Baltic Sea marine landscapes and habitats - *mapping and modelling*

BALANCE Technical Summary Report 2/4

Baltic Sea Region INTERREG III B

BALANCE

BALANCE Technical Summary Report, part 2/4

Baltic Sea marine landscapes and habitats: Mapping and modelling.

BALANCE Technical Summary Report part 2/4.

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0 EXECUTIVE SUMMARY

Part of the BSR INTERREG IIIB part-financed “BALANCE” project has focused its efforts on developing tools for identifying and mapping of ecologically relevant maps of the Baltic Sea, Kattegat and Skagerrak. The aim has been to been show that it is possible to agree to a joint approach to the development of ecological relevant models and maps at the regional sea level even though the area is shared by 10 independent States. The aim with these models and maps has also been to illustrate the use of ecological relevant maps as an integrated part of marine spatial planning as well as provide an informed input to existing/up-coming policy initiatives such as e.g. the HELCOM Baltic Sea Action Plan or the EU Marine Strategy Framework Directive.

This report summaries the work related to marine landscape and habitat mapping published in 17 independent BALANCE Interim Reports available at www.balance-eu.org.

The BALANCE mapping efforts has operated at two scales: 1) the Regional Sea scale and, 2) the local or national scale. The Baltic Sea marine landscapes have been developed for the entire Baltic Sea, Kattegat and Skagerrak, and provide a broad-scale ecological map for the entire region. Such a map can be used for broad-scale spatial planning, for implementing the EU Marine Strategy Framework Directive, the HELCOM Baltic Sea Action Plan or for assessing and planning of region-wide networks of e.g. marine protected areas.

Furthermore, numerous habitat mapping efforts occur throughout the Baltic Sea including modelling of spawning areas for commercial fish species such as coastal species such as Pike or Pikeperch to offshore species such as Cod and several approaches to the mapping of NATURA 2000 habitats such e.g. Baltic Esker Islands or Reefs. BALANCE has shown that there is a lot of high-quality mapping efforts going on in the individual countries. However, these efforts often are country specific e.g. the EC Habitats Directive Annex 1 habitat 1170 Reefs are mapped by many different methodologies making direct comparison and transnational assessments difficult, if not impossible. More effort to guide and enhance cooperation among individual national habitat mappers are necessary if e.g. regional assessments are to optimise the use of these efforts.

We hope that this report will inspire governments, managers and stakeholders to continue to participate in the development of systematic approach to mapping of marine landscapes and habitats in the Baltic Sea, thus further promoting informed management and planning within the Baltic Sea Region.

Jørgen Leth

May 2008

The Geological Surveys of Greenland and Denmark

1 INTRODUCTION

The Baltic Sea environmental degradation is caused by various commercial and leisure activities such as dredging, fisheries, tourism, coastal development and land based pollution sources, placing increasing pressures on vulnerable marine habitats and natural resources. Conflicting priorities and lack of integrated management planning is a key obstacle for resolving the current state of affairs. An ecosystem-based approach to management, based on transnational spatial planning, is a strong tool to overcome this challenge. Spatial planning is based on the integration of the complex information achieved by marine landscapes and habitat distribution maps, economic values and conservation status with information on user practices and stakeholders dependence on natural resources. With these tool in hand a holistic planning and informed decision-making can take place. It also contributes to a cost-effective and successful implementation of EC Directives, HELCOM recommendations and related policy documents.

Hitherto, a set of technical constraints have haltered the use of an integrated Baltic Sea management approach, including lack of data, lack of transnational ecological relevant maps, tedious data exchange, inconsistent data formats, and generally poorly coordinated efforts between stakeholders. BALANCE efforts have provided the Baltic Sea Region with key information and much-needed spatial planning tools that can be used to overcome such problems.

1.1 Aim of BALANCE mapping efforts

Part of the BALANCE activities aimed at identifying and mapping the distribution of Baltic Sea marine landscapes and habitats through the development of an agreed mapping approach. The aim with these models and maps was to illustrate the use of ecological relevant maps as an integrated part of marine spatial planning as well as provide an informed input to existing/up-coming policy initiatives such as e.g. the HELCOM Baltic Sea Action Plan or the EU Marine Strategy Framework Directive.

