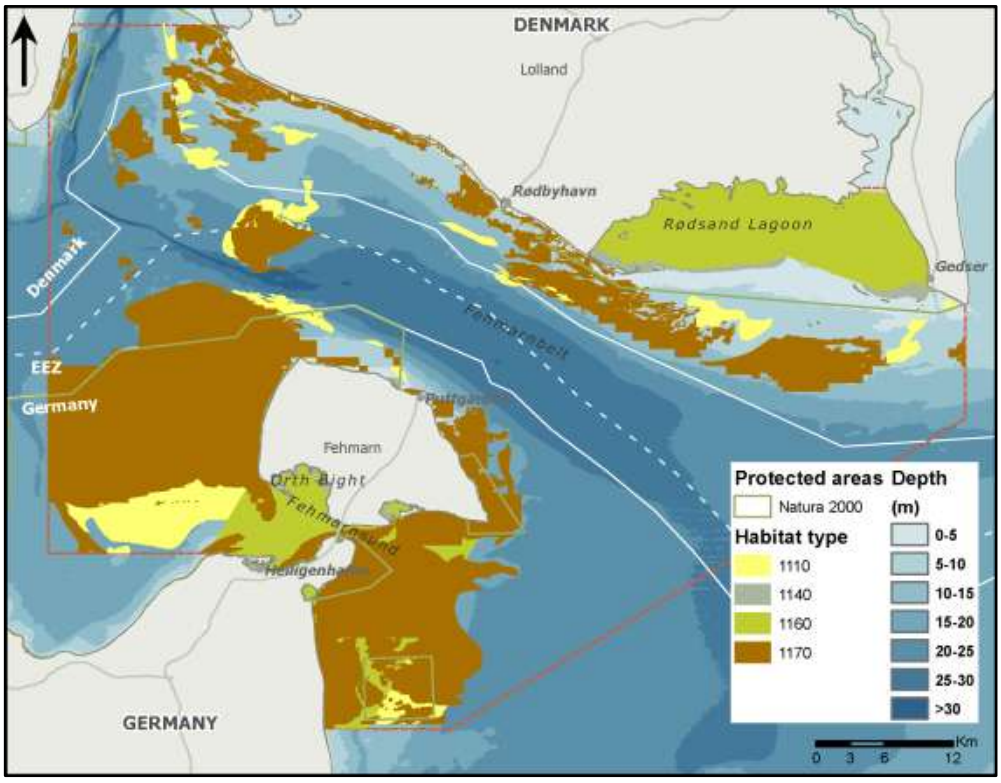
Final Report

FEHMARNBELT FIXED LINK
MARINE BIOLOGY SERVICES (FEMA)

Marine Fauna and Flora – Baseline

Benthic Habitat Mapping of the Fehmarnbelt Area

E2TR0020 - Volume III



Prepared for: Femern A/S
By: DHI/IOW/MariLim Consortium
in association with Cefas and DTU Aqua

Responsible editor:
FEMA consortium / co DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark

FEMA Project Director: Hanne Kaas, DHI
www.dhigroup.com

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CONTENTS

Lists of figures and tables are included as the final pages

APPENDICES

Note to the reader:
In this report the time for start of construction is artificially set to 1 October 2014 for the tunnel and 1 January 2015 for the bridge alternative. In the Danish EIA (VVM) and the German EIA (UVS/LBP) absolute year references are not used. Instead the time references are relative to start of construction works. In the VVM the same time reference is used for tunnel and bridge, i.e. year 0 corresponds to 2014/start of tunnel construction; year 1 corresponds to 2015/start of bridge construction etc. In the UVS/LBP individual time references are used for tunnel and bridge, i.e. for tunnel construction year 1 is equivalent to 2014 (construction starts 1 October in year 1) and for bridge construction year 1 is equivalent to 2015 (construction starts 1st January).

0 SUMMARY

Femern A/S is tasked with the designing and planning of a fixed link between Denmark and Germany across the Fehmarnbelt Baltic Sea strait. As part of the services provided by the Fehmarnbelt Marine Biology consortium, a baseline survey of the extent and distribution of benthic habitats in the Fehmarnbelt was performed. The main objective was to identify and delineate habitats occurring in the Fehmarnbelt area according to the EUNIS and the Habitats Directive classification systems. Due to the fact that the EUNIS classification for the Baltic Sea is still under development, it was necessary to develop a modified classification system based on EUNIS principles but tailored towards serving the purpose of the Environmental Impact Assessment work of the Fehmarnbelt Fixed Link including a documentation of HELCOM-Biotopes, §30-Biotopes (German Nature conservation act BNatSchG) and Riecken-Biotopes (Red List of endangered Biotopes in Germany)

A wealth of data sets was available for this task. These comprised acoustic and optic remote-sensing data (multibeam echosounder and aerial photography), sampling data (grain-size distribution of surface sediments), modelled data (bottom salinity, Secchi depth, length of surface water waves and bed shear stress) and predicted data (distribution of vegetation and fauna communities, coverage prediction of blue mussels).

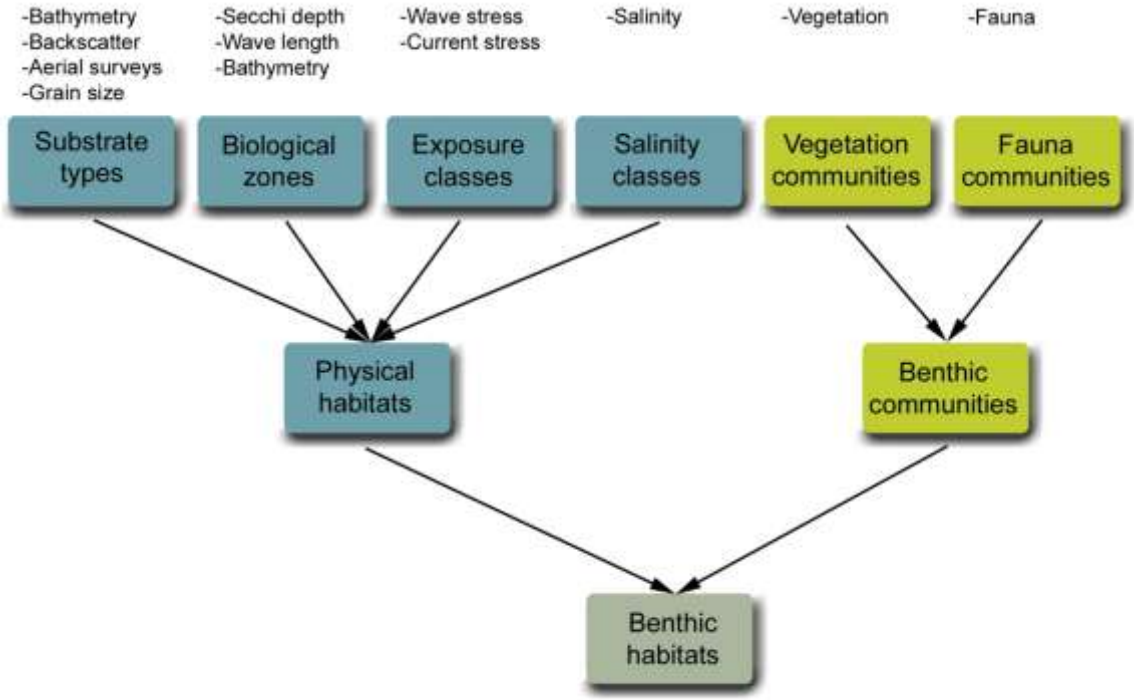


Figure 0-1 Overview of the workflow showing the step-wise approach taken in this study.

Several state-of-the-art methods were employed to analyse the various data sets. Geographic Information System-based terrain analysis was carried out on bathymetric data sets, yielding slope, rugosity, bathymetric position index, aspect and curvature surfaces. These were employed in further analyses including image anal-

ysis, spatial prediction of mud content and delineation of EU-Habitat Types. Object-oriented image analysis was used to interpret aerial photography and multibeam data. The mud content of the surficial seabed sediments was predicted using regression kriging. Grain-size and modelled hydrographical data were interpreted using classification schemes developed in recent international habitat mapping projects.

The habitat maps were derived in a step-wise approach (Figure 0-1). A substrate map of the greater Fehmarnbelt area was devised based on interpreted aerial photography, multibeam and singlebeam data, ground-truthed with seabed samples from archives and baseline surveys. The mapped seabed substrates in the investigation area are depicted in Figure 0-2. Coarse sediments can be found almost everywhere along the coast. The lower depth limit typically lies between 15 m and 20 m. Sands predominate in the littoral zone down to approximately 5 m water depths and border areas of coarse sediment. Towards the deeper basins, the grain size decreases (mud) due to decreasing exposure to waves and currents. Occurrences of mixed sediments are limited; they tend to occur in transition zones from coarse sediment to sand.

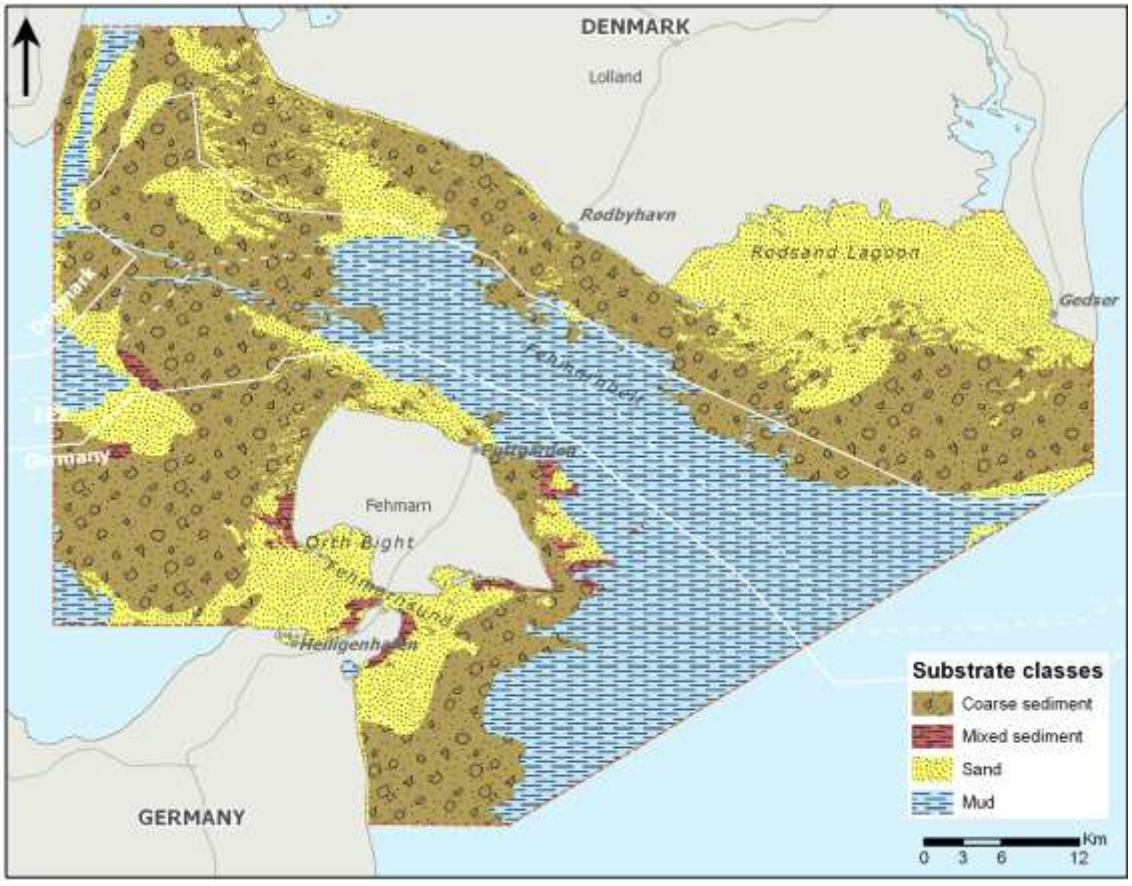


Figure 0-2 Distribution of seabed substrates.

Modelled environmental parameters including wavelength and Secchi depth were classified to derive maps of depth zones (infralittoral, circalittoral). These were then combined with the substrate information to derive a physical habitat map.

Predicted distribution (and coverage) of benthic vegetation and fauna communities was unified yielding a full coverage map of nine benthic communities in the investigation area (Figure 0-3). Due to the availability of suitable substrate and sufficient light, the vegetation-structured communities occupy the shallow coastal areas. An important shallow epifauna community is the Mytilus community, while *Dendrodoa* is the dominant deep water epifauna assemblage. Infauna communities are dominating the soft bottom zones of the investigation area.

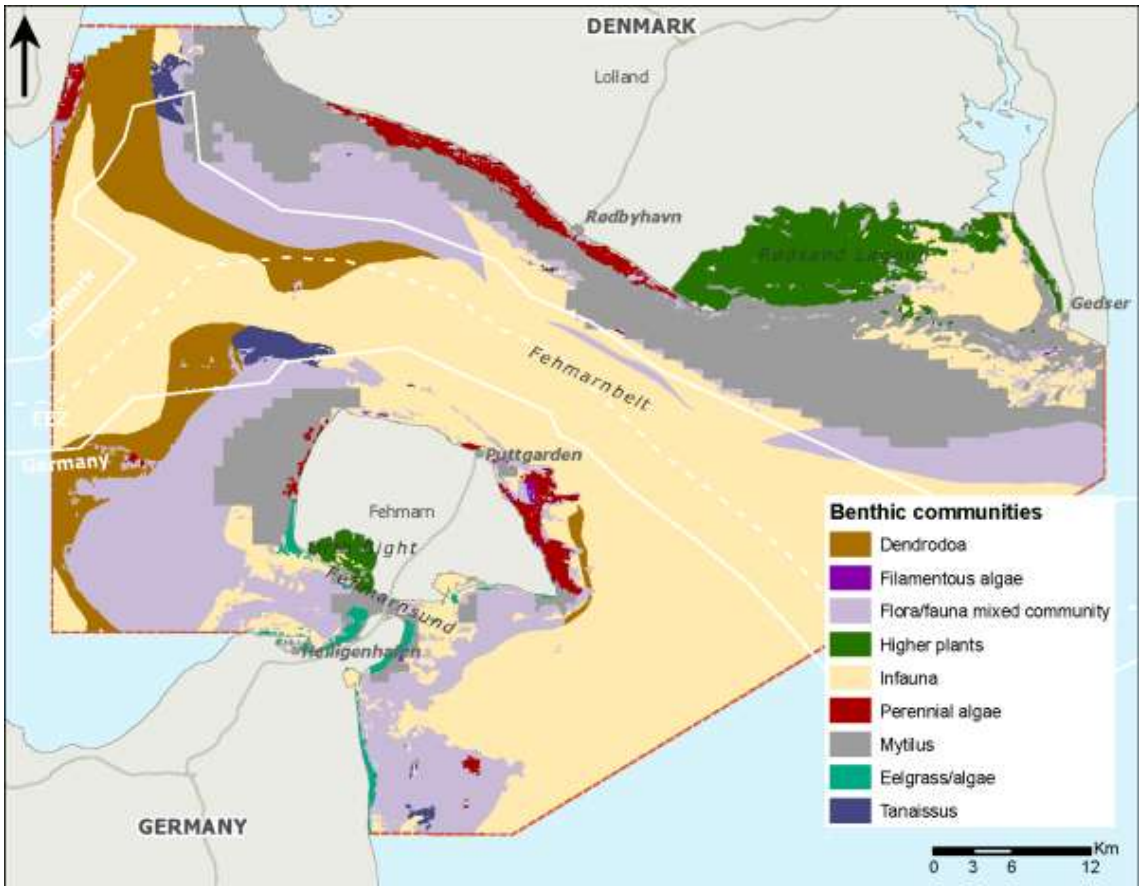


Figure 0-3 Distribution of benthic communities.

In a final step, the predicted distribution of benthic communities was integrated with the physical habitat information (substrate and depth zone) to provide a full habitat map of the local Fehmarnbelt area. Nineteen distinct benthic habitats were mapped and these are shown in Figure 0-4.

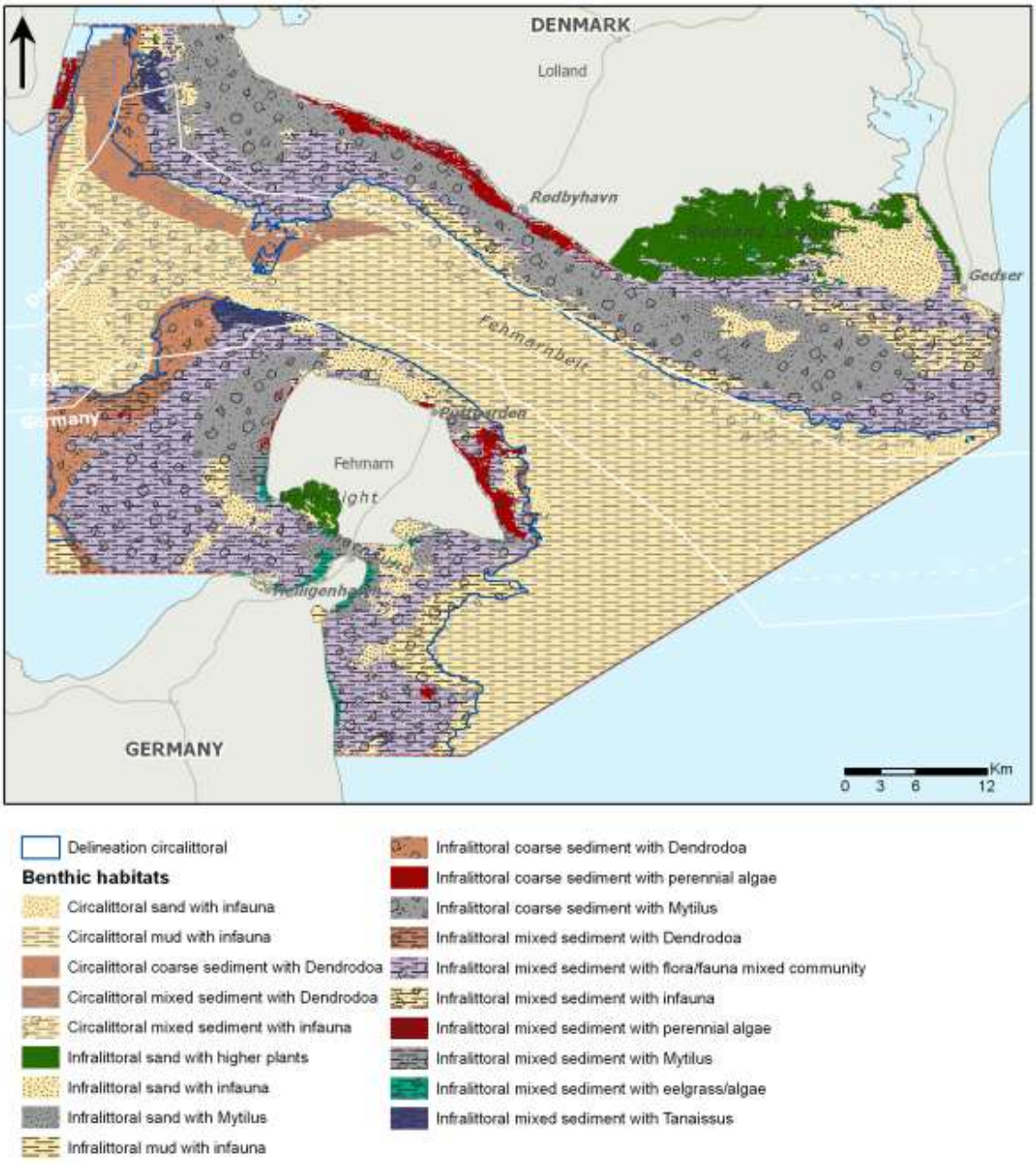


Figure 0-4 Distribution of benthic habitats.

There is a striking difference between the shallow infralittoral and the deep circalittoral zone in terms of complexity and diversity of habitats. The number of benthic habitats is restricted in the circalittoral (five benthic habitats) due to the absence of flora and the homogeneous substrate conditions. The largest areas are confined to pure soft bottom habitats, predominantly circalittoral mud with infauna and to a lesser extent circalittoral sand with infauna. Infauna inhabiting mud is constituted of long-living bivalve species and a great number of different polychaetes. It is distributed in the whole region of the deep basins in Kiel and Mecklenburg Bights as well as in the deep channel in Fehmarnbelt and off Langeland.

The number of benthic habitats in the infralittoral zone increases to fourteen, as the main distribution of many benthic communities is limited to shallower waters.

Coarse sediment covers a larger area in the infralittoral, but in contrast to mixed and soft bottoms it remains the smallest habitat. Coarse sediment with *Mytilus* is predominantly found at the south coast of Lolland, at the southeastern tip of Fehmarn (Staberhuk) and in Fehmarnsund. Coarse sediment with *Dendrodoa* is distributed west and northwest of Fehmarn in the transition zone to the deep basins of Kiel Bight. Coarse sediment with perennial algae predominantly occurs off the east coast of Fehmarn and south of Lolland. Infralittoral habitats with sandy substrates cover a significantly larger area than infralittoral muddy substrates. Infralittoral sand with higher plants like eelgrass or tasselweed is found in the sheltered regions of Rødsand Lagoon and Orth Bight. Infralittoral sandy habitats with little or no macrophyte vegetation are characterised by infauna. This infauna is dominated by common cockles or clams and is distributed in Rødsand Lagoon or Orth Bight. At exposed sites like the north of Fehmarn, Flügge Sand or sandy areas off Burger Binnensee habitats characterised by *Bathyporeia pilosa* do occur.

The EU-Habitat Types "Sandbanks which are slightly covered by sea water all the time", "Mudflats and sandflats not covered by seawater at low tide", "Large shallow inlets and bays" and "Reefs" were mapped in the investigation area. These are shown in Figure 0-5.

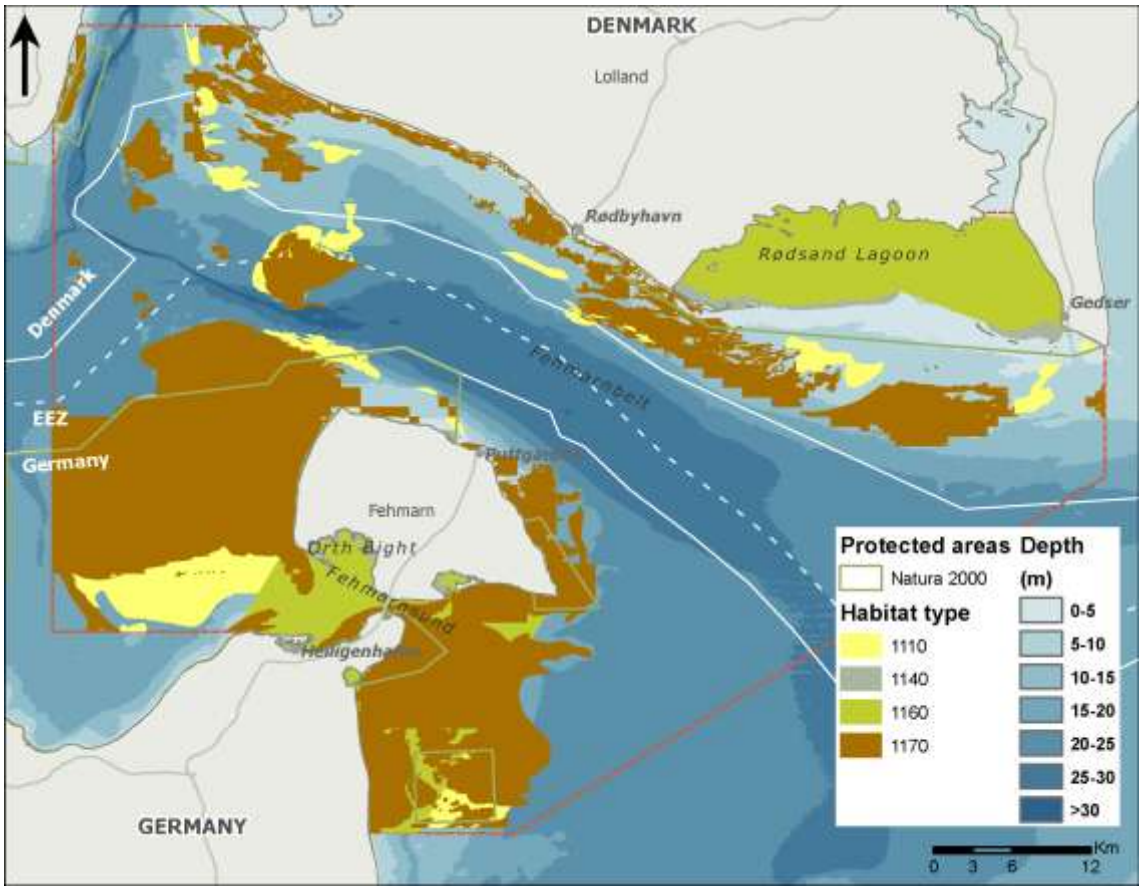


Figure 0-5 Distribution of EU-Habitat Types.

To illustrate other regional (HELCOM) and national habitat classification schemes (BNatSchG §30, Red List of Endangered Biotopes) in the investigation area on the basis of the developed benthic habitat classification, rules had to be defined to relate the different classification schemes with each other, e. g. certain substrate

types or habitat terms, as the various classification schemes use either different descriptors or criteria or have too vague definitions for a proper comparison.

The confidence in the produced maps was assessed using the Confidence Assessment Tool developed as part of the project Mapping European Seabed Habitats (MESH). Overall, the confidence was found to be high to very high.

1 INTRODUCTION

On 3rd September 2008, the Danish and German Ministers of Transport signed a state treaty for the establishment of a fixed link between Denmark and Germany across the Fehmarnbelt Baltic Sea strait. The proposed Fehmarnbelt Fixed Link will connect Rødbyhavn on the Danish side with Puttgarden on the German side, stretching over a distance of 19 km.

Femern A/S has the responsibility to design and plan the Fehmarnbelt Fixed Link. The planning and approval process involves environmental investigations, geotechnical investigations, investigations relating to maritime safety and the design of the link. The environmental investigations have been divided into seven areas: Hydrography, Marine Biology, Fish and Fishing, Birds, Marine Mammals, Environmental Investigations on Land and Archaeology. DHI and partners deliver the Marine Biology, Hydrography and Birds services to Femern A/S, based on integrated analyses.

As part of the Marine Biology baseline investigations, we have carried out a detailed mapping of seabed habitats within the Fehmarnbelt area.

Seabed habitat mapping can be defined as plotting the distribution and extent of habitats to create a map with complete coverage of the seabed showing distinct boundaries separating adjacent habitats (MESH Project, 2008). Definitions of the term "habitat" vary to a certain degree. Some researchers prefer to describe the physical and environmental conditions that support a particular biological community as a "habitat", while these conditions together with the community are termed "biotope" (Olenin, S. and Ducrotoy, J.-P., 2006). These definitions make a clearer distinction between abiotic and biotic components. However, this differs from the usage of the term "habitat" in this report: it means the physical and environmental conditions that support a particular biological community together with the community itself. Where no information on biological communities is available, the term "physical habitat" is used to describe the physical and environmental conditions only.

1.1 Objectives

The overall objective of the benthic fauna and flora baseline investigations is to determine the spatial distribution of benthic habitats in the greater Fehmarnbelt area and to document the species composition, biodiversity, abundance and biomass of the benthic fauna and flora communities (Femern A/S, 2010). This information is necessary for a subsequent Environmental Impact Assessment, and to establish a baseline for possible future monitoring.

More specifically, it is the objective of this baseline service to identify and delineate habitats occurring in the Fehmarnbelt area including parts of Kiel and Mecklenburg Bights. In particular, this encompasses:

- Mapping the spatial extent of benthic habitats on the basis of abiotic (physical) and biotic (biological) descriptors according to the EUNIS definitions (http://eunis.eea.europa.eu/habitats.jsp, Status: 31.10.2010); and
- Mapping the spatial extent of Natura 2000 habitats listed in Annex I of the Habitats Directive on the basis of the criteria catalogues of the EU (EU 2007), the Danish (Buchwald & Søgaard 2000, Dahl et al. 2004) and German authorities (Boedeker et al. 2006, http://www.blmp-online.de, preliminary draft

of mapping guidelines, provided by the Ministry of Energy, Agriculture, the Environment and Rural Areas, Schleswig-Holstein MELUR).
- Translating the resultant benthic habitats into other international and national habitat classifications: red list of marine biotopes after HELCOM (1998), legally protected biotopes after §30 BNatSchG and red list of endangered biotopes in Germany after Riecken et al. (2006).
- Assessing the importance of benthic habitats for ecosystem functioning.

A preliminary habitat map and report were presented in 2009, covering the Fehmarnbelt, Kiel Bight and parts of Mecklenburg Bight (FEMA, 2009). The presented results were entirely based on data that were available prior to the start of the habitat mapping programme. The resultant preliminary habitat map served as crucial input for the environmental baseline investigations carried out in 2009 and 2010. The purpose of this report is to present the results obtained during the integrated habitat mapping programme.

1.2 The Report

The Baseline Report is divided in the following sections plus references:

- Summary and Conclusion (Chapter 0) – an extended summary of the main findings
- Introduction (Chapter 1) – lists the objectives and outlines the structure of the report
- Habitat classification schemes (Chapter 2) – describes the different habitat classifications as well as the definitions and criteria used for mapping
- Materials and Methods (Chapter 3) – outlines the study site, describes the data sets and the methods and analyses used
- Benthic habitat classification (Chapter 4) – defines and describes the process of benthic habitat classification including all tested descriptors, physical habitats and benthic communities and describes the distribution of the benthic habitats in the Fehmarnbelt area
- EU-Habitat Types (Chapter 5) – describes the distribution of the habitat types of the Habitats Directive, Annex 1 in the Fehmarnbelt area
- HELCOM-Biotopes (Chapter 6) – describes the distribution of the HELCOM-Biotopes in the Fehmarnbelt area
- §30-Biotopes BNatSchG (Chapter 7) – describes the distribution of the §30-Biotopes in the Fehmarnbelt area (German part only)
- Riecken-Biotopes (Chapter 8) – describes the distribution of the Riecken-Biotopes in the Fehmarnbelt area (German part only)
- Existing pressures (Chapter 9) – describes the existing pressures on benthic habitats in Fehmarnbelt and neighbouring areas
- Importance (Chapter 10) – definition and distribution of importance of benthic habitats in the Fehmarnbelt area
- Confidence assessment (Chapter 11) – assesses the confidence of the provided output
- Discussion (Chapter 12) – provides a brief discussion of the employed methodologies and obtained results

2 HABITAT CLASSIFICATION

Habitat mapping might be carried out by developing a local classification based on the results of the investigation. However, applying a sufficiently detailed, comprehensive and widely accepted habitat classification system does have benefits in that it makes the results comparable beyond the boundaries of the investigation site.

Mapping is carried out methodically by a separate assessment of specific descriptors, which are used to define and delineate certain habitats. Which descriptors have to be used is an input requirement of the habitat classification in use. There are various classification systems in use world–wide; but within Europe, habitats are predominantly mapped according to the definitions of the European Nature Information System (EUNIS) and to Annex I of the Habitats Directive (EU-Habitat types). In the Baltic Sea, the HELCOM (Helsinki Commission) biotope classification is often used to map habitats (HELCOM 1998). Two additional habitat classifications exist in Germany, biotopes listed under §30 of the "Bundesnaturschutzgesetz" (BNatSchG) - and the Red List of endangered biotopes in Germany (Riecken et al. 2006), often called Riecken-Biotopes.

Classification schemes can be differentiated based on their general background: some offering a classification of all existing habitats in an area (e. g. EUNIS-Biotopes, HELCOM-Biotopes, Riecken-Biotopes), others list only certain protected habitats (EU-Habitat types, BNatSchG §30-Biotopes in Germany). Some of the listed classifications are only providing habitat terms without clear definitions or delineation criteria, which makes expert judgement necessary for habitat mapping.

In an ideal situation, the pan-European classifications (EUNIS, Habitat Directive) would be comparable with and relatable to regional (HELCOM) or national classifications (BNatSchG §30, Riecken) without discrepancies between them. However, in practice these various classification schemes use either different descriptors or criteria or have too vague definitions for a thorough comparison. Therefore rules had to be defined to relate the different classification schemes with each other, e. g. certain substrate types or habitat terms. The rules used are described in the Appendices (B–D).

2.1 Modified EUNIS classification

The European Environment Agency developed a classification scheme for habitats as part of its EUNIS system for managing species, site and habitat information. The EUNIS habitat classification scheme is a pan-European classification of terrestrial, freshwater and marine habitats and can be accessed from the EUNIS website (http://eunis.eea.europa.eu/habitats.jsp).

The EUNIS classification system provides a useful reference for mapping benthic (sublittoral seabed) habitats and has been used for large-scale mapping projects (e.g. Mapping European Seabed Habitats, http://www.searchmesh.net/). However, at the start of the project the EUNIS classification for the Baltic Sea was a reflection of the Red List of Marine and Coastal Biotopes and Biotope Complexes of the Baltic Sea, Belt Sea and Kattegat (HELCOM, 1998). As such it is not comprehensive, the characterisation of benthic biota is limited and the structure is not fully compatible with the rest of the EUNIS classification. To overcome these problems, the EU-SeaMap (Mapping European Seabed Habitats) project

(http://www.jncc.gov.uk/page-5020) was initiated, but outputs were only recently made public and are limited to modelled physical habitats only.

It was therefore decided to develop a tailor-made habitat classification scheme for the investigation area that uses EUNIS principles. The classification is hierarchical and habitat maps are derived in a step-wise approach (Figure 2-1): Different abiotic descriptors, relevant for the study site, are identified and combined to define and delineate physical habitats as a first step.

Secondly, different biological descriptors are combined to define and delineate benthic communities, which are theoretically adapted to certain physical habitats and characterise them.

In a third step physical habitats are combined with benthic communities to form benthic habitats. At this stage it became evident that many benthic communities are inhabiting a variety of apparently different physical habitats. This is caused by the fact that the splitting of physical habitats is possible on a finer scale level compared to benthic communities. Differences are physically measurable but might not be of relevance for species in choosing their habitat. As the term habitat is used to describe the living environment of certain adapted species or communities, it is not appropriate to classify habitats, which are only differentiable based on physical descriptors, have no practical relevance and are occasionally created accidentally by overlaying abiotic and biotic descriptors.

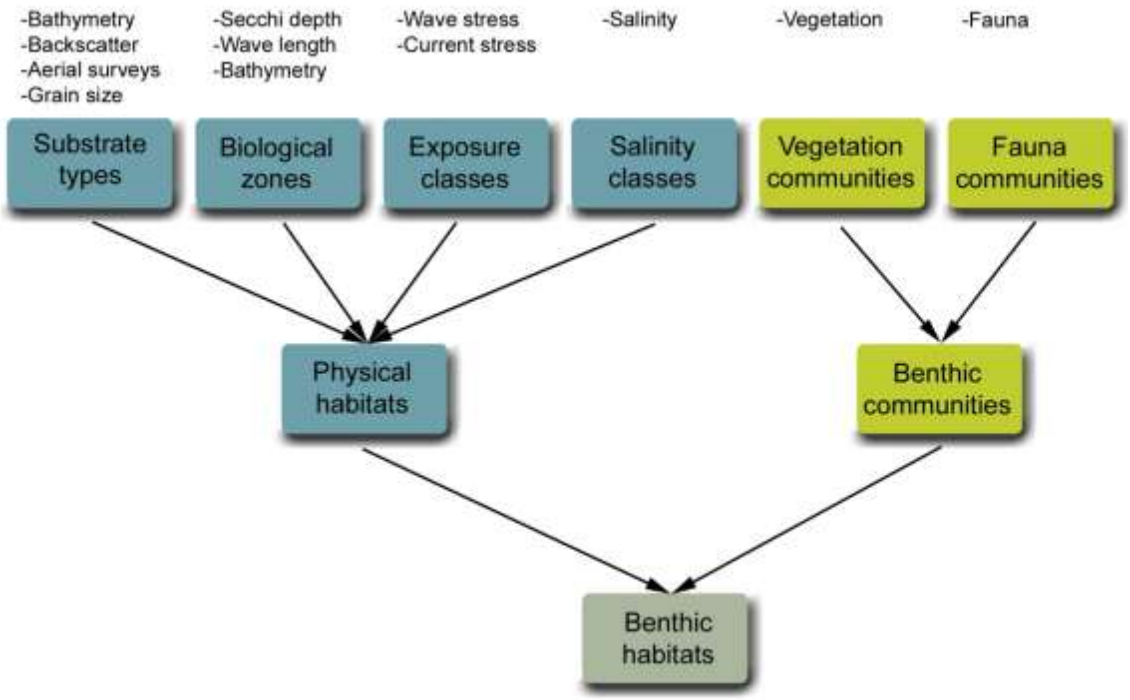


Figure 2-1 Overview of the workflow showing the step-wise approach taken in this study.

It is therefore essential in habitat mapping to evaluate the classification process by either eliminating or summarising descriptors or descriptor classes, which indicate

no clear delineation criteria for benthic habitats. In chapter 4.1 the abiotic descriptors tested (and their classes) as well as their suitability for habitat classification are described. Physical habitats are defined in chapter 4.2. In chapter 4.3 the summarising principles for biological descriptors are explained and in chapter 4.5 the benthic habitats are illustrated. Intermediate steps of the classification approach, which are redundant after the classification evaluation are described and illustrated in the Appendices (E–I).

2.2 EU-Habitat Types (Habitat Directive, Annex I)

The Habitats Directive is an important instrument for habitat and species conservation in Europe. The Directive lists about 1000 protected animal and plant species and more than 200 protected habitat types (Annexes I, II, IV and V of the Habitats Directive). The Habitats Directive focuses on the protection of specific habitat types, which have an outstanding importance for the conservation of biodiversity. These habitat types are listed in Annex I of the Directive. A network of protected areas (Natura 2000) has been established to ensure the survival of most threatened species and habitats. Habitat types listed in Annex I of the Directive are not only protected within the designated Natura 2000 sites.

Article 1 (d): priority natural habitat types means natural habitat types in danger of disappearance, which are present on the territory referred to in Article 2 and for the conservation of which the Community has particular responsibility in view of the proportion of their natural range which falls within the territory referred to in Article 2; these priority natural habitat types are indicated by an asterisk (*) in Annex I.

In the marine part of the investigation area four different habitat types (in agreement with national authorities) are distinguishable:

- 1110 Sandbanks, slightly covered by sea water all the time
- 1140 Mudflats and sandflats not covered by seawater at low tide
- 1160 Large shallow inlets and bays
- 1170 Reefs

The definitions of marine Annex I habitat types and their delineation criteria are given in the "Interpretation Manual of European Union Habitats" (EU 2007). Interpretations and definitions listed in this manual need to comply with the different geographical variations of those habitat types within the EU and are therefore too vague to allow an exact delineation and mapping of those types. Therefore additional descriptors and criteria described in several Danish and German references had to be used. The following references have been used for delineation[1]:

- Interpretation Manual of European Union Habitats (EU, 2007) [1]
- Denmark: Identification key of Danish habitat types (Buchwald & Søgaard 2000) [2], Descriptions of habitat types (Dahl et al. 2004) [3]
- German EEZ: complementary characteristics and criteria for habitat types sandbanks (1110) and reefs (1170) (Boedeker et al. 2006) [4]
- German coastal area: Mapping guidelines for habitat types sandbanks (1110), mudflats and sandflats (1140), large shallow inlets and bays (1160) und reefs (1170), (preliminary draft of mapping guidelines, provided by the Ministry of Energy, Agriculture, the Environment and Rural Areas, Schleswig-Holstein MELUR) [5])

[1] Numbers in brackets refer to which reference the delineation criteria in the Tables 2-1 to 2-4 belong to.

- German waters: Habitat type data sheets of German Marine Monitoring Program (Bund-Länder-Messprogramms – BLMP, http://www.blmp-online.de [6])

As national interpretations differ for several habitat types, some delineation criteria had to be used only in specific parts of the investigation area (Danish waters, German coastal waters and German EEZ). The criteria given for German coastal waters (within the responsibility of the Ministry of Energy, Agriculture, Environment and Rural Areas, Schleswig-Holstein, MELUR) and German EEZ (within the responsibility of the Federal Agency for Nature Conservation, BFN) are almost conforming, as both authorities have harmonised them during the Fehmarnbelt habitat mapping baseline survey.

Descriptors and delineation criteria are listed in the definition tables for each habitat type separately and numbers in brackets highlight, which reference form the basis for the descriptor or criteria in which geographical area. Danish specifications are missing for some descriptors. In such cases EU or German criteria have been used for delineation. Maps of habitat types produced on basis of those descriptors and criteria are described in Chapter 0.

Those maps have been checked manually in a final step and reclassified case-by-case in accordance to expert judgement and all raw data.

2.2.1 Sandbanks, slightly covered by sea water all the time (1110)

Submarine banks were delineated mainly following the methodology developed by Klein (2006). The delineation was however based on the local bathymetry regular grid with 50 m by 50 m cell size rather than a triangulated irregular network. The latter would require the underlying (ungridded) bathymetric data, which was not available. Slope analysis to delineate sandbanks based on gridded data was however successfully carried out in a previous study (Diesing et al., 2009).

The data density was considered low. Hence, critical slopes as low as 0.1º might be applicable. Different critical slopes between 0.1º and 0.5º were tested and a slope of 0.2º finally chosen, as this gave the best discrimination without adding too much "noise". Boundaries were drawn at the transition from the slope of the bank into the surrounding plains.

The described analysis yielded morphological banks, which were subsequently intersected with substrate information. Sand, muddy sand and coarse sediment were assumed to be substrates typical for sandbanks in line with the definitions given in the Interpretation Manual of European Union Habitats. However, this resulted in a certain overlap with reefs (see below), where the substrate is described as coarse sediment with boulders. In such cases, reefs were given preference.

Interpretations given in the EU manual and criteria used for delineation and mapping of sandbanks (1110) are listed in Table 2-1.

As substrate criteria are not allowing a clear delineation between sandbanks (1110) and reefs (1170), primarily biological criteria have been used for delineation.

As the range of communities for sandy substrates is also very variable, inverse conclusion has been used for delineation: only if epibenthic communities like macroalgae, blue mussels or *Dendrodoa* (as characteristic reef communities) have less than 10 % cover, a classification as sandbank is possible if all other delineation criteria are fulfilled.

A special case of sandbanks are fields of flow-transverse large-scale sand bodies. In the scientific literature they have been termed subaqueous dunes, sand waves and giant scale ripples, among others. In the following, we refer to such sand bodies with crest-to-crest distances on the order of tens to hundreds of metres as "mega ripples" in line with the terminology used by German authorities.

Table 2-1 Criteria for delineation and mapping of sandbanks (1110)

Morphology		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. [1]	
Germany	Topographically clearly visible elevation of the seabed [4] Rising from seabed (method according to Klein 2006) Slope gradient of 0.5° and more, border proceeds along the slope toe at the transition to the level sea bed, in shallow regions border proceeds along linear slope between the hanging sides [5] Not adjacent to coastline, if this is continuously sloping seawards [5]	Predominantly surrounded by deeper water (therefore not adjacent to coastline) In the present mapping a slope gradient of 0,2° showed the best accordance to the designated sandbanks. The threshold of the slope gradient in [5] is indeed 0.5°, but due to the precautionary principle this is uncritical as with a gradient of 0.2° greater areas occur. The delineation of the mega ripples (sand wave fields) resulted mainly from the bathymetry data (see chapter 3.3.1)
Denmark	No specific information, only statements about exposed and non-exposed banks [3] Rising sandy ground, not adjacent to land [2]	*German criteria applied*
Substrate type		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Consist mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including mud may also be present .[1]	
Germany	Mixture of predominantly sandy to gravelly substrates, patches with larger grain sizes like stones and boulders as well as muddy areas can be enclosed [4]	- muddy sand - sand - coarse sediment with stones - mixed sediment
Denmark	No specific information, only statements about mobile sediments [2,3]	*German criteria applied*
Depth zone		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Permanently below water [1] The shallowest part of the elevation generally lies in water depths < 20 m [1]	

Germany	Permanently immersed and mainly surrounded by deeper water [4] Above 20 m depth contour [5] Areas below 20 m depth contour, if they are connected with a sandbank, that lies above the 20 m depth contour [4,5]	Authorities' demand applied: Areas below 20 m depth contour to be included, if they are connected with a sandbank, that lies above the 20 m depth contour
Denmark	In shallow water and deeper water [3]	*German criteria applied*
Benthic communities		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Often without vegetation, elsewise vascular plants and stonewort [1] Invertebrates, which are characteristic for sandy sublittoral [1] Banks where sandy sediments occur in a layer over hard substrata are classed as sandbanks if the associated biota are dependent on the sand rather than on the underlying hard substrata. [1]	
Germany	Flora: without vegetation or only sparsely overgrown with macrophytes [4]	In accordance with authorities: - macrophytes < 10 % cover - *Mytilus*-community < 10% cover - without *Dendrodoa*-community (10 % cover of epibenthic communities as threshold between habitat type "reefs" [5,6] and other areas)
Denmark	Flora: without vegetation or only sparsely overgrown with macrophytes (mainly *Zostera*) [3]	*German criteria applied*

2.2.2 *Mudflats and sandflats (1140), not covered by seawater at low tide*

Interpretations given in the EU-Manual and criteria used for delineation and mapping of mud- and sandflats (1140) are listed in Table 2-2.

In the Baltic Sea, mudflats and sandflats are associated with the morphological structures of spits and sand bars, which exist because of a distinct sand transport and deposition along certain parts of the coast. This also results in the formation of larger shallow areas in front of the spits and bars. Steadily sloping sandy coastlines are not included in this type. The substrate criteria have no practical meaning for the delineation.

The Baltic Sea is practically tideless, but wind-induced water-level changes result in shallow areas associated with spits and bars falling dry several times a year. An exceedence analysis of the modelled water-level time series for the Fehmarnbelt area indicated that areas shallower than ca. 0.5 m fall dry six to twelve times a year. Areas associated with spits and bars and shallower than 0.5 m were defined as mudflats and sandflats to specify the vague requirement of the EU manual that mud- and sandflats should fall dry regularly (several times per year).

Within the German part of the investigation area 1 m below sea level was used to delineate mud- and sandflats to fulfill the requirements of the German authorities (MELUR), which argue that one "falling dry" occasion per year is sufficient to be re-

garded as regularly per year and that this may occur down to 1 m water depth. Mudflats and sandflats were delineated using nautical charts, the results from the aerial survey and expert knowledge of the local area as the local bathymetry 50 m-grid was too coarse to resolve these features.

Mudflats and sandflats are often associated and partly or fully included in the habitat type large shallow inlets and bays (see below). Where this was the case, they were given preference in those parts of inlets and bays that are shallower than 1 m (Germany) or 0.5 m (Denmark) respectively, although those areas also belong to Habitat Type 1160 Shallow bays and inlets.

The EU-Manual includes contradictory information about benthic communities for this habitat type: on the one hand it is listed that those flats are without any growth of vascular plants, but within a later text passage it is mentioned that eel-grass beds, which are vascular plants, should be included in this habitat type. In the German version this habitat type is translated as mud-and sandflats without vegetation. Due to these contradictory definitions the descriptor benthic communities was not used for delineation purpose. For the current mapping process vegetation is irrelevant as long as morphology and water depth criteria are fulfilled.

Table 2-2 Criteria for delineation and mapping of mud- and sandflats (1140)

Morphology		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	No information	
Germany	Shallow regions, which regularly (several times a year) fall dry. For delineation nautical charts or aerial photos have to be used alternatively [5]. Delineation around spits and at sandy areas and barriers, which are adjacent to coastline (results from aerial photos).	In the Baltic Sea only wind-induced flats. 1 m depth contour from nautical charts was used (in accordance with authorities) as lower boundary of the habitat type.
Denmark	No information	The 0.5 m depth contour from nautical charts as well as results from wind analyses were used to set the lower boundary of the habitat type.
Substrate type		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Sandy and muddy areas [1]	
Germany	- mud and sandy mud - sand and muddy sand	Sand to mud
Denmark	No information	*German criteria applied*
Depth zone		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Not covered at low tide; serves as feeding ground for game birds and wading birds [1]	
Germany	For wind-induced tidal flats individual seaward delineations have to be defined locally, as the water level oscillations through wind or post-oscillation (Seiches) in the Baltic is dependent on the respective location (e. g. much larger in	Seaward delineation at 1 m depth (authorities‘ demand)

	fiords) [5]	
Denmark	No information	Seaward delineation at 0.5 m depth to fulfil EU criterion „feeding ground for wading birds“ (regularly (6-12 times a year) falling dry)
Benthic communities		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Flora: without vascular plants, only covered by a layer consisting of cyanobacteria and diatoms respectively - but: eelgrass beds are also included in this type [1]	Note: In the English text of the Habitats Directive the expression “without vegetation” is missing in the title of the habitat type. In the German text this expression exists. Note: In [1] there is the expression “devoid of vascular plants”. Nevertheless eelgrass is mentioned as belonging community, although it is a vascular plant.
Germany	Wind-induced tidal flats can also be partly vegetated by other vascular plants and macroalgae (e. g. stonewort), dependent on frequency and duration of the desiccation [5].	Not used due to impreciseness.
Denmark	Without terrestrial plants, but eelgrass can occur. Important as feeding ground for birds [3].	Used for definition of seaward boundary (0.5 m).

2.2.3 Large shallow inlets and bays (1160)

Interpretations given in the EU-Manual and criteria used for delineation and mapping of large shallow inlets and bays (1140) are listed in Table 2-3.

For the German coastline exists a map for this habitat type (MELUR), which was used in the habitat mapping process for the German part of the investigation area although some of the EU criteria are not considered there, including “protected from wave action”. Within the Danish part the EU criteria were followed, as no additional national requirements exist.

In the Baltic Sea, the seabed of large shallow inlets and bays is typically covered by *Zostera* communities and due to a limited freshwater influence also by *Ruppia* and *Potamogeton spp*. Those areas can be found in bights and inlets that are enclosed to a degree that causes them to be sheltered from wave action. As mentioned in the EU manual the boundary between shallow inlets and bays and the seaward boundary can be defined using the distribution limit of the dominant *Zostera* and *Potamogeton* associations. However, the lower depth limit of *Zostera* and *Potamogeton* associations was historically located in deeper water depth compared to the current situation. Therefore this criterion is difficult to use for delineation.

The delineation of inlets and bays at the seaward side in Denmark is therefore not done by water depth or flora communities but in connection with the criterion morphology.

This Habitat Type may contain other EU-Habitat Types like sandbanks, mudflats or reefs.

Table 2-3 Criteria for delineation and mapping of large shallow inlets and bays (1160)

Morphology		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Large incisions or inlets in coastline, in which – in contrast to estuaries - the freshwater impact is generally limited and which lie sheltered from wave action [1]	
Germany	- presence of bay-shaped marine areas with contact to coast, which are sometimes sheltered by islands, projecting spits or offshore reefs and sandbanks - bays with fiord-like character, which comprise deeper zones and predominantly shallow areas, are completely assigned to this type The seaward delineation of the habitat type follows the widest expansion of the ecologically related shallow water area: - landward boundary is mean waterline - alternatively a feasible connection line between the most extending landmarks is defined as seaward boundary, which includes such areas [5]	Present delineation from Ministry of Energy, Agriculture, the Environment and Rural Areas (MELUR) was taken, which is an overall connection line between landmarks and not defined ecologically or morphologically
Denmark	Fiords, bays, „Noore“ or similar areas without direct exposition to the open sea [3]	Rødsand Lagoon, delineated as area without direct exposition to the open Baltic Sea (identified via aerial photos)
Substrate type		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Great diversity of sediments and substrates [1]	
Germany	Variety of sediments [5]	Criterion not used due to impreciseness
Denmark	Diverse [3]	Criterion not used due to impreciseness
Depth zone		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Shallow water. The limit of shallow water is sometimes defined by the distribution of the Zosteretea and Potametea associations. [1].	
Germany	Large shallow inlets and bays are ecologically defined in their depth expansion – overall depth limitation is not applied [5]	not used (see „morphology“)
Denmark	No information	not used (see „morphology“)
Benthic communities		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	The benthic communities are characterised by a well-developed zonation and high species richness. Characteristic plant species of large, shallow inlets and bays are *Zostera* spp., *Potamogeton* spp., *Ruppia maritima* and benthic algae	
Germany	Presence and zonation of macroflora and macrofauna, eelgrass beds	not used

Denmark	No information	EU-criterion used: tasselweed/dwarf eelgrass- (*Ruppia/Zostera noltii*) and pure eelgrass-communities are typical

2.2.4 *Reefs (1170)*

There exists no common international definition of the habitat type 1170 Reefs. The definition is developed by national experts, and neither streamlining nor intercalibration between the EU countries has been completed at this point. In the Fehmarnbelt Fixed Link EIA, this habitat is defined in Danish waters by using a reproducible approach that is based on the following three main criteria featuring in the Interpretation Manual of European Union Habitats: presences of hard substrate, structures arising from the seabed and the presence of biota. The definition applied is reflecting the general guidelines used by the Danish authorities:

Presence of hard substrate

Hard substrate is mapped using a number of different data and maps. The survey effort and resulting data basis for the mapping is differentiated according to the expected impact and practical application of the different methodologies as described in detail in chapters 3.2.1 to 3.2.3, 3.3.1 to 3.3.5 and 4.1.6:

- Sidescan sonar data: In the alignment and in shallow water at both sides of the alignment
- Multibeam echosounder data: Approximately 20 km to both sides of the alignment
- Ortho photo: In shallow water (applicable down to approximately 6 m)
- Bathymetry data (50 m): Known relationships between seabed morphology and substrate types (Werner et al., 1987) in the western Baltic Sea, for mapping in more remote areas where no remote-sensing data were available (for details see Chapter 7,). E.g. abrasion platforms and shoals are typically associated with coarse sediments, while the littoral zone and slopes and plateaus are covered with sands. Substrates were mapped based on relief (small-scale and large-scale) derived from bathymetry and substrate type from classified samples.
- Ground truthing from > 2000 sediment samples from archives and 560 sediment samples collected during the baseline sampling were used, as well as diver observations from the vegetation studies.

