard substrate geology") mapping of the continental shelf at scales of 1:50 000, 1:250 000, and 1:1 000 000 (Figures 3.17 and 3.18). They produce sedimentological and morpho-sedimentary maps in collaboration with local authorities, such as the LIMA and LIMA 2 projects (Guennoc *et al.*, 2001, 2002) and the CARTOMAR project (Guennoc and Duclos, 2007; Guennoc *et al.*, 2008).

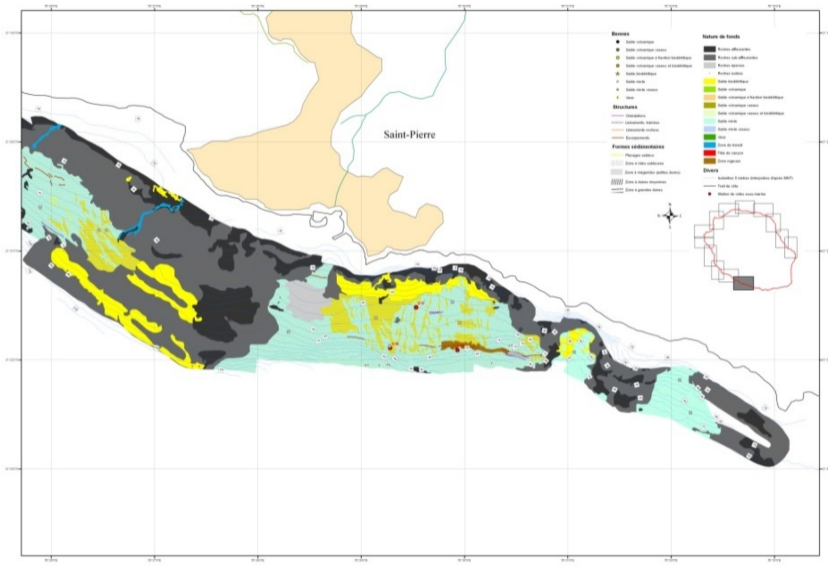


Figure 3.17. Map of the seabed sedimentology of the coastal area of the Réunion Island (Guennoc *et al.*, 2008).

Three other organizations and several universities collaborate with the French National Center for Research (CNRS) to improve the knowledge of coastal areas and continental shelf, and produce various maps, atlases, and reports.

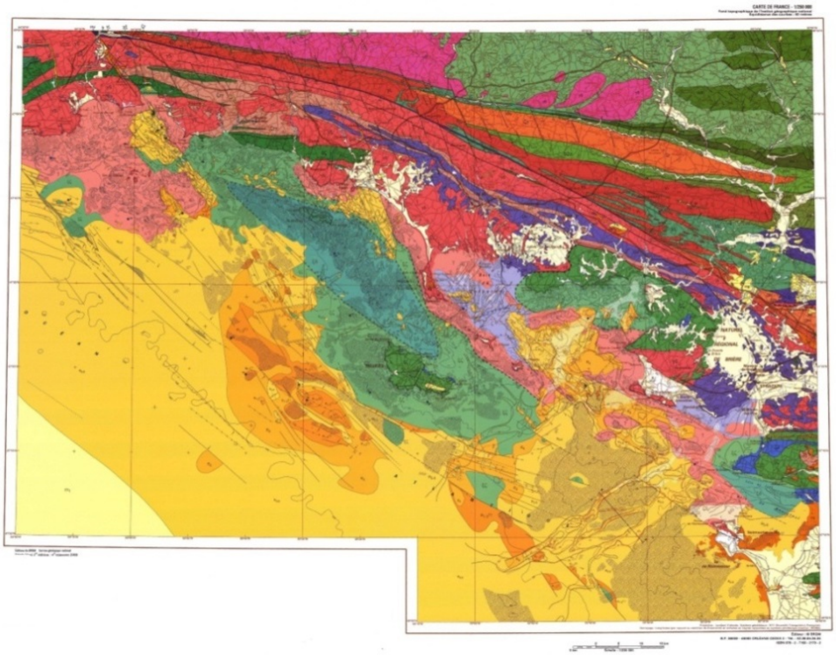


Figure 3.18. Geological map of France at a scale of 1:250 000 – Lorient (Sheet 15) (Thinon *et al.*, 2009).

The geological mapping of the continental shelf continues through the RGF national programme (Référentiel Géologique de la France) and is managed by BRGM. It will produce new or revised 1:250 000 scale maps. The Lorient 1:250 000 scale geological map (Figure 3.18) is the first to be published (Thinon *et al.*, 2009).

Research vessels that are owned by IFREMER, the Centre National Recherche Scientifique-Institut National Sciences Univers, the Institut Recherche Developpement, the Institut Polaire Francais Paul Emile Victor, and SHOM are managed by both the Coastal and the Deep-Water Fleet National Commission (French Oceanographic Fleet). A total of six research vessels (10–25 m in length) are dedicated to coastal and continental shelf studies. Four vessels are from IFREMER and two from CNRS INSU. Eight research vessels 30–120 m in length are dedicated to deep-water and continental shelf studies (four from IFREMER, two from IRD, and two from IPEV). SHOM owns four hydrographic and research vessels, and one is coshared with IFREMER. Vessels are equipped with corers, grabs, dredges, conventional, high-resolution, and very-high-resolution seismic acquisition systems (airgun, sparker, boomer, CHIRP, etc), sidescan sonar, bathymetric single-beam and multibeam systems, D-GPS, magnetometer, gravimeter, etc. Equipment is attached to the vessels or is swappable. The equipment is owned by IFREMER, CNRS-INSU, IPEV, IRD, BRGM, as well as universities.

Data are held by the national organizations responsible for seabed mapping. For contact information, see the section above. Publications can be ordered from:

- IFREMER: Editions QUAE (http://www.quae.com/fr/index.html).
- BRGM: Editions (http://www.brgm.fr/editions.jsp).
- SHOM: Editions (http://www.shom.fr/les-produits/produits-nautiques).

Since 2005, more than a dozen seabed mapping reports have been issued:

- Augris, C., and Clabaut, P. (Eds). 2013. Cartographie morpho-sédimentaire des petits fonds marins du cap d'Antifer au cap d'Ailly (Haute-Normandie). (Morpho-sedimentary mapping of coastal area between cap d'Antifer and

cap d'Ailly (Haute-Normandie).) Explanatory booklet and six maps at scale 1:20 000. Editions Quae, Versailles. IFREMER.

- Augris, C., and Simplet, L. 2011. Atlas géologique de la baie de Lannion (Côtes d'Armor – Finistère). (Geological atlas of the Bay of Lannion (Côtes d'Armor – Finistère).) Explanatory booklet and ten maps at scale 1:20 000. Editions Quae, Versailles. IFREMER.
- Augris, C., Caill-Milly, N., and De Casamajor, M. 2009. Atlas thématique de l'environnement marin du Pays Basque et du sud des Landes. Editions Quae, Versailles. IFREMER.
- Augris, C., Bonnot-Courtois, C., Ehrhold A., Maze, J-P., le Vot, M., Blanchard M., and Simplet, L. 2008. Carte des formations superficielles du domaine marin côtier de Saint-Malo à Granville (Ille-et-Vilaine – Manche). (Map of surface formations of the coastal marine area of Saint-Malo at Granville (Ille et Vilaine – Manche).) Scale 1:50 000. Editions Quae, Versailles. IFREMER.
- Augris, C., Bonnot-Courtois, C., Mazé, J-P., le Vot, M., Crusson, A., Simplet, L., Blanchard, M., and Houlgatte E. 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.
- Augris, C., Ménesguen, A., Hamon, D., Blanchet, A., Le Roy, P., Rolet, J., Jouet, G., *et al.* 2005a. Atlas thématique de l'environnement marin de la baie de Douarnenez (Finistère). Partenariat Ifremer et ville de Douarnenez. Ed. Ifremer, Atlas et Cartes, 10 cartes, échelle 1 : 25 000 et livret d'accompagnement. 135 pp.
- Augris, C., Blanchard, M., Bonnot-Courtois, C., and Houlgatte, E. 2005b. 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. 2005. Carte des formations superficielles sous-marines aux abords de Flamanville (Manche). (Map of surface deposits around Flamanville (Channel).) Scale 1: 15 000. Editions Quae, Versailles. IFREMER.
- Bonnot-Courtois, C., Mazé, J-P., Le Vot, M., Augris, C., Ehrhold, A., Simplet, L., and Blanchard, M. 2009. Carte morpho-sédimentaire de la baie du Mont-Saint-Michel (Ille-et-Vilaine – Manche). (Map of surface formations of Mont-Saint-Michel Bay (Ille et Vilaine – Manche).) Scale 1:25 000. Editions Quae, Versailles. IFREMER.
- Bourillet, J-F., De Chambure, L., and Loubrieu, B. 2012. Sur les traces des coraux d'eau froide du golfe de Gascogne. (Cold-water corals in the Bay of Biscay.) Eight geomorphological maps at scale 1 : 100 000. Editions Quae, Versailles. IFREMER.
- Bourillet, J-F. (Ed). 2007. Le canyon de Capbreton: Carte morpho-bathymétrique. (The Cap Breton canyon: morpho-bathymetric map.) Scale 1 : 50 000. Editions Quae, Versailles. IFREMER + Université Bordeaux.
- Guennoc, P., and Duclos, P-A. 2007. Cartographie morphosédimentologique du domaine côtier de la Martinique. Rapport BRGM/RP-56062-FR. 64 pp.

- Guennoc, P., Villain, C., Thinon, I., and Le Roy, M. 2008. CARTOMAR: Cartographie morphosédimentologique des fonds marins côtiers de La Réunion. Rapport final BRGM/RP-56579-FR. 43 pp.
- Thinon, I., Menier, D., Guennoc, P., and Proust, J-N. 2009. Carte géologique de la France à 1/250 000 de la marge continentale – Feuille LORIENT (15). Co-éditions BRGM Editions-CNRS Rennes.

Further information is available online at:

- http://www.ifremer.fr/sextant,
- http://www.ifremer.fr/sextant/fr/web/granulats-marins,
- http://infoterre.brgm.fr/viewer/MainTileForward.do,
- http://data.shom.fr/,
- http://www.extraplac.fr.

3.2.7 Germany

The national organizations responsible for seabed mapping within the EEZ are:

- Federal Maritime and Hydrographic Agency (BSH), Bernhard-Nocht-Str. 78, 20359 Hamburg, Germany. Contact person: Dr Manfred Zeiler; tel: +49 40 3190 3250; e-mail: Manfred.zeiler@bsh.de, (Sediment mapping).
- Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, 30655 Hannover, Germany. Contact person: Dr Lutz Reinhardt ; tel: +49 511 643 2786 ; e-mail: lutz.reinhardt@bgr.bund.de.
- State Authority for Mining, Energy and Geology, Lower Saxony (LBEG), Stilleweg 2, 30655 Hannover Germany. Contact person: Anke Krüger; tel: +49 511 643 3444; e-mail: anke.krueger@leg.niedersachsen.de.
- Federal Agency for Nature Conservation (BfN) on Vilm, 18581 Putbus/Rügen, Germany. Contact: tel: +49 03 83 01/86–0 ; e-mail: vilm.marin@bfn-vilm.de (Marine habitat mapping).

There is no national mapping programme for German waters, but there are two projects situated at the BSH that deal with seabed mapping. These are the Geoscientific Potential of the German North Sea (GPDN) and the programme for the full coverage mapping of the German EEZ in the North Sea and the Baltic Sea. The GPND generates two sediment distribution maps with different classifications based mainly on grab samples. Two maps on sediment distribution of the German North Sea at a scale of 1:250 000 are carried out in two different classification systems: (i) classification after Folk (1954) and (ii) modified classification after Figge (1981). The maps generated within the GPDN project are mainly based on more than 22 000 grab samples collected during the last 3–4 decades.

Full coverage mapping of the German EEZ in the North Sea and the Baltic Sea was started in 2012 by the Federal Agency for Nature Conservation (BfN). It will map marine biotopes in the EEZ of the North Sea and the Baltic. It is a long-term project divided into three phases. The first phase began in June 2012 and will be completed by October 2014. As part of this habitat mapping programme, full-coverage sediment mapping of the EEZ of the North Sea and the Baltic Sea will be conducted by the Federal Maritime and Hydrographic Agency (BSH). This mapping programme consists of three mapping levels:

- 100% coverage of Natura 2000 sites,

- 40% coverage outside of Natura 2000 sites in areas with a homogeneous sediment distribution,
- screening level: sidescan sonar data from marine surveys of the BSH.

One of the main objectives of the first phase is to realize full-coverage mapping of the Natura 2000 sites (see Figure 3.19) to create sediment distribution maps. The sidescan sonar mosaics will have a resolution of 1 m. Single-beam echosounder, sidescan sonar, grab sampler, and underwater video systems will be used during all campaigns. Multibeam echosounder data will be recorded, but will not be implemented during the first phase of the mapping programme.

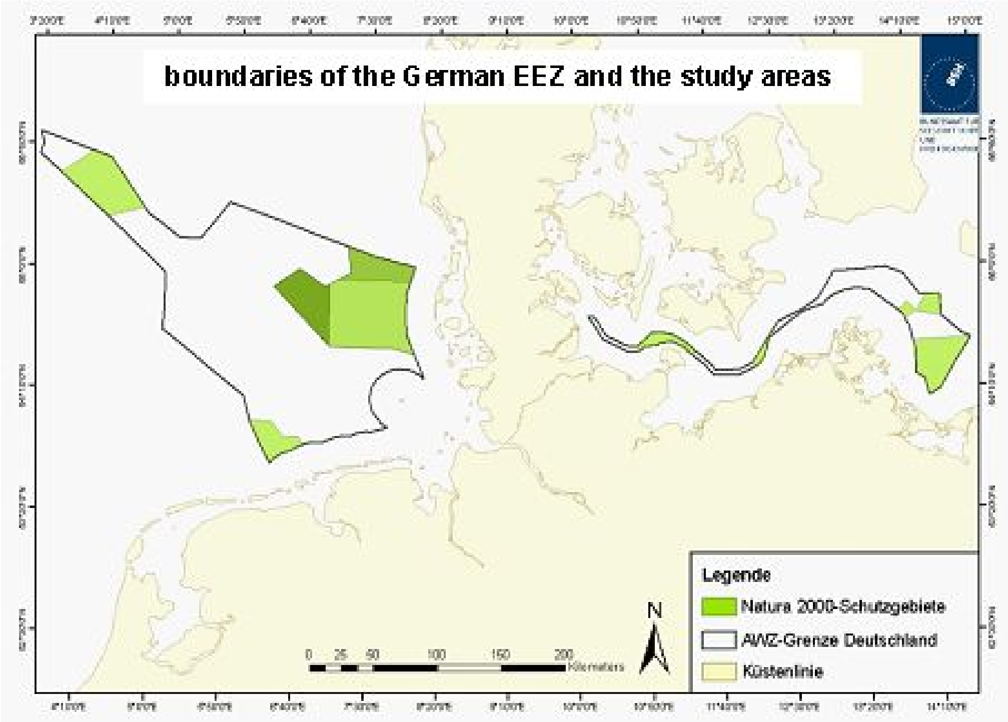


Figure 3.19. All Natura 2000 areas within the German EEZ will be mapped by the Federal Maritime and Hydrographic Agency (BSH) regarding the seabed sediments between 2012 and 2014.

Data will be held by the GPDN project partners using a map server via www.geopotenzial-nordsee.de/). The BSH will hold the data for sediment distribution maps within the Natura 2000 areas. The sediment distribution maps will be retrievable from the GeoSeaPortal of the BSH as WMS or WFS services (http://www.bsh.de/de/Meeresdaten/Geodaten).

Besides the full coverage mapping of the Natura 2000 sites, the project will develop a standardized mapping procedure for the sediment mapping, including the acquisition, processing, and interpretation of all data with consideration of the guidelines from MESH, BALANCE, etc.

3.2.8 Ireland

The national organizations responsible for seabed mapping are:

- Geological Survey of Ireland (GSI), Beggar's Bush, Haddington Road, Dublin 4, Ireland. Contact person: Koen Verbruggen, Principal Geologist; tel: +353 1 6782864; fax: +353 1 6782579; e-mail: koen.verbruggen@gsi.ie; websites: http://www.gsi.ie/. http://www.infomar.ie. Free downloads of digital mapping.

- Marine Institute (MI), Advanced Mapping Services, Marine Institute Headquarters, Rinville, Oranmore, Co. Galway, Ireland. Contact person: Thomas Furey; tel: +353 91 387200; fax: + 353 91 387201; e-mail: thomas.furey@marine.ie. General enquiries: institute.mail@marine.ie, Vessel chartering and surveying enquiries: rv@marine.ie; website: http://www.marine.ie.

Marine Data Online is an online service to provide quick and easy access to marine data and projects in Ireland. A summary of the content, currency, and format is given for each entry, conforming to the ISO19115 standard for geographic metadata. Requests for data can be made to http://data.marine.ie/.

There are other organizations also active in seabed mapping and research:

- Coastal and Marine Resources Centre, University College Cork, Haulbowline Naval Base, Cobh, Co. Cork, Ireland. Contact person: Gerry Sutton; tel: +353 2 14703113; e-mail: Gerry.sutton@ucc.ie.
- Department of Earth and Ocean Sciences, National University of Ireland, Galway, Ireland. Contact person: Prof. Colin Brown, Head of Department; tel: +353 91 524411 (University switchboard), +353 91 750337 (direct); e-mail: colin.brown@nuigalway.ie.

The Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR) programme is Ireland's national marine mapping programme. It is a joint venture between the Geological Survey of Ireland (GSI) and the Marine Institute (MI) and a successor to the Irish National Seabed Survey (INSS). The goal is the creation of a range of integrated mapping products of the physical, chemical, and biological features of the seabed in the near-shore area, and completing the mapping of all Irish waters.

The programme is funded by the Irish Government through the Department of Communications, Energy and Natural Resources, the parent Department of GSI at a cost of ca. €3 million $year^{-1}$. At the end of 2005, 432 000 km^2 had been mapped. Taken along with an earlier DCENR Petroleum Affairs Division programme, >81% of the Irish designated seabed area had been mapped by the end of 2005 (Figure 3.20). The INSS maps extend approximately to the 200 m contour. They represent a national asset that has provided Ireland with data as a foundation for present and future economic, environmental, infrastructural, social, and policy issues. In addition, significant capacity building has taken place both in terms of the infrastructures of Irish marine surveying and the training of personnel skilled in the design, planning, implementation, and management of a large-scale, integrated marine resource assessment.

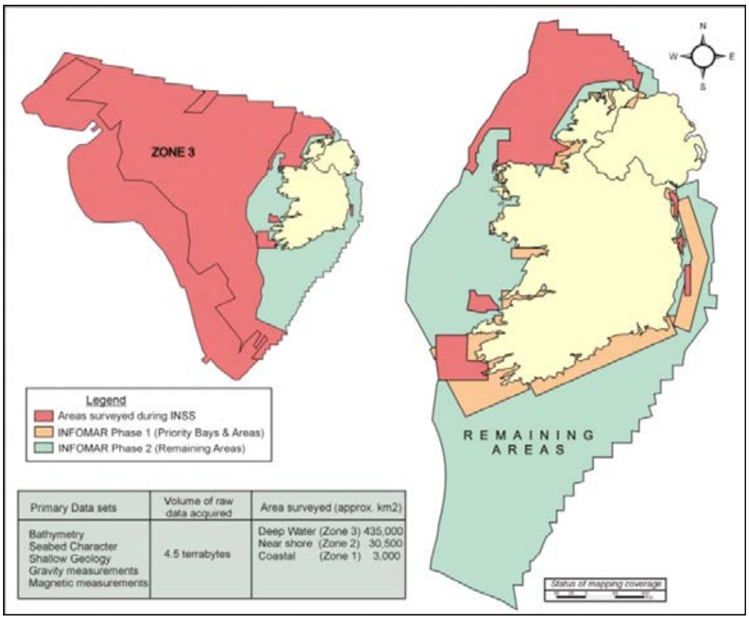


Figure 3.20. Area mapped by INSS and to be mapped by INFOMAR.

The INFOMAR programme is acquiring bathymetric data to international hydrographic standards (IHO Order 1 or better). The data are being used to address a range of diverse navigation, environmental, and cultural international legislative obligations. The INFOMAR programme is intended to address these outstanding issues, while also delivering an enhanced data management and delivery service for data gathered under both the INSS and INFOMAR. This data delivery strategy, based on free availability of all digital data once quality checked, is promoting the creation of value-added products.

INFOMAR has initially focused on 26 bays and three priority areas in its first ten years of operation between 2006 and 2015. These bays and priority areas were identified in 2002–2005 in consultation with over 50 organizations, including government departments, state agencies, coastal local authorities, industry sectors, and consultancy companies (Figure 3.21).

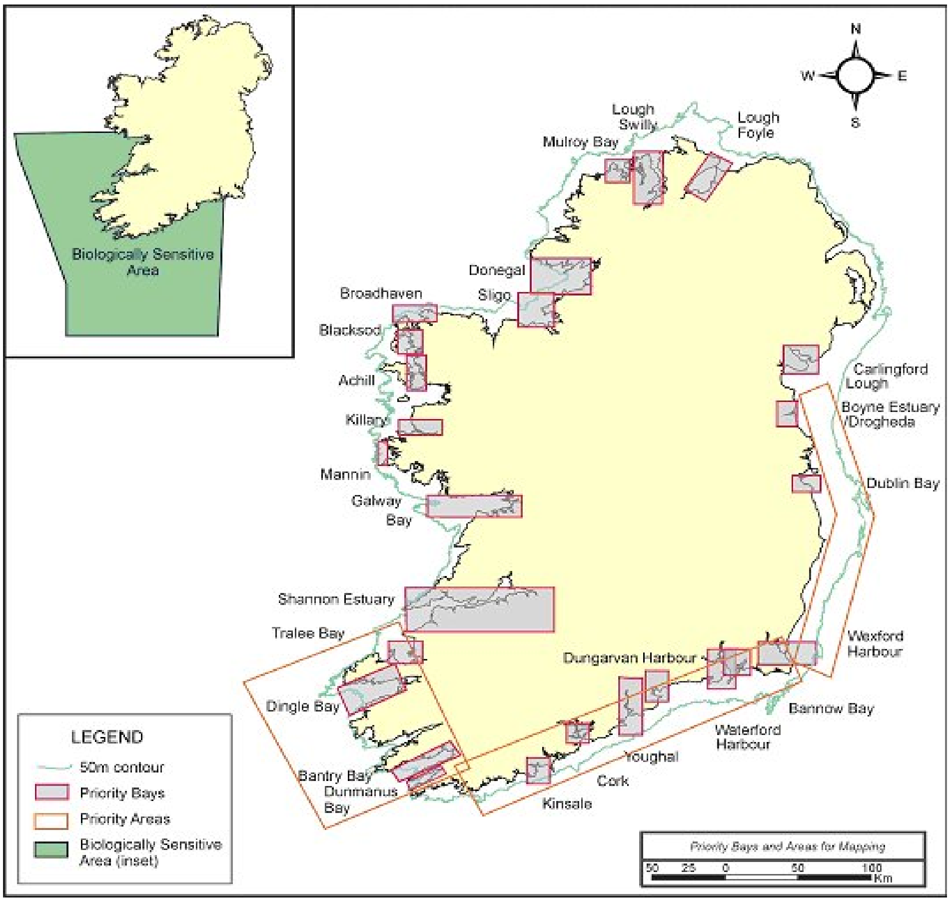


Figure 3.21. Detail of priority areas being mapped by INFOMAR.

The programme website (www.infomar.ie) and its linked web map viewers and data download sites are constantly updated to reflect the areas mapped. In general, if an area is bathymetrically mapped in year 1, the data will in year 2 have been fully processed, quality controlled, checked with UKHO (the charting agency for Irish waters), and available to download digitally and as contours, shaded relief, or backscatter charts. In year 3, the area will also have been groundtruth sampled and a seabed classification map and physical habitat map will be available.

After 2015, INFOMAR is scheduled to complete the mapping of the remaining 100 000 km² of all Irish waters, including the southern Celtic Sea (Figure 3.20).

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 heavily with the British Geological Survey in data acquisition and interpretation and production of the 1:250 000 scale seabed sediment sheets that cover part of the Irish waters (eastern coast and eastern parts of the northern and southern coasts, Malin, Isle-of-Man, and Anglesey, Cardigan Bay, Nymph Bank).

In 1999, the Irish Government allocated €32 million to fund the Irish National Seabed Survey (INSS) project that was designed to map Ireland's offshore areas in water depths greater than 200 m. The Geological Survey of Ireland (GSI) managed the project that mapped over 520 000 km² of the Irish extended EEZ and all Irish waters over 200 m in depth (Figure 3.22). Upon completion, this will have been the largest civilian marine mapping initiative in the world. For further details, see www.gsiseabed.ie.

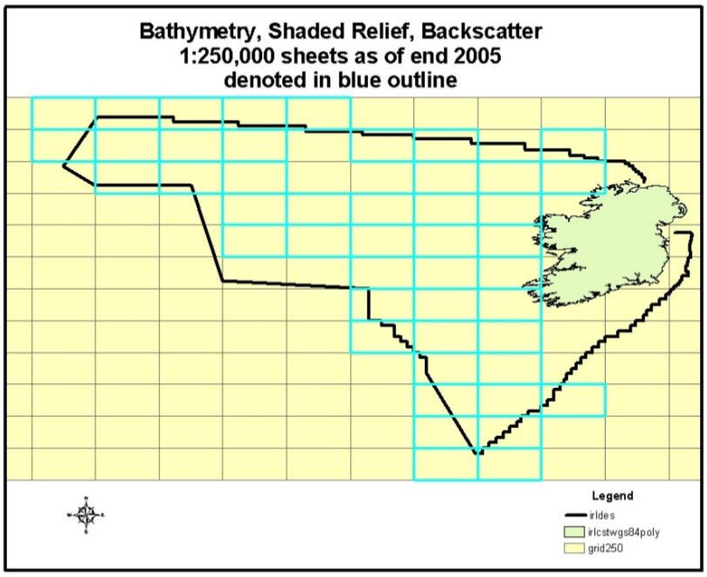


Figure 3.22. Irish bathymetric and backscatter maps produced in scale 1:250 000.

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. These are 2° longitude × 1° latitude map sheets at a scale of 1:250 000 (Figure 3.22). Maps of areas with shallower water are available at scales of 1:60 000 and 1:30 000 (Figure 3.21). They provide an accurate basis for further research and for additional maps customized to the needs of the various end-users. All the areas mapped under INSS have been produced at scales of 1:60 000 up to 1:250 000. Bathymetry, shaded relief, and backscatter data are available in both digital and pdf-chart format.

The INFOMAR seabed mapping programme produces seabed classification charts derived from multibeam data. Seabed classification is an advanced process in which a backscatter image is interrogated using special software in order to divide it into areas with similar characteristics (Figure 3.23). The software initially divides the image into manageable rectangular areas of a few metres. After these rectangles have been placed over the image, the acoustic data are examined in several ways, taking into account factors such as texture, morphology, hardness, and other statistical variables.

Areas with a similar nature are grouped together and divided into separate classes. These classes are colour-coded and charted (Figure 3.24). Finally, the classes on the chart are physically sampled in order to groundtruth the classification. This allows INFOMAR to match different sediment types with their corresponding colour classification, thereby producing classified geological maps of the seabed.

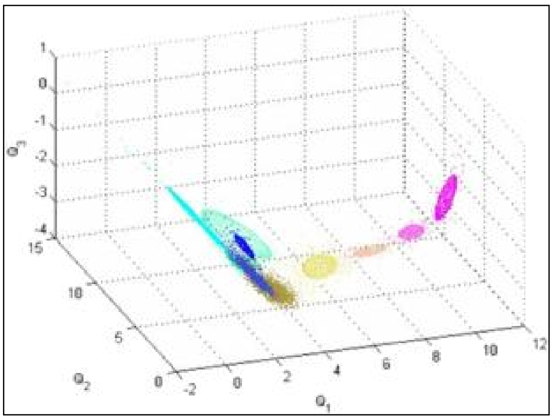


Figure 3.23. Example of images of multibeam backscatter data being analysed using QTC Multiview software where divisions are made in the datasets based on their attributes in "Q-space".

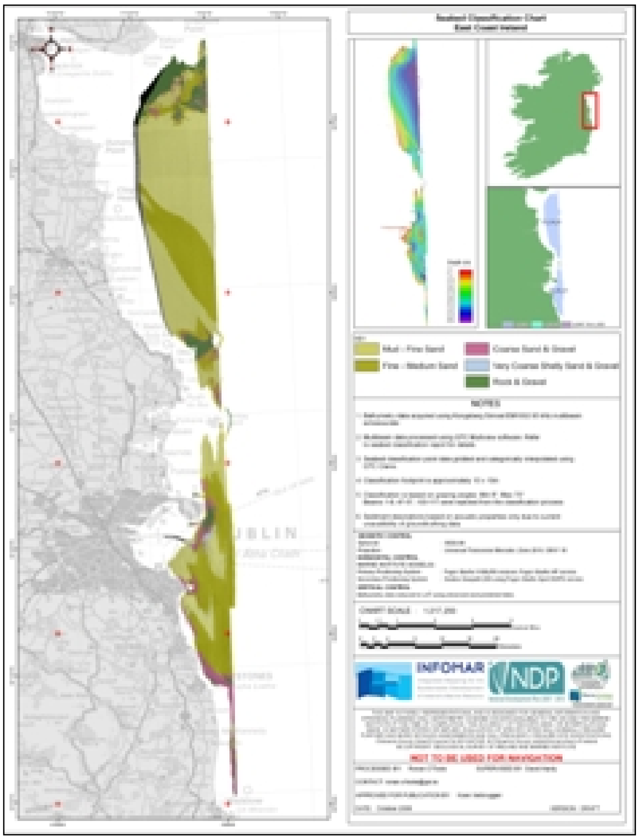


Figure 3.24. Example of the finished product showing a classification of the seabed (see Figure 3.23 above) from the surveyed area of the East Coast Priority Area.

For details about the progress of INFOMAR surveys in the 26 priority bays and three priority areas, navigate to the "Surveying" section of the INFOMAR website.

Under the GEOSEAS Project (FP7), data were added in the framework of the EU-Geo-Seas project (http://www.geo-seas.eu/) on sediments, geology, and geophysical parameters. Furthermore, hydrodynamic and sediment transport models were used to estimate impacts related to marine aggregate extraction.

Ireland also participated in the EMODNET Project funded by DG Mare. Ireland contributed to both the Geology and Hydrography modules. Within EMODnet-Geology, seabed sediments and pre-Quaternary were mapped on a scale of 1:1 000 000 (http://www.emodnet-geology.eu/) and further added to the OneGeology data portal (http://www.onegeology-europe.org) where data can be downloaded. The output was used as input to EUSeaMap, a European-wide broad-scale habitat modelling initiative (http://jncc.defra.gov.uk, for download).

The Coastal and Marine Resources Centre (CMRC) also holds a range of resource-reevant digital and analogue geophysical data and reports from work undertaken between 1998 and 2005 (IMAGIN). The IMAGIN project was a specific project on marine aggregate distribution carried out in the Irish Sea and completed in 2007; these data are available online. Access to the marine database is via the website at http://www.europeandataportal.eu/data/en/dataset/imagin-project-irish-sea-habitats.

The topic of offshore aggregates in Ireland was included with as part of a cost–benefit analysis of the INFOMAR programme carried out in 2008 and available online at www.infomar.ie. The report also estimated the potential value of offshore aggregates to the Irish economy as being up to €100 million. The key findings were as follows:

> "The use of marine aggregates is becoming an increasingly important issue in Ireland. As a result of the country's economic growth, the national consumption of aggregates per head of population has spiralled upward and is standing at four times the European average at peak. (Irish Sea Marine Aggregate Initiative (IMAGIN) report August 2007). These aggregates are currently drawn from the land, however, there are significant aggregate (sand and gravel) resources in Irish off-shore waters. Extraction of marine aggregates is a long established industry and is carried in many European maritime countries including the UK, Belgium and Holland.
>
> Despite considerable interest from commercial companies due to the rapid depletion of land-based resources in many areas, there has been no extraction of marine aggregates on a commercial basis. A recent assessment of the requirements for the development of aggregate resources identified the following:
>
> - Continued and enhanced support for existing areas of research including sedimentological studies, environmental modelling, biotope and seabed mapping;
> - Investigation of use of innovative techniques for resource evaluation;
> - Development of higher resolution hydrodynamic models leading to improved predictive capacity and better understanding of coastal systems.
>
> To date, Ireland has not explored the potential for commercial extraction of marine aggregate (sand and gravel). At present, there is no national policy on marine aggregate extraction, although this is being addressed through the Irish Sea Marine Aggregate Initiative (IMAGIN). A comprehensive dataset based on the mapping of the Irish inshore area will contribute to the decision making process relating to extraction of marine aggregate, its potential impact on biological communities and the most efficient methods of extraction. A specific recommendation of the IMAGIN study is the application of the project methodology to other areas and infill of widely spaced mapping lines by the INFOMAR Project.
>
> The extraction of marine aggregate has environmental as well as commercial implications as the 'carbon footprint' associated with the extraction and transport of marine aggregate has been found to be significantly less than that associated with land-based extraction activities".

INFOMAR, like INSS before it, is primarily a multibeam sonar survey, with subbottom profiling and subsequent seabed classification. This acoustic technique is providing detailed bathymetry data and knowledge of the nature of the seabed. In deeper waters, magnetic and gravity techniques are helping 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 echosounders,
- subbottom profiler (shallow seismic),
- water column measures of salinity, conductivity, temperature, and speed-of-sound profiles,
- seabed groundtruthing: sediment samples and video footage,
- sidescan sonar,
- 2D seismic data/sparker data in shallow bays,
- vibrocore data in research or complex areas.

Ancillary data are being collected on an opportunistic basis, and secondary projects can be initiated researching a wide range of marine topics:

- Atmospheric studies: automated samplers and analysers operated with minimal onboard assistance could be installed on the 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: study of the biodiversity, chemistry, bottom currents, sediment transport, and composition using grabs and corers or cameras.

A full list of the Irish marine research and survey vessels can be found at www.infomar.ie and www.marine.ie and include the RV “Celtic Explorer”, RV “Celtic Voyager”, and ROV “Holland” managed by the Marine Institute, and inshore vessels RV “Keary”, RV “Geo”, and RV “Cosantoir Bradan” managed by the GSI. In addition, the Commissioner for Irish Lights manages a large vessel with dynamic positioning (DP), the “Granuaile”, and a growing number of commercial contract companies have vessels suitable for offshore sampling and investigation.

GSI survey is the custodian of 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. Ireland currently has no specific standards that apply in relation to marine aggregates because no extraction other than for maerl or for limited national interest projects takes place.

3.2.9 Latvia

The national organization responsible for seabed mapping is:

- Latvian Environment, Geology and Meteorology Centre (LEGMC), Maskavas iela 165, Rīga, LV-1019, Latvia. Contact person: Inara Nulle; tel: +371 670 32 600; e-mail: inara.nulle@lvgmc.lv.

The previous organization, Latvian Environment, Geology and Meteorology Agency (LEGMA), established in 2005, was a state institution under the supervision of the Ministry of Environment uniting three institutions: the Latvian Environmental Agency, the Latvian Hydrometeorological Agency, and the State Geological Survey of Latvia. In July 2009, this organization was replaced by a new state limited-liability company, Latvian Environment, Geology and Meteorology Centre (LEGMC).

The LEGMC collects and processes environmental information and environment monitoring data. It is responsible for the dissemination of information about the state of the environment, ensuring the rational use and geological supervision of subsoil, implementation of the state policy in the spheres of geology, meteorology, climatology, hydrology, air quality, and transboundary air pollution. In fulfilling its tasks, LEGMC cooperates with national and international environmental protection, research, and other institutions and participates in different local and regional projects.

The geological jurisdiction of LEGMC includes 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 the dissemination of relevant geological information, various geological, geophysical, and geoecological investigations, etc.

The seabed geology of Latvian territorial waters and EEZ was mapped in detail in a reconnaissance programme, at scales of 1:200 000, 1:500 000, and 1:1 000 000.

During 1984–1991, geological mapping in the Latvian territorial waters was undertaken at the scale of 1:200 000. Only Sheets 0-34-XXIV, 0-34-XXX, 0-35-XXIX, and 0-35-XXV were compiled in full; these cover most of the Gulf of Riga. The areas of Sheets 0-34-XXII and 0-34-XXIII were covered partially (Figure 3.25). There was no mapping in the areas of Sheets 0-34-XXVIII and 0-34-XXXIV. Specialized marine geotechnical mapping was conducted in the area of Sheet 0-34-XXXIII.

The offshore mapping consisted of continuous seismoacoustic profiling, sidescan sonar investigations, echosounding, vibrocoring, and bottom grab sampling.

Maps were prepared, including maps of bottom sediment, Quaternary deposits, bedrock geology, mineral resources, geomorphology, landscape ecology, pre-Quaternary relief, and others. The maps were not published and are stored in the geological archives of LEGMC. No new maps have been made since 2005.

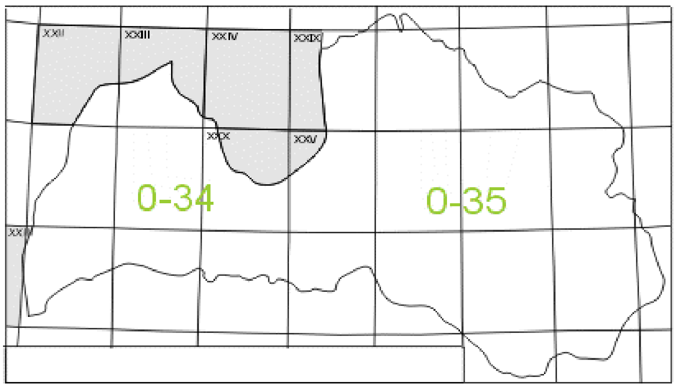


Figure 3.25. Scheme of the Baltic Sea, showing coverage of unpublished map areas within the Latvian territorial waters at the scale of 1:200 000.

In 1997, the following maps at the scale of 1:200 000 were published in cooperation with the Geological Survey of Estonia: The Gulf of Riga seabed pre-Quaternary and Quaternary deposits, landscape–ecological map, and map of bottom sediments (Figure 3.26). There is an accompanying explanatory note in English, and the legend is in Latvian, Estonian, and English. This information is used by fisheries and shipping managers as well as to coordinate activity among potentially competing activities.

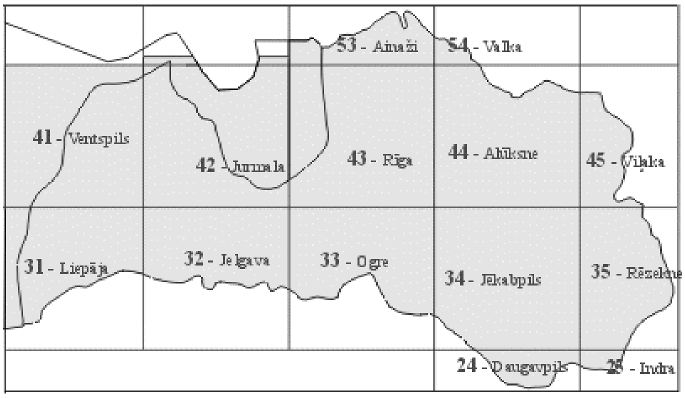


Figure.3.26. Scheme of the Baltic Sea, showing coverage of new published geological map areas in the Gulf of Riga.

The map of the bottom sediments in the Gulf of Riga is based on the geological mapping of 1984–1992 as well as generalized results of earlier studies and data from other institutions. The map shows the distribution of bottom sediments and conditions of sedimentation. Areas with occurrence of ferro-manganese nodules are indicated. The explanatory note includes descriptions of grain size of the bottom sediments, their mineralogical and chemical composition, physical–mechanical properties, and geochemical characteristics, based on data from more than 4700 stations.

The landscape map of the Gulf of Riga is based on the geological mapping of 1984–1992 and the results of investigations of zoobenthos and the distribution of temperature, salinity, and dissolved oxygen concentrations in bottom water carried out at the Institute of Biology of the Latvian Academy of Sciences. The map shows the distribution of the landscapes and their genetic interrelation with bottom sediments. In addition, distribution of the pollution of the bottom sediments is mapped at a scale of 1:1 000 000 for concentrations of organic carbon, lead, copper, zinc, cadmium, and mercury. The explanatory note includes descriptions of the landscapes, evaluation of the pollution of the bottom sediments, and the estimate of prospects for use of the basin in the national economy.

In 1995, the preparation of new geological maps of Latvian onshore and offshore areas began in order to provide resource managers with modern environmental information (Figure 3.26). The maps are based on the Latvian Co-ordinate 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 the scale of 1:200 000, several auxiliary maps at the 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 electronically. Printed maps, with descriptions and English summary, as well as digital maps and data, can be ordered from LEGMC.

Within the framework of a joint project (GEOBALT), two reconnaissance maps at a scale of 1:500 000 were published in 1998, showing the bathymetry and seabed sediments of the central Baltic Sea. These are accompanied by a subsidiary description. A special map showing the lithology, geochemistry, and morphology of the shore zone (Figure 3.27) was also published in 1998.

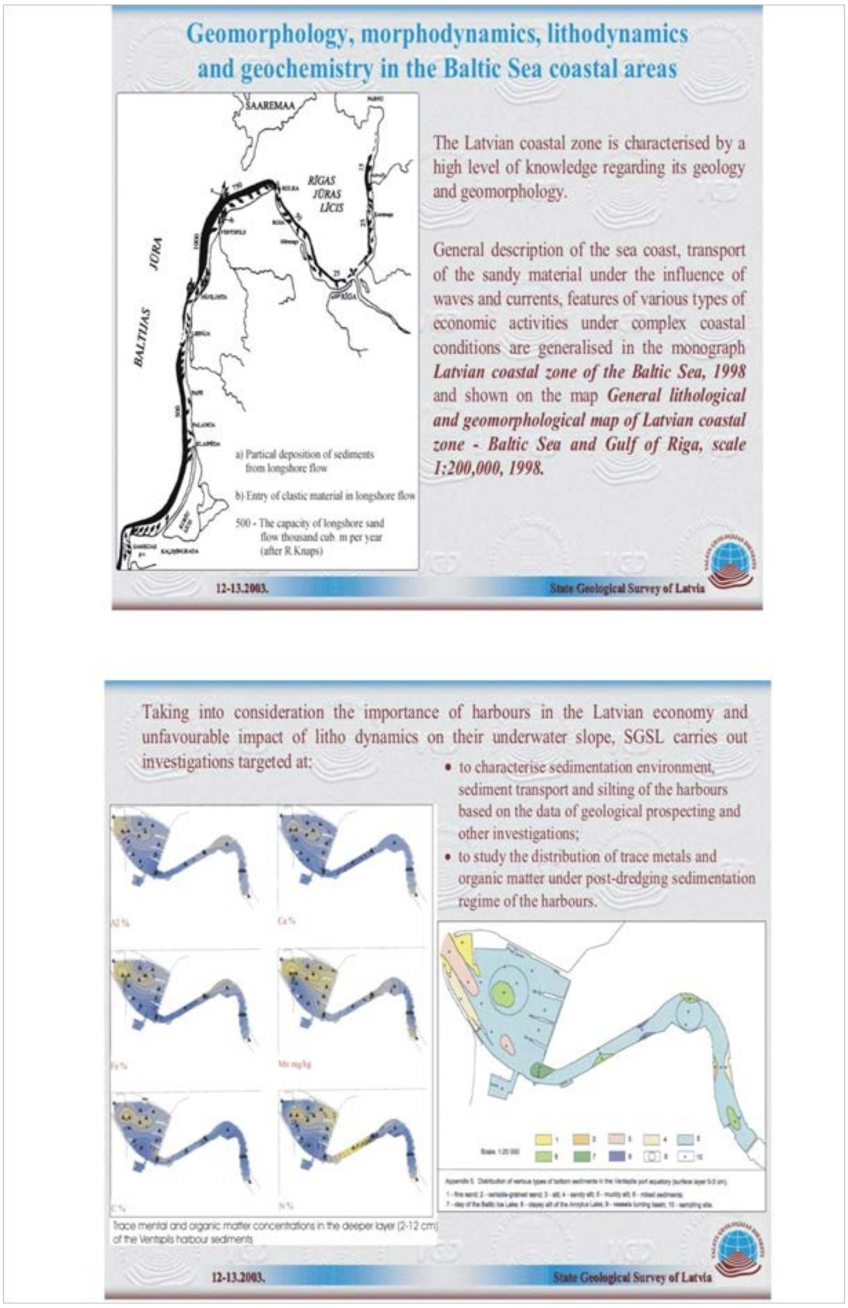


Figure. 3.27. Maps showing the lithology, geochemistry, and morphology of the Latvian shore zone.