Criteria and data requirements for the characterisation of marine landscapes and a holistic approach to habitat mapping have been set up. Various activities within 4 transnational pilot areas lead to the development of generic tools and guidelines for marine spatial planning in the Baltic Sea. For areas with little biological information habitat predictive models have been developed and validated as well as satellite and airborne remote sensing techniques in shallow waters evaluated.

1.2 Geographic scope of the Baltic Sea Region

Information on the geological development and the geographic configuration is essential for the understanding of the physical properties of the Baltic Sea and, by that, important for the development of Baltic marine landscapes and habitat maps.

Since the last glaciation the Baltic Sea has shifted between freshwater and brackish periods (e.g. Sauramo 1958, Saarnisto & Saarinen 2001, Björck 1995, Svensson 1991, Andrén et al. 2000, Heinsalu 2001 & Berglund et al. 2005). In the postglacial period, the Holocene, the world ocean level continued to rise, which finally resulted in the onset of the brackish Littorina Sea for approximately 8.000-7.500 years ago (e.g. Winterhalter et al. 1981, Witkowski et al. 2005, Virtasalo et al. 2006) enabling marine species to populate the area. The Littorina Sea had a higher average temperature and the salinity reached as high as 8psu in the Bothnian Bay. During the mid-Holocene, around 5.000 – 2.500 years ago a general cooling of the region began and at the same time the salinity began to decrease. This marked the end of the Littorina Sea and the beginning of the Late Littorina Sea (at around 3.000 cal BP), and later the onset of the Baltic Sea (Russel 1985). Thus began the shaping of the marine landscapes, as we know them today.