It was assessed that sidescan sonar data were needed in the alignment area because direct loss of stone reef areas could be expected due to construction work and permanent structures. Full coverage with sidescan sonar in combination with sediment and biota samples as well as ortho photos, where applicable, is the most comprehensive and precise methodology for mapping stone reefs. This methodology has therefore been applied in the shallow part of the investigation area and in the alignment.

Impacts on stone reefs outside the alignment area originating from burial by spilled sediments or light absorption by suspended sediments were in connection with the survey design expected to be minor, temporary and only impacting the biological components and not the physical characteristics of the stone reefs. It was therefore decided that the combination of multibeam with bathymetry, sediment samples, BPI index and biological data was sufficient for the mapping needs. This methodology is more conservative and could potentially lead to and overestimation of the reef areas. With the very dense support data from bathymetry, sediment and biota sampling it was assessed that the data basis for the mapping would be sufficient

and that the possible overestimation of the total reef area is minor and will not lead to an underestimation of the proportional eventual impact.

All baseline and impact assessment results confirm our assumptions and survey design basis. Hard substrate will be permanently impacted in the alignment area by land reclamations (tunnel and bridge) and the piers and pylons (bridge) and temporary impacted by the tunnel trench. Outside the alignment area no permanent impacts are expected on any biological components or physical structures of the stone reefs. Accordingly, no significant impacts are expected on Natura 2000 stone reef habitats. A less conservative survey would not change these conclusions.

Structures arising from the seabed

Those structures are mapped by a GIS analysis determining the bathymetric position index (BPI), a measure of the elevation of an area relative to its surroundings. No common definition is given for this criterion. Here, areas that arise from the seafloor are extracted by terrain analysis of the local bathymetry 50 m grid. The BPI (3.3.1) was calculated for each grid cell of the 50 m bathymetry model. Areas that had a positive BPI were classed as "arising from the seafloor".

Biota

The differentiation between sandbanks and reefs was mainly based on the benthic communities. The presence of macroalgae and mussels was considered characteristic for reefs in the Fehmarnbelt area. The predicted distributions of macroalgae and mussels were used and a threshold of 25 % coverage was set in the Danish part (deviating from Dahl et al. 2004) to avoid mapping sporadic boulder aggregations as reef. Coverage of more than 10 % with characteristic epibenthic communities (macroalgae, blue mussels, *Dendrodoa*) as a surrogate for hard substrate coverage are, according to German authorities, sufficient to delineate reef areas in the German part of the investigation area. In deeper waters, where direct information on biota living on cobbles and boulders was sparse, we employed the presence of the *Dendrodoa* fauna community as an indicator for reefs. For the German offshore areas, the BfN already provided an official map with a delineation of the habitat type reef within the Natura 2000 site Fehmarnbelt. This map was used as the basis for reef delineation in the German EEZ upon request of the BfN and additional reef areas where added to this core area where they where found according to the rules described here.

Accordingly, the reefs in the Danish part of the investigation area are mapped by combining at least 4 and at maximum 5 independent data sets and using a very dense set of seabed samples as ground truthing. Interpretations given in the EU manual and criteria used for delineation and mapping of reefs (1170) are listed in Table 2-4.

Concerning the substrate type there are overlapping criteria with sandbanks. Therefore the delineation between those two habitat types was mainly based on benthic communities as described in Chapter 2.2.1 For the Danish side of the investigation area a BPI neighbourhood size (explanation Chapter 3.3.1) of 6.250 m was used to implement the criterion "arising from the seabed" of the EU Manual, as this value correctly reproduces structures like Sagas Bank and Fehmarnbeltbank (Øjet). The BPI is not used for the German side due to the demand of the German authorities. Therefore in Denmark blue mussels with high coverage may exist also outside of the habitat type reef, if the BPI is less than or equal to zero.

Table 2-4 Criteria for delineation and mapping of reefs (1170)

Morphology		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Reefs arise from the sea floor in the sublittoral and littoral zone. The reef is topographically distinct from the surrounding seafloor. [1]	
Germany	Reefs are located adjacent to active cliffs, on sills and in channels [5] Topographically clearly visible elevation from seabed (arising from sublittoral sill, bank or slope) [4]	Not used, especially the aspect ”topographic elevation“. Only in EEZ a BPI-value > 0 was alternatively used to gather boundary areas of the reefs, which are not already included with other criteria.
Denmark	Rising stones or hard bottom, not adjacent to land (habitat type “reefs” does not include hard bottom, which is adjacent to land) [2]	Topographically visible elevations of the seabed, delineated by BPI-method
Substrate type		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	- Hard, compact substrate (rocks (including soft rock, e.g. chalk), boulders and cobbles (generally >63 mm in diameter).) [1] - Biogenic concretions, including bivalve mussel beds originating from living or dead organisms (e. g. blue mussel bed), i.e. biogenic hard bottoms which supply habitats for epibiotic species. [1]	
Germany	Geogenic reefs: hard substrates like boulders, stones, glacial drift with boulders and stones [4] Geogenic reefs: rock, erratic boulders, fields of boulders and stones or clay- and chalk outcrops [5,6] Biogenic reefs: mussel beds, also occurring on soft bottom [4] Biogenic reefs: *Mytilus edulis, Dreissena polymorpha*, existing for several years (i. e. they have to contain perennial mussels (3-4 age groups), coverage larger than 10 %). If distance between single mussel beds is less than 25 m, the whole complex is regarded as one reef [5,6]	Biogenic reefs: can occur anywhere, no limitations concerning the substrate Geogenic reefs: - coarse sediment with hard substrates - mixed sediment with with hard substrates - clay oupcrops Percentage cover of sediments derived from percentage cover of benthic communities (see there)
Denmark	Stones and boulders as well as gravel dominate, but mobile sediments may occur [3] At least 5 % hard substrate, centre zone at least 10 m^2 Biogenic substrate: e. g. horse mussel (*Modiolus*) [3]	Coarse sediment with hard substrates Mixed sediment with hard substrates Percentage cover of sediments derived from percentage cover of benthic communities (see there)
Depth zone		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	Reefs may extend from the sublittoral uninterrupted into the intertidal (littoral) zone or may only occur in the sublittoral zone, including deep water areas such as the bathyal. [1]	

Germany	From littoral (temporarily falling dry) to sublittoral [5,6] Sublittoral or falling dry at low tide [4]	Not relevant – mapping independent of water depth
Denmark	Shallow and deep [3]	Not relevant – mapping independent of water depth
Benthic communities		
Geographic area	**Criteria listed in references**	**Criteria used for delineation**
EU	-Plants: A large variety of red, brown and green algae (some living on the leaves of other algae).-Reef-forming animals: Bivalves (e.g. Modiolus modiolus, Mytilus sp., Dreissena polymorpha). -Non reef-forming animals: Typical groups are: hydroids, ascidians, cirripedia (barnacles), bryozoans and molluscs as well as diverse mobile species of crustaceans and fish. [1]	
Germany	Reefs offer habitats for epibenthic sessile and vagile species (species of phytal and cavity system of sessile species) as well as for macroalgae. They also serve as important passage areas with stepping stone-function for benthic animals, fishes and algae. Habitat specific sessile epibenthic species of the reefs are hydrozoans (sea anemones, sea firs), molluscs (blue mussels, zebra mussel), crustaceans (barnacles), bryozoans (moss animals) and tunicates (sea squirts). In the Baltic Sea a reef has to contain a centre zone of at least 0.05 ha with habitat specific epibenthic species. At geogenic reefs with a centre zone, the border of the reef is defined by a cover of > 10 % hard substrate against the surrounding substrate [5,6]. Geogenic reefs are characterised by benthic species, which are associated with hard substrate. When reefs are covered by mobile substrates, they should be classified as reefs, if the associated fauna is more dependent from the hard substrate as from the mobile substrate [4]	≥ 10 % cover with blue mussels (biogenic reefs) or macrophytes (representative for ≥ 10 % cover with hard substrate) or presence of *Dendrodoa*-community (epifauna)
Denmark	More than 10 % of the substrate surface is at least once a year covered by a characteristic hard bottom fauna and flora [3]	≥ 25 % cover with blue mussels (biogenic reefs) or macrophytes (representative for ≥ 25 % cover with hard substrate) or presence of *Dendrodoa*-community (epifauna)

2.3 HELCOM-Biotopes

The Red List of Marine and Coastal Biotopes and Biotope Complexes of the Baltic Sea, Belt Sea and Kattegat (HELCOM, 1998) includes a description and classification system for Baltic marine and coastal habitats. It is the only transnational classification system presently available for the Baltic Sea and represents a full classification system for all occurring biotopes. At the highest level, the HELCOM classification discriminates between pelagic marine, benthic marine and terrestrial. Only benthic marine habitats are relevant for this report. These are further subdivided based on

- Biological or depth zones: aphotic, sublittoral photic and hydrolittoral zone
- Substrate type: rocky, stony, hard clay, gravel, sandy, shell gravel, muddy, peat and mixed sediment
- Bottom morphology: reefs (only for rocky or stony bottoms) and sand banks (only for sandy bottoms) in the sublittoral photic or hydrolittoral zone but not in the aphotic zone, bubbling reefs
- Biological features: dominated by vegetation, sparse or no vegetation, mussel beds.

The HELCOM classification is currently under revision in the HELCOM-Red-List-Project and will be adapted to the EUNIS classification as far as possible. Final results for the new classification scheme are expected in June 2013. Habitats in the Fehmarnbelt were not mapped according to the HELCOM classification system of 1998 due to the fact that biological information features only marginally and is limited to the presence or absence of macrophyte vegetation and mussel beds and the already out-dated status of this classification.

However we provide a "translation" table (Appendix B), which outlines the relationship between the descriptors used for HELCOM biotopes (HELCOM 1998) and the descriptors used in this investigation, to enable the illustration of HELCOM biotopes in the investigation area (Chapter 0).

2.4 §30-Biotopes (BNatSchG Bundesnaturschutzgesetz)

The German nature conservation act (Bundesnaturschutzgesetz, BNatSchG), § 15, section 1 requires omitting avoidable adverse effects of intervention in nature and landscape. The term "nature and landscape" covers "all nature" and includes also the marine environment. Protected habitat types are listed in §30 BNatSchG.

It is not a full classification of all occurring biotopes but includes only a list of protected biotopes without any given specifications or delineation criteria. §30 BNatSchG has partly adopted EU habitat types. Relevant for the investigation area are:

- Coastal lagoons and "Bodden" (similar to "Large shallow inlets and bays")
- Mudflats and sandflats (including salt marshes)
- Reefs
- Sublittoral sandbanks
- Eelgrass beds and other marine macrophyte stands
- Species rich gravel, coarse sand and shell gravel bottoms

A "translation" table, which outlines the relationship between §30-Biotopes and the benthic habitats defined in this investigation is given in Appendix C, to enable the illustration of §30-Biotopes (Chapter 0).

2.5 Riecken-Biotopes (Red List of endangered Biotopes in Germany)

The Red List of endangered Biotopes in Germany (Riecken et al. 2006) includes a description and classification system for all German habitats. It represents a full classification system for all occurring biotopes. At the highest level, the Riecken classification discriminates between pelagic marine, benthic marine and terrestrial. Only benthic marine habitats are relevant for this report. These are further subdivided based on

- Geographical region: North Sea and Baltic Sea
- Water body type: inner and outer coastal waters (in accordance with German Water Framework Directive water type definitions)
- Substrate type: hard substrate, gravel, shell, sandy and peat biotopes as well as fine sediment biotopes (with additives of silt, mud, sand, gravel and stones)
- Bottom morphology: sand banks, level sandy bottoms, hard substrate reefs, level hard substrate bottoms
- Biological features: rich in macrophytes, sparse or without macrophytes, eel-grass beds, meadows of limnic or brackish aquatic plant species, biogenic reef (mussel beds)

Habitats in the Fehmarnbelt were not mapped according to the Riecken classification system due to the national character of this classification. However, we provide a "translation" table (Appendix D), which outlines the relationship between the descriptors used for Red List of endangered German biotopes (Riecken et al. 2006) and the descriptors used in this investigation, to enable the illustration of Riecken-Biotopes in the German part of the investigation area (Chapter 0).

3 MATERIALS AND METHODS

3.1 Investigation area

The area of investigation is defined by the requirements set by the objectives of the baseline study; i. e. it must ensure that it is possible to a) determine the basic characteristics of benthic habitats and EU-Habitat Types in the Fehmarnbelt area and in the nearest Natura 2000 sites, and b) determine impacts of the EIA scenario.

The extent of area of investigation has been based on existing knowledge on local conditions and impacts from physical structures and sediment spill as well as on the need for unaffected reference sites. For benthic habitats, impacts are only plausible in an area close to the Fixed Link, i.e. in a corridor of 15-20 km around the alignment area.

The investigation area includes sites outside the expected impact areas in order to assess the limits and significance of the impacts and in order to provide information of possible unaffected reference areas to support the design of a possible future monitoring programme.

Natura 2000 sites are by definition areas of special interest and the areas to be included in the investigation have been chosen to ensure that baseline and impact assessment are possible, if needed, even in the more remotely lying areas.

The following Natura 2000 sites have been included in the benthic habitat baseline investigations:

- DK00VA200 Reef southwest of Langeland (abbreviation: Langeland)
- DK006X238 Rødsand Lagoon
- DE 1332-301 Fehmarnbelt
- DE 1533-301 Staberhuk
- DE 1631-392 Marine areas of Eastern Kiel Bight (abbreviation: Eastern Kiel Bight)
- DE 1632-392 Coastal landscapes of Großenbrode and offshore areas (abbreviation: Großenbrode)
- DE 1733-301 Sagas Bank

Habitat mapping was carried out at two different spatial extents (Figure 3-1): Abiotic descriptors were mapped in the greater Fehmarnbelt area as supplementary data allowed a classification on a larger scale beyond the defined investigation area. Benthic habitats (Chapter 4.5) and EU-Habitat Types (Chapter 0) were mapped in the defined investigation area.

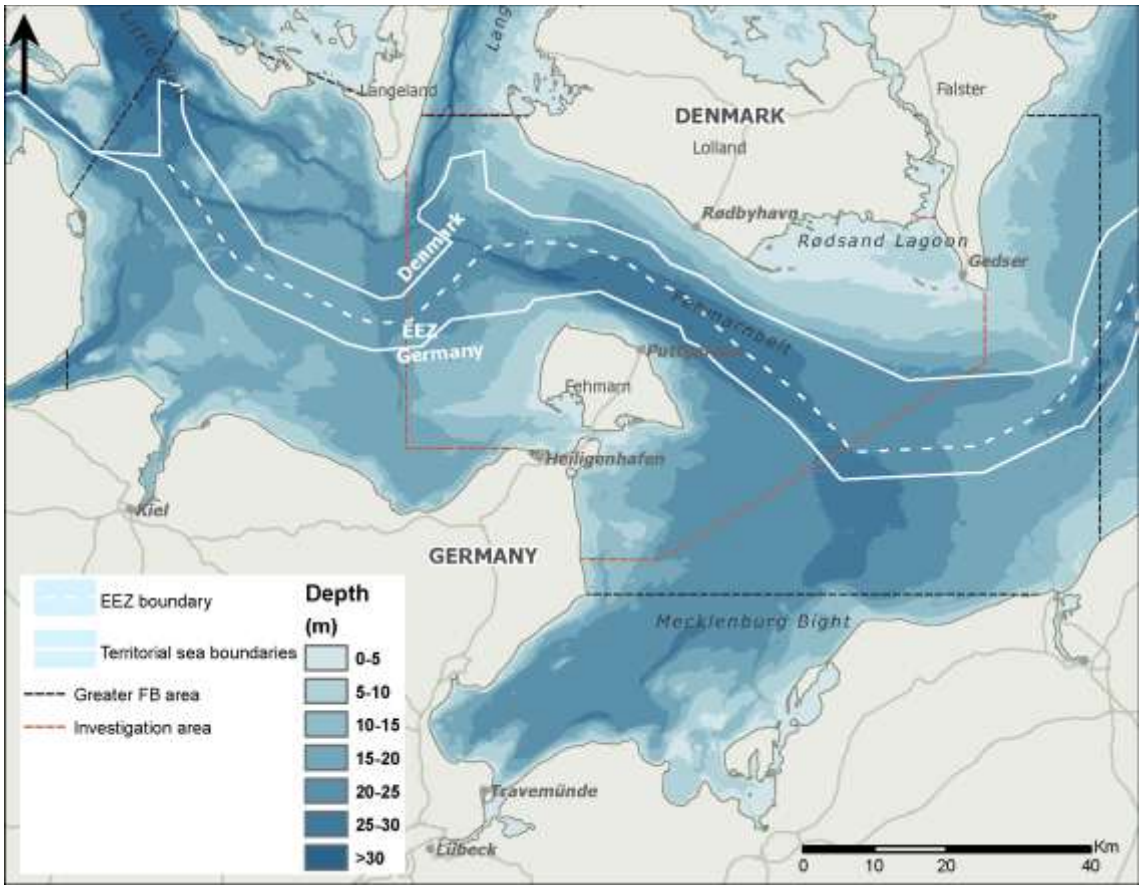


Figure 3-1 Spatial extent of the mapped areas.

3.2 Available data

With the exception of the aerial survey data (ortho photos), none of the data sets and layers described below were exclusively derived for the purpose of habitat mapping. The methods, data sets and layers are briefly described. Further information can be found in the respective technical reports that are referenced.

3.2.1 Remote sensing data

Bathymetry (Multibeam and singlebeam echosounder)
Two sets of bathymetric data were available (Figure 3-2):

- The "Local bathymetry 50 m grid" covers the bathymetry from Kattegat (South of Grenå to the tip of Kullen) in the north to the Baltic Sea east of Bornholm. The spatial resolution of the source data is variable but has been gridded to 50 m by 50 m. The bathymetry was created from three primary data sources. These are: (i) Topographic charts of the seabed provided by the Federal Maritime and Hydrographic Agency (BSH). (ii) Digital bathymetry of Danish waters provided by Farvandsvæsenet (FRV). A documentation of this data set can be found on the website of FRV (in Danish)2. (iii) Multibeam measurements of the Fehmarnbelt carried out in 2008 and 2009 (see below).

[2] http://frv.dk/SiteCollectionDocuments/Dybdemodeller/KattegatSyd.pdf

- The Fehmarnbelt proper between the Islands of Fehmarn and Lolland (see Figure 3-2) was surveyed with multibeam echosounder from May to July 2009 by MMT (formerly Marin Mätteknik). A total of 836 km^2 were mapped with water depths ranging from 6 m to 42 m. The data set was merged with multibeam data collected by Rambøll along the planned bridge/tunnel alignment and GEUS off the Lagoon of Rødsand and made available at a spatial resolution of 2 m.

Backscatter (Multibeam and sidescan sonar)

The multibeam survey carried out by MMT also provided backscatter intensity data. The data were processed by MMT with the Geocoder software to remove undesirable striping artefacts. This was an important prerequisite for further image analysis (Chapter 3.3.2). The spatial resolution of the backscatter grid originally was 2 m. After initial trials it was decided to down-sample the data set to 10 m for image analysis as similar results could be expected, yet the data set was easier and faster to process.

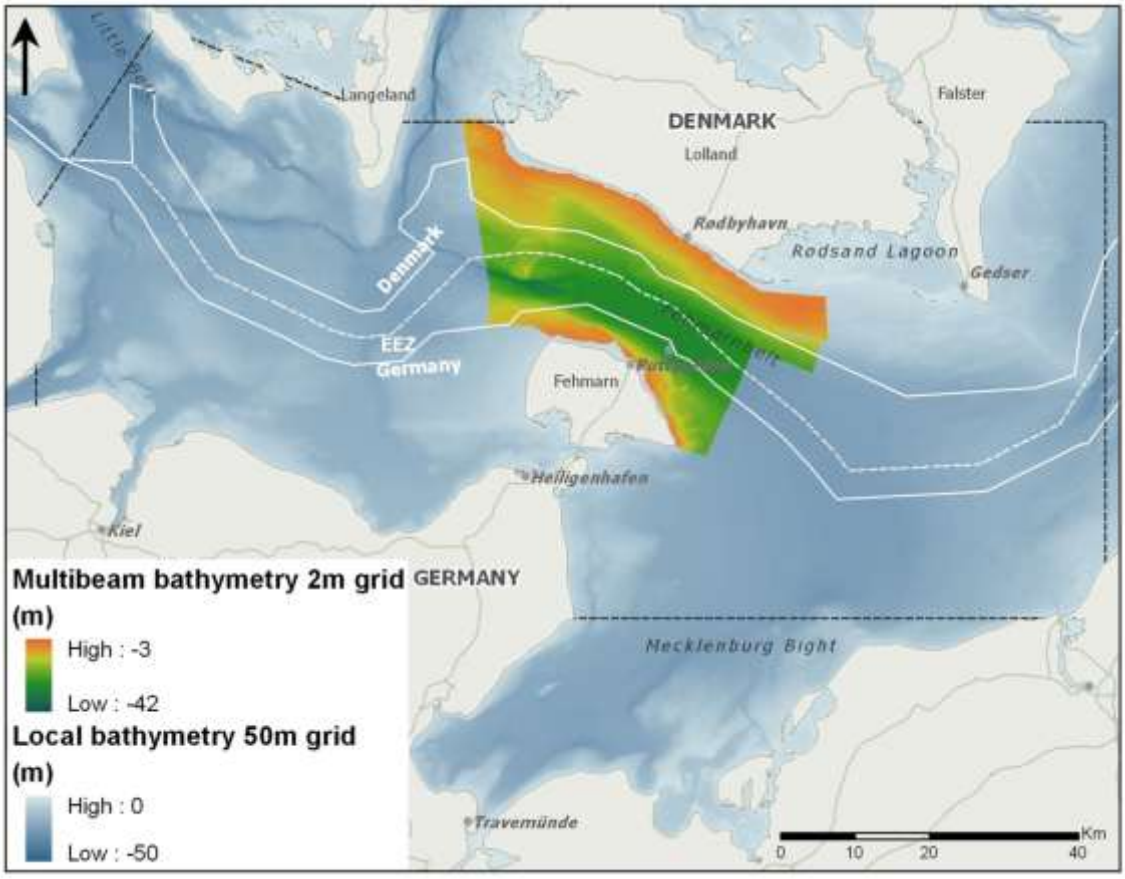


Figure 3-2 Available bathymetric data. The local bathymetry 50 m grid is displayed by applying a colour ramp to highlight seabed morphology.

Additionally, smaller blocks of sidescan sonar data were available from the proposed alignment undertaken as part of the geotechnical investigations by Rambøll (Rambøll, 2008) and four coastal areas east and west of the harbours of Puttgarden and Rødbyhavn, respectively, carried out by GEUS (GEUS, 2009a) (Figure 3-3). The

data were gridded to a spatial resolution of 0.25 m (GEUS data) and 0.1 m (Rambøll data).

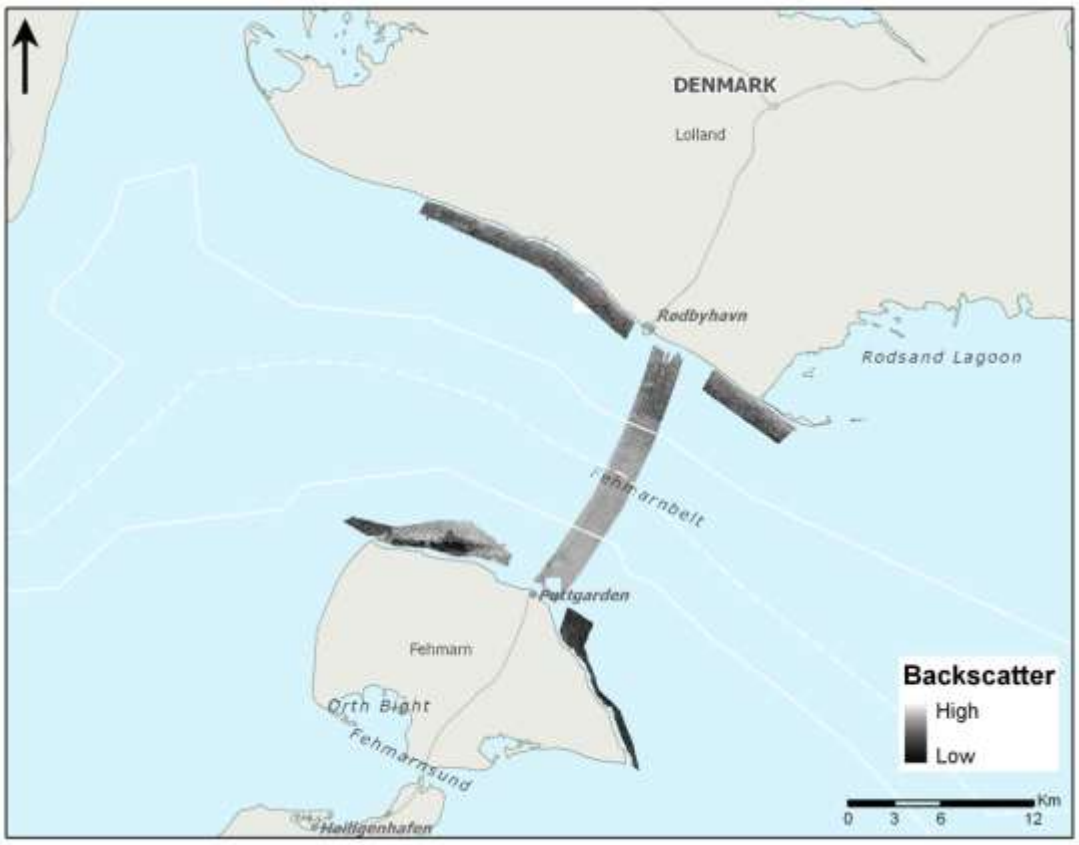


Figure 3-3 Sidescan sonar surveys in the Fehmarnbelt.

Aerial survey

An extensive aerial survey was carried out within the local Fehmarnbelt area in order to map shallow-water habitats with high spatial resolution (Figure 3-4). The company COWI took the photographs from an aeroplane between 16 and 20 April 2009. The covered area measured ca. 528 km^2 (146 km^2 in Germany and 382 km^2 in Denmark) and encompassed the whole coastline of Fehmarn including parts of the main land and the whole south coast of Lolland including the Rødsand lagoon and parts of southern Falster (Figure 3-4). The image resolution was 20 cm.

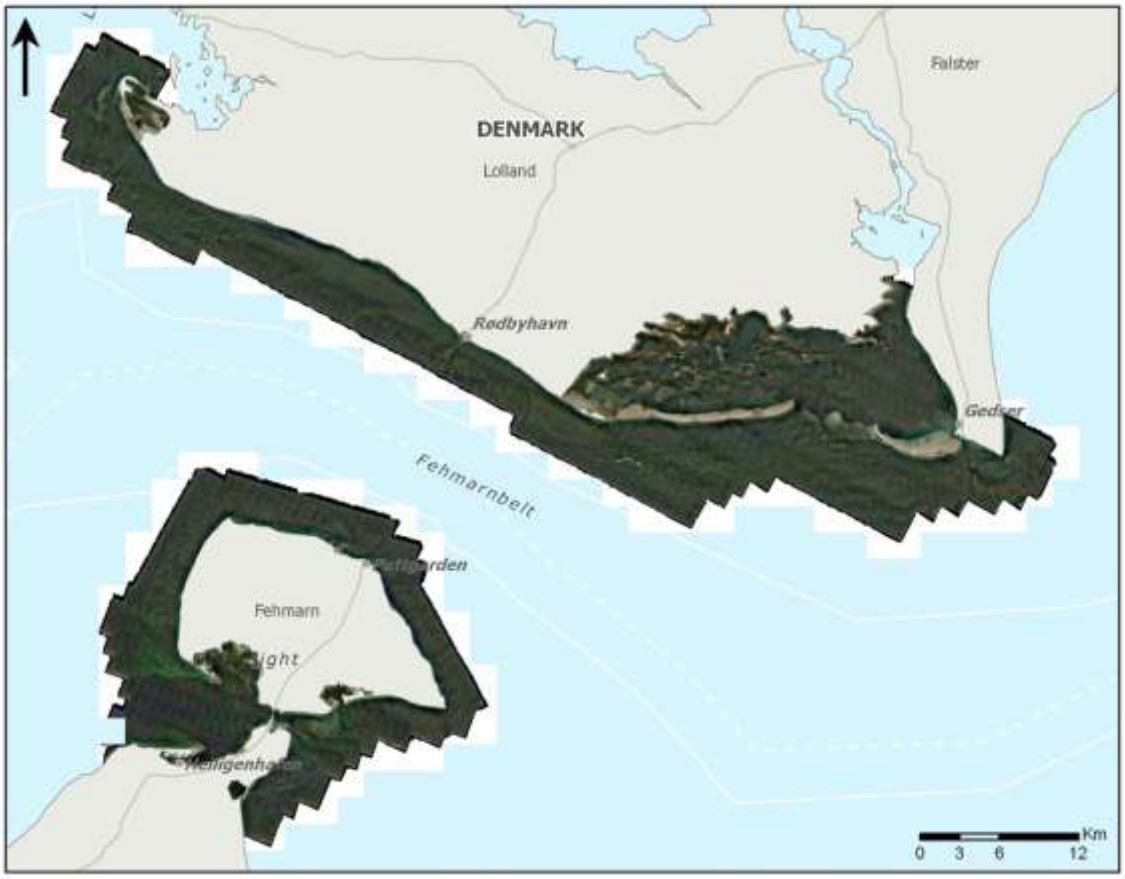


Figure 3-4 Aerial survey coverage.

3.2.2 *Grain size sampling data*

Archived legacy data from samples with content of mud, sand and gravel (weight-%) were obtained from three sources: (i) 1401 samples from the Leibniz Institute for Baltic Sea Research (IOW)[3], (ii) 888 samples from the Marine Environmental Data Base (MUDAB[4]) and (iii) 13 samples from MariLim GmbH. Additionally, a further 755 samples with mud content only were retrieved from the MUDAB database (Figure 3-5). The grain-size data have been collected over a long time-period from the 1930s to the 1990s. It is likely that the older data sets have positioning errors, which were deemed to be small in relation to the scale employed in this assessment. It is also known that coarse sediments are difficult to sample and they might therefore be underrepresented in the data sets.

[3] http://www.io-warnemuende.de/projects/dynas/dynas2/db/index.php

[4] http://www.bsh.de/en/Marine_data/Environmental_protection/MUDAB_database/index.jsp

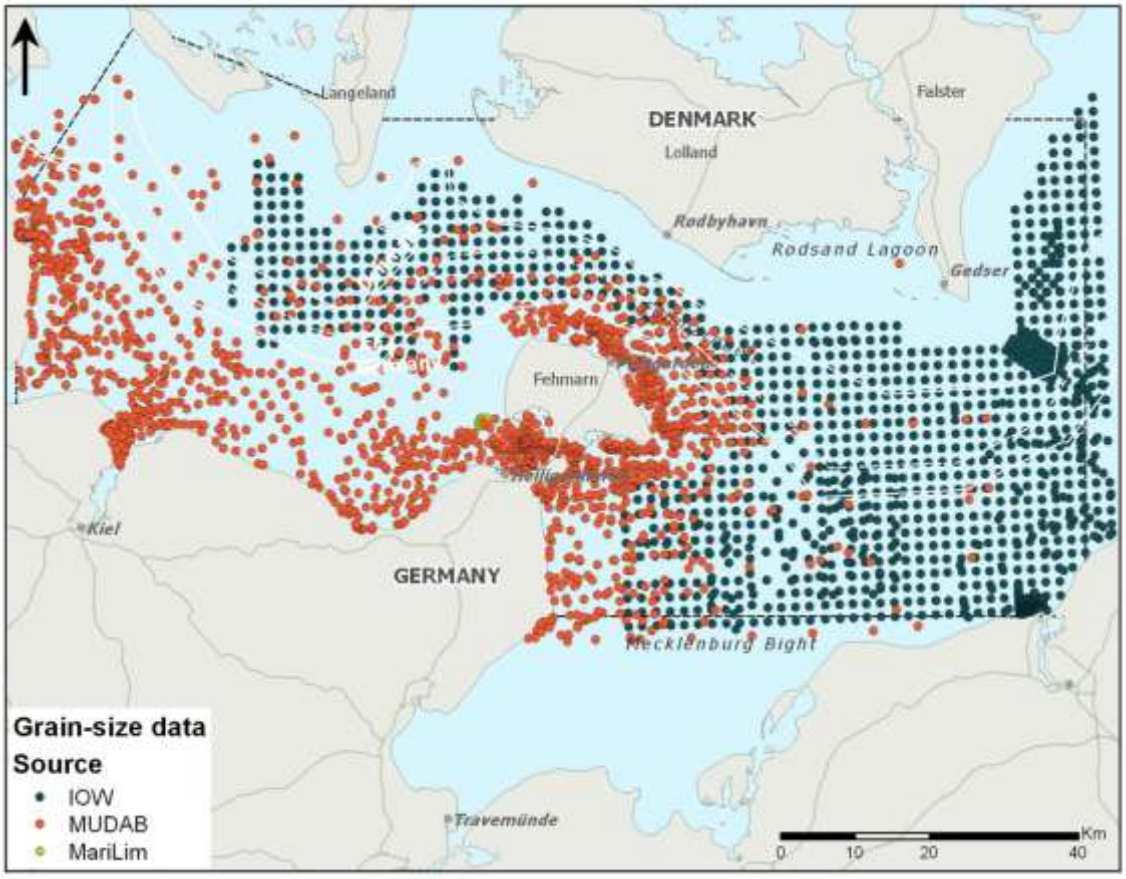


Figure 3-5 Positions of sediment samples retrieved from data archives.

Grain-size data collected as part of the marine biology and hydrography baseline sampling were incorporated in the analysis. In the latter case, 297 samples were collected and analysed by GEUS (2009b). The sampling locations were focused around the ports of Puttgarden and Rødbyhavn in water depths between 0 m and 6 m. A further 263 sediment samples were collected as part of the benthic fauna baseline investigations (FEMA, 2013b), covering the entire depth range in the local Fehmarnbelt area (Figure 3-6).

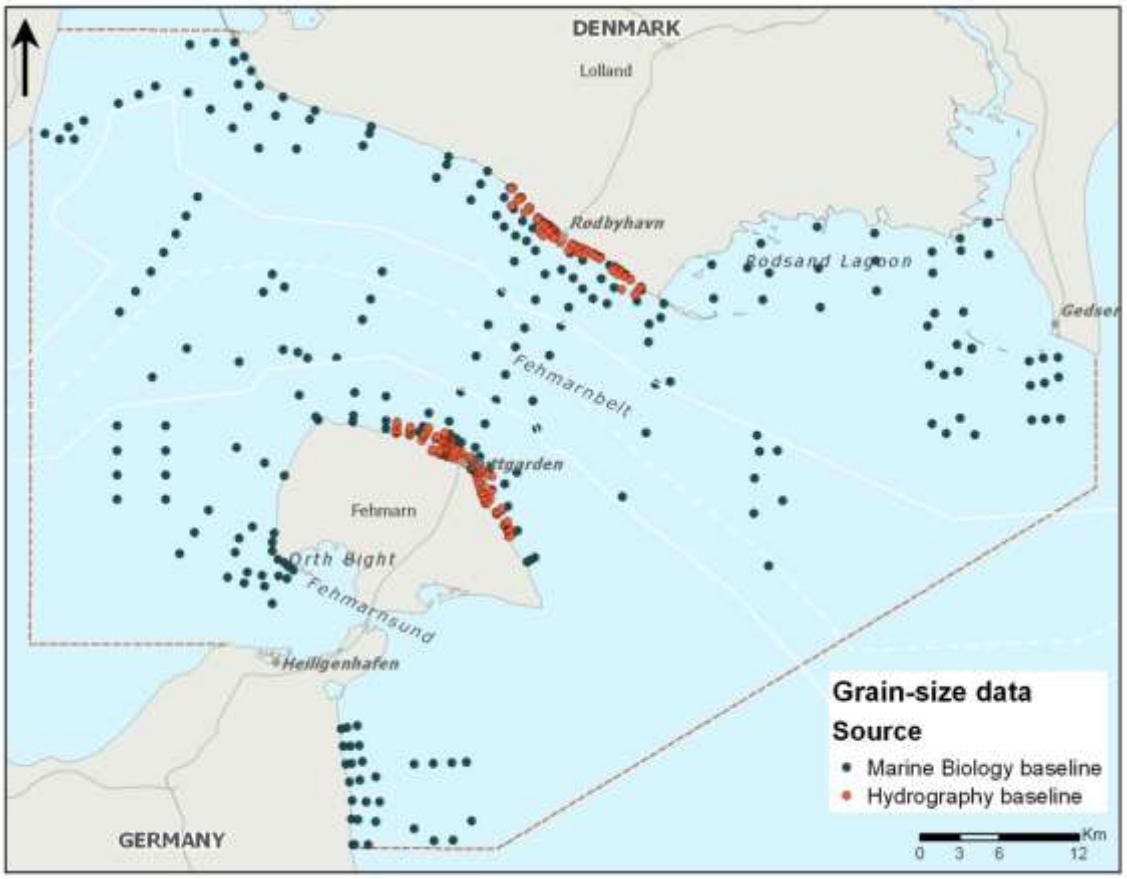


Figure 3-6 Positions of sediment samples collected as part of FEHY and FEMA baseline investigations.

3.2.3 *Hard substrate estimation data*

Substrate estimates from diver investigations or video analysis were used to determine the percentage of hard substrate within the investigation area. In contrast to grain size sampling, those estimates allow a classification of sediments with grain sizes > 63 mm (reworked glacial till (lag deposits) or coarse sediments with different percentages of gravel, pebbles, cobbles or boulders) as well as clay reefs.

Substrate estimates by divers were conducted as part of the benthic flora and fauna baseline investigations at 571 stations. At each station the percentage cover of different substrate classes (Table 3-1, Figure 3-7) was assessed within an area of 25 m^2 on 5 % accuracy. The exact description of the method and the station grid are included in the benthic flora baseline report (FEMA 2013a). In this report, the terms stones and/or hard substrate comprise the substrate classes boulders, cobbles and pebbles (Table 3-1).

Table 3-1 Substrate classification and the "visual translation" used by divers.

Substrate class		Grain size (mm) after EN ISO 14688	Description ("visual translation")
Boulders	Stones, hard substrate	> 630	Larger than a car tyre
Cobbles		> 200 – 630	Larger than a head
Pebbles		> 63 – 200	Lager than an egg
Gravel		> 2 – 63	Larger than the head of a match
Sand		> 0.063 – 2	Grain just visible

Substrate class	Grain size (mm) after EN ISO 14688	Description (“visual translation“)
Silt, clay, mud	> 0,002 – 0.063 ≤ 0,002	Grain not visible
Clay reef	–	Compact clay arising from bottom

Figure 3-7 Example photos of the different substrate classes assessed by divers: boulders (top row, left), cobbles (top row, right), pebbles (centre row, left), gravel (centre row, right), sand (bottom row, left) and clay reef (bottom row, right)

Substrate estimates by video analysis were conducted as part of the benthic flora and fauna baseline investigations on 105 transects. The cover of stones or sand along the transect was continuously assessed with a 6-step cover scale (modified Braun-Blanquet scale, 1951). The exact description of the method and the transect grid are included in the benthic flora baseline report (FEMA 2013a).

3.2.4 Modelled data

Bottom salinity
Annual mean bottom salinity was extracted from the FEHY local validation model for the period 01/10/2008 to 01/10/2009 (FEHY 2013a). The grid size was 500 m by 500 m (Figure 3-8).

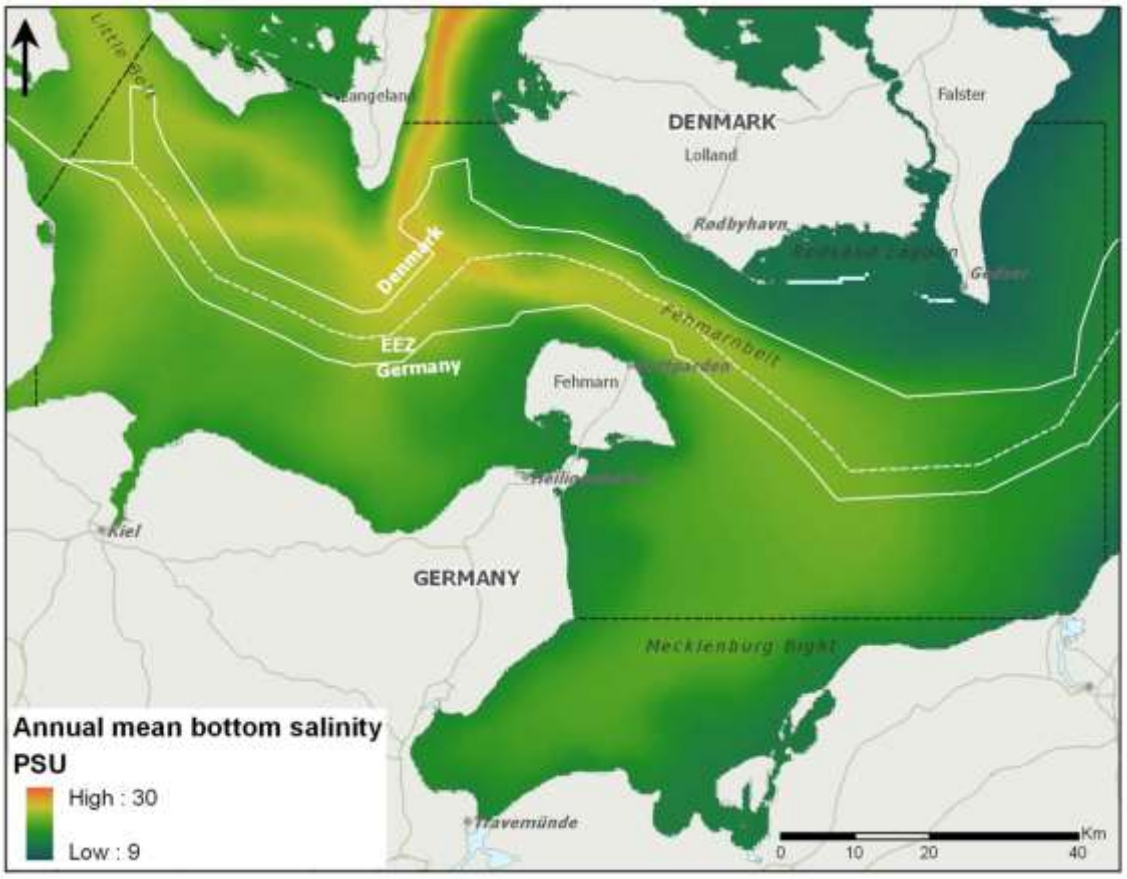


Figure 3-8 Modelled annual mean bottom salinity.

Secchi depth
Annual mean Secchi depths were extracted from the FEHY water quality local model covering the period 01/10/2008 to 01/10/2009 (FEHY 2013a). The grid size was 500 m by 500 m (Figure 3-9).

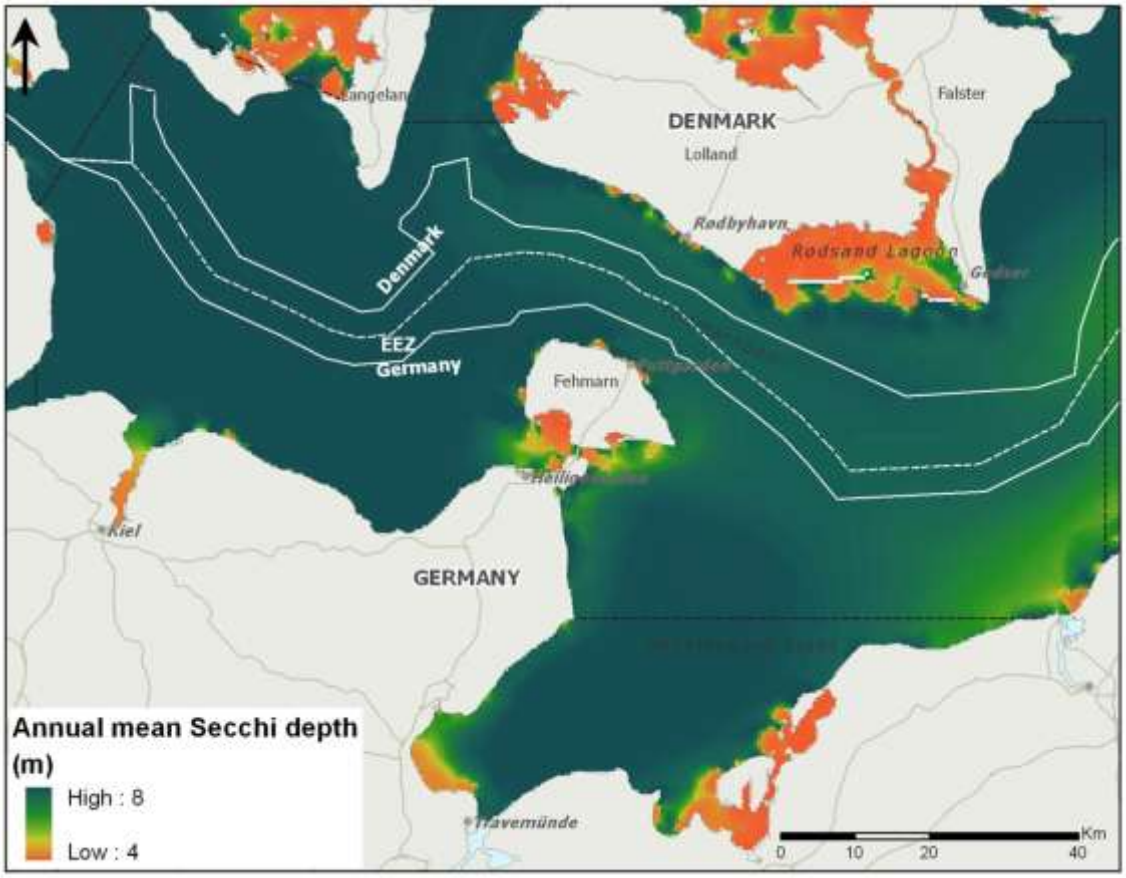


Figure 3-9 Modelled annual mean Secchi depths.

Wave length

Maximum wave lengths of surface water waves were modelled by FEHY (2010a) for the entire year 2005. These were provided as a 500 m by 500 m grid (Figure 3-10).

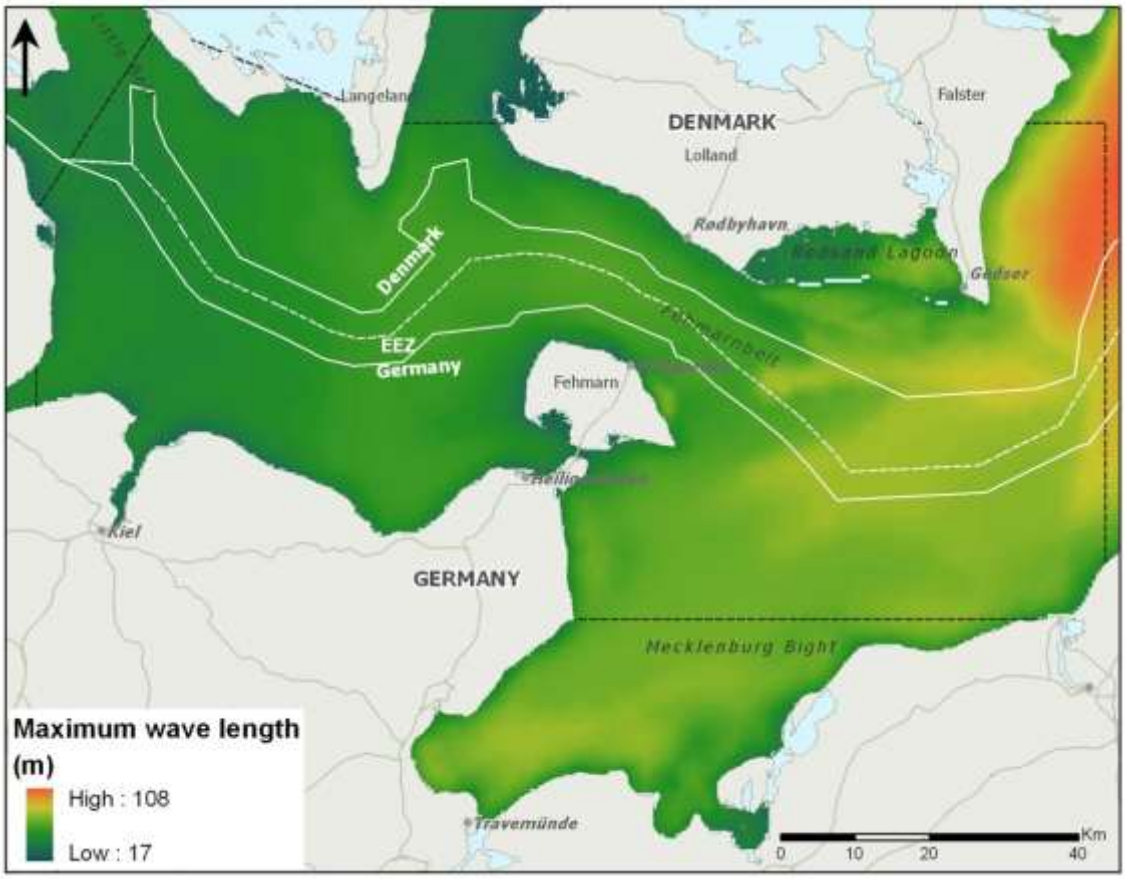


Figure 3-10 Modelled maximum wave length.

Bed shear stress

Maximum combined wave and current bed shear stress was modelled for the same period (FEHY, 2010b) and provided as a 250 m by 250 m grid (Figure 3-11).

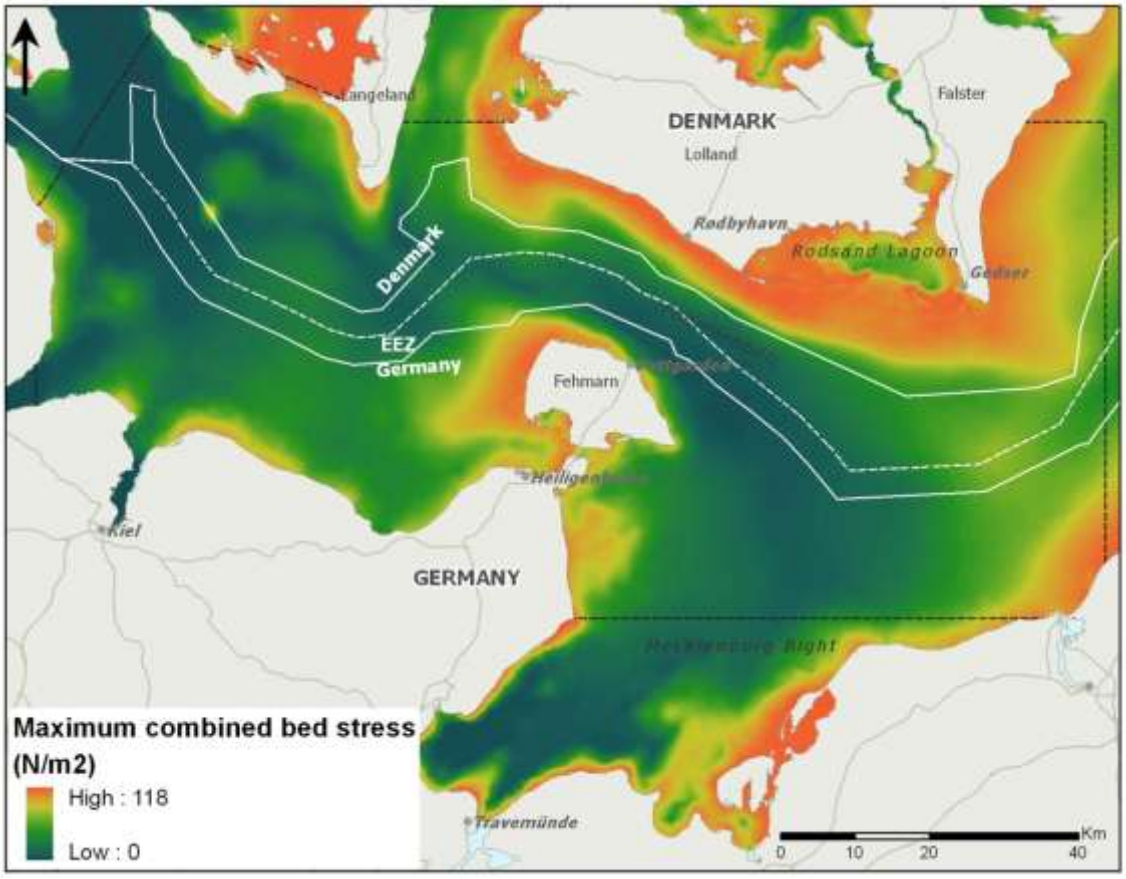


Figure 3-11 Modelled maximum combined bed stress.