Between 1975 and 1992, prospecting and exploration for construction sand, sand–gravel mix, and titanium–zirconium placers were carried out in the coastal zone of the Gulf of Riga, the Baltic Sea, and along the coast from Cape Ovishi to Pavilosta at a depth from the coastal zone to 30 m (Figure 3.28). A forecast of the impact of mining on the condition of the coast and benthos was made.

At the western and southern coastal slope of the Gulf of Riga, several sand deposits were discovered, but the deposits are not large, and the sand layer is thin. As a result, no sand extraction in the Gulf of Riga is planned. It is also necessary to preserve these areas as fish spawning grounds.

LEGMC does not own research vessels or specialized equipment for marine geological and geophysical investigations. Commercial geotechnical vessels and equipment from specialized Latvian geotechnical companies could be hired if funds are available. However, LEGMC does possess several computer systems and equipment for in-house processing of seismic and log data. LEGMC also has experience in the preparation of digital maps.

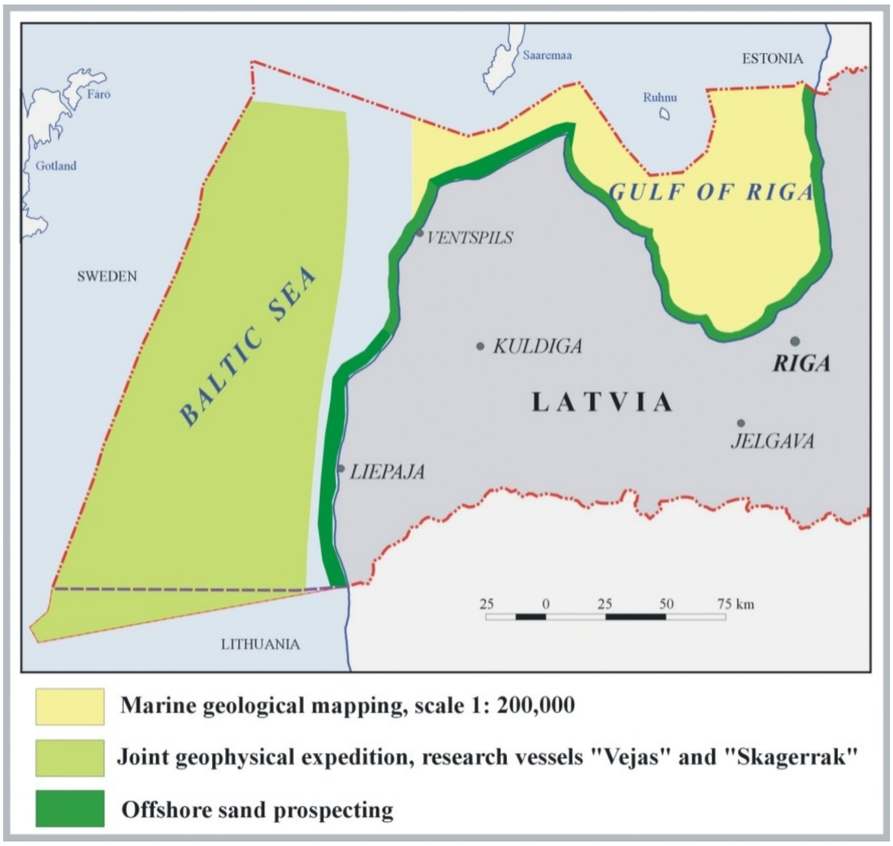


Figure 3.28. Scheme of the area, showing coverage of sand and gravel resources within Latvian territorial waters.

The State Geological Fund of LEGMC is the custodian of most of the data on bottom sediments and exploration for sand and gravel deposits. LEGMC uses standards developed in the former USSR between 1980 and 1990 for conducting marine geophysical, geotechnical, and ecological investigations. The existing map preparation standards are used for that purpose.

3.2.10 Lithuania

The national organization responsible for seabed mapping:

- Geological Survey of Lithuania (LGT), and Nature Research Centre, Institute of Geology and Geography (NRC–IGG), LT-03223 Vilnius, Sevcenkos Str. 13, Lithuania. Contact person: Dr L. Ž. Gelumbauskaitė and Prof. A. Grigelis; tel: +370 5 210 47 15; fax: +370 5 21 36 408; e-mail: leonora@geo.lt, or grigelis@geo.lt.

A total of 36% (3280 km²) of Lithuanian territorial waters and EEZ (ca. 9000 km²) has been mapped, as described below, at a scale of 1:50 000 (Figure 3.29). In addition, the entire Curonian Lagoon (426 km²) was mapped in 1998 and 1999. The detailed maps are archived at the LGT and LIGG, but no printed detailed maps are available. In 2000, the detailed mapping was cancelled due lack of funding.

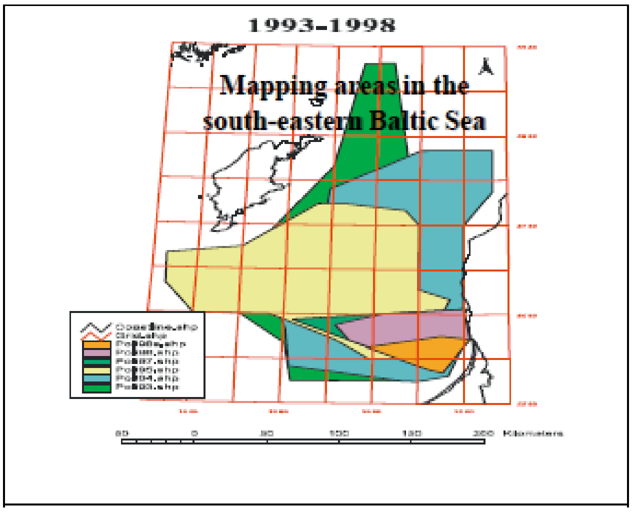


Figure 3.29. Mapping areas of the southeastern Baltic Sea covered in 1993–1998 at a scale 1:500 000 and 1:200 000.

Three geological maps (pre-Quaternary geology, Quaternary geology, and geomorphology) at a regional scale of 1:500 000) cover all of Lithuanian territorial waters and EEZ. Theses were compiled in 1992, completing data from geological–geophysical surveys undertaken previously during the Soviet period. All geophysical investigations, sampling, borehole, and laboratory data available since 1980 have been used. The maps form a foundation for comprehensive research of both geological structure and environmental conditions of the entire Baltic Sea. Maps at a regional scale of 1:500 000 with description in Russian and an English summary were published in 1992. No electronic version database was created for these data.

The basic, pre-Quaternary geological map of the southeastern Baltic Sea area at a scale of 1:500 000 was reviewed in 2011 and updated in January 2012. A digital version was created for this map (Figure 3.30).

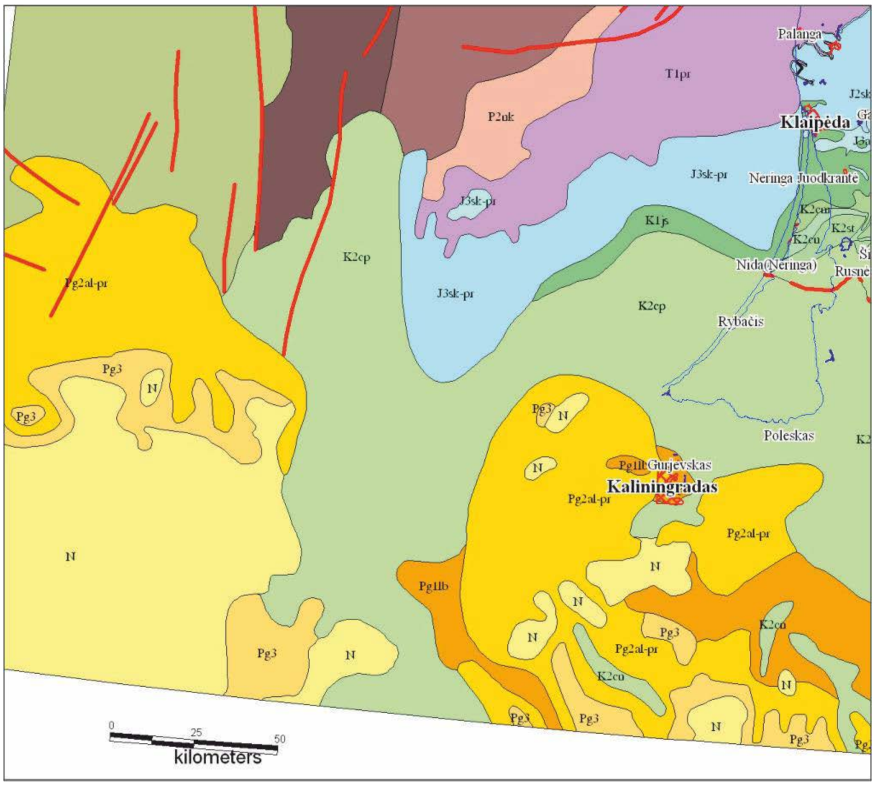


Figure 3.30. Pre-Quaternary geological map of the southeastern Baltic Sea area, at a scale of 1:500 000 (after Grigelis and Čyžienė (2011); updated in January 2012).

In 1998, digital maps of the bottom topography and sediments of the central Baltic Sea were compiled at a regional scale of 1:500 000. Maps and an explanatory note in English present relevant, new information collected by the states around the Baltic Sea. The maps were compiled in ARC/INFO format on the GIS base and issued in analogue format on two sheets and also on CD-ROM disk. They can be ordered from LIGG and the Geological Survey of Sweden. No new maps at this scale have been published since 2005.

Marine geological maps at a scale of 1:50 000 cover Lithuanian territorial waters to 20°30′E. Between 1993 and 2000, two sectors were mapped. The Klaipėda–Šventoji area was completed between 1993 and 1996 and covers 1630 km^2. The Nida–Klaipėda area was mapped between 1998 and 2000, covering an area of 1650 km^2. Core samples, shallow seismic data, and sidescan sonar measurements were collected on a dense grid. The maps are unpublished, but the data are archived in LIGG. The data are available on request to LIGG. Some deposits of aggregate resource were discovered. The example of mapped Holocene sediment types and thickness (m) is given for Klaipėda–Šventoji (Figure 3.31). No new maps at this scale have been published since 2005.

In 1998, within the framework of a joint Lithuanian–Swedish project (GEOBALT), two maps were published at a scale of 1:500 000 showing the bathymetry (Gelumbauskaitė, 1998) and seabed sediments (Repečka and Cato, 1998) of the central Baltic Sea, respectively. These are accompanied by a subsidiary description (Gelumbauskaitė *et al*., 1999). The maps are also available in CD-ROM format.

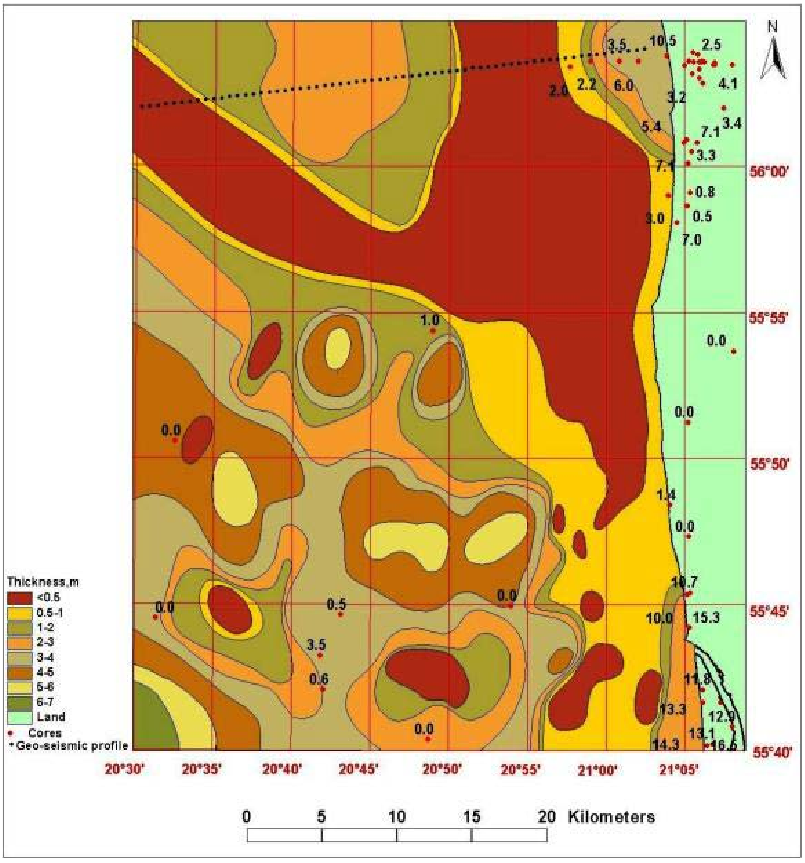


Figure 3.31. Types of Holocene sediments and thickness (m) of the Klaipėda–Šventoji area as recorded by mapping data at a scale of 1:50 000.

Sand and gravel deposits in Lithuanian territorial waters were found in the Klaipėda–Šventoji sector. Gravel occurs at water depths of 12–37 m over an area covering 290 km^2. The gravel deposit does not exceed 1 m in thickness, so the potential volume of gravel is low. There are also residual deposits of abraded morainal loam. Gravel may also be found along the submerged coast of the Litorina Sea. Sand covers about 537 km^2, but only 96 km^2 (5.9%) occurs in shallow waters at depths of 8–10 m.

For beach nourishment at the Palanga Resort, suitable marine sand deposits were mapped in 2007–2008. The volume of sand was estimated in the two areas shown in Figures 3.32 and 3.33. A total of 160 000 m^3 was successfully extracted in 2009 and 2011 to supply Palanga Resort's sandy beaches. The exploitation of the marine sand deposits was limited because of low quality and unstable open sea conditions.

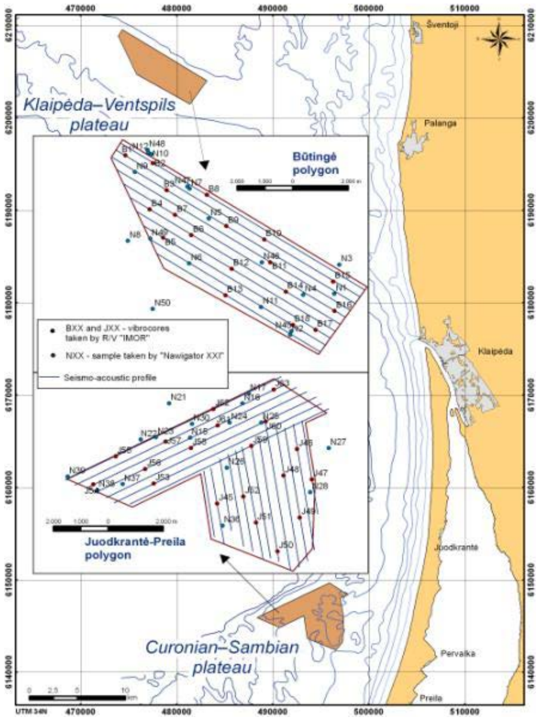


Figure. 3.32. Study sites of Būtingė and Juodkrantė areas of sand aggregates (after Gulbinskas *et al.*, 2009).

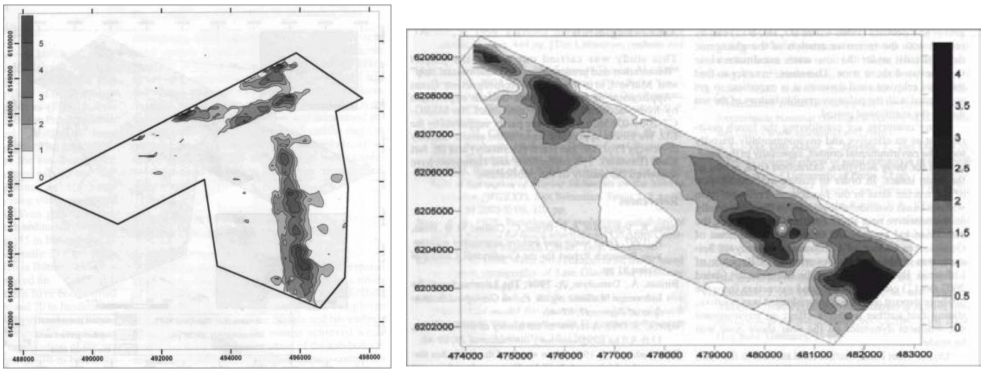


Figure 3.33. Left: Juodkrantė area of sand aggregates (after Gulbinskas *et al.*, 2009). Right: Būtingė area of sand aggregates (after Gulbinskas *et al.*, 2009).

The LIGG does not own a survey vessel, so mapping surveys were undertaken by renting commercial vessels, namely the RV "Vejas" (Klaipeda, Lithuania), RV "Doctor Lubecki" (Gdansk, Poland), and, in the lagoon waters, the RV "Peilboot Ludwig" (Kiel, Germany). All vessels were equipped with satellite navigation system, GPS or DGPS, sediment sampling, seismoacoustic, and scanning sonar systems, including survey computers.

Geological and geophysical information was collected with shallow seismic systems (100/1000 Hz, 10 kHz airgun; 0.3–22 kHz boomer in lagoon), echosounder (FURUNO II, 28 kHz; DESO 14, 210 kHz; SIMRAD 200 kHz in lagoon), subbottom profiler (Ore-Tech 3010-S, 3.5 kHz; X-STAR, 2–10 kHz), sidescan sonar systems (KATRAN-3M, 105+15 kHz; WESMAR SHD700SS, 307 kHz; EdgeTech DF1000, 100 and 325 kHZ in lagoon), CTD, long gravity corer (4/6 m), Niemisto corer (1.1 m), small gravity corer (lagoon waters, 0.8 m) including subsampling, grab Ocean-25, Van Veen grab, boxcorer (0.2 m^2). Additional analyses are conducted by laboratories under contract.

Geological Survey of Lithuania (LGT), and Nature Research Centre, Institute of Geology and Geography (NRC–IGG) are the custodians of these data.

3.2.11 The Netherlands

The national organization responsible for seabed mapping is:

- TNO – Geological Survey of the Netherlands (GSN), PO Box 80015, NL-3508 TA Utrecht, The Netherlands. Contact person: Dr Sytze van Heteren; tel. +31 88 866 4565; e-mail: sytze.vanheteren@tno.nl.
- Deltares Subsurface and Groundwater systems, PO Box 85467, NL-3508 AL Utrecht, The Netherlands. Contact person: Laura Vonhögen-Peeters; tel: +31 88 335 7168; e-mail: laura.vonhogen@deltares.nl.

Most of the Dutch sector of the North Sea was mapped at a scale of 1:250 000 under a reconnaissance mapping programme in collaboration with the British and Belgian Geological Surveys. Each printed sheet consists of three maps: seabed sediments and Holocene geology, Quaternary geology, and pre-Quaternary geology. The Terschelling Bank sheet is only available in digital form.

The coastal zone of the southern part of the Dutch sector was mapped at a scale of 1:100 000. Two sheets were printed (Rabsbank and Buitenbanken) showing the lithology of the upper 2 m, the thickness of the Holocene deposits, depth to the top of the Pleistocene, and the lithostratigraphy at the top of the Pleistocene.

The geological mapping programme of the Dutch part of the North Sea, with its associated data-acquisition surveys, was discontinued during the late 1990s. It has been replaced by a modelling programme that focuses on the flexible querying of a digital database (in Oracle) that includes core, seismic, and grain-size data. The main output of this programme has been a resource information system that enables the visualization of sand resources for different combinations of sand quality, extractability (presence or absence of unfavourable cover units), and extraction depth. This resource-information system is part of a conceptual decision-support system for the interactive visualization of potential sand-extraction scenarios and planned sand-extraction projects, helping to prioritize where, when, and at which spatial scale additional field data need to be collected.

The following full-coverage ArcGIS shapes, from the traditional 1:250 000 mapping programme, are available from GSN:

- seabed sediments,
- Folk 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.

In addition, various query results from the GSN/Deltares modelling efforts are available upon request (Figure 3.34).

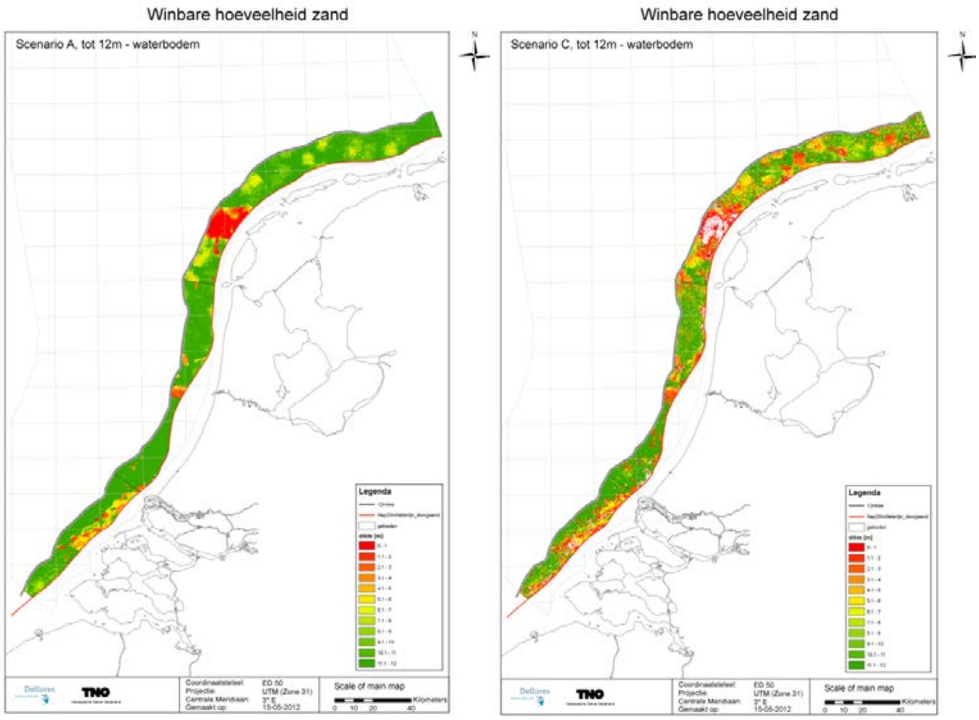


Figure 3.34. Total extractable sand with few requirements on sand quality and extractability (left) vs. total extractable sand with more stringent requirements on sand quality extractability. Red and green areas denote limited and abundant availability, respectively. The two images show the advantage of being able to visualize different scenarios. The image on the right indicates that potential sand resources may not be extractable. In the past, this multiple viewing was not possible.

The bathymetric mapping and monitoring programme is conducted by Rijkswaterstaat and the Hydrographic Service of the Royal Netherlands Navy. These two organizations produce detailed digital bathymetric maps of parts of the Dutch sector, primarily using multibeam echo sounding with sidescan sonar. Multibeam echosounding has replaced single-beam echosounding, but many areas have not yet been surveyed with this state-of-the-art equipment. Depending on the level of priority, areas are surveyed at different time-intervals. Shipping lanes may be monitored annually, whereas deep waters far offshore may not have been surveyed in 30 years. At extraction sites, soundings are also collected by commercial companies. Bathymetric data can be requested from the source holders (as individual surveys) or from Deltares. At Deltares, a large number of surveys have been merged to form a full-coverage grid for the Dutch part of the North Sea at cell sizes of 200 × 200 (Figure 3.35) or 25 × 25 m. The maps are also available as images. No maps at scales of 1:250 000 or 1:100 000 have been published on paper since 2005.

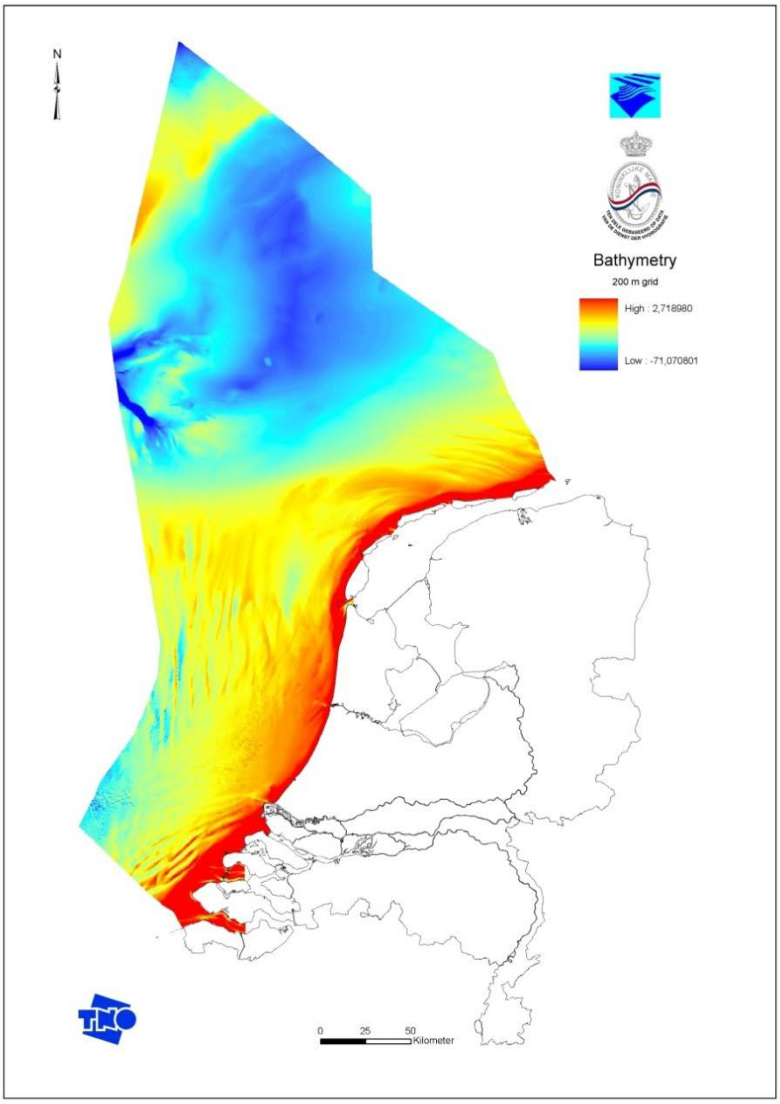


Figure 3.35. Bathymetric grid produced by merging individual sounding surveys for the Dutch part of the North Sea.

Acoustic data acquisition has been conducted with single-channel seismics (including EG&G X-star model SB 512), multichannel seismics (12- or 18-channel receivers, including 10 in^3 sleevegun sound source), sidescan sonar (Hydrographic Office), single-beam echosounders, and multibeam echosounders. Seabed sampling has been done with Hamon and Van Veen grabs, hydraulic vibrocorers and piston corers, and various counterflush/airlift systems (12–25 m penetration).

Bathymetric data and grids are owned by the Hydrographic Service and Rijkswaterstaat, and are available through Deltares. Detailed bathymetry can be provided at 200 × 200 m and 25 × 25 m cell sizes.

Printed copies or digital files of geological aspects, with a legend in English, can be ordered from the TNO (sytze.vanheteren@tno.nl) or Deltares (laura.vonhogen@deltares.nl) organizations. For some products, the approval of the source holder may be required. As part of various European standardization initiatives, some data are available in standardized formats through the Geo-Seas portal (www.geo-seas.org) and some data products through the EMODnet-Geology (www.emodnet-geology.eu) and OneGeology-Europe portals (http://onegeology-europe.brgm.fr/geoportal/viewer.jsp.)

Data of the Dutch subsurface, both shallow and deep data, are stored at the Geological Survey of the Netherlands in the national database DINO (www.dinoloket.nl). At present, the following marine data are digitally available:

Basic data:

- borehole information,
- shallow-seismic and sidescan data (the latter owned by the Hydrographic Service).

Mining data:

- exploration and survey data,
- production and storage data.

Data visualization:

- 3D-atlas of the deep subsurface,
- ArcGIS grids for various geological aspects.

TNO standards:

- lithostratigraphic nomenclator of the shallow subsurface,
- stratigraphic nomenclator of the deep subsurface,
- oil and gas maps of the Netherlands.

The Geological Survey of the Netherlands is preparing for a new law that will govern management and utilization of subsurface information. Under this law, a key register for the subsurface will be established: a single national database for subsurface data and information, which will have to be supported in consultation with all Dutch government bodies dealing with the subsurface. This transition requires the Survey to redesign a substantial part of its operation, from data acquisition and interpretation to delivery. It has also helped shape our view on geological surveying in the future. The key register, which became operational in 2013, contains vast quantities of subsurface data, as well as their interpretation into 3D models.

Therefore, the Geological Survey of the Netherlands uses this standard as the basis for its descriptions of drilling samples according to the Standard Description method for Boreholes (SBB). The oldest borehole description in DINO dates from 1834, and new descriptions are added every day. They are all labelled with a quality code.

In 1989, the Netherlands Standardization Institute (NNI) issued a national standard to ensure that the composition of the unconsolidated deposits is described in a consistent and unambiguous manner: NEN5104 Sediment Classification (Table 1). This standard improves the efficiency for comparing geological data. It defines the nomenclature of the lithological description of drilling samples for all unconsolidated deposits. The starting point for the classification is the division of a sample into fractions, one comprising organic matter and four others based on particle size.

Table 3.1. The national standard for sediment classification (NEN5104 Sediment Classification).

Particle size	Name of fraction
< 2 µm	Lutum (clay)
>2 µm – < 63 µm	Silt
>63 µm – < 2 000 µm	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, sand, loam, clay, and peat. A further subdivision is based on the presence and abundance of admixtures. More information about this classification system can be found at www.nen.nl/normshop; however, you must have a NEN subscription to download the standards.

The NEN5104 Sediment Classification system does not cover all sample characteristics. To supplement the key parameters addressed in NEN5104, a method was developed to define and describe additional characteristics as well: the Standaard Boor Beschrijvingsmethode (SBB; Standard Description method for Boreholes, see dinoloket.nl). The method provides standards for all the metadata necessary for describing a borehole and for the lithological characteristics of samples. Borehole descriptions that were produced on the basis of NEN5104 and SBB can be entered into DINO Boreholes. Descriptions can be entered digitally in the freeware program BORIS. After sending the descriptions to the Geological Survey of the Netherlands by e-mail, the information can be added to DINO following a mandatory quality check.

3.2.12 Norway

The national organization responsible for seabed mapping is:

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

Since 2005, the MAREANO programme (www.mareano.no) has mapped the seabed off northern Norway and published a series of seabed maps, including bathymetry, backscatter, geology, biology, habitats, and pollution. To date, about 90 000 km² have been mapped spanning broad environmental gradients, with water depths extending to 3000 m (Figure 3.36). Rich faunal diversity has been found within dramatic landscapes of deep canyons, steep continental slopes, and wide shelf plains.

MAREANO is an integrated, multidisciplinary, seabed mapping programme designed to fill knowledge gaps in the offshore area. The programme is run in collaboration between the Institute of Marine Research, the Geological Survey of Norway, and the Norwegian Hydrographic Service. In 2012, MAREANO continued its work in the Norwegian Sea and in new areas in the central Barents Sea. The ultimate goal is to map the seabed in all Norwegian offshore areas.

The results from MAREANO so far show that Norway has a rich and diverse offshore seabed. Both the geomorphology and sediment distribution patterns reflect the complex geological history and modern-day hydrodynamic processes. The structure of the seabed and processes operating there are intrinsically linked to biological life, and this is reflected in the distribution of habitats and biodiversity. The Skagerrak Project, conducted prior to the MAREANO programme, produced maps covering the Norwegian part of the Skagerrak and the northeastern North Sea, and a series of maps that include bedrock geology, Quaternary geology, thickness maps, Holocene sedimentation, etc. were also made. An overview of the Norwegian shelf with all published maps can be found on www.mareano.no.

NGU has run several mapping projects in the coastal zone and in fjords over the past few years. The largest of these, the Astafjord Project, mapped about 4000 km^2 along the coast of Troms County in northern Norway and produced a series of marine base maps. These can be found on https://www.ngu.no/en/topic/applications and www.mareano.no. Other mapped areas include the Oslofjord and the Trondheimsfjord.

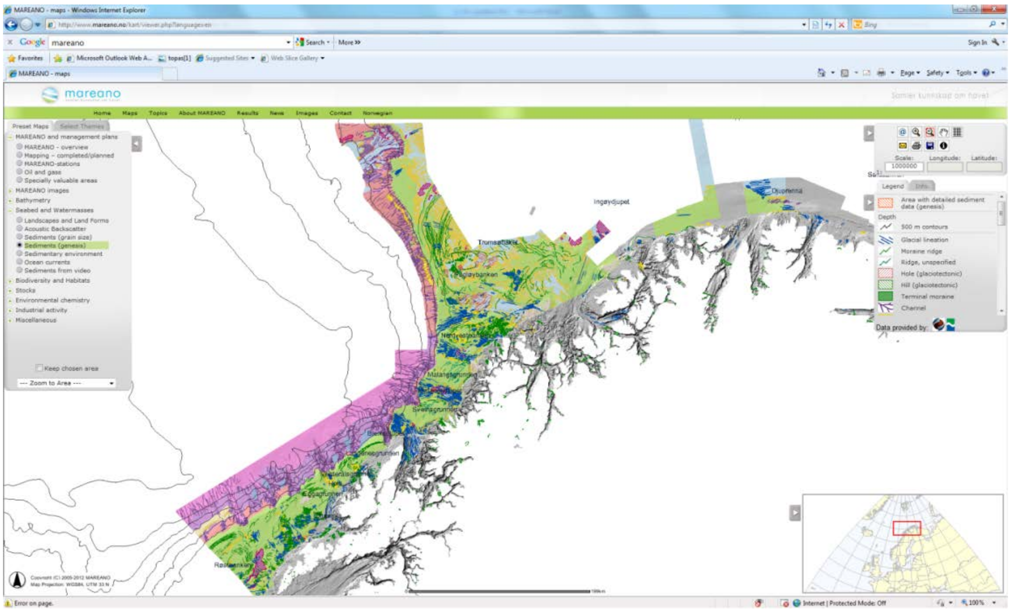


Figure 3.36. Screen dump from www.mareano.no showing the area mapped by MAREANO during 2005–2011. The screen dump shows the sediment genesis map.

Generally, submarine gravels have not been exploited along the Norwegian coast or in the fjords. Some carbonate sand and gravels are exploited mainly for use as agricultural fertilizers. NGU has mapped these resources in several counties along the coast.

NGU has a small survey vessel (RV "Seisma"), 18 m long. Equipment for depth measurements are interferometric sonar (Geoswath 250 kHz or 125 KHz, full coverage 0–200 m water depth), and WASSP multibeam echosounder (coverage 0–600 m). Seismic equipment includes Geopulse "boomer", Topas (parametric sonar), sleeveguns (15–40 in^3), and sparker. The vessel is equipped with various sampling devices such as gravity corer, multicorer, and grab samplers in addition to a camera for video inspection down to about 200 m water depth.

Geological Survey of Norway (NGU) is the custodian of these data.

3.2.13 Poland

The national organization responsible for seabed mapping is:

- Polish Geological Institute, National Research Institute, Branch of Marine Geology, Koscierska 5 st., 80-328 Gdansk, Poland. Contact person: Dr Regina Kramarska; tel: +48 58 5543134; fax: +48 58 5542910 ext 233; e-mail: regina.kramarska@pgi.gov.pl.

The Polish Republic's maritime areas border on the Baltic Sea together with Germany, Denmark, Sweden, and Russia. In addition to the 12-nautical mile territorial sea and EEZ, there are internal waters including a part of the Gulf of Gdańsk with Puck Bay, Puck Lagoon, and Vistula Lagoon as well as Szczecin Lagoon. Excluding the Szczecin Lagoon, the Polish Republic's maritime area covers 30 533 km^2. The shallow geology over the entire area has been mapped in detail at a scale of 1:200 000. Coverage is complete also for the pre-Quatenary geology at 1:500 000 (Figure 3.37). Seabed mapping has also been done for the Gulf of Gdansk area at 1:50 000 in the west and 1:100 000 in the east. Seabed mapping of Pomerania Bay at a scale of 1:100 000 was completed in 2013.

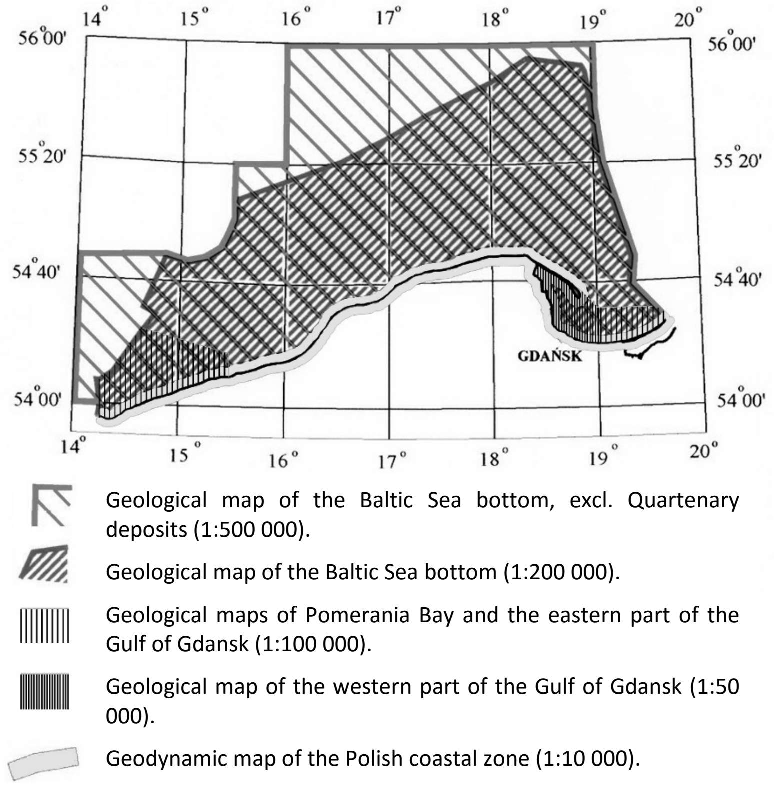


Figure 3.37. Map showing coverage of mapped areas within the Polish maritime areas (territorial waters and EEZ) at scales of 1:500 000, 1:200 000, 1:100 000, 1:50 000, and 1:10 000, respectively.

Data are stored in a database called NEPTUN (Oracle). Shallow seismic records are in digital format (CODA); other records are available as scanned raster files in the database GEOECHO (Oracle). Only echograms are archived in hard copies. Maps are available in GIS Arc Info format. Printed maps, with legends in Polish and English and description only in Polish, as well as digital maps, can be ordered from the Polish Geological Institute – National Research Institute, Branch of Marine Geology.

A 1:500 000 map has been published 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 up to 800 m and an explanatory text in Polish and English are provided.

This product provides a picture of the direct substratum of Quaternary in the southern Baltic region. It is also intended to define the structural relationships between the sub-Cainozoic layers and the deep geological structure, which has been well investigated for the needs of oil exploitation and to determine the structural conditions of development of the region during the Quaternary period.

The geological map was developed on the basis of an area of investigations that includes the Polish EEZ of the Baltic (up to 12 nautical miles from Bornholm), a part of the Danish sector (east of Christiansø Island), the adjoining German sector up to the

14° meridian, and a part of the Swedish sector up to latitude 55°. Geophysical investigations were made using a high-resolution seismic reflection system owned by the Netherlands Institute of Applied Geosciences. This instrument deployed a Texas Instruments 10 in^3 sleevegun (pressure 125 bars, frequency 30–640 Hz, excitation interval 12.5 m), and a Prakla Seismos 12-channel streamer (12.5 m between hydrophones). 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 cruises, ca. 4500 km of seismic profiles were taken. Profiles were arranged in the southeast–northwest and southwest–northeast directions in the western part of the investigated area, and in meridional and latitudinal directions in the central and eastern parts. Seismic data were processed and interpreted at the Polish Geological Institute using Landmark Graphics Corporation software. During the interpretation process, correlations were made with the results of deep-reflection seismics, seismoacoustics, and data from boreholes. The geological map of the Baltic seafloor is presented in 12 sheets containing the map of bottom sediments at 1:200 000, geological cross sections, geological profiles, and maps at 1:500 000 of geomorphology, lithodynamics, surficial sediments to a thickness of 1 m, and mineral resources. Legends are in Polish and English. There is also an explanatory booklet for each sheet in Polish.

Between 1976 and 1990, 30 000 km of echosounding profiles, some 5000 km of shallow seismic lines, 6051 samples of surface bottom deposits, and 827 cores were taken. In addition, 23 boreholes up to 30 m deep were completed. Laboratory work included 8850 analyses of grain size distributions, ca. 3570 analyses of heavy mineral content, and ca. 2150 analyses of heavy mineral composition. Carbon-14, thallium, pollen, and diatomological analyses were also carried out.

The geological map of the eastern part of the Gulf of Gdansk was published at a scale of 1:100 000, based on the investigations below. These were done between 2006 and 2008, covering an area of 564 km^2:

- 540 km echosounding profiling, 540 km sidescan sonar profiling, 230 km seismoacoustic profiling (boomer), 310 km seismoacoustic profiling (subbottom profiler),
- 29 sampling stations by boxcorer 5 × 5 km,
- 36 sampling stations by vibro corer (up to 3 m),
- 18 sampling stations by piston corer Kullenberg type,
- 50 analyses of grain size (sieves for sands and laser particle sizer for mud),
- 30 analyses of chemical elements (0–2 cm): Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mg, Mn, Ni, Pb, Sr, Ti, V, Zn, P, S and TOC PAHs analyses (12 samples, 0–2 cm) (Benzo [a] pyrene, Benzo [a] anthracene, Benzo [b] fluoranthene, Benzo [k] fluoranthene, Benzo [ghi] Terelene, Dibenzo [ah] anthracene, indeno [1,2,3-c,d] pyrene),
- 4 radiocarbon datings.

The following maps and cross-sections are available only in GIS format:

- Bathymetry, slope inclination, seabed sediments, seven geological cross sections, chemical elements and TOC (22 maps), PAHs – (Benzo [a] pyrene, Benzo [a] anthracene, Benzo [b] fluoranthene, Benzo [k] fluoranthene, Benzo [ghi] Terelene, Dibenzo [ah] anthracene, indeno [1,2,3-c,d] pyrene) – seven maps.

The geological map of the western part of the Gulf of Gdansk including Puck Lagoon was published at a scale of 1:50 000, based on the following investigations. These were done between 2006 and 2008 covering an area of 954 km^2. Data included:

- 1680 km echosounding profiling, 1680 km sidescan sonar profiling, 560 km seismoacoustic profiling (boomer), 1120 km seismoacoustic profiling (sub-bottom profiler),
- 70 sampling stations (grid 3 × 3 km) in Gulf of Gdansk by box corer and 55 sampling stations (grid 1.5 ×1.5 km) in Puck Lagoon by Kajak corer,
- 65 sampling stations by vibro corer up to 3 m,
- 31 sampling stations by piston corer Kullenberg type up to 3 m,
- 950 analyses of grain size (sieves for sands and laser particle sizer for mud),
- 131 analyses of chemical elements (surface 0–2 cm and selected core profiles): Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mg, Mn, Ni, Pb, Sr, Ti, V, Zn, P, S, and TOC PAHs analyses (58 samples, 0–2 cm) (Benzo [a] pyrene, Benzo [a] anthracene, Benzo [b] fluoranthene, Benzo [k] fluoranthene, Benzo [ghi] Terelene, Dibenzo [ah] anthracene, indeno [1,2,3-c,d] pyrene),
- 16 radiocarbon dating, 60 pollen analyses, 60 diatom analyses.

The following maps and cross sections are available in GIS format:

- Bathymetry, slope inclination, seabed sediments, 18 geological cross sections, chemical elements, and TOC (22 maps), PAHs – (Benzo [a] pyrene, Benzo [a] anthracene, Benzo [b] fluoranthene, Benzo [k] fluoranthene, Benzo [ghi] Terelene, Dibenzo [ah] anthracene, indeno [1,2,3-c,d] pyrene) – seven maps.

The geodynamic map of the Polish coastal zone consists of 64 sheets, produced at a scale of 1:10 000 and covering 520 km of the Polish coast. The geological structure and the geodynamics of the coastal zone are presented in a zone from 1 km inland to 1.5 km offshore. The maps also include elements of hydrogeological conditions, engineering geology, resource geology, and geozoologic assessment as well as geological cross sections.