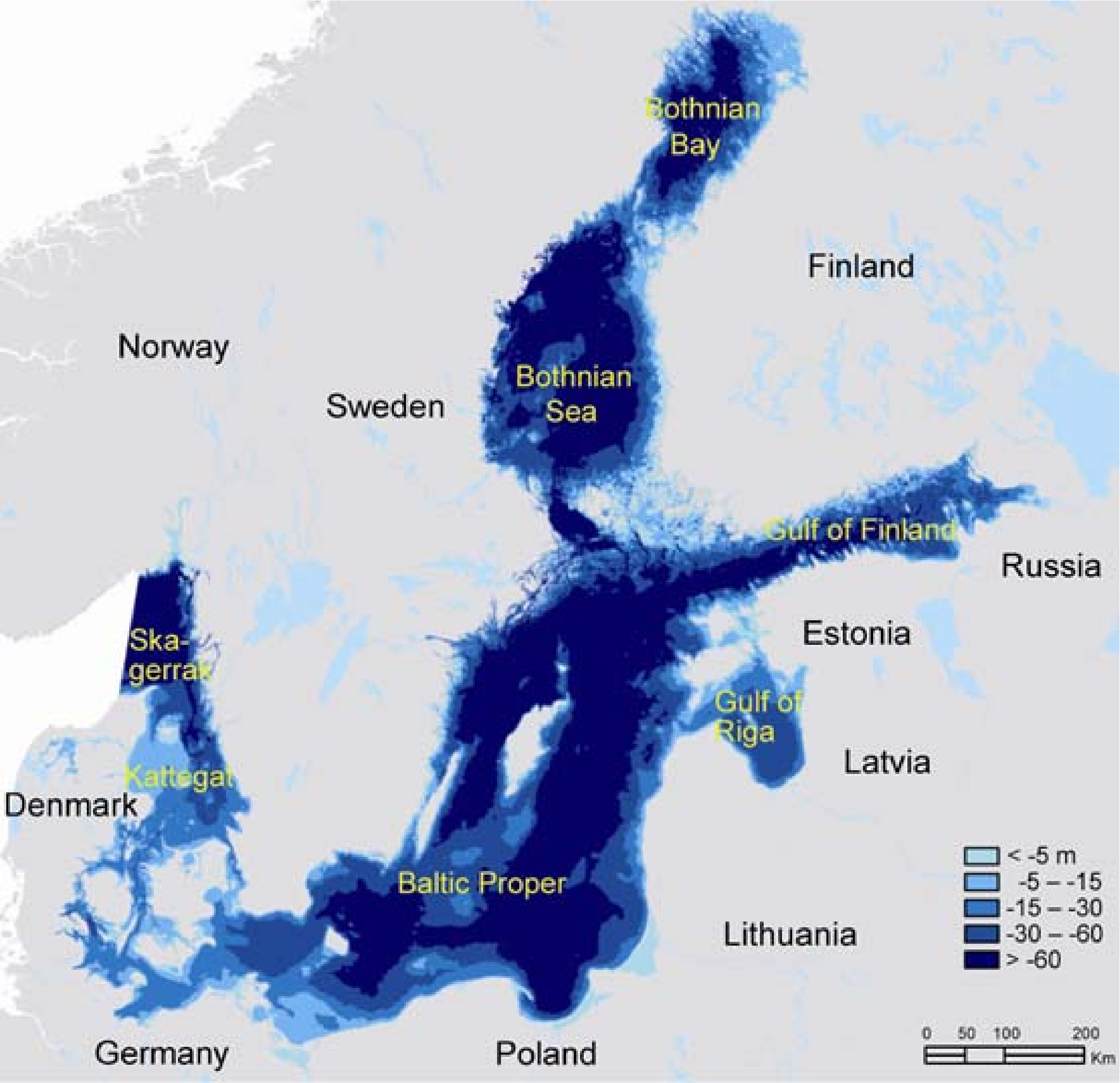

***Figure 1**. The BALANCE project working area.*

The Kattegat, the Danish Straits and the Baltic Sea together compose the second-largest brackish area in the world with a number of basins varying from almost freshwater in the northern part of the Bothnian Bay to the polyhaline/euhaline waters of the Kattegat with a distinct salinity gradient through the Danish Straits (tab. 1). The total volume of the Baltic Sea including the Danish Straits is approximately 21.700 km^3 with a surface area of 415.200 km^2 reaching depths of up to 459m with an average depth of 52m. Annually a volume of approximately a volume of 475 km^3 of fresh water passes through the Danish Straits. The Baltic Sea is also characterised by an almost total lack of tide, which makes the salinity regime very constant in often very large areas. Large islands, reefs and sandbanks dominate this area with the ancient channels forming the deepest part of the seabed. Numerous large inlets, bays and fjords are located along the coastline (fig. 1). The transition from the Kattegat to the Baltic Sea is dominated by the sills at Gedser-Darss and Drogden in the Sound, which acts as a physical barrier into the Baltic Sea for the relatively heavy saline waters of Kattegat.

Many areas are periodically or permanently stratified, which combined with the intense eutrophication causes large areas to be oxygen depleted (Ærtebjerg et al. 2003). The permanent stratification is maintained by temperature differences in the water column as well as the large annual input of fresh water from the many rivers in the region combined with occasional influx of denser more saline water from the Skagerrak over the thresholds in the Danish Straits. The weaker temporal stratification occurring in shallow waters normally will collapse due to storm events during autumn and winter mixing the water column. The Baltic Sea is characterized by large annual changes in surface temperature with up to 4 months of ice coverage in the Bothnian Bay (Jansson 1980).

Table 1: Physical characteristic of the Baltic Sea, Kattegat and Skagerrak (modified from Andersen & Pawlak 2006, Wennberg et al. 2006).

Sub-area	Area	Volume	Salinity range	Max. depth	Average depth
	km^2	km^3	Psu	m	m
1. Baltic Proper	211 069	13 045	5-10	459	62.1
2. Gulf of Bothnia	115 516	6 389	0-7	230	60.2
3. Gulf of Finland	29 600	1 100	0-7	123	38.0
4. Gulf of Riga	16 330	424	6-10	> 60	26.0
5. Danish Straits & Kattegat	42 408	802	8-32	109	18.9
Total Baltic Sea	415 266	21 721	0-32	459	52.3
Total HELCOM region	409 828[1]	-	-	-	-
Total Skagerrak	-	-	32-33	725	-

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[1] This value is based upon the shoreline data available for the marine landscape map in BALANCE delineated by the western HELCOM boundary. The difference between this value and the total Baltic Sea area may be caused by differences in delineation of the sea area or the resolution of shoreline available.