3.2.5 Predicted data (GAM Modelling, CART analysis)

Benthic flora communities

Distribution and coverage of different flora communities in the Fehmarnbelt area were mapped by combining sampling data of the baseline investigations 2009-2010 (FEMA, 2013a), aerial survey data and predicted habitat maps.

Predictive mapping was carried out using a Generalised Additive Model (GAM). Significant relationships between the physico-chemical factors most important for the distribution and abundance of benthic flora were employed for prediction. Environmental factors used to predict the distribution of macroalgae included water depth, bed shear stress, current speed, Secchi depth, seabed slope and mean grain size of seabed substrate. Those used to predict the distribution of angiosperms included water depth, shear stress, current speed and seabed slope. Key-communities were only assigned to areas with benthic vegetation cover >10 %. Further details can be found in FEMA (2013a).

Benthic fauna communities

The distribution of benthic faunal communities in the Fehmarnbelt area was predicted based on sampling data of the baseline investigations 2009-2010 (FEMA, 2013b). The community analysis was initiated by averaging the species abundance values over all replicates taken in all available campaigns. Macrobenthic communities were distinguished using hierarchical clustering based on Bray–Curtis similarities, with optimal number of groups being defined by analysing the community structure using a combination of SIMPROF (Clarke et al., 2008), IV-Analysis (Dufre-

ne and Legendre, 1997) and expert judgment. Classification And Regression Trees (CART) (Pesch et al., 2008) was chosen for the prediction. Environmental variables used as proxies were water depth, salinity, sediment characteristics (substrate class and mud content), seasonal oxygen content (summer mean and winter minima) and maximum combined shear stress. The distribution and coverage of flora communities were used as additional biotic parameters. Other abiotic parameters (e.g. water temperature, current directions, water quality parameters) were also trialled but found not to improve the model quality.

The CART analysis yielded 17 terminal nodes, each presenting a single community with a specific probability of correct classification. The decision tree was validated using cross-validation. The goodness of fit was shown in a misclassification matrix. Based on these results, a community distribution map was produced, using the predictors mentioned above. Validation by additional information from aerial photography, diver observations and video transects suggested the correction for some of the prediction result for small areas. Further details can be found in FEMA (2013b).

Blue mussels cover
Blue mussel coverage was predicted based on video observations along transects. Along most of the coastal transects, blue mussels were observed. However, the cover was highly variable both within and between transects. GAM was used to spatially predict mussel coverage. Water depth, modelled annual average bottom current speed and proportion of hard substrate were included as predictors. The GAM model was validated using 70 % of data to build the model and the remaining 30 % of data for cross validation. The predictability (Q^2) of the model was 53 %, which is considered as very satisfactory. Further details can be found in FEMA (2013b).

3.3 Data analysis

The different techniques utilised to analyse the data sets as described in Chapter 3.2 are detailed below.

3.3.1 Derivatives of bathymetry
Several parameters were derived from the available bathymetric data sets (Chapter 3.2.1). These derivatives included slope, rugosity, curvature, aspect and BPI and are essential parameters for the assessment of the abiotic descriptor seabed substrate (Chapter 4.1.6) or the delineation of EU-Habitat types (2.2). The parameters derived from bathymetry are listed in Table 3-2.

Table 3-2 Parameter derived from bathymetric data sets

Parameter	Data set	Software	Used for
Slope surface	Bathymetry 50 m grid	Spatial Analyst extension of ArcGIS	Delineation of 1110 sandbanks Delineation of different seabed substrates
	Bathymetry 2 m-grid	DMagic Fledermaus 7 Software	Delineation of 1110 sandbanks (mega ripples)
Rugosity	Bathymetry 50 m grid	ArcGIS Extension Benthic Terrain Modeler	Delineation of different seabed substrates Spatial prediction of mud content
	Bathymetry 2 m-grid	DMagic Fledermaus 7 Software	Delineation of different seabed substrates (e.g. coarse sediments, hard substrates)

Parameter	Data set	Software	Used for
BPI	Bathymetry 50 m grid	ArcGIS Extension Benthic Terrain Modeler	Delineation of different seabed substrates Delineation of 1170 reefs (in Denmark only)
Curvature and aspect	Bathymetry 50 m grid	Spatial Analyst extension of ArcGIS	Delineation of different seabed substrates

The slope surface was calculated from the local bathymetry 50 m grid with the Slope command in the Spatial Analyst extension of ArcGIS. The slope surface indicates the steepness of the seabed and was used for the spatial prediction of mud content (Chapter 3.3.4) and to delineate the boundaries of banks for further mapping of the habitat type sandbanks (Chapter 2.2.1). It was also helpful in placing boundaries between different substrate units. Mega ripples (as defined in this report, see chapter 2.2.1) were easily identifiable based on the 2 m-grid, but larger mega ripples could also be discerned from the 50 m-grid in places (e.g. south of Rødsand lagoon).

Rugosity was calculated from the local bathymetry 50 m grid using the ArcGIS Extension Benthic Terrain Modeler (Lundblad et al., 2006). Rugosity is a measure for small-scale variations of a surface, in this instance the seabed. It was used for the spatial prediction of mud content (Chapter 3.3.4). A second rugosity surface was calculated from the multibeam bathymetry data using DMagic of the Fledermaus 7 software package. It was used as an input layer for image analysis (Chapter 3.3.2).

Furthermore, aspect and curvature were calculated from the local bathymetry 50 m grid using the Spatial Analyst extension in ArcGIS. Both parameters were used as input data for the spatial prediction of mud.

The BPI was calculated from the local bathymetry 50 m grid using the ArcGIS extension Benthic Terrain Modeler. It is a measure of the spatial location of a geographical point relative to its surroundings. Positive BPI values denote regions that are higher than the surrounding area, e.g. crests. Conversely, negative values characterise depressions, while values near zero show either flat areas where the slope is near zero or areas of constant slope. A grid of such BPI values within a locale, or neighbourhood allows a model of the benthic terrain to be created. Further details can be found in Lundblad et al. (2006). The BPI was used as input data for the spatial prediction of mud content and to model areas "arising from the sea floor", which were used to delineate reefs in Denmark (Chapter 2.2.4).

We carried out a terrain analysis employing the BPI derived from the local bathymetry 50 m grid to model areas arising from the sea floor. Several neighbourhood sizes ranging from 250 m to 12500 m were calculated and the results explored. A neighbourhood size of 6250 m was finally chosen, as this was of a similar size to known features arising from the sea floor (e.g. Sagas Bank and Øjet) and therefore yielded the best results (Figure 3-12). Seabed areas with positive BPI values were taken to be arising from the sea floor.

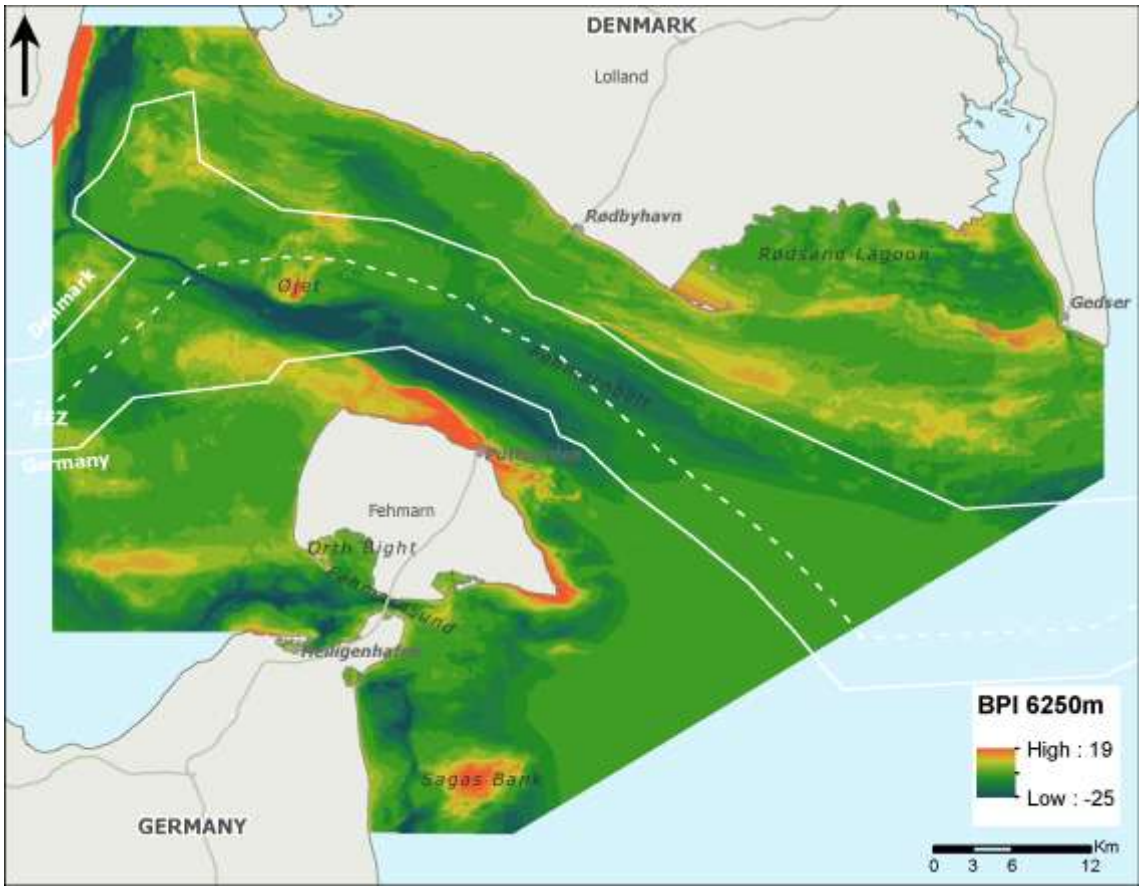


Figure 3-12 Results of terrain analysis employing the BPI with a neighbourhood size of 6250 m. Areas in reddish colours are interpreted as arising from the sea floor.

3.3.2 Image analysis

Remotely-sensed data, be it aerial photography or backscatter maps, provide vital clues on substrate characteristics. Traditionally, such maps were interpreted by expert judgement, whereby areas exhibiting similar characteristics were manually segmented. Whilst this can be an efficient way of interpreting the data, it is arguably prone to introducing subjectivity. In a quest for more objective and repeatable methods, object-based image analysis was developed in recent decades. Whilst this approach is used widespread in the analysis of optical remote-sensing data (Blaschke, 2010), it is still relatively novel in the context of backscatter data (Lucieer and Lamarche, 2011, Lucieer, 2008).

Aerial photographs

The aerial photographs were geo-referenced at COWI and orthophotos were produced from the original material. The geometric resolution was such, that one pixel of the images corresponds to 20 cm x 20 cm in nature (at sea level). No digital elevation model (DEM) was applied to the water area, so only objects at sea level have the full accuracy.

The images were then joined into a mosaic in a way that minimised any sun glints from waves and the sea surface. This is important to assure maximum visibility of the sea floor. The seam lines between the individual images were placed accordingly. The final map was colour-corrected to ensure a similar colour for similar objects homogeneously over the whole mapped area and finally had a colour depth of 24

bit (16.7 million colours). The map was transformed to the final coordinate system: UTM Zone 32N in the ETRS89 reference system.

The orthophoto map was segmented into optically similar regions using an object-oriented approach provided by the image-analysis software eCognition (www.ecognition.com). During several test-runs the optimal parameters for segmentation were developed. These parameters ensured that areas of similar properties were assigned to one segment following these rules:

- segments must be as large as possible, with a minimum dimension of 40 m in one direction
- the outer border of an area is more important than the internal structure, i.e. patchy areas are segmented as a whole rather than each patch separately
- coverage differences in habitats (vegetation density) are not considered, all coverage above 10 % is one habitat

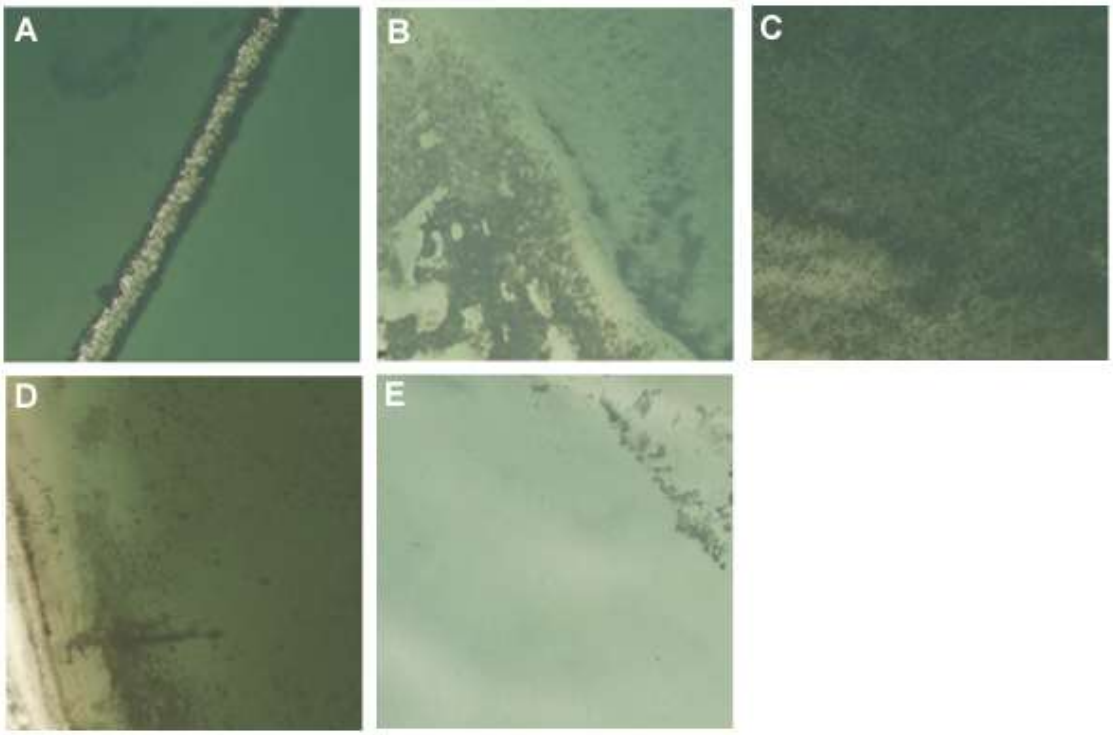
These specifications were translated into eCognition rule sets, where a multi-resolution segmentation was performed with a scale parameter of 750 and a Shape/Colour ratio of 0.9/0.1. As the image mosaic was too large to be processed at once, tile and stitch routines were used by developing and applying an eCognition server based rule set.

After pre-processing and automatic segmentation, a preliminary classification was applied. By developing classification rule sets it was possible to automatically classify sandy areas on the map. The classification rule sets included rules about a low standard variation and simultaneously specific requirements to the colour and saturation within each object. The resulting segmentation of the image was exported to a shape file (ESRI GIS shape format).

A total of eight different seabed structures groups (excluding unclassified areas) were discernable from the aerial photographs. In some cases a further differentiation within some structure groups is possible. These are listed in Table 3-3. Examples of selected structures are shown in Figure 3-13.

Table 3-3 Seabed structures discernable and analysed by aerial survey.

Seabed structures	Partly discernable detailed structures	Remark
Algae	Algae on hard bottom	mainly algae on boulders and cobbles. Pebbles and smaller particles are beyond the resolution of the images
Algae	Algae on hard bottom in shallow water	often very nearshore *Fucus* on boulders in less than 1 m water depth
Mixed bottom		mix of eelgrass, algae and mussels on varying sediment
Unclassified		no sight onto seabed due to deep waters or to strong light reflexion at water surface or waves; including harbours



The resulting map is shown in Figure 3-14. In total, around 934,563,000 m^2 of seabed were mapped and analysed in 6,218 objects (polygons). The image quality was generally good and allowed mapping of discernable structures down to the expected water depth of 6 m. Occasionally it was possible to map down to 8–10 m water depth. However, in some areas (Lolland coast between Næsby strand and Drummelholm) the aerial photographs could only be reliably analysed down to 2–3 m water depth due to limited visibility.

The distribution of structures was different on the German and the Danish side. While the German side was more heterogeneous and covered a smaller area, the Danish side was more homogenous and covered a larger area.

On the German side 300,846,110 m^2 of seabed were mapped and this resulted in 2,233 segments. The major part (97,428,808 m^2 or 32 %) was covered by sand, and 58,498,086 m^2 (19 %) was covered by blue mussels with algae, followed by 24,698,526 m^2 of mixed habitat (8 %), 22,244,707 m^2 of algae on hard bottom (7 %), and 11,682,011 m^2 of eelgrass (4 %).

On the Danish side 633,716,936 m^2 were mapped, resulting in 3,985 segments. Due to the more homogenous nature on the Danish side only three bottom types covered larger areas. The major part was covered by blue mussels with algae (263,559,074 m^2) and accounted for 42 % of the area. This was followed by 97,031,691 m^2 of eelgrass/algae mixed vegetation (15 %) and 40,020,964 m^2 of eelgrass (6 %).

Tasselweed and charophytes	Tasselweed and charophytes on soft bottom	In sheltered bays and lagoons with slightly reduced salinity values
Sand and unvegetated areas		All segments including vegetation/mussel coverage below 10%
Sand and unvegetated areas	Sand ripples	sandy areas with visible ripples, including mega ripples

Blue mussels		Blue mussels often associated with algae
Eelgrass		Eelgrass/algae mixed vegetation (soft bottom)
Artificial construc-tions		jetty spurs, bridges, piers, groynes and other constructions

Figure 3-13 Examples of shallow water seabed structures. A: Artificial constructions surrounded by algae on hard bottom. B: Eelgrass/algae mixed vegetation. C: Algae. D: Algae on hard bottom in shallow water. E: Sand with limited vegetation.

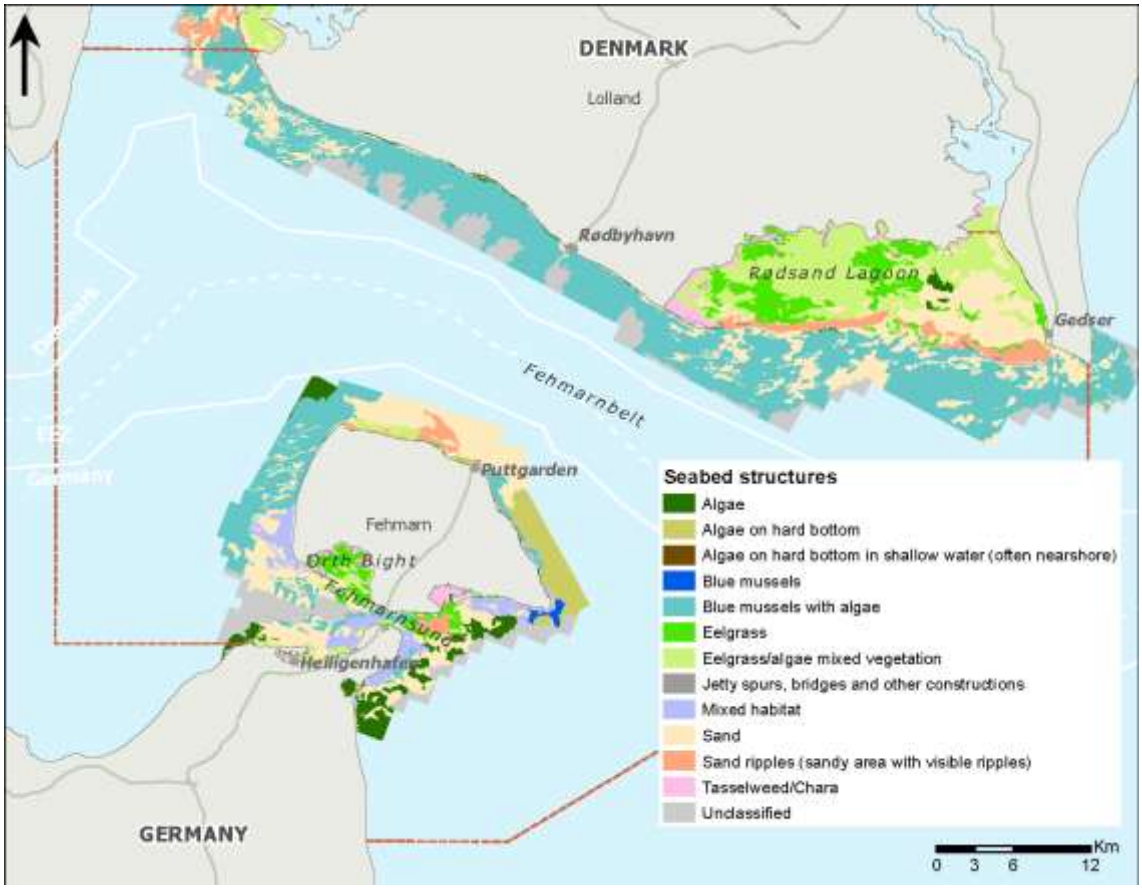


Figure 3-14 Shallow water seabed structures as mapped with aerial photography.

As algae and blue mussels grow mainly on hard bottom and eelgrass on soft bottom a classification of seabed structures to specific substrate types was necessary and possible to use aerial survey data for substrate classification in shallow waters (see Table 3-4, Figure 3-15).

Table 3-4 Substrate types derived from aerial survey seabed structures (reliable only in shallow water).

Seabed structure	Substrate type
Algae	Unknown
Algae on hard bottom	Hard bottom
Algae on hard bottom in shallow water	Hard bottom
Tasselweed and charophytes on soft bottom	Soft bottom

Seabed structure	Substrate type
Sand	Soft bottom
Sand ripples	Sand ripples
Blue mussels	Hard bottom
Blue mussels with algae	Hard bottom
Eelgrass	Soft bottom
Eelgrass/algae mixed vegetation	Mixed bottom
Artificial structures	Hard bottom
Mixed bottom	Mixed bottom
Unclassified	Unknown

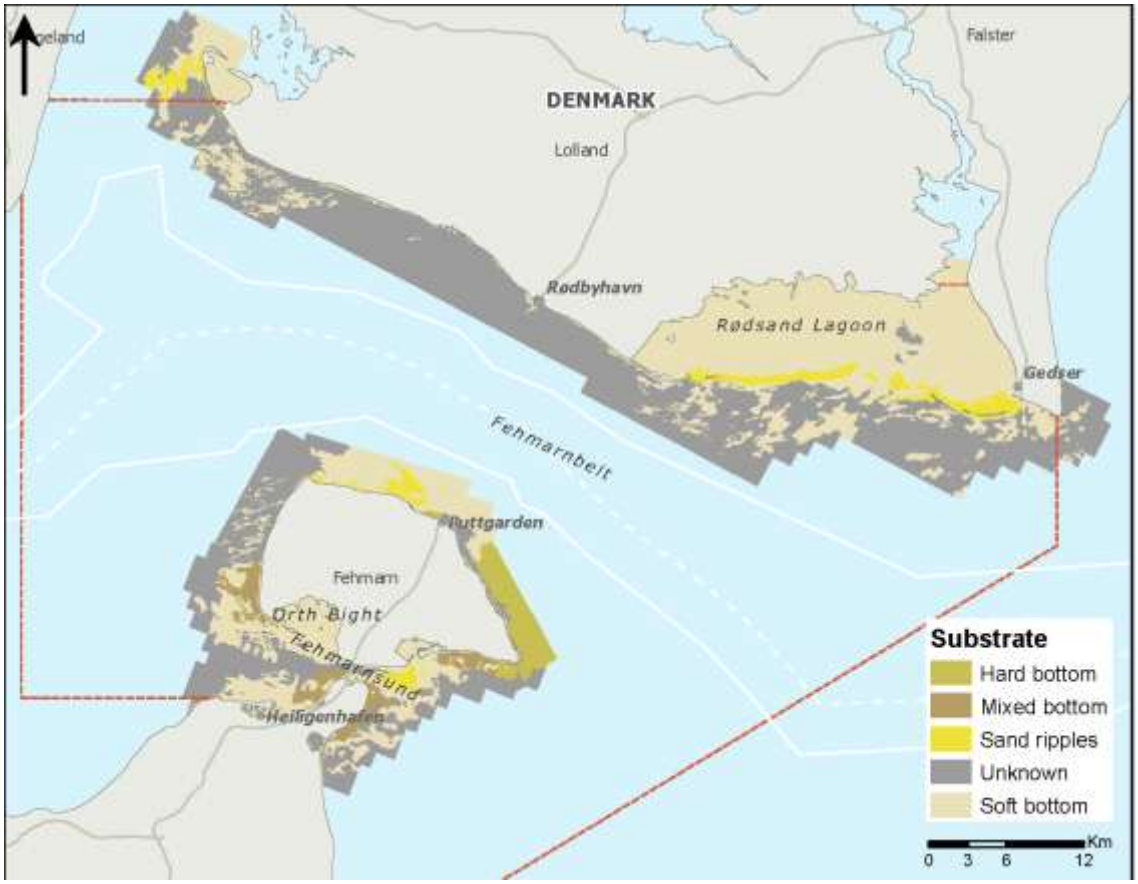


Figure 3-15 Substrate information derived from aerial photography interpretation.

Backscatter images

Acoustic remote sensing data, most notably multibeam and sidescan sonar, are sensitive to differences in seabed morphology and sediment texture and can be used to map underwater habitats (Kostylev et al., 2001, Lucieer, 2008).

A substrate map based on multibeam backscatter data was derived using object-based image analysis, in which multibeam survey data are segmented into polygonal objects, based on scale and homogeneity criteria. Colour, texture and contextual criteria are then applied to interactively classify the objects into a pre-defined set of substrate classes (Figure 3-16).

The segmentation and classification model was developed in the object-oriented software eCognition. The eCognition software applies a region-growing segmentation algorithm based on similarity in the multibeam backscatter signal of adjacent pixels restricted by scale and shape parameters to form compact, homogeneous segments. The specification of different scale parameters allowed us to develop a multi-scale segmentation procedure. At the upper level the across scene intensity variation in the backscatter image was captured in 15 Level 1 objects, and at the lower Level 2 we created the objects to form the basis for the subsequent object classification i.e. objects being homogeneous in terms of the targeted classes. This multi-level segmentation procedure was important, since it allowed us to restrict the classification analysis of Level 2 objects to be within individual Level 1 units and thereby focusing our analysis on intensity variations related to actual changes in seabed morphology rather than to intensity differences arising from external variations during data collection.

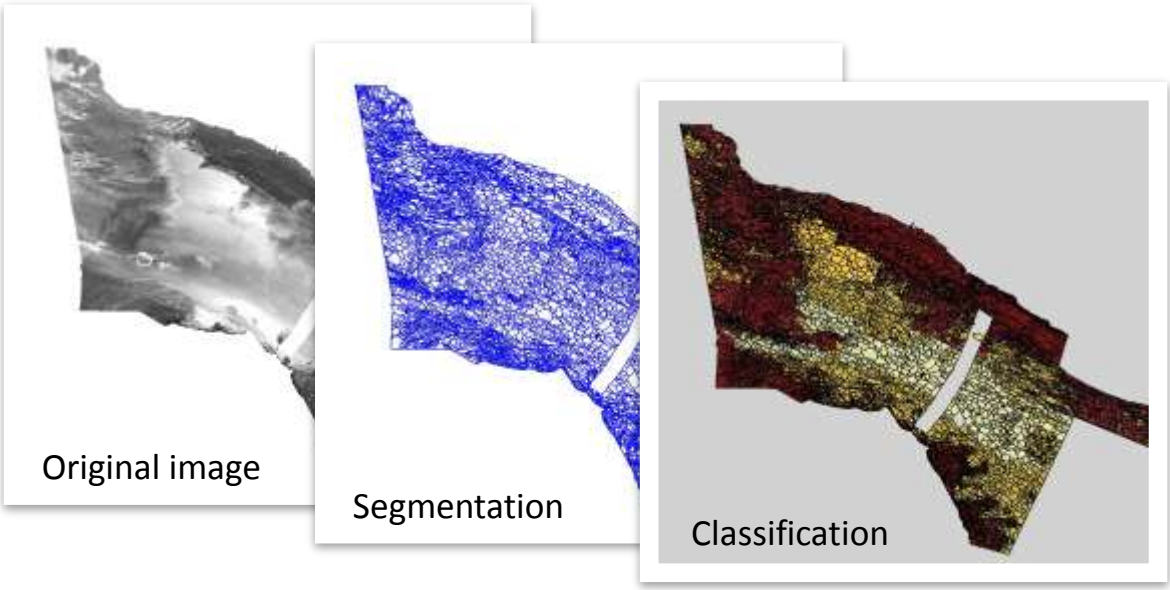


Figure 3-16 Workflow in object-oriented image classification

The generated segments do not have any associated class labels thus object classification was performed in a subsequent step. The goal of the object classification was to develop criteria to classify the objects into a pre-defined set of substrate classes. The backscatter strength, expressed in grey values from bright (low backscatter) to dark (high backscatter) is roughly related to the grain size of the seabed substrate (e.g. Collier and Brown, 2005, Goff et al., 2000). For example, it was known from previous experience that areas with high backscatter (dark grey) can be interpreted as coarse sediment or mixed sediment, while lower backscatter (light grey) was indicative of sand to sandy mud. Further discrimination was then based on available ground-truth data.

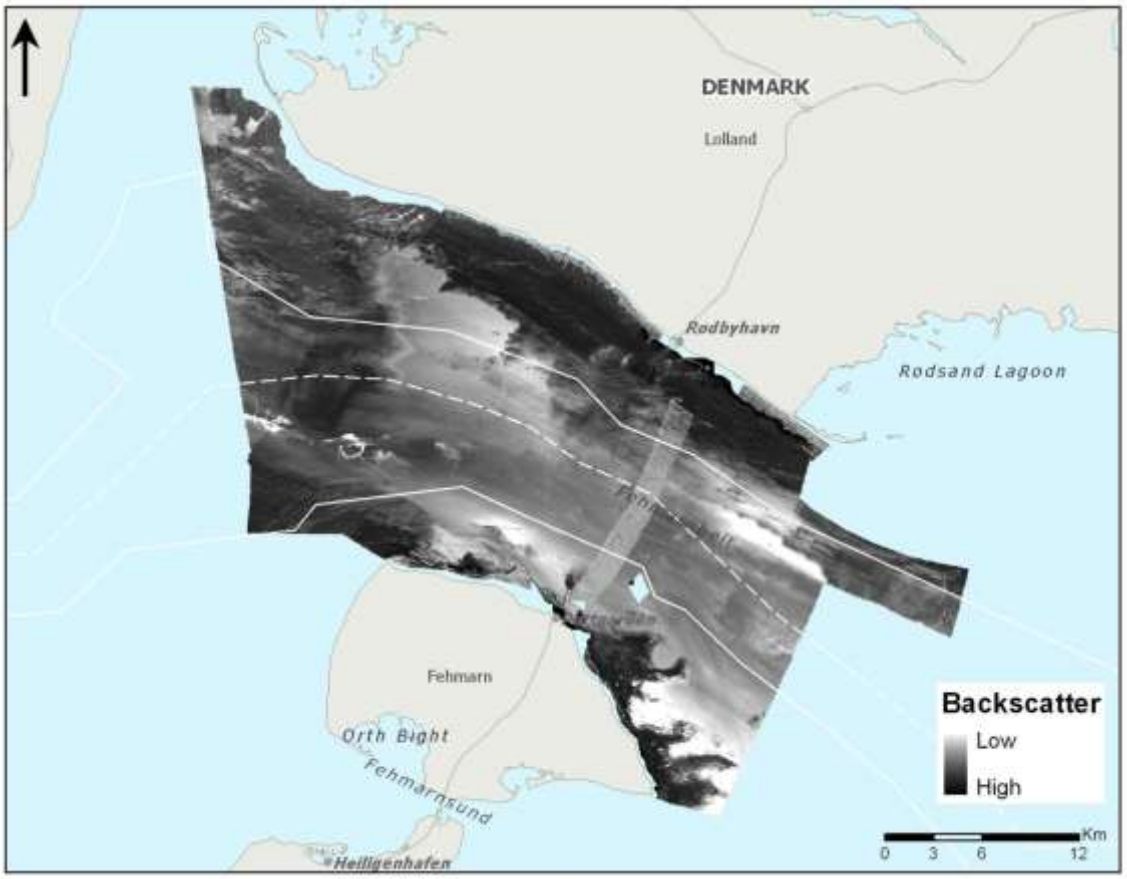


Figure 3-17 Backscatter data from multibeam and sidescan sonar surveys in the Fehmarnbelt.

Finding the right criteria for building a robust substrate classification is an iterative process of trial-and-error, and an accurate and reliable classification was only possible through collaboration between geophysicists and image analysis experts, and taking advantage of available reference material like underwater video recordings and sediment samples. In addition to the backscatter image, the multibeam bathymetry and derived rugosity layer were also used as input for the object classification. The final classification took advantage of these layers to develop a habitat mapping procedure based on the following colour, contextual and textural criteria:

- The backscatter intensity represents a first indicator of different substrate types. For example high backscatter values (dark tones) are typical for coarse material while low backscatter values (light tones) represent fine-grained material. Thus within each Level 1 object we classified the present Level 2 objects into dark and bright objects.
- This dark-bright classification was then further divided into actual substrate classes using contextual criteria such as depth (i.e. the presence of a certain substrate strongly depends on water depth), neighbourhood criteria (i.e. certain classes are more likely to be spatially associated than others) and relation to super-objects (i.e. substrate classes are not equally distributed thus certain substrate classes are more likely to be present within certain Level 1 objects than others).
- Textural pattern analysis of the rugosity layer was used to locate sandy areas dominated by sand waves.

This set of criteria or decision rules was implemented in a process tree in eCognition in order to create a draft substrate map, which was then subject to visual inspection and limited manual editing.

3.3.3 *Classification of grain-size data*

Grain-size data (content of mud, sand and gravel in weight-%) were used to derive sedimentary substrate classes. EUNIS discriminates between six classes, namely coarse sediment, sand, muddy sand, sandy mud, mud and mixed sediment. These are however only loosely defined. Four substrate classes (coarse sediment, sand and muddy sand, mud and sandy mud, mixed sediment) have been defined in MESH (Long, 2006) based on grain-size data (Figure 3-18-a). We have modified this scheme in an attempt to give more classification detail for further mapping of physical habitats and prediction of benthic communities.

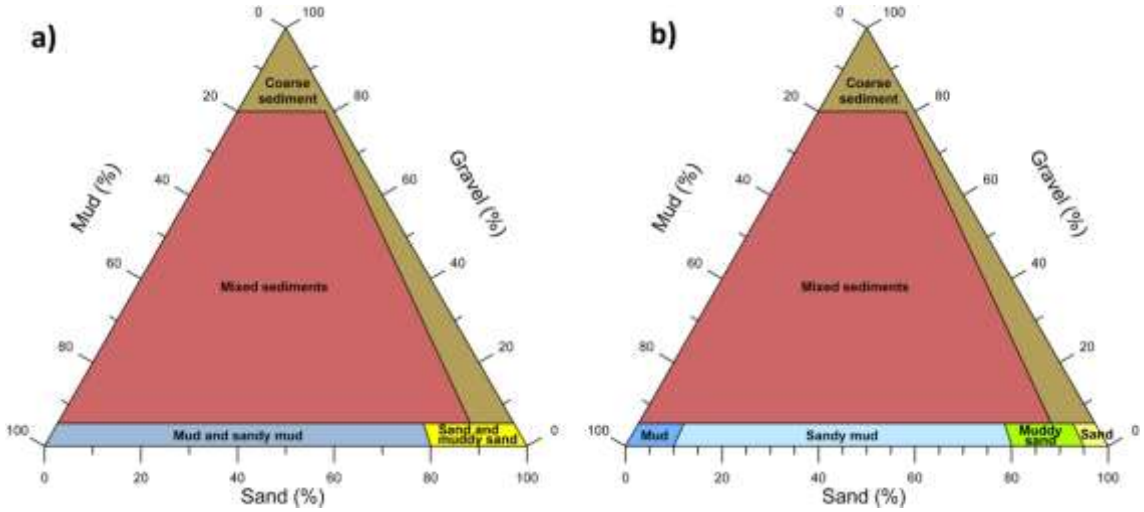


Figure 3-18 Definition of sedimentary substrate classes: a)as proposed by Long (2006) and b) modified version used in this study.

Figure 3-18-b shows a ternary diagram that has been developed by modifying the diagram of Long (2006). The former "sand and muddy sand" class was split at a value of 5% mud. This is in line with the definitions given in EUNIS. Likewise the former "mud and sandy mud" class was split at 90% mud. No concrete definition is given in EUNIS. Hence, this value was derived from the original Folk classification (Folk, 1954) on which the classification of Long (2006) is based.

A seabed sample consisting of certain percentages of mud, sand and gravel will be classified according to the field it plots in. Although mixed sediments make up the largest part of the diagram, these unsorted sediments are relatively rare. In most cases, samples tend to plot along the mud-to-sand and the sand-to-gravel axes. Figure 3-19 shows all available seabed samples classified by substrate type using the modified classification.

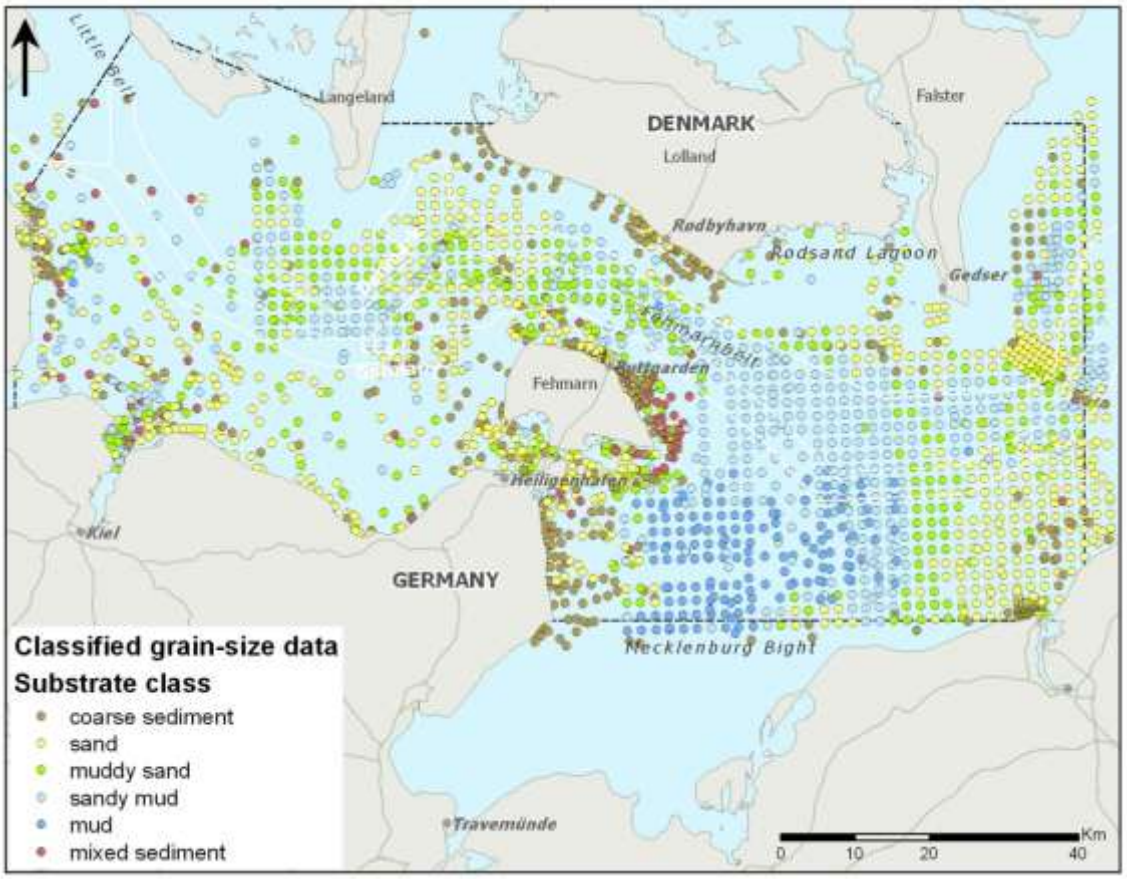


Figure 3-19 Classified grain size samples.

3.3.4 Spatial prediction of mud content

An interpolated surface of mud content was generated from point samples using a method called regression-kriging (Hengl et al., 2004). This process is a combination of the standard statistical technique of linear regression and the geostatistical interpolation method of kriging.

The technique can be used when a significantly correlated variable is exhaustively sampled throughout the study region. In this case a detailed bathymetric model was available for the study area. Bathymetry together with the derived parameters slope, rugosity, aspect, curvature and BPI (Chapter 3.3.1) were used as predictors for the target variable mud content.

The first stage involved using a linear regression to explain as much of the variability as possible of the target variable using the aforementioned predictors. The remaining variability is then passed to the kriging part of the process. The kriging system uses the spatial auto-correlation (the nearer two sample points are, the more likely they are to be similar) structure apparent in the data to estimate the target variable at the un-sampled locations.

Using the local bathymetry 50 m grid and derivatives thereof as explanatory variables means that the prediction of mud content follows bathymetric features resulting in a more realistic representation of the target variable than using a purely geostatistical approach. The resulting map can be seen in Figure 3-20.

The statistical analysis was performed in the statistical programming environment R 2.11.0 using the gstat package (Pebesma, 2004).

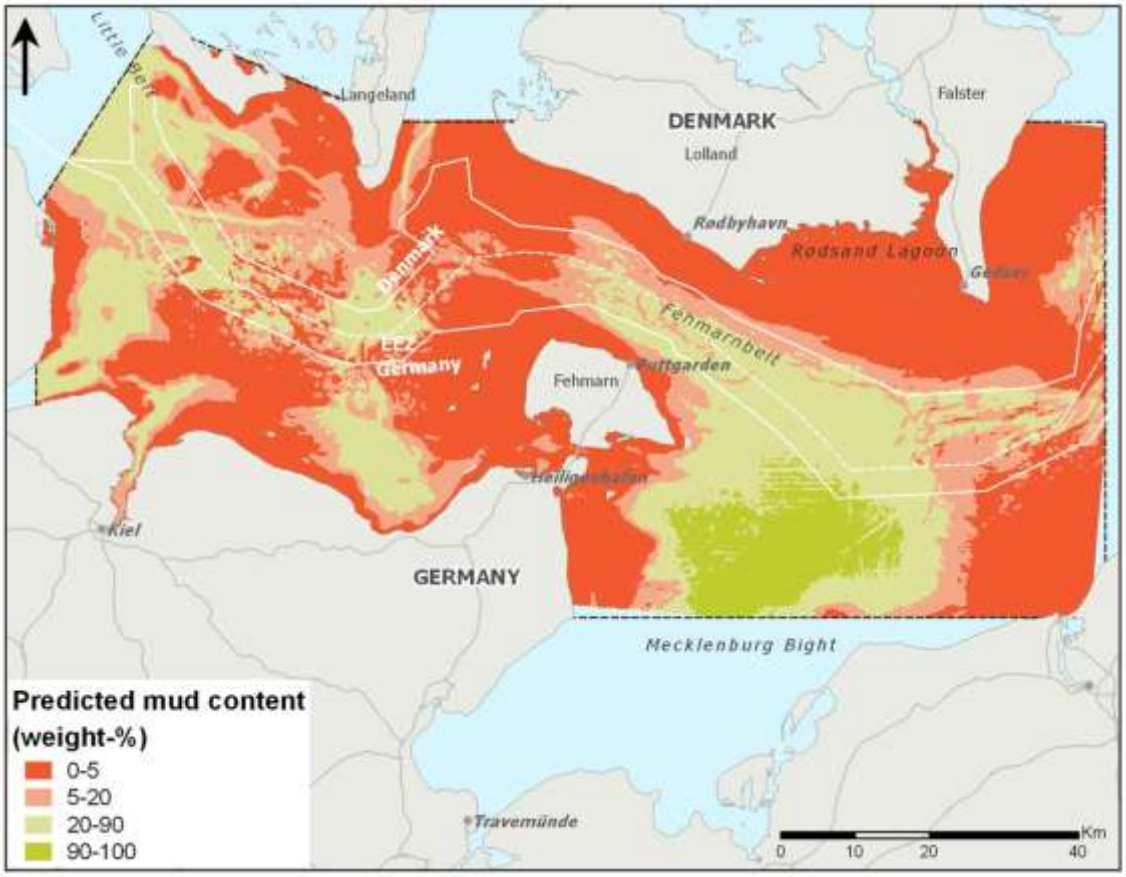


Figure 3-20 Predicted mud content.

3.3.5 Ground truthing

Remotely-sensed data sets and grain size analyses

Classified grain-size data (Chapter 3.3.3) were employed for ground-truthing the remote-sensing data sets. Where multibeam data existed, the classified grain-size data informed the classification of image-objects created from backscatter data employing object-based image analysis (Chapter 3.3.2). The results of the automated classification process were subsequently reviewed and limited manual edits were carried out where the initial classification results did significantly differ from ground-truth information. This was especially the case off the east coast of Fehmarn, where mixed sediments and muddy sand were initially not mapped, as these sediments have backscatter characteristics that are very similar to coarse sediment and sandy mud, respectively. Whether or not such manual edits were carried out was decided on a case by case basis, taking into account the vintage of the ground-truth data, local knowledge of the area and secondary information, e.g. bathymetry, seabed slope and information from published geological maps.

No backscatter information was available outside those areas in the Fehmarnbelt mapped with multibeam and sidescan sonar. Here, the ground-truth information had to be related to the seabed morphology as depicted by the local bathymetry

50 m grid displayed with artificial illumination to highlight morphological features (Figure 3-21). We were thereby making use of known relationships between seabed morphology and substrate type (Werner et al., 1987) in the western Baltic Sea (Table 3-5**Error! Reference source not found.**): Abrasion platforms and shoals are typically associated with coarse sediments, while the littoral zone and slopes and plateaus are covered with sands. Substrates were mapped based on relief (small-scale and large-scale) derived from bathymetry (Figure 3-21) and substrate type from classified grain size samples (Chapter 3.3.3). Boundaries were placed where there was an apparent break in slope or the small-scale relief was significantly different. Wherever there was a discrepancy between the interpretations based on relief and substrate type from classified samples, the former was assumed to be more precise due to the vintage of the legacy grain-size data. In order to further differentiate sediments in basins and channels, the predicted mud content was employed. Muddy sand was mapped where mud content was between 5 % and 20 %, sandy mud where it lay between 20 % and 90 % and mud where it was exceeding 90 %. Figure 3-20 also highlights abrasion platforms and shoals as areas of low mud content below 5 %.

Table 3-5 Relationships between morphology, relief and substrate type based on Werner et al. (1987), slightly modified (inclusion of littoral zone, changes to some depth limits and substrate types).

Morphological unit	Water depth (m)	Large-scale relief	Small-scale relief	Substrate type
Littoral zone	0 – 5	Sloping	Smooth	Sand
Abrasion platforms	4 – 15	Flat	Rough	Coarse sediment (mud content below 5 %)
Slopes and plateaus	10 – 20	Rough, flat	Smooth	Sand
Shoals	< 10	Rough	Rough	Coarse sediment, sand (mud content below 5 %)
Basins	> 20	Flat	Smooth	Muddy sand, sandy mud, mud
Channels	20 – 40	Steep	Smooth	Muddy sand, sandy mud

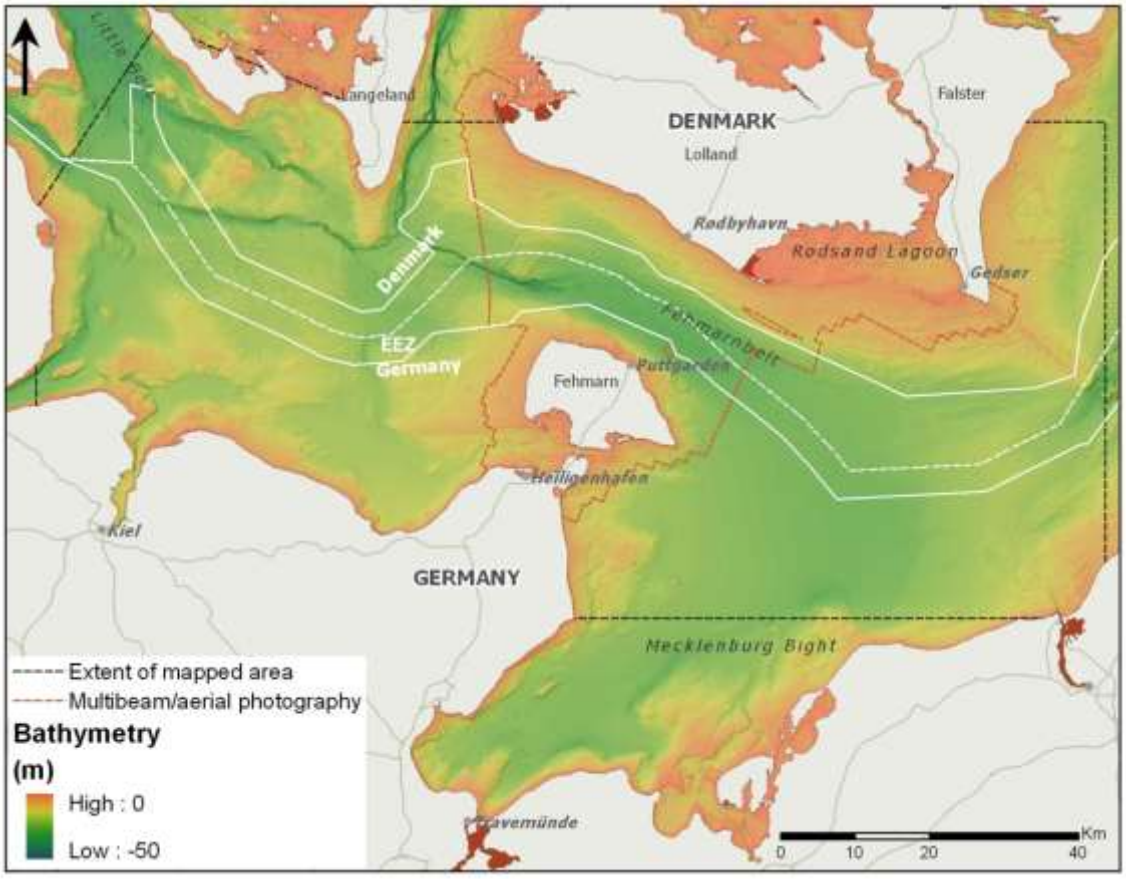


Figure 3-21 Local bathymetry 50 m grid displayed with artificial illumination to highlight morphological features.

Backscatter and hard substrate estimates

Although individual boulders, cobbles or pebbles were neither identifiable from the local bathymetry 50 m grid nor from the multibeam data because of too low resolution, it was nevertheless possible to map areas of likely occurrence of such hard substrates. Again, this is drawing on known relationships: Abrasion platforms and shoals are typically underlain by glacial till, an unsorted sediment encompassing the full range of grain sizes from clay to boulders. Glaciers deposited these sediments at the end of the last ice age. Since then, they have been drowned by the Baltic Sea due to rising sea levels as a consequence of ice cap melting. Partial erosion due to waves and currents has removed the finer components, leaving coarse sand, gravel and stones behind. Hence, abrasion platforms and shoals covered with coarse sediment are typically also covered with stones. To prove this point, those areas mapped with sidescan sonar where inspected and compared with multibeam data (Figure 3-22). These comparisons showed that the assumption made generally holds true, in that it is possible to identify stones, on the higher resolution sidescan data, that correspond to the areas of high backscatter on the multibeam data. It also became apparent that stones are distributed very unevenly as has been observed by others (Seibold et al., 1971).