The map was based on inland and offshore boring, seismoacoustic, sidescan sonar, and microseismic laboratory analyses of grain size, petrography, heavy mineral composition and quantity, $CaCO_3$ content, biostratigraphic analyses, and ^{14}C and TL age determinations. The map of the Polish coastal zone was compiled between 1995 and 2003 and was updated in 2005 with recent observations on erosion and accumulation. The map is available only in GIS format.

A geochemical atlas of the southern Baltic has also been produced. Distribution of elements in 0–1 cm layer and vertical distribution in selected cores are presented in printed form in 18 monoelement geochemical maps on the background of bathymetry and granulomeric type of sediments. During 1991–1993, cores were taken at 368 stations in regular 10 × 10 km grid. The top 0–6 cm mud layers of the cores were sectioned at 1 cm intervals. Sand deposits at 6–20 cm depth were sectioned at 2 cm intervals. All samples were placed in airtight plastic boxes, frozen, and stored at –20°C. For 498 samples, granulometric analysis was done, and 924 samples were chemically analyzed for total organic carbon, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mn, Ni, P, Pb, S, Sr, and V. The rate of sedimentation was determined using the ^{210}Pb method on six of the cores.

All analyses were done in the Central Chemical Laboratory of the Polish Geological Institute. Results were verified against international reference samples and through interlaboratory comparisons carried out at Warsaw University and the Institute of Oceanology of the Polish Academy of Sciences.

A geochemical atlas of the Vistula Lagoon was also produced at a scale of 1:150 000. The atlas contains a documentary map, bathymetric map, map of bottom sediments in Shepard'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, and Zn/Al ratios, as well as explanatory text in Polish and English. In 1994, bottom sediments were collected at 100 sampling stations in regular 2 × 2 km grid. The 20 cm length cores of muddy deposits were sectioned into 2 cm samples, the 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 performed for 100 surficial samples. In the fraction of samples < 0.2 mm, separated using a nylon sieve, 110 chemical tests determined the total concentrations of organic carbon, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mg, Mn, N, Ni, P, Pb, S, Sr, Ti, V, and Zn.

Geological prospecting and reconnaissance surveys, carried out by the Branch of Marine Geology of the Polish Geological Institute since 1980, identified various marine mineral aggregates in Polish waters of the Baltic Sea. In some cases, they are of potential economic significance. Three deposits have been documented of gravel, sandy gravel, and gravelly sand in the southern Baltic.

The “Słupsk Bank” deposit lies at depths between 16 and 20 m. The deposit is comprised of eight fields of sandy deposits in the middle and eastern parts of the bank, and an outwashed surface of till in the western part of the bank. The fields range in size between 0.8 and 10.5 km^2 and cover a total area of about 31.0 km^2. The deposit is between 0.3 and 2.0 m thick, with an average thickness of about 1.0 m. The average sand content (< 2.0 mm) is 64%. Geologically documented resources are 23.3 million m^3.

The “southern Middle Bank” deposit lies at depths between 16 and 30 m. The aggregate occurs in the form of irregular patches of varying thickness, resting on sandy substratum, and in the southwestern part of the Bank also on till. Nine fields have been identified, ranging in area from 0.53 to 16.9 km^2 and covering a total area of ca. 26.0 km^2. The deposit is between 0.3 and 5.0 m thick, with an average thickness of 0.92 m. The average sand content is 56.3%. Geologically documented resources are 31.0 million m^3.

The “Koszalin Bay” deposit is in shallow water zone at depths between 10.0 and 25.0 m. Seventeen fields occur in the form of isolated patches lying on a sandy substratum or, in the southwestern part, on till. The fields range in area between 0.3 and 3.6 km^2 for a total area of about 21.0 km^2. The deposit is between 0.3 and 1.8 m thick, with an average thickness of 0.9 m. The average sand content is 60.1%. Geologically documented resources are 19.2 million m^3.

Sand resources suitable for beach renourishment have been identified in seven areas of the open seabed. Four fields with documented resources are located in part of the Gulf of Gdansk north of the Hel Peninsula in the eastern part of the Polish EEZ. These are found at Jastarnia, Rozewie, Władysławowo, and the Hel Peninsula. Three fields have been located in Pomerania Bay in the western part of the Polish EEZ. These are at Dziwnów, Rewal, and Mrzeżyno.

- The Jastarnia field is located northeast of Jastarnia on the Hel Peninsula at a distance of 2.5–4 km from shore in waters 14–20 m deep. The area consists of two fields of medium sands, with an exploitation volume of 3 496 750 m^3.

- The Rozewie field is located northeast of Cape Rozewie and north of Władysławowo ca. 4–10 km from shore in waters 15–20 m deep. The area consists of 11 250 000 m^3 of medium and coarse sand.
- The Wladyslawowo field is located east of Władysławowo 3–5 km from shore in waters 14–18 m deep. It consists of two fields of medium sands, with a total volume of 103 000 m^3.
- The Hel Peninsula field is located northeast of Kuznica on the Hel Peninsula ca. 4–6 km from shore. It consists of 6 500 000 m^3 of medium sand.
- The Dziwnów field is located 7 km north of Dziwnów in waters 9.5–12.0 m deep. The deposit covers an area of 0.96 km^2 and contains ca. 1 700 000 m^3 of medium sands suitable for beach nourishment.
- The Rewal and Mrzezyno fields are located at similar water depths and distances from shore. They consist, respectively, of 12 000 000 m^3 and 13 600 000 m^3 of sand.

Apart from the deposits described above with proven resources, other potential regions of marine aggregate may also be found in the Polish EEZ. The most promising areas are on the northern and northwestern slopes of Słupsk Bank; there are also several smaller areas in the Pomeranian Bay and in the shallow water between Dziwnów and Kołobrzeg. Other potential deposits might be found in the area north of Łeba.

Accumulations of sand enriched with heavy minerals are well studied on the Odra Bank. In this area, the highest concentrations of heavy minerals occur in the form of small isolated patches or elongated belts. Layers of heavy minerals rarely exceed 40 cm in thickness and most are 15–20 cm thick. They tend to be composed of 0.2–1.0 cm thick laminae alternately rich and poor in heavy minerals. As a rule, the enriched sand contains >80% fine sand (0.25–0.063 mm) and is well to very-well sorted. As a result of documenting surveys on the northern and northeastern parts of the Odra Bank, nine deposits with a total area of 9.0 km^2 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 is enriched with about 0.5 million t of heavy minerals: garnet, zircon, rutile, ilmenite, magnetite, monazite, and others.

Two prospective areas with heavy minerals have also been found on the Słupsk Bank. On this bank, fine sand with high, heavy mineral content is 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% in one field and 3.1% in another. According to preliminary assessments, an average content of ilmenite is ca. 40 kg t^{-1} and 12 kg t^{-1} of sand and ca. 3.5 kg t^{-1}, 2.5 kg t^{-1}, 3.0 kg t^{-1}, and 9.5 kg t^{-1}, respectively, of zircon, rutile, monazite, and garnet.

Areas of medium and coarse-grained sand accumulations suitable for beach nourishment and other purposes are expected in shallow water, between 10 and 30 m depth north of Jarosławiec, Ustka, northwest of Łebsko Lakeon Czołpino Shoal, northeast of Łeba, northwest and northeast of Rozewie, and in the Gulf of Gdańsk. Preliminary evaluation of medium and coarse-sand areas in the Rozewie region, which could be used for nourishment of the Hel Peninsula beaches, suggests estimates of ca. 240 km^2. The sand layer is between 1 and 5 m thick. The largest potential areas of fine-sand accumulation are in Pomeranian Bay and on the Odra Bank. Other areas are also 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 also be used for industrial applications. The best quality are the well sorted fine sands of the Odra Bank, which can be used as raw material for the steel (moulding) and glass industries and as construction sands.

Large amounst of sands for land reclamation and construction of dams and embankments are known and dredged in the coastal zone of the Vistula Lagoon (Figure 3.37). The PGI has sampling equipment and software for seismic sampling data processing as well as software for data storage, visualization, and presentation. Equipment includes a piston corer Kullenberg (6 m), Niemisto corer (1 m), gemini corer (1 m), Oscorer (1 m), Van Veen type grabs, and a heavy box corer (0.6 m). Shallow seismic data are processed using MDPS Meridata. Analyses by PGI are carried out both inhouse and by contracted accredited laboratories. The custodian of these data is the Polish Geological Institute, National Research Institute, Branch of Marine Geology.

3.2.14 Portugal

The national organizations responsible for seabed mapping are:

- Laboratório Nacional de Energia e Geologia (www.lneg.pt), Estrada da Portela, Bairro do Zambujal, Apartado 7586 Alfragide, 2610-999 Amadora, Portugal. Contact person: Dr Pedro Terrinha; tel: +351 210 924 638; fax: +351 214 719 018; e-mail: pedro.terrinha@lneg.pt.
- Instituto Português do Mar e da Atmosfera (www.ipma.pt), Rua C do Aeroporto, 1749-077 Lisboa, Portugal. Contact person: Dr Pedro Terrinha; tel: +351 218 447 000; fax: +351 218 402 370; e-mail: pedro.terrinha@ipma.pt.
- Instituto Hidrográfico (http://www.hidrografico.pt/), Rua das Trinas 49, 1249-093 Lisboa, Portugal. Contact person: Dr Aurora Bizarro; tel: +351 210 943 127; e-mail: aurora.bizarro@hidrografico.pt.
- Estrutura de Missão para a Extensão da Plataforma Continental (http://www.emam.com.pt), Rua Costa Pinto, nº 165, 2770-047 Paço de Arcos, Portugal. Contact person: Pedro Madureira; tel: +351 213 004 165; fax: +351 213 905 225; e-mail: pedro.madureira@emam.com.

The Laboratório Nacional de Energia e Geologia (LNEG) is the Portuguese institution responsible for the onshore and offshore geological mapping; however, it does not have any permanent, systematic seabed mapping programme. In the past, a grid of sediment samples, sidescan sonar, and seismic reflection data, both inhouse and from the oil industry, permitted the publication of continental shelf maps at scales of 1:1 000 000 (Ed. 1978), 1:500 000 (Eds. 1992, 2010), and 1:200 000 (six sheets, one sheet published in 1984, two in 1992, and three pending).

Several projects were undertaken to evaluate the potential marine sand and gravel resources of the continental shelf in the 1980s, during which Dias *et al.* (1980, 1981), Dias (1987), and Dias and Nittrouer (1984) described and identified several unconsolidated deposit areas along the Portuguese shelf (Figure 3.38). This research characterized the composition and texture of the superficial deposits, but did not provide estimates of volume.

More recently (2001–2005), the potential marine sand and gravel resources on the insular shelves of Faial, Pico, S. Miguel, and Flores islands of the Azores archipelago have been evaluated in the GEMAS project (Quartau *et al.*, 2002, 2003, 2005, 2006, 2011; Bates, 2005; Quartau, 2007). This work characterized the composition and texture of the superficial deposits and provided volume estimates based on seismic reflection data (Figure 3.39).

The Instituto Português do Mar e da Atmosfera (IPMA) is a new public institute created in 2012, with the mandate to promote and coordinate scientific research, technological development, innovation, and services in the field of ocean and atmospheric sciences. IPMA integrated two former institutes, the Instituto de Metereologia and the Instituto de Investigação das Pescas e do Mar, and also the marine geology unit of LNEG. The jurisdictions of LNEG were transferred to IPMA, except for the responsibility for seabed mapping, which was to remain the purview of LNEG. The Instituto de Investigação das Pescas e do Mar, included now as a part of IPMA, participated in a European project called MESHatlantic, which ran from 2010 to 2013. Its goal was to harmonize the production and use of marine habitat maps covering the Atlantic area. So far three surveys have been made under this project. Two surveys were completed on the Portuguese continental shelf between Ovar and Nazaré in 2010. Grab samples and acoustic backscatter data were collected to develop a seabed classification system in QTC view (Figure 3.40). South of Sines in 2011, grab samples, sidescan sonar, and acoustic backscatter data were also collected for a seabed classification system (RoxAnn, Figure 3.41). Around the Formigas Islands and on neighbouring banks in the Azores archipelago, a multibeam bathymetry was completed in 2010 (Figure 3.42).

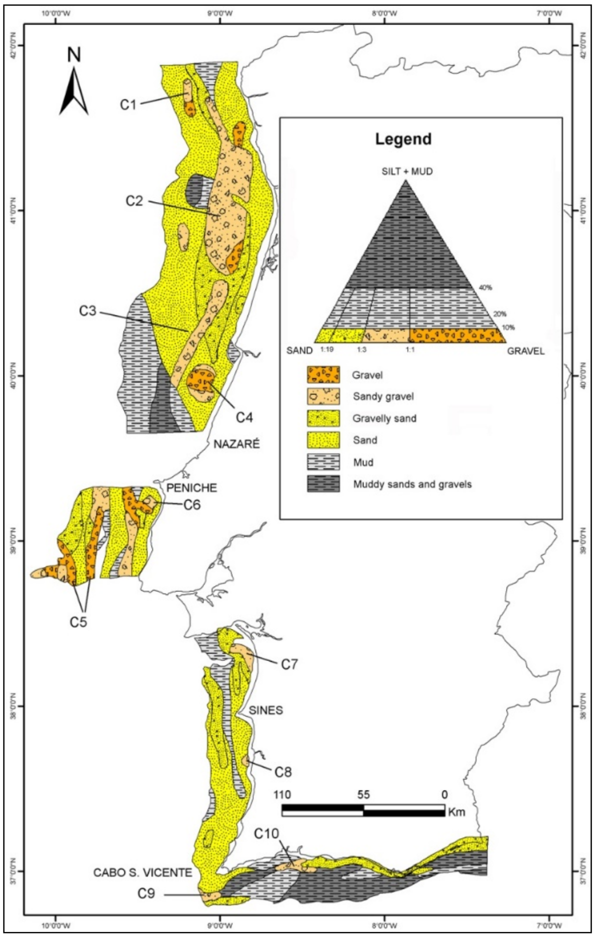


Figure 3.38. Map of the identified deposits according to their compositional and texture characterization. C1–C10 are identified marine aggregate deposits for potential exploration.

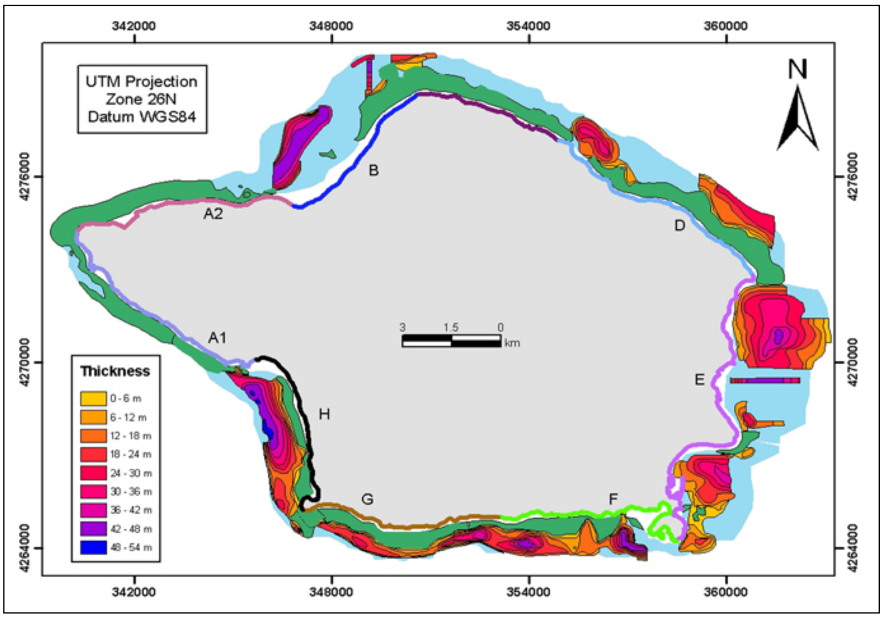


Figure. 3.39. Map of thickness of the sand bodies around the Faial Insular shelf. Green areas correspond to rocky outcrops and light blue to unmapped sediment thickness (adapted from Quartau, 2007).

Instituto Hidrográfico (IH), the Portuguese Hydrographic Institute, is the only state laboratory of the National Defense Ministry. It is responsible for the production of hydrographic and nautical charts and acquisition of environmental data (e.g. tidal timetables, marine weather forecast, nature and characterization of the seabed). Its main mission is to ensure human safety. IH cooperates in most of the military, research, and development activities taking place in the marine territory.

IH has published eight sedimentological charts at a scale of 1:150 000 covering the entire mainland continental shelf (Figure 3.43) between the coastline and the upper slope (–500 m). These charts are based on a systematic sampling of sediment collected in a regular 1 nautical mile grid. Sediment classification is based on sediment grain-size and calcium carbonate content.

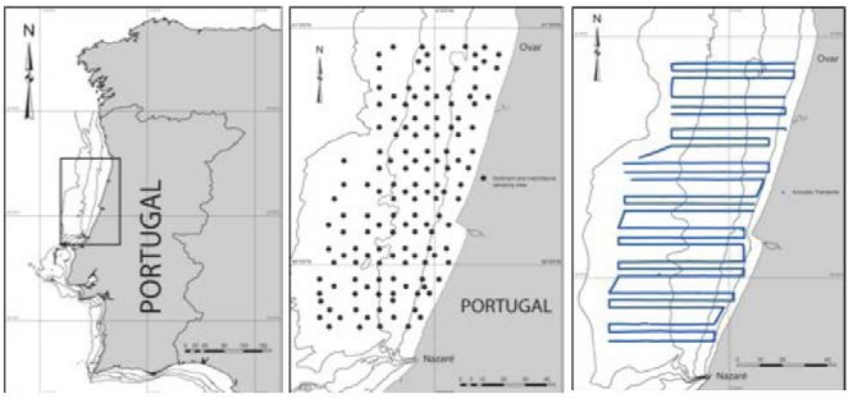


Figure 3.40. Map of grab samples and acoustic backscatter data transect of the Portuguese continental shelf area between Ovar and Nazaré. Source: http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974.

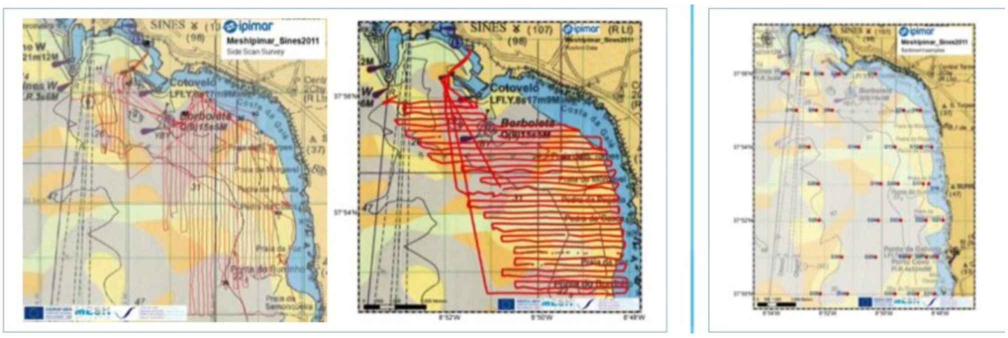


Figure 3.41. Map of sidescan sonar (left) and acoustic backscatter data (middle) transects and grab samples (right) of the Portuguese continental shelf south of Sines. Source: http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974.

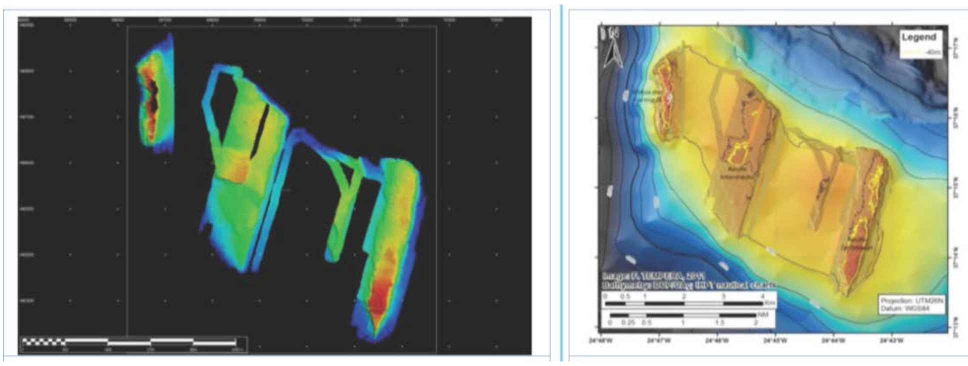


Figure 3.42. Map of the multibeam bathymetry around the Formigas islets and neighbouring banks in the Azores archipelago. Source: http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974.

In addition, IH was asked by insular governmental entities (the Secretaria de Estado do Equipamento Social, Governo Regional da Madeira) to evaluate the potential marine resources of the insular shelves of Madeira and Porto Santo islands (Instituto Hidrográfico, 2000, 2001, 2003, 2008).

Estrutura de Missão para a Extensão da Plataforma Continental (EMEPC) is the Task Group for the Extension of the Portuguese Continental Shelf beyond 200 nautical miles. In 2009, EMEPC submitted a report claiming the outer limits of its continental shelf beyond 200 nautical miles based on Article 76, paragraph 8 of the United Nations Convention on the Law of the Sea. In this regard, it has been doing seabed mapping, mainly outside the Portuguese EEZ (Figure 3.44). Data acquisition includes multibeam bathymetry, sediment samples, seismic reflection refraction, and gravimetric and magnetic surveys.

EMEPC is also responsible for the M@rBis project, which is a marine biodiversity georeferenced information system. The main goal of M@rBis is to provide the information needed to fulfill Portuguese commitments under the EU process of extending the Natura 2000 network to the marine environment. Four surveys were done for the M@rBis project, one at the Selvagens islands in the Madeira archipelago in 2010, a second survey at the Desertas and Porto Santo islands also in the Madeira archipelago, a third at the Formigas islet of the Azores archipelago in 2011, and a fourth in the Berlengas archipelago on the central continental shelf offshore of Peniche in 2012.

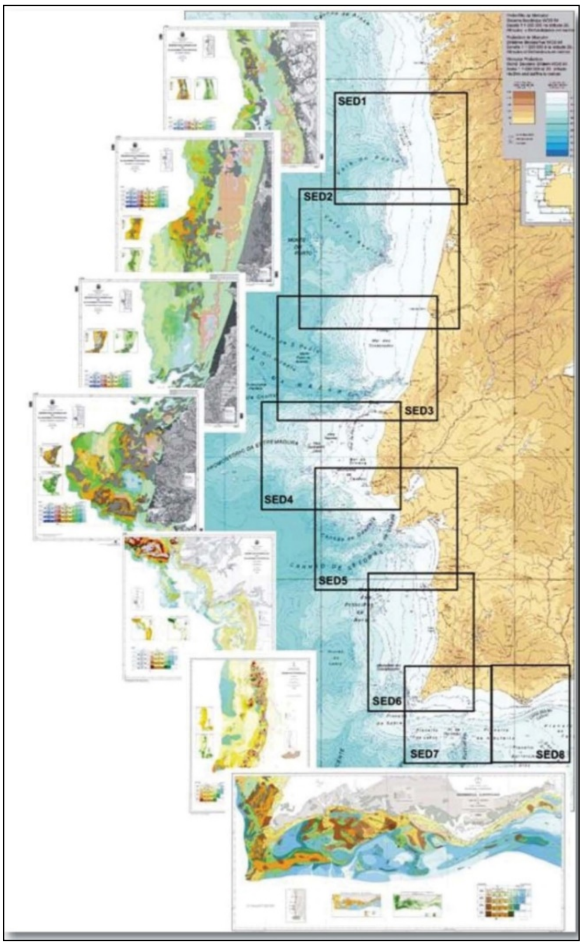


Figure 3.43. Superficial sediment mapping at the scale of 1:150 000 published by IH (from Instituto Hidrográfico, 2010).

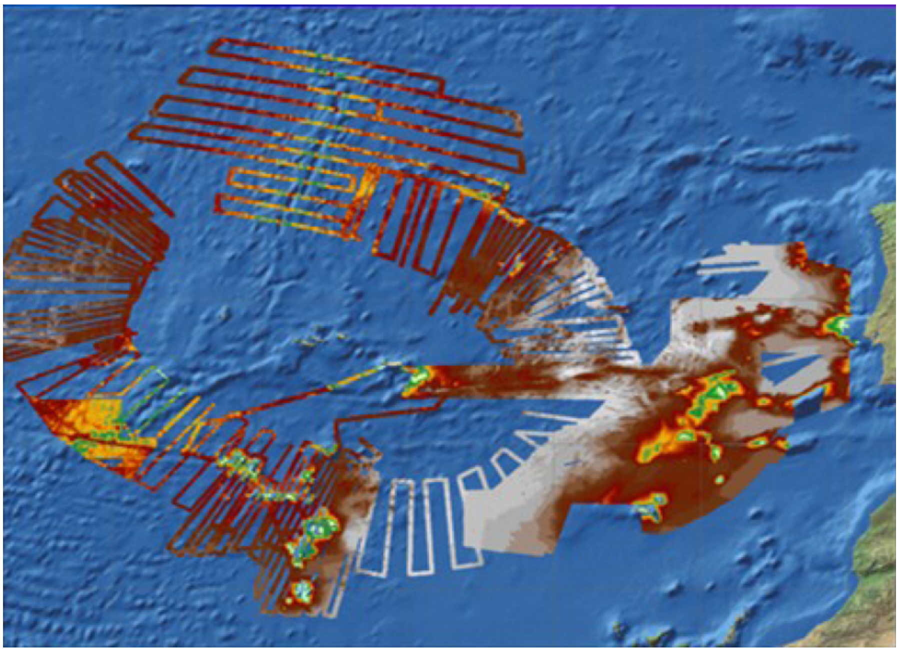


Figure 3.44. Multibeam mapping done within the scope of the extension of the Portuguese continental shelf beyond 200 nautical miles (EMEPC, 2009).

Additional data and seabed maps can be found online from the several European projects in which the Portuguese institutions have participated. LNEG has participated in EUMARSIN, EUROCORE, and EUROSEISMIC, which provides databases of cores, seabed samples, and seismic lines. Data can be accessed at http://www.eu-seased.net/. IH has also been participating in the Plan for Pan-European Infrastructure for Ocean and Marine Data Management (SeaDataNet) for online integrated data access to distributed heterogeneous systems and in the European Marine Observation and Data Network) Seabed Mapping (EMODnet), both providing online data at http://www.seadatanet.org/ and http://www.emodnet-hydrography.eu/. Finally, LNEG has been participating in the Geo-Seas project, which is expanding the existing SeaDataNet. Geo-Seas is an ocean data management infrastructure to handle marine geological and geophysical data, data products, and services. It will create a joint infrastructure covering both oceanographic and marine geoscientific data (http://www.geo-seas.eu/).

Several multipurpose vessels and equipment both from the Portuguese institutions and from foreign partners are used for seabed mapping. Bathymetrical, geological, and biological information was collected by the various institutes mentioned above. The custodians of these data are the Laboratório Nacional de Energia e Geologia (LNEG), Instituto Português do Mar e da Atmosfera (IPMA), Instituto Hidrográfico (IH), and Estrutura de Missão para a Extensão da Plataforma Continental (EMEPC).

3.2.15 Russian Federation

The national organization responsible for seabed mapping is:

- A.P. Karpinsky Russian Geological Research Institute (VSEGEI), Sredny pr., 74, 199106, Saint-Petersburg, Russia. Contact persons (marine geology mapping): Michail Spiridonov; e-mail: michail_spiridonov@vsegei.ru; – Daria Ryabchuk; e-mail: daria.ryabchuk@mail.ru.

No information has been provided to WGEXT.

3.2.16 Spain

The national organizations responsible for seabed mapping are:

- Instituto Geológico y Minero de España (IGME), C/ Rios Rosas, 23, Madrid-28003, Spain. Contact person: Teresa Medialdea Cela; tel: +34 913 495 861; fax: +34 914 426 216; e-mail: t.medialdea@igme.es.
- Directorate General for the Sustainability of the Coasts and the Sea, Division for the Protection of the Marine Environment, Ministry of Agriculture, Foof and Environment, Pza San Juan de la Cruz s/n, 28071, Madrid, Spain. Contact person: Jose L. Buceta, Technical Director, Resource mapping; tel: +34 915 976 652; fax: +34 915 976 902; e-mail: JBuceta@magrama.es.

The Spanish continental margins have been geologically mapped since 1980 (FOMAR Program, scale 1:200 000). The marine sheets are edited by 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:

- morpho-structural 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.

An explicative document (in Spanish) with supplemental maps, including sampling and coring sites and geophysical tracks are also provided. The various marine sheets can be ordered from the Instituto Geológico y Minero de Epaña (IGME).

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

Mapping of the Spanish EEZ was initiated in 1995. Surveys are carried out by several institutions: the Marine Hydrographic Institute (IHM), the Royal Institute and Observatory of the Navy (ROA), the Spanish Institute of Oceanography (IEO), and the Spanish Geological Survey (IGME). To date, these maps cover the Canary Islands, Galicia, and the Balearic Islands. Twenty-six maps have been published, including topobathymetric, 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 survey equipment included multibeam echosounders, a parametric echosounder, marine gravimeter, and proton magnetometer. The EEZ data can be ordered from the Instituto Hidrográfico de la Marina, Plaza de San Severiano nº 3, 11007-Cádiz, Spain.

Several seabed sedimentological studies were completed before 1980, but marine geological mapping was not the target. No maps were published.

The marine sand and gravel deposits within Spanish territorial waters are not intensively exploited. In fact, there is a great lack of information about existing locations of marine gravel and sand deposits. Only local uses of shallow sand/gravel deposits are known.

As a strategy for achieving conservation and sustainable multiple use of the coastal zones, increasing the tourism potential of such zones, the Spanish Ministry of Agriculture, Food and Environment, responsible for the Integrated Coastal Zone Management, uses marine sand deposits for beach nourishment. The search for marine aggregates in sand deposits in shallow water (< 40 m deep) requires special oceanographic surveys, which are not carried out by IGME. The Ministry itself has an annual budget to plan and execute those surveys using private consulting companies. The Ministry of Agriculture, Food and Environment does not publish any public information. Nevertheless, IGME can obtain the available information by request if necessary. However, the IGME does not have resource mapping as a priority. The marine sheets offer two sedimentological maps at a scale of 1:400 000 showing the general distribution of surface sediments along the continental shelf and part of the upper slope. The grid of sampling surveys covers the entire shelf area.

In the period between the late 1980s and 1994, the Directorate General of Coasts carried out a comprehensive geophysical survey covering water depths from 10 to 40 m along the Spanish coast. This research was done to locate and assess marine sand for beach nourishment that could be exploited by conventional dredging equipment that existed at the time. Areas were investigated along the Atlantic Spanish northern coast (Figure 3.45), and along the southern coast of Spain (Figure 3.46). The areas investigated in the Canary Islands are included in the ICES Area, but not in the OSPAR area (Figure 3.47). Only Huelva and Cadiz provinces are included in the OSPAR–ICES Area.

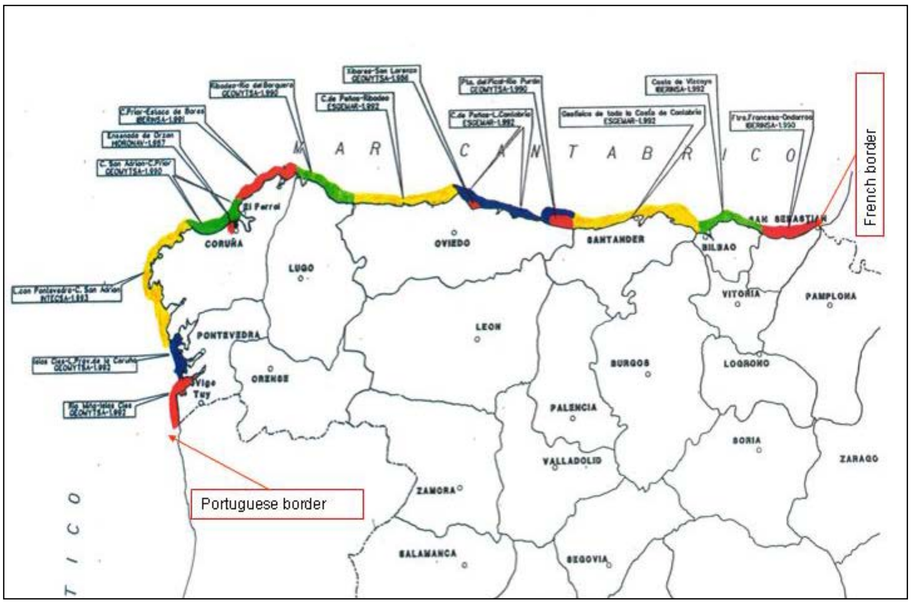


Figure 3.45. Map showing the different areas mapped with respect to sand and gravel resources on the Atlantic Spanish northern coast.

In the first phase, the work consisted of the charting of bathymetrical and seismic profiles as well as gathering and analysing surface sediment samples from the seabed. In this way, information has been collected about the thickness of the non-consolidated sediment layers and about the definition of its physical characteristics once on land.

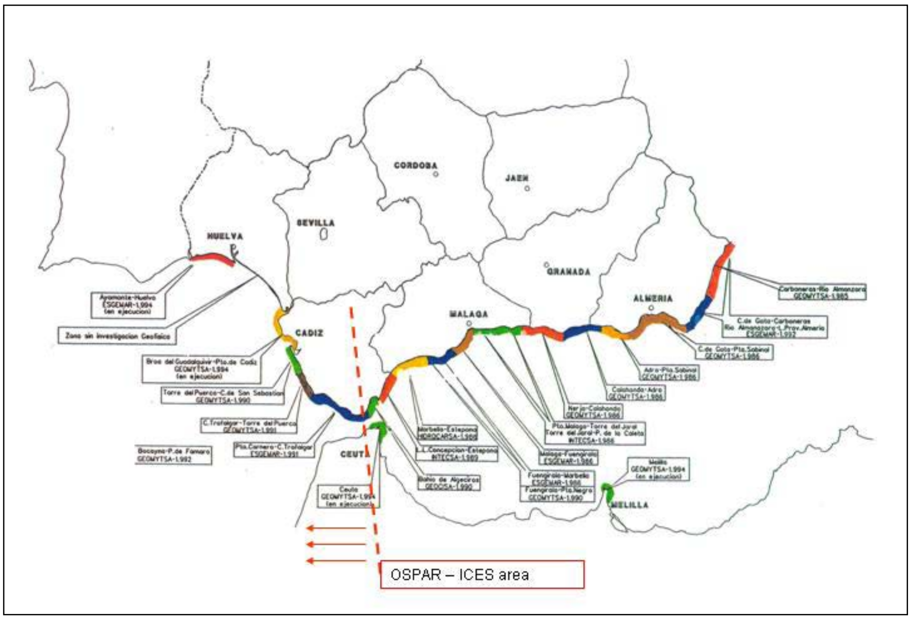


Figure 3.46. Map showing the different areas mapped with respect to sand and gravel resources on the southern coast of Spain (only Huelva and Cadiz provinces are included in the OSPAR–ICES Area).

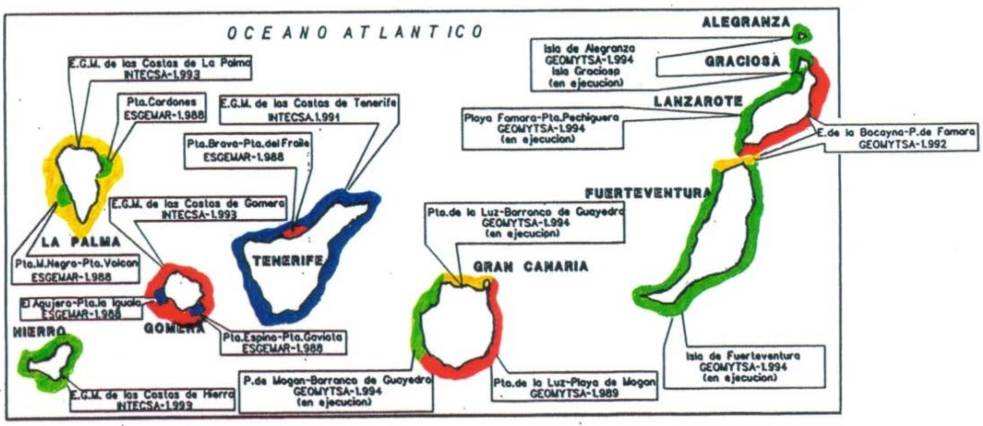


Figure 3.47. Map showing the different areas mapped with respect to sand and gravel resources in the Canary Islands (included in the ICES Area, but not in the OSPAR scope).

In a second phase, research was carried out only around potentially exploitable sand deposits. Deep samples were collected from the seabed with a vibrocorer. Undisturbed sediment cores up to 6–8 m long were extracted to define the extent of the resource. Granulometrical and mineralogical characteristics were analyzed as well as the presence of pollutants, such as heavy metals, organic compounds, microbiology, etc. In 2005, this old information, which had hitherto existed only on paper, was digitalized. Now, the Spanish Directorate General of Coasts (DGC) has included all of this information in a thematic geographical information system (GIS).

In Article 8.1 of the EU Marine Strategy Framework Directive, EU Member States are requested to make an initial assessment of their marine waters, including an analysis of the predominant pressures and impact on the environmental status of those waters. Spain has implemented the Directive through the Law 41/2010 for the protection of the marine environment. Spain is currently developing an inventory of pressures and impacts supported by a GIS which identifies sand and gravel resources as a potential pressure on the marine environment. This GIS will also include a mapping of physical features and habitat types of the seabed.

In 2000, the DGC launched a second comprehensive project known as "Coastal ecocartography." Because of the increasing pressures on the coastal areas, primarily because of the tourism industry, the Directorate General of Coasts requested the most complete knowledge of the characteristics of the coastal ecosystems and how they function. The scope of the study is the coastal public domain, including the terrestrial littoral area and the marine environment down to a depth of 50 m. Coastal ecocartography started in the Canary Islands and represents a long and continuous process of field work by a large interdisciplinary team. The study takes into consideration all of the aspects necessary for the complete categorization of the coastal area.

Some of the more notable field tasks are mentioned below.

<u>Description of the physical environment</u>:

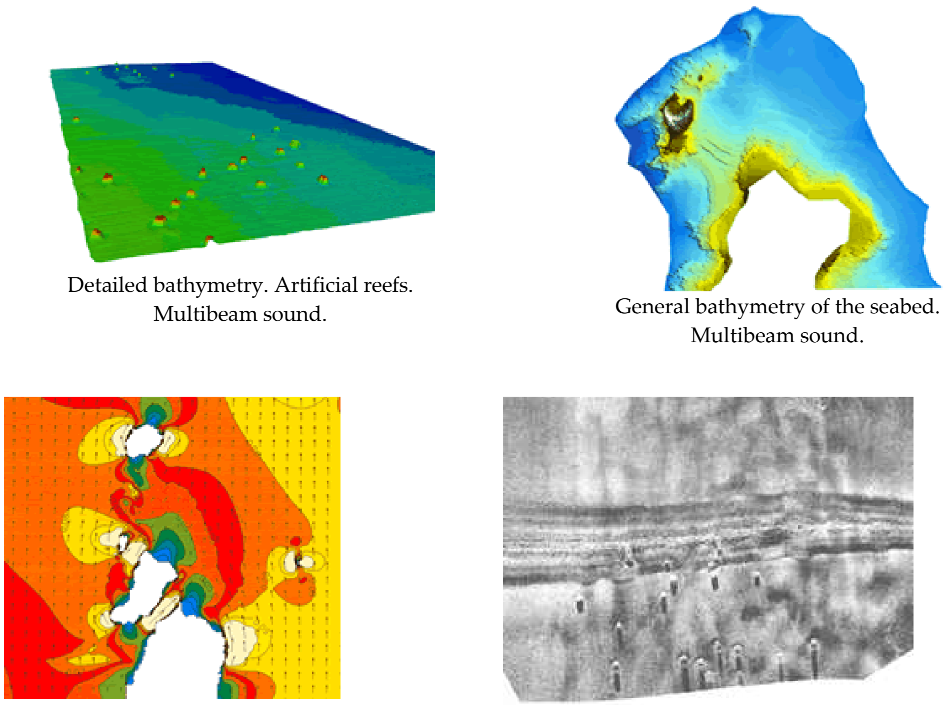
- bathymetry of the platform using multibeam sound,
- topography of beaches and coastal area,
- coastal dynamics and general circulation of currents,
- underwater geomorphology using sidescan sonar,
- colour aerial photography and digital orthophotography of the coastal area.

Description of the biotic environment:

- 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.

These data are compiled in a GIS that allows queries, analyses, and diagnoses combining all the themes considered in the physical and biological studies (e.g. Figure 3.48). To date, mapping has been completed for Gran Canaria, Lanzarote, La Palma, El Hierro, La Gomera, and Fuerteventura in the Canary Islands; the regional government is undertaking a similar initiative for Tenerife Island. In the Mediterranean, work has been completed in Málaga, Alicante, Valencia, Castellón, Menorca, and Formentera.

The project for the Study of the Spanish Continental Shelf (ESPACE) project started in 1999. The goal is to obtain detailed and quality information about bathymetry according to the International Hydrographic Organization parameters and to complete a comprehensive cartography of the seabed, including benthic bionomy, sediment quality, and morphology (rocks, granulometric distribution, seagrass or algae meadows, obstacles, etc.). This was done with high-resolution geophysical techniques: multibeam sounder (EM 302 and EM 3002) and parametric sounder (TOPAS PS018). The project is an initiative of the Spanish General Fisheries Secretariat, Ministry of Agriculture, Food and Environment, which currently has three vessels available. Two vessels are equipped for deep-sea mapping and one for shallow water.



Detailed bathymetry. Artificial reefs. Multibeam sound.

General bathymetry of the seabed. Multibeam sound.

Measurement of currents and tides. Modelling of currents.

Geomorphology of the seabed. Sidescan sonar.

Figure 3.48. Various types of thematic information retrieved from the ecocartography project.

A multidisciplinary cartography team carried out the project. An annual campaign included surveys of the bathymetry and physical and biological classification of the seabed from the coastline to the continental shelf border out to water depths of 100–200 m. The Spanish coast has been divided in 186 map sheets at a scale of 1:50 000. To date, mapping has been completed for most of the Mediterranean coast. Cartography in the ICES Area has started in the Canary Islands at Hierro Island. Two million hectares of continental shelf have been mapped (e.g. Figures 3.49 and 3.50).

This mapping 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, conservation of species, habitats and cultural heritage, etc.

Some Autonomous Communities have also developed seabed maps within their jurisdictions (e.g. País Vasco, Andalucía, and Canarias). The work being carried out in the País Vasco is similar to the Coastal Ecocartography Project. It is included in a project of the Autonomous Government developed by the AZTI Foundation, which is a comprehensive study of the seabed characteristics at depths of 0–100 m. The work started in 2005 and was intended to be completed by 2007. Multibeam, sidescan sonar, and high-definition seismic surveys have begun. In 2005, 40% of the seabed between 0 and 50 m depth had been surveyed with multibeam together with groundtruthing via sediment samples, video and photo images, and scuba diving inspections. Benthic populations and the presence of organic and inorganic pollutants are also being analysed. Ortophotography and lidar topographic data are being used to characterize the coastal interface and intertidal region.

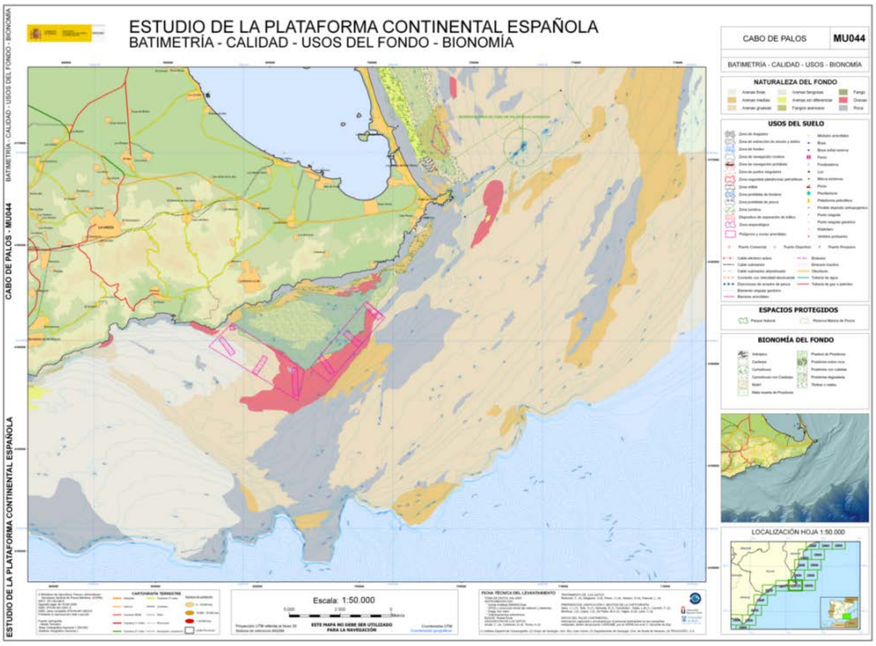


Figure 3.49. Example of thematic maps produced within the framework of the ESPACE (Study of the Spanish Continental Shelf) project.