2 DEVELOPING THE MARINE LANDSCAPES

The general deterioration of the marine environment and the continued increase of human exploitation of its resources have resulted in the wide recognition that an ecosystem-based approach to the management of the human activities in the marine environment is necessary for promoting a future sustainable development. To promote such an approach, broad-scale spatial information linking ecologically relevant information to human activities is needed for the marine environment.

2.1 Rationale

The variety of current needs for broad-scale information is made tangible through various initiatives and legal requirements, such as the implementation of EU directives (EC Habitats Directive, EU Water Framework Directive, EU INSPIRE Directive and the EU Marine Strategy Directive), the identification of marine protected areas (MPAs) and the assessment of the ecological coherence and representativity of existing MPA networks, e.g. the Natura 2000 and the Baltic Sea Protected Areas network. Also transnational solutions to initiatives like the Baltic Sea Action Plan undertaken by the Baltic Sea States under the Helsinki Convention have to be provided.

Meeting these needs creates several political and technical challenges for the countries sharing the Baltic Sea, e.g. integrating the former eastern European countries into the European Community and enabling access to existing national environmental data. Biological information is needed in offshore areas where biological information is sparse. Any differences in methodology for collecting, storing and classifying of marine environmental data have to be overcome. Furthermore, relevant transnational and cross-sector information for various stakeholders utilising the marine environment, such as fisheries, marine aggregates, wind farms, nature conservation, shipping etc. should be provided.

More and more countries and the EU Commission recognise that in order to improve the management of the marine environment an approach is needed that is operational on the relatively limited amount of data available for offshore areas. Similarly, over the last few years there has been a wide recognition that nature conservation and general protection of the marine environment should strive to ensure that a network of marine protected areas are protecting a representative part of the ecological units (marine landscapes and/or habitats) present within a specific regional sea rather than the preservation of a few specific habitats or species.

Thus, given the needs mentioned above and the wish for an improved, cost-effective approach to marine management several countries have developed, tested and utilized *“the marine landscape concept”* in their quest for developing an ecosystem-based approach to management of human activities.

2.2 Origin and definitions of marine landscapes

The concept of marine landscape classification and mapping was introduced by Roff & Taylor (2000) in a viewpoint on a Canadian framework for marine nature conservation. Day & Roff (2000) applied marine landscapes as a tool for assisting the planning of networks of representative Marine Protected Areas (MPAs) protecting a certain amount of the identified marine landscapes. The tool should be based on sound ecological principles and apply a more scientific and ecosystem-based approach to marine nature conservation. The marine landscape approach has since been adopted and tested in Europe by the Joint Nature Conservation Committee in the Irish Sea Pilot Project (Vincent et al. 2004) and later expanded to include the entire UK territorial water in the UKSeaMap project (Connor et al. 2007). Likewise, the MESH project (supported by NWE INTERREG IIIB) has improved the classification and mapping of seabed habitats for the north-western European waters. The initiatives mentioned above identified three main groups of marine landscapes (Vincent et al. 2004). These are:

- *Coastal (physiographic) marine features such as fjords and estuaries where the seabed and water body are closely interlinked. In this group, both the seabed and the overlying water are included within the marine landscape*;

- *Seabed features (including topographic [and benthic ecologically relevant features]) which occur away from the coast, i.e. the seabed of open sea areas. In this group, the marine landscapes comprise the seabed and water at the substrate/water interface*;

- *Water column marine landscapes [pelagic] of open sea areas, such as mixed and stratified water bodies and frontal systems. In this group, the marine landscapes comprise the water column above the substrate/water interface*.

In the BALANCE project three main groups are identified and defined: i) The physiographic marine features of the coast, ii) the topographic features of the seabed and iii) the ecologically relevant benthic landscapes identified on salinity, sediments and photic depth (as light touching the seabed). It was not possible to identify the water column marine landscapes for the Baltic Sea, though an approach were developed identifying the broad-scale pelagic habitats for Baltic cod and sprat. Thus, BALANCE gratefully builds upon the efforts mentioned above in order to learn from previous experiences as well as to avoid potential future conflicts between terminologies when these initiatives “meet” in e.g. the North Sea and Skagerrak.