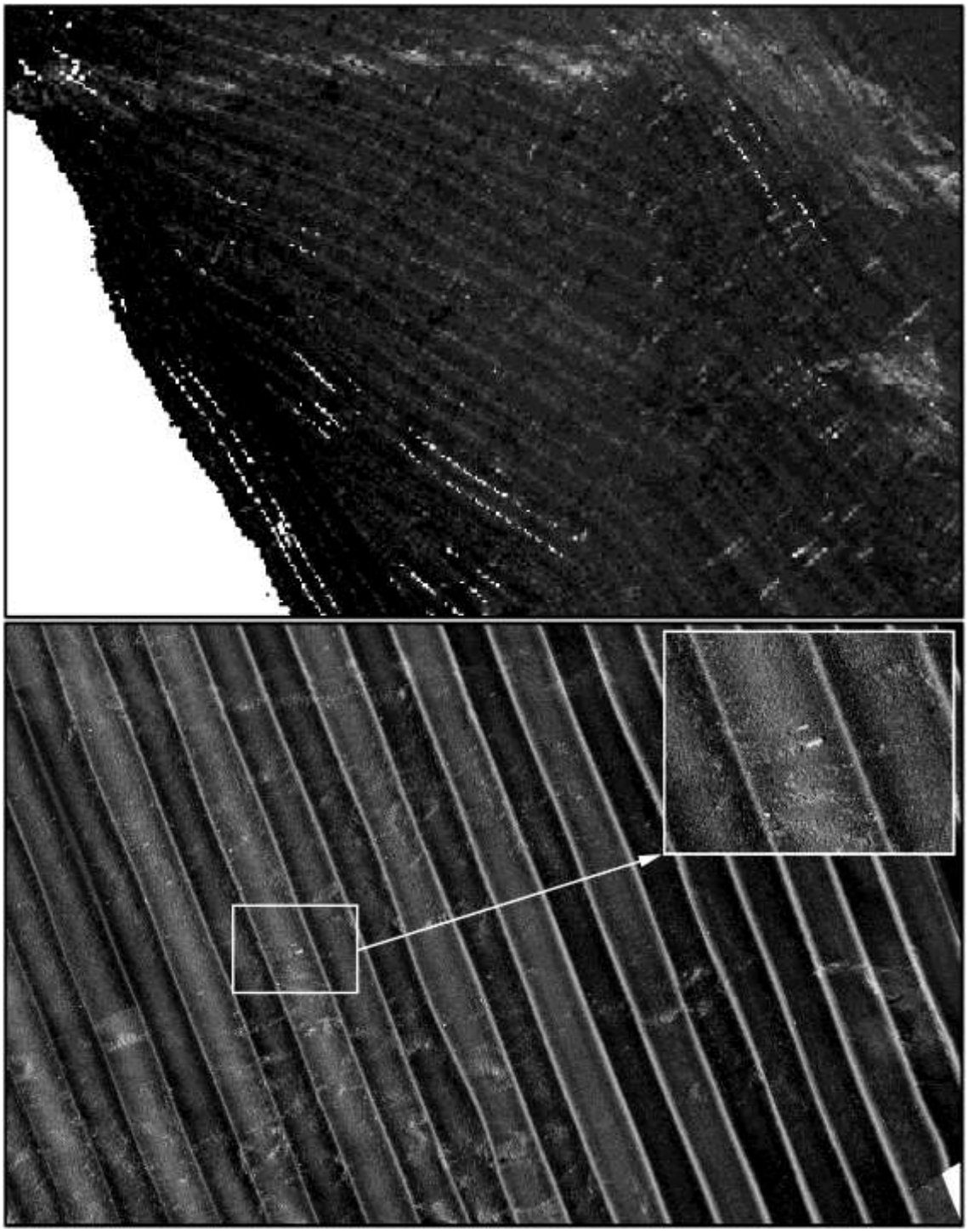


Figure 3-22 Comparison of multibeam (top panel) and sidescan sonar (bottom panel) backscatter from an area southeast of Puttgarden. The multibeam data shows predominantly high backscatter (dark tones), but no boulders are discernable. The sidescan data reveals that boulders are abundant in the high backscatter area, but the distribution is very uneven. Inset shows two large stones casting acoustic shadows (white, elongated areas). White stripes in the sidescan data are artefacts and indicate the sidescan's path. Distance between paths is approximately 50 m.

Hard substrate coverage estimates of the seabed were carried out by divers and video recording (Chapter 3.2.3). The results for hard substrates > 63 mm (boul-

ders, cobbles and pebbles) are shown in Figure 3-23 and broadly support the view that stones occur in areas of high backscatter intensity. There are, however, some exceptions, largely located off the Danish coast. Where sidescan sonar data exists, these observations are not supported as stones can be seen in the sidescan data in the vicinity of the respective stations. The best explanation for this apparent discrepancy is the fact that the densities at which stones occur on the seabed in water depths encountered in this case (ca. 5 – 15 m) are relatively low and decrease with increasing water depth. Bohling et al. (2009) investigated stone densities off Boknis Eck in the western Kiel Bight in water depths ranging from 6 m to 16 m. They found mean and maximum numbers of stones per 100 m^2 of 2.5 and 9, respectively. This indicates that the coverage estimates, carried out on a quarter of the size might potentially miss stones, especially in deeper waters as suggested by Figure 3-23.

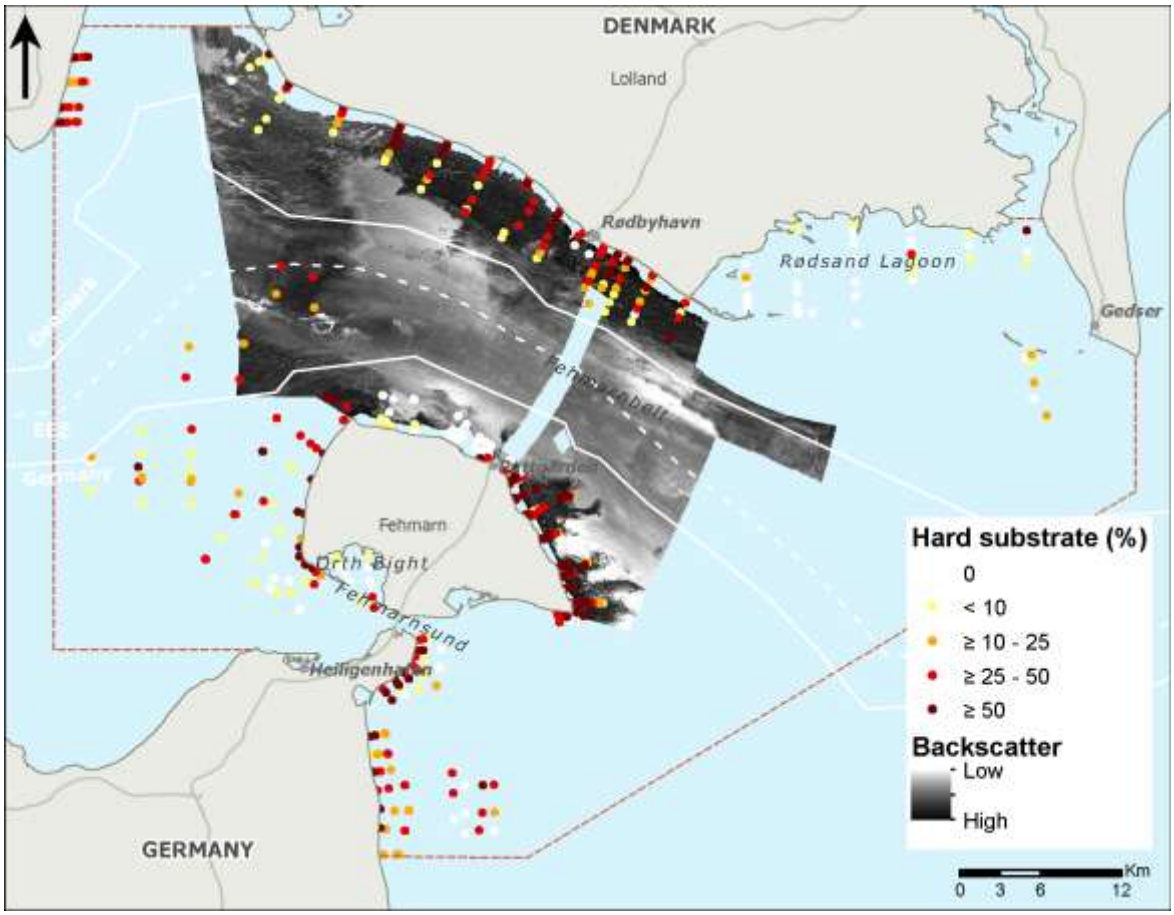


Figure 3-23 Ground-truthing of backscatter data with hard substrate estimation data

Aerial survey and hard substrate estimates

Data coverage for shallow water substrate information (< 6 m) is low as only few grain size samples exist and bathymetry or backscatter data are only available for deeper areas. To fill this spatial gap the substrate information of the aerial survey was harmonised with the substrate estimates made by divers and video (Figure 3-24). Thus, it was possible to identify areas with hard bottom or mixed bottom in the littoral zone, which would have been categorised as sand if only morphological features were used.

It should be noted that the substrate map created by aerial survey and substrate estimations by divers and video contains no substrate classes in a geological sense as this is not based on or ground-truthed with grain size analyses, but with substrate coverage estimations of grain sizes > 63 mm. Therefore this map contains two substrate classes (hard bottom and mixed bottom) which are not existing in a geological sense. Hard bottom comprises areas with more than 50 % coverage of hard substrate (grain sizes > 63 mm) and mixed bottom areas with 10 – 50 % coverage of this grain size range. Therefore, mixed bottom means here a small-scale mosaic of different bottom types. An identification of hard and mixed bottom areas is important for the delineation of reefs in shallow waters.

Areas, which have been classified as ”unknown“ in the aerial survey (mainly due to poor visibility) are also classified as "unknown" for the substrate information. This concerns mainly areas deeper than 6 m, which lie at the limit of a reliable aerial survey analysis. In those areas substrate classification is relying on previously mentioned methods (bathymetry, backscatter, grain size or morphological information).

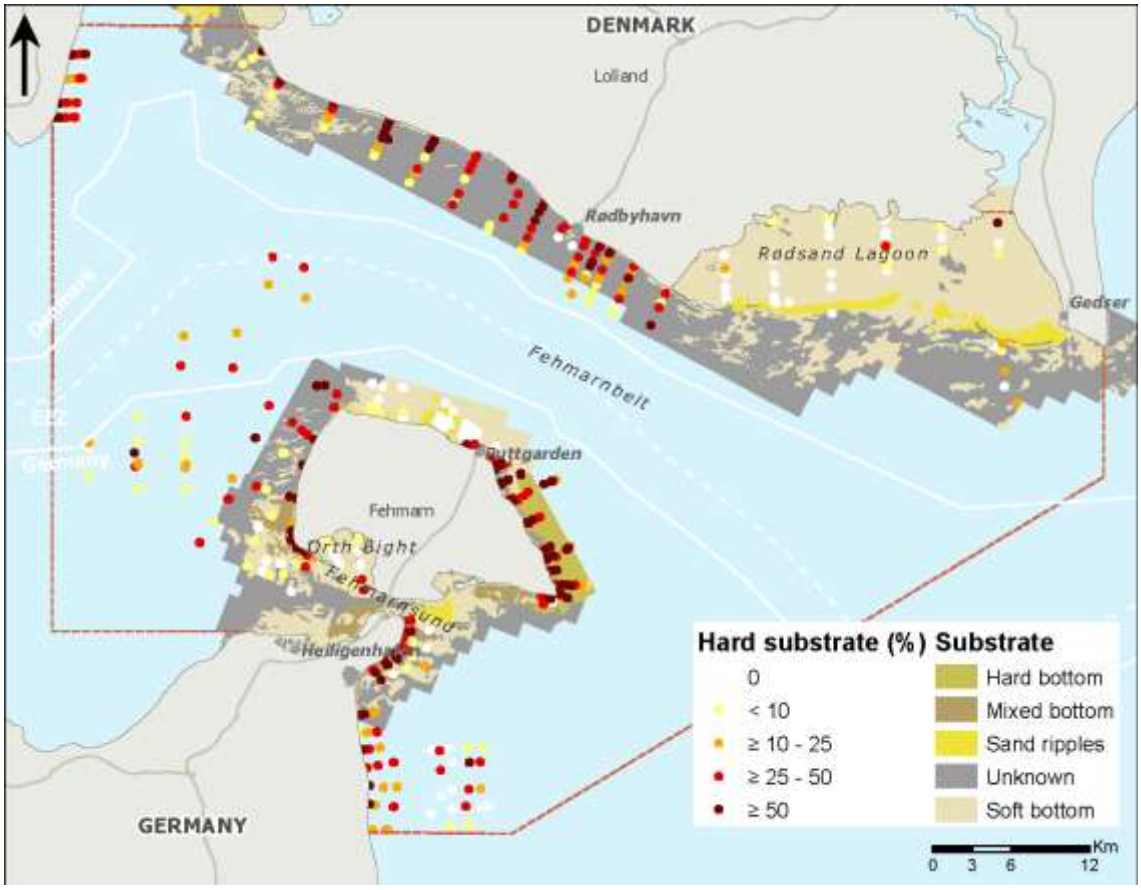


Figure 3-24 Ground-truthing of aerial survey substrate information with hard substrate estimation data.

3.4 Confidence assessment

We have employed the MESH Confidence Assessment tool in order to provide a measure of confidence in the produced habitat maps. The MESH project developed

a systematic approach using a multi-criteria questionnaire to help users assess the confidence of a map. The evaluation process addresses three main questions:

- How good is the remote sensing?
- How good is the ground truthing?
- How good is the data interpretation?

The selection of these questions owes to the fact that MESH promotes the creation of habitat maps through the interpretation of remote-sensing data and ground-truthing data. The MESH Confidence Assessment scheme is a compromise between being comprehensive and being easy to use. It is not designed to identify subtle differences between maps. It should also not be confused with accuracy, which is a measure of the predictive power of a map. Confidence, instead, is an assessment of the reliability of a map given its purpose.

The MESH Confidence Assessment Tool is available either as a template MS Excel spreadsheet or as a Flash tool[5].

Confidence is rated on a scale from 0 to 100. The following descriptive terms apply:

0 – 19:	Very low confidence
20 – 37:	Low confidence
37 – 58:	Moderate confidence
58 – 79:	High confidence
80 – 100:	Very high confidence

[5] http://www.searchmesh.net/confidence/confidenceAssessment.html

4 STEP-WISE APPROACH TO BENTHIC HABITAT MAPPING

As described in Chapter 2.1 the habitat classification and maps were derived in a step-wise approach by testing and using several abiotic and biotic descriptors. The last step of the classification includes an evaluation of the descriptors and descriptor classes in use, often resulting in an exclusion or simplification of descriptors and/or descriptor classes.

In the following chapters the abiotic = physical (Chapter 4.1) and biotic = biological descriptors (Chapter 4.3) tested for habitat classification are described separately as well as the two components of benthic habitats: physical habitats (Chapter 4.2) and biological communities (Chapter 4.4). The final benthic habitat classification and map is described in Chapter 4.5. Intermediate classification steps, which have become redundant during the evaluation process are described and illustrated in several Appendices (E–I).

4.1 Abiotic (physical) descriptors

Abiotic descriptors tested were modelled data and seabed substrate. Those descriptors were classified to fit the applied EUNIS habitat classification scheme. As data for several abiotic descriptors are available from the greater Fehmarnbelt area, they are illustrated in that area. Descriptors finally used for habitat classification are only illustrated for the investigation area.

4.1.1 Bottom salinity

Bottom salinity was grouped into three classes: low mesohaline (7.5 – 11 PSU), high mesohaline (11 – 18 PSU) and polyhaline (18 – 30 PSU). These classes are the same as those used for the BALANCE (Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) project (http://www.balance-eu.org/), although the naming is slightly different. They are also in line with those proposed in EUSeaMap. For a justification of choosing the aforementioned salinity ranges see Leth (2008: Table 2). Figure 4-1 shows the spatial distribution of the three bottom salinity classes within the greater Fehmarnbelt area.

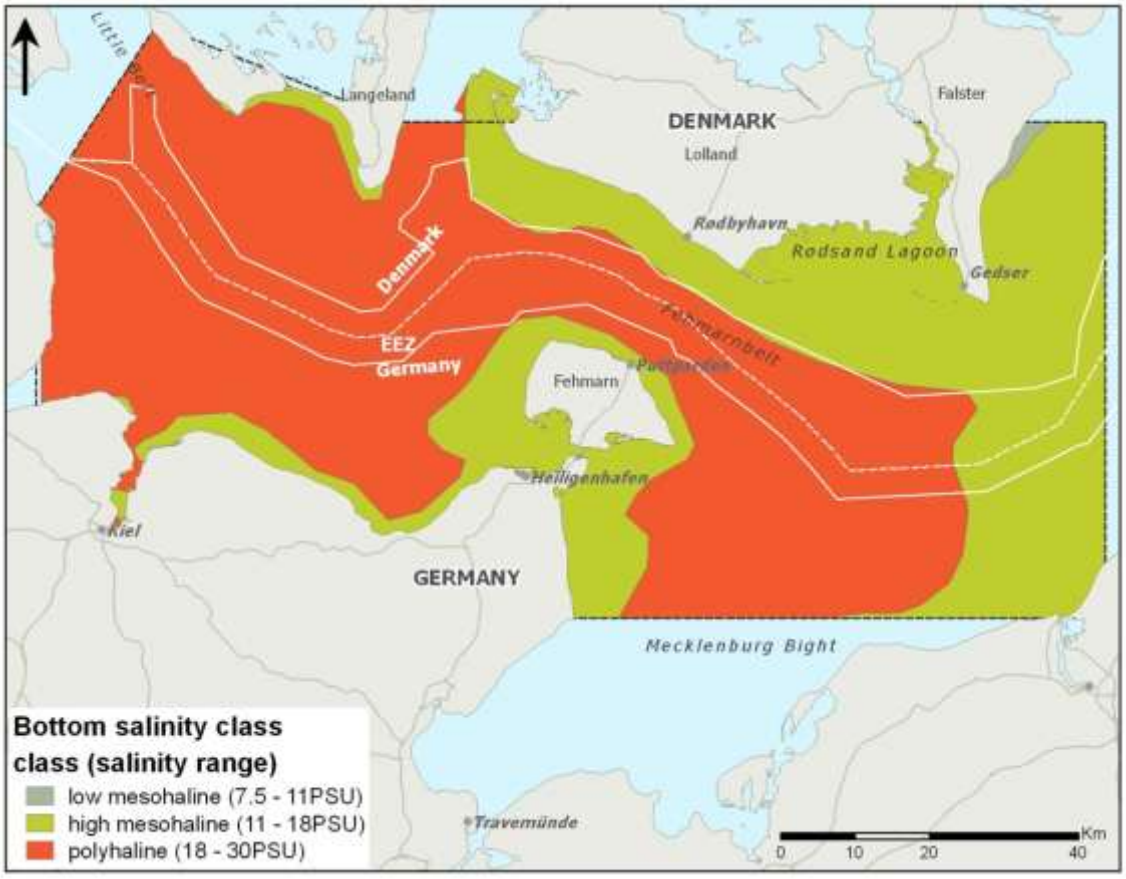


Figure 4-1 Bottom salinity classes.

Bottom salinity is an important descriptor for benthic communities on a Baltic-wide scale. A strong salinity gradient is characteristic for the local Fehmarnbelt area. Benthic communities are therefore adapted to changing salinities and show no clear discrimination for this descriptor. Bottom salinity was therefore used in a first step for habitat classification (Appendix A, G) but excluded as a descriptor in the later evaluation process.

4.1.2 Bed shear stress (Exposure)

Maximum combined bed stress was grouped into three bed shear stress classes. These are "sheltered" (0 – 1.8 N/m^2), "moderately exposed" (1.8 – 4.0 N/m^2) and "exposed" (> 4.0 N/m^2). The class intervals are the same as have been used in UKSeaMap and MESH, although the naming is different. The spatial distribution of the different bed shear stress classes (as exposure classes) is shown in Figure 4-2. It should be noted that bed shear stress predictions for shallow bays are likely to be unreliable due to the coarse resolution of the model.

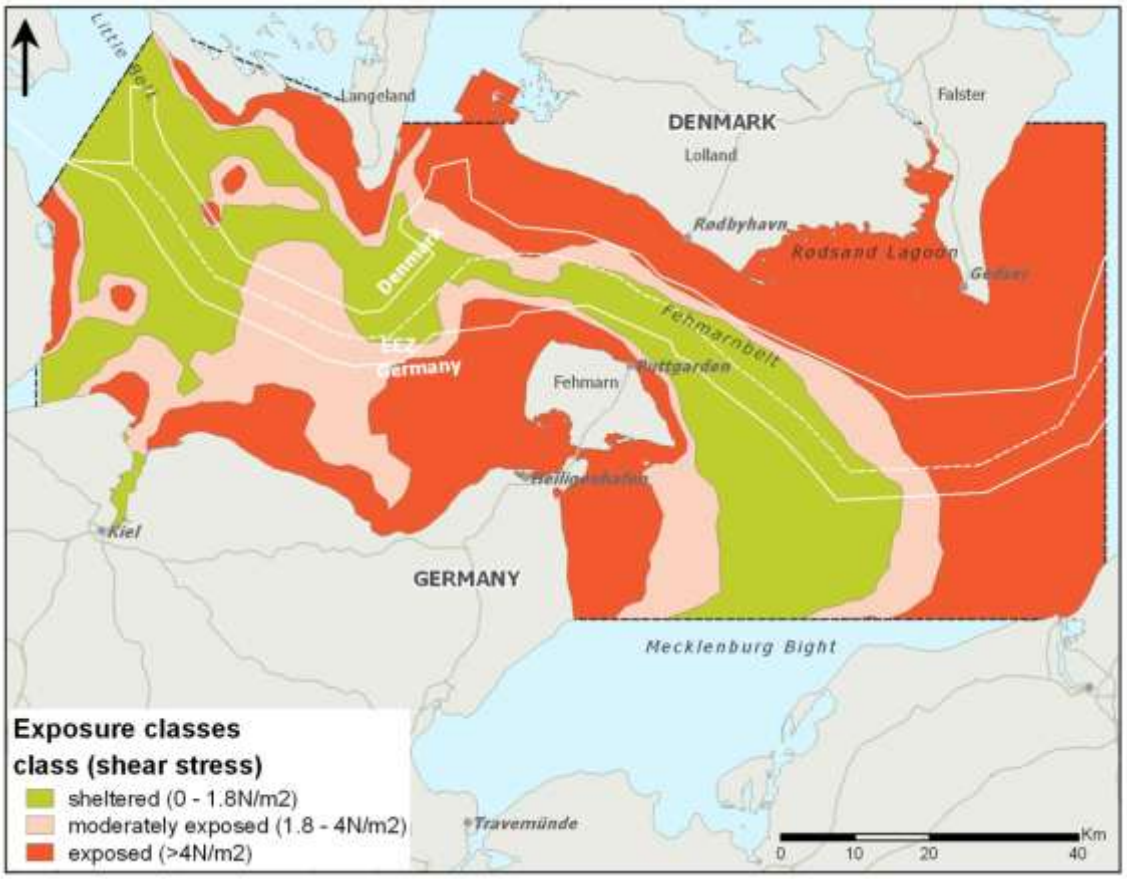


Figure 4-2 Bed shear stress (Exposure classes).

Although there are some benthic communities, which are characteristic for either exposed or sheltered areas, none of the above described descriptors and classes, which can be used as indicators for exposure, provide reasonable results in the distribution of those benthic communities. Sheltered areas like Rødsand Lagoon, Orth Bight or Burger Binnensee, which harbour specific benthic communities, are grouped in the same class like exposed shallow areas along the outer coastline. The selectivity or the discriminatory power of these descriptors or the defined classes is too low. Bed shear stress was therefore used only in a first step for habitat classification (Appendix A, G) but excluded as a descriptor during the later evaluation process.

4.1.3 Wave base

Wavelength was converted to wave base, which equals half the wavelength. It is generally assumed that the influence of surface waves can have a significant effect down to that depth. The map of maximum wave base was interfaced with the local bathymetry 50 m grid, resulting in the distribution shown in Figure 4-3. Seabed shallower than the wave base ("above wave base") was at least episodically affected by wave action, while seabed below the wave base remained undisturbed by waves throughout the model period.

Wave base is used to define the deep circalittoral depth zone (Chapter 4.1.5) used in the EUNIS classification system.

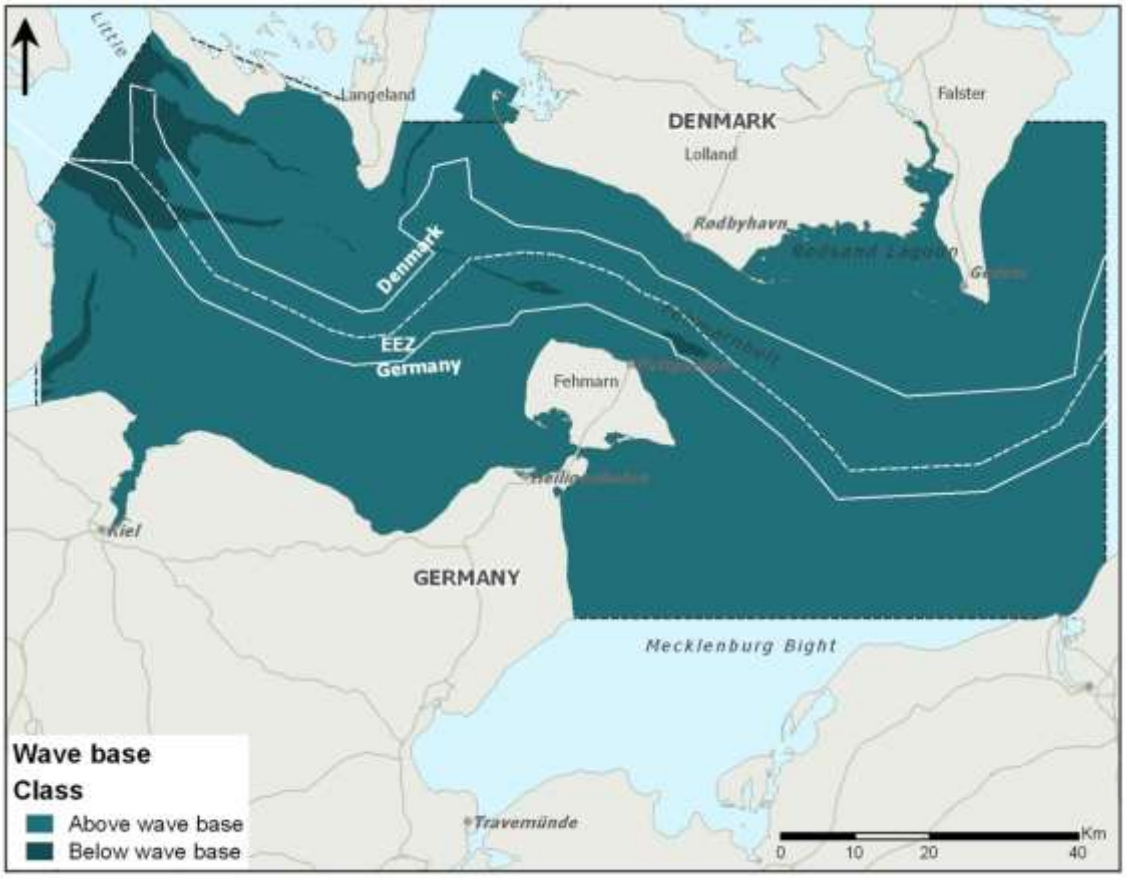


Figure 4-3 Seabed above and below wave base.

4.1.4 Secchi depth

The Secchi depth is a measure to define the clarity of water. The deeper the Secchi depth is the clearer the water column. Secchi depth was transformed into the depth at which the surface irradiance (100 %) is reduced to 1 %. The value of 1 % was chosen as this is commonly used to describe the lower limit of the photic zone (e.g. Morel and Berthon, 1989), although it is known that some seaweeds and benthic microalgae can grow at light levels much lower than this (e.g. Lüning and Dring, 1979).

In the water column, light decreases exponentially with depth. If we assume the light-attenuating components are evenly distributed in the water column then the attenuation coefficient K_d is constant with depth. Thus:

$$I_z = I_o e^{-z \cdot K_d} \rightarrow -z \cdot K_d = \ln\left(\frac{I_z}{I_o}\right),$$

whereby I_z is light intensity at depth z and I_0 is light intensity at the surface. If it is further assumed that the Secchi depth (z_{SD}) equals the depth with 15 % light, then:

$$K_d = \frac{\ln\left(\frac{15}{100}\right)}{-z_{SD}}$$

Thus the depth with 1 % light left ($z_{1\%}$) may be estimated from:

$$z_{1\%} = \frac{\ln\left(\frac{1}{100}\right)}{-K_d}$$

Or in short:

$$z_{1\%} = z_{SD}\frac{\ln(0.01)}{\ln(0.15)} = 2.43 \cdot z_{SD}$$

It should however be cautioned that an even distribution of light-attenuating components in the water column might not always be the case, e.g. during spring blooms.

The map of the 1 % depth was compared to the local bathymetry 50 m grid (Figure 3-2). In cases where the seabed was shallower than the 1 % depth the seabed was classed "photic". In all other cases it was classed "aphotic" (Figure 4-4).

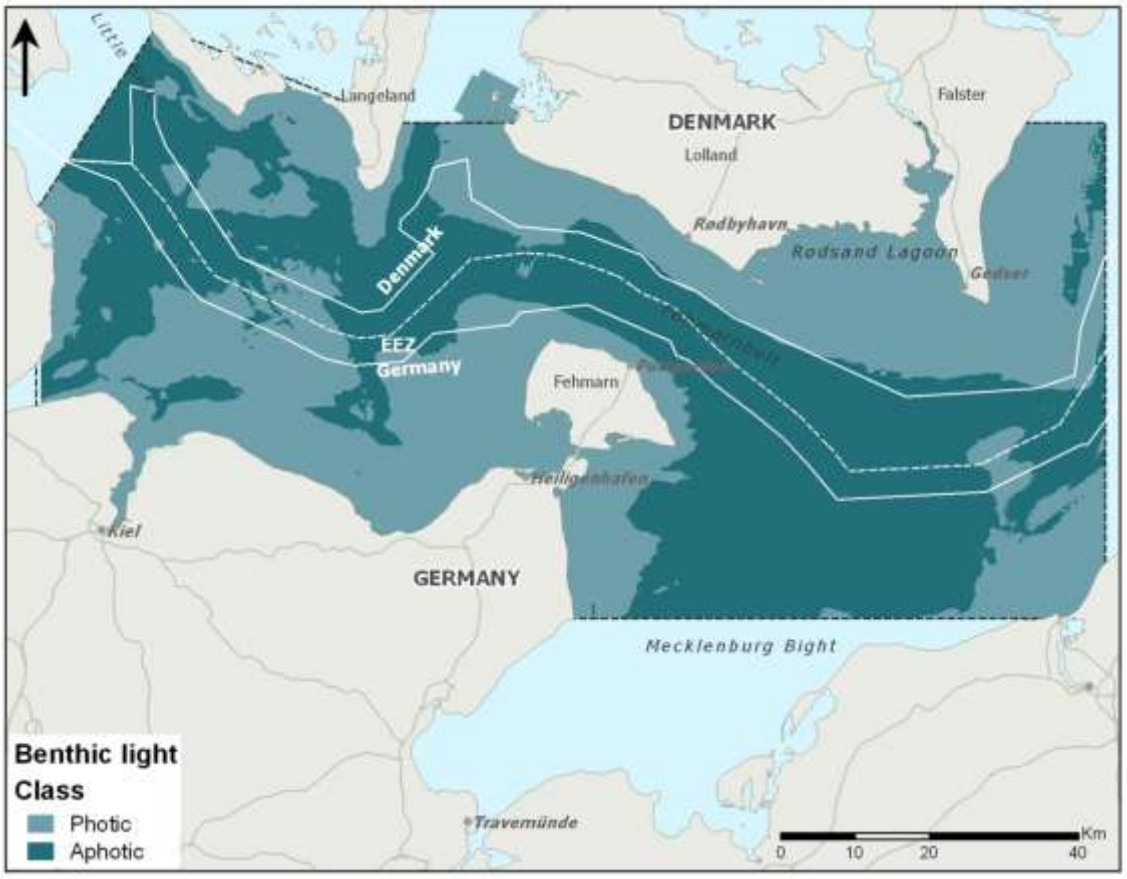


Figure 4-4 Photic and aphotic seabed zones.

4.1.5 Depth zones

Finally, biologically relevant depth zones were derived by a combination of the descriptors Secchi depth and wave base in agreement with the EUNIS classification. Overall four classes of depth zones used in EUNIS can be discriminated in the investigation area:

- Littoral is the zone that falls regularly dry. As the Baltic Sea is practically tideless this refers to wind-induced water-level changes, which cannot be clearly defined. Furthermore this zone comprises a very narrow band along the coastline and therefore this class was not used in this approach).
- Infralittoral refers to the photic seabed, which is also affected by wave action. Light levels are high enough to sustain vegetation growth.
- Circalittoral is the aphotic zone of the seabed that is wave-influenced. Light levels in this zone are too low for most plants, although some seaweeds and microalgae are able to cope with greatly reduced light levels.
- Deep Circalittoral is the aphotic zone of the seabed and undisturbed by waves.

Those three defined depth zone were used for habitat classification in the first step (Appendix E), but reduced to infralittoral and circalittoral during the later evaluation process. The previously mapped deep circalittoral was assigned to the circalittoral class. This was justifiable as the deep circalittoral occupied a relatively small area (25 km^2 or 0.9% of seabed area) and the biological communities found there did not differ from those in the circalittoral, thus making the distinction insignificant. The resultant depth zones are shown in Figure 4-5.

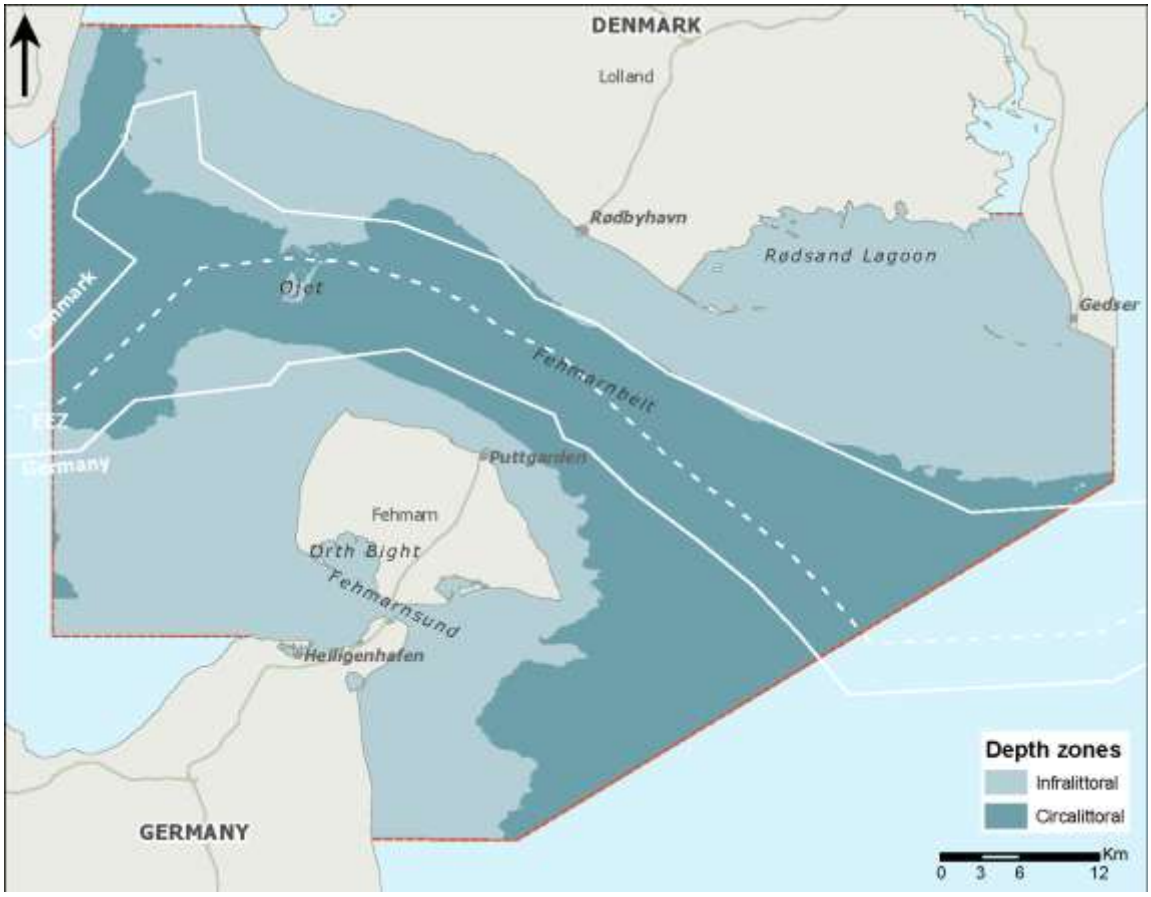


Figure 4-5 Distribution of depth zones (finally used as abiotic descriptor) within the investigation area.

4.1.6 *Seabed substrate*

A map of seabed substrate types was developed based on remote-sensing data (bathymetry, backscatter and aerial photography), which have been interpreted by seabed morphology, seabed grain size samples and hard substrate cover estimates (Chapter 3.3.5).

This substrate map was produced for the greater Fehmarnbelt area. Quality and resolution of data sources did, however, vary within the mapped area. Newly acquired high-resolution multibeam bathymetry/backscatter data and aerial photography were restricted to the Fehmarnbelt proper, Rødsand lagoon and the coastal zone around Fehmarn Island. For the remaining areas (mainly Kiel and Mecklenburg Bights), only the local bathymetry 50 m grid was available. Likewise, newly gathered sampling data (grain size, hard substrate estimates) was limited to the local Fehmarnbelt area, while legacy data retrieved from archives was used for the remaining areas.

Three individually interpreted substrate layers (based on the local bathymetry 50 m grid, multibeam and aerial photography) were merged into one substrate map. There was a certain spatial overlap between the individual layers, so rules had to be established as to which information would be given priority. The interpretation of multibeam data was given the highest priority, although the spatial resolution was lower compared to the interpretations of aerial surveys. This was however justifiable as multibeam data were only collected in water depths of 6 m or deeper, while aerial surveys were deemed to be effective down to 6 m water depths in these environments, based on previous experience. Hence, multibeam data was only given priority where aerial photography was increasingly ineffective in imaging the seabed. Both interpreted layers were given priority over the interpretations based on the local bathymetry 50 m grid.

As mentioned in Chapter 3.3.3, EUNIS discriminates between six classes, namely coarse sediment, sand, muddy sand, sandy mud, mud and mixed sediments. These are however only loosely defined. Four substrate classes (coarse sediment, sand and muddy sand, mud and sandy mud, mixed sediment) have been defined in MESH (Long, 2006) based on grain-size data (Figure 3-18-a). This scheme was modified in an attempt to reflect all six EUNIS classes and to give more classification detail for further mapping of physical habitats (Figure 3-18-b). Initially, the substrate map included these six substrate classes supplemented with a "thin sandy mud" class (Appendix F).

These seven seabed substrate classes were reduced to four classes during the evaluation process, as the benthic communities assessed showed no specific adaption to some of the original classes. The four final substrate classes are as follows:

- Mud (and sandy mud): This substrate class includes the smallest grain sizes (typically clay, silt and fine sand) and is characterised by a high proportion of organic content. Larger grain sizes and/or stones are not occurring.
- Sand (and muddy sand): This substrate class includes all forms of sandy substrates comprising fine, medium and coarse sand. Admixtures of mud (<20%) and gravel (<5%) are limited. Stones are not occurring
- Mixed sediment: This substrate class includes all forms of sediments of the former two classes, which are mixed with stones but with emphasis on the smaller grain sizes. This must be regarded as a spatial mosaic of different grains sizes that exist in close proximity. This class does not refer to the geological class "mixed sediment" of Long (2006), for which mixtures of all grain sizes are expected in a single sediment sample (without stones).

- Coarse sediment: This substrate type includes all stone fields as well as the transition to gravel or sand, but with emphasis on the larger grain sizes.

The spatial distribution of those substrate classes in the investigation is illustrated in Figure 4-6. Mud is restricted to the deep areas of the central Fehmarnbelt and the neighbouring basin of Mecklenburg Bight. In the western part of the investigation area this seabed substrate class occurs only within a deep channel of the Fehmarnbelt and east of Langeland. Organic matter accumulates there due to the specific current situation.

Sand occurs widespread in the shallow waters within Rødsand Lagoon, Fehmarnsund including neighbouring Orth Bight and off the north coast of Fehmarn. In deeper waters this substrate class characterises the transition between coarse sediment and mud areas.

Mixed sediment is distributed in the shallow water around Wagrien and along the southwest, south and southeast coast of Fehmarn. In deeper waters mixed sediments are distributed in the transitional area between the abrasion platforms and the muddy basins.

Coarse sediment has the highest percentage of area in the investigation area. Large continuous areas from shallow water to 15-20 m depth occur along the east, northwest and west coast of Fehmarn as well as east of Langeland and off parts of the south coast of Lolland.

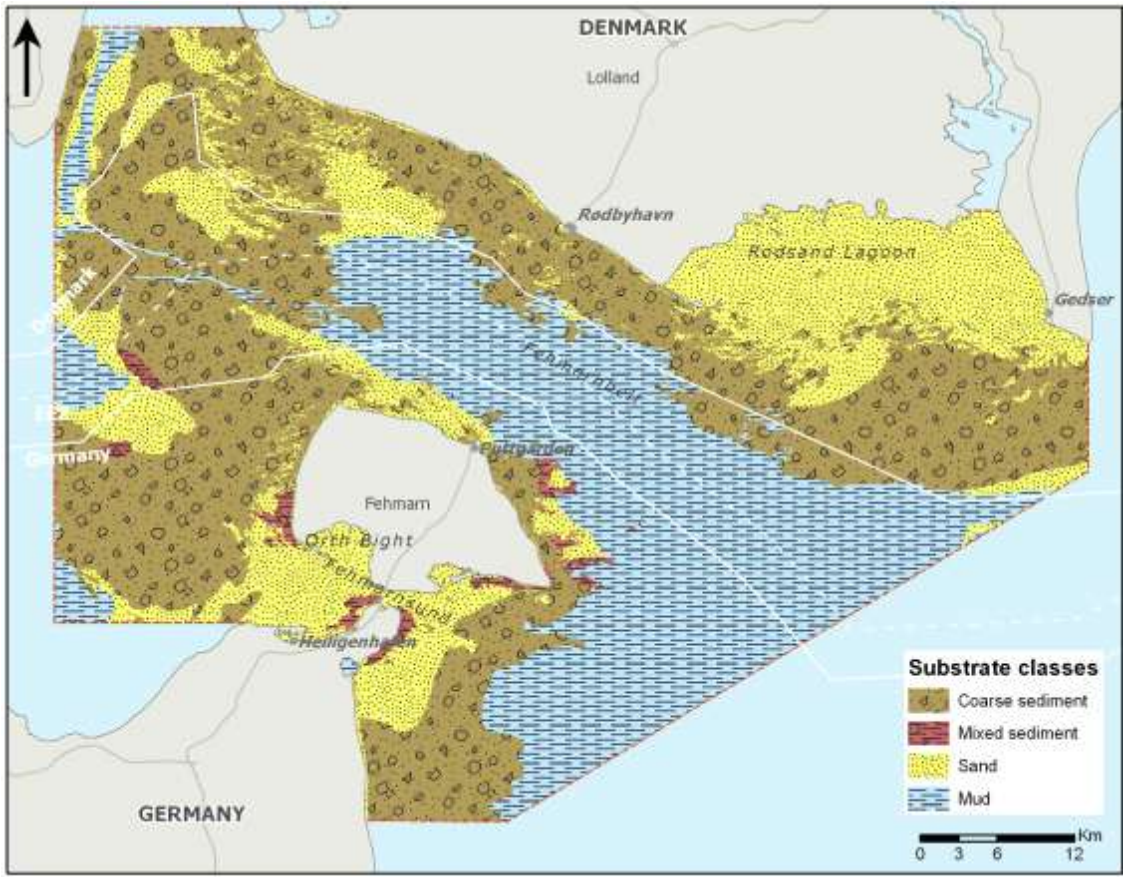


Figure 4-6 Distribution of seabed substrates.

4.2 Physical habitats

Intersecting GIS data layers of several abiotic descriptors produces a map of physical habitats. Initial tests of intersections included the abiotic descriptors depth zone, bottom salinity, exposure and seabed substrate. Descriptions and results are presented in Appendix G. As described in Chapter 2.1 physical habitats can be mapped and differentiated on a much finer scale compared to biological descriptors as differences are physically measurable but are of no relevance for species in choosing their habitat. For the final benthic habitat classification presented in Chapter 4.5, physical habitats, derived by intersecting the descriptor depth zone (with the classes infralittoral and circalittoral) and the descriptor seabed substrate (with the classes coarse sediment, sand, mud and mixed sediments) were sufficient for classification.

Eight physical habitats can be distinguished in total for the investigation area. Their spatial distribution is illustrated in Figure 4-7. The same substrate types have the same colour and pattern with infralittoral physical habitats having a stronger colour shade. All four substrate types are distributed in the infralittoral and circalittoral but with different spatial extent:

In the infralittoral zone, coarse sediment and sand are the dominating substrate types. Mud occurs rarely in the infralittoral and mixed sediments are only distributed along the German coastal zone.

In the circalittoral zone, mud areas have the highest percentage in the investigation area and have, following the infralittoral coarse sediments, the second highest extent of all physical habitats in the investigation area. However coarse sediment is also very common in the circalittoral especially in the Danish part of the investigation area. In contrast, mixed sediments are very scarce in the circalittoral zone.

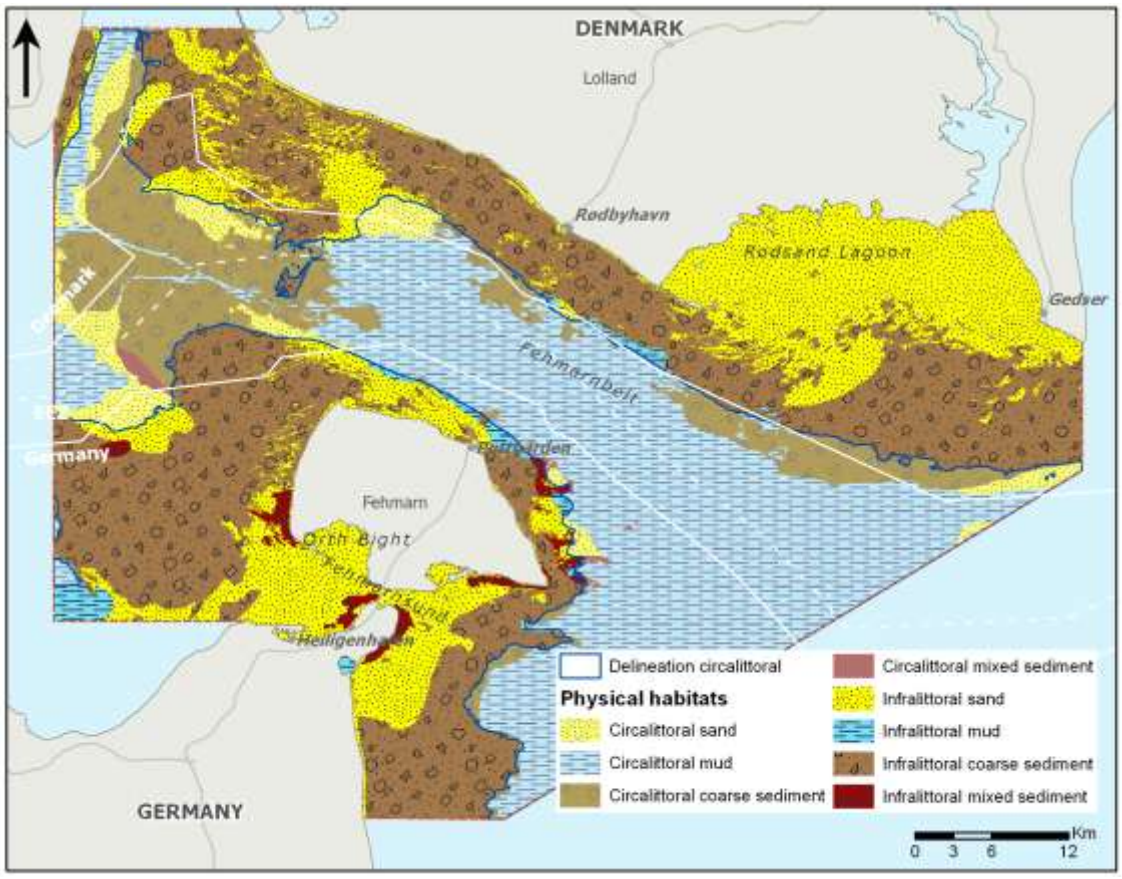


Figure 4-7 Distribution of physical habitats.

4.3 Biotic (biological) descriptors

4.3.1 Benthic flora communities

Eight flora communities and one extra category of vegetation stands were mapped in the investigation area. Five hard bottom (macroalgae), two soft bottom (angiosperms) and one mixed bottom community (angiosperms/algae) were identified. The resulting map is shown in Figure 4-8. More details on the characteristics of communities can be found in the benthic flora baseline report (FEMA, 2013a).

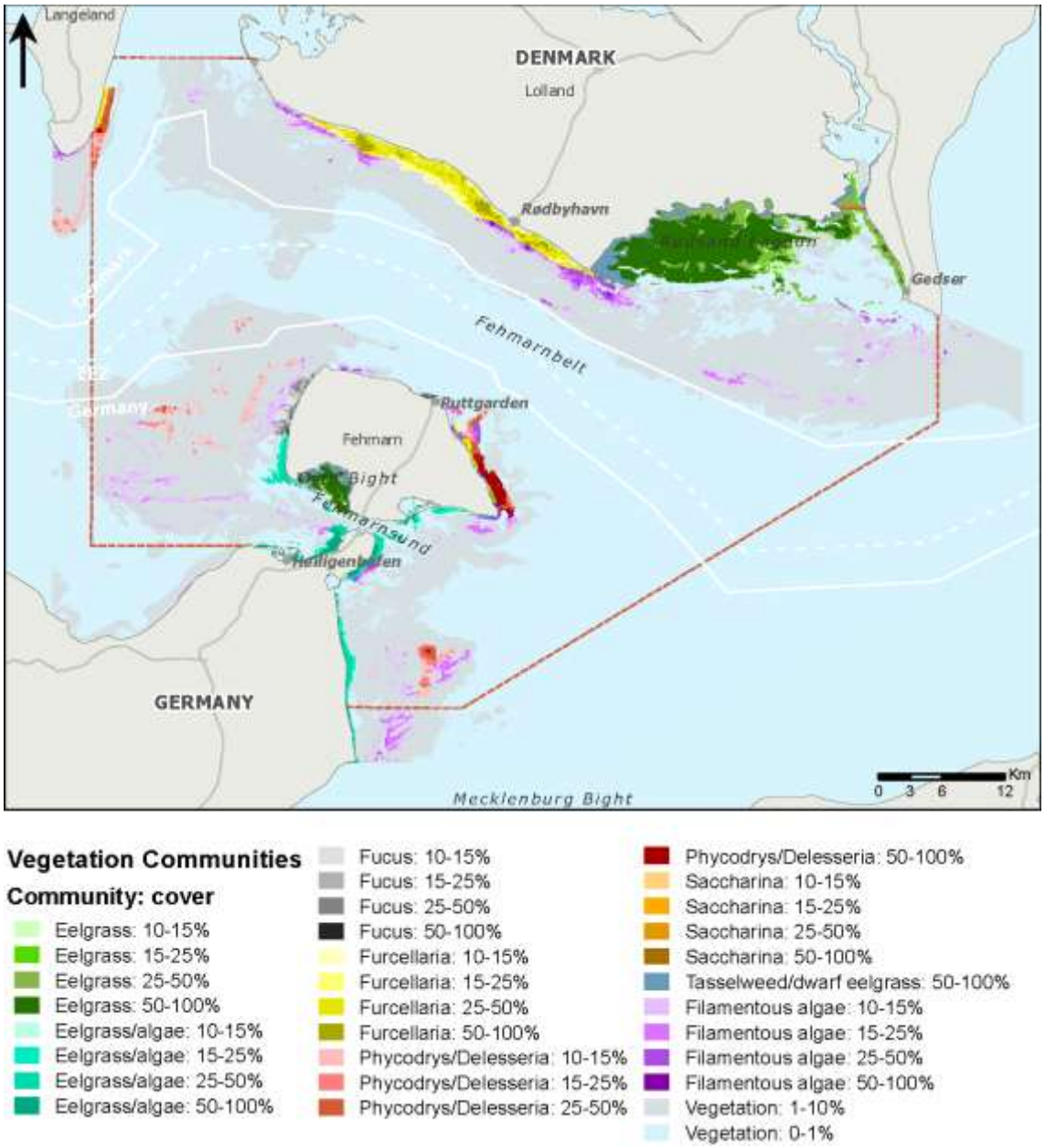


Figure 4-8 Predicted distribution and coverage for the benthic flora communities.