Figure 3.50. Example of thematic maps produced within the framework of the ESPACE (Study of the Spanish Continental Shelf) project.

The survey equipment used in this research includes the following:

<u>Geophysical surveys (monochannel continuous-reflection seismic equipment)</u>:

- sparker,
- boomer,
- single- and multibeam echosounders,
- sidescan sonar systems,
- subbottom profiler 3.5 kHz,
- parametric echosounder,
- airgun and multichannel seismic reflection equipment are sometimes used.

<u>Sampling surveys (typical equipment)</u>:

- Van Veen grabs (or similar ones),
- gravity and piston corers,
- rock corers,
- sometimes vibrocorers and underwater cameras.

Analyses of IGME are carried out by accredited laboratories. The available information can be obtained via IGME by request. See also http://www.seadatanet.org/.

3.2.17 Sweden

The national organization responsible for seabed mapping is:

- Geological Survey of Sweden (SGU), PO Box 670, SE-751 28 Uppsala, Sweden. Contact person: Dr Johan Nyberg; e-mail: johan.nyberg@sgu.se or Prof. Ingemar Cato; e-mail: ingemar.cato@sgu.se; or SGU switchboard: tel: +46 18 179 000; fax: +46 18 179 210.

The Swedish territorial waters and EEZ cover 156 000 km². Of this area, 22% has been geologically mapped at a scale of 1:100 000 and 59% mapped at a reconnaissance scale of 1:500 000 (Figure 3.51). The reconnaissance mapping of the remaining part was finished in 2008. Printed maps, with description and English summary, as well as digital maps and data can be ordered from the Geological Survey of Sweden (SGU); kundservice@sgu.se.

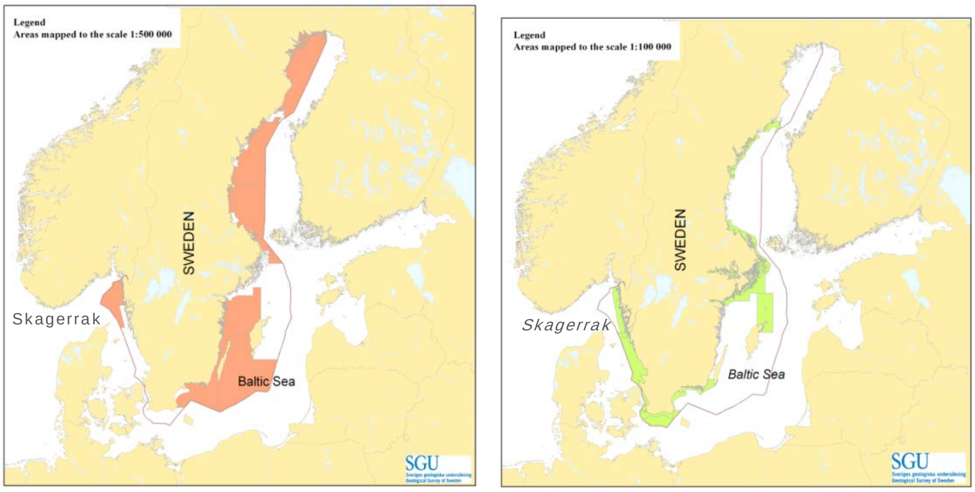


Figure 3.51. Map of the Skagerrak and Baltic Sea showing the coverage in 2012 of mapped areas within the Swedish territorial waters and EEZ at scales of 1:500 000 (reconnaissance mapping, left) and 1:100 000 (detailed mapping, right), respectively.

Geological reconnaissance maps/databases at a scale of 1:500 000 contain the same information in the 10 km wide corridors as the maps at scale 1:100 000 described below. The difference is the lack of total coverage with sidescan sonar, the less dense grid of runlines (about 10–15 km apart), and fewer bottom samples and coring which form the basis of the final map. However, the resolution of data collection along the tracks is the same in the corridors as for the maps at the scale of 1:100 000.

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 databases. The investigations for this type of reconnaissance maps/databases started in 2000 and were finished in 2008.

Published maps at a scale of 1:500 000 are presently only available in print on demand.

Seabed sediments and Quaternary stratigraphy maps/databases at a scale of 1:100 000 show the distribution of the predominant sediment in the top-most 50 cm of the seabed according to character and genesis. Each map sheet is accompanied by a supplemental map at the same scale showing the sediment stratigraphy down to the bedrock surface at selected sections. These two maps are accompanied by a descriptions including bottom photos, diagrams, and thematic maps at the scale of 1:250 000 which show, for example, the distribution of pre-Quaternary rocks, till, glaciofluvial deposits, sand volumes, thickness of postglacial and glacial clay, the distributions of about 60 inorganic elements and ca. 50 organic micropollutants of environmental interest, land upheaval, sampling/coring sites, and tracklines. The maps are projected in Gauss with both the Swedish grid net SWEREF99 TM and the longitude and latitude system in WGS84 (Figure 3.52).

Since 1996, this kind of mapping is based on almost full coverage with sidescan sonar (conventional or CHIRP type) and partly with multibeam sonar. 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 onwards is stored in various databases. Contact SGU for information and availability.

Since 2005, the following maps have been published at a scale of 1:100 000:

- SGU 2005: The Marine Geological Map 9I Landsortdjupet–Nynäshamn at scale 1:100 000. Sea bed sediments. Sveriges Geologiska Undersökning Ser. K 3:1.
- SGU 2005: The Marine Geological Map 9I Landsortdjupet–Nynäshamn at scale 1:100 000. Geological sections. Sveriges Geologiska Undersökning Ser. K 3:2.
- SGU 2006: Bottenförhållanden och geologisk utveckling i Göta älv at scale 1:50 000. Sveriges Geologiska Undersökning Ser. K 43.
- SGU 2009: The Marine Geological Map Lake Mälaren at scale 1:100 000. Lake bed sediments. Sveriges Geologiska Undersökning Ser. K 223:1.
- SGU 2009: The Marine Geological Map Lake Mälaren at scale 1:100 000. Geological sections. Sveriges Geologiska Undersökning Ser. K 223:1.
- SGU 2012: The Marine Geological Map Holmögadd–Umeå at scale 1:100 000. Sea bed sediments. Sveriges Geologiska Undersökning Ser. K 411:1.
- SGU 2012: The Marine Geological Map Holmögadd–Umeå at scale 1:100 000. Geological sections. Sveriges Geologiska Undersökning Ser. K 411:2.
- SGU 2012: The Marine Geological Map Eggegrund–Gävle at scale 1:100 000. Sea bed sediments. Sveriges Geologiska Undersökning Ser. K 412:1.
- SGU 2012: The Marine Geological Map Eggegrund–Gävle at scale 1:100 000. Geological sections. Sveriges Geologiska Undersökning Ser. K 412:2.
- SGU 2012: The Marine Geological Map Hävringe–Norrköping at scale 1:100 000. Sea bed sediments. Sveriges Geologiska Undersökning Ser. K 414:1.
- SGU 2012: The Marine Geological Map Hävringe–Norrköping at scale 1:100 000. Geological sections. Sveriges Geologiska Undersökning Ser. K 414:2.
- SGU 2012: The Marine Geological Map Hanöbukten at scale 1:100 000. Sea bed sediments. Sveriges Geologiska Undersökning Ser. K. 415:1.
- SGU 2012: The Marine Geological Map Hanöbukten at scale 1:100 000. Geological sections. Sveriges Geologiska Undersökning Ser K. 415:2.

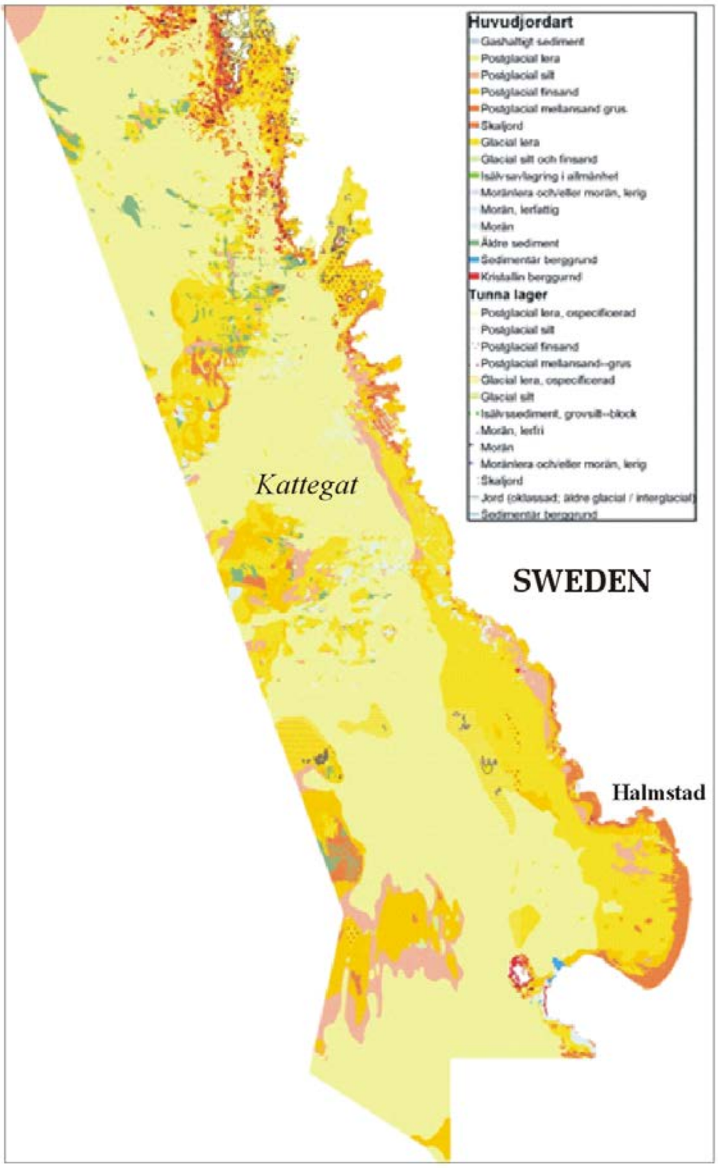


Figure 3.52. Example of a Swedish seabed map at the scale of 1:100 000, showing the distribution of various sediments within the Swedish EEZ of Kattegat.

Seabed sediment maps at the scale of 1:50 000 cover the Swedish part of the Öresund between Denmark and Sweden. The maps are based on a dense grid of sampling and coring and some shallow seismic and sidescan sonar surveys. The content of the map is very much the same as the information presented in the above-mentioned maps at a scale of 1:100 000. The maps of Öresund have also been compiled with a new legend into the scale of 1:100 000. Detailed information of the aggregate resources within the mapped area is available on request to SGU. No maps at a scale of 1:50 000 have been published since 2005.

An outline map of the bedrock geology in Swedish territorial waters and EEZ at the scale of 1:1 000 000 has been published (Ahlberg, 1986). In cooperation with the National Forest and Nature Agency of Denmark and the Geological Surveys of Denmark and Greenland (GEUS), a map at the scale of 1:500 000 showing the bottom sediments around Denmark and western Sweden has also been published (Kuijpers *et al.*, 1992). In the National Atlas of Sweden, outline sedimentary and bedrock maps at a scale of

1:2 500 000 over the Baltic Sea, Kattegat, and Skagerrak were published in 1992 (Cato *et al.*, 1992) and 1994 (Cato and Kjellin, 1994, updated 2009; Figure 3.53).

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

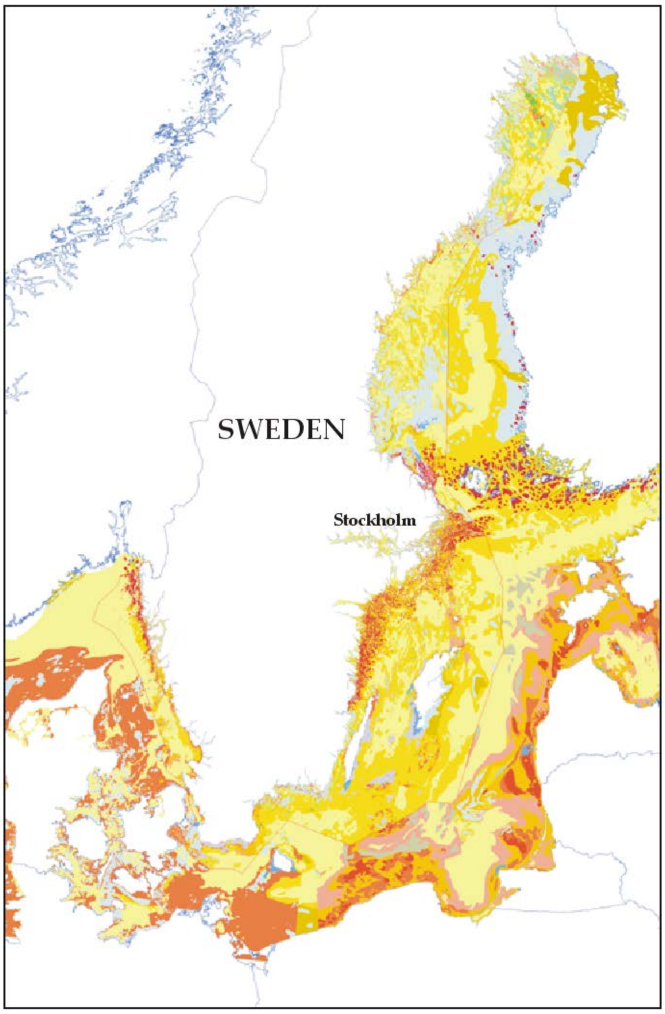


Figure 3.53. Seabed sediment map of the Baltic Sea, Kattegat, and Skagerrak at a scale of 1:2 500 000 (Cato and Kjellin, 1994, updated in 2009).

The information of the seabed areas mapped by SGU has been remapped according to the European Nature Information System (EUNIS) for habitat classification. The process has been described by Erlandsson and Lindeberg (2007) and Hallberg *et al.* (2010). In addition, mobility maps have been developed showing the coarsest grain size, according to the EUNIS grain-size scale, which erode (become mobile) within different areas due to the effect of wind-induced waves (Hallberg *et al.*, 2010).

Seabed and pre-Quaternary sediments were mapped in the EMODnet–Geology project on a scale of 1:1 million (http://www.emodnet-geology.eu/) and further contributed to the One-Geology data portal (http://www.onegeology-europe.org), from where data can be downloaded. The output was used as input to EUSeaMap, a European-wide, broad-scale habitat modelling initiative (http://jncc.defra.gov.uk).

Other published maps since 2005 include:

- Erlandsson, C., and Lindeberg, G. 2007. Harmonizing marine geological data with the EUNIS habitat classification. BALANCE Interim Report No. 13. 80 pp.
- Hallberg, O., Nyberg, J., Elhammer, A., and Erlandsson, C. 2010. Ytsubstratklassning av maringeologisk information. Sveriges Geologiska Undersökning, SGU-Rapport 2010-6.

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. Extraction has been done on a small scale, concentrated in areas of the Kattegat, Öresund, east of Fårö Island (northern Gotland), and in the Luleå archipelago.

The marine sand extraction amounted to ca. 70 000 m^3 or about 100 000 t $year^{-1}$, i.e. hardly 1% of the total extraction in Sweden during those years. Sand and gravel of poorer quality were used as fill, whereas deposits of high quality, e.g. those with high silica and low iron content, were used for the manufacturing of cement, glass, and glass fibre, and within the ceramics industry.

In 2004, 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 the historical record of sand and gravel extraction in marine areas of Sweden. An updated map on aggregate deposits of potential interest is shown in Figure 3.54 and examples of the detailed characteristics of these deposits are shown in Figure 3.55.

The SGU owns a twin-hull, sandwich-constructed survey vessel, SV "Ocean Surveyor", of 514 GRT, 38 m long, and 12 m wide. The vessel has six winches, 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, DGPS, Syledis positioning system including survey computers, sector scanning sonar, and doppler log.

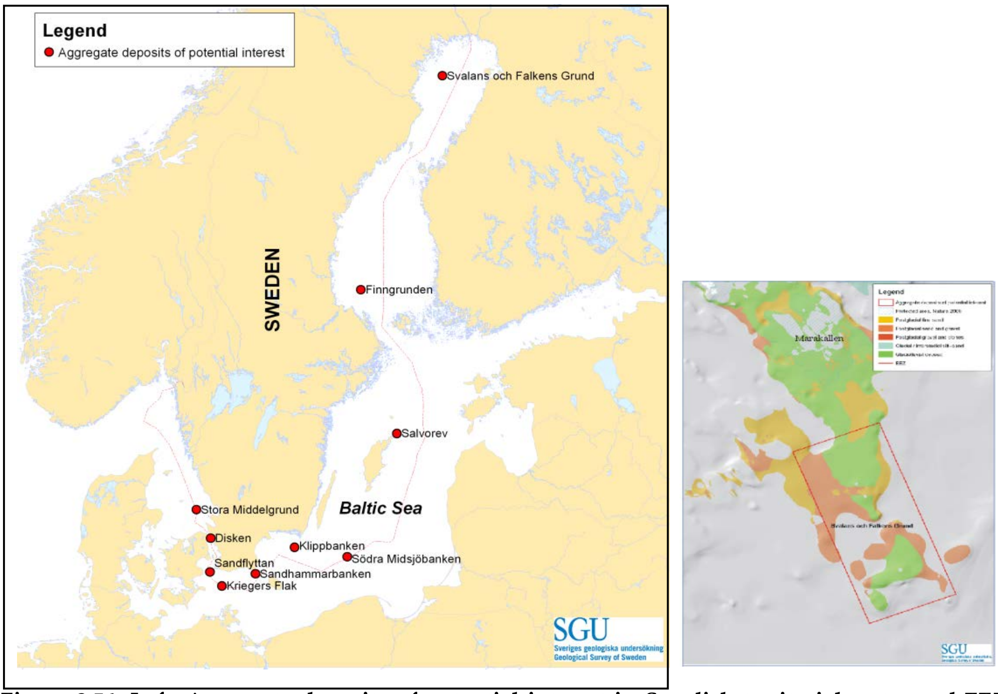


Figure 3.54. Left: Aggregate deposits of potential interest in Swedish territorial water and EEZ. Right: Svalans and Falkens deposit.

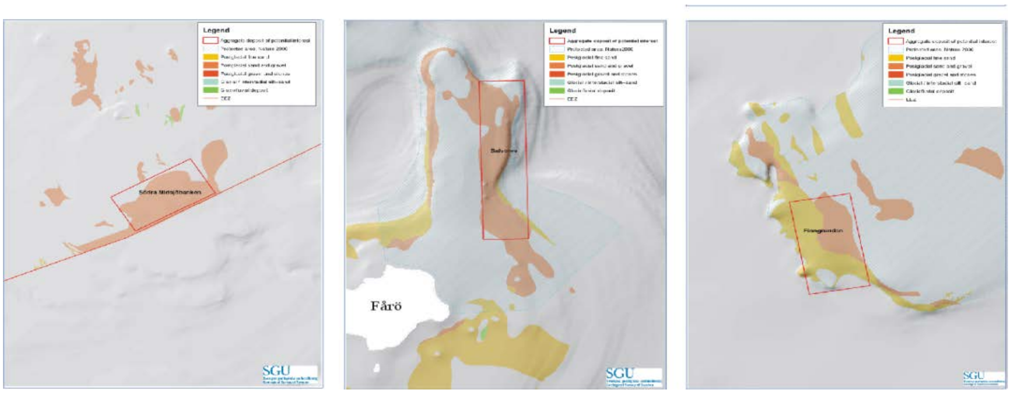


Figure 3.55. Details of potential Swedish aggregates deposits. From left: Salvorev, Klipperbank, and Kriegers Flak.

Geological information is collected with shallow seismic systems (boomer, sparker, sleeve gun), sidescan sonar systems (50, 100, 500, and 100/500 kHz chirp), pingers (3.5/7 kHz and 8 kHz chirp), echosounders, multibeam, CTD-sond, and various sampling and corer devices: vibrohammer 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. Analyses of SGU are carried out by contracted accredited laboratories, and SGU is the custodian of these data.

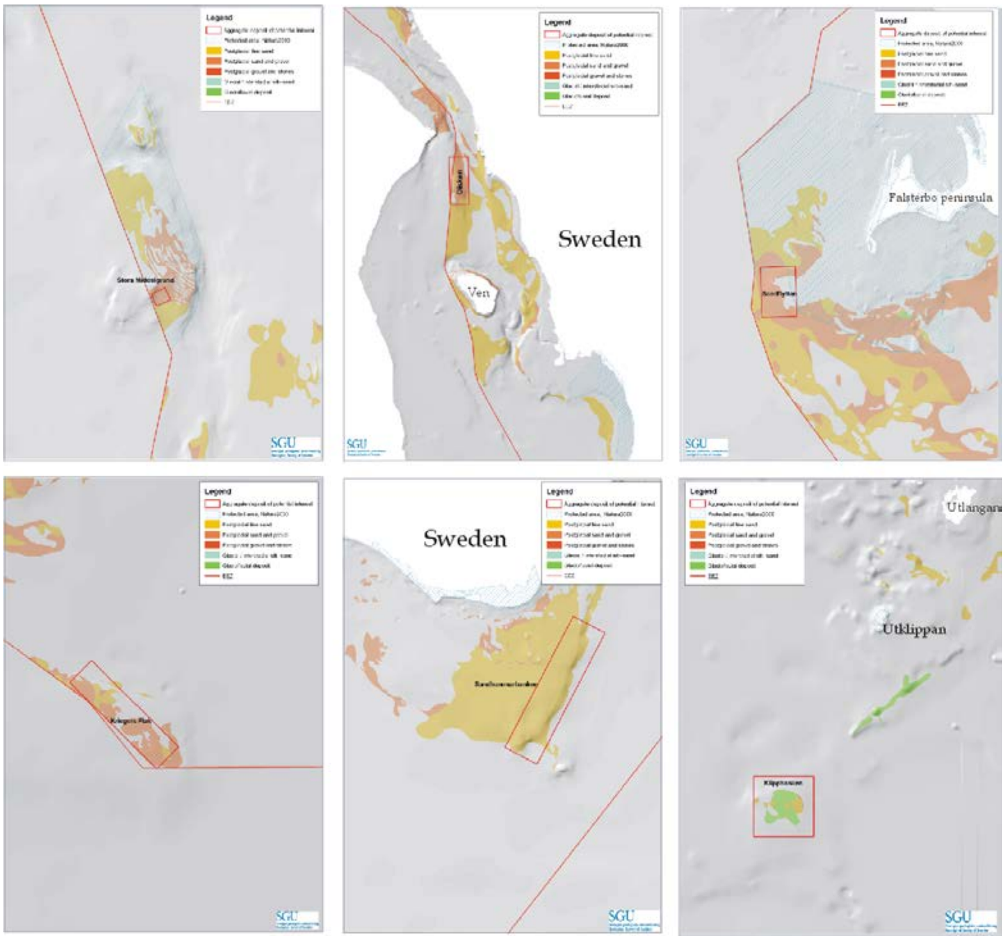


Figure 3.56. Details of potential Swedish aggregate deposits. From left above: St. Middelgrund, Disken, and Sandflyttan; from left below: Kriegers Flak, Sandhammar-banken, and Klippgrunden.

3.2.18 United Kingdom

The national organization responsible for seabed mapping is:

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

The British Geological Survey (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 maps of seabed sediments, Quaternary geology, and solid geology. An overview of the areas mapped is shown in Figure 3.57. 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 industry. 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/catalogue/home.html or by writing to the BGS Central Enquiries Desk, British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham, NG12 5GG; 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 completion of unmapped areas of the UK seabed and offshore data acquisition using subbottom seismic profiling, sidescan sonar, sampling/coring, and multibeam echosounder data.

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 ca. 9000 seabed samples; analytical data for up to 38 elements are included in the database and have been interpreted in an offshore geochemical atlas.

Marine aggregates contribute 21% of the sand and gravel needs of England and Wales, including 33% of southeastern England's sand and gravel requirements and 90% of the sand needed in southern Wales. The industry employs 2500 people on British-registered vessels and on land. Extraction of marine aggregates involves < 1% of the UK seabed (0.8%); most extraction takes place at water depths between 10 and 35 m. Since 1955, ca. 500 million t of aggregates have 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-mix concrete industries in the UK.

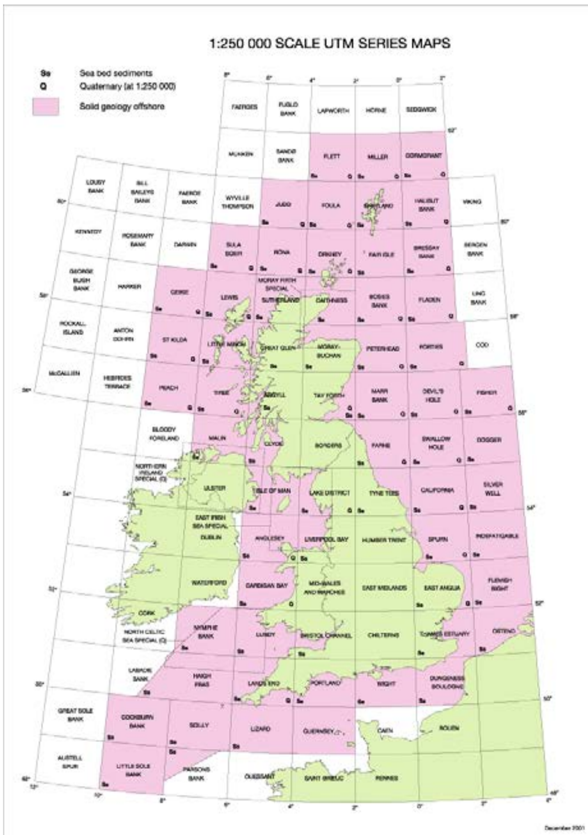


Figure 3.57. BGS published maps of offshore geology at a scale of 1:250 000.

Contacts:

- The Crown Estate, 16 Carlton House. Terrace, London SW1Y5AH, United Kingdom; tel: +44 207 210 4377; fax: +44 207 930 8187; website: http://www.thecrownestate.co.uk/home.htm.
- British Marine Aggregate Producers Association, Gillingham House 38-44 Gillingham Street, London, SW1V1HU; tel: +44 207 963 8000; fax: +44 207 963 8001; e-mail: bmpa@qpa.org; website: http://www.bmapa.org/.

Regional surveys of the UK seabed acquired geological data using a range of shallow seismic systems (deep-tow and surface-tow boomer, sparker, air gun, water gun) sidescan sonar systems, pingers, and echosounders. Samples and cores were collected mainly using Shipek grabs, gravity cores, vibrocores, and rockdrills, as well as bore-holes acquired by wireline drilling. Underwater videos were used from submersibles in a few locations.

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 which can be found at http://www.researchshipunit.com/.

3.2.19 United States

The national organizations responsible for seabed mapping are:

- United States Geological Survey (USGS) Coastal and Marine Geology Program, http://marine.usgs.gov/index.php. Woods Hole Coastal and Marine Science Centre, 384 Woods Hole Road, Woods Hole, MA 02543-1598, United States; tel: +1 508 548 8700; fax: +1 508 457 2310; e-mail: bbuczkowski@usgs.gov.
- Rolling Deck to Repository (R2R), http://www.rvdata.us/, c/o Lamont-Doherty Earth Observatory of Columbia University, 61 Route 9W, Palisades, NY 10964, United States; tel: +1 845 359 2900; fax: +1 845 365 8101; e-mail: info@rvdata.us.
- National Oceanic and Atmospheric Administration, National Geophysical Data Centre, http://www.ngdc.noaa.gov/, NOAA, Mail Code E/GC, 325 Broadway, Boulder, CO 80305-3328, United States; tel: +1 303 497 6826; fax: +1 303 497 6513; e-mail: ngdc.info@noaa.gov.

In the ICES Area of the northeastern coast of the United States, recent mapping products of the USGS Coastal and Marine Geology Program include bathymetry, sediment type, and sonar mosaics, which include some core and subbottom data (Figures 3.58 and 3.59, http://cmgds.marine.usgs.gov/). In addition, a complete collection of maps, fact sheets, Open-File reports, abstracts, and other publications relating to the research of the USGS Coastal and Marine Geology Program in the Atlantic Ocean are available online. The marine maps are available online: (http://coastalmap.marine.usgs.gov/regional/contusa/eastcoast/index.html).

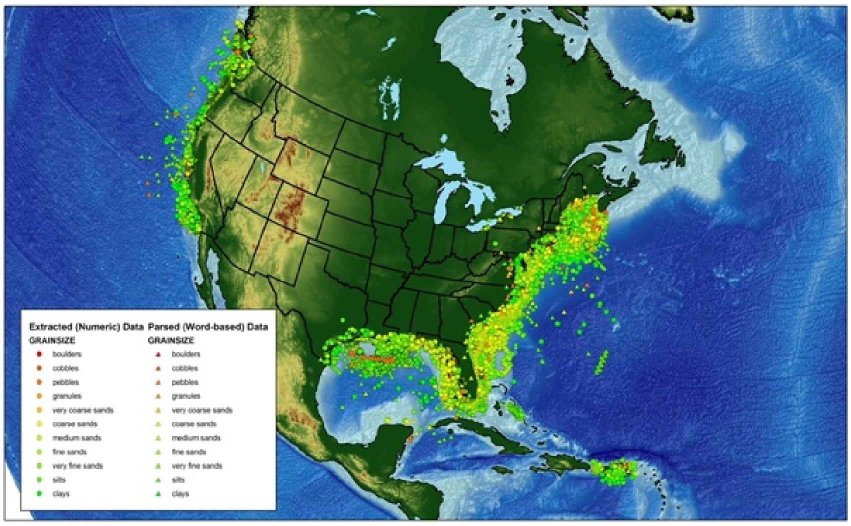


Figure 3.58. Distribution of data points with sediment classification data displayed as part of the US SEABED project.

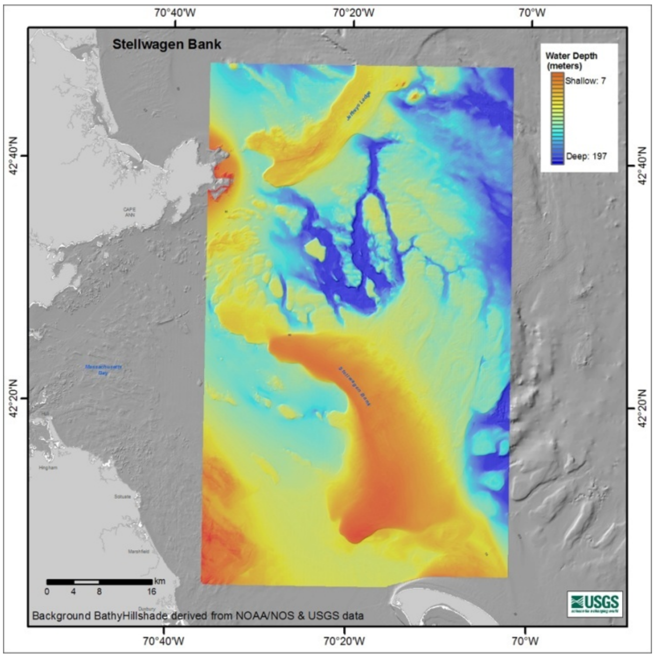


Figure 3.59. High-resolution bathymetric data available from NOAA and USGS for the Stellwagen Bank National Marine Sanctuary, Massachusetts.

Numerous vessels are utilized in the collection of marine geophysical and geological data, both dedicated ships and ships of opportunity. Equipment used to collect data and physical samples is owned and maintained by United States government scientific offices, academic institutions, and private research firms. This equipment includes various types of single-beam and interferometric sonar, Chirp and other seismic subbottom profilers, corers, grabs, dredges, and other sampling devices. Detailed information on the range of equipment used by the USGS Coastal and Marine Geology Program is available online through the Sea-floor Mapping Technology website: http://woodshole.er.usgs.gov/operations/sfmapping/default.htm.

Data are held by the National Geophysical Data Center (NGDC), located in Boulder, CO, which is part of the US Department of Commerce (USDOC), National Oceanic and Atmospheric Administration (NOAA). It is one of three NOAA National Data Centers.

NGDC provides long-term scientific data stewardship for geophysical data, ensuring quality, integrity, and accessibility. This includes geology, gravity, magnetic, bathymetric, and subbottom data describing the seabed and subsea surface. NGDC stewards NOAA geophysical data, the US academic data from the Rolling Deck to Repository (R2R) Program, data collected as part of the US Extended Continental Shelf project, US hydrographic data for nautical charting, and bathymetric data from other nations through the International Hydrographic Agency Data Center for Digital Bathymetry. Their goal is to provide long-term management of and access to ocean and coastal data and derived products in a manner that permits easy access and use by the greatest range of users. The NGDC fully supports NOAA's integrated ocean and coastal mapping motto to "map once, use many times".

The R2R program, funded by the National Science Foundation, is building a centralized infrastructure to ensure that the underway sensor data from academic research vessels are routinely and consistently documented, assessed for quality, preserved in long-term archives, and disseminated to the scientific community (Figure 3.60). Geophysical data, including single- and multibeam echosounder, gravity, and magnetics data, are submitted to the NOAA NGDC, accompanied by ISO 19115-2 standard metadata and quality-controlled trackline navigation for each expedition, including links to related material in the Index to Marine and Lacustrine Geological Samples. As of October 2012, R2R had catalogued over 2750 expeditions and 12 million data files/documents from 25 active-service vessels.

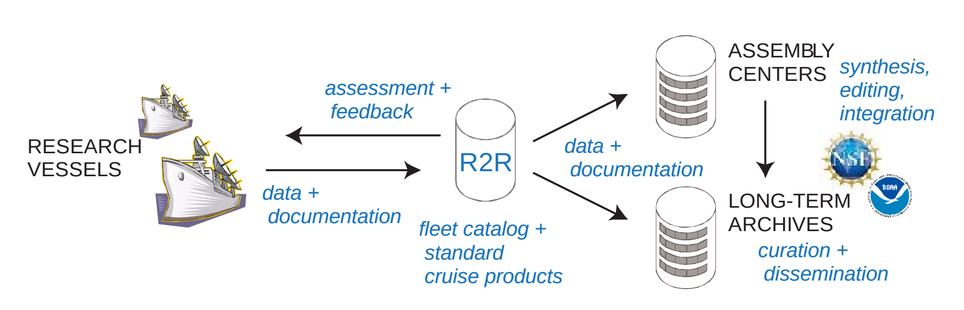


Figure 3.60. Data flow in R2R.

4 Effects of extraction on the marine environment

4.1 Introduction

Each year across the ICES Area, ca. 100 million m³ of sand and gravel are extracted from licensed areas of the seabed (as described in Chapter 2) to supplement that taken from terrestrial sources. Planning constraints tend to restrict the amount of aggregate that can be removed from terrestrial sources, and the use of marine resources reduces the pressure to work agriculturally, environmentally, or hydrologically valuable land. Marine-harvested aggregate provides an important source of fill for major coastal infrastructure projects; it also aids in maintaining coastal defences and keeping beaches supplied with sediment (Chapter 2). However, there are also environmental and heritage impacts caused by the extraction of marine aggregates, and these impacts are subject to assessment for environmental acceptability before a licence can be granted to dredge, with licences often subject to monitoring or mitigation conditions (Chapter 5).

As described in Chapter 2, marine aggregate extraction has increased slightly over the years since the last ICES WGEXT *ICES Cooperative Research Report* (Sutton and Boyd, 2009), not including the large volumes of material which have been required for the Maasvlakte 2 (210 million m³ to date) and Sand Motor (21.5 million m³) projects in the Netherlands. As reported in Sutton and Boyd (2009), the previous expansion of marine extraction activity coincided with an increase in the public's interest in the environmental impact of aggregate extraction and an increase in environmental research into these impacts. In addition, there have also been regulatory drivers ongoing throughout to protect the marine environment, through EU Directives [e.g. EU Habitats Directive, EU Marine Strategy Framework Directive (MSFD)], through national governmental legislation (e.g. UK Marine and Coastal Access Act), as well as through international conventions (e.g. OSPAR, HELCOM, and ICES). The MSFD descriptors of GES concerning the state of the seabed are the primary focus in the future work of ICES WGEXT (Descriptor 1: Biological diversity, Descriptor 6: Seafloor integrity, and Descriptor 7: Hydrographical conditions).

Dredging operations may influence the physical and biological characteristics of the impacted areas both (i) directly through removal of surficial seabed sediments, increases in turbidity from sediment plumes (Duclos, 2012), and damage to seabed integrity caused by the extraction process (Le Bot *et al.*, 2010), and (ii) indirectly by smothering flora and fauna through deposition of fine sediment from surface and bottom sediment plumes (Desprez *et al.*, 2010), by the release of nutrients and chemicals (Newell *et al.*, 1999), and by increases in underwater noise (Cefas, 2003). These impacts can affect both the seabed and the water column in the immediate area within and around the dredging site, but can also affect habitat quality or ecosystem functioning in a wider area, which may then influence (for example) the transport of fish larvae and the abundance of food for fish, birds, and mammals (Newell *et al.*, 1998; Van Dalfsen *et al.*, 2000; Boyd *et al.*, 2005; Pearce, 2008; Daskalov *et al.*, 2011; Desprez *et al.*, 2014).

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 60 years, becoming more significant from the 1960s (see Dickson and Lee, 1972; Shelton and Rolfe, 1972; Millner *et al*., 1977; De Groot, 1979). Initially, concern focused on the potential impacts on the benthic macrofauna and the consequent effects on fish resources and commercial fisheries. This interest has expanded over the years to include most components of the marine ecosystem (reviews by De Groot, 1986; ICES, 1992, 2001; Foden *et al*., 2009).

The last issue of the *ICES Cooperative Research Report* (Sutton and Boyd, 2009) focused on research and knowledge up to 2006 and will be briefly summarized in the following section. However, this chapter will primarily focus on developments since 2006, and, therefore, the previous report should be read in conjunction with the present report. The chapter splits environmental effects into physical, chemical, and biological and, where relevant, illustrates impacts with case studies. The chapter also addresses recovery following aggregate extraction before identifying knowledge gaps and priorities for future research.

4.2 Research programmes

Across the ICES Member Countries, several large research programmes have been running which coordinate aggregate research needs. Some examples are provided below.

4.2.1 The Aggregate Levy Sustainability Fund (ALSF) – UK

In 2002, the UK government imposed a levy on the production of all primary aggregates to reflect the environmental costs of winning these materials. A proportion of the revenue generated was used to provide a source of funding for research aimed at minimizing the effects of aggregate production. This fund, delivered through Defra, was known as the Aggregate Levy Sustainability Fund (ALSF) (http://www.cefas.defra.gov.uk/alsf.aspx). The objectives of the ALSF were to:

- minimize the demand for primary aggregates,
- promote environmentally friendly extraction and transport,
- reduce the effect of local aggregate extraction.

The main focus of Theme 2, the Marine ALSF was to minimize the impacts of marine aggregate extraction. During 2002–2011, £25 million worth of marine-themed research was conducted in five strategic themes to:

- develop and use seabed mapping techniques to improve the evidence base of the nature, distribution, and sensitivity of marine environmental and archaeological resources relevant to marine aggregate activities;
- increase understanding of the effects and the significance of aggregate dredging activities;
- develop monitoring, mitigation, and management techniques, where applicable, underpinned by scientific research;
- research and understand the socio-economic issues associated with aggregate dredging activities;
- promote the coordination and establishment of sustainable archives for the dissemination of research related to these aims to a wide range of stakeholders.

The UK also has government programmes of research, funded by Defra, which look to undertake research to underpin policy and legislation. One project undertaken was "Regulating Marine Aggregate Extraction" (Walker *et al.*, 2013), which looked to collate and review all the research undertaken through Defra, the ALSF, and wider Europe in relation to key policy/regulatory control considerations of licence conditions, monitoring, and the EIA process. This report has been used extensively within Section 4 because much of the literature collated and reviewed is of relevance.

4.2.2 Suivi des Impacts de l'Extraction de Granulats Marins (SIEGMA) – France

This experimental monitoring programme covered the period between 2004 and 2011 (http://www.siegma.fr/) on two sites along the French coast of the English Channel (Dieppe and Baie de Seine). The programme was set up to promote communication between dredging companies and fishers as well as cooperation between scientists to get a better understanding of the global impact of marine aggregate extraction on the English Channel marine environment. The following research topics were studied to characterize aggregate impacts and their duration on (i) turbidity in the water column, (ii) morphology and sediments of the seabed, (iii) benthic communities, (iv) demersal fish communities, (v) trophic relationships between fish and benthos, and (vi) habitats and biodiversity (structure and function).

The main objectives of the programme were to:

- improve the international knowledge on the impacts of dredging and the restoration process of extraction areas,
- obtain original data on demersal fish communities and trophic relationships between fish and benthos, as per several ICES recommendations (ICES, 1992, 2001).

4.2.3 Building with Nature Programme (Ecoshape) – The Netherlands

The Dutch national programme ”Building with Nature” (http://www.ecoshape.nl/) started in 2008 and is an innovative, long-term research programme aimed at developing new design concepts for the layout and sustainable exploitation of river, coastal, and delta areas. It is dedicated to research on the role of natural processes in design and management of (coastal) projects. Opportunities to use natural processes or to positively support natural ecosystems are identified and integrated into the planning and designs, balancing natural ecosystems and human intervention. The programme is focused on infrastructure development in marine, coastal, and estuarine environments, although inland construction works in freshwater systems are also included.

“Building with Nature” is an initiative of the Dutch dredging industry. It is a multidisciplinary programme in which ecologists, scientists, and technical specialists will work, design, and create together, with nature as the starting point in the design process, to gain new knowledge on effectively developing and using ecosystems.

The program focuses on:

- identifying, understanding, and quantifying natural processes,
- integration of these processes in the design and planning process,
- identification of the way in which they can be addressed in the decision process.

A number of case studies have been put forward, designed to test the programme in real-world situations. The case study “landscaping for ecological enhancement” will investigate the promotion of an ecosystem approach in marine extraction projects through an ecological design and realization aimed at exploring the opportunities for landscaping of an extraction area.

4.2.4 MEP: Rijkswaterstaat, LaMER, and Sand Engine – The Netherlands

Three sand extraction projects have combined to form a unified project (MEP) to ensure maximum coordination on both a scientific and management level (see Rozemeijer, 2012 for further information). The scope of this MEP is based on monitoring needs and gaps in knowledge. The topics of the MEP are summarized below:

1. Silt modelling. Two topics were addressed:
    a) What is the behaviour of the plume that is generated by the extraction (near-field and mid-field effect) in order to derive settling rates of silt? It was concluded that plume measurements are not a suitable means for assessment. In addition, the plume only represents 8–15% of the total silt mass.
    b) What is the exchange coefficient of silt between water and bottom for impact modelling purposes?
2. Impact of silt and algae on benthos (describing the relationship between food conditions and growth of *Ensis directus*).
3. Disturbance by transport and above-water presence of trailing suction hopper dredgers (TSHDs) for seals and common scoters.
4. Disturbance of seals by underwater noise.
5. Quick scan methods for shell banks.
6. Benthic trend analysis.
7. Recolonization of the Zeeland banks.

4.3 Physical effects

Marine sand and gravel is primarily dredged with the use of trailer or static suction hopper dredgers. A full description of dredge methods is provided in Chapter 2, Section 2.6. The process of extracting aggregate (both the physical removal and the subsequent return to the seabed of unwanted sediment) causes physical changes to the marine environment. The potential physical impact of the extraction is site-specific and linked to many factors such as dredging method and intensity, hydrodynamics, sediment grain size, and bottom topography (ICES, 2009; Tillin *et al*., 2011). Physical recovery from aggregate dredging is considered complete when dredge tracks and scours are no longer detectable and where sediment composition is "similar" to either predredge conditions or local reference sites (Foden *et al.*, 2009; ICES, 2009). In the UK, there is a condition attached to the extraction licence, using the term "similar substrate", which is intended to maximize the potential for biological recovery (Cooper *et al.*, 2007a); however, the use of the word "similar" is open to interpretation, and there is a need to set quantifiable limits for acceptable change in sediment composition. A method for doing this is outlined in Cooper (2012), with extensive testing undertaken in Cooper (in press), detailed in Section 4.3.2. Physical changes to the seabed will also affect the three MSFD descriptors of interest to WGEXT (detailed in Section 4.1), and these descriptors will need to be taken into account when assessing the impacts of aggregate extraction in the future.

4.3.1 Alteration of topography

The action of extracting aggregate creates furrows or depressions/pits on the seabed, altering the topography from that which existed previously. Furrows (dredge tracks) are created by trailer suction hopper dredgers, are approximately 1–3 m wide and 0.3 m deep initially (Kenny and Rees, 1994), but can be up to 1 m deep (Velegrakis *et al.*, 2010). Depressions are formed by static dredging, which can be 4–25 m deep and up to 200 m in diameter (HELCOM, 1999; Boyd *et al.*, 2004; ICES, 2009). With regard to the alteration of topography, it is the issue of recovery that is most important relative to effects on the marine environment.

The length of time that furrows or depressions remain as distinctive features on the seabed can range from a month to decades (see review in Foden *et al.*, 2009). The time-scale depends on the seabed sediments and the hydrodynamic regime present in the area, as the hydrodynamics (mainly tidal currents) play a large part in determining the character and stability of surficial sediments as well as broad-scale community patterns (van der Veer *et al.*, 1985; Rees *et al.*, 1999; Birklund and Wijsman, 2005; Boers, 2005a; Diesing *et al.*, 2006; Smith *et al.*, 2006; Kubicki *et al.*, 2007; Eggleton *et al.*, 2011). Overall, furrows will remain visible for a few months in mobile sand areas with high hydrodynamics to several years or even decades in regions with stable coarse seabed sedimentation (ICES, 2009). In more stable gravelly areas, weathered dredge tracks are still apparent after a decade in areas of moderate energy (Cooper *et al.*, 2007a). Filling of the furrow can take place by erosion of the slopes and trapping of fine sediments from overflow discharges (Krause *et al.*, 2010; Le Bot *et al.*, 2010) or from natural transport (Cooper *et al.*, 2007b; Le Bot *et al.*, 2010). In Great Britain, 50% of the extraction areas are located in coarse sediments with moderate hydrodynamics where the average duration of physical restoration of seabeds is estimated to be 20 years (Foden *et al.*, 2009).

With regard to depressions and pits, reviews and modelling work (Hoogewoning and Boers, 2001; Boers, 2005b; van Rijn *et al.*, 2005) have found that the sedimentation of material in extraction pits depends on two main 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;
- Trapping efficiency of the pit, which depends on pit dimensions, orientation, and sediment characteristics.

The rate of infill has also been found to vary 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. More recent modeling studies of large-scale offshore sand extraction for a variety of pit designs demonstrated that the evolution (migration) of a pit is more related to hydrodynamic conditions (tidal currents) than to the geometry of the site (Roos *et al.*, 2008). In the case of deep pits created by anchor dredging, several decades are sometimes insufficient for recovery, especially in sectors with low hydrodynamics and weak sediment transport (Szymelfenig *et al.*, 2006; Kubicki *et al.*, 2007). In certain cases, years of extraction can lead to the creation of permanent depressions like the one observed on the Kwintebank off the coast of Belgium (ICES, 2006; Vanaverbeke *et al.*, 2006; Degrendele *et al.*, 2010; Van Lancker *et al.*, 2010).

Any alteration of topography may also have indirect impacts on other activities such as commercial fishing. Cooper (2005) investigated the perceived impacts of aggregate extraction on commercial fishers. The results indicated a general avoidance of aggregate areas by trawlers, due to perceived changes in the nature of the seabed (dredge tracks and depressions). However, this perceived avoidance was not observed in the eastern English Channel by UK or French researchers, where fishing activity appears to have increased (Vanstaen *et al.*, 2010; Desprez *et al.*, 2014; Marchal *et al.*, in press).

4.3.2 Substrate alteration

Removal of aggregate can lead to a change in the seabed substrate by removing layers of aggregate to leave a new substrate exposed (for example, removing gravel and leaving a top layer of sand) or by altering the particle-size distribution. In addition, the removal of a significant thickness of sediment can cause a localized drop in current strength associated with the increase in water depth. This reduced strength in bottom current can cause the deposition of fine sediments within the dredged depressions from overflow discharges (Krause *et al.*, 2010) or from natural sediment transport (Desprez, 2000; Cooper *et al.*, 2007b; Le Bot *et al.*, 2010). The process of screening (removing fractions of aggregate that are unwanted in one area and introducing them to another area of the seabed) can also change the seabed sediments.

Such changes in substrate range from minor alterations to the surficial granulometry (McCauley *et al.*, 1977; Poiner and Kennedy, 1984) to an increase in the proportion of sands (Boyd *et al.*, 2005; Cooper *et al.*, 2007b; Barrio Froján *et al.*, 2011; Wan Hussin *et al.*, 2012) or silt (Byrnes *et al.*, 2004; Krause *et al.*, 2010) or to an increase in gravel as a result of the exposure of coarser sediments (Kenny *et al.*, 1998; Cooper *et al.*, 2007b). A transition from a sandy-gravelly bottom with diverse epifauna to a sandy bottom with less diverse infauna can occur with the use of screening and overflow (Boyd *et al.*, 2005; ICES, 2009; Desprez *et al.*, 2010). It is accepted that the process of screening will change seabed sediments to a greater degree than the other mechanisms described above, returning between 0.2- and fivefold the cargo load to the seabed, depending on end-user requirements. For example, as much as 7223 t $cargo^{-1}$ can be discharged from a 4500 t capacity ship in a single dredge event (Hitchcock and Drucker, 1996). Changes in seabed sediment due to the deposition of fine material are described in studies such as Newell *et al.* (2004a) and Barrio Frojan *et al.* (2011). A comprehensive review of the impacts of screening is provided in Tillin *et al.* (2011).

Again, as for the alteration of topography, the longevity of sediment change/recovery time also depends on local hydrodynamics. Both sustained screening (e.g. Area 408 and Area 222 in the UK; Boyd *et al.*, 2004; Cooper, 2005; Smith *et al.*, 2006; Barrio Froján *et al.*, 2011; Wan Hussin *et al.*, 2012) and dredging without screening (e.g. Area X of Hastings Shingle Bank in the UK and Dieppe in France; Desprez, 2000; Cooper, 2005; Cooper *et al.*, 2007a, 2008; Le Bot *et al.*, 2010) can modify the sedimentary environment. Studies have demonstrated that sediment change may prevent or delay recovery to a pre-dredged state (Cooper *et al.*, 2011a; Wan Hussin *et al.*, 2012). Recovery in sandy environments is likely to occur more quickly than in gravel environments, but recovery time can still be prolonged if there is a change in the sediment. Cooper *et al.* (2011a) found that faunal communities around the coast differ in their sensitivity to changes in sediment composition, with sensitivity depending on the proportion of gravel and the level of natural physical disturbance. Research has shown that leaving a similar substrate to that which existed previously seems to aid the recovery process (Van Dalfsen and Essink, 2001; Simonini *et al.*, 2007; Cooper *et al.*, 2008; Barrio Froján *et al.*, 2011; Wan Hussin *et al.*, 2012). Given the importance of a similar substrate being left for recovery, there is a condition attached to UK aggregate licences requiring a ”similar substrate” be left upon cessation of dredging. Historically, ”similar” has not been defined, which has caused issues regarding enforcement of the licence condition; however, Cooper (2012) outlined a methodology for assessment of similar substrate and Cooper (in press) extensively tested this methodology on data from the eastern English Channel.

CASE STUDY – UK

Cooper (2012, 2013) developed and tested an approach for the setting of limits for acceptable change in sediment particle size composition in areas subject to the effects of marine aggregate dredging. According to Cooper (2013), the approach works by identifying the range of sediment particle size composition naturally found in association with the pre-dredge faunal assemblage(s) in the wider region (see Figure 4.1). Theoretically, as long as sediment composition within areas of impact remains within this range, which can be specified as a licence condition, then it should be possible for a return of the pre-dredge faunal assemblage after cessation of dredging. Cooper (2013) highlights the following potential advantage of this approach:

1. It has a clear scientific rationale, with the aim of maximizing the sustainability of marine aggregate dredging.
2. The environment itself defines the limits of acceptable change. This is important given results in Cooper *et al.* (2011a) which showed that benthic faunal communities are not uniformly sensitive to changes in sediment composition, with lower sensitivity in high-energy sandy areas and higher sensitivity in low-energy gravel areas.
3. It allows for change in sediment composition as a result of dredging. This is important because some degree of change is highly likely as targeted resource deposits are rarely, if ever, uniform in composition.
4. As changes in sediment composition are easily measurable, this means that it should be clear when conditions are not within acceptable limits, allowing for an appropriate management response (see Cooper, 2012).
5. It has the potential to reduce the costs of monitoring by focusing on sediments. As we come to understand more about the effects of ongoing dredging on sediments and fauna, it is surely right to focus attention more on ensuring that the environment is left in a condition which will maximize the chances of long-term faunal recovery.

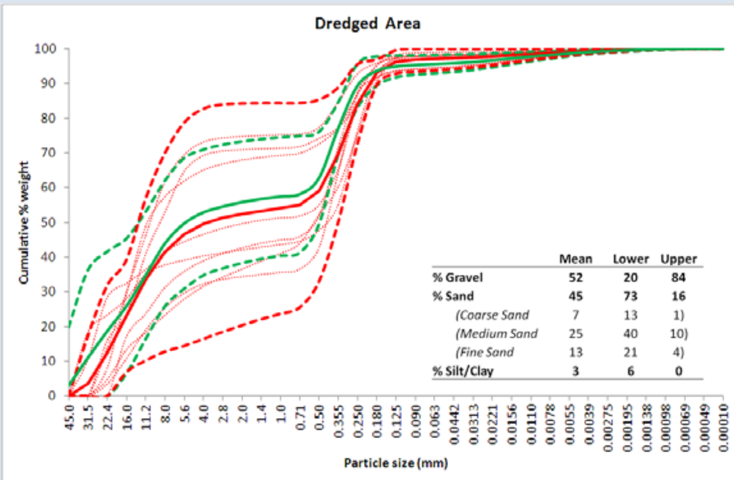


Figure 4.1. Example of a particle-size analysis curve envelope, with the green lines being pre-dredge and the red lines being post-dredge. The solid and dashed lines show the mean and upper/lower limits of the distribution. The inset table shows the composition of dredged sediments based on these three lines (Cooper, 2012).

4.3.3 Impacts on hydrodynamics

Changes to the depth and topography of the seabed due to dredging can cause changes in wave propagation over dredged areas, leading to changes in wave height and wave direction. Similarly, bathymetric changes can change tidal current speed and direction. Predictions in the changes of hydrodynamic (wave and tidal) conditions are based on direct observations, numerical modelling, or inferred from bedform asymmetry and type. Numerical modelling is an accepted approach to make predictions, and a number of models can be applied to estimate particular indicators such as sediment budget, wave height, tidal current, and sandbank height variability. The need and type of modelling is dependent on site-specific processes and sensitivities. Reviews and validation studies of hydrodynamic modelling have been undertaken in strategic projects such as SANDPIT (Van Rijn *et al.*, 2005) and also within Wolf *et al.* (2000) as part of the JERICHO (Joint Evaluation of Remote sensing Information for Coastal defence and Harbour Organisations) project and demonstrate the results of modelling and use of validation data. Other reviews such as Idier *et al.* (2010) discuss the use and coupling of models depending on the Coastal State Indicators (CSIs) being assessed.

The SANDPIT project report (Van Rijn *et al.*, 2005) was undertaken to develop reliable prediction techniques and guidelines to better understand, simulate, and predict the morphological behaviour of large-scale marine aggregate extraction areas and the associated sand transport processes at the middle and lower shoreface and the surrounding coastal zone. The project undertook purpose-designed field measurements at a site in the North Sea to obtain a better understanding of shoreface conditions and a proper validation of numerical models. 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, 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.

The degree of confidence that can be given to the results of numerical modelling depends on the (i) ability of the model to accurately represent the processes being studied; (ii) confidence that can be placed in the supporting data; (iii) degree of data calibration; and (iv) subsequent success of validation of the calibrated model. The maximum possible degree of confidence and performance potential of the model may ultimately be limited by the quantity and quality of the data used to build and calibrate/validate the model (Lambkin *et al.*, 2009). There may always be limitations in models where there is an incomplete understanding and uncertainty in the accurate representation of certain natural processes, limitation in numerical accuracy of equations or methods used, and the accuracy of the computer itself (Lambkin *et al.*, 2009).

4.3.4 Impacts on the coast

Changes in seabed morphology and associated hydrodynamic effects have the potential to affect adjacent coastlines. Assessment of changes in wave and tidal conditions looks at both the near-field and far-field changes to consider these potential impacts at the coastline. Van Rijn *et al.* (2005) undertook a review of the impacts of aggregate extraction at the coastline, which is summarized in ICES (2009). Van Rijn *et al.* (2005) distinguished four zones related to their location on the shoreface and described the impacts of a pit located in each zone. Below the 25 m depth contour, no impacts were observed on wave regime, sediment transport, or stability of the coastline. Studies such as Kortekaas *et al.* (2010) demonstrate how wave and wave-induced, sediment-transport indicators can be simulated using a numerical model and indicate the conditions that are likely to cause significant modifications in sediment transport along a section of the German coast.

Beach drawdown can occur due to natural processes, particularly after storms when sediment is transported down a beach profile into depressions offshore. This is part of the natural movement of sediment up and down a beach profile, where sediment will also be moved onshore during calmer conditions. If dredging is undertaken within the area of sediment movement known as the "active beach profile", then material can become trapped within depressions caused by dredging, preventing it from moving back onshore during calmer conditions (Brampton and Evans, 1998). Phillips (2008) investigated areas where critical beach loss has been associated with dredging activities. This study noted that five years of beach monitoring along an area of the southern Wales coastline had not found a qualitative or quantitative link between marine aggregate dredging and beach erosion. The study notes that natural changes such as changing wind direction and increased easterly storms were most significant in affecting beach formation processes.

Farther offshore, the removal of sediment during marine aggregate extraction may impact sediment transport pathways that replenish the coastline. In the southern North Sea, sandbanks were considered primary targets for the marine aggregate industry because it was thought that natural sediment transport processes (tidal currents, wave activity) that form and maintain them are able to counterbalance the loss of sediment due to extraction. The elongated depression observed in the most heavily exploited areas has put in doubt this notion of "dredging with nature" (Van Lancker *et al.*, 2010), as this depression has significantly modified the sediment transport pathways as a consequence of a change in seabed morphology that modified the near-bed morphodynamics related to tide and/or storm events (Poulos and Ballay, 2010; Van Lancker *et al.*, 2010). Predicting this potential change requires an assessment of sediment transport pathways. Studies such as the Southern North Sea Sediment Transport Study Phase 2 (Wallingford, 2002) investigated and described the sediment transport along the eastern coastline of England between Yorkshire and Kent. The study provides a fuller understanding and description of sediment movements and processes along the eastern coast of Britain.

4.3.5 Sediment plumes and turbidity changes

Elevated turbidity can arise as a result of three sources:

- Mechanical disturbance of bottom sediments by the head of the suction pipe (limited in nature).
- Overflow of water/sediment from the dredging. The loss of fine sediments caused by overtopping water generates a turbid plume, representing 5–15% of the extraction volume, depending on the nature of the bottom (gravel or sand) and the silt content (Spearman *et al.*, 2011).

- Screening (undertaken widely in the UK and the process by which sand or gravel is selectively discharged overboard depending on sediment composition requirements of the end user) also creates a turbid plume.

The process of overflow and screening causes a plume of sediment to form (usually along the tidal axis) as material is discharged overboard. The sediment plume which forms during screening will vary in size depending on the area, the local hydrodynamics, and the nature and amount of the material being screened (Hill *et al.,* 2011). For example, Newell *et al.* (2004a) reported a detectable plume up to 2 km from the dredge site, with settlement of sand and gravel taking place within 500 m, but effects on the seabed (change in sediment composition) extending at least 1,250 m from the site. Andrews Survey (2004) results, at the same site, showed a plume that was traceable for ca. 4000 m (double that of the Newell *et al.* survey), but which had similar detectable effects on the benthos (1750 m). Duclos (2012) found that the silty fraction of the turbid plume could be observed up to 8.5 km from the dredge site in Baie de Seine and 3.5 km in Dieppe during spring tides, with settling measured up to 6.5 km from the site in Baie de Seine and 3.2 km in Dieppe.

Hitchcock and Bell (2004) found a near-bed plume that travelled >4.5 km; however, without screening, the overflow plume was more limited (300 m downstream of the site), showing that plume effects are much more pronounced when screening takes place. Similarly, dredging gravel without screening caused only 1.6 t of sediment to be rejected from a 2000 t load (Boyd and Rees, 2003), showing that the volume of sediment lost by overflow alone is much reduced compared to that lost when screening is used. Without screening, the turbid plume does not substantially affect the environment after the dredging activity has finished (Newell *et al.*, 2002). A study by Dearnley *et al.* (2009) sampled sediment concentrations within the overflow mixture, which helped to quantify the volume of material that will contribute to a suspended sediment plume. The results observed a range in silt and sand concentrations in the overspill; silt concentrations of 132–6272 mg l^{-1} in the overflow mixture during loading, and sand concentrations of 91–123 090 mg l^{-1} in the overflow mixture. In a study by Duclos (2012), there was a mean concentration of 6–18.8 g l^{-1} (respectively through side doors and well) silty sands in the overspill, with an immediate dilution down to 20 mg l^{-1} during the first 10 min, resulting in very local and short-term elevated levels of turbidity around the dredger corresponding to the settling phase of the sandy fraction.

The settling time of the plume depends mainly on the fines content, but also on the extraction method and hydrodynamic conditions. Gravels fall out of suspension and settle on the seabed almost instantaneously, while sands settle within 300–500 m and silts and finer elements within 500 m–3.5 km (Newell *et al.* 1998; Hitchcock *et al.,* 1999; ICES, 2007, 2009). Below 500 m, the plume consists of an organic mixture of fats, lipids, and carbohydrates, with little sediment content, which could correspond with the organic matter from benthic animals that were injured during the extraction process and rejected with the water overflow (Hitchcock *et al.,* 1999; Newell *et al.,* 1999). Therefore, while plumes from screening can be quite extensive, the area that will be affected by increased turbidity or smothering is more limited. In the eastern Channel, fine–medium sands settle rapidly (< 15 min) at a maximum distance of 250 m from the dredger in Baie de Seine and 800 m in Dieppe (Duclos, 2012). After one year of extraction in the Baie de Seine, individual tracks and depressions were partly filled with fine sediments from overflow discharge and natural transport (Duclos, 2012), with a slight (non-significant) fining of sediments. In Dieppe, after several years of repeated extractions, the large-scale release of fine sands changed the nature of the sediment (Le Bot *et al*., 2010; Section 4.3.2).

Under calm meteorological and hydrological conditions 75–90% of the volume of natural silt is incorporated in bottom sediments, where it will be released by wave action caused by strong winds. In the Netherlands, this occurs typically at depths ≥6 ft (Suijlen and Duin, 2001). The material returned overboard adds to the natural silt volumes already present. For example, in the Netherlands, the signal in acoustic measurements is increased by 1–5% due to silt from the overflow (Harezlak *et al.*, 2012). Figure 4.2 shows the temporal alignment of suspended particulate matter (SPM) concentrations and wave heights. The alignment of "wave events" and increases in the concentration of suspended material at a height of 30 cm above the seabed is evident. Concentrations of suspended material tend to lag a little behind the increased wave heights. This suggests that time is needed to free material from the sediment and/or that (some) peaks in SPM refer to material that originates from locations away from the point where measurements were being made (Witbaard *et al.*, 2012).

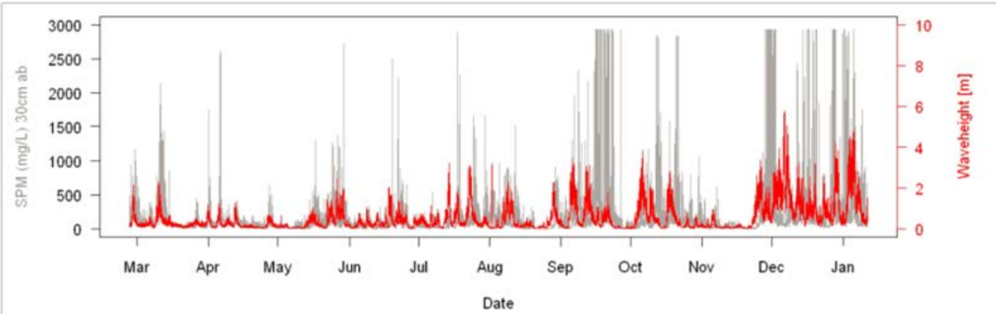


Figure 4.2. Temporal alignment of suspended particulate matter concentration and wave heights measured at 10-min intervals.

As a response to a concern about turbidity, Eggleton *et al.* (2011) assessed the natural variability of turbidity within four of the main UK aggregate extraction regions (Humber, East Coast, Thames, and the South Coast). Region-specific results have been generated by the project, showing the highest turbidity in the East Coast and Thames regions (mean concentrations up to 90 mg l^{-1}) compared with lowest values in the South Coast. EIA assessments of turbidity can now be compared to these results to give context to the predicted effects of screening and overflow. The Eggleton *et al.* (2011) report goes on to discuss the findings related to the benthos, which future EIAs can also use when relating increased suspended particulate matter (SPM) and turbidity to impacts on benthos.

Measuring sediment concentrations and settling rates of sediment plumes caused by extraction is not always straightforward and is often time-consuming. Therefore, modelling tools can be used, and are further being developed, to assess the impacts of dredging on silt and algae (Harezlak *et al*., 2012). Within the MEP programme in the Netherlands (Rozemeijer, 2012), improvement in modelling instruments to derive the behaviour of silt in the near- and mid-field are being developed (Grasmeijer and Eleveld, 2010). In addition, modelling instruments to derive the behaviour of silt in the far-field are also being developed, e.g. by improving the assessment of the exchange coefficient of silt between the water column and seabed (van Kessel *et al*., 2012).

Increased turbidity, as a consequence of material being returned overboard or from bottom-forming plumes from the passage of the draghead, can cause significant impacts. Turbidity can reduce light and, therefore, reduce production of phytoplankton. It may also disrupt the feeding and respiration of zooplankton and affect filter feeders (e.g. clogging). Turbidity may also cause avoidance behaviour in visual predatory fish, affect migration/movements of fish, affect the buoyancy of pelagic eggs or the development/survival of eggs and larvae, or hamper sight predators like terns (Westerberg *et al.*, 1996; Birklund and Wijsman, 2005). As these impacts primarily relate to the biological environment, they will be described in further detail in Section 4.5.

4.3.6 Underwater sound and other disturbance

Disturbance of fish, birds, and marine mammals can have a range of impacts. It can be physiological or behavioural. Response of animals to disturbance may vary both temporally and spatially among groups within an area and may result in greater avoidance or tolerance of certain areas depending on the source and type of the disturbance. Elements that might affect how animals respond to disturbance events can include the quality of the occupied site, the distance, availability, and quality of other suitable habitats, the risk of predation, density of competitors, or the investment that an individual or group has made in a site (Gill *et al.*, 2001). Responses may also be specific to an individual or may occur at a group or population level.

4.3.7 Underwater sound

The operation of vessels and mechanical activity during dredging creates underwater sound within the marine environment. Internationally, there is growing concern about the potential harmful impact of anthropogenic sound on marine life, causing, for example, temporary or permanent hearing loss, disturbance from feeding or spawning grounds, causing a barrier to migration or possible injury or death. A number of studies have investigated the underwater sound levels of marine aggregate extraction and the potential to cause adverse effects to marine life, such as fish or marine mammals (Cefas, 2003; Dreschler *et al.*, 2009; Robinson *et al.*, 2011). Initial results indicate that the sound level radiated by a dredger undertaking full dredging activities reduces by 6 dB, i.e. half, the sound pressure for every doubling of distance from the dredger (Cefas, 2003) and are in line with those expected for a cargo ship travelling at moderate speed (Dreschler *et al.*, 2009; de Jong *et al.*, 2010; Robinson *et al.*, 2011). The underwater sound is primarily caused by propulsion propeller cavitation rather than the action of dredging. However, extracting gravel does cause additional sound impact (Dreschler *et al.*, 2009; Robinson *et al.*, 2011). In the UK, underwater sound from aggregate extraction has been largely discounted as a significant impact. Similarly, in the Netherlands, underwater sound levels from dredgers were not in the top seven major underwater sound sources (Ainslie *et al.*, 2009).

Underwater sound generated is below levels that will cause permanent or temporary loss of hearing in fish, although members of the salmonid and clupeid groups of fish that are more sensitive to underwater sound disturbance, would be aware of the dredging activities, and this may impact their behaviour (Cefas, 2003). Noise from multiple dredgers has the potential to overlap within an area; however, this underwater sound will not be additive, and while some species of fish (and mammals) may be aware of the underwater sound and this might change their behaviour, the underwater sound generated is not at a level where there would be a temporary or permanent effect on hearing. While underwater sound levels have been accurately measured and are, therefore, relatively predictable if the vessels used are comparable, the environmental effects of underwater sound are more dependent on the sensitivity of the local ecosystem. As underwater sound is a continuous source that might last for extended periods, potential adverse effects in areas of high ecological sensitivity should not be overlooked (Thomsen *et al.*, 2009). In the Netherlands, several programmes have been run to further investigate impacts of underwater sound. For example, controlled exposure tests were developed to establish the effects of underwater sound produced by dredgers

(Newell and Measures, 2010). Most research concerns marine mammals; however, low frequency sounds (< 1 kHz) may affect fish species (McCauley *et al*., 2003; Popper, 2003; Popper *et al*., 2004) as more than 50 families use sounds that are generally < 2–3 kHz (Wahlberg and Westerberg, 2005). Further work may become necessary as soon as indicators (or thresholds) have been developed for the ambient noise descriptor under the MSFD. Regulations in Belgium, for example, limit the level of anthropogenic impulse sounds to < 185 dB or 1 μPa (0–max. SPL) at a distance of 750 m from the source (Belgische Staat, 2012).

4.3.8 Presence of vessels and activity

Visual disturbance by dredgers may also have an impact on marine mammal and bird species. The MEP Programme in the Netherlands (Section 4.2.4) is undertaking work investigating aggregate disturbance on common scoters (*Melanitta nigra*) and harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals. Other species of concern include the red-throated diver (*Gavia stellata*), which is a protected species under the EU Birds Directive.

The common scoter is a species that aggregates at locations with large live shell banks. At certain sites in the Netherlands, such banks are situated between extraction sites and the coastline. These birds are known to be very sensitive to disturbance. Within the MEP programme, regular aerial surveys have been undertaken to describe the common scoter distribution together with the presence of other bird species and potential factors of disturbance (e.g. fishing boats). At spots with high numbers of scoters, benthos samples have been taken for both quantity and quality of the shellfish. Overall, it has been concluded that scoters seem attracted to high densities of shrimp and shellfish, but there is a limit to the extent they tolerate disturbance (Leopold *et al.*, 2013). Further work is ongoing concerning the reason for a decline in the common scoter in Dutch waters, investigating changes in food quality and quantity and occurrence of disturbance. Further work relevant to disturbance from aggregate extraction will be reported in future WGEXT annual reports.

Close proximities of dredgers to seals (< 700 m) can cause seals to enter the water, causing the animal to lose unnecessary heat (Erdsack *et al.*, 2012). Hauling out is also important for suckling pups, with disturbance of seals into the water interrupting suckling and potentially reducing pup fitness and survival chances. Within the MEP programme, several studies were undertaken on the direct impact of boat disturbance on seal behaviour. Little change in behaviour was observed, apart from reactions to close approaches by dredgers (< 700 m) or a sudden increase in noise levels. However, it was also noted that habituation to dredgers can occur (Bouma *et al.*, 2010; Didderen *et al.*, 2012).

4.4 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 in the Baltic Sea, an anoxic zone underlying the commercial deposits can be exposed by static suction hopper dredging. An anoxic zone is mainly the consequence of static dredging in semi-enclosed seas (low salinity) with low hydrodynamics like the Baltic Sea (Thatje *et al*., 1999; Szymelfenig *et al*., 2006; Schwarzer, 2010). 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 limits any chemical impact (ICES, 2009). The best prevention is to limit extraction in areas located near estuaries where chronic pollution is recognized.

4.5 Biological effects

The act of extracting aggregate causes a number of physical impacts described in Section 4.2 above and in the previous *CRR* No. 297 (Sutton and Boyd, 2009). As the distribution of marine organisms and communities is strongly related to hydrodynamic, morphological, and sediment parameters (McLusky and Elliott, 2004; Baptist *et al.*, 2006; Degraer *et al.*, 2008b; Pesch *et al.*, 2008), any physical changes in the seabed will lead to a response in the composition of its natural benthic assemblages (see case study Buiten Ratel). This will affect habitat quality in a wider area, transport of fish larvae, and abundance of food for fish, birds, and mammals. 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.

Case Study Buiten Ratel: Biological (and physical) impact

Sand extraction in the Belgian part of the North Sea (BPNS) has been concentrated in zones 2a and 2b (Kwintebank) for several consecutive years (1976–2005). During this period, at least 70% of the total volume extracted in Belgium occurred on the Kwintebank (zones 2a and 2b), and this has resulted in a closure of two 5 m depressions on the Kwintebank (Degrendele *et al.*, 2010). Consequently, sand extraction activities shifted towards the Buiten Ratel, a nearby sandbank. Since 2005, extraction increased steadily on the Buiten Ratel and constituted 73% of the total Belgian extraction in 2010 (1 514 487 m^3). Most extraction on the Buiten Ratel occurs in a small area of ca. 1 × 2 km. Bathymetric evolution in the area was measured with a multibeam echosounder (Kongsberg EM3002D). The results of the bathymetric measurements confirm the almost perfect correlation between extracted volumes and bathymetric evolution ($r^2 = 0.99$). All bathymetric changes can be explained by dredging activities (Roche *et al.*, 2011).

Macrobenthic sampling by Van Veen grab in the area revealed distinct changes in species composition between high-impacted and low, far-field zero- and near-field zero-impacted areas. Part of this distinction can be explained by natural variation in sediment composition, but it seems that intensive dredging on the Buiten Ratel contributes to a more diverse benthic community. Species composition of the low and far-field zero-impacted locations is a typical example of the *Nephtys cirrosa* biotope of the BPNS (Van Hoey *et al.*, 2004). These groups are characterized by fewer, but more dominant species, i.e. 2–3 species contributing 50% of the overall abundance, and all species are characteristic for medium sands. On the other hand, the near-field zero and high-impacted group are in species composition more related to the *Ophelia borealis* biotope of the BPNS (Van Hoey *et al.*, 2004), which is indicated by the presence of *Ophelia* species in both groups. However, the near-field zero group has fewer species, as observed by Van Veen sampling (average 15 ± s.e. 2.6/0.1 m^2), with a couple of dominant species (i.e. four species contributing 50% of the overall abundance), and with all species being characteristic for coarse–medium sands, as can be expected for this type of community. The high impact group, on the other hand, is characterized by a higher number of species (average 21 ± s.e. 2.5/0.1 m^2), which are present in lower densities, i.e. ten species contributing 50% of the overall abundance. The species from the high-impact group are a mixture of species characteristic for coarse–medium sand and for very fine sand. These results indicate that the increase in diversity is due to the inflow of species characteristic of fine sediment to this naturally coarse sediment area. These species are attracted to the area because of the presence of very fine sand, even though the percentage of this sand is low. It is probably induced by dredging activities, creating an overflow and/or increased availability of these fines from heavy disturbance of the seabed (De Backer *et al.*, 2011).

So, intensive dredging at the Buiten Ratel caused a small increase in fine sediment that triggered a shift in the *Ophelia borealis* community towards a variant of the richer and more diverse *Abra alba* community, which led to a local unexpected biodiversity increase in the impacted area. This community is a young, dynamic (transitional) community that is far from reaching stable equilibrium, stressing the need to continue regular monitoring in the dredging area. However, caution is needed in the long run because increasing human activities and impacts at larger scales might lead to homogenization of the sediment on a wider scale (through a loss of habitat heterogeneity), potentially resulting in a ”negative” diversity-disturbance response and a decrease in biodiversity.

4.5.1 Benthos

4.5.1.1 Direct effects

It is well known that the direct removal of surface aggregate sediments and the non-selective extraction of associated fauna results in a local decrease in species abundance, diversity, and biomass (Kenny *et al.*, 1998; Newell *et al.*, 1998, 2002; Sardá *et al.*, 2000; van Dalfsen *et al.*, 2000; van Dalfsen and Essink, 2001; ICES, 2009). This may range from almost total defaunation (e.g. Desprez, 2000), or more commonly, to a significant reduction in fauna (e.g. Boyd and Rees, 2003; Andrews Surveys, 2004), or to a more subtle and less significant change (e.g. Robinson *et al.*, 2005). Differences in impact and subsequent recovery depend on a number of factors, including the nature and intensity of extraction, local hydrodynamics, and sediment characteristics. A meta-analysis approach was recently used to assess the effect of dredging-induced changes in sediment composition under various conditions of natural physical disturbance for the structure and function of benthic macrofaunal communities (Cooper *et al.*, 2011a). Results showed that the sensitivity of macrofauna increased as both the proportion of gravel increased and the level of natural physical disturbance decreased.

4.5.1.2 Indirect effects

The main indirect impact of dredging is linked to the deposition of sediment from the overflow or screening plume, which can cause smothering/damage to sensitive benthic receptors. The scale of the secondary sedimentary footprint is dependent on site-specific factors such as sediment composition and hydrodynamic conditions (Tillin *et al.*, 2011). As discussed in Section 4.2.5, dispersed sediment can travel up to 6.5 km from the source of dredging, with almost all the sediment fraction settling out within this distance. The creation of sediment plumes has the potential to adversely impact benthic organisms through an increase in sediment-induced scour, smothering, and through damage and blockage to respiratory and feeding organs (Tillin *et al.*, 2011). Studies such as Last *et al.* (2011) investigated the impacts of increased SPM and smothering on a number of benthic species. The authors concluded that response to burial and SPM was very variable between species and noted mismatches between their results and certain widely used databases (see case study below).

CASE STUDY: LAST *ET AL.* (2011)
Recent work by Last *et al*. (2011) investigated the response and survivorship of various species of commercial or conservational importance under a range of environmental and depositional conditions. The species chosen were based on their prevalence in areas of interest for aggregate extraction (North Sea and eastern English Channel), the diverse range of behavioural and physiological characteristics they exhibit and, in some cases, due to their commercial and/or conservation importance.
Sabellaria spinulosa (ross worm) and *Ophiura ophiura* (brittlestar) were highly tolerant to short-term burial (≤ 32 d), with brittlestars able to re-emerge from all depths and all sediment fractions. However, those specimens that remained buried (< 10%) did not survive. The ross worm showed no effect of burial with any depth. Last *et al.* describe the use of "emergence tubes" by the ross worm, which they hypothesize is a mechanism by which the ross worm can avoid gradual burial.
Mytilus edulis (blue mussel) was found to be moderately tolerant of short-term burial, with mussels able to emerge from 2 cm depth of burial. Mussels had a limited ability to re-emerge from sediment depths and percentage mortality increased with a fining of sediments. Other findings also report that the blue mussel is tolerant of repeated burial events.
Sagartiogeton lacerates (sea anemone) was highly tolerant of shorter term (≤ 16 d) burial events, with < 1% mortality. The sea anemone was able to survive under burial conditions and re-emerge from depths of 2 cm. Percentage mortality, as with the other species, increased with both depth and increasingly finer sediment fraction.
Psammechinus miliaris (green sea urchin) was moderately tolerant of shorter-term (≤ 12 d) burial events. Survivorship was partly due to their ability to re-emerge from coarse sediment, even from depths of up to 7 cm. However, after 12 d of burial, mortality in the specimens that remained buried was high. Percentage mortality increased with progressively finer sediment fractions.
Finally, the yellow sea squirt (*Ciona intestinalis*) was highly intolerant of burial events, with 100% mortality of all individuals buried for at least 2 d. The species demonstrated no ability to re-emerge from burial, and no significant difference was found in sediment fraction effect.
A comparative assessment of escape ability showed that of all species under investigation, brittlestars had the greatest escape ability, followed by the green sea urchin. The blue mussel, queen scallop, and sea anemone all showed similar emergence responses over time. Furthermore, the yellow sea squirt was unable to escape burial irrespective of sediment fraction or depth of burial.
Two test conditions of SPM were also tested (high SPM, equivalent of near-dredge conditions and low SPM, equivalent of wider secondary-impact conditions). All species survived the higher SPM conditions, although the authors concluded that there were some higher energetic costs compared with control conditions. Reactions of different species varied, with the blue mussel reducing shell gape cycles

and the queen scallop displaying more "clap" or "cough" escape and sediment expulsion responses under high SPM conditions compared to the low SPM and control conditions. Growth rates of the ross worm showed significantly higher tube growth under high SPM conditions, while the brown crab (*C. pagurus*) gained significantly less weight in the high SPM conditions compared to the controlled conditions.

The majority of studies (Desprez, 2000; Newell *et al.*, 2002; Boyd and Rees, 2003; Cooper *et al.*, 2007b; Desprez *et al.*, 2010) suggest that adverse biological change is constrained to 100–200 m from the dredge area, even where sedimentary change has been detected at greater distances. However, there are also other studies that have demonstrated adverse biological change >1 km from the dredge area. The differences in results are seen across a variety of regions, sediment, and hydrodynamic (e.g. tidal currents) energy types. Similarly to that discussed in relation to secondary sediment footprint, there may also be site-specific factors that influence the footprint of change, e.g. dredging intensity, sediment composition, screening activity. Also, studies used differing sample plans according to the purpose of the investigation, which can influence the distance at which an impact was detected. Desprez (2000), for example, identified a specific area of depositional effect within 200 m of the licence area in a direction perpendicular to that of the strongest tidal currents (taking account of the ellipsoid tidal current pattern), while Newell *et al.* (2002) and Boyd and Rees (2003) took samples along a distance gradient from the dredge area. More recently, biological consequences of the secondary footprint were observed up to 2 km from the dredge site in the direction of and after remobilization by local tidal currents (Desprez *et al.*, 2010).

In addition to negative impacts to the benthic community, studies have also recorded enhancement in the benthic community (in terms of biomass) beyond the dredge area. The study by Newell *et al.* (2002) in the UK noted an enhancement of benthic biomass at distances beyond the suppressed area (>500 m northwest), suggesting an enrichment of the benthos from organic matter released either from the water column or from benthic boundary plumes.

A direct consequence of increased turbidity from aggregate extraction is the reduction in light penetration into the water column, which can negatively affect phytoplankton growth (Cloern, 1987). Phytoplankton constitutes the basis of the foodweb, thus a decreased availability can affect higher trophic levels. In addition to reduced phytoplankton abundance in the water column, elevated silt concentrations may impede the intake of phytoplankton by shellfish and potentially cause additional stress (i.e. higher energetic costs) to these organisms as they need to excrete silt in the form of pseudo-faeces. Shellfish make up an important component of the coastal foodweb, for example for shellfish-eating birds such the common scoter as well as demersal fish (Kaiser *et al.*, 2006; Tulp *et al.*, 2010). As such, the impacts of aggregate extraction on shellfish species are being investigated in the Netherlands by modelling the impact of reduced algae on shellfish growth. Model results are being compared to observations in the field, and while some adjustments to the model are needed, the model and approach have been used in a recent EIA and showed reduced shellfish growth as a result of extraction (case study: MEP below, Rozemeijer, 2012).

CASE STUDY: MEP, THE NETHERLANDS (ROZEMEIJER, 2012)

In order to predict potential effects of large quantities of sand extraction in the Dutch coastal zone, one aspect of the MEP Rijkswaterstaat LaMER programme focused on the impact of reduced algae on growth of shellfish. To quantify these effects, the development of a shellfish physiological growth model was initiated (Rozemeijer, 2012). For this study, *Ensis directus* was taken as a model organism, because of its high dominance in biomass in the Dutch coastal zone (Goudswaard *et al.*, 2012).

A physiological growth model was developed using Cardoso *et al.* (2011), Kamermans *et al.* (2011), Wijsman (2011), Kamermans and Dedert (2012), and Schellekens (2012a, 2012b). Incorporation of these new results made it possible to account for the effect of silt on the uptake of algae and could be used to predict growth of *E. directus* in several locations in the North Sea on the basis of modelled environmental data (Schellekens, 2012a, 2012b). These calculations were then used to assess the effect of sand extraction on the growth of *E. directus*.

Actual growth in the field was compared to model-predicted growth to validate the model. As a first step, the unadjusted form of the model (Schellekens, 2012a, 2012b) was applied. This original model fits maximum growth well and suggests that the model describes potential shell growth well. However, the model overestimates the average growth rate of *E. directus* (Figure 4.3) due to the measured chlorophyll concentration. Chlorophyll concentrations of 30–35% of the original led to the best fit of the data.

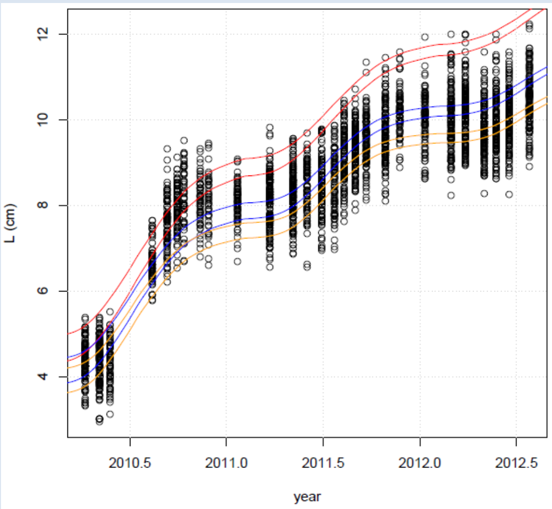


Figure 4.3. Development of shell length of *E. directus*. Black dots: measured length. Lines: modelled length. Red lines: model outcome on basis of measured Chl *a* concentration assuming two times of recruitment (top line: 1 May and lower line: 1 June). Blue lines: idem except for 40% of measured Chl *a* concentration. Yellow lines: idem except for 30% of measured Chl *a* concentration (Schellekens and Witbaard, 2012).

Other factors that may cause the model to require adjustment include:

- The high density of *E. directus*, which could lead to local depletion of algae (Daan and Mulder, 2006).
- Wrong estimation of algae concentrations as the measurements were taken 45 cm from the bottom and not near bottom. However, this seems unlikely given the increasing concentrations of algae measured from higher to lower in the water column (Witbaard *et al.*, 2012).
- Hampered uptake because of much higher SPM concentrations near bottom than used with measured concentrations at 30 cm.
- Different affinities of uptake for different species of algae (e.g. Troost *et al.*, 2010).
- Different food quality for different algae species and detritus.
- A winter pause in food uptake by *E. directus*.

The study also found that the condition of *E. directus* at this site was substantially below optimum. Further work is necessary to determine implications for other species and for the coastal zone. Applying the approach and the model in the latest EIA for sand extraction also showed reduced growth of as a result of extraction.

4.5.2 Higher trophic levels

4.5.2.1 Direct effects

Species such as herring (*Clupea harengus*), black bream (*Spondyliosoma cantharus*), sand eel (Ammodytidae), and crabs require certain substrate conditions for spawning or breeding activity. Changes in or loss of a preferred grain size can disturb mobile species in these areas. In addition, ovigerous female brown crabs prefer to overwinter on coarse gravelly material and are, therefore, susceptible to direct dredging impacts. Studies such as de Groot (1979) have highlighted the importance of historical spawning grounds for herring and its specialist requirement for coarse gravel (ICES, 2011), increasing its vulnerability to disturbance if marine aggregate extraction occurs within spawning areas.

Stelzenmüller *et al.* (2010) developed a marine spatial risk assessment framework to investigate the vulnerability of 11 species of fish and shellfish to aggregate extraction (based on life history traits such as ability to switch diet, affinity to seabed, and reproductive strategy). These species were likely to be affected by aggregate extraction and had either commercial or conservational importance. The authors calculated a sensitivity index (SI) for each species and modelled their distribution around the UK. This work allowed them to produce GIS maps of occurrence for each species and a sensitivity of each aggregate region for these 11 species (based on the distribution maps, their SI, and a measure of uncertainty). The highest sensitivity occurred in coastal regions and where nursery and spawning areas of four important commercial species occurred [cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), sole (*Solea solea*), and whiting (*Merlangius merlangus*)]. The study concluded that the risk framework could be applied to other ecosystem components, pressures, and scales, but also highlighted the need for suitable data to inform the assessment.