All flora communities are confined to the photic zone. As plants feature a structuring component within habitats, not only the characterisation of the community but also the percentage cover (%) is important as a further criterion (see importance Chapter 0). These percentage cover values have already been taken into account in the prediction of flora communities.

Regarding their ecology the benthic flora communities can be classified into four superior functional groups. The term higher plants characterises plants, which only occur on soft bottom. They are exclusively perennial and by forming stable habitats they are of specific relevance in habitat importance (Chapter 0). The term algae characterises species, which require hard bottom as settling ground. A further specification into perennial and annual algae is possible, whereas the term "perennial" is synonymous with forming stable habitats. In contrast the term "filamentous" char-

acterises species with annual or opportunistic life cycles and therefore without the ability to form stable habitats. In areas with mixed sediment (hard and soft bottom) higher plants and algae may occur together. Those areas have often a high relevance for habitat complexity and species diversitiy as communiies of hard and soft bottoms are combined.

The classification of the flora communities, their preferred substrate types and their respective superior functional group is shown Table 4-1.

Table 4-1 The defined flora communities and their assignment to the different substrate types and to the superior functional groups.

Flora community	Percentage cover (%)	Substrate class / biological structure component	Superior functional group
Filamentous algae	≥ 10–25 ≥ 25–50 ≥ 50	Coarse sediment Mixed sediment Blue mussels	Filamentous algae
Fucus *Furcellaria* *Phycodrys/ Delesseria* *Saccharina*	≥ 10–25 ≥ 25–50 ≥ 50	Coarse sediment Mixed sediment	Perennial algae
Tasselweed/dwarf eelgrass Eelgrass	≥ 10–25 ≥ 25–50 ≥ 50	Sand Mud	Higher plants
Eelgrass/algae	≥ 10–25 ≥ 25–50 ≥ 50	Mixed sediment	Higher plants/algae
Single plants	≥ 1–10	Coarse sediment Mixed sediment Sand Mud	

4.3.2 Benthic fauna communities

Nine fauna communities were mapped in the investigation area. Further details on the characteristics of the communities can be found in the benthic fauna baseline report (FEMA, 2013b).The resulting map is shown in Figure 4-8.

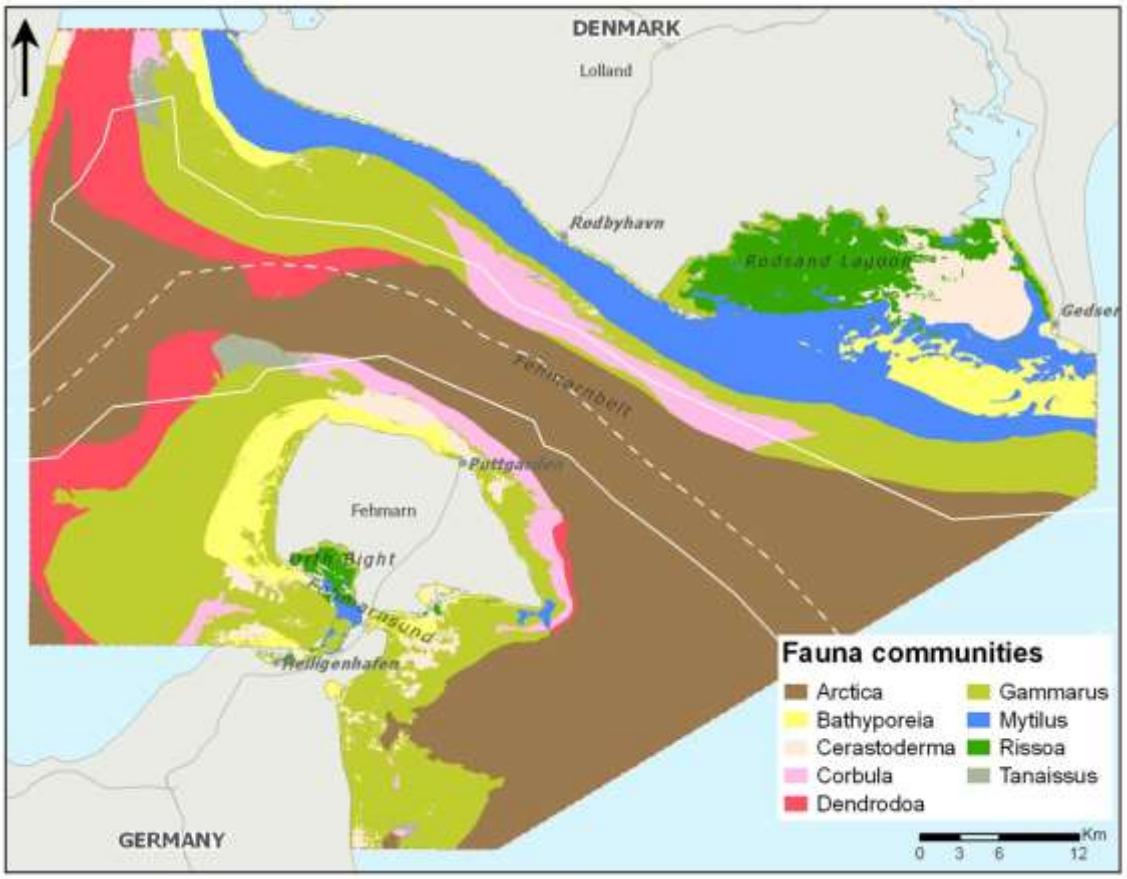


Figure 4-9 Predicted distribution of benthic fauna communities.

Fauna communities can also be described and grouped regarding their substrate preference. Four communities are characteristic of pure soft bottoms (sand and mud) and one is characteristic of coarse sand or gravel. These communities live in the sediment, hence they are summarised as infauna. The remaining four communities settle on the sediment and are therefore summarised as epifauna. A consistent assignment of epifauna to hard bottoms is not possible, as not only hard substrate but also soft bottoms can be colonised (e. g. *Mytilus*). Additionally certain epifauna communities are associated with characteristic soft bottom flora communities (higher plants).

The classification of the fauna communities, their respective substrate types and their superior functional group is shown in Table 4-2.

Table 4-2 The defined fauna communities and their assignment to the different substrate types and to the superior functional groups.

Fauna community	Substrate class / biological structure component	Superior functional group
Arctica	Sand Mud	Infauna
Bathyporeia	Sand	Infauna
Cerastoderma	Sand	Infauna
Corbula	Sand Mud	Infauna

Fauna community	Substrate class / biological structure component	Superior functional group
Dendrodoa	Coarse sediment Mixed sediment	Epifauna
Gammarus	Blue mussels Algae and higher plants	Epifauna
Mytilus	Coarse sediment Mixed sediment Sand	Epifauna
Rissoa	Higher plants	Epifauna
Tanaissus	Coarse sand, gravel	Infauna

4.3.3 Blue mussel cover

The coverage of blue mussels was analysed by predictive mapping (chapter 3.2.5). *Mytilus,* like perennial algae, exhibits a habitat-forming function (biogenic reef). Therefore it is necessary (in contrast to the other fauna communities) to consider the criterion percentage cover. The cover of blue mussels has been separately modelled for the derivation of fauna communities. It is based on a separate investigation program and on a discrete prediction method, which is further explained in (FEMA, 2013b).

The predicted spatial cover of *Mytilus* has been verified by diver observations and video investigations ("ground truthing") to ensure a uniform presentation of percentage cover of flora communities and blue mussels. The prediction cells of the model grid have been adjusted to the observed percentage cover, when deviations arose. Video analyses had a higher confidence compared to the very locally restricted diving investigations due to their greater spatial range. The verified spatial prediction of the blue mussel cover is shown in Figure 4-8.

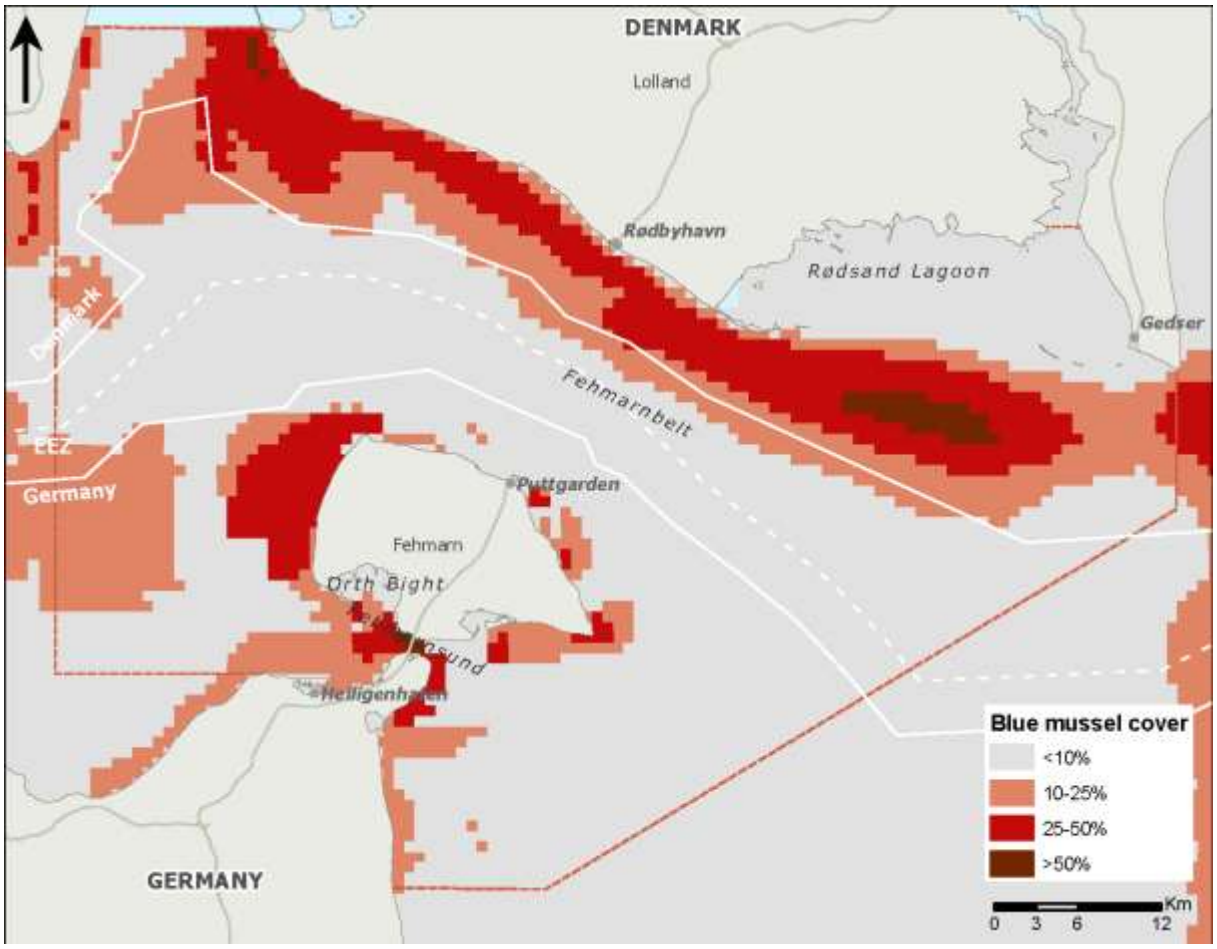


Figure 4-10 Predicted blue mussel cover after ground-truthing with diving and video analysis.

4.4 Benthic communities

Intersecting GIS data layers of the three biotic descriptors (benthic flora communities, benthic fauna communities, blue mussel cover) produces a map of benthic communities. There can be overlaps of the respective datasets as flora and fauna as well as blue mussel cover may occur in the same areas in the photic zone. As double naming of communities is disadvantageous and does not lead to a better characterisation of communities the different information has to be combined in an adequate manner to get a consistent and reasonable community name. First attempts of intersections are presented in Appendix H.

Benthic flora as well as blue mussels occupy a special position in terms of habitat delineation. They can be regarded as a benthic community, which inhabits a certain physical habitat and they can be habitat-forming themselves. The physical habitat, expanded by a biological structure component is again inhabited by further benthic epifauna communities. The biological structures and also the hard substrates in the sediment have to exhibit a certain density so that they master a habitat function and a specialised epifauna community can be formed. The special position of flora and blue mussels must be taken into account in the rules to define the resulting biota community:

- The benthic community is named after the respective floral component or after *Mytilus,* when this exhibits a cover ≥ 25 %. The component is present in a sufficient measure to be characteristic for the habitat and the following communities.

- The community is named after the floral component when both plants and *Mytilus* occur with covers > 25 %. Plants provide a habitat, which is more stable than a blue mussel habitat, because *Mytilus* underlies high fluctuations due to predation or variable spat fall. An exception is the community of filamentous algae, which (as annual plants) also show high fluctuations and often settle on blue mussels. In these cases the community is named after *Mytilus*.

- The community is named flora/fauna mixed community when flora, blue mussels and/or *Gammarus*-community show a cover of 10-25 %.

- All areas with a cover of flora or *Mytilus* < 10 % are delineated by and named after the respective occurring fauna community. In this case the biological habitat-forming components only have a minor impact on the characteristics of the habitat due to a too low density.

- A further unification or containment in the number of benthic communities has been achieved by an aggregation of certain communities on the basis of their superior functional groups. Exceptions are the *Mytilus*- and *Tanaissus*-communities. They are characteristic for specific habitats with special protective status (*Mytilus*: biogenic reefs; *Tanaissus*: species-rich coarse sand, gravel and shell grounds) and their occurrence in the investigation area has to remain transparent and traceable.

From this combination and unification nine benthic communities (Table 4-3) arise. Their spatial distribution is shown in Figure 0-1.

Table 4-3 Nine benthic communities, their delineation rules and their indicator function for certain habitat types.

Benthic community	**Assigned flora and fauna communities and their percentage cover**	**Indicator community for**
Dendrodoa	*Dendrodoa*-community	Reefs and hard substrate areas in deeper photic and aphotic zone
Filamentous algae	Filamentous algae -community with cover > 25 %	Mobile sediments or hard substrates in surf zone
Flora/fauna mixed community	All flora communities and/or *Mytilus*-community with cover 10–25 % *Gammarus*-community	Mixed habitats in photic zone with different substrates and habitat-building biological components (plants, *Mytilus*)
Higher plants	Eelgrass and tasselweed/dwarf eelgrass-community with cover > 25 % *Rissoa*-community	Eelgrass beds and inner coastal waters dominated by macrophyte vegetation like stonewort, tasselweed, pondweeds, etc. as well as habitat type 1160 “Large shallow inlets and bays”
Infauna	*Bathyporeia*- and *Cerastoderma*-community	Sandbanks and level sandy biotopes in shallow waters
	Arctica- and *Corbula*-community	Muddy and sandy mud grounds in greater depths
Perennial algae	*Fucus*-, *Furcellaria*-, *Phycodrys*/*Delesseria*- and *Saccharina*-community with cover > 25 %	Reefs and hard substrate areas in photic zone

Mytilus	*Mytilus*-community with cover > 25 %	Biogenic reef and hard substrate areas in photic zone
Eelgrass/algae	Eelgrass/algae-community with cover > 25 %	Eelgrass beds and mixed habitats in photic zone
Tanaissus	*Tanaissus*-community	Coarse sandy and gravelly grounds

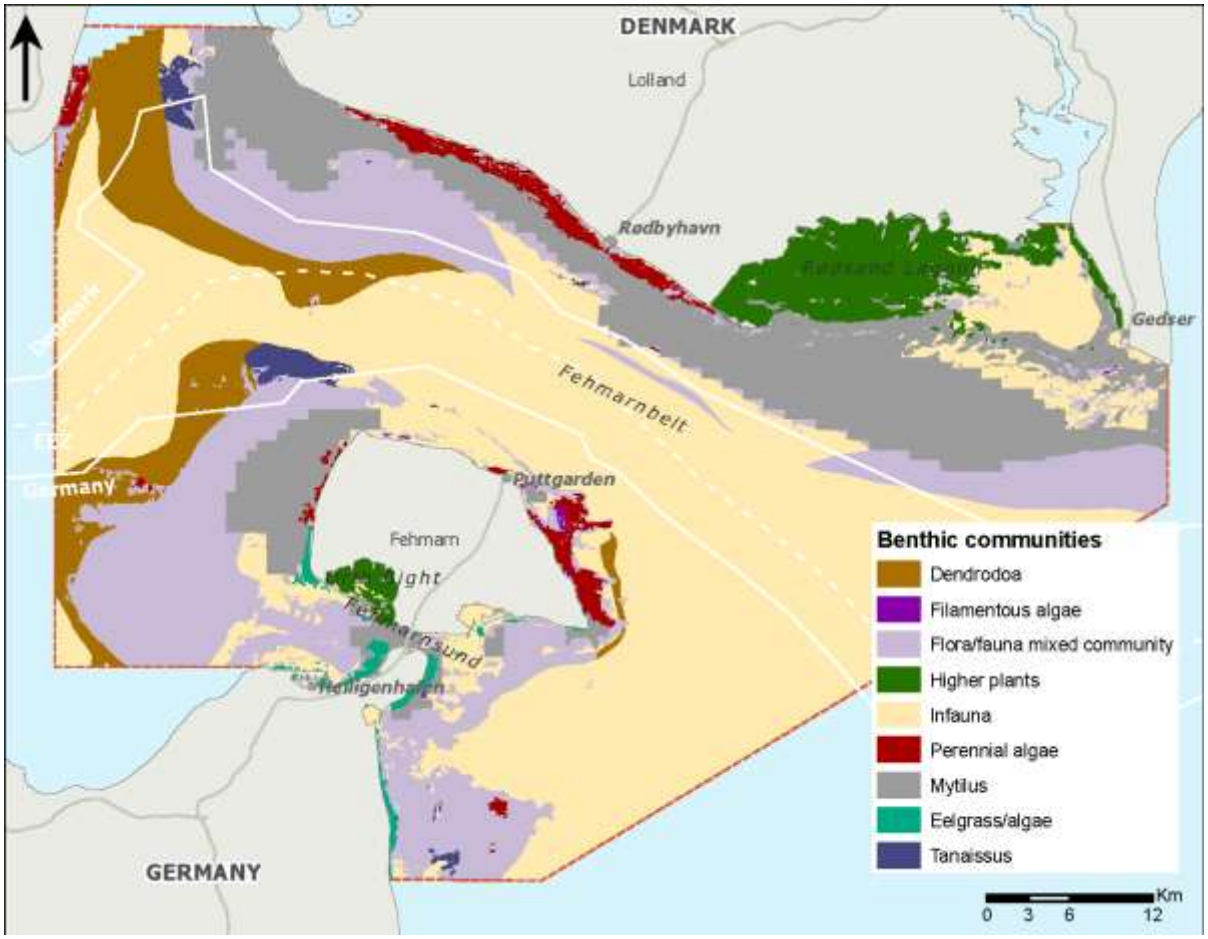


Figure 4-11 Distribution of benthic communities in the investigation area.

4.5 Benthic habitats (final version)

Intersecting GIS data layers of the physical habitats with benthic communities produces a map of benthic habitats. First tests of intersections with intermediate steps of physical habitats and intermediate steps of benthic communities yielded a number of benthic habitats higher than 100, with many combinations occurring only with very limited spatial extent. This high number of habitats occurs as an artefact, if the abiotic descriptors and the resulting physical habitats are assessed in such detail that the benthic communities are not reflecting this. Differences are physically measurable but are of no relevance for species in choosing their habitat. As the term habitat is used to describe the living environment of certain adapted species or communities, it is not appropriate to classify habitats, which are only differentiable on physical descriptors, but have practically no relevance.

In addition the substrate classes are not reflecting the actual density of hard substrates, but only delineate areas with theoretically high amount of stones. For pre-

dictive mapping of benthic flora and fauna communities the distribution and density of hard substrates has been taken into account. If intersecting substrate classes with benthic communities are resulting in misleading or mistacable groupings like

- epibenthic or macroalgae communities in combination with sand or mud (although the communities need hard substrates) or

- infaunal or higher plant communities in combination with coarse sediment (although the communities need sand, mud or at least mixed sediments),

the community prediction is given a higher priority. As term for the benthic habitat the name of the benthic community is maintained but the substrate class is changed to mixed sediment to characterise the variable substrate composition.

For the final definition of benthic habitats the abiotic descriptors depth zone (two classes: infra- and circalittoral) and seabed substrate (four classes: coarse and mixed sediment, mud and sand) define eight physical habitats in total. The biotic descriptors flora (four classes: filamentous algae, perennial algae, higher plants, eelgrass/algae) and fauna communities (four classes: infauna, *Dendrodoa*, *Tanaissus*, *Gammarus*) and blue mussel cover (two classes: 10–25 %, >25 %) define nine benthic communities in total.

By intersecting eight physical habitats with nine benthic communities we were able to differentiate 19 benthic habitats in the investigation area. Their characterisation arises from their components benthic communities and physical habitats. The spatial distribution of the benthic habitats is shown in Figure 4-12, their spatial extent is listed in Table 4-4.

Only five benthic habitats occur in the circalittoral zone, as the number is reduced due to the absence of flora and the homogeneous substrate conditions. The largest areas are confined to soft bottom habitats, whereas mud with infauna dominates (27.76 %) over sand with infauna (1.69 %). Infauna inhabiting mud is constituted of long-living bivalve species and a great number of different polychaetes. It is distributed in the whole region of the deep basins in Kiel and Mecklenburg Bight as well as in the deep channel in Fehmarnbelt and off Langeland.

The lack of larger grain sizes in the circalittoral zone becomes noticeable through only a small area covered by a habitat with epifauna (1.92 %). It is characterised only by one community (*Dendrodoa*), which consists of tunicates, bryozoans, sponges or sea anemones. In the transition zone between circalittoral soft bottoms of the deep basins and elevated circalittoral banks with coarse sediments there are mixed sediments, which are inhabited by *Dendrodoa* (1.61. %) or infauna (10.85 %), depending on the substrate conditions. All other fauna communities (like *Mytilus* or *Tanaissus*) as well as plants are confined to the infralittoral zone.

The number of benthic habitats in the infralittoral zone increases to 14, as the main distribution of many benthic communities is limited to shallower waters. Coarse sediment covers a larger area in the infralittoral, but in contrast to mixed and soft bottoms it remains the smallest habitat. Different characterising communities occur (*Mytilus* – 10.22 %, *Dendrodoa* – 2.26 %, perennial algae – 1.39 %). Coarse sediment with *Mytilus* is predominantly found off the south coast of Lolland, at the southeastern tip of Fehmarn (Staberhuk) and in Fehmarnsund. Coarse sediment with *Dendrodoa* is distributed west and northwest of Fehmarn in the transition zone to the deep basins of Kiel Bight. Coarse sediment with perennial algae predominantly occurs off the east coast of Fehmarn and south of Lolland.

Infralittoral habitats with sandy substrates cover a significantly larger area than infralittoral muddy substrates (only 0.78 %). They can be vegetated with higher plants like eelgrass or tasselweed (4.16 %) and are found in the sheltered regions of Rødsand lagoon or Orth Bight. Infralittoral sandy habitats without or with sparse macrophyte vegetation (4.58 %) are characterised by infauna. This infauna community is dominated by common cockles or clams and can then also be found in the sheltered regions of Rødsand lagoon or Orth Bight. At exposed sites like the north of Fehmarn, Flügge Sand or sandy areas off Burger Binnensee habitats characterised by *Bathyporeia pilosa* prevail.

All other habitats in the infralittoral represent mixed forms of already described hard and soft bottom habitats. Depending on the mixing ratio of the respective substrates there are flora communities (perennial algae – 0.10 %, eelgrass/algae – 0.48 %), *Mytilus* (0.25 %), *Dendrodoa* (1.11 %), *Tanaissus* (0.72 %) or infauna (4.60 %). The largest area in the infralittoral zone is covered by mixed sediment with flora/fauna mixed communities (22.98 %). *Mytilus* as well as plant components only exhibit 10-25 % percentage cover here. Differences to soft bottom habitats with infauna are nevertheless detectable as the presence of *Mytilus* and plants have an effect on which species occur. This mixed habitat is predominantly found west of Fehmarn but also between Fehmarn and Sagas Bank as well as on the coast of Lolland. These are regions, which belong to wave platforms in which the wave conditions do not lead to a stronger abrasion (and therewith to an exhumation of new hard substrate).

Table 4-4 Spatial extent (in km²) of benthic habitats within the investigation area and their distribution into the different geographic zones as well as their percentage related to the total investigation area (2,918.79 km²).

Benthic habitats	Total area	Denmark (national + EEZ)	Germany (national)	Germany (EEZ)
Circalittoral sand with infauna	49.21 (1.69 %)	29.94	5.24	14.02
Circalittoral mud with infauna	810.25 (27.76 %)	273.95	324.35	211.95
Circalittoral coarse sediment with *Dendrodoa*	55.95 (1.92 %)	40.30	1.08	14.57
Circalittoral mixed sediment with *Dendrodoa*	47.03 (1.61 %)	40.80	4.69	1.54
Circalittoral mixed sediment with infauna	316.77 (10.85 %)	201.30	44.67	70.80
Infralittoral sand with higher plants	121.33 (4.16 %)	109.65	11.68	–
Infralittoral sand with infauna	133.77 (4.58 %)	82.83	50.13	0.81
Infralittoral sand with *Mytilus*	74.75 (2.56 %)	57.67	17.08	–
Infralittoral mud with infauna	22.63 (0.78 %)	5.87	16.76	–
Infralittoral coarse sediment with *Dendrodoa*	65.84 (2.26 %)	13.27	30.61	21.96
Infralittoral coarse sediment with perennial algae	40.56 (1.39 %)	26.03	14.50	0.03
Infralittoral coarse sediment with *Mytilus*	298.24 (10.22 %)	243.73	54.51	–
Infralittoral mixed sediment with *Dendrodoa*	32.30 (1.11 %)	10.67	21.48	0.16
Infralittoral mixed sediment with flora/fauna mixed community	670.61 (22.98 %)	277.47	381.54	11.60

Benthic habitats	Total area	Denmark (national + EEZ)	Germany (national)	Germany (EEZ)
Infralittoral mixed sediment with infauna	134.14 (4.60 %)	71.53	61.75	0.85
Infralittoral mixed sediment with perennial algae	2.86 (0.10 %)	0.30	2.56	–
Infralittoral mixed sediment with *Mytilus*	7.39 (0.25 %)	0.98	6.42	–
Infralittoral mixed sediment with eelgrass/algae	14.10 (0.48 %)	1.25	12.85	–
Infralittoral mixed sediment with *Tanaissus*	21.05 (0.72 %)	8.38	2.23	10.44

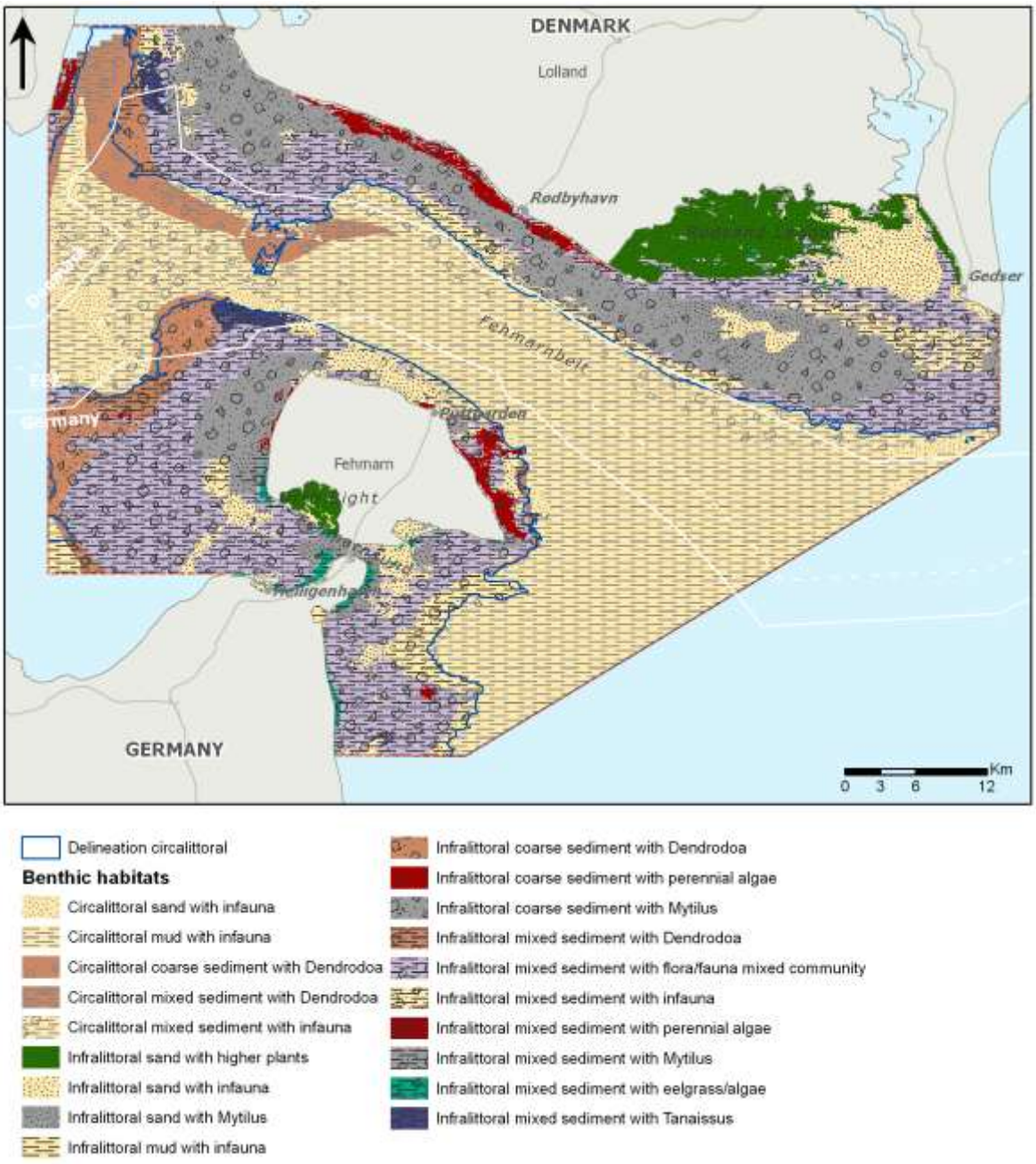


Figure 4-12 Distribution of benthic habitats.

5 EU-HABITAT TYPES (HABITAT DIRECTIVE, ANNEX I)

The delineation of the different habitat types is based on the descriptors and criteria described in Chapter 2.2. The criteria on the German side strictly follow the mapping guidelines and requirements of the German authorities. Therefore the delineation criteria differ between German and Danish investigation areas.

These are partly delineations of habitat types suggested by the authorities. These have only yet been derived usind abiotic criteria. Thus the areas of the respective habitat type, derived in this investigation might differ from the official specifications since it also uses biological criteria. This is described and discussed for the respective habitat types in the following sections.

5.1 Sandbanks (1110)

In total 138.60 km^2 of the investigation area were assigned to the habitat type "Sandbanks" (Figure 5-1) The largest continuous sandbank areas are Fehmarnbank (53.94 km^2) - also called Flügge Sand - at the western side of the Fehmarnsund, and Sagas Bank (18.36 km^2), east of Fehmarnsund. Putlosbank and Fehmarnbeltbank (Øjet) build further morphologically discriminable structures with predominant sandy substrate and the respective dominating fauna communities. Besides these banks there are also different mega ripple fields within the investigation area, which can also be assigned to this habitat type. They are elongated, morphologically distinguishable structures with predominant sandy substrate and occur in Fehmarnbelt, Langelandbelt, Fehmarnsund and south of Rødsand lagoon.

All mapped structures lie completely or for the largest part above the 20 m depth contour. Only in Fehmarnbeltbank (Øjet) there are deeper sandbank areas, whereas the peak is in depths < 20 m. In comparison to the officially assigned areas (Table 5-1) the habitat type sandbanks in the German EEZ results in an area almost twice as large as hitherto assigned. For the German coastal area the current mapping results in a slightly smaller area. Conversely, on the Danish side significantly fewer areas are characterised as sandbanks (¼ of hitherto assigned areas).

Table 5-1 Comparison of currently mapped areas of the habitat type "Sandbanks" (1110) and the respective officially assigned areas (km^2)

Habitat type	Denmark (national+ EEZ)		Germany (national)		German EEZ	
	current mapping	assigned	current mapping	assigned	current mapping	assigned
Sandbanks (1110)	43.45	181.36	87.41	94.14	7.29	4.52

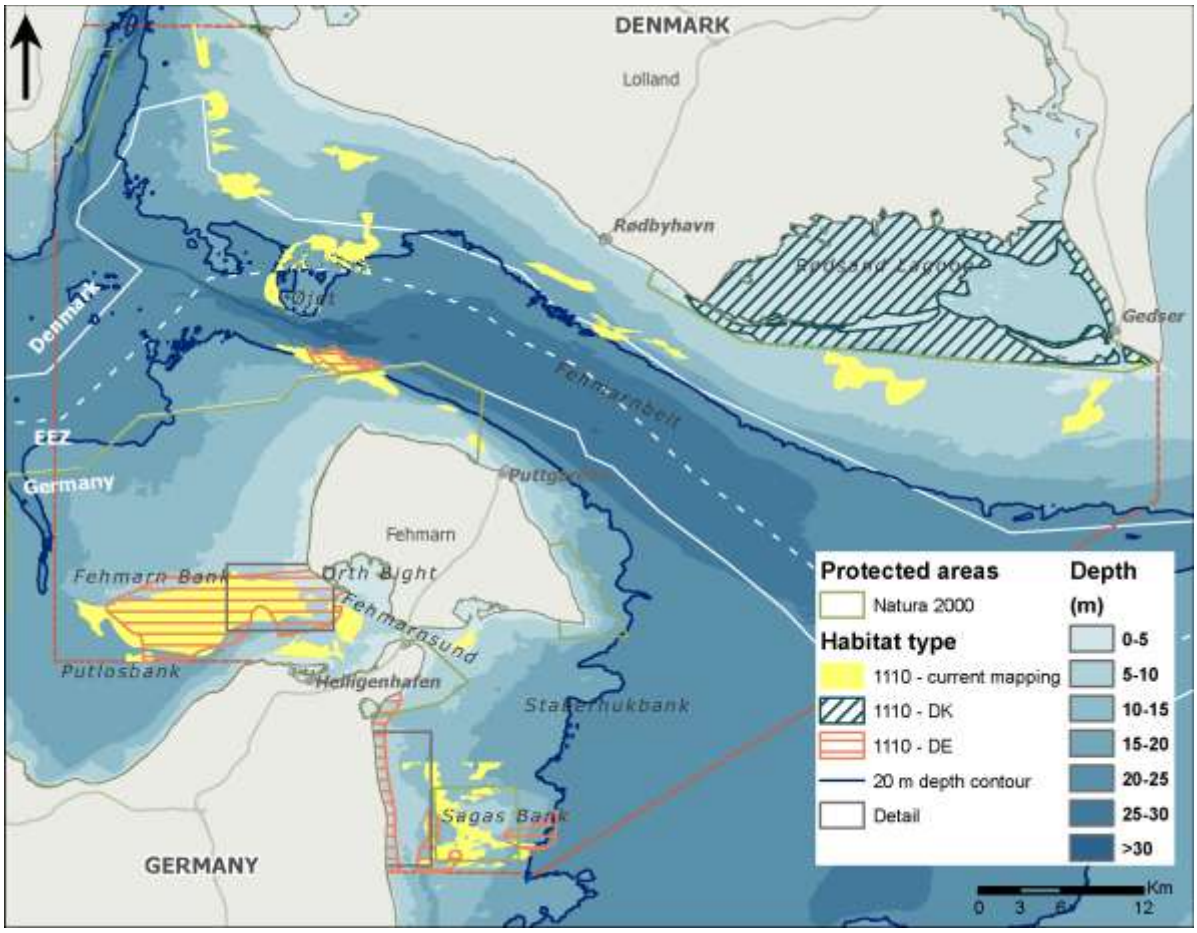


Figure 5-1 Habitat type "Sandbanks" (1110) within the investigation area (for details see Figure 5-2 and Figure 5-3).

This smaller area on the Danish side is due to the so far nearly complete assignment of the Rødsand lagoon to the habitat type sandbank. In the current mapping this lagoon is characterised as habitat type 1160 "Large shallow inlets and bays" (see below). It is noticeable, that especially the zone dominated by macrophyte vegetation (eelgrass- or tasselweed-community) is the one declared as sandbank. This is contradictory to the Danish (and German) specifications, whereby sandbanks have to be without or only with little macrophyte vegetation. According to the Danish authorities this was a misclassification and has therefore to be corrected accordingly. Therefore in the current mapping significantly larger areas are characterised as sandbanks than officially assigned. This also results from an assignment of habitat type areas only within designated Natura 2000 sites, whereas the present investigation is a mapping of habitat types in the whole investigation area, irrespective of an assignment to a Natura 2000 site.

In the course of a detailed verification for the German parts, some of the areas officially assigned as habitat type 1170 "Reefs" are characterised as sandbanks or level sandy biotopes in the current mapping. Biological investigations reveal that there are only flora- and fauna-components characteristic for sandy bottoms. This can be seen in the northern part of Flügge Sand and in some parts of Sagas Bank. A detailed presentation with underwater photos from the different areas of the habitat mapping can be found in Chapter 5.4 (habitat type reefs, Figure 5-8 and Figure 5-9).

However, there are also areas on the German side, which have been officially assigned to sandbanks but are now characterised as reefs or level sandy biotopes without the characteristic morphological criteria of sandbanks. In Figure 5-2 one of these areas on the southwestern site of Fehmarn is shown in detail with characteristic underwater photos. There are mixed sediment conditions in shallow waters (< 4-5 m depth). Besides sandy areas or areas with eelgrass there are also clay reefs and smaller and / or larger stones with a percentage cover of > 10 %, overgrown with blue mussels. Therefore these areas fulfill the criteria of the habitat type 1170 "Reefs" (percentage cover of shard substrates or blue mussels > 10 %) and not the criteria of the habitat type 1110 "Sandbanks".

Furthermore there are variable stands of blue mussels on sandy bottoms in this region. According to the authorities these areas should be characterised as (biogenic) reef, unless the percentage cover of blue mussels is < 10 %. This regulatory requirement has been followed in the present mapping, which means that areas that have been reported to the authorities as a sandbank are now classified as (biogenic) reef. The temporal variability of the blue mussel stands leads to a varying habitat typification depending on investigation date and year.

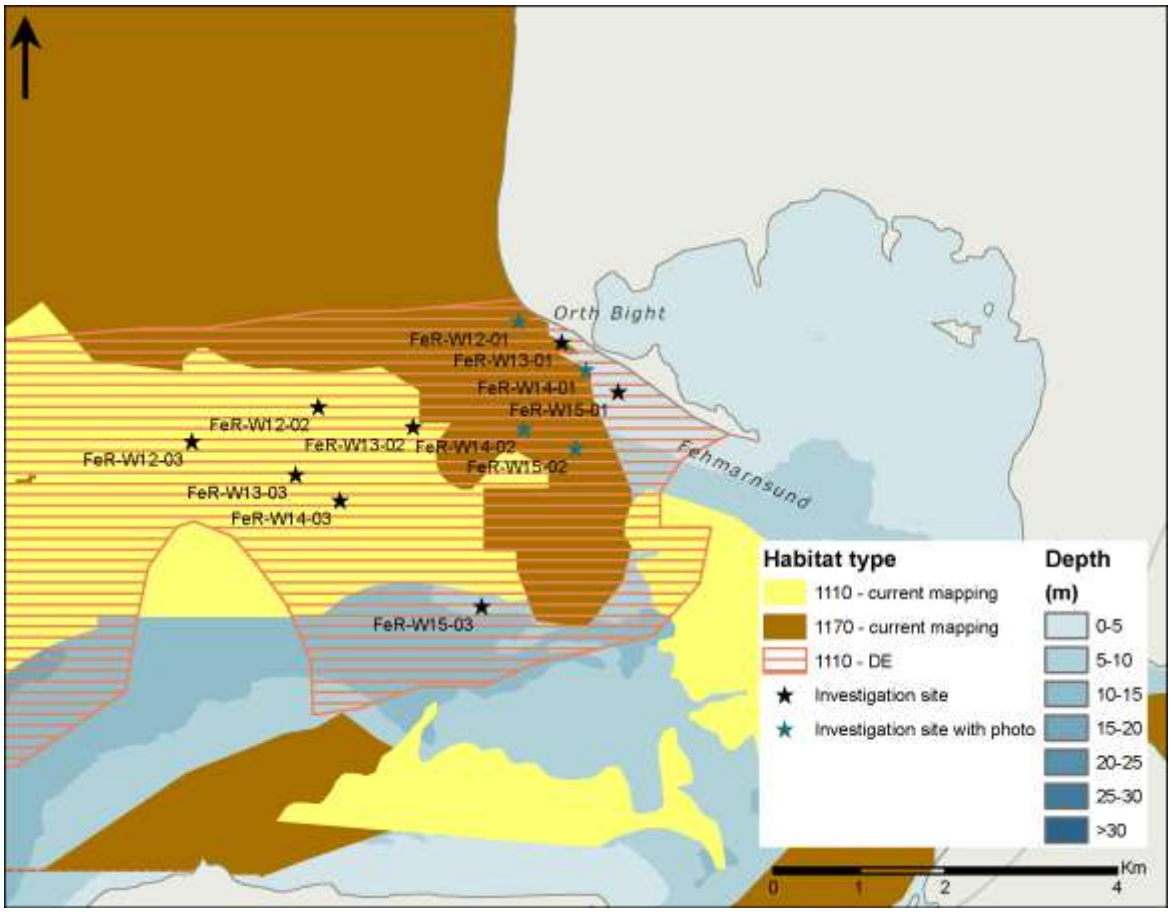
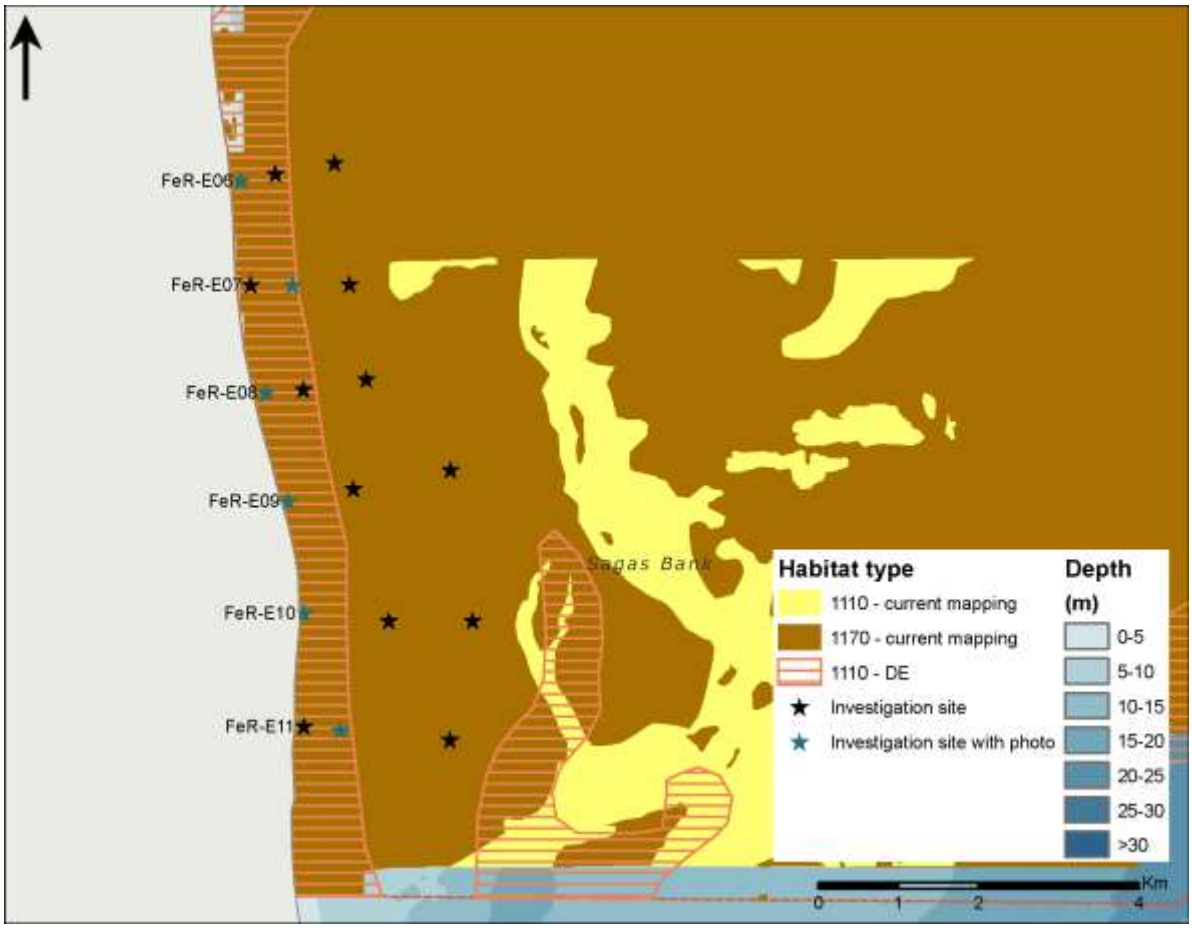
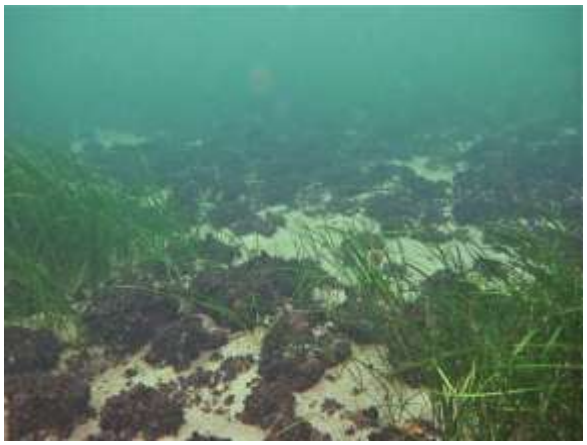


Figure 5-2 *Detailed map for the south-western part of Fehmarn (Krummsteert, Flügge Sand) and photos showing two shallow stations (FeR-W12-01, top left; FeR-W14-01, top right), which are assigned to the habitat type reef due to a presence of clay reefs or stones with a percentage cover > 10 %. Additionally, there are four photos showing two stations (FeR-W14-02, mid; FeR-W15-02, bottom), which might be either mapped as sandbanks (left side) or reefs (right side) due to variable blue mussel stands.*

In Figure 5-3 the second of these areas on the south-eastern coast of Großenbrode is shown in detail with characteristic underwater photos. In shallow waters there occur mixed bottoms built up by sandy areas, clay reefs and hard substrate.

Hard substrates and/or blue mussels are present with percentage covers > 10 %, so that the criteria for habitat type 1170 "Reefs" and not the ones for habitat type 1110 "Sandbanks" (as assigned from the authorities) are fulfilled.


FeR-E06
FeR-E07
FeR-E08
FeR-E09
FeR-E10
FeR-E11
Sagas Bank
Habitat type
1110 - current mapping
1170 - current mapping
1110 - DE
Investigation site
Investigation site with photo
Depth
(m)
0-5
5-10
10-15
15-20
20-25
25-30
>30
Km
0
1
2
4



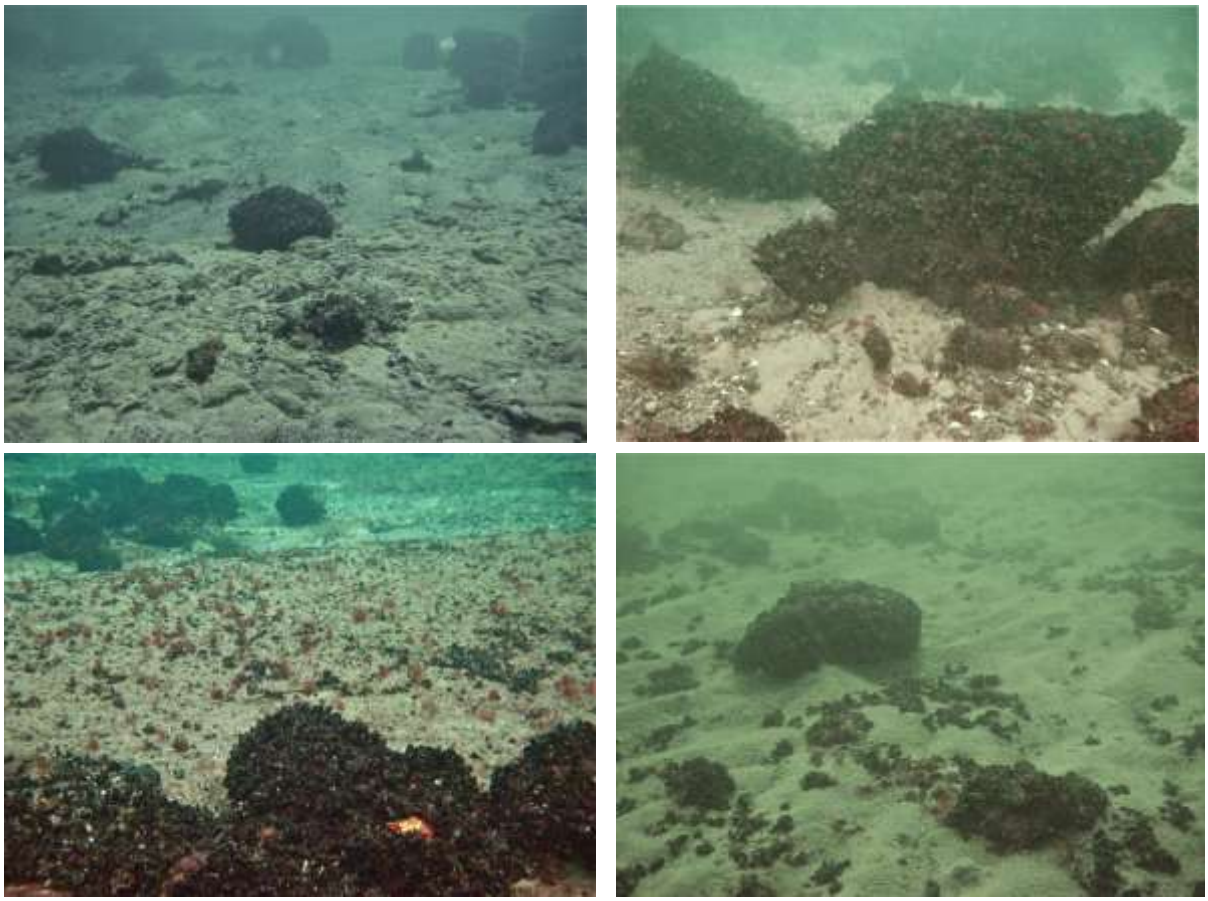


Figure 5-3 Detailed map for the southeastern coast of Großenbrode and photos showing the stations FeR-E06-01/07-02 (top), FeR-E08-01/09-01 (mid) und FeR-E10-01/11-02 (bottom).

5.2 Mudflats and sandflats (1140)

In the Baltic Sea, this habitat type consists of wind-induced flats and areas are significantly smaller than other EU-habitat types. In total 20.76 km^2 of the investigation area were assigned to the habitat type mudflats and sandflats. This type occurs in five geographically separated regions, which by nature exclusively comprise extremely shallow waters (Figure 5-4).