4.5.2.2 Indirect effects

Many fish species [e.g. plaice, sole, gurnard (*Chelidonichthys cuculus*), red mullet (*Mullus surmuletus*), and cod] feed primarily on benthic organisms. The change in benthic communities caused by aggregate extraction may affect the higher trophic levels (e.g. fish and birds) as the increase in extraction surface in a given geographical area leads to a potential change in habitat and thus in food sources.

A preliminary study on a commercial site in France (Desprez, 2008; Desprez *et al.*, 2014) has shown that the impact observed on the biomass of demersal species within the extraction area was nil (or even positive for a number of species), while their abundance was only reduced by 35%. This low impact was explained by the low extraction intensity (< 1 h ha^{-1} $year^{-1}$) and the spatial and temporal zoning of the dredging activity. Moreover, the joint study of trophic relationships (stomach contents of the main commercial species) showed how the evolution of certain fish populations could be explained by changes in benthic prey availability (mainly for sole, cod, and seabream) in the new morpho-sedimentary context of the extraction area resulting in an increased habitat heterogeneity (Impacts case study: Fish in the eastern English Channel).

Impacts Case Study: Fish in the eastern English Channel (SIEGMA programme)

Between 2004 and 2011, three combined studies (benthos, fish, and stomach contents monitoring) were undertaken at two sites in France (Dieppe and Baie de Seine). The aim of this work was to provide the first data on the impact of extraction of sandy gravels on fish, with evidence of the potential role of benthos availability on the diet of fish species (Desprez *et al.*, 2014).In the Baie de Seine, fish monitoring between 2007 and 2011 showed a strong impact of aggregate extraction on fish presence (Figure 4.4), both for the number of species (–50%) for abundance and biomass (–92%). This strong impact, different from that observed in Dieppe, was explained by the difference in extraction intensity, low in Dieppe, but medium–high in the Baie de Sein e (Desprez *et al.*, 2014).

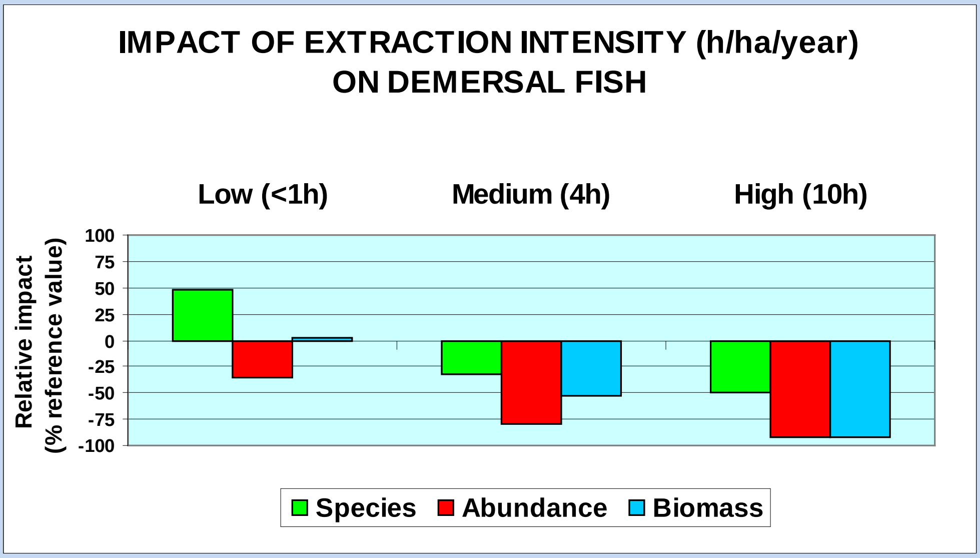


Figure 4.4. The role of dredging intensity in determining impact on demersal fish community (Desprez *et al.*, 2014). X-axis shows three different sample sites of increasing dredging intensity (h ha^{-1} year^{-1}); Low <1 h; Medium = 4 h; High = 10 h. Y-axis shows the deviation (expressed in % of the reference values) for the three community parameters.

Abundance of most of the species strongly decreased in the Baie de Seine, except for sole which was temporarily attracted to the extraction sites during the first stages of the extraction process. During 1–3 months, abundance of sole was increased 50-fold in the dredging site and up to sixfold in the proximal surroundings. This temporary attraction was explained by the analysis of stomach contents (Figure 4.5), showing a modification of diet (trophic opportunism) according to the increase in benthic prey availability with crushed benthos returned with overspill (Desprez *et al.*, 2014).

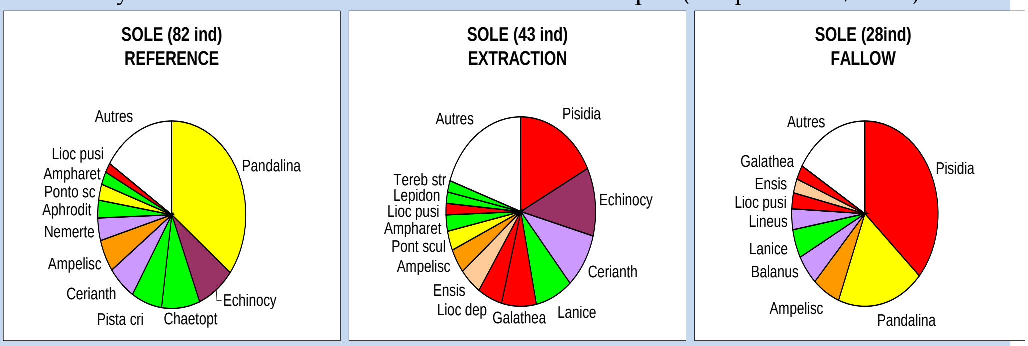


Figure 4.5. Sole diet adaptability in the Baie de Seine (dominance of shrimp (yellow) and annelids (green) in the reference area; dominance of decapods (red) during and after extraction).

The general conclusions drawn from the Dieppe study were that dab (*Limanda limanda*) and whiting (*Merlangius merlangus*) were the two fish species most adversely affected by dredging; however, sole and rays appeared to flourish in areas where the sediment had been modified by the deposition of sandy material. Red mullet was not adversely affected by dredging because they were able to adapt their diet to the specific benthic communities of the different impacted areas. Black sea bream, gurnard, and cod were absent from the sandy reference and deposition areas, but were attracted to dredging areas by the abundance of opportunistic benthic species (mainly crab species *Pisidia* and *Galathea*), which recolonize areas once activity has ceased. At this site, the red mullet was the key species to characterize the different habitats linked to the extraction activity (dredging, oversanding deposits, fallow and recolonization areas).

More recent studies at the Dieppe extraction site found that, as for the Baie de Seine, sole were very adaptable in their diet and always abundant within the extraction and especially the deposition areas compared to reference areas, allowing a permanent fishing activity (Marchal *et al.*, 2014).

A study by Pearce (2008) investigated the importance of benthic communities within marine aggregate areas as a food resource for higher trophic levels. The stomach contents of demersal fish species sampled by 2 m beam trawl were investigated, and samples were obtained from all marine aggregate producing regions. The study noted that the alterations to the benthos due to dredging were likely to cause alterations to the diet of demersal fish, which may be unfavourable. However, given the natural levels of trophic adaptability observed, a change in dietary composition may not be damaging to the fish population as the majority of species studied are likely to switch prey sources, providing sufficient biomass is available to support them. A similar study by Greening and Kenny (1996) indicated that there was no difference in the number of prey taxa in the stomachs of fish from dredged and non-dredged sites. However, this is at odds with the conclusions from the Dieppe and Baie de Seine studies, which found that sole and red mullet were the only species to be adaptable in their diet.

There have been few direct studies on changes in fish populations due to marine aggregate extraction. A study by Boyd *et al.* (2001) compared the commercial fish landings caught in an aggregate zone to those obtained from ports distant to dredging. A localized decline in catches of Dover sole (*Solea solea*) was observed, and the study considered that this may be a result of the reduced abundance of prey items within the extraction area, as Dover sole derive much of their food from benthic species. Longline fisheries for cod, whiting, and rays showed no evidence of such a decline; this may be because the other species analysed are known to have a preference for hyper- and epibenthic species as prey. Fish species were also sampled within and in the vicinity of the Dieppe extraction site (Sutton and Boyd, 2009), reporting various reactions to extraction depending on the species of fish and the adaptability of their diet (see case study). In the eastern Channel region, analysis of the fish assemblages suggests reductions in abundance have occurred for a number of species since 2006. Furthermore, interruptions to recruitment in the plaice and sole populations have been observed (Drabble, 2012).

Predicting the disturbance of mobile species, such as fish or marine mammals, is particularly difficult because there are few studies that have directly investigated disturbance in relation to marine aggregate extraction or suggested that significant impacts will occur. Mobile species are also more likely to be influenced by other impacts or anthropogenic activities outside of a licence area, again making direct predictions between marine aggregate extraction and mobile species difficult. There should be little impact on pelagic fish species apart from during their larval phase and on eggs which are laid on the seabed itself, as adults are able to avoid the sediment plume and some species are attracted by the benthos rejected by the overspill (Desprez *et al.*, 2014). A study by Kenny *et al.* (2010) looked at the long-term trends of the ecological status of the English east coast aggregate-producing region, which included consideration of fish stocks. The study noted that long-term trends appear to be dominated by wider factors that govern trends at the North Sea scale, as declining fish stocks were observed in both the North Sea and east coast aggregate-producing region.

Cook and Burton (2010) reviewed the potential impacts of aggregate extraction on seabirds. One direct effect was the issue of increased turbidity, and to what extent this affects a bird's ability to see prey. Vision for foraging is important for a number of species of seabirds, including terns, the common guillemot (*Uria aalge*), and the northern gannet (*Morus bassanus*). However, for the most part, material falls out of suspension relatively quickly (mostly within 500 m), meaning that this increased turbidity is short term and within a limited area.

While there is little evidence that can clearly define the impacts to higher trophic levels due to marine aggregate extraction, studies do highlight the complexities in assessing this impact. Species-specific factors such as trophic adaptability in diet may influence the significance of impacts on a local scale. The ability of species at higher trophic levels to adapt will be influenced by the cumulative effects of dredging, along with other activities that may similarly impact food resource.

4.6 Cumulative impacts

There is also the issue of cumulative impacts of multiple extraction areas in close proximity. With multiple licences, communities can be subject to additive levels of secondary (plume) effects (Cooper *et al.*, 2007b), with the possibility of altering the sediment substrate to a greater extent than extraction at one site alone. The industry-led Regional Environmental Assessments (REAs) investigated cumulative impacts of aggregate extraction in five different regions of the UK; this process is further described in Chapter 5. Repeat licences at the same site can also lead to the creation of permanent features, such as the depression formed on the Kwintebank (ICES, 2006; Vanaverbeke *et al.*, 2006; Van Lancker *et al.*, 2010). The new hydrodynamics around this depression have led to a different and unstable sediment type and a differing benthic community.

In addition, impact on the seabed is not limited to aggregate extraction, but also includes other human activities such as fishing, dredge material disposal, and wind-farm development. These differing activities cause physical and biological impacts to the marine environment, which may further increase biological and physical impact/stress at aggregate sites. Therefore, there is a need for integrated management of the exploitation of marine resources that goes beyond the single protection of species and habitats within an aggregate site.

Overall, there is still a continuing need for work to further resolve the cumulative effects of multiple licence areas on wider aspects of ecosystem function, including a greater emphasis on potential effects on species and communities of conservation and economic significance at a regional scale (Newell and Measures, 2010; Tillin *et al.*, 2011). Cumulative assessments are also becoming increasingly important as marine spatial planning develops, allowing the management and mitigation of combined human activities (Tillin *et al*., 2011). These assessments are beginning to be assessed through the Regional Environmental Assessments, which have looked at the cumulative assessments at a regional level (Chapter 5).

4.7 Recovery

Numerous studies have investigated recovery after dredging has ceased. The ALSF has also produced a monograph series on recovery that describes the key physical and biological impacts and the contributory factors affecting them, as well as reviewing key case studies (Hill *et al*., 2011).

4.7.1 Physical recovery

The definition of physical recovery is provided in Section 4.3, which also covers physical recovery in detail as it proved impossible to separate the physical impacts of aggregate extraction from the recovery of the physical environment after the cessation of dredging. A summary of physical recovery is provided in Table 4.1 below.

Table 4.1. Recovery rate of physical environment according to sediment type, hydrodynamics, and dredging intensity.

Recovery of topography		Extensive dredging	Intensive dredging
Sandy sediments	High hydrodynamism	Depending on site characteristics; < 1 year	Low–strong modification of topography depending on site characteristics; site-dependent; < 10 years to "never"
	Low hydrodynamism	Depending on site characteristics; >1 year	Strong modification of topography and potential recovery of sediment depending on site characteristics; >10 years to "never"
Coarse sediments	High or low hydrodynamism	Depending on site characteristics; ~10 years	Strong modification of topography and low potential recovery of sediment depending on site characteristics; 20+ years to "never"

4.8 Biological recovery

4.8.1 Benthos

Biological recovery is determined to have occurred when the benthic community composition, abundance, and biomass is similar to that which existed prior to dredging. However, in practice, being similar is quite often considered as not statistically differing, which is often not realistic for benthic community composition when the post-dredge sediment is different from the initial one, such as in Dieppe (Desprez *et al*., 2014). In that situation, the initial homogeneous bottom of coarse shelly sands has evolved to a heterogeneous seabed with several habitats (crest of pebbles, grooves with heterogeneous muddy sediments, surrounding areas with deposition of fine sands) with corresponding communities. The benthic composition is mainly dependent on the sediment composition of the site, so with this insight, it is important that sediment composition pre- and post-dredging is similar. However, "similar" sediments are hard to define as well; therefore, in the UK, work is now ongoing to define recovery by the use of the particle-size distribution of the sediment (Section 4.3.2, UK case study). Biological recovery is determined by local hydrodynamics, type of benthic community, range of sediment particle size, and changes in substrate type. Rate of recovery has been shown to be inversely proportional to dredging intensity (example shown in Figure 4.4), taking a few months in less intensively exploited sites (< 1 h ha^{-1} $year^{-1}$) and up to several years in intensively exploited sites (>10 h ha^{-1} $year^{-1}$) before the pre-dredge biomass is reached (Cooper *et al.*, 2007a; Foden *et al.*, 2009; Desprez *et al.*, 2014).

Recovery rate is also linked to the surface of the disturbed area, with a more rapid recovery at smaller sites than at larger sites (Foden *et al.*, 2009) in relation to the proximity or remoteness of recolonizing adults. Foden *et al.* (2009) undertook a study looking at biological recovery in a range of substrate types and hydrodynamic environments and found biological recovery to be exceptionally varied, taking longer in areas of low-energy hydrodynamics independent of sediment type. Recovery varied from less than one year (Wustrow, Baltic Sea) to decades (Area 222 in the UK; see Recovery Case Study 1). Cooper *et al.* (2011a, 2011b) studied various aggregate areas in the UK and found that changes in sediment composition was more (or less) important for faunal recovery depending on the initial sediment and the degree of natural disturbance, i.e. in certain areas (generally sandy environments with a high natural disturbance), changes in sediment composition did not matter with regard to faunal recolonization, while in other areas (more stable gravel environments with a low natural disturbance), changes in sediment composition were a large factor in faunal recovery. The Cooper *et al.* (2011a, 2011b) studies also found that the proportion of gravel was important in determining sensitivity and recovery at aggregate extraction sites.

As previously mentioned, the duration of biological recovery is linked to the type of benthic community and hydrodynamic conditions of the site (ICES, 2009). In general, community biodiversity tends to increase with size and heterogeneity of the sediment and with substrate stability. Sandy habitats have a high resilience, with predominately infaunal species adapted to natural disturbances and quickly able to recolonize an extraction site. In contrast, gravel-bottom communities tend to be more stable and characterized by slow-growing species with a long life cycle. Therefore, it takes longer to recolonize these extraction sites (Chesworth, 2007).

Regarding coarse substrate, recolonization at Hastings Shingle Bank (HSB) in the UK has been studied for a number of years looking at both low- and high-intensity dredged areas, without any impact from screening. Recolonization was observed to be relatively rapid after cessation of dredging (Cooper, 2005; Cooper *et al.*, 2007a), with conditions being suitable for colonization by *Sabellaria spinulosa* (Pearce *et al.*, 2007). Biological recovery (in terms of species variety and population density) was observed in deposits exposed to lower levels of dredging six–seven years after cessation of dredging (Boyd *et al.*, 2004; Cooper *et al.*, 2007a). The potential for full recovery has been related to the physical nature of the seabed not being permanently altered by dredging (Cooper *et al.*, 2008). At a site in Dieppe, recovery monitoring showed that the number of species rapidly recovered after two years and that abundance was much higher than the reference site after seven years due to the proliferation of opportunistic species; however, biomass remained 50% lower after 15 years (Figure 4.6; Desprez *et al.*, 2014).

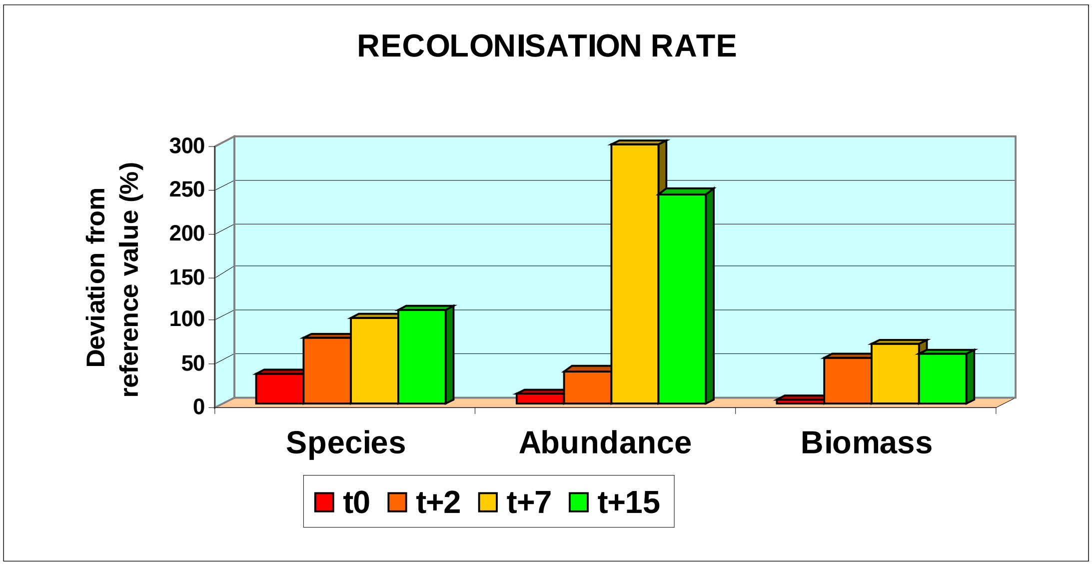


Figure 4.6. Evolution of the species number, abundance, and biomass of benthic communities on the former intense extraction site of Dieppe between 1995 and 2010. The *y*-axis shows the deviation (expressed in percentage of the reference values).

Recolonization in Area 222 in the UK has also been studied for a number of years, again investigating recovery at both high- and low-intensity dredged areas (see Recovery Case Study 1). Preliminary observations of biological recovery 4 years after cessation of dredging indicated that the fauna remained in a perturbed state (Boyd *et al.*, 2003). The most recent observations 11 years after cessation of dredging (Wan Hussin *et al.*, 2012) indicate that biological recovery has still not taken place in the high-intensity area and is predicted to take 15–20 years.

Recovery Case Study 1: Area 222, UK

Dredging ceased at Area 222 in 1996, and studies have focused on the residual effects within areas subjected to high- and low-intensity dredging.

The first study by Boyd *et al.* (2004) undertook sampling four, five, six, and seven years after cessation of dredging. Results indicated that there was no evidence of a shift to smaller-sized epifaunal specimens at the dredged sites; instead, there was an absence or reduction in the abundance of epifaunal species belonging to smaller size classes, which is equated to a decline in productivity. In comparing high- and low-intensity dredging areas Smith *et al*. (2006) noted that the diversity and abundance of epifaunal assemblages were generally lower at intensively dredged treatments compared to reference stations. This study also noted that, at times, mobile decapod crustaceans and certain fish and gastropod mollusc species were recorded at intensively dredged treatments, which may be indicative of the epifaunal community response to disturbance.

Studies by Boyd *et al.* (2003, 2004) investigated the recovery of areas exposed to high and low levels of dredging intensity. Abundance and total numbers of species were significantly lower in an area most recently exposed to the highest level of dredging intensity compared to samples taken from an area of low intensity and from a reference site. Multivariate measures indicated that there were significant differences between macrofaunal assemblages in the areas exposed to different dredging intensities. Sediment in the highest-intensity dredging area contained proportionally more sand than other sampled sediments.

Observations on physical recovery (Boyd *et al.*, 2004) note that the physical effects (i.e. presence of weathered dredge tracks or pits) can be detected at least ten years after cessation of dredging. Sediment at the high-intensity site is noted to be much finer than both the lower-intensity dredging and reference sites seven years after cessation of dredging (Cooper, 2005). Physical recovery was later observed to be almost complete 11 years after cessation of dredging (Wan Hussin *et al.*, 2012) in the high-intensity area, allowing biological recovery to take place. However, it should be noted that the highest-intensity areas (regions of static dredging) were not subject to assessment, and physical recovery in these areas could take much longer.

Preliminary observation of biological recovery four years after cessation of dredging indicate that the fauna remains in a perturbed state (Boyd *et al.*, 2003). Observations seven years after cessation of dredging continue to show fauna remaining in a perturbed state in areas previously subjected to high levels of dredging intensity (Boyd *et al.*, 2004), and distinct differences in the nature of the assemblage when compared to low-intensity dredging areas (Boyd *et al.*, 2005; Cooper, 2005). Deposits exposed to lower levels of dredging are observed to be substantially recovered 6–7 years after cessation of dredging (Boyd *et al.*, 2004; Cooper, 2005). Recent studies 11 years after cessation of dredging (Wan Hussin *et al.*, 2012) indicate that biological recovery has still not taken place in the high-intensity area and is predicted to take 15–20 years.

Overall in gravel habitats, after an initial colonization within months of cessation, the restoration of species richness and biomass can take more than ten years (Cooper *et al.* 2007a; ICES, 2009). However, in a highly dynamic environment continuously subjected to disturbance, full recolonization can occur much faster (Robinson *et al.*, 2005).

In sandy environments, biological recovery tends to be quicker (van Dalfsen *et al.*, 2000; Moulaert and Hostens, 2007; Recovery Case Study 2), as these environments are typically poor in species and biomass. However, recovery still varies depending on location, local hydrodynamics, and any changes in sediment. For example, in sandy areas with high hydrodynamics, Chesworth (2007) found no detectable change in sediment composition. Consequently, a fairly rapid return to the original community was observed because of the capacity of species to withstand natural perturbation of the bottom sediments. In more stable sandy environments, such as a site located in the Adriatic Sea, an initial rapid phase (6–12 months) of recolonization by the original species was observed, followed by a slower phase of restoration ending 30 months after the cessation of extraction activity (Simonini *et al.*, 2007).

RECOVERY CASE STUDY 2: KWINTEBANK, BELGIUM – BIOLOGICAL AND PHYSICAL RECOVERY

Analyses of the records of ship registers and electronic monitoring systems of trailer suction hopper dredgers reveal that, from the beginning of extraction in 1976 until 2005, 75% of the total extracted volume of aggregate in Belgium originated from only one sandbank: the Kwintebank. This has resulted in the closure of two areas of the bank with deep depressions, one in February 2003 (Degrendele *et al.*, 2010), with the second (located to the north) closed in 2010, as federal legislation prohibits further exploitation when a deepening of 5 m occurs with respect to the most recent hydrographical charts.

An understanding of the morphological evolution of both depressions is based on data obtained: (i) from measurement before closure for extraction in both depressions and (ii) on the subsequent post-dredging evolution until November

2010 (Degrendele *et al.*, 2010; Roche *et al.*, 2011). Sedimentological and morphological analysis based on data acquired in 1999–2010 (before and after extraction) shows the stability of both depressions of the Kwintebank after cessation of dredging. Multibeam echosounder data demonstrates that, regarding bathymetry and geomorphology, extraction has a local (non-cumulative) impact and that potential recovery is nonexistent (Bellec *et al.*, 2010; Degrendele *et al.*, 2010). These results also demonstrate that, at a decadal scale, the sand of the Kwintebank should be considered as a nonrenewable resource and that extraction has a local (non-cumulative) impact.

The biological study in both depressions has assessed the impact of intensive extraction after the closure of the areas on the Kwintebank. For both closed areas on the Kwintebank, similar patterns have been observed within the biological recovery processes. For the central depression, the observed trends are statistically significant, while this is not the case for the northern depression. Nevertheless, there is, in both areas, a rapid increase in density, mainly due to opportunistic, interstitial, and juvenile species, which are the same in both areas. However, density in the central depression remains very low compared to what is expected in similar habitats. Species richness and diversity also increase one–two years after cessation of dredging. After two years, these community parameters stabilize and show natural variation over years. Community structure in both areas does not show any large shifts over years, but in the central depression, there was evidence of an impoverished community in (spring) 2003 (De Backer *et al.*, 2011).

It is, however, not possible to conclude whether the benthic community has fully recovered to pre-extraction conditions because sampling started only after cessation of dredging activities. Furthermore, extraction goes back more than 30 years, and there is no exact knowledge of the pre-impact situation of these communities. However, present results indicate that during sand extraction, community impacts were generally much lower than expected, and that recolonization started as soon as anthropogenic pressure stopped. This suggests that there are no immediate long-term effects of the intensive dredging activities on the Kwintebank, and that it takes the surrounding community only one–two years to colonize the impacted area in these highly dynamic sandy areas. Biomass recovery, however, takes longer, ranging from two years in the northern depression to five years in the central depression (De Backer *et al.*, 2011).

The infilling of dredge furrows by sand and fine sediment particles can lead to a shift in sediment composition, with associated implications for the recovery of species assemblages, such as colonization by new communities, for example, those characteristic of mobile sands (Boyd *et al.*, 2005; Cooper *et al.*, 2007a; ICES, 2009; Ware *et al.*, 2009; Desprez *et al.*, 2010; Hill *et al.*, 2011). Enhanced numbers of mobile decapods, certain fish species, echinoderms, and gastropod species are observed in areas recently exposed to high-intensity dredging. This invasion of mobile scavengers and predators, mainly through migration of adults, is a common feature of disturbed areas that provide suitable food availability (Smith *et al.*, 2006). Thus, where sediment conditions change significantly and permanently, recovery to an original biological community may not be possible.

Despite the various studies investigating benthic recovery, few are on a sufficient timescale to document full recovery. For example, Newell *et al.* (2004b) studied the recovery at Area 122/123 after ten years of dredging, and while the authors could report that population density had been restored to 60–80% of the surrounding deposits within approximately six months, biomass restoration was not complete at the end of the study (18 months later). Therefore, there is uncertainty in predicting recovery times, especially given the environmental (local hydrodynamics and range of particle size) and extraction (degree of screening) variables within each aggregate site. Physical change and recovery are also linked to benthic recovery, and this is also likely to vary depending on the intensity and method of extraction as well as the area over which sediment has been removed. A UK project recently provided a tool, different from the traditional monitoring of restoration sites after cessation of extraction activities (Frost *et al.*, 2007; Newell *et al.*, 2007), which has shown the limitations in predicting recovery. Recovery requires long (and unpredictable) periods (Newell and Garner, 2007; ICES, 2009). This new tool provides a predictive framework for the restoration of the biodiversity and structure of benthic communities based on knowledge of the life cycle of the species (reproduction, growth, longevity, habitat preferences, and sensitivity to interference). A summary of benthic recovery is provided in Table 4.2 below. More in-depth reviews of recovery can be found in Foden *et al.* (2009).

Table 4.2. Recovery rate of benthos according to sediment type, hydrodynamics, and dredging intensity.

Recovery of benthos		Extensive dredging	Intensive dredging
Sandy sediments	High hydrodynamism	< 1 year	< 5 years
	Low hydrodynamism	>1 year	< 10 years
Coarse sediments	High or low hydrodynamism	5–7 years	15–20+ years

4.8.1.1 Higher trophic levels

Experimental trawling undertaken between 2004 and 2006 in the different subareas of the commercial site of Dieppe (Desprez, 2008; Desprez *et al.,* 2014) showed that the dominant fish species are characteristic of new/disturbed sediments and their associated benthic prey:

- Sole and plaice are a constant presence in the fine sands of the deposition area of overflow, colonized by bivalves and mobile endofauna.
- Black bream is the dominant species of the coarse bottoms of the dredge and fallow areas, where they feed on opportunistic decapods.
- Gurnard and black bream are the characteristic species of the heterogeneous sediments of the former dredged area recolonized by a more diverse fauna with shrimps and dragonets.

Ten years after the cessation of extraction, the results achieved in Dieppe showed higher values for species number (+17%), abundance (+60%), and biomass (+80%) of the recolonizing fish community at the dredged site compared to the reference sites, whilst recolonization by benthos was not fully achieved. Recently, the fish monitoring of an experimental extraction in Baie de Seine provided useful information on the recovery rate of the original fish community (Desprez *et al.,* 2014). The area was subjected to one month of intensive extraction, removing 150 000 t. Species numbers recovered after 1.5 years, while abundance had fully recovered after 2.5 years. In this case, the original benthic community had recovered after two years. Overall, the above studies seem to suggest that full benthic recovery may not be required for fish and higher trophic-level recovery to take place. However, this is not conclusive evidence based on just the two studies presented, and further work is required.

4.8.2 Ecosystem function recovery

Cooper *et al.* (2008) assessed the use of different metrics/indices (infaunal trophic index, somatic production, biological traits analysis, taxonomic distinctness, and Rao's quadratic entropy coefficient) to investigate the rate of recovery on ecosystem function after recent aggregate extraction activity at the Hastings Shingle Bank (UK). All of these indices behaved in a broadly similar fashion, and the results obtained from each functional analysis technique were compared with the results of traditional metrics of assessment (e.g. number of species, abundance, biomass). In the case of low-intensity dredging, the functional capacity of the macrobenthic assemblage appeared to have recovered in less than five years, at least one–two years before recovery as measured by traditional techniques (six–seven years). However, these indices were seen as complementary to traditional metrics of assessment, and while some suggested faster rates of functional recovery, they still indicated that the disturbed area of seabed was capable of a full recovery.

Barrio Froján *et al.* (2011) revisited data from studies (2004 and 2005) previously undertaken in Area 408 in the UK, looking at recovery in terms of functional diversity (compared to traditional univariate techniques). Five years after dredging ceased, recovery of functional diversity had not occurred at either high- or low-intensity dredge sites within Area 408. The authors showed that despite the considerable difference in intensity between the high- and low-intensity sites, dredging had a similar and persistent effect on the benthic assemblages, making it impossible to differentiate among dredged sites. This work suggested that it is the initial act of dredging and not the intensity or persistence that has had the greatest effect. However, this conclusion is difficult to prove at Area 408 because of the proximity of the dredged sites and the screening that took place. Fine sediments from the screening activity could potentially have settled over an area that included the low-intensity site.

Wan Hussin *et al.* (2012) studied the impacts of physical disturbance on recovery of a macrofaunal community in Area 222 (UK). The use of both traditional indices (abundance, biomass, and species diversity) and functional analysis techniques (somatic production, taxonomic distinctness, infaunal trophic index, biological traits analysis, and Rao's quadratic entropy) indicated that macrofauna at a low-intensity dredging site within Area 222 had fully recovered at least seven years after dredging ceased. At a high-intensity dredge site within Area 222, most of the indices recorded that recovery had yet to take place even 11 years after cessation of dredging.

Given the fish results from the Desprez (2008) and Desprez *et al.* (2014) studies, where fish recovery took place despite the lack of full benthic recovery, more research will be required to fully understand the drivers in ecosystem-function recovery. Species-specific factors such as trophic adaptability in diet may influence the significance of impacts and functional recovery on a local scale. However, the ability of species at higher trophic levels to adapt will also be influenced by the cumulative effects of dredging, along with other activities that may similarly impact food resources.

In addition to benthic recovery, where sediment conditions change significantly and permanently, recovery to an original biological community may not be possible. However, if communities are able to reach a new "equilibrium" of species, adequate recovery may have taken place in terms of the ecological functions the community provides

(Hill *et al.*, 2011), as shown with the increased habitat diversity in Dieppe (Desprez *et al.*, 2014).

4.9 Importance of dredging intensity for effects and recovery

Dredging intensity also plays a role in impacting the biological and physical environment. The first anthropogenic sediment disturbance, such as dredging, in a previously unaffected site generates the highest mortality of biota; subsequent repeat activity will result in relatively less damage per dredge (Jennings and Kaiser, 1998; Desprez *et al.*, 2014). Most of the macrobenthos live in the upper 30 cm of sediment, (which is also the depth to which most UK dredgers remove surface sand and gravel in one pass of the draghead), so mortality rates are directly related to the surface area of extraction (van Dalfsen *et al.*, 2000). After this layer has been removed, continued dredging beyond that depth is unlikely to have any further significant biological impact. Therefore, this suggests that a lower-intensity dredge over a larger area has more impact than high-intensity dredging in a smaller area (on the benthic fauna at least), although it can also be said that lower-intensity dredging is more likely to leave areas of relatively undisturbed sediment/fauna that can act as refuge areas, aiding recolonization. Extensive spatial extraction results in fragmentation of original habitat in a mosaic of areas, grooves without fauna, undisturbed areas, and intermediate areas affected by unstable and deposited sediments (due to overflow and/or screening), but without functional consequences (e.g. no reduction in biomass) on the higher trophic levels (Bonvicini Pagliai *et al.*, 1985; Hobbs, 2006; Impacts case study: Fish in the eastern English Channel, Section 4.5.2.2).

Ware *et al.* (2010) also suggest that intensive dredging over a small area is less damaging than low-intensity extraction of large volumes over a wide area (however, they do note that (i) longer-term changes relating to bathymetric, hydrological, and sediment substrate change must be considered following cessation of dredging, (ii) the volumes extracted from the high-intensity site were relatively low, and (iii) results might change with the removal of larger tonnages). In this case, abundance especially seemed to be less affected by high-intensity dredging. Again, the reasoning for their suggestion is that benthic species are either epifaunal or infaunal and inhabit only the top 10–20 cm of sediment; once removed, there is little more significant impact. Within the Ware *et al.* (2010) study, volumes extracted at the high-intensity site were relatively low, and it is noted that if large volumes had been removed, the results may have been different. However, research by Barrio Froján *et al.* (2011), looking at ecosystem-functional diversity, seems to support the Ware *et al.* (2010) conclusions concerning dredge intensity.

On the other hand, recovery after low-intensity dredging may be quicker than after high-intensity dredging because it can leave undisturbed deposits between dredged furrows that may provide an important source of adult animals that can migrate in and recolonize impacted areas (Hill *et al.*, 2011). Hill *et al.* (2011) also stated that recovery has been found to be more rapid where dredging intensity was low or limited to small areas. Eggleton *et al.* (2011) stated that in regions of low–moderate natural disturbance, low-intensity dredging over a wider area could result in faster recovery of biological communities (using traditional metrics of species density and diversity). However, Eggleton *et al.* (2011) goes on to state that this recovery was not necessarily comparable to reference conditions and could be more of a colonization community, as discussed by Cooper *et al.* (2007a). In terms of physical recovery, Cooper (2005) found that intensive dredging left a very uneven seabed topography compared with the lower-intensity dredging. In addition, they found that dredge tracks in high-intensity sites were narrow and deep, while those in less intensive areas were wide and shallow, with the wide and shallow tracks seeming to recover more quickly. The latter is in contrast to the view that once the top layer of sediment is removed, there is little further significant impact to the benthic community.

The experimental extraction in the Baie de Seine demonstrated the role of extraction intensity on the benthic community of a sandy gravel area (Table 4.3; Desprez *et al.*, 2014).

Table 4.3. Effects of extraction intensity on the main benthic population indices in the Baie de Seine (Desprez *et al.*, 2014).

Parameters (% reference value)	Low intensity (<1 h ha^{-1} year^{-1})	Medium intensity (4 h ha^{-1} year^{-1})	High intensity (10 h ha^{-1} year^{-1})
Species number	93	78	58
Abundance	68	34	29
Biomass	46	26	19

At low intensity, the number of species was unaffected, while the decreases in abundance and biomass were already strong. With increasing intensity, species number progressively decreased, while the impact on abundance and biomass seemed to progressively stabilize. The results from this short-term experiment (one year) show differences compared with impact levels reviewed in Hill *et al.* (2011), but are in accordance with observations of Cooper (2005).

4.10 Restoration

Where seabed sediments have been significantly and permanently changed, there is a question concerning the need for restoration. There are legislative requirements for restoration within the OSPAR Convention 1992 and in various European Directives (Cooper *et al.*, 2010). In UK licences, there is a condition to ensure that similar substrate is present at the cessation of dredging. Where similar substrate is not left in place, enforcement actions could be taken to restore the habitat. Restoration is further discussed in Chapter 5 because it is predominately a post-extraction mitigation technique.

4.11 Environmental indicators

Environmental indicators are described by Ware *et al.* (2010) as "a measure, or suite of integrated measures, which synthesise a large amount of relatively complex environmental information into a single metric for which a known cause-effect relationship exists."

In 2006, the European Commission adopted the Marine Strategy Framework Directive (MSFD) to protect the marine environment, endorsing political commitment from EU Member States to consider an ecosystem approach to marine planning and management. The MSFD has raised the profile of indicators as an effective method of determining good environmental status (GES), with indicators required for use within each of the 11 descriptors of GES. Indicators should be (Ware *et al.*, 2010):

- legally robust and relevant to the regulatory or policy objectives in question,
- responsive: sensitive and tightly linked in time to a manageable human activity,
- communicable: relatively easy to understand by non-scientists and those who will decide on their use,

- measurable and representative over the spatial scale to which the indicator is to be applied,
- based on readily available, routinely collected, and cost-effective data of known quality,
- based on existing time-series data and known stressor–response relationship, with corresponding target levels or thresholds that signal the onset of conditions that may result in significant ecosystem degradation.

Regarding aggregates, indicators would be useful as a measure of changes in the ecosystem or for changes in a particular receptor (e.g. benthos) under different pressures related to aggregate extraction. Ware *et al.* (2010) provided options for aggregate indicators based on impacts to the physical and biological environment, including the percentage of silt/sand and gravel and benthic indices such as diversity and biomass (Van Hoey *et al.,* 2010). Other indicators such as biological traits of benthic community (Bremner *et al.*, 2006, 2008) and habitat heterogeneity (Hewill *et al.*, 2008) have also been proposed. Criteria for species richness and abundance typically used to summarize the conclusions of most monitoring actions using benthic communities prove that the indicators are effective and understandable (Ware *et al.*, 2009). They are also usual components of disturbance models because they generally respond well and are measurable along well-defined gradients; increasing extraction intensity usually results in a corresponding decrease in the number and abundance of species. Nowadays, benthic indicators are used in the evaluation of the impact of certain human activities on benthos (Josefson *et al.*, 2009; Borja *et al.*, 2011a) or in the evaluation of good environmental status under the MSFD (Borja *et al.*, 2011b; Van Hoey *et al.*, 2013). However, while some indicators are used to a certain extent already, there is further work to be done for indicators to be used as a method to assess the impacts of aggregate extraction.

4.12 Knowledge gaps and future priorities

While much is known about the impacts of aggregate extraction, the degree of knowledge and man's ability to predict the extent of impacts associated with dredging on physical and biological features are variable, with some impacts being better understood than others. A report by Walker *et al.* (2013; Tables 4.4–4.6) examined the current scientific understanding of the impacts, our ability to predict these impacts, and the degree of change associated with them.

Table 4.4. Summary of conclusions from dredging predictions – direct impacts (from Walker *et al.*, 2013).

Prediction	Predictable change?	Degree of change predictable?
Prediction – dredging modifies the sediment substrate.	Yes – dredging causes changes in particle size in stable sediments due to changes in sediment size with resource depth or deposition of overspill and screening material. In mobile environments, sediment can be predicted not to change significantly as long as natural sediment movements remain.	No – at a fine scale, it will not always be possible to predict changes in sediment resource with depth. It will not be possible to predict the degree of change in sediment (i.e. fining) due to deposition of screened material.

Prediction	Predictable change?	Degree of change predictable?
Prediction – dredging modifies the topography of the seabed.	Yes – dredging will cause furrows or pits and modify the seabed depth.	No – the reworking of surface sediment to remove furrows or pits is dependent on local hydrodynamic conditions. The degree of sediment infilling and seabed movement will be dependent on local sediment transport conditions.
Prediction – dredging reduces the abundance, diversity, and biomass of the macrobenthic community.	Yes – dredging will cause changes to the benthic community that will commonly result in a reduction in the abundance, diversity, and biomass of the macrobenthic community.	No – the degree of change will be dependent on site-specific factors. There are many variables that influence changes to the benthic community. As such, this does not allow precise predictions of the exact changes to be made.
Prediction – dredging will cause an increase in suspended sediment.	Yes – a proportion of sediment will be dispersed into the water column when the vessel is dredging.	Yes – there are a number of modeling tools to predict the dispersion and water-column concentration of suspended sediment material.

Table 4.5. Summary of conclusions from dredging predictions – indirect impacts (from Walker *et al*., 2013).

Prediction	Predictable change?	Degree of change predictable?
Prediction – dredging will cause a secondary footprint due to deposition of suspended sediments.	Yes – if screening is undertaken, the proportion of sediment dispersed into the water column is likely to settle beyond the dredge area.	Yes – in part. The footprint of likely change can be predicted using numerical modeling. The degree of sedimentary change is dependent on a number of site-specific impacts and cannot be predicted.
Prediction – the secondary footprint of sediment deposition will reduce the abundance, diversity, and biomass of the macrobenthic community.	No – evidence presents differing results, and it is not possible to predict with certainty that there will be an adverse impact to the macrobenthic community within the secondary footprint.	No – where impacts have been detected, the distance of impact and the degree of change is variable.
Prediction – negative impacts to the benthic community will impact higher trophic levels (predators) via loss in food resource.	No – individual species will adapt to the change/loss in benthic food resource differently; therefore, the response may not always be an adverse impact.	No – there will be many influencing factors such as the feeding ecology of local species, cumulative effects, the response to changes in the benthic community (e.g. potential to adapt to feed on

Prediction	Predictable change?	Degree of change predictable?
		high abundance of opportunistic species).
Prediction – dredging and associated sediment suspension will cause disturbance of mobile species.	No – while there are potential risks of disturbance, the significance of any response by mobile species is not well understood.	No – site-specific factors and external cumulative impacts will affect the degree of disturbance so it is impossible to know the extent to which marine species will be disturbed by the activity.
Prediction – changes in seabed morphology will cause changes to wave condition and tidal currents.	Yes – depending on the suitability of a numerical model and associated data, changes to wave and tidal conditions are predicted to change due to changing bathymetry and topography within the dredge area.	Yes – similar models exist that can predict changes to wave and tidal conditions. If suitable data are available to calibrate and validate the model, the degree of change can be predicted. However, this change needs to be placed in the correct spatial and temporal context.
Prediction – changes in seabed morphology will impact the coastline via changes to sediment transport and beach drawdown.	Yes – creation of digital elevation models (from swath bathymetry records) over several years can identify areas of accretion and erosion and associated transport rates.	No – gross predictions of sediment transport rates are available from models, but these have not been thoroughly calibrated. Detailed predictions on local-scale morphology changes are still in the research area.

Table 4.6. Summary of conclusions from dredging predictions – recovery (from Walker *et al.*, 2013).

Prediction	Predictable change?	Degree of change predictable?
Prediction – the seabed substrate and morphology will recover following cessation of dredging activity.	Yes – all studies indicate that a degree of physical recovery does occur on cessation of dredging. However, there is variation in length of time to reach the final endpoint within the evidence and it, therefore, cannot be predicted.	No – it is not possible to predict the length of time for full physical recovery to occur, due to a number of site-specific factors.
Prediction – the benthic biological community will recover following cessation of dredging activity.	Yes – all studies have shown some degree of recovery after cessation of dredging. However, there is variation in the length of time it takes for full recovery to be achieved, if at all, which cannot be predicted.	No – it is not possible to predict the length of time it will take for full biological recovery, due to a number of site-specific factors.

The above tables show that even with a comprehensive evidence base, there are still gaps in knowledge, and it is difficult to predict the impacts of aggregate extraction in the marine environment. However, it is necessary to understand and quantify the pressures and impacts from aggregate extraction and other human activities to underpin effective environmental impact assessment and marine planning and to provide the basis for integrated marine management (Eastwood *et al.*, 2006; Borja and Dauer, 2008;

Halpern *et al.*, 2008; Foden *et al.*, 2009). Further work and data are necessary to enable predictions of impact and degree of impact to be made.

However, there is no database where all data concerning aggregate extraction are held. For example, in the UK, while industry monitoring data can be made available for specific projects, it is not readily available in a database for use. Such a database, encompassing all ICES Member Countries, would increase the data available for research projects and may help to answer some of the gaps identified in Tables 4.4–4.6 (Walker *et al.,* 2013), further helping to ensure effective marine management. However, work would be required to ensure that the data were compatible for combined use.

4.13 Recommendations to ICES (for future ICES WGEXT work)

- Create an ICES database containing all aggregate related data. The database should include scientific research and EIA licensing and monitoring data.
- Ensure standardization of data across ICES Member Countries.
- There is still a need to further investigate the cumulative impacts of multiple licence areas and activities on the marine environment, especially regarding wider ecosystem function. Cumulative assessments are becoming increasingly important with the development of marine spatial planning, allowing the management and mitigation of combined human activities (Tillin *et al*., 2011).
- Cumulative assessment guidance and framework for assessment should be developed. It is acknowledged that this work may be developed within another ICES or OSPAR working groups, and steps should be taken to investigate and align guidance as appropriate.

4.14 Conclusions

The impacts of aggregate extraction are well known and understood. Yet, despite a large evidence base, the predictability of an impact and the degree of change are not always known, with further research being required. The need for marine aggregates is unlikely to diminish in future years, especially given the planning constraints and resource exhaustion from terrestrial sources. Therefore, moving forward, WGEXT will continue to detail research developments on the impacts of marine aggregate extraction. In particular, further research is needed concerning cumulative effects, and WGEXT will have to pay particular attention to requirements under the MSFD, particularly the descriptors concerning the state of the seabed (Descriptor 1: Biological diversity, Descriptor 6: Seafloor integrity, and Descriptor 7: Hydrographical conditions).

5 Approaches to mitigation of the effects of dredging activities and associated monitoring

5.1 Introduction

There is a growing awareness of the environmental consequences of marine aggregate extraction, highlighting the need for sustainable exploitation of marine resources to meet society's increasing demand for supplies. The geomorphological and especially the ecological implications, benefits, economic requirements, and governance aspects associated with extraction all require assessment prior to dredging taking place.

Sand and gravel extraction will have an impact on the seabed at the dredge site and potentially its surroundings. Effects can be short- or long-term and/or cumulative. Many studies have revealed that some effects of extraction may be measurable long after the activity has finished, whereas other effects are short-term and localized (see Chapter 4). In order to describe the impacts, it is necessary to understand the dynamics and relationships in the chain of effects between project, dredging methodologies, and ecosystem. Only through this understanding and collection of sound information can the decision-making and licensing take place, upon which monitoring and mitigation can be based.

Current legislation is designed to ensure that dredging is only permitted where the proposed activity has no unacceptable impacts on the marine environment and maritime heritage. Extraction activities will continue to be in competition with other activities and sea users. Therefore, extraction operations need to be planned and managed carefully, with a need to assess the consequences of the total chain of activities. The granting of permits to extract sand and gravel lies with competent authorities, with differences in approaches and procedures within ICES Member Countries (see Chapter 6).

An environmental impact assessment (EIA) is an essential part of the licensing procedure. It is aimed at identifying and describing the predicted impacts of the extraction activity on the marine environment, but also includes cumulative impacts and impacts on other interests. Where significant adverse impacts are expected, measurements can be proposed that mitigate these effects on the environment. Under the EC Directive 85/337 (EIA Directive), mitigation is defined as "measurements envisaged in order to avoid, reduce, and, if possible, remedy significant adverse effects". Such measurements can be taken before the actual activity starts (pre-dredging), during the dredging activity, or after the dredging has ceased (post-dredging), the latter to enable or facilitate restoration or recovery processes.

Mitigation measures and compliance monitoring are generally specified as licence conditions and could include, e.g. area restrictions or zoning, seasonal restrictions, and prohibitions on screening. It is, therefore, essential to monitor progress of the works to verify the predictions made by the EIAs, measure actual impacts of the works, and assess effectiveness of the mitigation measures. Through this, additional mitigation measures could be brought forward if any unacceptable and/or unexpected adverse impact is observed. Monitoring is also important to follow the development of the dredging site after the activities have ceased to provide information for future projects on recoverability of the marine environment and to ensure that no adverse impacts have occurred as a result of the dredging activities.

A monitoring programme should be developed, for which suggestions are given in the ICES Guidelines (ICES, 2003), for the management of marine sediment extraction.

Monitoring should be site-specific and should have clearly defined objectives identified 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 if the impacts are as predicted in the environmental statement.

So far, WGEXT has not assessed options for, or differences in, dealing with mitigation amongst ICES Member Countries; therefore, a clear view on mitigation is not available. This chapter is a first attempt and reviews mitigation measurements and the accompanying monitoring. Research and monitoring aimed at describing the impacts of dredging activities were described in Chapter 4.

5.2 Reasons for mitigation and monitoring

Mitigation and monitoring are aimed at avoidance of or minimizing identified and unwanted geomorphological, ecological, or socio-economical implications of an activity. If this still leads to unacceptable situations, actions could be undertaken to repair, rehabilitate, or restore the affected environment or compensate for the impact by replacing or providing substitute resources or environments. It is, however, seldomly looked upon as practical to restore extraction sites to their original state. Monitoring can inform us whether mitigation measurements are sufficient and effective. Therefore, monitoring actions should be carefully designed, planned, and follow proper procedures based on a predefined set of indicators and criteria.

5.3 Legislation

Mitigation measurements could come forward in order to comply with national or international legislation. The marine environment is protected by (inter)national conventions and regulations, such as the United Nations Convention on Law of the Sea (LOSC), the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), the EU Water Framework Directive (WFD), and the EU Bird and Habitat Directives. All of these have the objective of preventing and eliminating pollution and taking measures necessary to protect the maritime area from the adverse effects of human activities, amongst which aggregate extraction is also recognized as potentially harmful. In 2006, the European Commission adopted the Marine Strategy Framework Directive to protect the marine environment, endorsing political commitment from the EU Member States to consider an ecosystem approach to marine planning and management.

Still, (inter)national legislation, policy, and public awareness regarding infrastructural activities relate primarily to economic value, whereas environmental effects are seen as inevitable and should be minimized to acceptable standards. These, however, are often defined without much scientific justification. When effects cannot be avoided, they should be minimized in time and space or even compensated for in other areas.

It is, therefore, necessary to understand and quantify the pressures and impacts from major human activities, such as aggregate extraction, to underpin effective environmental impact assessment and marine planning and to provide the basis for integrated marine management (Eastwood *et al.*, 2006; Borja *et al.*, 2008; Foden *et al.*, 2008, 2009; Halpern *et al.*, 2008). In 2003 the OSPAR Commission appointed a working group on marine spatial planning. From the above, it is obvious that management of the aggregate extraction process is of utmost importance.

The legislative grounds for monitoring and mitigation can differ between the various countries (see Chapter 6). In the UK, site-specific pre-, during, and post-dredging monitoring requirements are part of the licensing procedure. In Belgium, the monitoring of ongoing and finalized extraction activities form part of the general overall monitoring programme for the Belgian EEZ and are not licence-specific. Whilst in the Netherlands, monitoring could be issued as part of the licensing procedure, depending on the scale of the extraction. In several countries, separate studies are conducted and issued by authorities to gain more insights to potential impacts from extraction activities.

5.4 Monitoring and mitigation of maritime archaeology and cultural heritage

During marine sand and gravel mining operations, there is a growing requirement to consider the potential impacts on maritime archaeology and wider cultural heritage. Heritage issues that have to be taken into account include the more obvious ship and aircraft remains, but also evidence relating to prehistoric landscapes, including faunal remains such as mammoth teeth and bones and the early tools used by our ancestors. Archaeology or cultural heritage sites are vulnerable to extraction, and losses cannot be restored. For this reason, guidance on procedures and mitigation measurements are part of the licensing and operating process in several countries.

5.4.1 The Netherlands

Related to historical and archaeological discoveries, a protocol has been set up to manage important archaeological findings. Actions include the ability to stop all activities when items, traces, or remains are detected that could be suspected of having historical, archaeological, or scientific importance. The location of the findings and artefacts found should be reported to competent authorities (Rijksdienst voor het Cultureel Erfgoed, Afdeling Beleid Maritiem Internationaal). Measures should be taken to minimize further impact to the site, and a buffer zone of 100 m around important objects should be maintained.

The province of South Holland initiated a large-scale coastal nourishment of 21.5 million m^3 marine sand under the name “Sand Motor” as an alternative for long-term nourishment needs in order to protect and develop a part of the South Holland coast. Whilst the EIA undertaken included the marine environmental impact of the operation, a large part of the process focused on the effects of nourishment at the coast. The Authorities on Cultural Heritage suggested a new approach, where not only research is executed towards the presence of historical wrecks, but also to the prehistoric landscape and its habitation.

5.4.2 United Kingdom

The British Marine Aggregate Producers Association (BMAPA) has worked in partnership with English Heritage, statutory advisor to the UK Government on England’s historic environment, to develop a Guidance Note which ensures that marine heritage issues are comprehensively addressed at every stage of marine aggregate development and production in English waters. This includes a requirement for seabed mapping prior to dredging in order to establish the positions of any wrecks and debris and the potential for submerged prehistoric landscapes. Where features of archaeological significance are encountered, localized dredging restrictions may be employed, such as exclusion zones.

BMAPA has also developed a reporting protocol for archaeological finds discovered during the dredging process, again in partnership with English Heritage. The protocol has been voluntarily applied by BMAPA member companies across all of its operations and captures over 27 dredging vessels and 60 marine aggregate wharves. The protocol is supported by marine archaeological experts, who provide advice to operators and ensure that finds reported by dredger vessel crews and those working at wharves are able to be correctly identified, recorded, and archived. The protocol acts as a safety net, and where finds relating to ship or aircraft wreckage can be directly related to a particular location, the archaeological experts are able to provide advice to operators on appropriate mitigation measures, such as exclusion zones to prevent further damage before additional investigations are undertaken.

The Guidance Note and Reporting Protocol, together with annual reports and examples of recent finds associated with marine aggregate operations can be accessed through www.wessexarch.co.uk/projects/marine/bmapa/index.html.

5.5 Monitoring and mitigation of environmental receptors

Research is needed to better understand the dynamics and relationships in the chain of effects between the project, dredging methodologies, and ecosystem development so that decision-making and licensing can be based on sound information. Monitoring prior to, during, and after extraction will provide information and data on the impacts of the extraction process as well as on processes that are involved in recovery of the dredging sites. This will feed back into the general EIA process. The information can be translated into required mitigation actions, may lead to revised monitoring requirements, and will allow the development of standards of good practice.

A UK research project recently published updated guidelines for undertaking monitoring at aggregate sites, which provides information for monitoring at all stages of the extraction process[2]. As described in the ICES Guidelines (ICES, 2003), it is important 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.

5.6 Pre-extraction mitigation measurements and monitoring

Monitoring and mitigation are important in the early stages of aggregate extraction licensing. Describing the dredge area and its surroundings before extraction takes place is vital for the decisions on mitigation measurement as well as to establish a baseline for future monitoring and comparison (De Backer *et al*., 2010). To be able to demonstrate possible environmental impacts, monitoring should be conducted in the dredging area (primary impact zone), at sites outside the area of direct impact (but within the sphere of predicted influence or secondary-impact zones), and at sites outside of all influence (reference sites). The reference sites should be similar in terms of habitat characteristics to the primary- and secondary-impact zones.

The environmental impacts of dredging may potentially be reduced beforehand by deciding upon certain practices and mitigation measurements under which the dredging activities are allowed. These can involve spatial and temporal mitigation and application of suitable dredging practices (Lloyd Jones *et al.*, 2010). Spatial mitigation techniques are common in dredging projects worldwide, i.e. potential impacts are mitigated by reducing the total area of seabed dredged (Lloyd Jones *et al.*, 2010). Within individual licence areas, spatial mitigation may also minimize the environmental effects. For example, for the marine extraction of over 200 million m^3 sand needed to develop the Rotterdam harbour extension (Maasvlakte 2), the maximum dredging depth allowed was substantially increased to –20 m below the original seabed to reduce the size of the area affected. Through zoning, the spatial footprint of directly impacted

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[2] http://www.cefas.defra.gov.uk/media/477907/mepf-benthicguidelines.pdf.

areas can also be reduced. Reducing the area dredged potentially mitigates the effects of dredging in a number of ways, including:

- reducing the area of direct removal of biomass,
- allowing the majority of an area to be undredged or undergo recolonization at any particular time,
- restricting total volume per year,
- reducing the area over which sediments are returned to the seabed,
- targeting sediments with low silt and clay content to help reduce the formation of plumes, and
- reducing conflict with other users of an area.

Temporal mitigation measures are aimed at avoiding impacts during certain periods. Restricted dredging or minimizing sediments entering the water column during specific seasons, time-frames, or tidal states, for example, could be installed to reduce the risks to spawning periods (Lloyd Jones *et al.*, 2010). The English aggregate dredging industry mitigates against these effects by adopting temporal mitigation measures, i.e. through minimizing or avoiding screening (or prohibiting dredging entirely) in certain licence areas during particular environmental windows. Temporal mitigation may take place at certain phases of flood or ebb, e.g. during the spring-neap tidal cycle, or over particular seasons. As an example, mitigation of the potential effects of benthic boundary-layer plumes on breeding areas for crab has been achieved by dredging only when the tidal stream transports sediments away from sensitive areas. In Lloyd Jones *et al.* (2010), examples of international case studies are given where spatial and temporal mitigation techniques were successfully used.

Any environmental assessment of aggregate extraction will include identification of physical and biological impacts of dredging. The nature and scale of these impacts will need to be within "acceptable limits" for consent to be granted, including consideration of mitigation measures. Mitigations of physical and biological impacts are identified within environmental statements and may include:

- working within discrete subareas;
- optimizing the distance between other dredging areas;
- delaying implementation of a licence until dredging in adjacent areas has ceased;
- restricting the times when dredging is allowed;
- limiting extraction rates;
- limiting the total quantity of material that can be removed;
- restricting the type of dredger that operates;
- prohibiting the screening of sediments at sea;
- optimizing dredging depth;
- enacting restrictions on sediment quality with respect to silt content.

5.6.1 New approaches in extraction designs

Traditionally, environmental impacts are considered negative, leading to regulators taking the precautionary approach. This has resulted in environmental policies that set restrictions and limitations to the extraction operations. More recently, regulators are assessing the impacts using rigid criteria for physical parameters such as turbidity, overflow, or sedimentation, which are often set at fixed levels. In theory, the setting of such rigid thresholds is intended to protect the natural environment. In reality, however, these criteria often lack ecological meaning and their scientific justification is often poor as they typically ignore site-specific background conditions, particularly spatial and temporal variability, non-linear stress responses, and natural dynamics of the ecosystems involved. The potential post-dredging value of the dredge site is rarely considered, as a result of which opportunities that could improve or add to the overall sustainability of the dredging project are missed. An example of taking into account the post-dredging environment is given below in the case study Building with Nature, seabed landscaping in the Netherlands.

CASE STUDY: BUILDING WITH NATURE – SEABED LANDSCAPING, THE NETHERLANDS

Ecological landscaping in licence areas involves the realization of bed-level gradients and other morphological features in newly dredged pits (Van Dalfsen and Aarninkhof, 2009; Mulder and Van Dalfsen, 2011). Whereas present extraction policies aim at rapid recovery and restoration of the original habitat on the seabed, ecological landscaping aims to promote opportunities for nature and economy through development of new, enriched habitats in landscaped dredge areas. The concept of ecological landscaping in sand mining areas is inspired by terrestrial infrastructure projects, where ecological engineering has almost become a standard component of licensing procedures for sand and gravel extraction operations. Developing a similar approach in the marine environment may facilitate social and political acceptance of future dredging works, thus accelerating licensing procedures and project realization.

In the framework of the Ecoshape Building with Nature programme (www.ecoshape.nl), the case study "Landscaping for ecological enhancement" will investigate the promotion of an ecosystem approach for marine extraction projects through an ecological design and realization, turning threats into sustainable opportunities (http://www.ecoshape.nl/en_GB/seabed-landscaping.html). Through landscaping of an extraction area according to a predefined design of its dimensions (shape and contours), the characteristics of the seabed within the extraction area will be arranged, even with possible effects on the surrounding area. The intention of landscaping is to realize different bed forms and/or combinations of sediment characteristics that will create different habitat conditions. These will result in differences in settlement rates and patterns, ultimately resulting in different benthic communities.

The understanding of the interactions and feedbacks between physical and biological processes can, therefore, be deployed to alter the environment in such a way that ecologically valuable habitats can develop. This, in turn, will attract fish, mammals, and birds, giving opportunities for enhancing the ecological and economic potential of the post-dredging situation.

A pilot dredge area has been designed to test the feasibility of this concept. The pilot experiment will generate answers to questions such as: Do the desired enriched habitats (as observed across natural tidal sand banks) indeed develop into landscaped dredge areas, and if so, on what time-scale; which communities will develop over time, and how long will these habitats persist, etc.? These types of questions can only be addressed on the basis of a real-world pilot experiment. Considering the scale of such an experiment, this can only be achieved by linking the experiment to a running dredging project involving substantial sand mining. The ecological dredged-area experiment was realized in the extraction area used for the Rotterdam harbour extension (Maasvlakte 2). Using this large dredging site as a test, possibilities for landscaping a dredging site can be investigated. Monitoring of such pilot areas must have an effective design that enables evaluation of the approach to connect large- and small-scale impacts, and must indicate its wider applicability.

Application of ecological landscaping in dredge areas implies exchange of the existing habitat into a new habitat, which is not foreseen in current legislation (Aarninkhof *et al.*, 2010). The assessment of post-dredging ecological benefits and their inclusion in evaluation frameworks thus requires a mind shift in current policies, permit requirements, and our approach towards the design and realization of sand mining areas. Present regulations and stakeholder perception may both conflict with the concept of ecological landscaping of dredging sites. Discussions should be started to explore both negative and positive consequences of extraction, as well as to increase awareness of the potential of ecological landscaping.

5.7 Mitigation measurements and monitoring during extraction

Most mitigation implemented during extraction is determined at the pre-dredge stage and is, therefore, discussed above in Section 5.6. Monitoring, whether physical or biological, is undertaken throughout the lifetime of the licence to ensure that the predictions made in the environmental statement (ES) are within the scope of the ES and that there are no impacts beyond what was predicted or described. It is through this monitoring work that the regulator can assess whether the original mitigation measures are suitable and fit for purpose, or whether further measurements are required to limit the impacts on the habitats and species in the marine environment. Monitoring varies widely depending on the sensitivities identified during the EIA.

An example is the fallow experiments (see Figure 4.5 and the associated case study) summarized below:

- Baie de Seine: Impacts were similar between one month of medium intensity and one year of high intensity. Impacts were insignificant (close to nil) with a low-extraction intensity (i.e. extensive extraction).
- Dieppe: Temporal and spatial zoning with low-intensity areas (extensive extraction) provide (i) an area of high benthic abundance and production with opportunistic species of feeding importance for fish, and (ii) increased diversity of habitats.

5.8 Post-extraction mitigation measurements and monitoring

After extraction has ceased at the site, monitoring and mitigation still play a part in the licensing process. Continued monitoring allows the regulator and statutory consultees to follow rates of recovery; this information can be applied to other similar areas. This information can also be used to identify whether mitigation is required to restore conditions at the site to a state similar to that before dredging took place. An example of this may be the need for restoration.

5.8.1 Restoration

Where seabed sediments have been significantly and permanently changed, there is a question concerning the need for restoration. There are legislative requirements for restoration within the OSPAR Convention 1992 and in various European Directives (Cooper *et al.*, 2010). In UK licences, there is a condition to ensure that similar substrate is present at the cessation of dredging. Where similar substrate is not left in place, enforcement actions could be taken to restore the habitat.

Bellew and Drabble (2004) reported on the feasibility and merits of undertaking restoration at marine aggregate dredging sites. Remediation is defined simply as "the action taken at a site following anthropogenic disturbance to restore or enhance its ecological value". There have been several studies investigating small-scale restoration (Collins and Mallinson, 2007; Newell and Garner, 2007; Cooper *et al*., 2011b). Cooper *et al*. (2010) undertook a study to look at various restoration options (bed levelling, dredging/disposal to restore topographic changes, and capping (gravel seeding) and to look at the benefits (results) vs. the costs of undertaking the work (see case study below). Cooper *et al*. (2011b) also undertook a more extensive gravel seeding study in the UK, the results and consequences of which are discussed in the case study below.

In any case, sediments extracted by the aggregate industry represent only a fraction of the high diversity of habitats and marine life (due to a variety of seabed sediment types and various habitats requirements of rare and endangered species). The extraction of marine aggregates is only likely to pose a serious threat to the biodiversity of the wider ecosystem if exploitation involves areas of gravel biotopes that are small and poorly represented in the geographic area and/or if the impacts affect sensitive or threatened species, all of which should be assessed within an EIA prior to extraction being permitted. In addition, it should be noted that a low-intensity dredging strategy adopted in Dieppe, with both spatial and temporal zoning, led to an increase in habitat diversity without significant functional impact (Desprez, 2012).

CASE STUDY: RE-SEEDING, UNITED KINGDOM

Changes in seabed sediments, as a result of dredging, are well known and are commonly associated with screening (Sutton and Boyd, 2009), as discussed earlier in Chapter 4. This change in seabed sediment has previously been monitored through existing regulations. The Marine Mineral Guidance 1 (ODPM, 2002) states that "dredging should aim to leave the seabed in a similar physical condition to that present before dredging started". More recently, aggregate licences have specified a specific condition to ensure that substrate is left in a similar grade of condition to that which existed before dredging commenced. However, there is no clear definition of "similar". This can be problematic when defining whether impacts of dredging are acceptable and if there is a need for restoration. Legislative calls for restoration are clearly identified within the obligations of the OSPAR Convention 1992, various European directives, and within various UK marine policy documents. The EC Wild Birds and Habitats & Species Directives, adopted in 1979 and 1992, respectively (Council Directive 92/43/EEC, Council Directive 79/409/EEC), also set out obligations for restoration of species and habitats as well as their preservation and maintenance. More recently, similar obligations have been presented within the EC Marine Strategy Framework Directive (Council Directive 08/56/EC), in which the general duties include a marine strategy that should "…protect and preserve the marine environment, prevent its deterioration or, where practicable, restore marine ecosystems in areas where they have been adversely affected".

Results of several small-scale restoration experiments have shown that it may be possible to address, to some extent, some of the residual impacts left by extraction activities. For example, Newell and Garner (2007) looked at the use of waste shell material for helping to restore the composition of sediments and to promote benthic faunal recolonization, particularly of species which require that type of substrate for attachment. Further work using the seeding of scallop shells resulted in a return of 70% of species in seven months, which would have required more than five years for natural recolonization (Guay and Himmelman, 2004; Collins and Mallinson, 2007; Cooper *et al.*, 2007a). Bed levelling has also been trailed in the Bay of Seine, off the French coast, after cessation of dredging, with the aim of speeding up recolonization. However, the results showed no real improvement beyond what would occur naturally (Duclos, 2012), and the absence of benefits of restoration could not justify the costs (M. Desprez, pers. comm.).

Another study by Cooper *et al*. (2011b) investigated the practicality and effectiveness of gravel seeding to aid recolonization in UK aggregate Area 408 located off the Humber Estuary in the southern North Sea. The zone selected for the trial was 2.56 km^2, and dredging ceased at the site in 2000 after 1 459 131 t were extracted between 1996 and 1999. Annual screening at the site was estimated to be around 285 000 t (Newell *et al.*, 2002). Newell *et al.* (2001) and Evans (2002) have also provided evidence of the persistence of this material on the seabed in the area extending for at least 2 km along the axes of net sediment transport (in a southeasterly direction). It is thought that the presence of this material is responsible for the suppression of biomass (Cooper, 2005; Robinson *et al*., 2005), species richness, and abundance (Cooper, 2005) in the area.

The aim of the research was not to replace the extracted material, but to provide a capping layer of approximately 15–20 cm in depth. It was calculated this would require 5000 m^3 or 9000 t of gravel, which equates to approximately two dredger loads. After the cessation of dredging, three areas were created (100 × 250 m): a control zone, a treatment area inside the previous active dredge zone, and a reference site outside the zone of influence. The control zone and the treatment zone areas were chosen to ensure equal levels of extraction. The first survey was undertaken in May 2005 and formed the baseline. Three further surveys were then conducted, immediately after the gravel had been deposited (July 2005), and then in July 2006 and May 2007. A 0.1 m^2 Hamon grab was used to collect the ten random samples taken from each site. However, it must be noted that the research lacked any replication, with only one zone for each treatment.

Whilst the lack of replication limits the conclusions, the study showed strong evidence for the existence of a treatment effect. There was a clear difference between the control and treatment sites after the deposition. However, there was still more sand evident in the treatment site than in the reference site. Seeding resulted in a 22% increase in the mean gravel content compared to the control site. By the end of the study, the physical effect was still present, but there appeared to be increasing sand cover within the treatment site. This is likely a result of mobilized sand from the surrounding seabed.

Early indications showed that patterns of biological colonization and succession followed what was expected. These changes (increased diversity, biomass, and individuals) resulted from an increase in the occurrence of species more commonly associated with the reference site. Although strong conclusions could not be drawn due to a lack of replication and variability in the data, probably reflecting the patchy physical effect, it highlights the problem of trying to recreate such a habitat and the need to set more realistic targets for restoration. Elliot *et al.* (2007) suggests that this form of remediation would be more appropriately termed “enhancement” rather than “restoration”.

Although the small-scale case studies mentioned suggest, to some degree, that restoration is possible, there is no consideration of the financial implications of such a requirement. Therefore, Cooper *et al*. (2010), commissioned by the Marine Aggregate Levy Sustainability Fund (MALSF), produced a report assessing whether the benefits of restoration justified the costs. Area 222, situated 22 miles off the coast of Felixstowe in southeastern England, was selected for the study. A licence was first granted in 1971 and relinquished in 1997, following the removal of 10.2 million t of material. After dredging, a programme of research was undertaken to assess the physical and biological status of the site. While restoration was possible, the cost of restoration averaged £0.30 m^{-2} for bed levelling, £0.83 m^{-2} for gravel seeding, and £1.62 m^{-2} for dredging and disposal, totalling between £712 143 and £1 189 660 for the site. The authors stated that there were three important issues to be determined following aggregate extraction: (i) necessity, (ii) technical feasibility, and (iii) affordability of restoration. The report concluded that restoration of Area 222 was not warranted, as the costs of restoration outweighed the benefits to the area. However, the authors also stated that this decision was dependant on the specific aggregate area in question, and that a site-specific cost–benefit analysis would be necessary. In any case, mitigating against impact and monitoring a site to detect change during the licence should remove the requirement for restoration.

Since the introduction of the EIA Directive, marine developers/regulators have assessed environmental acceptability of any proposed development by means of an EIA. This has led to good knowledge of local, site-specific information; however, there was less known about regional issues/impacts. Awareness of this gap in knowledge has been more recently considered through the assessment of cumulative impacts. This has led to the development of Marine Aggregate Regional Environmental Assessments (MAREA). The MAREAs were developed to allow the EIAs to be considered in a regional context and, therefore, allow better understanding of the interaction with the surrounding environment, other aggregate licence areas, and other sea users.

Case Study: REA

The process of undertaking a MAREA has been guided by a group of regulators/advisors known as the Regulatory Advisory Group (RAG), which is made up of the Joint Nature Conservation Committee, Natural England, English Heritage, Cefas, the Marine Management Organisation with support from industry, and The Crown Estate. RAG developed guidelines that identified a series of overarching objectives to help steer the MAREA process. The guidance recognizes that this process is industry-led and non-statutory; hence the guidance offers recommendations rather than binding requirements.

The aims of the guidance document were to: (i) provide evidence-based assessments of the distribution and importance of regional resources and potential impacts from aggregate extraction; (ii) provide context for the EIAs and highlight site-specific issues that individual EIAs may need to focus on; (iii) assess the impacts of different development scenarios; (iv) provide a robust assessment of cumulative impacts at the regional level using consistent methods; and (v) make recommendations for monitoring EIAs and gaps in knowledge.

Key to the process was the ability to address cumulative impacts with a regional context. Whilst there has been much debate over how to address such issues, it was essential that the REA process adopted a consistent approach.

Objectives were to (i) assess key issues of risk to the marine environment and make the best use of resources, especially data collection, evaluation, and assessment; (ii) provide an objective, evidence-based assessment of potential impacts derived from particular dredging scenarios; (iii) act as a reference source on the distribution and importance of regional resources (living and non-living) and the potential activities on these resources; (iv) have a geographic and temporal scale that reflected the scale of the key issues; (v) provide a robust assessment of cumulative impacts at the regional level; (vi) provide updated assessments as part of the ongoing REA process; (vii) identify where data collected during the process needed to be supplemented by targeted survey programmes; (viii) provide consistency and standardization of approach; and (ix) provide a legacy of data for industry and regulators.

There are five regions: the eastern English Channel, the Outer Thames, the Anglian, the South Coast, and the Humber. The first regional assessment was undertaken in the English Channel by the East Channel Association. Six dredging companies were involved, and it was completed in 2003 before the RAG suggested recommendations in 2008, based on regional environmental assesment. However, experiences from this first process helped feed into the other four regional assessments. The next two MAREAs to be completed were the Thames and the South Coast. The South Coast MAREA was undertaken by the South Coast Dredging Association (SCDA), which consists of seven dredging companies. The Thames Estuary Dredging Association (TEDA), a consortium of five dredging companies, undertook the Outer Thames Estuary MAREA for the Thames region. The next area was the Anglian REA, which was recently completed by AODA (Anglian Offshore Dredging Association), comprised of five companies. The final MAREA to be developed was the Humber and Outer Wash region by the Humber Aggregate Dredging Association (HADA), which is comprised of six aggregate companies. All of the companies involved have licence areas, application areas, and/or prospecting areas within each of the study areas.

Further regional work has also emerged from the Regional Environmental Characterisation (REC) surveys that were commissioned by Defra under the MALSF. They were undertaken for the southern coast, the eastern English Channel, the outer Thames Estuary, the East Anglian coast, and the Humber Estuary in the North Sea. The aim of the RECs was to provide an environmental reference and regional-scale context, in the form of habitat mapping/characterization, against which to judge marine aggregate dredging licence applications. The RECs were designed to assist regulators in making informed decisions, notably with regard to marine aggregate licence applications.

Both the MAREAs and RECs have gone a long way in helping to assess impacts at a regional level, including cumulative issues, but also identifying site-specific issues for individual licence areas.

5.9 Conclusions and recommendations

Information on mitigation activities amongst ICES Member Countries has not been addressed specifically by WGEXT. Discussions and case studies on dredging impact and monitoring were described in the annual reports as part of the environmental impacts of dredging. This chapter is a first attempt to give an overview of options for mitigation being used within the Member Countries.

Recommendation:

As it is recognized that extraction activities, if undertaken in an inappropriate way, may cause significant harm to the marine and coastal environment, it is recommended that mitigation be examined more systematically in future years by the WGEXT in order to identify options and describe current practices. Consideration should also be given to whether existing research and monitoring techniques (e.g. BACI approach) are adequate.

The establishment of a Natura 2000 network at sea is an important issue in view of increased activity of marine extraction. Strategic planning of extraction activities is particularly important in the marine environment with its many constraints. It requires a better understanding of:

- the marine environment and especially of the priority areas for the protection of the species and habitats of public interest (CBD, 2008; ICES, 2008; OSPAR, 2008) i.e. the concept of biodiversity,
- the impact of dredging on the environment (i.e. the concept of sustainable development),
- to ensure that the impact assessment and resulting decisions are based on the best available scientific knowledge (ECC, 2008; ICES, 2008).

Increased information on the use and developments in mitigation measurements and monitoring in extraction activities will help in developing a sustainable industry that complies with these spatial and legislative developments in the marine environment. Increased knowledge of the potential of ecological engineering may also facilitate tailor-made decisions whether landscaping of dredging areas should be considered as an option for mitigation and to manage the afterlife of a dredging site. It is, therefore, recommended that further research be conducted that is aimed at assessing the opportunities for designing extraction sites to obtain a beneficial effect on the ecological functions of a dredging area.

6 Policy, legislative frameworks, and resource management of the extraction of marine sediments

6.1 Introduction

The main objectives of this chapter are to:

- show the development of regulations and review the regulating regime and environmental impact assessment (EIA) approaches during the seven-year period 2005–2011;
- 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 that they 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;
- identify the regulations and use the black box or other electronic control systems;
- identify the use of the ICES Guidelines (ICES, 2003) in policy and legislation.

The information presented in this section is based on the previous *ICES Cooperative Research Report No. 297* (Sutton and Boyd, 2009) and 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) during the period 2005–2011.

As the information in this chapter is based on information that is delivered for the successive annual reports by ICES Member Countries, there is a lack of consistency in the subjects and details that are given. Nevertheless, it provides a good overview of what is going on in the different countries regarding policy and management of marine extraction. A direct comparison of the similarities and differences among countries is given in the tables on the use of the ICES Guidelines, on the use of black box and electronic monitoring systems, and on the monitoring programmes on effects of extraction.

6.2 Review of developments in national authorization, administrative framework and procedures, and approaches to environmental impact assessment

6.2.1 Belgium

Exploration and exploitation of sand and gravel in certain areas on the Belgian continental shelf are regulated by the law of 13 June 1969, amended by the laws of 20 January 1999 and 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 EIA decree foresees the possibility that an integrated EIA can be produced. This is possible because the extraction zones in Belgium are defined by RD, 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 who 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 3-year review report in light of continuing research.

In the procedure decree, three control zones are defined, each divided into sectors for which a concession can be issued. 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 6.1.

Within Zone 2, the central and northern depression in zones 2a and 2b are closed for extraction. At the end of 2010 (Ministerial Decree 24.12.10, published BS January 2011), four extraction zones (4a, b, c, and d) were assigned in exploration Zone 4 on the Belgian continental shelf, together comprising a new exploitation area of 46 km^2.

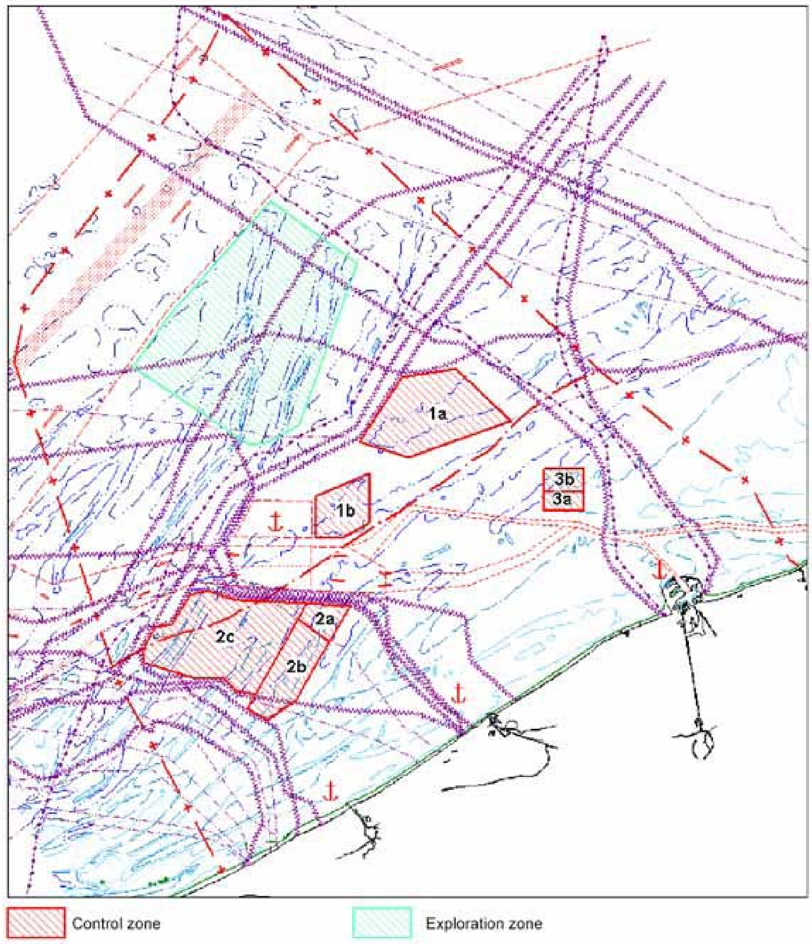

Figure 6.1. Map showing marine sediment extraction zones on the Belgian continental shelf.

6.2.2 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 maintenance of sustainable marine ecosystems and 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.

Canada has not reported any changes in policy or regulations in the period 2005–2011.

6.2.3 Denmark

In Denmark, the policy legislation, as described in *ICES Cooperative Research Report No. 297* (Sutton and Boyd, 2009), did not change until 2009. In that year, the Raw Materials Act changed (Order no. 950 of 24 September 2009) and entered into force on 1 January 2010. There are no changes in the management of marine aggregate extraction activities.

At the same time, four Executive Orders came into force:

- areas for common extraction of resources from the seabed,
- fees for extraction of resources from the seabed,
- auction of areas for extraction of resources from the seabed,
- application for permission to exploitation and extraction from the seabed.

Information (in Danish) can be found at the following website: http://www.naturstyrelsen.dk/Vandet/Havet/Raastoffer/.

The full legislation on the new Mining Code can be found at the following website: https://www.retsinformation.dk/Forms/R0710.aspx?id=127110.

An English version of the Raw Materials Act should be available as well. The Ministry of the Environment, Nature Agency is responsible for administering the new legislation. The Ministry of the Environment, Agency for Spatial and Environmental Planning is responsible for administering new procedures.

The general UAIS system (Automatic Identification System), designed to provide information about one ship to other ships and to coastal authorities, is now used on a regular basis by the Agency to monitor dredging activities in Danish waters. Special applications have been developed to customize the system to the actual needs, e.g. selection of vessels, monitoring periods, and storing of historical information.

6.2.4 Estonia

In 2003, an EIA was executed under Estonian law for the extraction of 1 300 000 m^3 of sand from the Gulf of Finland in the Estonian 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 extraction. In 2004, one area was licensed for extraction.

Estonia has not reported any changes in policy or regulations in the period 2005–2011.

6.2.5 Finland

Metsähallitus (Administration of Forests) is responsible for the administration of land and sea areas owned by the state. Metsähallitus was changed to a state-owned company in 1994, and the company diverted its business operations relating to soil resources to the Morenia Company in March 2006. Morenia sells licences for marine sand extraction in Finnish 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 statute (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 changed on 1 April 1999 to implement the amendments required by Council Directive 97/11/EC, and a new statute (268/1999) was given in the same context. An environmental impact assessment is 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 Århus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters on 1 September 2004. The Finnish government, in 2005, submitted a new proposal to change the act and statute on the Environmental Impact Assessment procedures to implement the Convention and Council Directive 2003/35/EC.

A new statute (713/2006) on the Environmental Impact Assessments replaced the old statute (268/1999) on 1 September 2006, with minor changes.

6.2.6 France

Since 1997, calcareous and siliceous aggregates have been placed under the same legal regulation by the Ministry of Industry. New regulations were also adopted in July 2006 (Décret n° 2006-798 du 6 juillet 2006, Ministère de l'Economie, des Finances et de l'Industrie).

In the past, several applications were required to obtain a mining permit, after which a state permission was required, before a final authorization to begin mining work was issued. Investigation procedures were made complex by a succession of consultations and public inquiries at different steps of the same project, which led to investigations lasting several years. The new regulation clarifies the statutory directives and reviews the arrangements connected to extraction of marine aggregates from the public seabed and from the continental shelf into a single decree. Now only one application is required to obtain the mining permit, state permission, and authorization to begin mining work. This application includes an impact study completed at the beginning of the administrative procedure. The required preliminary studies and monitoring measures are detailed within the new decree. A joint coordinated assessment of the application takes place and includes a single consultation of the administrative services concerned. This consultation covers all aspects of the application and occurs only once during the assessment period. There will also be only one public inquiry, instead of two successive ones. Local dialogue commissions are set up, including all services and concerned parties (representatives from the different marine user-groups, especially fishers). A monitoring committee is also set up by the regional authority.

Because of the reorganization of the French Government in November 2007, the DIREM (Direction des Ressources Energétiques et Minérales), a subdivision of the DGEMP (Direction Générale de l'Energie et des Matières Premières), formerly under the MINEFI (Ministère de l'Economie, des Finances et de l'Industrie), is now under the authority of the MEEDE (Ministère de l'Ecologie, du Développement Durable et de l'Energie).

In May 2010, the Ministry of Environment produced a guideline for impact assessment of aggregate extraction projects on the Natura 2000 sites. The additional content is to take into account habitats and species of common interest and to investigate mitigation measures.

For more information see the following website: http://www.developpement-durable.gouv.fr/-Mines-et-ressources-minerales-.html.

6.2.7 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 coastal (and island) stability and fisheries. It also states that extraction cannot be permitted when the impact on plants and animals exceeds the acceptable limit. In addition, the Mining Regulation covers activities that have a particular impact on these beds 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.

6.2.7.1 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.

6.2.7.2 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 objectives for planning, as well as the development plan itself, and performing the strategic environmental impact assessments.

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.

6.2.8 Ireland

Within the 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.

6.2.8.1 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). 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 feet (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 feet (10 m) below the surface of the demised foreshore.

6.2.8.2 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.

6.2.8.3 New legislation affecting the regulation of marine aggregate extraction

In 2007, the competent authority (Department of the Marine Communications and Natural Resources), which is responsible for administering current legislation that pertains to extraction of marine aggregates and other activities on the "foreshore", has sought (via the e-Tender.ie website) responses from interested parties in relation to a formal review of existing legislation to undertake a strategic review of the legislative framework, structures, and procedures in place to manage the state-owned foreshore. The object of the review is to outline options, informed by best international practice, for putting in place a modernized legislative framework and improved systems and procedures for coastal-zone management, which will best fit the medium- to long-term requirements in this area.

The review shall be in the form of a report to the Minister for Communications, Marine and Natural Resources and will be a strategic review encompassing legal, marine planning/environmental, and economic considerations. In particular, the review will:

- identify and examine current legislative and procedural arrangements for coastal-zone management in Ireland;
- outline a strategic vision for improved coastal-zone management;
- review and recommend options for the development of a modernized legislative framework for coastal-zone management, new and improved procedures and practices that will ensure improved coastal-zone management, and improved customer service;
- indicate the resource requirements necessary to implement the various options outlined.

The review should encompass, but not be limited to:

- legislative and other arrangements in place in selected EU Member States,
- legislative provisions currently in force in Ireland,
- current lease-processing arrangements, including existing skills base and support structures,
- current valuation of foreshore leases,
- other related administrative structures,
- existing involvement of other public bodies (outside the Department) in the coastal-zone management process.

The review shall provide a project plan on the implementation of the proposed recommendation, including the required steps to transition efficiently from the current structure and systems to the recommended one.

Since 2008, Ireland has not reported any follow-up on this topic.

6.2.9 The Netherlands

The extraction of sediments from waters under management of the national government is regulated by the "Besluit Ontgrondingen Rijkswateren" (Decree Extraction in National Waters). This decree is in force from February 2008 onwards and includes amendments on the Extraction Law 1965 earlier amended in 1997. This document includes the policy and management of extraction of aggregates (sand, shells, etc.) from the North Sea.

The most important amendments of the Extraction Law include:

- short procedure (maximum of eight weeks) for extraction sites < 10 million m^3, < 500 ha, < 2 m, and not near to each other;
- short procedure for lengthening the licence period maximum by 50%;
- trial extractions (dredgers or prospecting) directly by information or mentioning (maximum of 40 000 m^3 or 10 cargo/tracks).

No change in content is made relating to policy and regulations that are formulated in the Second Extraction Plan for the North Sea (2004), the National Document on Spatial Planning (2006), The Integrated Management Plan for the North Sea 2015 (2005 and updated in 2011), and policy documents on shell extraction. Licences are granted by the Ministry of Infrastructure and the Environment (former Ministry of Transport, Public work and Water Management), Directorate-General Rijkswaterstaat.