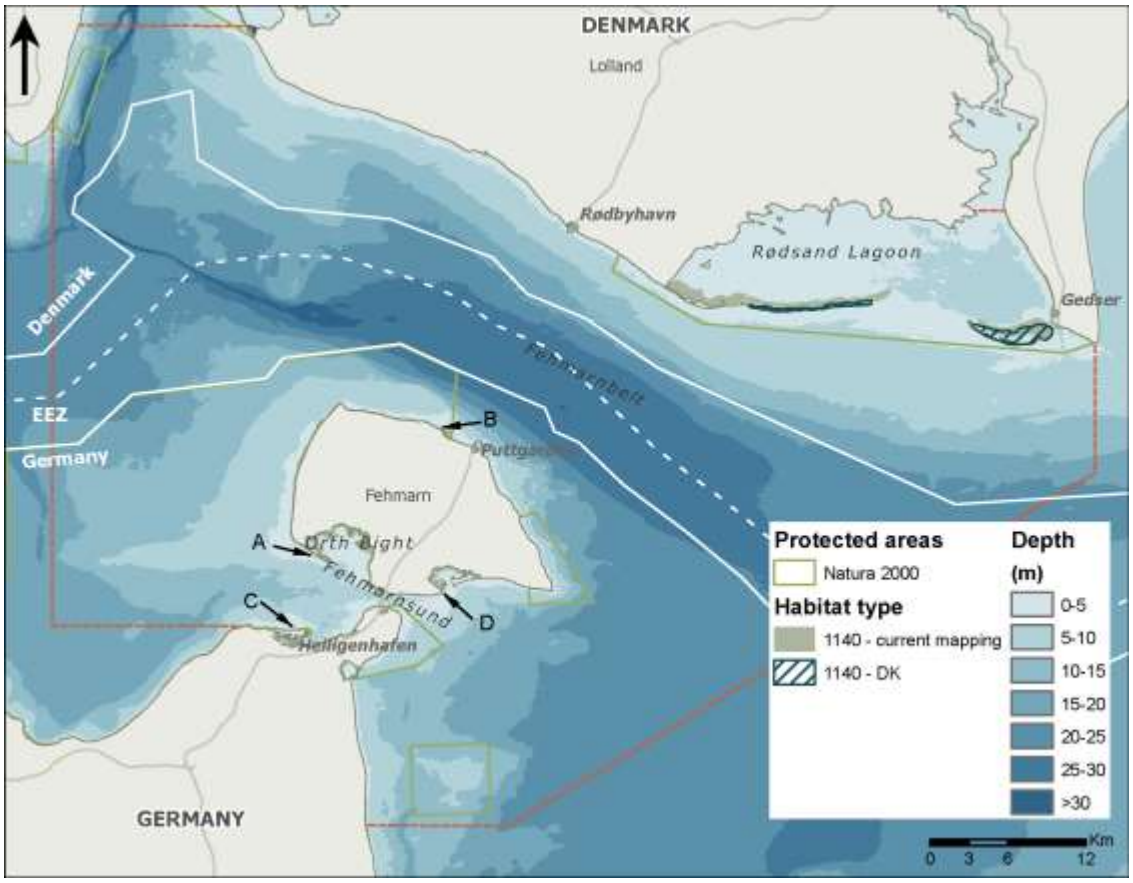
Four of these regions are in Germany (Orth Bight, Graswarder, Grüner Brink and Burger Binnensee); one is in Denmark (spits of Rødsand lagoon). The largest area of wind-induced flats can be found at the seaward opening of the Rødsand lagoon. The largest area on the German side is in Orth Bight (3.84 km^2). With the exception of Grüner Brink all wind-induced flats are part of or lie adjacent to the habitat type "Large shallow inlets and bays".

In comparison to the officially assigned areas (Table 5-2), the habitat type mudflats and sandflats in Denmark results in an area almost twice as large (factor 0.76) as hitherto assigned. Mapped and assigned areas lie in the same region (sand barrier seaward opening of Rødsand lagoon). The larger areas possibly result from the seaward delineation of the habitat type at 0.5 m water depth around the sand barrier, whereas the Danish authorities apparently used other criteria; however the delineation criterion is not specified in the available documents and has not been commented by the authorities. In Germany no wind-induced flats have been offi-

cially assigned. The delineation of the habitat type at 1.0 m water depth is carried out in accordance with guidance from the German authorities, as they also regard a single event as equal to the term "regularly" falling dry.

Table 5-2 Comparison of currently mapped areas of the habitat type "Mudflats and sandflats" (1140) and the respective officially assigned areas (km²) (n/a: not applicable, n.p.: not present)

Habitat type	Denmark (coastal + EEZ)		Germany (national)		Germany (EEZ)	
	current mapping	assigned	current mapping	assigned	current mapping	assigned
Mudflats and sandflats (1140)	13.65	7.76	7.11	n/a	n.p.	n.p.



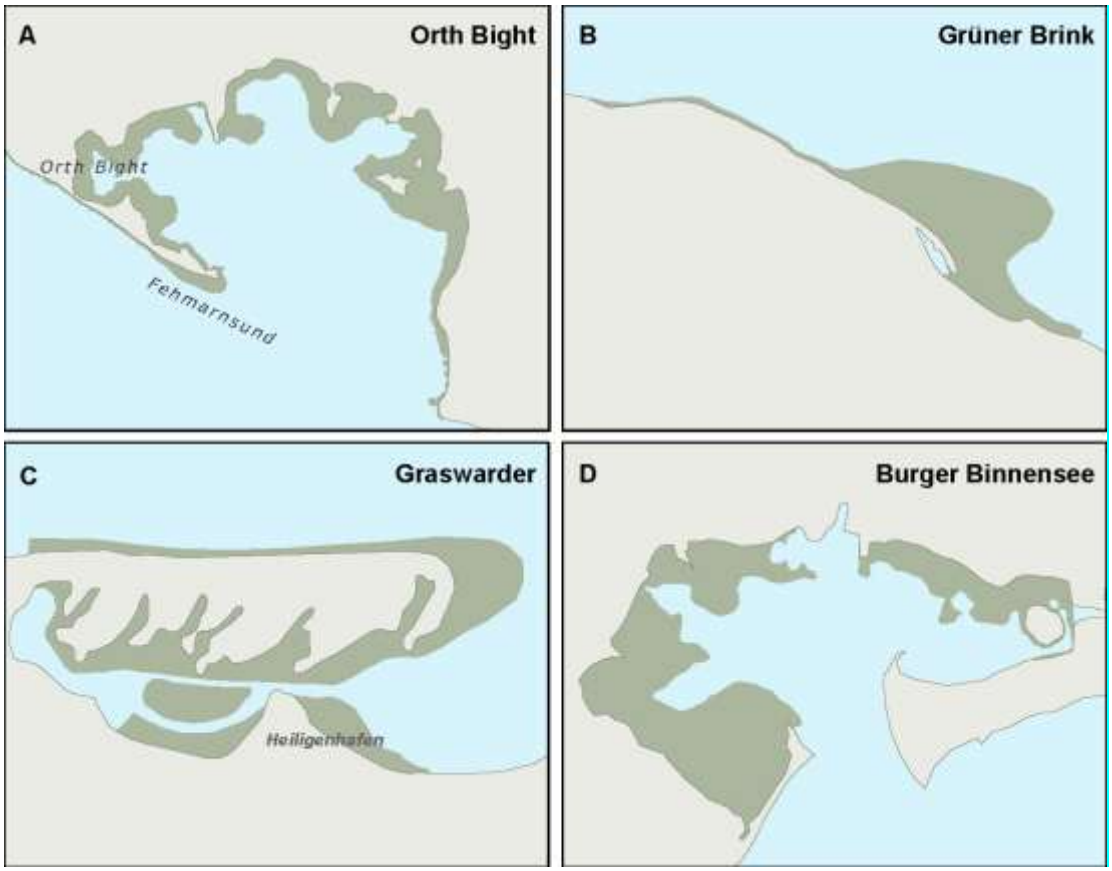


Figure 5-4 Habitat type "Mudflats and sandflats" (1140) (grey) within the investigation area (for details see A to D)

5.3 Large shallow inlets and bays (1160)

The habitat type "Large shallow inlets and bays" comprises 413.48 km^2 in total (Figure 5-5) and includes one area on the Danish (Rødsand lagoon: 178.14 km^2) and one on German side (Fehmarnsund and adjacent south-eastern areas: 235.34 km^2). In comparison to the officially assigned areas (Table 5-3), the habitat type large shallow inlets and bays in Denmark results in an area significantly larger (factor 1.96) as hitherto assigned. This is due to the above mentioned misclassification of certain parts of Rødsand lagoon (see Chapter 5.1): Areas with dense macrophyte vegetation have been assigned to sandbanks, although - according to the Danish guideline - they have to be without or only with little macrophyte vegetation; and the deep macrophyte-free ground of the Rødsand lagoon is characterised as habitat type 1160, although - according to the guideline - there should be plenty of macrophyte vegetation. These are mis-assignments and have been confirmed by the authorities. The hitherto assigned areas within the German coastal region comply with the current mapping, as the official criteria have been adapted from the authorities.

Table 5-3 Comparison of currently mapped areas of the habitat type "Large shallow inlets and bays" (1160) and the respective officially assigned areas (km²) (n.p.: not present)

Habitat type	Denmark (coastal + EEZ)		Germany (national)		Germany (EEZ)	
	current mapping	assigned	current mapping		current mapping	assigned
Large shallow inlets and bays (1160)	178.14	60.15	235.34	235.34	n.p.	n.p.

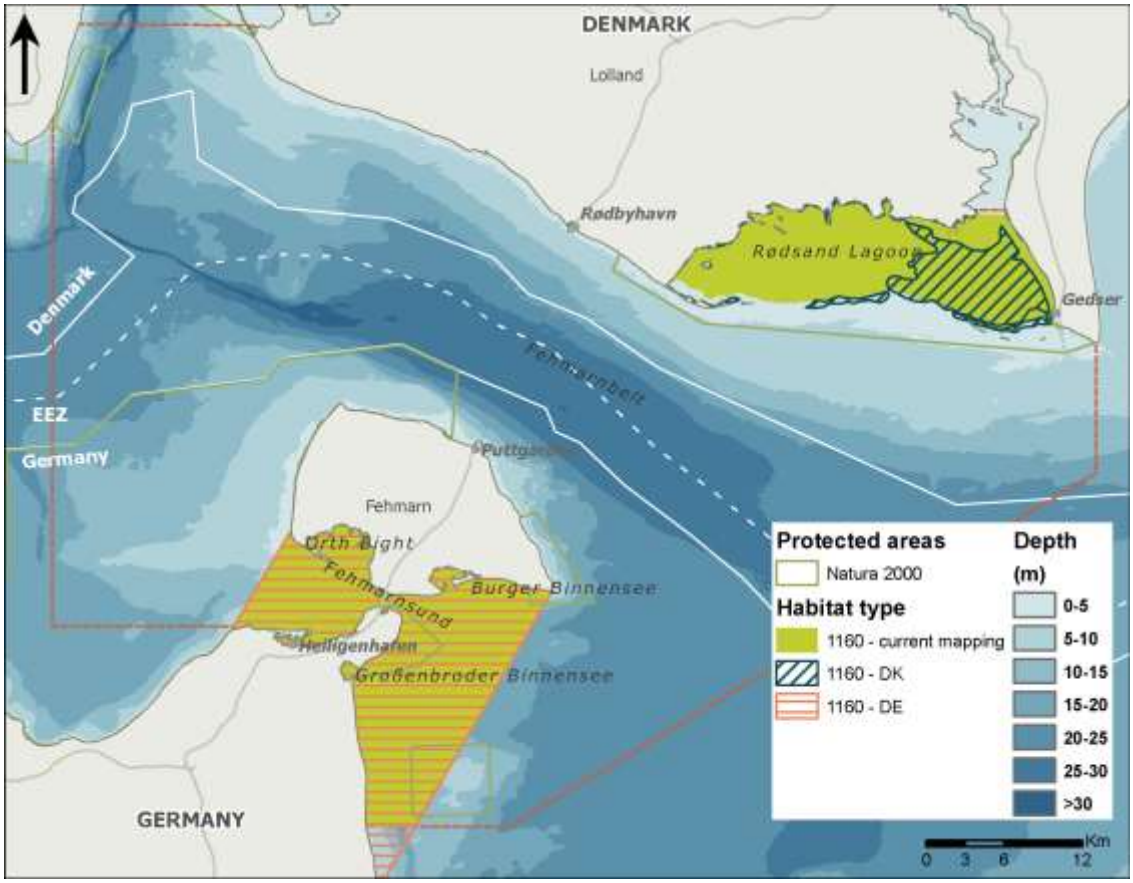


Figure 5-5 Habitat type "Large shallow inlets and bays" (1160) within the investigation area.

5.4 Reefs (1170)

In total 778.51 km² of the investigation area were assigned to the habitat type "Reefs" (Figure 5-7). The largest continuous reef areas are found offshore Rødsand lagoon and on the west coast of Fehmarn, where the substrate is dominated by gravel and pebbles (Figure 5-6). On the east coast of Fehmarn and off Langeland there exist significantly smaller reef areas. However they are dominated by stones almost from the shoreline to the 15 m or 20 m depth contour (Figure 5-6). Such dense stone fields stretching from the shoreline to the deeper waters are rare in the German Baltic Sea. Further reefs can be found at Fehmarnbeltbank (Øjet), Staberhukbank and Sagas Bank, in the western Fehmarnsund and on the eastcoast of Wagrien (up to Dahmeshöved). While stones may occur in these regions (in lower densities), the substrate composition of inshore areas is dominated by smaller

grain sizes, and these regions predominantly consist of coarse sand, gravel, clay reefs and biogenic reefs (blue mussel beds) (Figure 5-6).

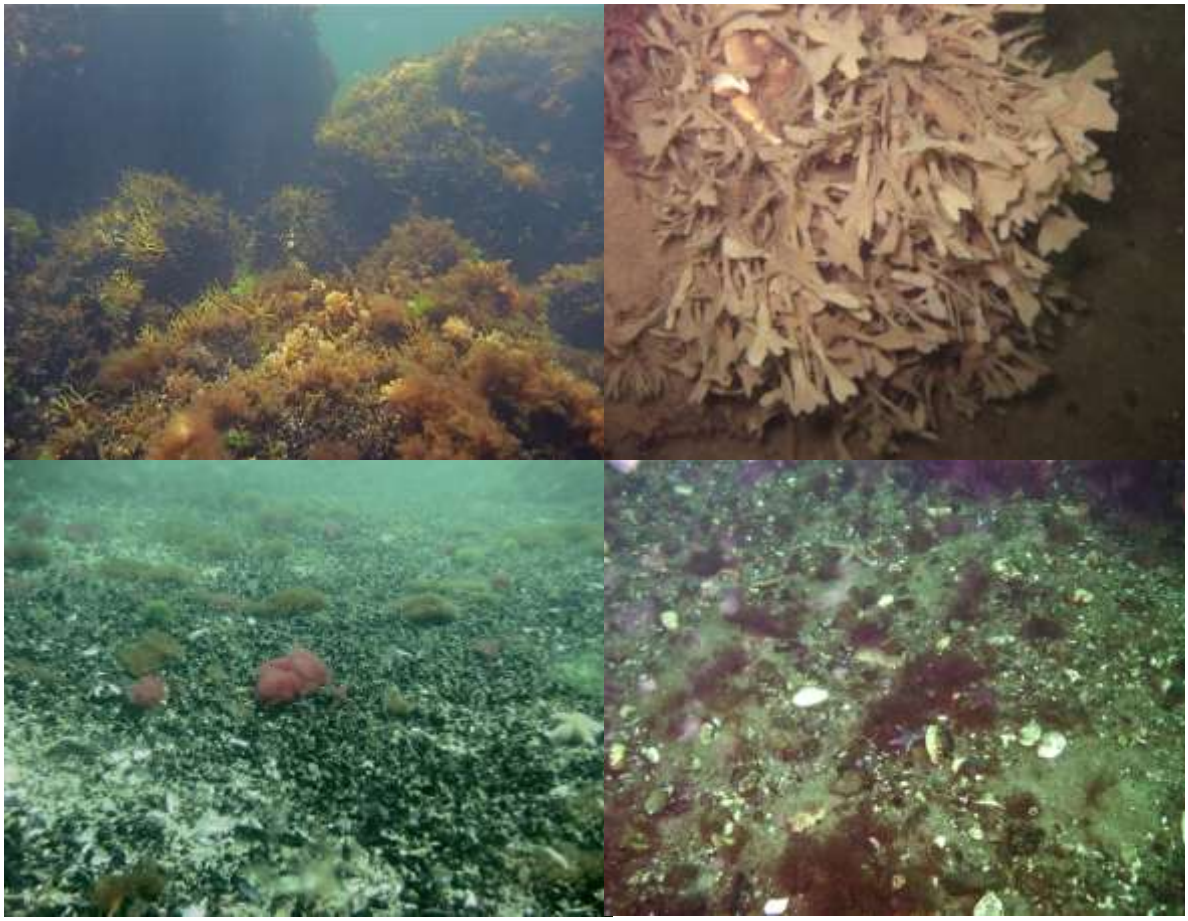


Figure 5-6 *Different characteristics of the habitat type Reefs within the investigation area: boulders and cobbles on the east coast of Fehmarn in shallow waters (top left) and 20 m depth (top right); areas with coarse sediment and blue mussel bed (bottom left) or filamentous algae (bottom right) on the west- and northwest coast of Fehmarn.*

Table 5-4 *Comparison of currently mapped areas of the habitat type "Reefs" (1170) and the respective officially assigned areas (km²)*

Habitat type	Denmark (coastal + EEZ)		Germany (national)		Germany (EEZ)	
	current mapping	assigned	current mapping		current mapping	assigned
Reefs (1170)	196.62	13.46	516.93	432.40	72.97	57.56

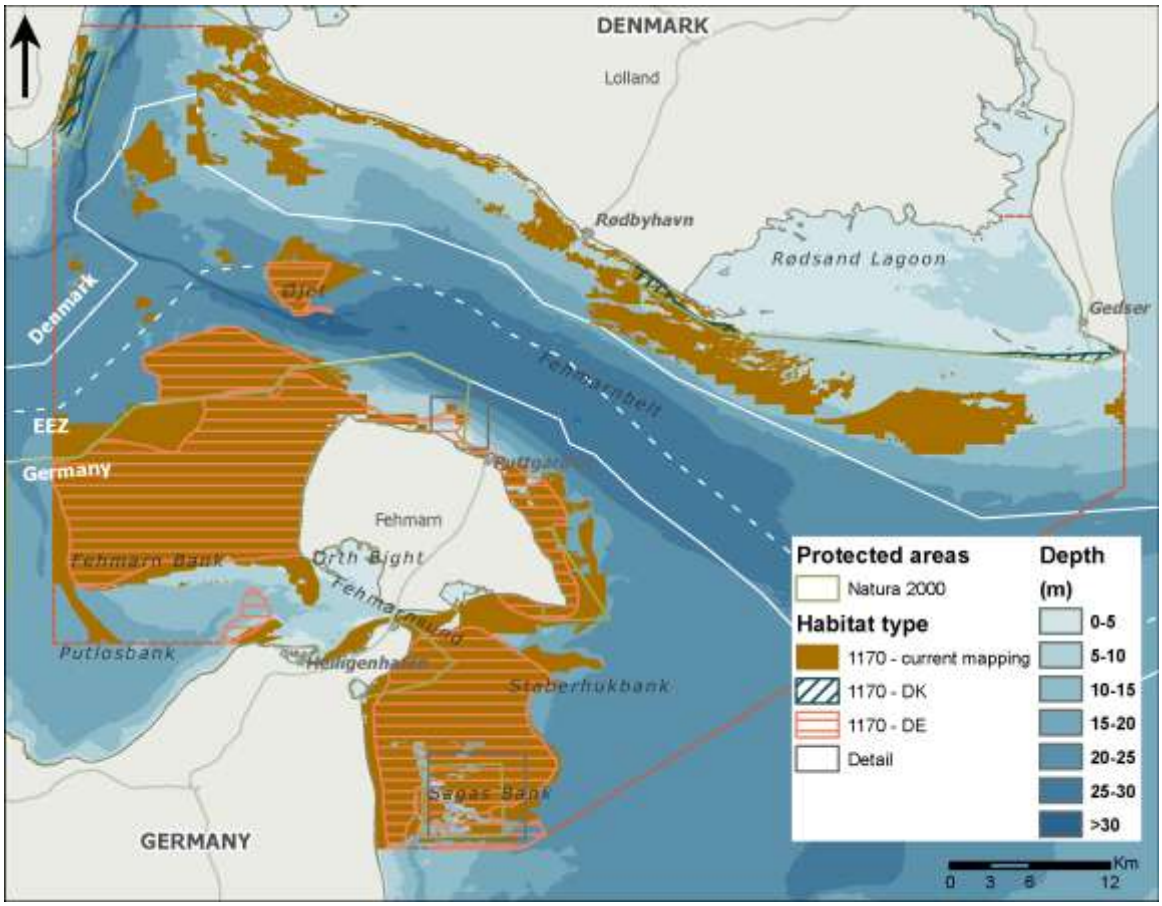


Figure 5-7 Habitat type "Reefs" (1170) within the investigation area (for details see Figure 5-8 and Figure 5-9).

In comparison to the officially assigned areas (Table 5-4), the habitat type reefs in Denmark occurs in an area almost 15-times larger than hitherto assigned. In the official Danish maps concerning the habitat types only small bands off Rødsand lagoon and off Langeland are assigned as reefs. This is due to the fact that in Denmark no habitat types outside of Natura 2000 sites have been mapped so far.

In the German EEZ the mapped area is slightly larger than the one hitherto assigned. The area at Fehmarnbeltbank (Øjet) is larger and the area northwest of Fehmarn slightly smaller than the assigned ones, as neither the substrate composition nor the occurring benthic communities on the western side of the area comply with the criteria of the habitat type reef. Instead, at the western margin of the Natura 2000 site Fehmarnbelt an entirely new area was mapped.

In German coastal waters the mapped area is slightly larger than the one delineated by the authorities. Currently only a preliminary map with potential reef areas is available from the authorities, which is primarily based on bathymetric data and which has recently been verified by the authorities using multibeam echosounder mapping (not published yet). Therefore not all criteria described in the mapping guideline have been followed, yet. Thus the areas are only potential morphological reefs (delineated from substrate characteristics) but without biological verification.

Hence, an incorrect assignment of several reef areas is documented on the basis of the present baseline study, which also includes the biological verification. Below, this is exemplarily described and illustrated with underwater photos for two areas.

The first area characterised as reef is on the north side of Fehmarn (near Grüner Brink), though the occurring communities document an affiliation to level sandy biotopes or partly (with respective slope) to the habitat type sandbanks (Figure 5-8).

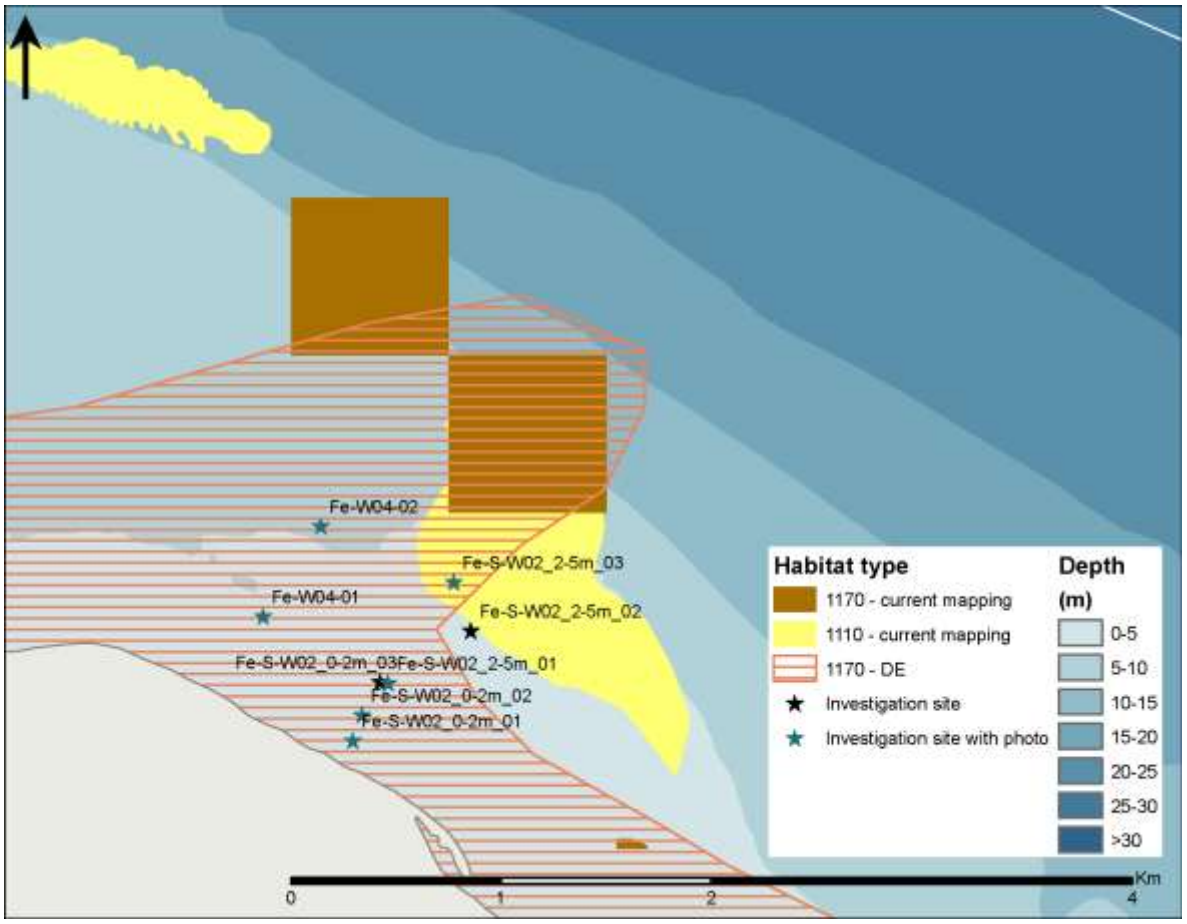
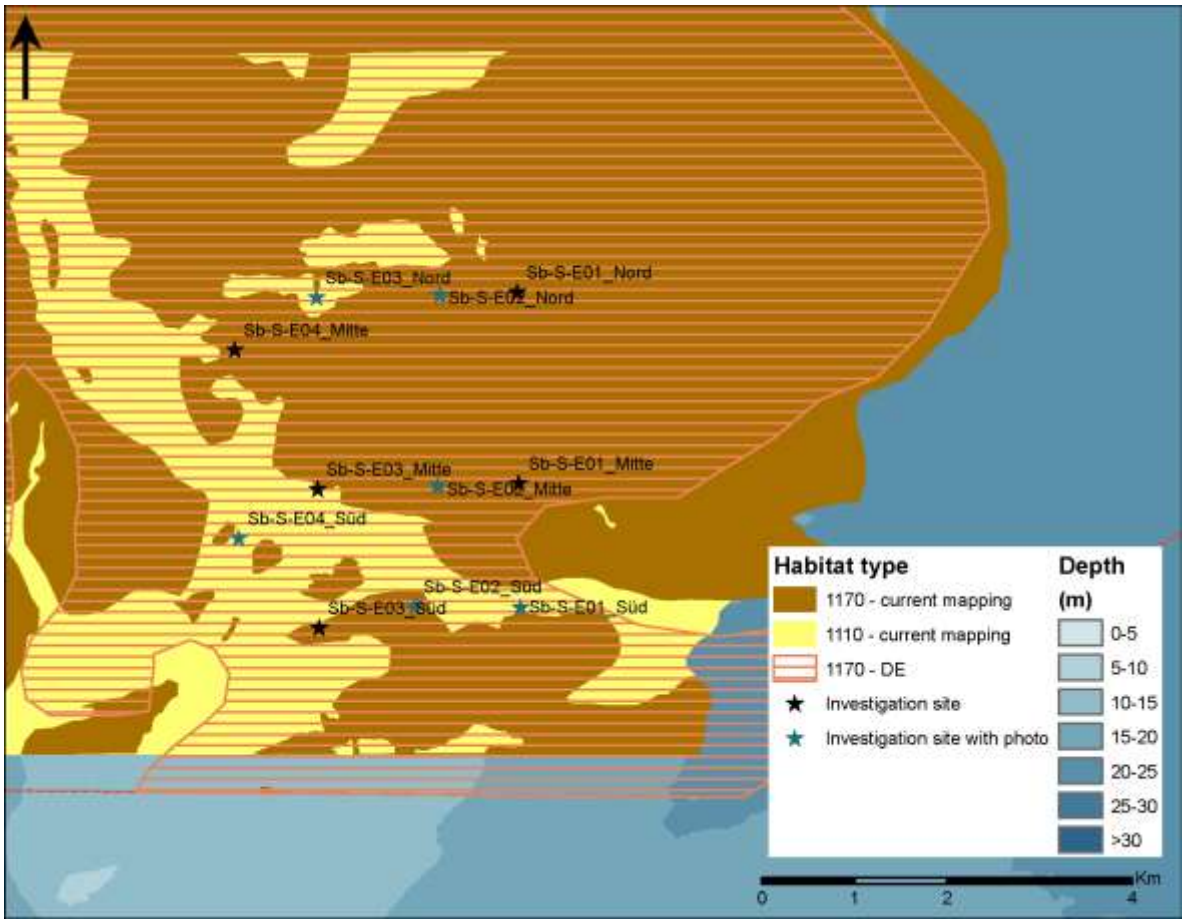


Figure 5-8 Detailed map for the northern part of Fehmarn and photos showing two transects: Fe-W04 (Fe-W04-01, top left; Fe-W04-02, top right) and Fe-S-W02 with depth interval 0–2m (Fe-S-W02_0-2m_01, mid left; Fe-S-W02_0-2m_02, mid right) and 2–5 m (Fe-S-W02_2-5m_01, bottom left; Fe-S-W02_2-5m_03, bottom right)

The second area assigned as reef is Sagas Bank, which is in its entirety officially classified as reef; but in the current mapping there are random patches of sand-bank areas (Figure 5-9).


Sb-S-E03_Nord
Sb-S-E01_Nord
Sb-S-E02_Nord
Sb-S-E04_Mitte
Sb-S-E03_Mitte
Sb-S-E01_Mitte
Sb-S-E02_Mitte
Sb-S-E04_Süd
Sb-S-E02_Süd
Sb-S-E03_Süd
Sb-S-E01_Süd
Habitat type
1170 - current mapping
1110 - current mapping
1170 - DE
Investigation site
Investigation site with photo
Depth
(m)
0-5
5-10
10-15
15-20
20-25
25-30
>30
0
1
2
4
Km

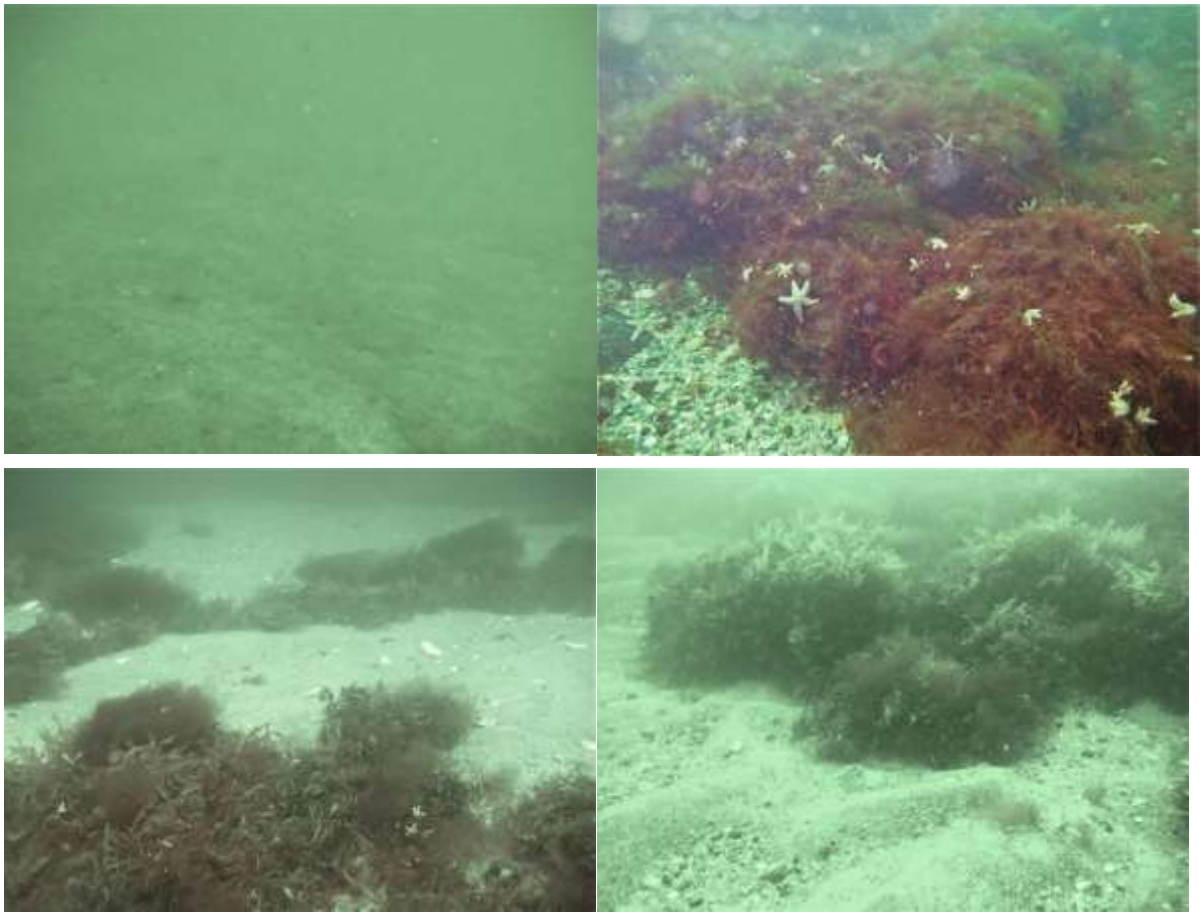


Figure 5-9 *Detailed map for Sagas Bank and photos showing different stations: Sb-S-E03-Nord (top left), Sb-S-E04_Süd (top right) and Sb-S-E01_Süd (mid left) show the area mapped as habitat type sandbank; Sb-S-E02_Nord (mid right), Sb-S-E02_Mitte (bottom left) und Sb-S-E02_Süd (bottom right) show the area mapped as habitat type reef.*

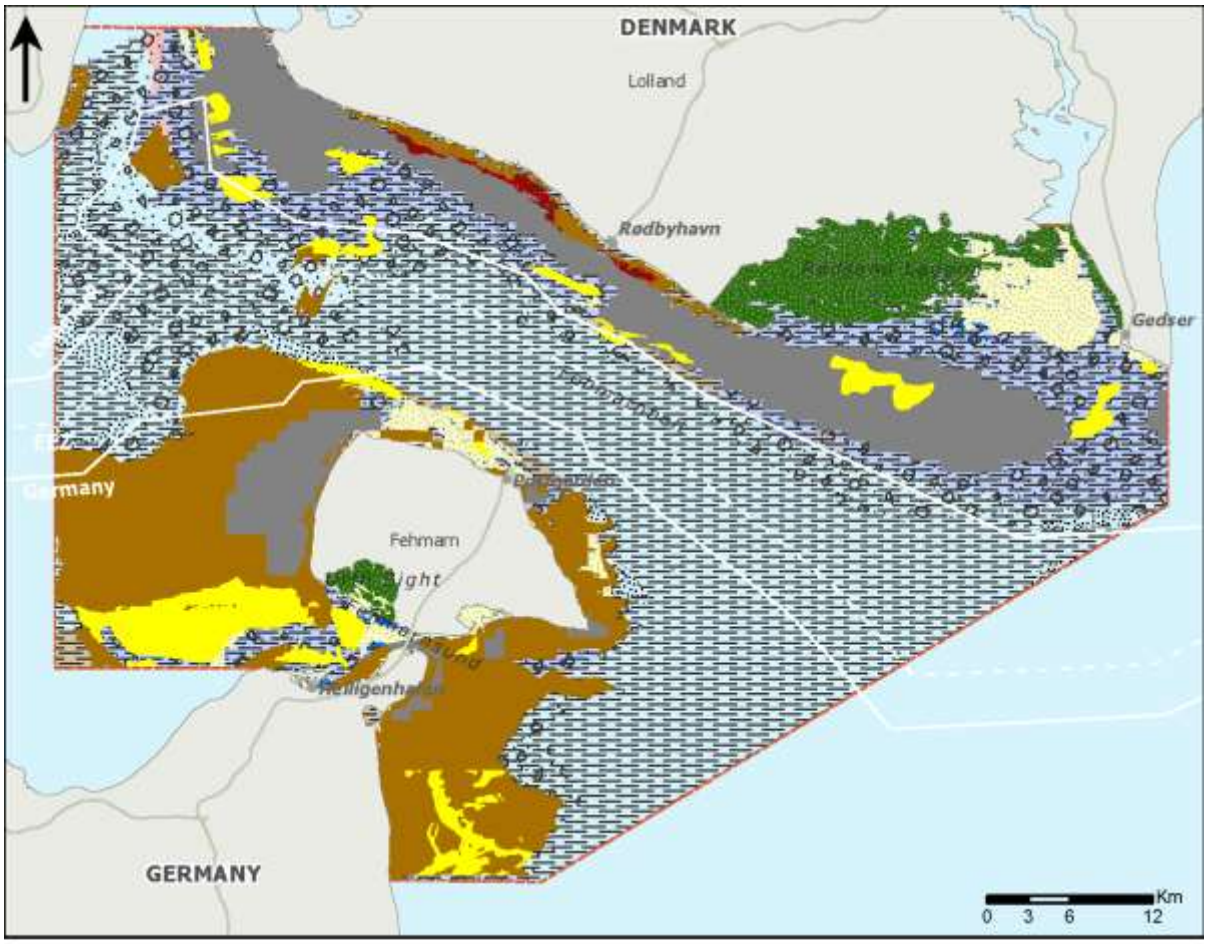
6 HELCOM BIOTOPES

In total there are ten HELCOM-biotopes (HELCOM 1998) within the photic zone and four HELCOM-biotopes in the aphotic zone of the investigation area. Neither reefs nor sandbanks were defined for the aphotic zone as the HELCOM classification has defined those biotopes only for the photic zone. Areras in the aphotic zone, which have been classified as Natura 2000 habitats sandbanks or reefs in this study, are categorised to the HELCOM biotopes sandy or stony bottoms.

The spatial distribution of the HELCOM-biotopes is shown in Figure 6-1 and their respective areas are listed in Table 6-1. The largest area in the aphotic zone is dominated by muddy and mixed sediment bottoms. In the photic zone reefs account for the highest proportion, followed by the mixed sediment bottoms with little or no macrophyte vegetation and blue mussel beds. All three biotopes dominated by vegetation exhibit significantly smaller areas than the three aforementioned HELCOM-biotopes, whereas sandy bottoms dominated by macrophytes, stony and mixed sediment grounds with dominant macrophyte vegetation prevail.

Table 6-1 Spatial extent (in km²) of HELCOM-Biotopes within the investigation area and their distribution into the different geographic zones as well as their percentage related to the total area (2,918.79 km²)

HELCOM-Biotopes	Total area	Denmark (national + EEZ)	Germany (national)	German EEZ
Photic zone				
2.2.2.1 Level stony bottoms with little or no macrophyte vegetation	4.43 (0.15 %)	4.43	–	–
2.2.2.2 Level stony bottoms dominated by macrophyte vegetation	8.92 (0.31 %)	8.92	–	–
2.2.2.3 Reefs	468.16 (16.04 %)	29.71	395.23	43.22
2.5.2.1 Level sandy bottoms with little or no macrophyte vegetation	105.00 (3.60 %)	65.81	39.19	–
2.5.2.2 Level sandy bottoms dominated by macrophyte vegetation	121.33 (4.16 %)	109.65	11.68	–
2.5.2.4 Sandbanks with or without macrophyte vegetation	128.93 (4.42 %)	40.08	86.30	2.55
2.7.2.1 Muddy bottoms with little or no macrophyte vegetation	22.55 (0.77 %)	5.83	16.72	–
2.8.2.1 Mixed sediment bottoms with little or no macrophyte vegetation	396.36 (13.58 %)	341.28	55.07	0.01
2.8.2.2 Mixed sediment bottoms dominated by macrophyte vegetation	3.44 (0.12 %)	1.54	1.90	–
2.9.2.1 Mussel beds with little or no macrophyte vegetation	380.39 (13.03 %)	302.38	78.00	–
Aphotic zone				
2.2.1 Stony bottoms	55.95 (1.92 %)	40.30	1.08	14.57
2.5.1 Sandy bottoms	49.21 (1.69 %)	29.94	5.24	14.02
2.7.1 Muddy bottoms	810.25 (27.76 %)	273.95	324.35	211.95
2.8.1. Mixed sediment bottoms	363.87 (12.47 %)	242.10	49.37	72.40



HELCOM-biotopes

Aphotic zone

- 2.2.1 Stony bottoms
- 2.5.1 Sandy bottoms
- 2.7.1 Muddy bottoms
- 2.8.1 Mixed sediment bottoms

Photic zone

- 2.2.2.1 Level bottoms with little or no macrophytes
- 2.2.2.2 Level bottoms dominated by macrophytes
- 2.2.2.3 Reefs
- 2.5.2.1 Level bottoms with little or no macrophytes
- 2.5.2.2 Level bottoms dominated by macrophytes
- 2.5.2.4 Banks with or without macrophytes
- 2.7.2.1 Muddy bottoms with little or no macrophytes
- 2.8.2.1 Mixed sediment bottoms with little or no macrophytes
- 2.8.2.2 Mixed sediment bottoms dominated by macrophytes
- 2.9.2.1 Mussel beds

Figure 6-1 Distribution of HELCOM-biotopes within the investigation area

7 §30-BIOTOPES (BNATSCHG BUNDESNATURSCHUTZGESETZ)

In total there are five §30-Biotopes within the investigation area. The spatial distribution of the §30-Biotopes is shown in Figure 7-1 and their respective areas are listed in Table 7-1. As this is a national legislation, the areas of the §30-biotopes are only described and discussed for the German area. Due to the broad definition for reefs and sandbanks there are some overlaps. Thus species-rich coarse sandy, gravelly and shelly grounds may contain a certain proportion of hard substrate. With a percentage > 10 % these areas also comply with the criteria for reefs. Furthermore there are regions, which exhibit eelgrass beds, clay reefs and/or hard substrate at the same time. When the hard substrate is vegetated, these areas can be classified into three different §30-biotopes: eelgrass beds, other macrophyte stands and reefs. Combination rules for the correct classification of benthic habitats into §30-biotopes and the prerequisites, which have to be fulfilled to generate overlaps of §30-biotopes, are listed in Appendix C.

The largest proportion of protected biotopes is occupied by reefs (38.79 % without overlaps with other §30-biotopes), followed by sandbanks (6.46 % without overlaps with other §30-biotopes). Biotopes characterised by specific plants (eelgrass beds/ macrophyte stands) or fauna communities (e. g. *Tanaissus*-community in species-rich coarse sand) only have little proportions (0.96 % without overlaps with other §30-biotopes). Areas with an overlap of §30-biotopes are of particular importance, as there might occur different communities. Thus, these areas are characterised by increased habitat complexity (Chapter 0, Importance). Such areas predominantly occur in shallow waters, where macrophyte stands can build a special habitat structure beneath the present substrate component. In total these biotopes have a proportion of only 2.86 %.

Table 7-1 Spatial extent (in km²) of §30-biotopes within the investigation area and their distribution into the different geographic zones (without DK) as well as their percentage related to the total investigated German area (1,423.26 km²)

§30-biotopes (BNatschG)	Total area	Denmark (national + EEZ)	Germany (national)	German EEZ
Species-rich coarse sand, gravel and shell grounds	0.13 (0.01 %)	–	0.12	0.01
Species-rich coarse sand, gravel and shell grounds + reefs	9.76 (0.69 %)	–	1.08	8.68
Species-rich coarse sand, gravel and shell grounds + sandbanks	2.78 (0.20 %)	–	1.04	1.74
Reefs (without overlapping with other §30-biotopes)	552.10 (38.79 %)	–	487.85	64.25
Eelgrass beds/ other macrophyte stands	13.58 (0.95 %)	–	13.58	–
Eelgrass beds/ other macrophyte stands + reefs	10.95 (0.77 %)	–	10.95	–
Other macrophyte stands + reefs	17.09 (1.20 %)	–	17.06	0.03
Sublittoral sandbanks (without overlapping with other §30-biotopes)	91.92 (6.46 %)	–	86.37	5.55
Areas without §30-biotopes	724.95 (50.94 %)	–	446.51	278.44

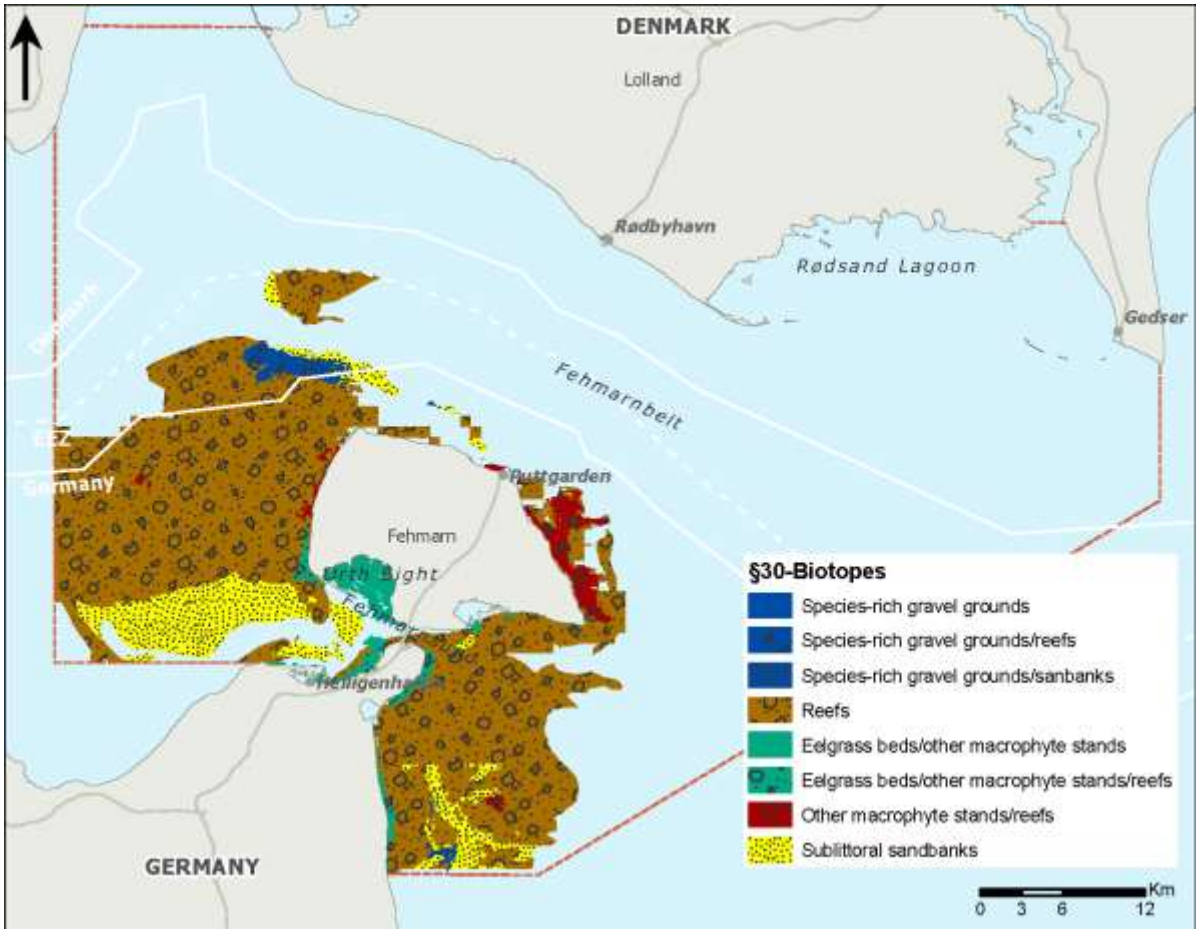


Figure 7-1 Distribution of §30-Biotopes within the German part of the investigation area

8 RIECKEN-BIOTOPES (RED LIST OF ENDANGERED BIOTOPES IN GERMANY)

In total there are three red listed biotopes within the inner coastal waters and eight biotopes within the outer coastal waters of the investigation area. The spatial distribution of the Riecken-biotopes is shown in Figure 8-1 and their respective areas are listed in Table 8-1. As this is a national red list, the areas of these biotopes are only described and discussed for the German area.

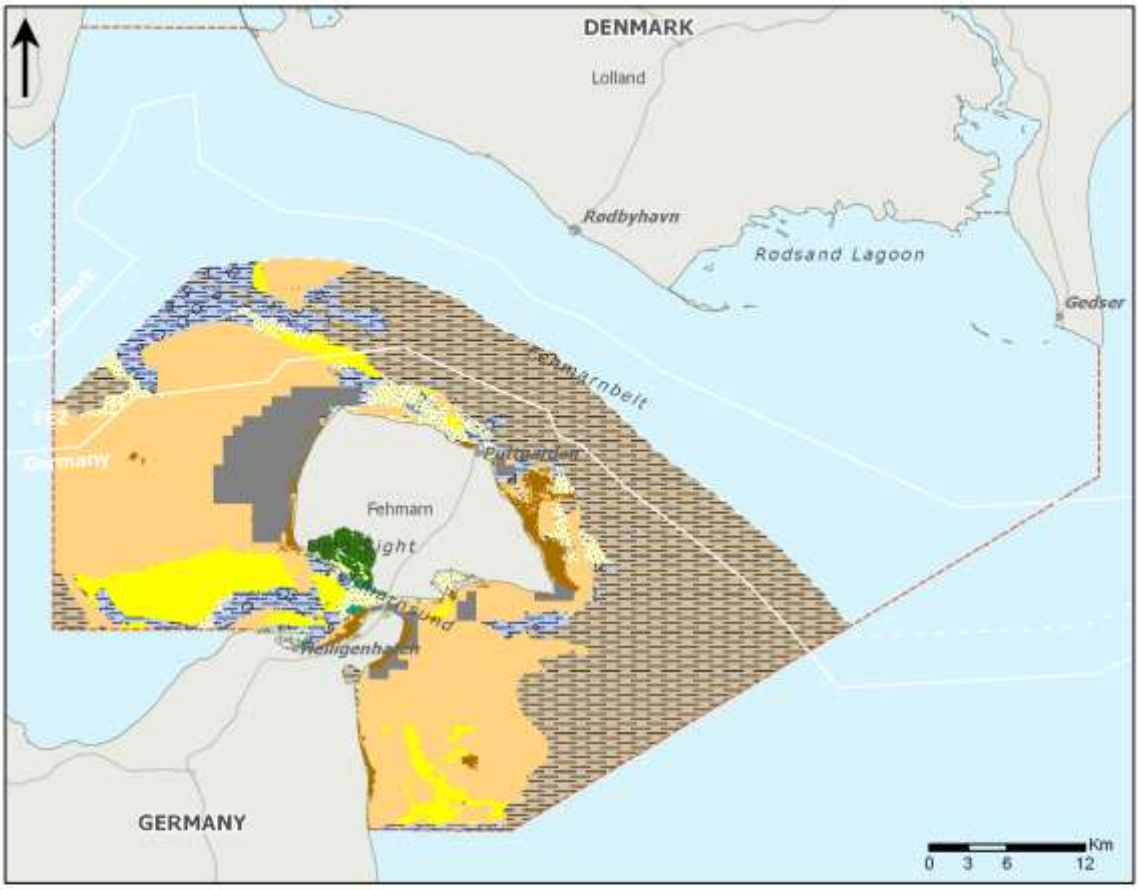
According to the WFD typification only the Orth Bight is classified as inner coastal water within the investigation area. The largest area is occupied by the biotope "04.02.06.02 Level sandy biotopes, dominated by macrophyte vegetation (predominantly freshwater and brackish species, e. g. stonewort, pondweed)". Referring to the red list this biotope is an indicator for the habitat type 1160 "Large shallow inlets and bays". The other biotopes of the inner coastal waters according to Riecken et al. (2006) are "04.02.06.01 Level sandy biotopes without or with little macrophyte vegetation" and "04.02.08.02 Fine substrate biotope with mixed substrates" and only comprise a small area (< 0.01 %).

The Fehmarnbelt and surrounding marine regions are characterised by outer coastal water biotopes. The largest area is occupied by the biotope „02.02.08.01 Fine substrate with mud" (38.79 %), followed by "02.02.02.01 Hard substrate reefs without or with little macrophyte vegetation" (34.01 %) and "02.02.08.02 Fine substrate biotope with mixed substrate" (8.22 %). Biotopes dominated by macrophyte vegetation only have small percentage areas of 1.2 % ("02.02.02.02 Hard substrate reefs, dominated by vegetation") and 0.90 % ("02.02.09 eelgrass beds"). Most of the areas in the last-mentioned biotope also lie in the reef areas designated by the authority. They remain characterised as eelgrass beds, as with this term a more specific biotope-classification is given. The biotopes "02.02.07 Sandbanks", "02.02.03 Biogenic reef (blue mussel bed)" and "02.02.06 Level sandy biotopes" show percentage covers of 6.66, 5.48 and 3.81 % within the investigation area, respectively.