An EIA has to be made when an extraction exceeds an area of 500 ha and/or a volume of 10 million m^{-3} per licence (2003–2006). An exception was made for the territorial zone where, for an area of 100 ha, an EIA was required. 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 real NAP 20 m depth contour. The depth contour is defined by NAP (Amsterdam Ordnance Datum ~ Mean Sea Level). There are some exceptions to this, e.g. extraction in access channels to harbours. Seaward of the established NAP 20 m depth contour extraction is allowed in principle. Exceptions occur in 500 m zones around cables, pipelines, and platforms. Agreements concerning extraction in military areas have been reached with military authorities. Extraction in these areas is allowed under certain conditions.

From 2007 onwards, the effects of extraction on protected areas or protected species, as defined in EU Directives are no longer covered by the Extraction Law, but by Nature Laws. In 2009, a new policy document on water management, the National Water Plan, is published. Changes regarding extraction of marine sand are:

- The zone between the established NAP 20 m contour and the 12 mile boundary is designated for sand extraction above other uses of the sea.
- For regular extractions (licences of less than 10 million m^3), a depth of more than 2 m below the seabed is allowed if an EIA advises this. For larger-scale extractions (>10 million m^3 per licence), this was already made possible in the Second Extraction Plan for the North Sea (2004).

In the revised Integrated Management Plan North Sea 2015 (2011), as implementation of the National Water Plan, an integrated comparative assessment framework is formulated consisting of the following elements:

- Description of the activity, including spatial claim and taking into account the precautionary principle.
- Assessment of spatial claim regarding other use of the sea. Sand extraction is defined as of national interest and has priority in the zone mentioned in the National Water Plan. Seaward of this zone, other uses of national interest, such as wind energy, have priority over sand extraction. Landward of this zone, sand extraction is not allowed, with a few exceptions. Off the coast of the Delta Area, a zone is defined where extraction of coarse sand has priority.
- Assessment of the necessity of the activity to take place in the North Sea and the influence on nature areas. Sand extraction, as an activity of national interest, is not involved in this assessment.
- Mitigation of negative effects of the activity, including sand extraction, on nature and other uses of the sea.
- Compensation of effects when mitigation is not completely possible.

To anticipate an increase in sand extraction for coastal nourishments due to sea-level rise, a new strategy on marine sand extraction is formulated that aims at a regional approach from one or more of the following starting points: costs, natural and ecological values, sustainability, spatial planning, and resource management. The implementation is foreseen for 2013.

6.2.10 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.

Norway has not reported any changes in policy or regulations in the period 2005–2011.

6.2.11 Poland

Permits are given by the Licence Bureau of the Ministry of Environment under the Polish Geological and Mining Law (1994; supplements in 1996, 2001). For geological and mining surveillance, the District Mining Office is the administrator.

For licences regarding reconnaissance and exploration, the following documents are required:

- application from the investor to the Ministry of Environment,
- description of the project of geological (exploratory) work,
- an 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),
- an EIA of the exploitation,
- delimitation of mining territory and premises (approved by the District Mining Office),
- a plan of resources field development and a detailed plan of exploitation (approved by the Ministry of Environment),
- an annual balance of resources,
- a quarterly report on exploitation.

The fee for exploitation depends on the quarterly volume of exploited raw material.

Poland has not reported any changes in policy or regulations in the period 2005–2011.

6.2.12 Portugal

There are two types of legislation, one concerning the exploitation of geological resources and another concerning the protection of the natural environment.

6.2.12.1 Exploitation of geological resources

Three laws (Decreto-Lei 90/1990, Decreto-Lei 89/1990, and Decreto-Lei 88/1990) define the different types of geological resources and their rules for exploitation. Five main types of geological resources were defined in the law 90/1990:

- mineral deposits (all minerals that contain metals, minerals that contain radioactivity, coals, pyrites, phosphates, asbestos, talc, kaolin, diatomite, barite, quartz, feldspar, precious and semi-precious stones),
- hydromineral resources (mineral natural waters and industrial mineral waters),

- geothermal resources (fluids and geological formations of high temperature),
- mineral masses (all the rocks and minerals not considered mineral deposits),
- spring waters.

The first three are considered strategic geological resources because they are rare and/or very valuable for the national economy and are, therefore, owned by the state. At this stage, no reference was made to marine aggregates because they were not defined in any of these laws. Later in 2005, the Despacho nº 10 320/2005 considered marine aggregates as mineral deposits. Any exploitation of geological resources requires EIA studies.

6.2.12.2 Environmental protection laws

Environmently sensitive areas are protected by the REN (National Ecological Reserve), which defines all the sensitive areas needed to maintain ecological equilibrium as well as rules for permitted human uses of these areas. These consist of a series of legislation that was first defined in 1983 and has been updated throughout the years:

- Decreto-Lei nº 321/83,
- Decreto-Lei nº 93/90,
- Decreto-Lei nº 180/2006,
- Decreto-Lei nº 166/2008,
- Portaria nº 1356/2008 e Declaração de Rectificação nº 63-B/2008 (ex-cepções).

The Decreto-Lei nº 166/2008 defines an area of coastal protection between the coast-line and the 30 m depth contour. In the Portaria nº 1356/2008, it is very clearly stated that exploitation of geological resources is not allowed in the area of coastal protection. Marine aggregate extraction is only allowed for beach nourishment. Aggregate extraction is only allowed below the –30 m contour depth.

Until 2010, no marine aggregate extraction has occurred except for beach nourishment. In 2010, there was one dredging enterprise that was licensed for exploration in eight areas of the mainland continental shelf between the –20 and –50 m contours. Exploration studies have occurred in six of the eight areas (Figure 6.2).

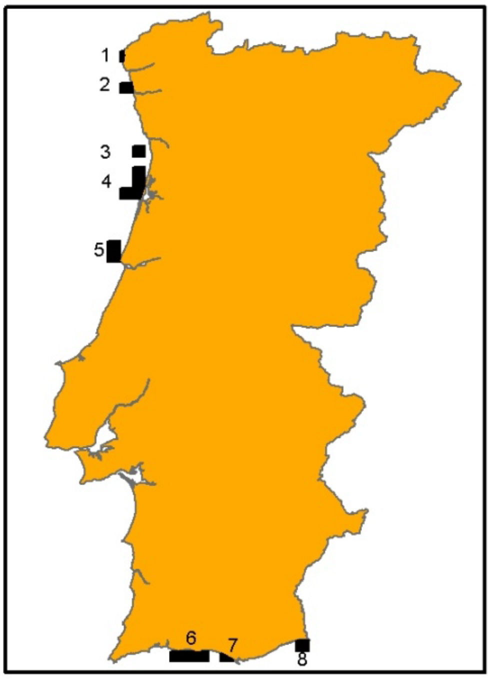

Figure 6.2. Enterprise licence areas for exploration in eight areas of the mainland continental shelf.

The islands (Madeira and Azores archipelago) have already been doing marine aggregate dredging for some years (at least since the 1990s), and they have autonomy to prepare their own relevant legislation.

6.2.12.3 Madeira legislation

The more recent law in Madeira regulating marine aggregate extraction is the Decreto Legislativo Regional nº 28/2008/M (12 August 2008). The following is a resume:

> "From the coastline to 200 m onshore or 200 m offshore, it can be explored for coastline nourishment and protection. However, artisanal exploitation of round pebbles and cobbles is allowed for in the construction of house façades and for patrimonial buildings. 200 m offshore the coastline marine aggregates can be explored, but requires EIA (sediment characterization and studies of sedimentary dynamics)."

In Porto Santo Island, exploitation is only allowed for beach nourishment. In the Desertas and Selvagens Islets, exploitation is forbidden.

6.2.12.4 Azores legislation

The more recent law in the Azores regulating marine aggregate extraction is the Decreto Legislativo Regional nº 9/2010/A (8 March 2010). The following is a resume:

> "From the coastline to 50 m onshore or 250 m offshore, aggregates can be extracted for coastline nourishment and protection. Beyond 250 m offshore, aggregates can be extracted as long as environmental impacts over the ecosystems and coastal and beach erosion is taken into account. Exploitation of round pebbles and cobbles is allowed as long as the volumes do not exceed 100 m^3 for each 1000 m stretch of coastline and not occur negative impacts over the coastline (e.g. beach or cliff erosion)."

There have been detailed exploration studies of the insular shelves for aggregate evaluation in Madeira and Azores archipelago requested from the Regional Government of each archipelago. In the Azores, the shelves of four islands (Faial, Pico, S. Miguel, and Flores) have been studied in detail by doing bathymetric, high-resolution seismic reflection, and sediment sampling mapping. In Madeira, the entire southern insular shelf has been studied in detail by doing bathymetric, high-resolution seismic reflection, and sediment sampling mapping.

6.2.13 Spain

The extraction of marine sediments in Spanish waters is regulated by the following laws:

- Shores Act (22/1988, July 28) and Royal Decree 1471/1999, December 1, which further develops its regulations;
- Royal Legislative Decree 1302/1986, June 28, on Environmental Impact Assessment (developed through Royal Decree 1131/1988, September 30), amended by Act 6/2001, May 8, which transposed Directive 97/11/CE to the Spanish legislation;
- State Ports and Merchant Navy Act (Act 27/1992, November 24, modified by Act 48/2003, November 26, 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 in charge of authorizing any marine sediment extraction, with the only exception being navigational dredging. It is also in charge of all data collection regarding this issue and compiling annual information from its peripheral services. According to article 63.2 of the Shores Act, marine sediment exploitation is only allowed for beach nourishment, always being prohibited for construction purposes.

The Shores Act also establishes the need to always carry out a mandatory 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 Directive 97/11/CE, transposed to the Spanish legal system by Act 6/2001. Regional legislation regarding environmental impact assessment is also applicable to these projects, and in case 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 that would include sand extraction for beach nourishment, the only marine sediment exploitation permitted in Spain.

Furthermore, in accordance with the Habitats Directive, transposed to the Spanish legislation by Royal Decree 1997/1995, of December 7, a stricter and more detailed evaluation of extraction activities is carried out in proposed special areas of conservation (sites of community importance or special areas of conservation for birds) or in their vicinity in order to prevent any alteration of their natural integrity. Moreover, in protected areas designated by regional governments, management plans regulate all activities, and they often rule out all marine sediment exploitation.

It is also important to mention that Spain, in order to achieve better execution of studies about sand deposits before their use, has published a "Methodology guide for the development of environmental impact studies of sand extraction for beach nourishment" (Buceta Miller, 2004).

Before any sand or gravel extraction is authorized and in addition to the environmental assessment, it is mandatory to consult with the environmental authorities (whose power belongs to the Autonomous Communities), the navigation authority (Merchant Navy), and the fisheries authorities (this jurisdiction belongs to the Autonomous Communities in internal waters and to the State Administration, through the Agriculture and Fisheries Ministry, in exterior waters).

Following the OSPAR 2003-15 recommendation for all ICES Member Countries to follow the ICES guidelines for the management of marine sediment extraction (ICES, 2003), they were translated into Spanish in 2005 and distributed to all relevant authorities in Spain.

Harbour dredging, including that destined to fill port structures, is not considered 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.

In 2006, two new laws in connection with environment management were approved. They supplement the legislation on the extraction of sediments:

- Law 9/2006 of April 28. The objective is to evaluate the effects of certain plans and programmes on the environment. It introduces into Spanish law the strategic environmental evaluation of plans and programmes and incorporates the Directive 2001742/CE of the European Parliament and of the Council of June 27, 2001. There is also a modification to the Royal Legislative Decree 1302/1986, 28 June, on Environmental Impact Assessment to transpose correctly the Directives 85/337/CE and 97/11/CE.
- Law 27/2006 of July 18 regulates the right to access information, public participation, and access to the justice on environment affaires (it incorporates the Directives 2003/4/CE and 2003/35/CE).

In 2008, a new Law of Evaluation of Environmental Impact of projects (RDL 1/2008 of 11 January) was approved. In the specific case of marine sand extractions, the EIA procedure should be followed for projects included in Annex I of RDL 1/2008:

- marine sand extractions with extracting volumes >3 000 000 m^3 $year^{-1}$,
- marine sand extractions with extracting volumes not reaching that threshold taking place in particularly sensitive zones designated in the Council Directives 79/409/EEC and 92/43/EEC or in wetlands included in the Ramsar Convention,
- all projects included in Annex II of RDL 1/2008 according to the autonomic regulations.

On the other hand, it will be necessary to consult with the competent environmental organization in the following cases (projects included in Annex II of RDL 1/2008):

- marine sand extractions (projects not included in Annex I of RDL 1/2008),

- any change or extension of the projects that appear in Annexes I and II of RDL 1/2008, already authorized, executed, or in the process of execution that could have adverse significant effects on the environment,
- projects not included either in Annex I or II of RDL 1/2008 when required by the autonomic regulation.

For the projects included in Annex II of RDL 1/2008, an environmental document must be submitted with the content established in the RDL 1/2008 to the environmental organization for its assessment and determination of the need or not of submitting the project to an environmental evaluation.

Spain has approved and published in 2010 the technical instruction for the environmental management of marine sand extraction. The instruction regulates, from an environmental point of view, those projects of marine extraction undertaken in the coastal public domain intended to obtain sand for beach restoration and creation. It establishes the general criteria that contribute to the goal of ensuring environmental integration of such actions for the sake of better preservation of the marine environment. The instruction is divided into 21 articles and is preceded by an analysis that sets the terms of reference of the document. The overall content includes a first part of the procedural framework for such actions: administrative procedure, legal framework, and technical/environmental documentation necessary for marine sediment extraction. All extraction activities should be correctly justified, and environmental impact assessment is compulsory in Spain for extractions above 3 000 000 m^3 or when affected areas are protected by the Birds or Habitat Directives or the Ramsar Convention.

A Spanish version of this technical instruction is available at the following link: http://www.mma.es/secciones/acm/aguas_marinas_litoral/directrices/pdf/directrices_arena.pdf.

On 29 December 2010, Spanish Law 41/2010 on the Protection of the Marine Environment was passed as a result of the transposition of Directive 2008/56/CE (Marine Strategy Framework Directive). It provides a general framework for the protection of the environment in Spanish jurisdictional waters, focusing on the development of marine strategies, the creation of the Spanish network of marine protected areas, and the regulation of dumping of wastes and other matters.

6.2.14 Sweden

The Geological Survey of Sweden is responsible for the administration and licensing of the extraction of marine aggregates. Licensing in the EEZ beyond the territorial 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.

Sweden has not reported any changes in policy or regulations in the period 2005–2011.

6.2.15 United Kingdom

In 2009, the Marine and Coastal Access Act received royal assent. The key areas of interest of the Act focus on:

- instigation of the Marine Management Organisation,
- implementation of marine planning,
- rationalization of marine licensing,

- marine nature conservation,
- fishery management and marine enforcement,
- environmental data and information,
- migratory and freshwater fisheries,
- coastal access,
- coastal and estuary management.

The Marine Management Organisation, taking over the role of the existing Marine and Fisheries Agency, was established in April 2010. Marine Scotland was established as the Scottish marine management organization in April 2009. These organizations take responsibility for managing marine licensing, including marine aggregates, in England and Scotland, respectively.

From 2007 until 2011, the key legislation governing the extraction of marine minerals (aggregates) in the UK was:

- The Environmental Impact Assessment and Natural Habitats (Extraction of Minerals by Marine Dredging; England and Northern Ireland) Regulations 2007;
- The Environmental Impact Assessment and Natural Habitats (Extraction of Minerals by Marine Dredging; Wales) Regulations 2007;
- The Environmental Impact Assessment and Natural Habitats (Extraction of Minerals by Marine Dredging; Scotland) Regulations 2007.

During 2011, the key legislation governing the extraction of marine minerals (aggregates) in the UK changed. The previous legislation was replaced by provisions made under the Marine and Coastal Access Act 2009 (http://www.legislation.gov.uk/ukpga/2009/23/contents).

Dredging is specifically included as a licensable activity under Section 66 of the Act, which came into force on 6 April 2011: "To carry out any form of dredging within the UK marine licensing area (whether or not involving the removal of any material from the sea or sea bed)".

In England, the regulations are accompanied by procedural guidance in Marine Licensing Guidance 3: Dredging, disposal and aggregate dredging. April 2011 (https://www.gov.uk/guidance/apply-to-construct-on-remove-from-and-dispose-to-the-seabed).

Previous guidance documents, namely "Marine Minerals Guidance Note 2", which supplements the existing "Marine Minerals Guidance Note 1", are still available. These documents contain guidance on environmental assessment, mitigation, and monitoring criteria, based in part on the 2003 ICES Guidelines (ICES, 2003). In England, the marine licence will be issued by the Marine Management Organisation (MMO), in Wales by the Welsh Assembly Government, and in Scotland by Marine Scotland.

Further information on these regulations and the changed responsibilities as a result of the Marine and Coastal Access Act can be found at www.marinemanagement.org.uk for England, at www.wales.gov.uk for Wales, and at www.scotland.gov.uk/marinescotland for Scotland.

6.2.16 United States

The Outer Continental Shelf Act 1983 (amended in 1994) allows the leasing of areas of the shelf for sand and gravel extraction. In 1999, the Minerals Management Service

(MMS), a bureau within the US Department of the Interior, 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 specified in the Sustainable Fisheries Act (1996), which has required the National Marine Fisheries Service (NMFS) to define essential habitats for various commercial species. All federal agencies must consult the NMFS on any action that may adversely affect essential fish habitats.

The MMS 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.

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 MMS. 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. A summary of US code for submerged lands can be found at: http://www4.law.cornell.edu/uscode/43/ch29.html.

The legal authority for the issuance of negotiated non-competitive leases for OCS sand and gravel is given in Section 8(k) of the Outer Continental Shelf Lands Act (OCSLA). Public Law 103-426, enacted in 1994, allows the MMS to convey, on a non-competitive basis, the rights to OCS sand, gravel, or shell resources funded in whole, part, or authorized by the Federal Government (http://www.boemre.gov/).

In 2009, the Commonwealth of Masssachusetts promulgated a comprehensive ocean management plan to deal broadly with marine issues of renewable energy, deep-water aquaculture, offshore sand mining, and other activities.

The BP oil spill in the Gulf of Mexico in summer 2010 led to the dissolution of the MMS and it’s reincarnation as the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). Although it is not apparent from its home page (http://www.boemre.gov/), this agency is still responsible for offshore sand and gravel mining.

6.2.17 Other countries

No reports were received from Iceland, Latvia, Lithuania, or Russia.

6.3 Review and evaluation of the use and application of the ICES WGEXT 2003 Guidelines

WGEXT discussed the implementation of the 2003 ICES Guidelines (ICES, 2003) across ICES Member Countries. All countries who provided information reported that the Guidelines remain appropriately detailed, clear, up to date, and used within their national procedures for marine sediment extraction. Some countries implement the Guidelines through their own guidance/legislation in support of these procedures or through acceptance of OSPAR recommendations. In addition to Table 6.1 below, it should be mentioned that Spain has translated the Guidelines into Spanish and distributed them to all relevant authorities in Spain

Table 6.1. Adoption of ICES Guidelines (ICES, 2003) by ICES Member Countries.

	Denmark	Sweden	Netherlands	Belgium	France	Finland	UK
Has your country adopted ICES Guidelines?	No formal adoption	Yes	Accepted and used as recommendation of OSPAR.	Accepted and used as recommendation of OSPAR.	No formal adoption	No, but Finland has formally adopted the HELCOM Recommendation 19/1 (1998).	Accepted and used
If so, how are they implemented: as guidelines (informally) or through legislation/policy (formally)?	The principles in the ICES Guidelines are integrated in the legislation.	Through legislation	Through formal guidelines for conduct of EIAs and by licensing authority.	Used by state and licensing authority.	The licensing authority and consultancies that produce EIAs informally follow ICES Guidelines.	N/A	Implemented through Guidelines (MMG1)
Does your country take account of all the recommendations made in ICES Guidelines?	The recommendations are considered during the evaluation of an application for dredging licence.	Yes, where appropriate	Yes, where appropriate	Yes, where appropriate	Yes – infomally used in production of EIAs and licensing.	N/A	Yes, where appropriate
If not, which sections are not relevant and why?	No data	N/A	N/A	N/A	N/A	N/A	N/A
Does your country offer any guidance in addition to that outlined in the ICES Guidelines?	No data	Additional requirement under the Swedish Environmental Code	Dutch policy on marine sand extraction	No	No	No	Yes

If so, what is the additional guidance? (A copy can be appended to this report where appropriate)	No data	Meetings with local people and authorities and the Environmental Court	National Water Plan	N/A	N/A	N/A	Marine Minerals Guidance Note 2, Interim Marine Aggregate Dredging Policy (Wales), Guidelines on Regional Environmental Assessment, Guidance on Coastal Impact Studies, Benthic Survey Guidelines
Does your country consider ICES Guidelines to be clear and up to date?	No data	Yes	Yes	Yes	Yes	N/A	Yes
If not, what specific amendments are suggested?	No data	N/A	N/A	N/A	N/A	N/A	N/A

6.4 Review of the use of black box and electronic monitoring systems

To better understand different approaches to electronic compliance monitoring across ICES Member Countries, WGEXT decided to capture information on these systems in Member Countries. It is clear that there are great similarities in some aspects of how the different systems operate, principally the use of GPS to identify the location of vessel operations and GIS software to analyse data generated by these systems, but also that there are differences. The systems operating in Belgium and the Netherlands are most similar. The following table provides a summary of data provided by WGEXT members.

Table 6.2. Use of EMS/black box.

Country	Requirement for black box system	Responsibility and cost	Enforcement provisions /penalties	determination of dredging and interpretation	data storage and availability
Belgium	Legislative requirement in dredging licences. The legislative requirement for regulation (See article 34 § 1, 2, 3 and 4 of the "Koninklijk besluit betreffende de voorwaarden, de geografische begrenzing en de toekenningsprocedure van concessies voor de exploratie en de exploitatie van de minerale en andere niet-levende rijkdommen in de territoriale zee en op het continentaal plat", 1 September 2004). The system is currently only used to monitor aggregate extraction activities.	The operator is responsible for installation and maintenance of vessel-bound equipment, and the state is responsible for data collection and interpretation. This is further defined within the legislation.	The FPS Economy is charged to take action (warning to the companies, possible withdrawal of the permit and penalties according to the "Koninklijk besluit betreffende de voorwaarden, de geografische begrenzing en de toekenningsprocedure van concessies voor de exploratie en de exploitatie van de minerale en andere niet-levende rijkdommen in de territoriale zee en op het continentaal plat", 1 September 2004). The enforcement procedure includes a detailed analysis of the breach (excluding minor breaches and corrupted data). An explanation is requested from the company and a warning issued. After multiple breaches of the same type the procedure is either	Cartographic analysis + volumetric/time analysis. Sensors on pumps on/off also inform interepretation. The FPS Economy and the Management Unit of the North Sea (MUMM) are both responsible for a detailed analyse of the BB data with a GIS, crossing these data with extraction register data and bathymetrical data to evaluate the impact of the extraction on the bathymetry of the sandbanks.	The Continental Shelf Service of the FPS Economy is the exclusive owner of the data generated by the BB systems. According to an official agreement, the Continental Shelf Service of the FPS Economy and the MUMM are in charge of the management of the BB systems (control of the BB systems on the ships, regular "manual" uploading of the data from the memory card of the BB systems, pre-processing of the data, regular infraction reporting). The MUMM transmits all the BB preprocessed information and the reports to the Continental Shelf Service of the FPS Economy.

Country	Requirement for black box system	Responsibility and cost	Enforcement provisions /penalties	determination of dredging and interpretation	data storage and availability
			repeated or the permit withdrawn and, if applicable, legal action is taken.		
Denmark	Legislative requirement in dredging licences. The system is also used by the agency to monitor disposal of dredged materials.	Operator is responsible for system onboard. Data concerning dredging vessels are online downloaded from the Danish Maritime Safety Administration and stored in the agency.	Penalties in accordance with the Raw Materials Act. Standard administrative procedures according to the law are applied for enforcement.	Information from a standard UAIS system is transmitted via VHF. No additional sensors are used onboard the vessel to identify whether dredging is taking place. Mapinfo is used to gather and interpret data. Vessel speed is used as the method to determine any irregularities.	Data concerning dredging vessels are online downloaded from the Danish Maritime Safety Administration and stored in the agency.
France	Legislative requirement in dredging licences. The system is also used to monitor dredging activity within large ports.	The operator is responsible for buying and maintaining the system.	No penalties currently imposed.	Data are obtained using a standard AIS system. Some vessels also have pump sensors.	
The Netherlands	Legislative requirement in dredging licences. The system is also used by the agency to monitor the disposal of dredged materials if it is a commercial enterprise. The system is used both for enforcement and to report area of seabed disturbance to OSPAR.	The government pays for the installation of black boxes, and the data must be made available by the operator to the government. The operator is responsible for the running costs of the system.	Can withdraw licence and impose a fine as a penalty method. The Ministry of Financial Affairs can also impose further penalties.	Data (dredging tracks) is projected as a GIS layer over dredging area. Determination of dredging activity is dependent on individual vessel speed. Large ships may also have sensors on pipes and drag head that also inform interpretation. Data can also be projected over bathymetric data to show dredge tracks.	Data are transmitted from the vessel straight to the government office.

Country	Requirement for black box system	Responsibility and cost	Enforcement provisions /penalties	determination of dredging and interpretation	data storage and availability
Portugal	New legislation in Azores requires dredging vessels to have a gps system – detail unavailable at present.				
Spain	In Spain, there is no obligation to use black boxes; it depends on the control and mitigation plans from the EIA and local laws.				
United Kingdom	Since 1993, The Crown Estate commissioners have required that all vessles dredging Crown Estate minerals be fitted with an electronic monitoring system (EMS). More recently, the use of EMS has become a legislative requirement under 2007 EIA regulations. The system is currently only used to monitor aggregate extraction activities.	The operator is responsible for the installation and maintenance of the system. The Crown Estate is responsible for software and data collection.	A person who commits an offence under the Environmental Impact Assessment and Natural Habitats (Extraction of Minerals by Marine Dredging) (England and Northern Ireland) Regulations 2007 shall be liable: (i) on summary conviction, to a fine not exceeding the statutory maximum; or (ii) on indictment, to a fine. The Dredging Permission may be revoked, suspended, or varied.	Determination of dredging activity is obtained from typically draghead sensors and a density meter or vibration sensor. The number and type of sensors vary between operators and ships. The dredging-status indicator setup is agreed by both the operator and The Crown Estate. Data are processed to convert into a usable format to view in ArcGIS to identify potentially illegal dredging activity based on a number of predetermined factors.	The Crown Estate owns the data. EMS records are analysed and processed by The Crown Estate as landowner and unprocessed data are shared with the regulator (MMO) and Welsh Assembly Government (WAG), who conduct their own interpretation (through Cefas).
USA	Often required as a permit condition.	The operator is responsible for the implementation.	The local permitting agency enforces/monitors the use of the EMS/black box system on a case-by-case basis.	Each system's setup (speed, draft, pump rate, etc.) is implemented as required by the permit conditions.	The system is predominantly used for compliance monitoring only; therefore, the

Country	Requirement for black box system	Responsibility and cost	Enforcement provisions /penalties	determination of dredging and interpretation	data storage and availability
					data are not generally available.

6.5 Review and evaluation on the scope and implementation of monitoring programmes on the effects of extraction

In order to better understand the approaches to control and monitor the effects of marine sediment extraction, WGEXT members provided information to complete the following table.

Table 6.3. Implementation of monitoring programmes.

	Belgium	Finland	France	Netherlands	Sweden	UK
Is monitoring obligatory (e.g. licence condition)?	Yes	Yes	Yes	Yes, if licence is based on EIA.	Yes	Yes, if licence is based on EIA.
Organization/body responsible for monitoring (state/operators)	State	State must ensure monitoring is undertaken by licence holder.	State must ensure monitoring is undertaken by licence holder.	State must ensure monitoring is undertaken by licence holder.	State must ensure monitoring is undertaken by licence holder.	National regulator must ensure monitoring is undertaken by licence holder.
Organization(s)/bodies undertaking monitoring (licence holder/state organizations)	State	Licence holder and/or consultants appointed by the licence holder.	Licence holder and/or consultants appointed by the licence holder.	Licence holder and/or consultants appointed by the licence holder.	Licence holder and/or consultants appointed by the licence holder.	Licence holder and/or consultants appointed by the licence holder.

	Belgium	**Finland**	**France**	**Netherlands**	**Sweden**	**UK**
Organization/body that pays for monitoring	Licence holder	Licence holder	Licence holder	Licence holder	Licence holder	Licence holder
Organization(s)/bodies that design(s)/revise(s)/approve(s) monitoring programmes	Advisory committee comprising state and licence holder	Designed by licence holder and approved by the state.	Designed by licence holder based on recommendations from IFREMER, the state, and consultation with stakeholders. Approved by the state. Revisions can be suggested by any party, but must be approved by the state.	Designed by licence holder and approved by the state. Revisions can be suggested by either party, but must be approved by the state.	Designed by licence holder and approved by the state. Revisions can be suggested by either party, but must be approved by the state.	Designed by licence holder and approved by the regulator. Revisions can be suggested by licence holder or regulator (and their advisors), but must be approved by the regulator.
Organization/body responsible for reporting/monitoring	State	Licence holder	Licence holder	Licence holder	Licence holder	Licence holder
Organization(s)/bodies responsible for evaluating/monitoring	State	Local environmental authorities	State and IFREMER	State	State	Regulator (and their advisors)
How are the results of monitoring used?	To ensure compliance with licence conditions, enable management action (compliance monitoring), to assist management of	To ensure compliance with licence conditions, enable management action, to assist management of future licensing	To ensure compliance with licence conditions, enable management action, to assist management of future licensing and adapting policy.	To ensure compliance with licence conditions, enable management action (compliance monitoring), to assist management of future licensing and adapting policy.	To ensure compliance with licence conditions, enable management action, to assist management of future licensing	To ensure compliance with licence conditions, enable management action, to assist management of future licensing and adapting policy.

	Belgium	Finland	France	Netherlands	Sweden	UK
	future licensing and adapting policy.	and adapting policy.			and adapting policy.	
How are monitoring data owned/stored/ disseminated?	Data stored by state and published in most cases.	Held by licence holders and published. Data are provided to state and made public.	Data are held by the licence holder, but provided to the state, and a summary of the EIA made available to the public.	Not well organized at present.	Data is archived at the Swedish Geological Survey and EPA.	Held by the licence holder and provided to the regulator who maintains a public register.

6.6 Conclusions and recommendations

There is an increasing awareness of the necessity to execute the extraction of marine sediments with an attitude of stewardship for the environment. This is shown by the attention given by the EU Member States in their policy and legislation for the identification (Section 4), monitoring, and mitigation (Section 5) of the effects of extraction. Special attention is given in most countries to the Directives of the EU. Recently, the Marine Strategy Framework Directive (MSFD) has come into force. WGEXT has discussed the implications of this Directive with regard to the extraction of marine sediment. The following good environmental status (GES) descriptors under MSFD are considered of direct relevance to the work of WGEXT:

- Descriptor 6 (seafloor integrity) is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.
- Descriptor 11 (introduction of energy, including underwater noise) is at levels that do not adversely affect the marine environment.

WGEXT suggests that in defining "adverse", it should be accepted that direct changes to the physical structure of the seabed will result from the extraction of marine sediments. Defining "adverse" as being no environmental change from existing (predredge) conditions would, in the opinion of the group, be inappropriate and detrimental to the continued ability of Member Countries to extract marine sediments from their seabed.

WGEXT is content that, in the context of appropriate consent regimes which provide for rigorous environmental assessment and evaluation of each proposal to extract sediment, these impacts may be considered to be within environmentally acceptable limits and, therefore, not adverse. These assessments should take account of the 2003 "ICES Guidelines for the Management of Marine Sediment Extraction" (ICES, 2003), as adopted by OSPAR, which provide for the adoption of appropriate extraction-site locations, and implementation of mitigation and monitoring programmes. In the EIAs for marine extraction, the acceptable limits of impact on the benthic ecosystem and the marine environment in light of GES descriptors 6 and 11 should be addressed. In addition, descriptors 1 (biodiversity), 4 (foodwebs), and 7 (hydrological conditions) should also be considered.

With respect to Descriptor 11, WGEXT recognizes that extraction of marine sediment generates underwater noise; however, the impacts of this on the marine ecosystem are currently being investigated.

The ICES WGEXT Guidelines (ICES, 2003) are used by a number of countries in policy and legislation. Some countries implement the Guidelines through their own guidance/legislation in support of these procedures or through acceptance of OSPAR recommendations. In other countries, the Guidelines are used informally by the licensing authorities and the consultants producing EIAs.

WGEXT discussed the ongoing validity of the Guidelines and agreed that they remained fit for purpose in their current form and are of ongoing use to Member Countries and OSPAR. The group that considers updates to the Guidelines may be necessary in light of MSFD and will, therefore, be a focus as part of future work.

The increasing use of black boxes and other electronic monitoring systems leads to a better insight into the areas that are really affected by sand extraction.

Besides the use of EMS/black-box data for compliance monitoring to control licence conditions, they can be used for the measurement of dredging intensity. This clearly has implications for ongoing scientific evaluation of impacts and approaches to mitigation and monitoring of activities. WGEXT, therefore, agreed on the need to collect data on how ICES Member Countries measure and categorize dredging intensity to better inform discussion on how the impacts of extraction can be better compared.

Recommendations:

- ICES should bring forward WGEXT's interpretation of GES descriptors 6 and 11 to the EU.
- ICES Member Countries, where necessary, should discuss the implication of MSFD GES Descriptor 6 with their own administrations, using the text provided by WGEXT.
- WGEXT should review the 2003 ICES Guidelines on Marine Aggregate Extraction (ICES, 2003), specifically in relation to GES descriptors under the MSFD.

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Annex 2: Summary of marine aggregate extraction statistics

Belgium: extraction figures presented in m³

Year	Industrial purposes	Beach nourishment	Total marine aggregate extraction
1988	584 759	n/d	584 759
1989	963 709	n/d	963 709
1990	957 908	n/d	957 908
1991	1 448 116	n/d	1 448 116
1992	1 232 773	1 017 215	2 249 988
1993	1 448 413	1 19 396	1 567 809
1994	1 602 040	2 78 593	1 880 633
1995	1 669 488	1 679 939	3 349 427
1996	1 443 669	1 149 399	2 593 068
1997	3 893 302*	184 700	4 078 002
1998	1 392 901	148 837	1 541 738
1999	1 685 170	1 126 701	2 811 871
2000	1 900 974	416 714	2 317 688
2001	1 911 057	139 197	2 050 254
2002	1 619 216	137 764	1 756 980
2003	1 653 804	160 919	1 814 723
2004	1 551 000	1 268 410	2 819 410
2005	1 363 165	428 269	1 791 434
2006	1 588 614	455 364	2 043 978
2007	1 539 699	450 146	1 989 845
2008	1 761 454	506 931	2 268 385
2009	1 673 696	288 480	1 962 176
2010	1 840 651	335 753	2 176 404
2011	2 778 298	699 045	3 477 343

* Higher production as a result of sand extracted for a pipeline fill.

Canada: extraction figures presented in m³

Year*	Total aggregate production
1992	325 000

* There has been no marine aggregate production since 1992.

Denmark: extraction figures presented in m³

Year	Reclamation (sand)	Beach nourishment (sand)	Construction aggregates (sand & gravel)	Total marine aggregate production (sand & gravel)
1978	1 612 006	0	2 972 213	4 584 219
1979	2 510 836	0	2 482 667	4 993 503
1980	1 102 980	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	1 300 000	2 800 000	2 100 000	6 200 000
2004	1 900 000	2 600 000	2 000 000	6 500 000
2005	6 100 000	2 900 000	2 300 000	11 300 000
2006	3 100 000	2 500 000	2 700 000	8 300 000
2007	2 600 000	1 900 000	3 000 000	7 500 000
2008	1 100 000	2 100 000	3 100 000	6 300 000
2009	1 700 000	1 900 000	2 500 000	6 100 000
2010	1 300 000	2.300 000	2 100 000	5 700 000
2011	2 400 000	2 400 000	2 700 000	7 500 000

Estonia: extraction figures presented in m³

No data before 2003.

Year	Reclamation
2003	2 237 000
2004	609 100
2005	0
2006	0
2007	0
2008	732 700
2009	*909 400
2010	*179 000
2011	0

* Construction sand.

Finland: extraction figures presented in m³

Year	Total marine aggregate extraction
1992	< 500 000
1993	< 500 000
1994	< 500 000
1995	< 500 000
1996	< 500 000
1997	n/d
1998	n/d
1999	n/d
2000	0
2001	0
2002	0
2003	0
2004	1 600 000
2005	2 388 000
2006	2 196 707
2007	0
2008	0
2009	0
2010	0
2011	0

France (Atlantic coast/English Channel): extraction figures presented in m³

Year	Marine aggregate extraction (industrial)	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	3 758 829	467 000
2001	4 024 601	464 000
2002	5 115 855	476 000
2003	5 905 369	475 000
2004	6 379 030	470 500
2005	7 033 384	472 000
2006	*6 985 545	n/d
2007	*7 769 204	495 700
2008	*7 534 982	495 700
2009	*7 667 088	501 000
2010	*7 711 588	*481 000
2011	*7 711 588	*481 000

* Granted or permitted volumes.

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	2 206 119	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
2006	147 411	1 250 000	215 212	1 279 153
2007	n/d	n/d	n/d	n/d
2008	131 591	581 018	n/d	n/d
2009	212 273	230 406	19 049 878	1 065 993
2010	1 535 479	986 251	60 410	834 300
2011	1 511 985	116 660	43 613	884 312

Greenland and the Faroes

No data available.

Iceland: extraction figures presented in m³

Year	Marine aggregate extraction	Marine non-aggregate extraction		Total extraction
	Gravel & sand	Shell sand	Maerl	
2000	1 435 665	147 280	0	1 582 945
2001	1 189 950	133 640	0	1 323 590
2002	861 315	114 250	0	975 565
2003	1 155 485	83 920	0	1 239 405
2004	1 412 430	118 340	0	1 530 770
2005	1 259 157	143 780	13 740	1 416 677
2006	1 253 464	151 460	20 535	1 425 459
2007	1 145 390	158 300	21 666	1 325 356
2008	921 000	134 680	50 445	1 106 125
2009	374 885	69 360	25 435	469 680
2010	125 800	39 760	54 450	220 010
2011	138 700	40 740	n/d	n/d

Ireland: extraction figures presented in m³

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
2006	0	0	7 169
2007	n/d	n/d	n/d
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0

Latvia

Year	Aggregate production
2010	0
2011	n/d

Lithuania: extraction figures presented in m³

Year	Beach nourishment
2010	110 000
2011	119 000

The Netherlands: extraction figures presented in m³

Year	Reclamation/ fill	Beach nourishment	Construction aggregates	Total
1974	2 787 962	0	n/d	2 787 962
1975	1 530 791	700 098	n/d	2 230 889
1976	1 902 409	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	13 554 273
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	*14 693 649	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	17 243 360	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

Year	Reclamation/ fill	Beach nourishment	Construction aggregates	Total
2003	12 223 337	10 460 271	1 204 329	23 887 937
2004	11 757 877	10 625,337	1 206 632	23 589 846
2005	*13 452 492	15 311 486	1 858 994	28 757 673
2006	*10 374 805	11 457 285	1 545 920	23 378 010
2007	11 134 376	15 184 709	1 982 300	28 301 385
2008	11 596 100	13 000 583	1 734 031	26 330 714
2009	**87 234 428	30 934 121	2 531 790	120 700 339
2010	**97 683 169	22 049 597	2 799 669	122 532 435
2011	†22 761 377	††37 293 360	2 893 967	62 948 704

* Higher production as a result of sand extracted for a pipeline fill.

** Higher production as a result of sand extracted for the Maasvlakte 2.

† Higher production as a result of sand extracted for the Maasvlakte 2 and pipeline fill.

†† Higher production as a result of sand extracted for the Sandengine.

Norway: extraction figures presented in m³

Year	Carbonate (shell) sand	Total marine 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
2006	n/d	n/d
2007	A few thousand	A few thousand
2008	A few thousand	A few thousand
2009	A few thousand	A few thousand
2010	A few thousand	A few thousand
2011	A few thousand	A few thousand

Poland: extraction figures presented in m³

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	974798	0	974 798
1994	251 410	6 400	257 810
1995	280 720	0	280 720
1996	134 000	0	134 000
1997	247 310	3 200	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	438 414	0	438 414
2004	1 042 896	0	1 042 896
2005	1 043 925	0	1 043 925
2006	548 856	0	548 856
2007	977 358	0	977 358
2008	238 948	158	239 041
2009	702 590	0	702 590
2010	970 923	0	970 923
2011	n/d	n/d	n/d

Portugal (Atlantic coast, including the Azores Islands): extraction figures presented in m³

Year	Beach nourishment	Construction aggregate
1998	1 285 000	
1999		6 083
2000		145 519
2001		146 791
2002		115 613
2003		176 285
2004		197 636
2005		159 968
2006	370 000	181 691
2007	500 000	141 991
2008	1 000 000	144 647
2009	1 000 000	134 021
2010	1 250 000	124 132
2011	600 000	126 381

Russian Federation

No data available.

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
2006	116 869
2007	26 906
2008	595 073
2009	n/d
2010	207 000
2011	0

Sweden: extraction figures presented in m³

Year	Marine silica sand (glass production)	Reclamation/fill	Beach nourishment
1990	171 770		0
1991	116 797		0
1992	52 739		0
1993	0		0
1994	0		0
1995	0		0
1996	0		0
1997	0		0
1998	0	*2 500 000	0
1999	0		0
2000	0		0
2001	0		0
2002	0		0
2003	0		0
2004	0		0
2005	0		0
2006	0		0
2007	0		0
2008	0		0
2009	0		0
2010	0		0
2011	0		96 562

* In 1998, 2 500 000 m³ of chalk was dredged for fill as part of the Öresund Link Project.

United Kingdom: extraction figures presented in m³

Year	Reclamation/fill (sand & gravel)	Beach nourishment (sand & gravel)	Construction aggregates (sand & 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	296 230	567 057	12 437 472	13 300 759
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	9 968	2 951 914	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	618435	12 313 480	13 213 062
2003	556 488	719 839	12 112 872	13 389 199

Year	Reclamation/fill (sand & gravel)	Beach nourishment (sand & gravel)	Construction aggregates (sand & gravel)	Total marine aggregate production
2004	156202	916 634	11 908 342	12 981 178
2005	0	921 984	11 859 724	12 781 708
2006	331 179	2 165 925	12 135 792	14 632 896
2007	0	1 264 165	12 712 740	13 976905
2008	125 004	1 203 689	11 647 328	12 976 021
2009	2 208 396	498 349	9 457 522	12 164 267
2010	135 115	450 094	9 115 245	9 700 454
2011	187 625	712 558	10 614 887	11 515 070

NB – Figures converted from tonnes using a standard conversion factor of 1.66 t m^{-3}.

United States (Atlantic Seaboard): extraction figures presented in t and m^3

Year	Construction aggregate (t)	Beach recharge (m^3)
1990	2 300 000	16 350 000
1991	2 300 000	7 115 000
1992	2 300 000	12 320 000
1993	2 300 000	11 900 000
1994	2 300 000	9 350 000
1995	2 300 000	13 400 000
1996	2 300 000	13 200 000
1997	2 300 000	11 400 000
1998	2 300 000	6 000 000
1999	2 300 000	8 600 000
2000	2 300 000	15 800 000
2001	2 300 000	19 700 000
2002	2 300 000	9 600 000
2003	2 800 000	12 600 000
2004	3 300 000	4 500 000
2005	1 400 000	5 751 000
2006	1 200 000	1 615 000
2007	1 200 000	3 529 000
2008	1 000 000	3 246 016
2009	666 397	3 965 898
2010	819 591	3 696 000
2011	778 308	4 489 111

Abbreviations and acronyms

ALSF	Aggregate Levy Sustainability Fund (under DEFRA, UK)
BACI	Before and After/Control and Impact Analysis
BOEM	US Bureau of Ocean Energy Management
EIA	environmental impact assessment
EIR	environmental impact report
EMODnet	European Marine Observation and Data Network
EMS	electronic monitoring system
EUNIS	European Nature Information System
GES	good environmental status
MALSF	Marine Aggregate Levy Sustainability Fund (under DEFRA, UK)
MAREA	marine aggregate regional environmental assessment
MESH	Mapping European Seabed Habitats (www.searchmesh.net)
MSFD	EU Marine Strategy Framework Directive
OCS	The US Federal Outer Continental Shelf
RAG	Regulatory Advisory Group (UK government bodies supported by the industry)
REA	regional environmental assessment
SPL	sound pressure level
SPM	suspended particulate matter
TSHD	trailer suction hopper dredger