Table 8-1 Spatial extent (km^2) of red listed biotopes within the investigation area and their distribution into the different geographic zones as well as their percentage related to the total investigated area (1,423.26 km^2)

Red-listed biotopes of endangered biotope types in Germany	Total area	Denmark (national + EEZ)	Germany (national)	Germany (EEZ)
Inner coastal waters				
04.02.06.01 Level sandy biotopes, with little or no macrophyte vegetation	1.53 (0.11 %)	–	1.53	–
04.02.06.02 Level sandy biotopes, dominated by macrophyte vegetation (predominantly freshwater and brackish species, e. g. stonewort, pondweeds)	11.68 (0.82 %)	–	11.68	–
04.02.08.02 Fine substrate biotopes with mixed substrates (mosaics and mixtures of mud, sand, partly associated with gravel and stones)	0.02 (<0.01 %)	–	0.02	–
Outer coastal waters				

Red-listed biotopes of endangered biotope types in Germany	Total area	Denmark (national + EEZ)	Germany (national)	Germany (EEZ)
02.02.02.01 Hard substrate reefs, with little or no macrophyte vegetation	483.86 (34.01 %)	–	410.92	72.94
02.02.02.02 Hard substrate reefs, dominated by macrophyte vegetation	17.06 (1.20 %)	–	17.06	0.03
02.02.03 Biogenic reef	78.00 (5.48 %)	–	78.00	–
02.02.06 Level sandy biotopes	54.15 (3.81 %)	–	42.66	11.49
02.02.07 Sandbank (incl. mega ripples)	94.70 (6.66 %)	–	87.41	7.29
02.02.08.01 Fine substrate biotopes with muddy substrate (dominated by silt and clay)	552.07 (38.79 %)	–	340.47	211.60
02.02.08.02 Fine substrate biotopes with mixed substrates (mosaics and mixtures of mud, sand, partly associated with gravel and stones)	116.90 (8.22 %)	–	61.53	55.36
02.02.09 Eelgrass beds of outer coastal regions in the Baltic Sea (areas partly assigned as habitat type reef)	12.85 (0.90 %)	–	12.85	–



Riecken-Biotope

Outer coastal waters

- 02.02.02.01 Hard substrate reefs, with little or no macrophyte vegetation
- 02.02.02.02 Hard substrate reefs, dominated by macrophyte vegetation
- 02.02.03 Biogenic reef
- 02.02.06 Level sandy biotopes
- 02.02.07 Sandbank (incl. mega ripples)
- 02.02.08.01 Fine substrate biotopes with muddy substrate (dominated by silt and clay)
- 02.02.08.02 Fine substrate biotopes with mixed substrates (mosaics and mixtures of mud, sand, partly associated with gravel and stones)
- 02.02.09 Eelgrass beds of outer coastal regions in the Baltic Sea (areas partly assigned as habitat type reef)

Inner coastal waters

- 04.02.06.01 Level sandy biotopes, with little or no macrophyte vegetation
- 04.02.06.02 Level sandy biotopes, dominated by macrophyte vegetation (predominantly freshwater and brackish species)
- 04.02.08.02 Fine substrate biotopes with mixed substrates (mosaics and mixtures of mud, sand, partly associated with gravel and stones)

Figure 8-1 Distribution of Riecken-Biotopes within the German part of the investigation area

9 EXISTING PRESSURES

As benthic habitats are based on benthic flora and fauna communities, the existing pressures for benthic habitats are the same as for those two components.

Eutrophication, declining quality of seabed substrate (e.g. increasing siltation, smothering, declining depth of redox layer) or physical disturbance (e. g. bottom trawling, sediment extraction) are some of the most relevant pressures for benthic habitats. A detailed description is given in the baseline surveys of benthic flora and fauna (FEMA 2013a, FEMA 2013b).

10 IMPORTANCE

Importance of benthic habitats is being used when assessing the severity of loss of habitats.
The importance of benthic habitats is defined by their functional value for the ecosystem due to its functions as

- a permanent, three-dimensional habitat for benthic flora, benthic fauna and demersal fish,
- a breeding and nursery ground for pelagic fish and
- a feeding ground for benthic fauna, fish, birds and marine mammals.

Several criteria have been defined by expert judgement to evaluate the value of benthic habitats for those functions and enable a classification of habitats into four importance classes. Those criteria are listed in Table 10-1 and shortly described below:

Complexity (Multidimensionality)
The more complex a habitat is structured, the greater the number of different niches offering possible living space (Kostylev et al. 2005). The more species occupying those niches, the greater the number of species, which are having an interrelationship with those inhabitants producing even more ecological niches due to for example different food preferences. Therefore the biodiversity (sum of diversities in different ecosystem levels like plants, invertebrates, fish, etc.) is increasing with increasing complexity of a habitat (Doherty et al. 2000).

The structure of benthic habitats can be used as a measure for complexity by taking the different dimensions of habitats into account: the part of the habitat ranging into the sediment, the surface layer of the bottom (bottom/water column boundary) and the part of the habitat ranging into the water column.

Sediment layer: Soft bottom habitats (sand and mud) offer more and deeper living space compared to hard bottom habitats. Although there exist a few specialist species, which are able to penetrate hard bottoms (e.g. some mussels or snails), the number of species, which live within soft sediments, is several times greater. The redox layer is determining the maximum depth for colonisation for most infauna species. Some invertebrates are able to deepen the redox layer by bioturbation. Sandy substrates have deeper redox layers than muddy substrates. However, sandy substrates contain less organic material, which could be utilised as food. Consequently, muddy sediments have a greater species diversity compared to sandy sediments at identical water depths despite shallower redox layers. For soft bottoms, species diversity increases with water depths in the Baltic Sea, because the general hydrographical conditions enable the occurrence of truly marine species (as compared to brackish) in deeper waters due to higher salinites. Additionally, the higher exposure to waves and currents in shallow waters affects species numbers negatively.

The living space within the sediment is macroscopically restricted to one ecosystem level, the invertebrates. Wading birds use the very shallow soft bottom habitats as feeding ground. Vegetation or fish are more closely related to the bottom/water boundary layer.

Surface layer: The number of species able to anchor in soft bottom habitats is much smaller compared to hard bottom surfaces. However, all three levels of ecosystem organisation (macrophytes, invertebrates and fish) exist for both kinds of habitats

(soft and hard bottoms). Higher plants or charophytes grow exclusively on soft bottom, macroalgae predominantly on hard bottom. Some anthozoans and blue mussels are able to settle on soft bottom, the surface of hard bottoms is overgrown by a variety of different invertebrates like sponges, bryozoans, hydrozoans and tunicates but also blue mussels. Other invertebrates use the surface of hard bottoms as feeding ground. Flatfish and sand gobies use the surface layer as feeding, breeding and living ground, however the protection afforded by soft bottom habitats is too low to support a higher number of fish species. For demersal fish, which are associated with hard bottoms, it is often hard to differentiate, if the surface layer ifself or parts of the sediment (stones), reaching into the water column, are decisive as a living ground.

Water column: Only soft bottoms with vegetation or blue mussels extend into the water column. The complexity of those habitats is then based on the growth form and size of the epibiota. The plant structure of rooted macrophytes is more simplified compared to many macroalgae. There exists overall less rooted macrophytes than macroalgae growing on hard bottom. Thus, the number of niches for invertebrates is lower in rooted vegetation stands resulting in a lower species number of invertebrates. Fish use soft bottom vegetation as living ground (e.g. pipefish and sea stickleback), as breeding (e.g. herring) and feeding ground. Additionally, several birds are feeding on rooted vegetation (e.g. widgeons and swans). In hard bottom vegetation there are more niches for invertebrates and thereby more respective species due to a higher species number of macroalgae and the higher variability of the plants in terms of size and branching structure. Depending on the diameter of stones there is a greater protective function for fish, irrespective of the presence or absence of vegetation. Thus a greater number of fish species is associated with hard bottom as living, breeding and nursery ground. Certain marine ducks feed on blue mussels and use hard as well as soft bottom as feeding ground, if they provide sufficient mussel beds.

Stability (durability)
The characteristic stability of a habitat determines the particular function as permanent biotope. Hard substrates with larger grain size are more stable than hard substrates with smaller grain sizes. Deep muddy grounds show a higher stability than shallow mobile sediments (sand, gravel), which are steadily affected by storms and waves. Habitats with perennial plant species provide sufficient protection even in the winter months. Hard substrates – as reef component - have a greater importance as mussel beds, which can be predated by starfish and marine ducks in a very short time.

Some species are associated with mobile bottoms. Due to the limited presence of the structuring component (substrate, plants and blue mussels) there are less niches and therefore less specifically adapted species. Those habitats often only accommodate generalists, i.e. species that are present in many habitats, and usually they operate rather as feeding ground than as living or breeding ground.

Fragmentation (from minimal density)
The density (% cover) of the components extending into the water column (stones, plants and blue mussels) is important for all species needing those structures for permanent settlement. With limited cover and thus fragmentation of the habitat the protective function and the attractiveness as feeding ground diminish, especially for highly vagile animals (Hovel et al. 2002, Hovel & Lipcius 2001, 2002, Hovel 2003, Hovel & Fonseca 2005). Investigations dealing with a required minimum density to avoid fragmentation are missing. Generally, the dominance of a structuring component is addressed qualitatively.

For the habitat definitions, a cover of > 25 % was set as threshold for the structuring components in order to differentiate them from the habitats with smaller cover of the structural component. A cover of at least one fourth of the available area still exhibits a sufficient protective function for vagile invertebrates and fishes.

Table 10-1 Criteria used to assess ecological function (and therefore importance) of benthic habitats

Criteria	Description
Complexity	The more complex a benthic habitat is developed, i.e. how many dimensions (water column, bottom and boundary layer) are included, the more ecological niches can be offered and the more ecosystematic levels (plants, invertebrates, fishes etc.) are present and increase the total diversity.
Stability	The lower the changes of the structuring components (substrate, plants, blue mussels) in the benthic habitat are, the more distinct is the protective function of the habitat. Instable habitats rather operate as feeding ground than as living or breeding ground.
Fragmentation	The denser the structuring components (substrate, plants, blue mussels) in a benthic habitat are, the more distinct is the protective function of the habitat. This especially affects larger vagile invertebrates and fishes.

The results of the importance classification were verified to be in line with international and national laws and regulations and adjusted if necessary. For example, areas with §30-Biotopes (only DE) or/and EU-Habitat Types (DK and DE), are generally of high importance. In Table 10-2 all benthic habitats with the respective importance are listed. Figure 10-1 shows the spatial distribution of the importance of the benthic habitats in the investigation area. The classification into the four given importance levels are consecutively explained.

Generally it can be deduced from the criteria's explanations given above that hard bottoms have a higher importance than mixed or soft bottoms. Communities settling on stones thereby further increase the complexity. Perennial vegetation also has a higher importance than blue mussels due to their higher persistence. Soft bottoms with vegetation have a higher importance than those without vegetation due to their three-dimensionality in the water column.

Very high

All benthic habitats characterised by coarse or mixed sediment and long-living communities like *Dendrodoa, perennial algae* or *eelgrass/algae* are included. Coarse sediment (high percentage of boulders, cobbles and pebbles) extends the three-dimensional biotope into the water column. Respective epibenthic flora and fauna on their part also extend and form the biotope in a diverse manner. Although smaller percentages of stones in mixed sediment decrease the protective function of the habitat, the very high complexity is maintained by the epibenthic biota. Substrates with larger grain sizes and long-living communities are characterised by a high stability and are therefore used as living as well as feeding ground. Additionally, the benthic habitat *Infralittoral sand with higher plants* is classified as having a very high importance level, because the large-sized plants extend the three-dimensionality into the water column. Furthermore higher plants are perennial, plants with a steady biomass throughout the year. Thus, the habitat not only has a function as living ground but also a special function as breeding and nursery ground for fishes and as feeding ground for birds.

High

All benthic habitats characterised by coarse, mixed or soft sediment (*sand*, *mud*) in combination with short-living communities (*Mytilus*) or a low epibenthic percentage cover (*flora/fauna-mixed community*) are included. In contrast to the communities

classified as having a very high importance, the possible extension into the water column is limited. This is due to the small size (*Mytilus*) or the low cover, so that a definitive classification into one community is not possible (*flora/fauna-mixed community*). The protective function of the habitat is lost, if the cover/density of the epibenthic component is too low. Benthic habitats with *Mytilus* additionally have a lower stability because predation by starfish and significantly varying reproductive success limit the longevity of the habitat. Blue mussel beds are a food resource for different marine ducks.

Medium

All benthic habitats characterised by mixed sediments in combination with *Infauna* communities are included. Mixed sediments migth contain stones, but their density is too low to build up an essential epibenthic community. The complexity of the habitat is therefore confined to the zone within the sediment. A further extension into the water column is missing. The different sediment conditions promote the presence of different infauna species, as not only species from sandy or muddy but also from gravelly or coarse sandy grounds find an appropriate habitat here. The diversity is largely restricted to one ecosystematic level (invertebrates).

Minor

All benthic habitats exclusively characterised by soft bottom (*sand*, *mud*) in combination with *Infauna* communities are included. Neither the substrate nor a benthic component extends the biotope into the water column. Within the sediment or at the sediment surface there are niches for invertebrates and some fish species. In shallow waters these are a food source for birds. The complexity and the stability (mobile sediments especially in shallow waters) of the habitat are limited.

Table 10-2 Matrix for importance of benthic habitats

Importance	Benthic habitats	Habitat type, §30 biotope	Description
Very high	Circalittoral or infralittoral coarse or mixed sediment with *Dendrodoa*	DK: areas partly designated as habitat type DE: areas completely designated as habitat type and §30-biotope	Considerable extension of the benthic habitat into the water column by substrate or epibenthic biota High stability due to long-living epibenthic biota and immobile substrates Throughout high densities of structuring components (stones, epibenthic biota)
	Infralittoral coarse or mixed sediment with perennial algae	DK: areas partly designated as habitat type DE: areas completely designated as habitat type and §30-biotope	
	Infralittoral mixed sediment with eelgrass/algae	DK: areas partly designated as habitat type DE: areas completely designated as habitat type and §30-biotope	
	Infralittoral sand with higher plants	DK: areas partly designated as habitat type DE: areas completely designated as habitat type and §30-biotope	
High	Infralittoral mixed sediment with flora/fauna-mixed community	DK: areas partly designated as habitat type DE: areas partly designated as habitat type and §30-biotope	Limited extension of the benthic habitat into the water column as epibenthic biota is only present at ground level Limited stability due to signifi-
	Infralittoral coarse or	DK: areas partly designated as	

Importance	Benthic habitats	Habitat type, §30 biotope	Description
	mixed sediment with *Mytilus*	habitat type DE: areas completely designated as habitat type and §30-biotope	cantly varying epibenthic biota Densities of structuring component (stones) partly limited
	Infralittoral sand with *Mytilus*	DK: areas partly designated as habitat type DE: areas completely designated as habitat type and §30-biotope	
Medium	Circalittoral or infralittoral mixed sediment with Infauna	DK: areas partly designated as habitat type DE: areas partly designated as habitat type and §30-biotope	Only little extension of the benthic habitat into the water column as epibenthic biota is missing Low densities of structuring component (stones) Different substrate components offer different habitats for invertebrates in the sediment
	Infralittoral mixed sediment with *Tanaissus*	DK: areas partly designated as habitat type DE: areas partly designated as habitat type and completely designated as §30-biotope	
Minor	Circalittoral or infralittoral sand with Infauna	DK: areas partly designated as habitat type DE: areas partly designated as habitat type and §30-biotope	No extension of the benthic habitat into the water column (neither by substrate nor by epibenthic biota) Low stability in shallow waters due to mobile sediments
	Circalittoral or infralittoral mud with Infauna	DK: areas partly designated as habitat type DE: areas partly designated as habitat type and §30-biotope	

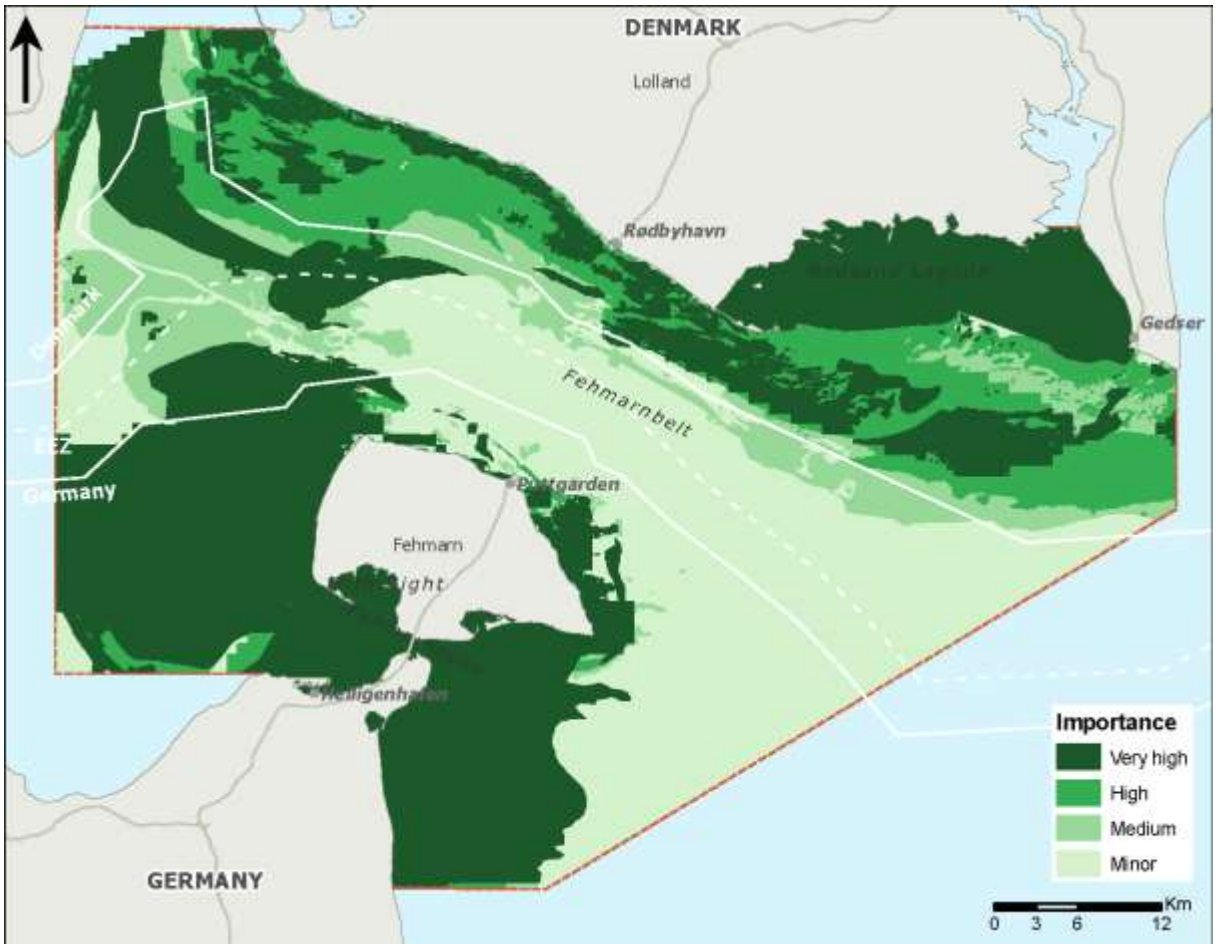


Figure 10-1 Importance of benthic habitats in the investigation area

11 CONFIDENCE ASSESSMENT

The confidence in the produced habitat maps for the local Fehmarnbelt area was assessed using the MESH Confidence Assessment tool. The mapped area was sub-divided into sub-units, mainly based on the different remote sensing techniques employed (local bathymetry 50 m grid, multibeam, aerial photography). The sub-units were then scored separately, following the guidance of the MESH Confidence Assessment. Results are shown in Figure 11-1, Table 11-1 and Appendix I.

Table 11-1 Results of the confidence assessment.

Data set	Remote-sensing score	Ground-truthing score	Interpretation score	Overall score
Multibeam	100	80	75	85
Aerial photography	87	80	75	81
Local bathymetry 50m	67	80	75	74

The highest score of 85 (very high confidence) on a scale from 0 to 100 was obtained for the central Fehmarnbelt area, which was mapped with multibeam bathymetry/backscatter and intensively ground-truthed with grabs, dredges and video. A slightly lower but still very high confidence level of 81 was achieved in areas mapped with aerial photography, but ground-truthed in the same fashion. This is mainly due to the fact that approved international standards on aerial photo collection are less developed as compared to standards for multibeam data collection (IHO Order 1). Finally, those areas neither mapped with multibeam nor aerial photography still scored high (74). The lower score was due to the remote-sensing method (mainly single-beam data collected over several years). It was however still relatively high, as the bulk of data was collected by hydrographic authorities (Federal Maritime and Hydrographic Agency, BSH and Farvandsvæsenet) and hence it can be assumed that the standards for data collection were high.

The ground-truthing scored very high in all cases, mainly due to the fact that a wide array of methods was used to sample infauna, epifauna and vegetation and the sampling data was of low age. The score might still be an underestimation as the subdivision lowered the sample density per habitat type in the final map classification. For example, in the aerial photography sub-unit, no deep water habitats were sampled; however they were sampled on the whole map scale.

The score was comparatively low for the interpretation. This is due to the fact that no accuracy assessment was carried out, as no independent sampling data was available to test the interpretations. Accuracy assessments were however carried out for the individual predicted biological data layers (benthic faunal communities, eelgrass and macroalgae) used to produce the habitat maps. Hence the interpretation score might be slightly underestimated.

Overall, these results give high to very high confidence in the produced habitat maps for the local Fehmarnbelt area, with highest confidence in the area closest to the proposed alignment. Less, but still high confidence has to be accepted in areas farther away from the proposed alignment.

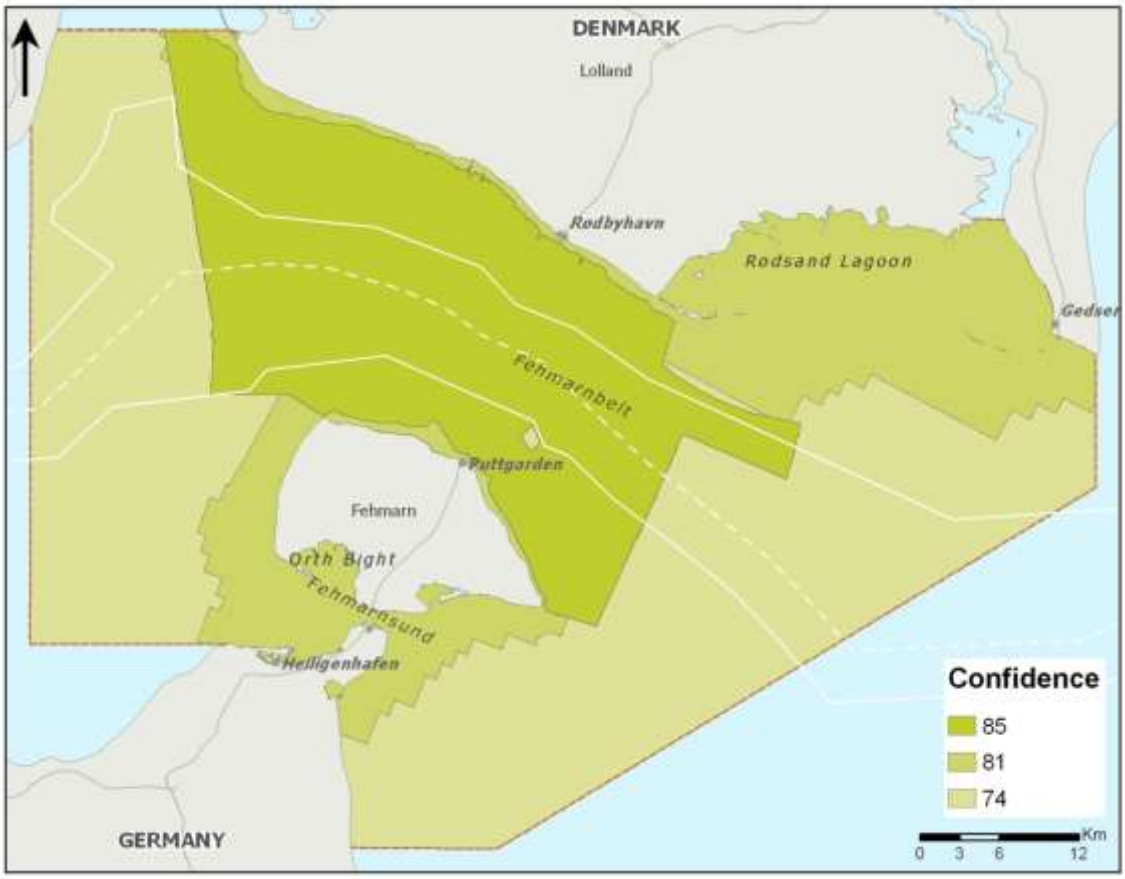


Figure 11-1 Assessed confidence on a scale from 0 to 100 for the habitat maps of local Fehmarnbelt area.

12 DISCUSSION

In total, 1509 km^2 (51.5% of the total mapped area) of seabed in the local Fehmarnbelt area were mapped with 100 % coverage employing state-of-the-art remote sensing techniques. These included aerial photography in the shallow coastal zone down to ca. 6 m water depth and multibeam bathymetry and backscatter data collected in deeper waters. Multibeam is an efficient tool for mapping the seabed with full coverage. The width of the seafloor (called swathe) covered is however dependent on water depth and hence it takes longer to map the same area in shallow waters as compared to deeper waters. Besides this, survey operations become increasingly difficult due to the limited water depths, which require shallow draft vessels. Alternatively, these areas can be readily mapped with high-resolution aerial photography, provided there is sufficient transparency of the water. Previous work has shown that this technique can be applied down to 6 m water depth in the western Baltic Sea, hence providing an ideal complementary technique to multibeam.

The resulting high-quality remote-sensing data sets give high detail and spatial precision. Resulting imagery was subsequently analysed using object-based image processing and interpretation software, providing a reproducible and more objective approach to seabed mapping. This technique is routinely used to interpret aerial photography. Applying it to acoustically sensed imagery (backscatter images) is a relatively novel approach, but its applicability has been proven previously (Lucieer and Lamarche, 2011, Lucieer, 2008).

For the remaining 1421 km^2, making up 48.5% of the total mapped area, the remote-sensing data was less detailed, as only hydrographic survey data gridded to 50 m was available. This means that less detail could be mapped, as can be seen from the produced maps. It was also not possible to employ image analysis on this data set, so the interpretation was largely based on expert judgement. However, areas mapped in this fashion are situated farther away from the proposed alignment and cover large areas of the rather homogenous Mecklenburg Bight.

Benthic vegetation and fauna baseline stations and ground-truthing stations for habitat mapping purposes were identical in order to ensure resource efficiency and consistency between the different baseline studies. This had the drawback that stations were picked prior to the production of a detailed substrate map based on the newly gathered survey data. The selection of station locations was however based on then existing knowledge including the preliminary habitat map (FEMA, 2009).

Baseline sampling data included information on grain size and substrate. These were used to ground-truth the remotely sensed data when deriving the substrate map. In turn, the substrate map formed an environmental factor to predicting the spatial distribution of benthic faunal communities and vegetation, which were ultimately used to derive the habitat maps. Again, this approach ensures consistency between the different baseline studies. The correspondence found between predicted community occurrence and mapped substrate types, judged by expert interpretation, was generally high.

Classification of modelled environmental data was based on agreed principles, e.g. the salinity classes followed those proposed as part of the BALANCE project. Such a classification might serve as a useful proxy for biological components. However, such rigid classifications do not necessarily explain the distribution of mapped benthic communities in every instance. For example, a light level of 1 % surface irradi-

ance is conventionally used to map the lower limit of the photic zone. While the general agreement with available data on the distribution of macroalgae is good, it is also known that certain algae are able to cope with much lower light levels. As one example, Lüning and Dring (1979) found that certain red algae (including *Delesseria sanguinea* also found in the Fehmarnbelt) had light limits as low as 0.3 – 0.05 % surface irradiance off Helgoland Island. In Fehmarnbelt, *Delesseria sanguinea* is very common in water depths between 15 m and 25 m (Zettler and Gosselck, 2006), i.e. also in depths greater than the modelled limit of the photic zone (18–19 m).

Overall, a very solid database was available for habitat mapping and the resultant map scored high to very high in the MESH confidence assessment.

The mapped local Fehmarnbelt area can broadly be divided into two realms: (i) a shallow zone (ca. 0 – 15 m water depth) and a deep water zone (ca. 20 – 40 m water depth). The shallow zone is characterised by high mesohaline waters (salinities ranging from 11 to 18 PSU) and the seabed is photic. With the exception of sheltered bays it is exposed to waves and currents and has an erosional character testified by low mud content and the predominance of coarse sediments, boulders and sand.

On the other hand, the deep water zone is characterised by polyhaline waters (salinities in excess of 18 PSU). The seabed is aphotic and the exposure to waves and currents is generally low. As a consequence of the latter, this environment is largely depositional and typified by the widespread occurrence of sandy mud and mud. The boundaries between the described environmental characteristics (high mesohaline – polyhaline, photic – aphotic, exposed – sheltered, erosional – depositional) are all situated in a comparatively narrow zone around 15 m water depth. As a consequence, this "transitional" zone between the two described zones is relatively narrow. Habitats located in this zone are consequently of limited spatial extent.

Associated with the two depth zones are characteristic habitats, dictated by the physical and environmental conditions. Shallow habitats include eelgrass beds in sunlit, sheltered bays on sandy substrates (Rødsand Lagoon and Orth Bight). Sublittoral eelgrass beds are rarely found deeper than 5 m water depth, which might be attributed to their ecophysiological light requirements. Associated with eelgrass beds is the *Rissoa* epibenthic community.

Perennial algae require a stable hard substrate, provided by cobbles, boulders or blue mussels, and adequate light levels found in the infralittoral. Several perennial algae communities were mapped off the coasts of Lolland, Fehmarn, Langeland and on Sagas Bank. Another characteristic habitat of the shallow zone is the *Cerastoderma* community in infralittoral sand, otherwise epifauna communities associated with infralittoral coarse sediment/boulders dominate the shallow zone.

The deep water zone appears to be more homogenous in terms of environmental conditions and habitats. Large areas are dominated by the *Arctica* community in circalittoral mud and sandy mud, the most widespread habitat found in the mapped area. The *Arctica* community further extends into circalittoral patchy sandy mud and coarse sediment. Bordering these habitats, we find the *Corbula* community in circalittoral mud and sandy mud in slightly lower water depths.

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Table of figures

List of tables

A P P E N D I C E S

A P P E N D I X A

Detailed key of mapped habitats

1 MARINE HABITATS

11 Littoral rock and other hard substrata[6]

12 Littoral sediment

13 Infralittoral rock and other hard substrata

131 Exposed infralittoral rock and other hard substrata

1311 Exposed infralittoral rock and other hard substrata in low mesohaline waters

1312 Exposed infralittoral rock and other hard substrata in high mesohaline waters

1313 Exposed infralittoral rock and other hard substrata in polyhaline waters

132 Moderately exposed infralittoral rock and other hard substrata

1321 Moderately exposed infralittoral rock and other hard substrata in low mesohaline waters

1322 Moderately exposed infralittoral rock and other hard substrata in high mesohaline waters

1323 Moderately exposed infralittoral rock and other hard substrata in polyhaline waters

133 Sheltered infralittoral rock and other hard substrata

1331 Sheltered infralittoral rock and other hard substrata in low mesohaline waters

1332 Sheltered infralittoral rock and other hard substrata in high mesohaline waters

1333 Sheltered infralittoral rock and other hard substrata in polyhaline waters

14 Circalittoral rock and other hard substrata

141 Exposed circalittoral rock and other hard substrata

1411 Exposed circalittoral rock and other hard substrata in low mesohaline waters

1412 Exposed circalittoral rock and other hard substrata in high mesohaline waters

1413 Exposed circalittoral rock and other hard substrata in polyhaline waters

142 Moderately exposed circalittoral rock and other hard substrata

1421 Moderately exposed circalittoral rock and other hard substrata in low mesohaline waters

1422 Moderately exposed circalittoral rock and other hard substrata in high mesohaline waters

1423 Moderately exposed circalittoral rock and other hard substrata in polyhaline waters

143 Sheltered circalittoral rock and other hard substrata

1431 Sheltered circalittoral rock and other hard substrata in low mesohaline waters

1432 Sheltered circalittoral rock and other hard substrata in high mesohaline waters

1433 Sheltered circalittoral rock and other hard substrata in polyhaline waters

14332 Mytilus community

144 Exposed deep circalittoral rock and other hard substrata

1441 Exposed deep circalittoral rock and other hard substrata in low mesohaline waters

1442 Exposed deep circalittoral rock and other hard substrata in high mesohaline waters

1443 Exposed deep circalittoral rock and other hard substrata in polyhaline waters

145 Moderately exposed deep circalittoral rock and other hard substrata

[6] Those habitats greyed out have not been found in the study site

1451 Moderately exposed deep circalittoral rock and other hard substrata in low mesohaline waters
1452 Moderately exposed deep circalittoral rock and other hard substrata in high mesohaline waters
1453 Moderately exposed deep circalittoral rock and other hard substrata in polyhaline waters
146 Sheltered deep circalittoral rock and other hard substrata
1461 Sheltered deep circalittoral rock and other hard substrata in low mesohaline waters
1462 Sheltered deep circalittoral rock and other hard substrata in high mesohaline waters
1463 Sheltered deep circalittoral rock and other hard substrata in polyhaline waters
15 Sublittoral sediment
151 Sublittoral coarse sediment
1511 Infralittoral coarse sediment in low mesohaline waters
1512 Infralittoral coarse sediment in high mesohaline waters
1513 Infralittoral coarse sediment in polyhaline waters
1514 Circalittoral coarse sediment in low mesohaline waters
1515 Circalittoral coarse sediment in high mesohaline waters
1516 Circalittoral coarse sediment in polyhaline waters
1517 Deep circalittoral coarse sediment in low mesohaline waters
1518 Deep circalittoral coarse sediment in high mesohaline waters
1519 Deep circalittoral coarse sediment in polyhaline waters
152 Sublittoral sand and muddy sand
1521 Infralittoral sand and muddy sand in low mesohaline waters
15211 Infralittoral sand in low mesohaline waters
15212 Infralittoral muddy sand in low mesohaline waters
1522 Infralittoral sand and muddy sand in high mesohaline waters
15221 Infralittoral sand in high mesohaline waters
15222 Infralittoral muddy sand in high mesohaline waters
1523 Infralittoral sand and muddy sand in polyhaline waters
15231 Infralittoral sand in polyhaline waters
15232 Infralittoral muddy sand in polyhaline waters
1524 Circalittoral sand and muddy sand in low mesohaline waters
15241 Circalittoral sand in low mesohaline waters
15242 Circalittoral muddy sand in low mesohaline waters
1525 Circalittoral sand and muddy sand in high mesohaline waters
15251 Circalittoral sand in high mesohaline waters
15252 Circalittoral muddy sand in high mesohaline waters
1526 Circalittoral sand and muddy sand in polyhaline waters
15261 Circalittoral sand in polyhaline waters
15262 Circalittoral muddy sand in polyhaline waters
1527 Deep circalittoral sand and muddy sand in low mesohaline waters
15271 Deep circalittoral sand in low mesohaline waters
15272 Deep circalittoral muddy sand in low mesohaline waters
1528 Deep circalittoral sand and muddy sand in high mesohaline waters
15281 Deep circalittoral sand in high mesohaline waters
15282 Deep circalittoral muddy sand in high mesohaline waters
1529 Deep circalittoral sand and muddy sand in polyhaline waters
15291 Deep circalittoral sand in polyhaline waters
15292 Deep circalittoral muddy sand in polyhaline waters
153 Sublittoral mud and sandy mud
1531 Infralittoral mud and sandy mud in low mesohaline waters
15311 Infralittoral sandy mud in low mesohaline waters

15312 Infralittoral mud in low mesohaline waters
1532 Infralittoral mud and sandy mud in high mesohaline waters
15321 Infralittoral sandy mud in high mesohaline waters
15322 Infralittoral mud in high mesohaline waters
1533 Infralittoral mud and sandy mud in polyhaline waters
15331 Infralittoral sandy mud in polyhaline waters
15332 Infralittoral mud in polyhaline waters
1534 Circalittoral mud and sandy mud in low mesohaline waters
15341 Circalittoral sandy mud in low mesohaline waters
15342 Circalittoral mud in low mesohaline waters
1535 Circalittoral mud and sandy mud in high mesohaline waters
15351 Circalittoral sandy mud in high mesohaline waters
15352 Circalittoral mud in high mesohaline waters
1536 Circalittoral mud and sandy mud in polyhaline waters
15361 Circalittoral sandy mud in polyhaline waters
15362 Circalittoral mud in polyhaline waters
1537 Deep circalittoral mud and sandy mud in low mesohaline waters
15371 Deep circalittoral sandy mud in low mesohaline waters
15372 Deep circalittoral mud in low mesohaline waters
1538 Deep circalittoral mud and sandy mud in high mesohaline waters
15381 Deep circalittoral sandy mud in high mesohaline waters
15382 Deep circalittoral mud in high mesohaline waters
1539 Deep circalittoral mud and sandy mud in polyhaline waters
15391 Deep circalittoral sandy mud in polyhaline waters
15392 Deep circalittoral mud in polyhaline waters
154 Sublittoral mixed sediment
1541 Infralittoral mixed sediment in low mesohaline waters
1542 Infralittoral mixed sediment in high mesohaline waters

1543 Infralittoral mixed sediment in polyhaline waters
1544 Circalittoral mixed sediment in low mesohaline waters
1545 Circalittoral mixed sediment in high mesohaline waters
1546 Circalittoral mixed sediment in polyhaline waters
1547 Deep circalittoral mixed sediment in low mesohaline waters
1548 Deep circalittoral mixed sediment in high mesohaline waters
1549 Deep circalittoral mixed sediment in polyhaline waters

A P P E N D I X B

Relationship HELCOM-Biotopes – Benthic Habitats

This is a classification of all marine biotopes and not only of especially endangered biotopes. Therefore all benthic habitats have to be assigned to a respective HELCOM-Biotope. As not all delineation criteria are identical (substrates, biologic parameters), there are specific rules to correlate the benthic EUNIS-habitats to the HELCOM-Biotopes:

1) The differentiation in aphotic and photic zone is assigned to the EUNIS-classes circalittoral and infralittoral. The littoral is not covered by the current mapping and is also not clearly defined due to the wind-induced water level oscillations in the Baltic Sea.

2) The HELCOM substrate information is classified according to the following scheme:

- stony bottoms → coarse sediment
- sandy bottoms → sand
- muddy bottoms → mud
- mixed sediment bottom → mixed sediment

3) The HELCOM biological information is classified into categories of benthic habitats according to the following scheme:

- dominated by macrophytes → all habitats with higher plants, eelgrass/algae and perennial algae
- with little or no macrophytes → all habitats with *Dendrodoa*, Infauna, *Tanaissus* or flora/fauna-mixed community
- mussel beds → all habitats with *Mytilus*

4) The differentiation in level stony or sandy bottoms and reefs or sandbanks is not included in the derivation of the benthic habitats. HELCOM also states no delineation criteria. However, reefs and sandbanks have been mapped according to Annex I of the Habitats Directive. All areas of reefs and sandbanks are assigned to reef and sandbank biotopes in HELCOM, although the substrate type of some areas might not in line with the substrate definitions given in the HELCOM classification for sandbanks and reefs (e. g. mixed sediments). In the aphotic zone HELCOM does not define reefs or sandbanks. These areas are therefore assigned to the level substrate biotopes.

In

Table 0-1 the characterising terms of the HELCOM biotopes are assigned to the respective EUNIS-habitats and habitat types according to the above mentioned specifications.

It should be noted that overlaps of several HELCOM-biotopes could occur. Thus fine substrate biotopes with mixed substrates (mosaics and mixtures of mud, sand, partly associated with gravel and boulders) might contain a certain amount of hard substrate. With an amount of hard substrate exceeding 10 % it has to be classified as biotope "reef". With a certain slope gradient and an amount of hard substrate below 10 % it has to be classified as biotope "sandbank".

Table 0-1 Correlation table of delineation criteria of HELCOM and of benthic habitats (grey entry = biotop without delineation by habitat type definitions)

Categories of HELCOM-biotopes	Habitat type	Categories of benthic habitats
Mixed sediment bottoms		Mixed sediment with flora/fauna-mixed community, infauna or *Tanaissus*
Muddy bottoms		Mud with infauna
Level sandy bottoms		Sand with infauna
Sandbanks	Sandbank (1110)	Sand, mud or mixed sediment with infauna (parts) or *Tanaissus* (parts)
Level stony bottoms	Reefs (1170)	Coarse sediment with *Dendrodoa*, perennial algae or *Mytilus* → reefs
Reefs	Reefs (1170)	Coarse sediment with *Dendrodoa*, flora/fauna-mixed community (parts), infauna (parts), eelgrass/algae (parts)
Mussel beds	Reefs (1170)	Coarse sediment, mixed sediment or sand with *Mytilus*
... dominated by macrophyte vegetation		All habitats with higher plants, perennial algae, eelgrass/algae
... with little or no macrophytes		All habitats with infauna, *Tanaissus* or flora/fauna-mixed community
Aphotic zone		All circalittoral habitats
Photic zone		All infralittoral habitats

A P P E N D I X C

Relationship §30-Biotopes – Benthic Habitats

In §30 of the Federal Nature Conservation Act (BNatSchG) the legally protected biotopes in Germany are listed, including marine biotopes. There is neither a differentiation into North or Baltic Sea nor information about inner/outer coastal waters, circalittoral/infralittoral or any other criteria. Thus a classification of the benthic EUNIS-habitats into §30-Biotopes is only possible with additional specified definitions and criteria:

1) For delineation of the biotope ”reef“, criteria of EU-Habitat Type mapping have been used. By the use of the broadly defined term “reefs” several benthic habitats are assigned to the biotope “reefs”.
2) For delineation of the biotope ”sandbanks“, criteria of EU-Habitat Type mapping have been used. By the use of the broadly defined term “sandbanks” several benthic habitats are assigned to the biotope “sandbanks”.
3) Muddy grounds with burrowing benthic megafauna do not occur in the Baltic Sea due to the absence of this type of fauna. Information refers to North Sea species like Norway lobster (*Nephrops*) or burrowing mud shrimps (*Callianassa*). Therefore no areas in the investigation area have been assigned to this §30-Biotope.
4) There is no detailed information on the meaning of species-rich in “species-rich gravel, coarse sand and shell grounds” and on the associated fauna and flora. However, Naberhaus et al. (2012) mention that communities with the bristleworms *Ophelia* spp. and *Travisia forbesi* can be attributed to species-rich coarse sand and gravel grounds. In the current mapping these species have exclusively been associated with the *Tanaissus*-community. Therefore all areas with this community are assigned to this §30-Biotope.
5) For eelgrass beds and other macrophyte stands detailed definitions (composition, density, area and structure) are missing. Likewise it is not clear, if the term macrophyte stand only comprises higher plants (as usual in limnology) or also macroalgae, and if only certain algae are legally protected. In the current mapping all benthic habitats with higher plants and eelgrass/algae are assigned to the §30-Biotope “eelgrass beds”, because both communities include the eelgrass *Zostera marina*. The higher plant community also comprises the dwarf eelgrass *Zostera noltii*. This classification is in accordance to Naberhaus et al. (2012). Since the term macrophytes is also used for macroalgae in the marine sector, all benthic habitats with perennial algae have been assigned to the §30-Biotope ”other macrophyte stands”. Hence, annual opportunistic macroalgae are not included.

In

Table 0-1 the characterising terms of the §30-Biotopes are assigned to the respective benthic habitats and EU-Habitat Types according to the above mentioned specifications.

It should be noted that overlaps of several §30-Biotopes might occur. Thus species-rich coarse sand, gravel and shell grounds can contain a certain amount of hard substrate. With an amount of hard substrate exceeding 10 % it has to be classified as biotope "reef". With a certain slope gradient and an amount of hard substrate below 10 % it has to be classified as biotope "sandbank".

Eelgrass beds can also be found in mixed sediments with a certain amount of hard substrate (stones or clay reefs) along the outer coastline. However, with an amount of hard substrate exceeding 10 %, those areas have to be classified as biotope "reef", too.

"Other macrophyte stands" - defined as perennial macroalgae - need hard substrate as settling ground. All areas with the perennial macroalgae community are therefore automatically classified into the biotope "reefs".

Table 0-2 Correlation table of §30-Biotopes and benthic habitats

§30-biotopes	Habitat type	Benthic habitat	Comment
Species-rich coarse sand, gravel and shell grounds	Sandbank (1110) -parts Reefs (1170) - parts	*Tanaissus*-community	Overlapping with biotope reefs and biotope sandbanks
Reefs	Reefs (1170)	Coarse and mixed sediments with *Dendrodoa*, flora/fauna-mixed community (parts), infauna (parts), perennial algae, *Mytilus*, *Tanaissus* (parts)	Overlapping with biotope species-rich coarse sand, gravel and shell grounds, eelgrass beds and other macrophyte stands
Sublittoral sandbanks	Sandbanks (1110)	Sand, mud with infauna Mixed sediments with flora/fauna-mixed community (parts), infauna (parts), *Tanaissus* (parts)	Overlapping with species-rich coarse sandy, gravelly and shelly grounds
Muddy grounds with burrowing benthic mega fauna		–	Not relevant for Baltic Sea
Eelgrass beds	Large shallow inlets and bays (1160) - parts	Sand with higher plants Mixed sediments with eelgrass/algae	Overlapping with biotope reefs
Other macrophyte stands	Reefs (1170)	Coarse or mixed sediment with perennial algae	Overlapping with biotope reefs or the same as biotope reefs

A P P E N D I X D

Relationship Riecken-Biotopes – Benthic Habitats

In the red list of the endangered biotope types in Germany (Riecken et al. 2006) the different biotope types are listed, separated by North and Baltic Sea and inner and outer coastal waters. Further classification criteria are:

- Substrate: hard substrate biotope, sand biotope, fine substrate biotope (sometimes exclusively silt), clay (sometimes with intermixture of sand, gravel or stones)
- Bottom topography: sandbank, level sandy biotope, hard substrate reef
- Biological information: dominated by macrophytes, little or no macrophytes, eelgrass beds, freshwater or brackish species, biogenic reef

A differentiation into circalittoral and infralittoral or photic and aphotic zone is not included.

It is a classification of all marine biotopes and not only of specific endangered ones. That means that all benthic habitats have to be assigned to a respective biotope of the present red list. As not all delineation criteria are identical (substrates, biologic parameters), there are specific rules to correlate the benthic EUNIS-habitats to the red listed biotopes:

1) The differentiation between inner and outer coastal waters is not included in the derivation of the benthic habitats, but their spatial distribution in the investigation area is known. The distinction was made by means of the typology of the coastal waters according to the Water Framework Directive (WFD). In the WFD the inner coastal waters are represented by the national German water types B1 and B2 and the outer coastal waters by the types B3 and B4 (Reimers 2005). A classification of the benthic habitats into inner and outer coastal waters on the basis of WFD typology and water body-assignment is possible. Consequently, all benthic habitats within Orth Bight are assigned to inner coastal waters and all habitats outside Orth Bight are assigned to outer coastal waters.
2) Substrate information from Riecken et al. (2006) was classified into substrate categories of benthic habitats according to the following scheme:
   - Hard substrate biotope → coarse sediment
   - Sand biotope → sand
   - Fine substrate biotope with muddy substrate (dominated by silt and clay) → mud
   - Fine substrate biotope with mixed substrate (mosaics and mixtures of mud, sand, partly associated with gravel and stones) → mixed sediment
3) Biological information from Riecken et al. (2006) was classified into categories of benthic habitats according to the following scheme:
   - Eelgrass beds → all habitats with eelgrass/algae
   - Hard substrate biotopes rich in macrophytes → coarse and mixed sediment with perennial algae
   - Rich in macrophytes, predominantly freshwater or brackish species, e. g. stonewort, pondweeds → higher plants
   - Biogenic reef → all habitats with Mytilus
   - Little or no macrophytes → all habitats with Dendrodoa, Infauna, Tanaissus or flora/fauna-mixed community
4) Differentiations into level hard substrate and level sand biotope as well as hard substrate reefs and sandbanks are not included in the derivation of the benthic habitats. In Riecken et al. (2006) there are also no delineation criteria stated. All areas of reefs and sandbanks have been assigned to the respective reef and sandbank biotopes according to Riecken et al. (2006). Thus the biotope types

02.02.01/04.02.01 ”shallow, natural hard substrate biotope of outer/inner coastal waters of the Baltic Sea“ does not occur, as all areas of the habitat type mapping with hard substrates are assigned to hard substrate reefs. A differentiation depending on the typology is not existent.

In Table 0-3 the characterising terms of the Riecken biotopes are assigned to the respective benthic habitats and habitat types according to the above mentioned specifications. It should be noted that overlaps of several biotopes according to Riecken et al. (2006) could occur.

Thus fine substrate biotopes with mixed substrates (mosaics and mixtures of mud, sand, partly associated with gravel and stones) might contain a certain amount of hard substrate. With an amount of hard substrate exceeding 10 % it has to be classified as biotope “reef”. With a certain slope gradient and an amount of hard substrate below 10 % it has to be classified as biotope “sandbank”.

Eelgrass beds can also be found in mixed sediments with a certain amount of hard substrate (stones or clay reefs) along the outer coastline. However, with an amount of hard substrate exceeding 10 % it has to be classified as biotope “reef”, too.

“Other macrophyte stands” - defined as perennial macroalgae - need hard substrate as settling ground. All areas with the perennial macroalgae-community are therefore automatically classified into the biotope “reefs”.

Table 0-3 Correlation table of delineation criteria of Riecken et al. (2006) and of benthic habitats (grey entry = biotop without delineation by habitat type definitions)

Categories of red listed biotope types	Habitat type	Categories of benthic habitats
Fine substrate biotope with mixed substrate (mosaics and mixtures of mud, sand, partly associated with gravel and stones)		Mixed sediment with flora/fauna-mixed community, infauna or *Tanaissus*
Fine substrate biotope with muddy substrate (dominated by silt and clay)		Mud with infauna
Level sand biotopes		Sand with infauna
Sandbanks	Sandbanks (1110)	Sand, mud or mixed sediment with infauna (parts) or *Tanaissus* (parts)
Shallow, natural hard substrate biotope	Reefs (1170)	Coarse sediment with *Dendrodoa*, perennial algae or *Mytilus* → hard substrate reef
Hard substrate reefs	Reefs (1170)	Coarse or mixed sediment with *Dendrodoa*, flora/fauna-mixed community (parts), infauna (parts), eelgrass/algae (parts)
Biogenic reefs	Reefs (1170)	Coarse sediment, mixed sediment or sand with *Mytilus*
Eelgrass beds		All habitats with eelgrass/algae
… rich in macrophytes, predominantly freshwater or brackish species, e. g. stonewort, pondweeds		All habitats with higher plants
... rich inf macrophytes		All habitats with perennial algae
... little or no macrophytes		All habitats with infauna, *Tanaissus* or flora/fauna-mixed

Categories of red listed biotope types	Habitat type	Categories of benthic habitats
		community
Inner coastal water		All habitats in Orth Bight (WFD-water type B2)
Outer coastal water		All habitats outside Orth Bight (WFD-water type B3, B4)

A P P E N D I X E

Depth zones (intermediate steps)

Three classes of depth zones (biological zones) could be identified and mapped in the investigation area (Figure App. E-1). The deeper circalitoral was included in the circalitoral in thelater evaluation process of the habitat classification as no benthic communities were related specifically to this zone type.

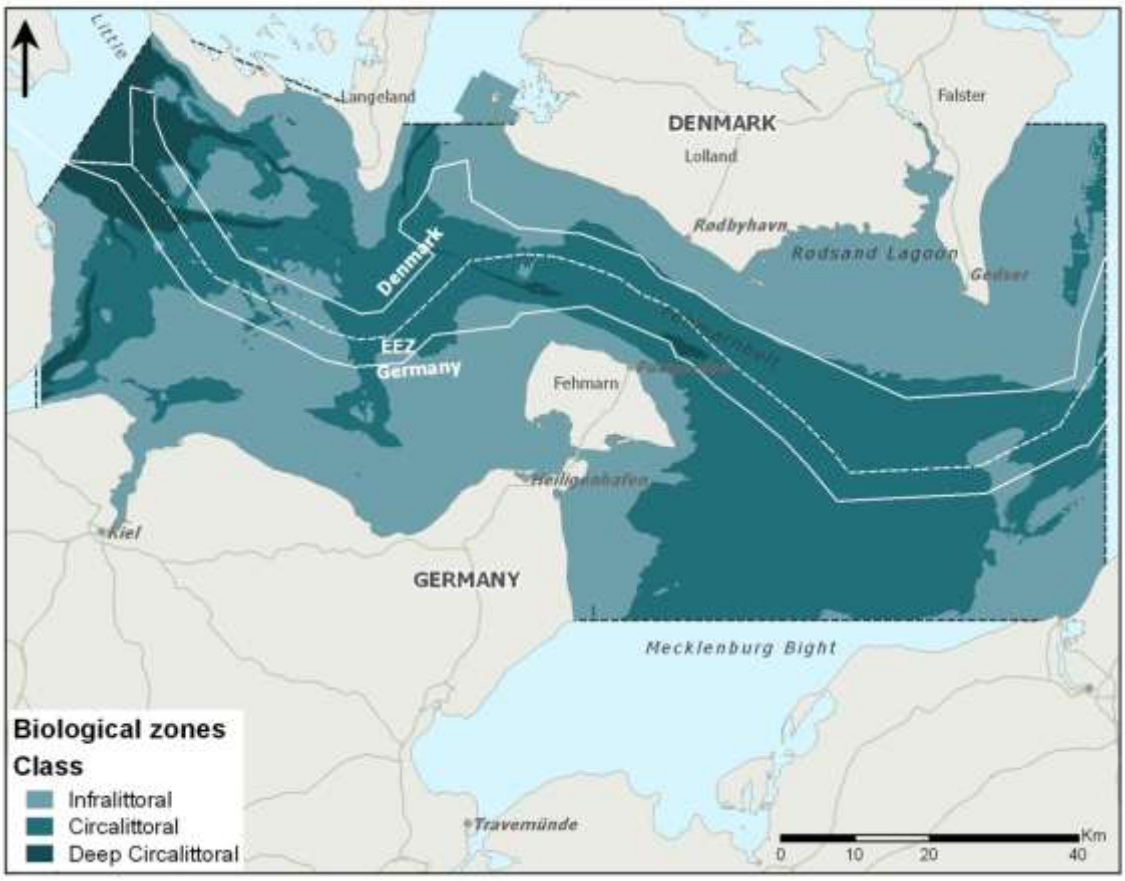


Figure App. E-1 Biological zones.

A P P E N D I X F

Seabed substrates (intermediate steps)

The mapped seabed substrates are depicted in Figure App. F- 1. Coarse sediments and boulders can be found almost everywhere along the coasts. The lower depth limit typically lies between 15 m and 20 m. Occasionally, coarse sediments and boulders are found in water depths greater than this, e.g. between Fehmarn and Langeland Islands. Sands predominate in the littoral zone down to approximately 5 m water depths and border areas of coarse sediment with boulders. Towards the deeper basins, the grain size decreases due to decreasing exposure to waves and currents (Figure App. F- 2). Muddy sands, bordering sandy areas, blend into sandy mud, which covers large parts of the Fehmarnbelt, Mecklenburg Bight and several sub-basins of Kiel Bight. Mud is restricted to the central part of Mecklenburg Bight. Occurrences of mixed sediments are limited; they tend to occur in transition zones from coarse sediment to sandy mud.

Within the deep (>25 m water depths) parts of the Fehmarnbelt, the blanket of sandy mud is apparently very thin ("thin sandy mud" in Figure App. F- 1): Sampling carried out as part of the benthic fauna baseline investigations (FEMA, 2011a) consistently retrieved sandy mud from the seabed. In contrast to this, the backscatter intensity is relatively high, which is untypical for such fine-grained sediment. The most likely explanation for this apparent disparity is a very thin (a few cm) layer of sandy mud on top of coarser or more consolidated sediments. The backscatter intensity, which is integrated over the top ≈10 cm of the sediment column at the sonar frequencies employed, would thereby increase. A similar effect was encountered by Callaway et al. (2009), who mapped rocky reef under a thin blanket of mud. Anecdotal evidence (Michael Zettler, IOW, pers. comm.) also points in the same direction, as samples retrieved in this area often show a thin layer of sandy mud on top of older sediments. The fact that the layer of sandy mud is so thin in the central Fehmarnbelt is most likely related to the relatively high bottom current speeds encountered in this region (Figure App. F- 2).

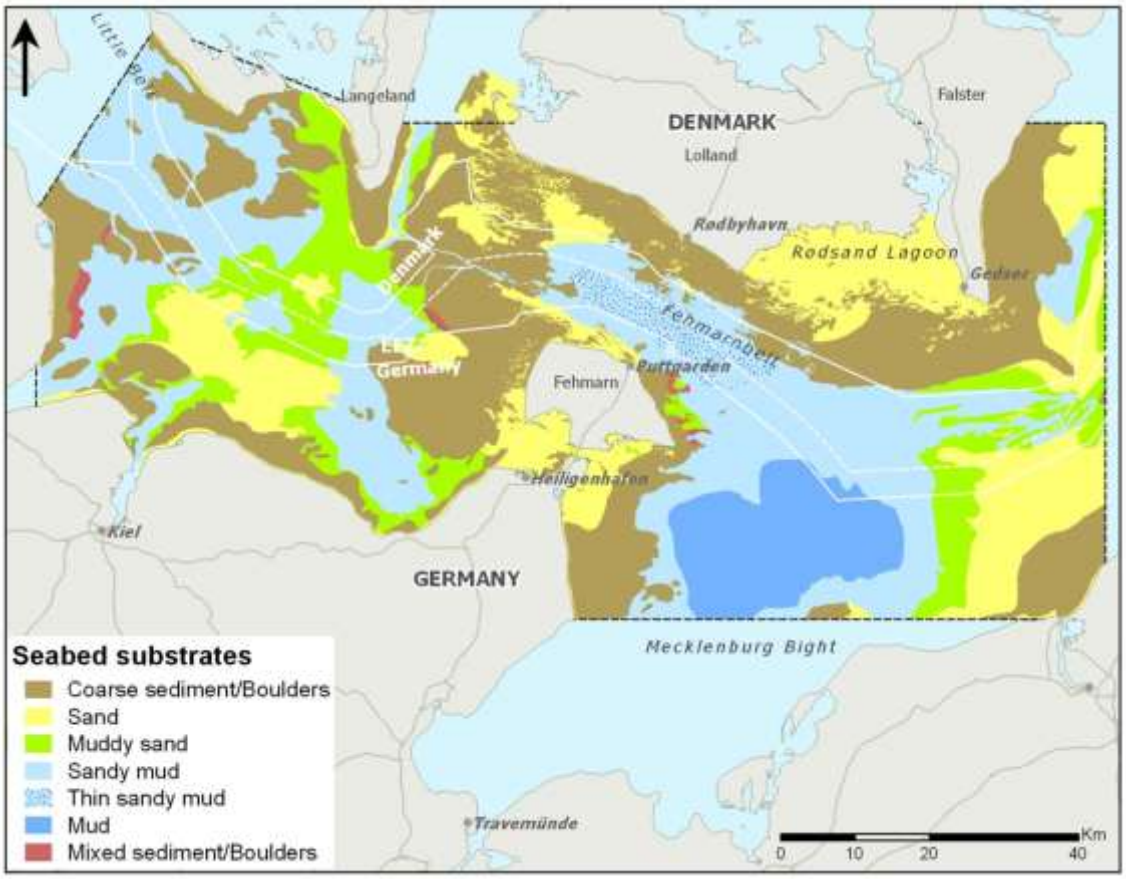


Figure App. F- 1 Map of seabed substrates.

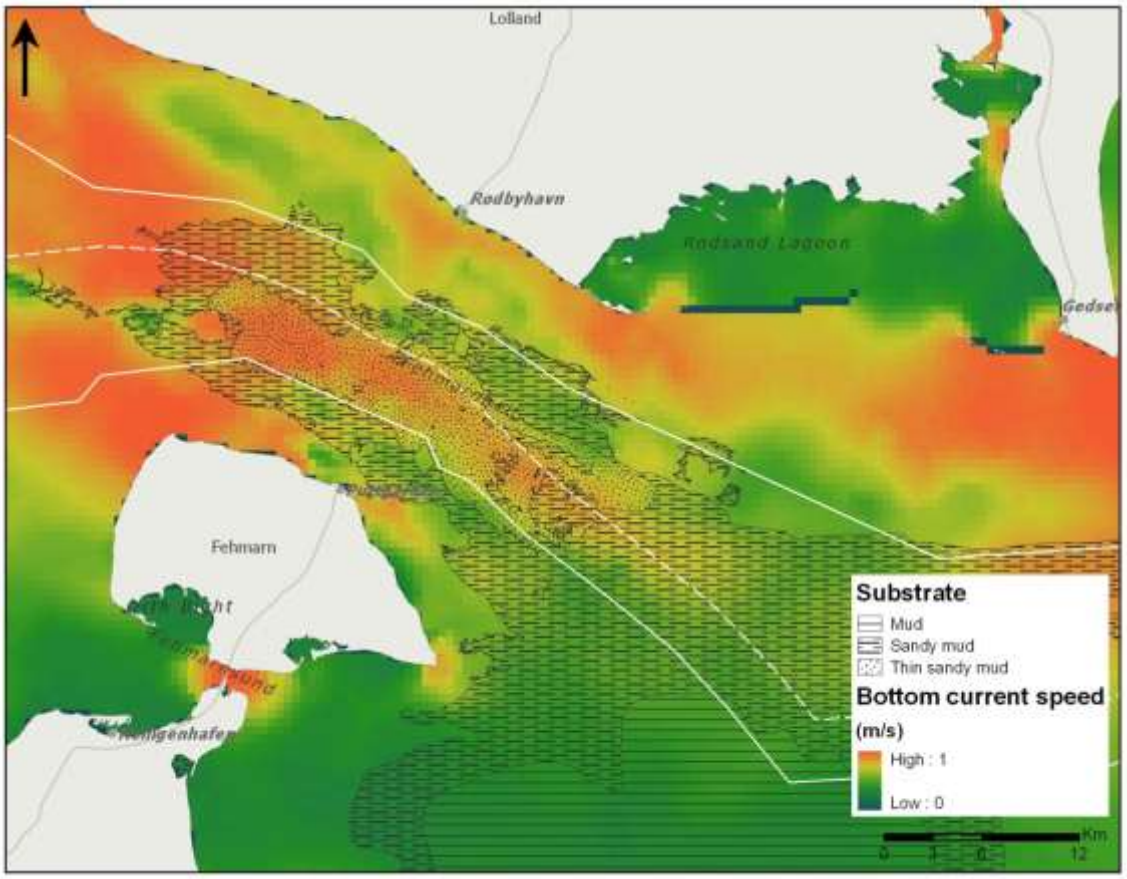


Figure App. F- 2 Within the area of muddy substrates, thin sandy mud does occur where bottom current speeds are high.

Although the area of thin sandy mud is discernable from the data, it was deemed insignificant in an ecological sense, i.e. it did not support different benthic fauna communities. The differentiation between sandy mud and thin sandy mud was therefore henceforth dropped.

A P P E N D I X G

Physical habitats (intermediate steps)

A physical habitat map was produced for the greater Fehmarnbelt area. Mapping of physical habitats was based on the substrate map, biological zones, classified bottom salinity and exposure classes. The physical habitats were derived through an intersection of these four data layers. The physical habitat map summarises the abiotic characteristics of the seabed and can be seen as a surrogate map in the absence of biological data (which was only added on later in the process of habitat mapping).

In total, 43 different physical habitats were differentiated (Figure App. G- 1). Colours were given by sedimentary habitat type, with red and amber colours representing coarse sediment, green and yellow colours representing sand/muddy sand, blue colours representing mud/sandy mud and purple colours representing mixed sediment. Symbol overlays further differentiate sand/muddy sand and mud/sandy mud. Symbols also indicate different levels of exposure: cross-hatching representing exposed, horizontal lines representing moderately exposed and vertical lines indicating sheltered areas. The symbols also detail the location of hard substrates, as exposure classes were only mapped together with the presence of hard substrate. Hard substrate was either associated with coarse sediment or some types of mixed sediment. As it has the same descriptors regarding biological zone and salinity these can be inferred from the associated sedimentary habitat.

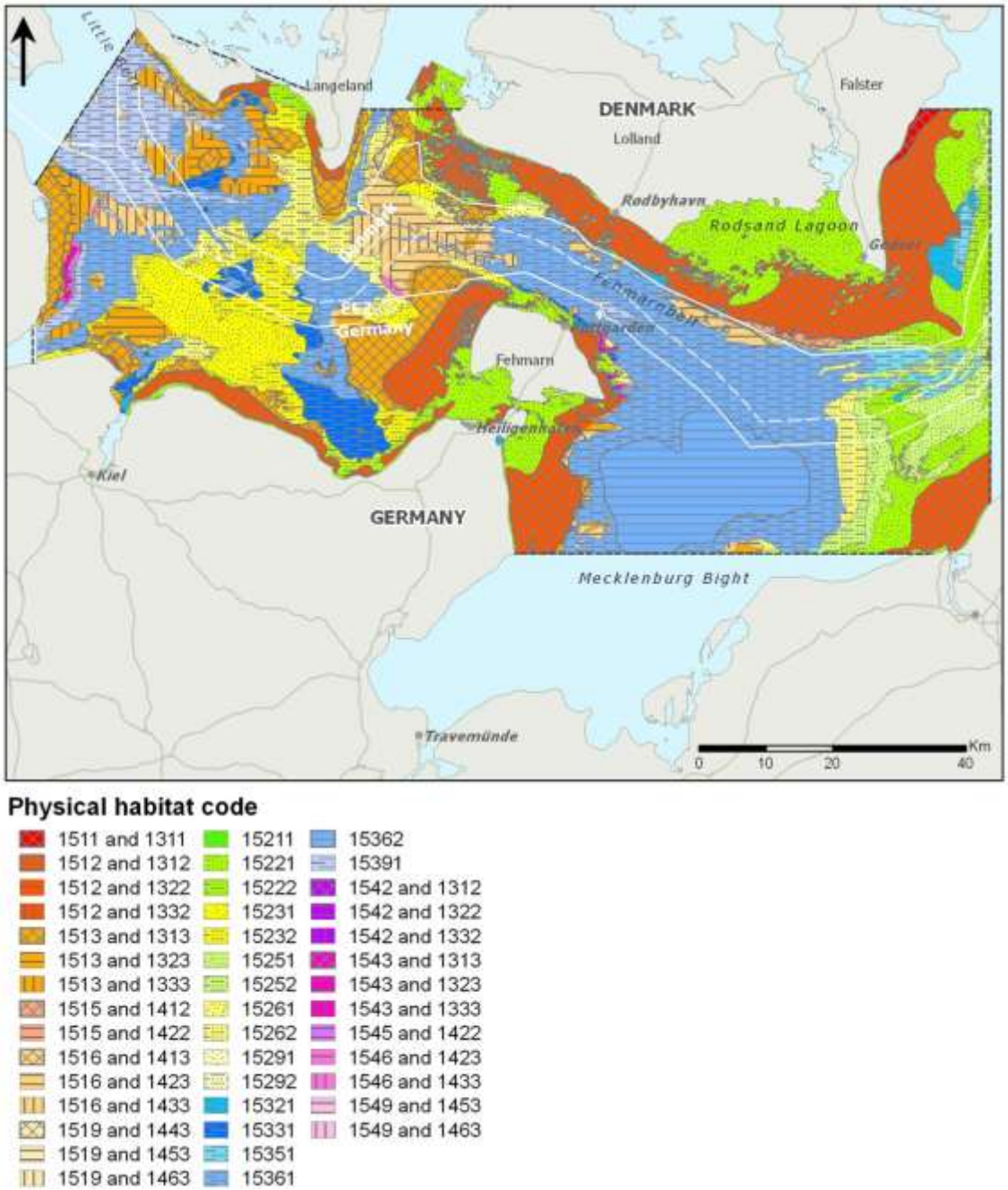


Figure App. G- 1 Map of physical habitats. Habitat codes are explained in Appendix A.

A P P E N D I X H

Benthic communities (intermediate steps)

To derive a unified biota layer, the shape files of the three input layers (benthic flora, benthic fauna communities, blue mussel cover) were combined using the ArcGIS Union Tool. Combinations of the feature's vegetation community, its coverage and faunal community were analysed. The following rules were used to define the resulting biota community taking into account both vegetation and faunal features:

1. If the coverage of a vegetation community exceeded 25%, the name of this particular community was assigned to the resulting biota class. In such cases the key vegetation species provides habitat for epifauna and thereby determines the structure of the faunal community.

2. The combinations with a coverage range of any vegetation community from 10 to 25% were assigned to "mixed vegetation/infauna-community".

3. Where vegetation coverage was less than 10%, fauna was considered as the key feature and the biota class was named after the benthic fauna community.

A simplified benthic community map was derived in the following way: Among the flora communities, Eelgrass and Tasselweed/dwarf eelgrass were grouped as Angiosperms. Fucus, Furcellaria, Phycodrys/Delesseria and Saccharina were summarised as Perennial algae. The fauna communities were combined into four broad groups, namely shallow infauna (*Bathyporeia* and *Cerastoderma*), deep infauna (*Arctica*, Corbula and *Tanaissus*), shallow epifauna (*Gammarus*, *Mytilus*, *Rissoa* and Mixed vegetation/infauna community) and deep epifauna (*Dendrodoa*).

The distribution of benthic vegetation and fauna communities is shown in Figure App. H- 1. Due to the availability of suitable substrate and sufficient light, the vegetation-structured communities occupy the shallow coastal areas while infauna communities spatially dominate in deeper water depths. The communities structured by macroalgae vegetation encompass the *Fucus, Furcellaria, Phycodrys/Delesseria, Saccharina* and filamentous algae communities.

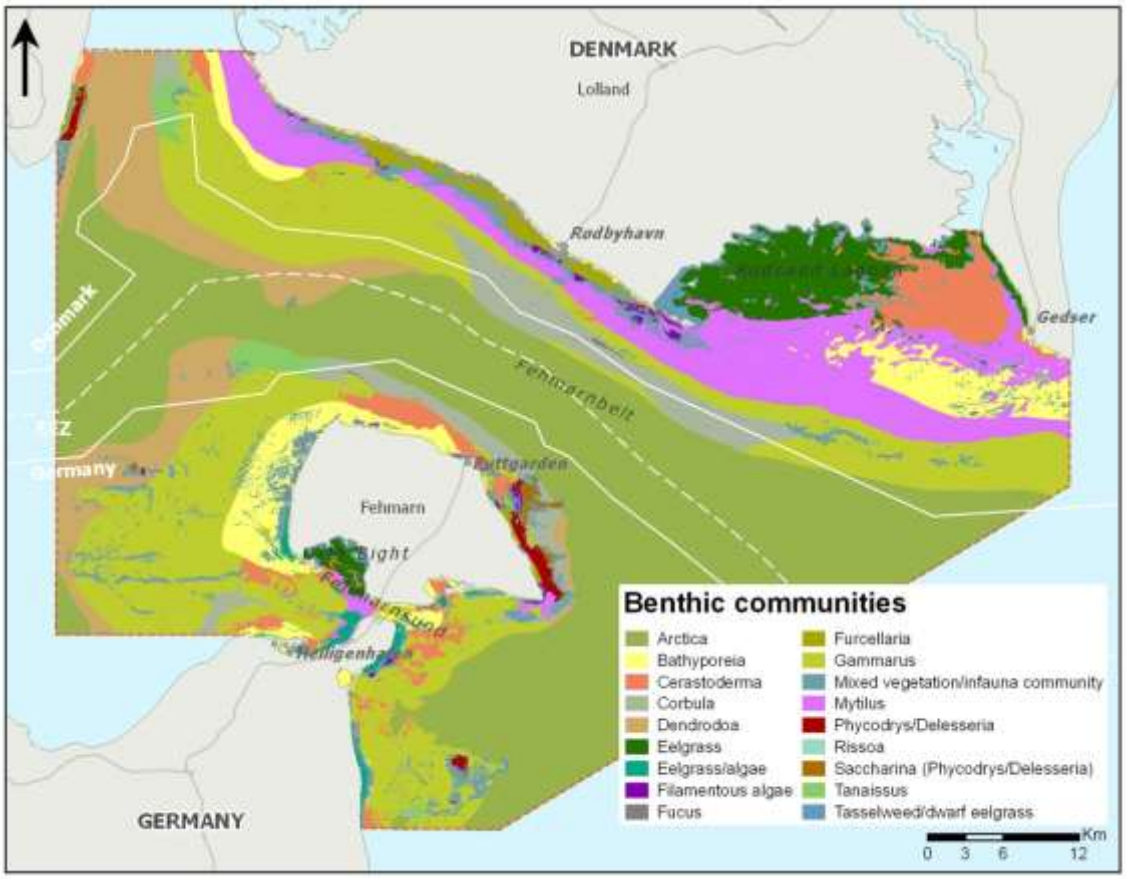


Figure App. H- 1 Distribution of benthic vegetation and fauna communities.

The *Fucus* community was found at depths between 1–5 m, but was spatially restricted to few locations along the western and north-eastern coasts of Fehmarn. Key habitat forming species are serrated wrack (*Fucus serratus*) and bladderwrack (Fucus vesiculosus). Accompanying species are the perennial red algae *Ahnfeltia plicata* and the filamentous algae *Polysiphonia fucoides*.

The *Furcellaria* community occurs at depths between 2–8 m and is widely distributed along the Danish coast. *Coccotylus/Phyllophora* is an abundant and steadily accompanying taxa group in mixed *Furcellaria* stocks as well as epiphytic growing algae of the genus *Ceramium*.

The *Phycodrys/Delesseria* community was found at depths between 5–19 m. Key species are the perennial red algae Phycodrys rubens and *Delesseria sanguinea*. These red algae are accompanied by different other red algae like *Coccotylus/Phyllophora, Membranoptera alata, Brongniartella byssoides, Cystoclonium purpureum* and/or *Rhodomela confervoides*. It is especially widely distributed off the eastern coast of Fehmarn, but also occurs along the south-eastern coastline of Langeland and in a small patch west of Fehmarn.

The *Saccharina* community occurred in the same regions found at depths between 12–19 m. Key species is the perennial brown alga *Saccharina latissima*. Accompanying species are rare and belong to the annual, filamentous functional algae group (e.g. *Desmarestia aculeata*, *Polysiphonia stricta*) or are a key species of other communities (e.g. *Delesseria sanguinea*).

Many scattered sites within the study area showed a dominance of filamentous, opportunistic algae (filamentous algae community). The species composition and abundance of this group is very variable between sites and depths. No single species can be listed as key species.

On soft bottoms two angiosperm communities were identified: the Eelgrass and the Tasselweed/dwarf eelgrass community.

The Eelgrass community was found at depths between 1–5 m and was widely distributed in western Rødsand Lagoon and Orth Bight. Key species for this community is the common eelgrass (*Zostera marina*). Accompanying species are small epiphytic growing algae (*Aglaothamnion/Callithamnion* and/or *Ceramium tenuicorne*).

The Tasselweed/dwarf eelgrass community was distributed between 0.25 m and 1.5 m water depth and spatially restricted to the sheltered shallow water zones of Rødsand Lagoon and Orth Bight. Key species are the narrow-leaf angiosperms tasselweed (*Ruppia cirrhosa/maritima*) and dwarf eelgrass (*Zostera noltii*). These angiosperms are accompanied by different characeans (*Chara aspera, Chara baltica, Tolypella nidifica*) and other angiosperms like pondweed *Potamogeton pectinatus* or *Zannichellia palustris*.

A mixed eelgrass/algae community structured by both higher plants and perennial/annual macroalgae is found outside of sheltered bays along the south coast and south-west coast of Fehmarn, east and west of Wagrien and south of Großenbrode.

Nine benthic faunal communities were mapped. These comprised four epifauna and five infauna-dominated communities. Typical epifauna communities in shallow waters are the *Gammarus*, *Mytilus* and *Rissoa* communities. Whereas the *Gammarus* and *Mytilus* communities occur on hard substrate and, to varying degrees, macroalgae, the *Rissoa* community is associated with eelgrass (*Zostera* sp.) beds.

The *Gammarus* community is a predominantly shallow water epifauna community that is found where benthic vegetation or mussels are covering the seabed to a varying degree. Filamentous algae (even with low cover) provide a hiding and living space for the epifauna. The name-giving genus *Gammarus* is an amphipod associated with algae and mussel communities where they feed on anything from algae and seaweeds to detritus. Characteristic species include *Gammarus oceanicus* and *Gammarus salinus*, the amphipod *Microdeutopus gryllotalpa*, the isopods *Idotea balthica*, *Idotea chelipes*, and *Jaera albifrons*, all of which are associated with algae.

The *Mytilus* community is not directly linked with mussel banks, but the blue mussel can be regarded as the main structuring biotic feature within these areas. Its community structure is therefore also variable and locally depends on the surrounding sediments. Typical *Mytilus* aggregations in shallow, well mixed and thus oxygenated waters consist of high densities and are associ-

ated with several crustacean and gastropod species. The *Mytilus* community located in deeper waters consists of a high-density mussel community with typical saltwater epibenthic species.

The *Rissoa* community is a shallow water epifauna community that is restricted to eelgrass beds. It is composed of species that are able to utilise the special conditions in eelgrass communities. The name-giving genus *Rissoa* is represented in the community by *Rissoa membranacae*, *Rissoa parva*, and *Rissoa violacea.*

Infauna communities in shallow waters are the Bathyporeia and the Cerastoderma community. The *Bathyporeia* community is found in wave-exposed areas, where frequent remobilisation of sand prevents the establishment of other communities (e.g. south-east of the Rødsand Lagoon and off the north coast of Fehmarn). In very exposed locations, the community may occur down to 10 m water depth. The name-giving amphipod Bathyporeia pilosa is adapted to live in these dynamic conditions. It burrows in sand, but is also a good swimmer and gnaws sand particles to feed on diatoms.

The *Cerastoderma* community is the typical shallow water soft sediment community and is found in low hydrodynamic energy sandy substrates. In the mapped area, the community was mainly restricted to the eastern part of the Rødsand Lagoon, off the north coast of Fehmarn, and near Flügge Sand off the south-western coast of Fehmarn. The characteristic species of this community are the bivalves *Cerastoderma edule, Mya arenaria* and *Macoma balthica*.

The *Corbula* community, which occupies seabed slopes in water depths of 10-20 m, forms the transition between the mesohaline shallow water communities and the polyhaline deep water communities along the coast of Fehmarn and Lolland. It occupies a wide variety of substrate including sand, muddy sand, coarse sand, boulders and small mussel beds. The most frequent species in the community are *Corbula gibba, Diastylis rathkei, Scoloplos armiger, Hydrobia ulvae* and the bivalves *Kurtiella bidentata*, *Mytilus edulis* and *Macoma balthica*.

The *Dendrodoa* community occurs in polyhaline, deeper waters. The identified community is a mixture of an epibenthic hard substrate assemblage and an infauna community inhabiting the surrounding soft bottoms, the latter being strongly related to the *Tanaissus* community (see below). The epibenthic part of the community is however the main characteristic of the *Dendrodoa*-community. The ascidian *Dendrodoa* lives attached to algae, on empty shells of *Arctica islandica* and on live mussels (*Mytilus edulis*). Filter feeding bivalves and sponges dominate the biomass. Single species of amphipods, ascidians, anthozoans and polychaetes were also found.

The *Tanaissus* community is a typical infauna community occurring mainly in medium to coarse sands on sandbanks. Similar to the *Bathyporeia* community it is mainly found in areas with strong currents, but is characterised by a higher species number and a specific community structure. It is locally influenced by drifting algae and mussels. A few filter feeder species and several large predators dominate in the biomass. However, several small-sized species of several groups, including bivalves, polychaetes and crustaceans attain high abundances.

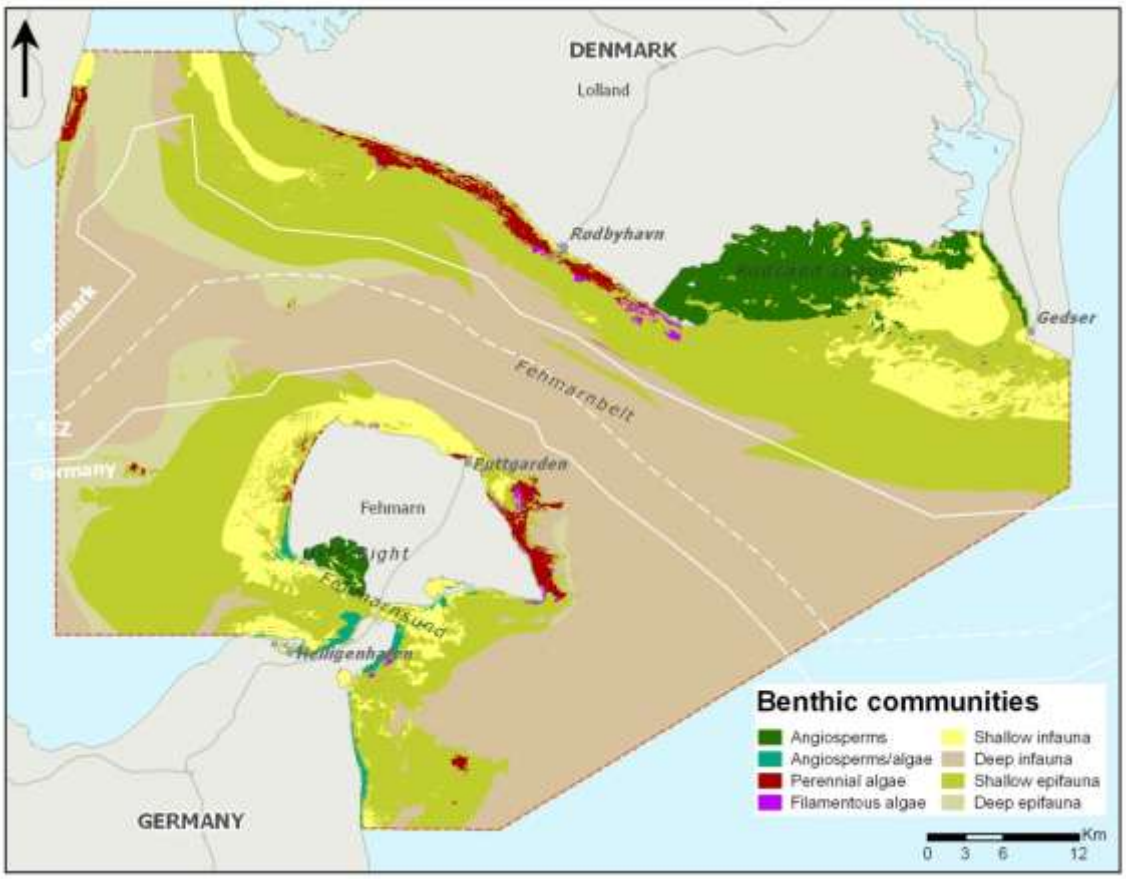


Figure App. H- 2 Distribution of simplified benthic communities.

The deep parts of the local Fehmarnbelt area are structured by infauna. The *Arctica* community is confined to the deeper waters in Kiel Bight, the central Fehmarnbelt and Mecklenburg Bight and occupies the largest part of the mapped area. It is the typical soft-sediment community in deeper, polyhaline waters of the Fehmarnbelt area. The community includes a large number of taxa, with a decreasing trend from west to east. The filter feeding bivalve *Arctica islandica* dominates the biomass whereas the polychaetes *Terebellides stroemi, Lagis koreni* and *Scoloplos armiger* and the bivalve *Abra alba* were the most abundant species.

Areas with mixed vegetation/infauna-community occur in scattered patches. The species composition and abundance within this group are highly variable between sites and depths, but both vegetation with associated epifauna and infauna species play a substantial role. No single species can be listed as key species.

A simplified benthic community map based on eight broader classes is shown in Figure App. H- 2.

A P P E N D I X I

Benthic habitats (intermediate steps)

Benthic habitat maps were produced for the local Fehmarnbelt area, as biological data were limited to this extent. Mapping of habitats was based on biological zones, substrate types and predicted benthic community distribution. Predicted biological data were used as only these layers were giving full coverage information. Two habitat maps were produced based on the full and simplified benthic community maps shown in Appendix H. While the resulting full habitat map gives maximum information detail and may serve as input for further analyses, the simplified habitat map summarises the main characteristics of benthic habitats in the Fehmarnbelt area.

The habitats were derived through an intersection of the aforementioned data layers. To a limited extent, this process yielded combinations of substrate and biota that were deemed unlikely or impossible (e.g. the *Arctica* community in sand). Expert judgement was used to identify and remove those combinations. No biological attribute was assigned to the physical habitat in such a case. The spatial extent of unlikely or impossible combinations was however rather restricted.

In four cases, combinations originally deemed impossible were retained after re-inspection of available substrate information. These were the *Arctica* and *Corbula* communities intersecting with coarse sediment/boulders or mixed sediment/boulders. These two communities require a soft and fine-grained substrate, such as sandy mud or mud. They should therefore not occur on such coarse substrates as in this case. However, it became apparent from sampling and backscatter data that patches or thin blankets of sandy mud might occur in these otherwise coarse grained areas. Such patchy areas were typically located between platforms/shoals and channels/basins, which are transitional areas that might experience both erosion (during storms) and accumulation of sediment (during fair weather). Hence, coarse and fine substrates are often found juxtaposed. We have therefore interpreted those areas as mosaics of coarse sediments and sandy mud inhabited by either the *Arctica* or *Corbula* community.

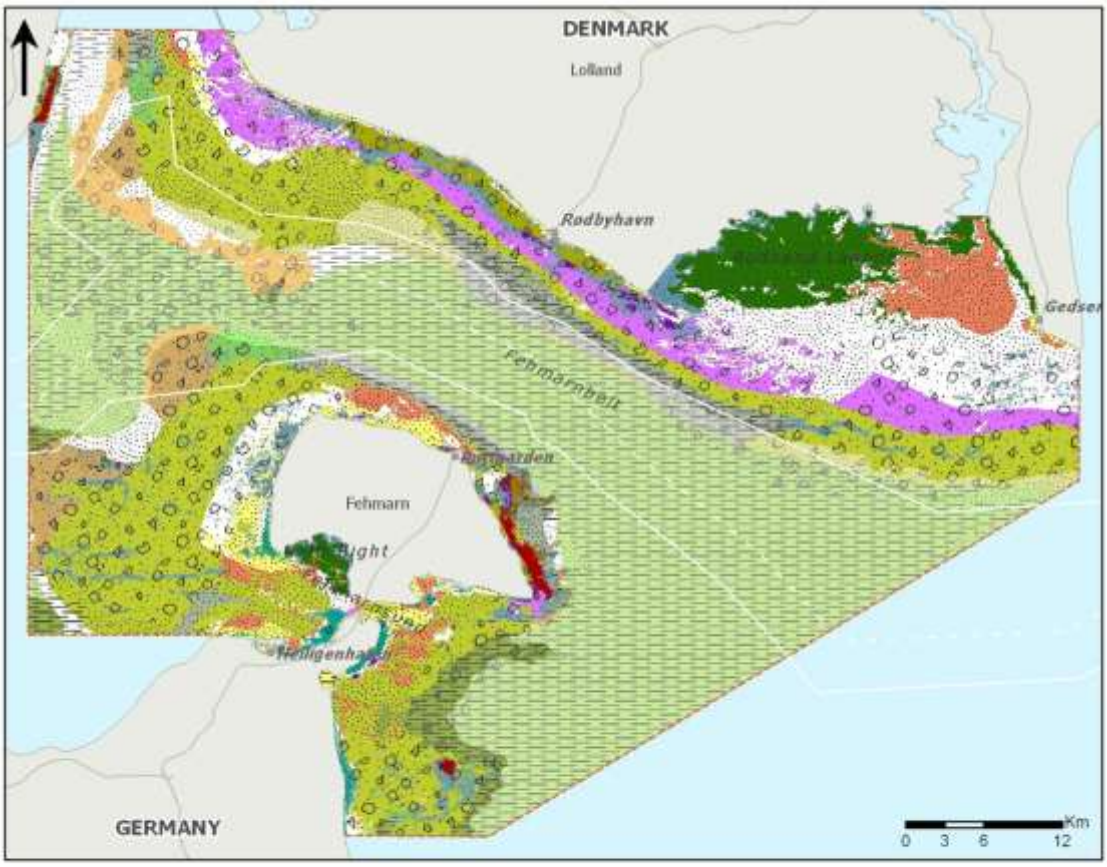
A total of 62 habitat types were differentiated and have been mapped for the local Fehmarnbelt area. Every habitat was given a colour based on the associated benthic community. The biological zone is indicated by the tone, i.e. infralittoral habitats have darker tones than the respective circalittoral habitats. The substrate type is indicated by different symbol overlays as shown in Figure App. I- 1. The benthic habitats of the Fehmarnbelt area are displayed in Figure App. I- 2.

Figure App. I- 1 Key to the symbology used for substrate types in Figure App. I- 2 and Figure App. I- 3.

There is a striking difference between the shallow infralittoral and the deep circalittoral zone in terms of complexity and diversity of habitats. *Gammarus* on infralittoral coarse sediment/boulders is the most widespread habitat in the infralittoral. Further infralittoral habitats of importance, both spatially and ecologically, include *Mytilus* on infralittoral coarse sediment/boulders, Eelgrass on infralittoral sand and muddy sand, Mixed vegetation/infauna community on infralittoral coarse sediment/boulders, *Cerastoderma* in infralittoral sand and muddy sand, Bathyporeia in infralittoral sand and muddy sand, *Furcellaria* on infralittoral coarse sediment/boulders and *Phycodrys/Delesseria* on infralittoral coarse sediment/boulders among others.

Contrary to this, the circalittoral is largely dominated by *Arctica* in circalittoral mud and sandy mud, which covers more than one quarter of the mapped area. Several communities, including *Corbula*, *Dendrodoa* and *Tanaissus*, tend to occur in a transitional zone straddling the boundary between infralittoral and circalittoral.

The simplified version of the habitat map (Figure App. I- 3) highlights the main characteristics of the mapped area. Angiosperms (mainly eelgrass) on infralittoral sand are found in Orth Bight and the western half of Rødsand Lagoon. Perennial algae on infralittoral coarse sediment/boulders dominate off the coast of Lolland and east of Fehmarn, with smaller occurrences on Sagas Bank, off the coast of Langeland, west of Fehmarn and west of Puttgarden (*Fucus*). Mixed angiosperms/algae communities are mainly found south of Fehmarn adjacent to the German mainland coast on a wide variety of infralittoral sediments.



Benthic habitats

- Arctica in Circalittoral Mud and sandy mud
- Arctica in Circalittoral Sand and muddy sand
- Arctica in Circalittoral patchy Sandy mud and Coarse sediment/Boulders
- Arctica in Circalittoral patchy Sandy mud and Mixed sediment/Boulders
- Arctica in Infralittoral Mud and sandy mud
- Arctica in Infralittoral Sand and muddy sand
- Arctica in Infralittoral patchy Sandy mud and Coarse sediment/Boulders
- Arctica in Infralittoral patchy Sandy mud and Mixed sediment/Boulders
- Bathyporeia in Infralittoral Mud and sandy mud
- Bathyporeia in Infralittoral Sand and muddy sand
- Cerastoderma in Infralittoral Mud and sandy mud
- Cerastoderma in Infralittoral Sand and muddy sand
- Circalittoral Mud and sandy mud
- Circalittoral Sand and muddy sand
- Corbula in Circalittoral Mud and sandy mud
- Corbula in Circalittoral Sand and muddy sand
- Corbula in Circalittoral patchy Sandy mud and Coarse sediment/Boulders
- Corbula in Circalittoral patchy Sandy mud and Mixed sediment/Boulders
- Corbula in Infralittoral Mud and sandy mud
- Corbula in Infralittoral Sand and muddy sand
- Corbula in Infralittoral patchy Sandy mud and Coarse sediment/Boulders
- Corbula in Infralittoral patchy Sandy mud and Mixed sediment/Boulders
- Dendrodoa on Circalittoral Coarse sediment/Boulders
- Dendrodoa on Circalittoral Mixed sediment/Boulders
- Dendrodoa on Infralittoral Coarse sediment/Boulders
- Dendrodoa on Infralittoral Mixed sediment/Boulders
- Eelgrass on Infralittoral Coarse sediment/Boulders
- Eelgrass on Infralittoral Sand and muddy sand
- Eelgrass/algae on Infralittoral Coarse sediment/Boulders
- Eelgrass/algae on Infralittoral Mud and sandy mud
- Eelgrass/algae on Infralittoral Sand and muddy sand
- Filamentous algae on Infralittoral Coarse sediment/Boulders
- Filamentous algae on Infralittoral Mud and sandy mud
- Filamentous algae on Infralittoral Sand and muddy sand
- Fucus on Infralittoral Coarse sediment/Boulders
- Furcellaria on Infralittoral Coarse sediment/Boulders
- Gammarus on Circalittoral Coarse sediment/Boulders
- Gammarus on Circalittoral Mud and sandy mud
- Gammarus on Circalittoral Sand and muddy sand
- Gammarus on Infralittoral Coarse sediment/Boulders
- Gammarus on Infralittoral Mixed sediment/Boulders
- Gammarus on Infralittoral Mud and sandy mud
- Gammarus on Infralittoral Sand and muddy sand
- Infralittoral Coarse sediment/Boulders
- Infralittoral Mud and sandy mud
- Infralittoral Sand and muddy sand
- Mixed vegetation/infauna community on Infralittoral Coarse sediment/Boulders
- Mixed vegetation/infauna community on Infralittoral Mixed sediment/Boulders
- Mixed vegetation/infauna community on Infralittoral Sand and muddy sand
- Mytilus on Infralittoral Coarse sediment/Boulders
- Phycodrys/Delesseria on Infralittoral Coarse sediment/Boulders
- Phycodrys/Delesseria on Infralittoral Mixed sediment/Boulders
- Rissoa on Infralittoral Sand and muddy sand
- Saccharina (Phycodrys/Delesseria) on Infralittoral Coarse sediment/Boulders
- Saccharina (Phycodrys/Delesseria) on Infralittoral Mixed sediment/Boulders
- Tanaissus in Circalittoral Coarse sediment/Boulders
- Tanaissus in Circalittoral Mud and sandy mud
- Tanaissus in Circalittoral Sand and muddy sand
- Tanaissus in Infralittoral Coarse sediment/Boulders
- Tanaissus in Infralittoral Mud and sandy mud
- Tanaissus in Infralittoral Sand and muddy sand
- Tasselweed/dwarf eelgrass on Infralittoral Sand and muddy sand

Figure App. I- 2 Benthic habitats of the local Fehmarnbelt area.

Shallow epifauna communities dominate in areas with infralittoral coarse and hard substrates. Shallow infauna is largely restricted to infralittoral sands in

the eastern half of Rødsand Lagoon and around Fehmarn. The deep circalittoral is mainly characterised by deep infauna in circalittoral mud and sandy mud, while deep epifauna is restricted to transitional areas in the west of the mapped area exhibiting coarse and mixed sediments with boulders.

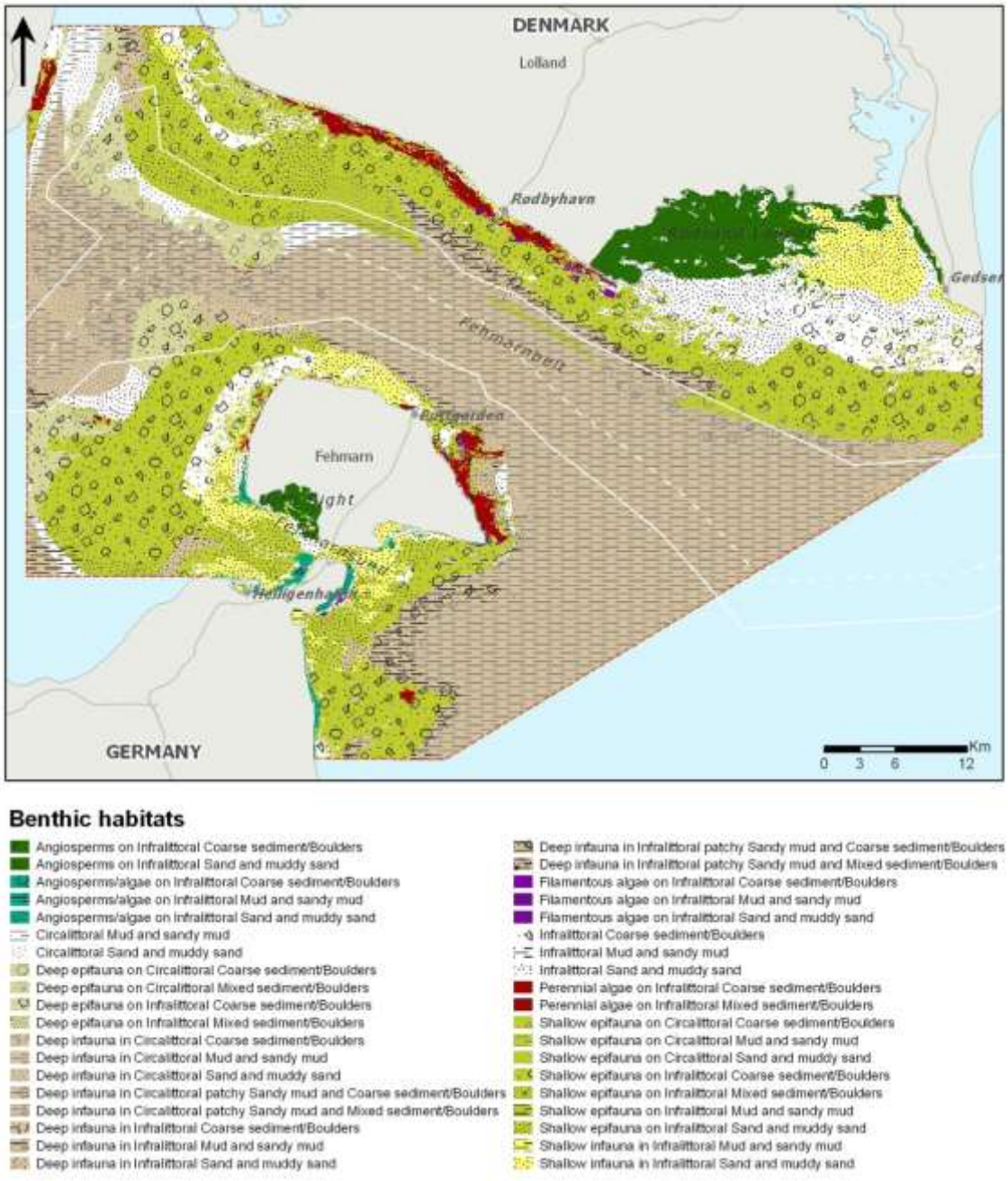


Figure App. I- 3 Simplified map of benthic habitats.

A P P E N D I X J

Confidence assessment

Data set	RemoteTechnique	RemoteCoverage	RemotePositioning	RemoteStdsAp-	RemoteVintage	BGTTechnique	PGTTechnique	GTPositioning	GTDensity	GTStdsApplied	GTVintage	GTInterpretation	RemoteInterpreta-	DetailLevel	MapAccuracy	Remote score	GT score	Interpretation score	Overall score
Multibeam	3	3	3	3	3	3	3	2	1	2	3	2	3	3	1	**100**	**80**	**75**	**85**
Aerial	3	3	2	2	3	3	3	2	1	2	3	2	3	3	1	**87**	**80**	**75**	**81**
Local ba-thymetry	2	2	2	3	1	3	3	2	1	2	3	2	3	3	1	**67**	**80**	**75**	**74**

Remote Techniques
An assessment of whether the remote technique(s) used to produce this map were appropriate to the environment they were used to survey. If necessary, adjust your assessment to account for technique(s) which, although appropriate, were used in deep water and consequently have a significantly reduced resolution (i.e size of foot-print):
3 = technique(s) highly appropriate
2 = technique(s) moderately appropriate
1 = technique(s) inappropriate

Remote Coverage
An assessment of the coverage of the remote sensing data including consideration of heterogeneity of the seabed: (See Coverage x Heterogeneity matrix below)

Coverage scores – use these to determine coverage then combine with heterogeneity assessment to derive final scores
3 = good coverage; 100% (or greater) coverage or AGDS track spacing <50m
2 = moderate coverage; swath approx 50% coverage or AGDS track spacing <100m
1 = poor coverage; large gaps between swaths or AGDS track spacing >100m

Final scores
3 = good coverage OR moderate coverage + low heterogeneity
2 = moderate coverage + moderate heterogeneity OR poor coverage + low hetero-geneity
1 = moderate coverage + high heterogeneity OR poor coverage + moderate or high heterogeneity

Remote Positioning
An indication of the positioning method used for the remote data:
3 = differential GPS
2 = GPS (not differential) or other non-satellite 'electronic' navigation system
1 = chart based navigation, or dead-reckoning

Remote Standards
An assessment of whether standards have been applied to the collection of the re-mote data. This field gives an indication of whether some data quality control has been carried out:
3 = remote data collected to approved standards
2 = remote data collected to 'internal' standards
1 = no standards applied to the collection of the remote data

Remote Vintage
An indication of the age of the remote data:
3 = < 5yrs old.
2 = 5 to 10 yrs old.
1 = > 10 years old

Biological Ground Truthing Technique
An assessment of whether the ground-truthing techniques used to produce this map were appropriate to the environment they were used to survey. Use scores for soft or hard substrata as appropriate to the area surveyed.

Soft substrata predominate (i.e. those having infauna and epifauna)
3 = infauna AND epifauna sampled AND observed (video/stills, direct human observation)
2= infauna AND epifauna sampled, but NOT observed (video/stills, direct human observation)
1 = infauna OR epifauna sampled, but not both. No observation.

Hard substrata predominate (i.e. those with no infauna)
3 = sampling included direct human observation (shore survey or diver survey)
2 = sampling included video or stills but NO direct human observation
1 = benthic sampling only (e.g. grabs, trawls)

Physical Ground Truthing Technique
An assessment of whether the combination of geophysical sampling techniques were appropriate to the environment they were used to survey. Use scores for soft or hard substrata as appropriate to the area surveyed..

Soft substrata predominate (i.e. gravel, sand, mud)
3 = full geophysical analysis (i.e. granulometry and/or geophysical testing (penetrometry, shear strenght etc))
2 = sediments described following visual inspection of grab or core samples (e.g. slightly shelly, muddy sand)
1 = sediments described on the basis of remote observation (by camera).

Hard substrata predominate (i.e. rock outcrops, boulders, cobbles)
3 = sampling included in-situ, direct human observation (shore survey or diver survey)
2 = sampling included video or photographic observation, but NO in-situ, direct human observation
1 = samples obtained only by rock dredge (or similar)

Ground Truthing Position
An indication of the positioning method used for the ground-truth data:
3 = differential GPS
2 = GPS (not differential) or other non-satellite 'electronic' navigation system
1 = chart based navigation, or dead-reckoning

Ground Truthing Sample Density
An assessment of what proportion of the polygons or classes (groups of polygons with the same 'habitat' attribute) actually contain ground-truth data:
3 = Every class in the map classification was sampled at least 3 times
2 = Every class in the map classification was sampled

1 = Not all classes in the map classification were sampled (some classes have no ground-truth data)

Ground Truthing Standards Applied
An assessment of whether standards have been applied to the collection of the ground-truth data. This field gives an indication of whether some data quality control has been carried out:
3 = ground-truth samples collected to approved standards
2 = ground-truth samples collected to 'internal' standards
1 = no standards applied to the collection of ground-truth samples

Ground Truthing Vintage
An indication of the age of the ground-truth data:
3 = < 5yrs old
2 = 5 to 10 yrs old
1 = > 10 years old

Ground Truthing Interpretation
An indication of the confidence in the interpretation of the ground-truthing data. Score a maximum of 1 if physical ground-truth data but no biological ground-truth data were collected:
3 = Evidence of expert interpretation; full descriptions and taxon list provided for each habitat class
2 = Evidence of expert interpretation, but no detailed description or taxon list supplied for each habitat class
1 = No evidence of expert interpretation; limited descriptions available

Remote Interpretation
An indication of the confidence in the interpretation of the remotely sensed data:
3 = Appropriate technique used and documentation provided
2 = Appropriate technique used but no documentation provided
1 = Inappropriate technique used

Note that interpretation techniques can range from 'by eye' digitising of side scan by experts to statistical classification techniques.

Detail Level
The level of detail to which the 'habitat' classes in the map have been classified:
3 = Classes defined on the basis of detailed biological analysis
2 = Classes defined on the basis of major characterising species or lifeforms
1 = Classes defined on the basis of physical information, or broad biological zones

Map Accuracy
A test of the accuracy of the map:
3 = high accuracy, proven by external accuracy assessment
2 = high accuracy, proven by internal accuracy assessment
1 = low accuracy, proved by either external or internal assessment OR no accuracy assessment made