2.3 The methodology applied in the Baltic Sea Region

The approach to marine landscape mapping within the Baltic Sea is based on the use of available physical, chemical and hydrographic data to prepare ecologically meaningful maps for areas with little or no biological information. It is basically a broad-scale mapping/modelling approach based on presenting geophysical and hydrographical data in thematic GIS layers from which “marine landscapes” can be derived. In order to limit the number of possible landscapes the thematic layers are typically presented in a limited number of categories reflecting shifts in major ecological entities (e.g. distinguish between habitats assumed to be within or below the photic zone).

The given justification for including each of the geophysical and chemical features is based on its ecological relevance. After developing the Baltic Sea marine landscapes map, the justification of the individual marine landscapes using biological dataset and ground-truthing was conducted in order to test the ecological validity of the derived classes. The test will need to continue in the years after the end of the project.

The approach aims to recognise the ecological linkage between major assemblages of species and the physical environment in which they reside. It can be applied to characterising broad-scale benthic complexity using parameters such as surface sediment, temperature, water motion, photic depth and slope and for semi-enclosed areas, like the Baltic Sea, salinity and oxygen content. The mapping of the marine landscapes in the Baltic Sea follows to some extent the approach developed for UK waters (Vincent et al. 2004, Connor et al. 2007).

2.3.1 Process adopted

As the first step the necessary environmental parameters and data sets were selected for the identification of marine landscapes in the Baltic Sea, because the number of data sets applied influences the analysis as well as the final product. The challenge in marine landscape mapping is identifying the right balance between including relevant thematic maps and keeping the number of identified landscapes at a manageable level.

The next step was to harmonise and standardise the selected individual data sets and present them in unified formats. The individual data sets were obtained from relevant sources within the Baltic Sea region. Some of the data sets had to be reclassified from a large number of records due the different approaches to e.g. sediment classification, while others were unclassified continuous data e.g. salinity. The geographic coordinate system chosen was WGS84 and the projection was UTM34N. All datasets was converted to this unified system.

To produce the broad-scale benthic marine landscape map from a number of different sources efficiently raster map algebra in a GIS was used. All vector data was thus converted into the same grid format with identical grid cell size and location and presented within the same database. A draft map of each parameter was produced. This method allowed the combining of the individual data layers into a single map layer. The quality of data collated differs from high to low-resolution data. Some of the modelled datasets has 7km resolution while others have ~600m resolution. All datasets were re-gridded to a 200 × 200m grid. This process ensures data continuity but it does not increase the output map resolution.

Another major challenge to overcome in the development of ecological_relevant marine landscapes for Baltic Sea was the subdivision of the physio-chemical parameters into sensible, ecologically relevant categories. Several attempts to divide the parameters were made using judgement and feedback from various experts covering a broad range of scientific disciplines. In the end the categories were classified based on information on critical values for either important structuring species (e.g. lower lethal salinity tolerance for *Fucus serratus* identifying where *Fucus vesiculosus* become the dominating submerged brown seaweed) and/or key species (e.g. ecological requirement for cod reproduction).

2.3.2 Selecting environmental parameters

The applied approach has identified three different kinds of broad-scales characterisations of the marine environment. However, the focus has been on the ecologically relevant entities – the benthic marine landscapes.

Firstly, the topographic features were identified using only bathymetry and sediment distribution. This approach identified the topographic layout and complexity of the seabed and includes bedforms such as deep-water channels or sediment plains. This approach is good for describing the complexity and general layout of the seafloor, but it has not been possible to distinguish between the individual features based their ecology.

Secondly, the physiographic features were identified based only upon the geographic layout of the shoreline, thus showing the geographic layout of the coastal area of the Baltic Sea. The features include e.g. archipelagos or coastal lagoons. These features are to some extent ecological relevant, and some of them occur in the EC Habitats Directive. These features have been included as they shape the coastline, and are important for coastal spatial planning.

Thirdly, ecologically relevant entities of the Baltic seabed were identified using "primary" environmental parameters which all have an influence upon the benthic distribution of species assemblages. The primary environmental parameters included were sediment, salinity and the photic – non-photic zone (where 1% of available light reaches the seabed). Fig 2a..d shows the three environmental parameters used for the benthic marine landscape production and the bathymetry map of the Baltic sea..

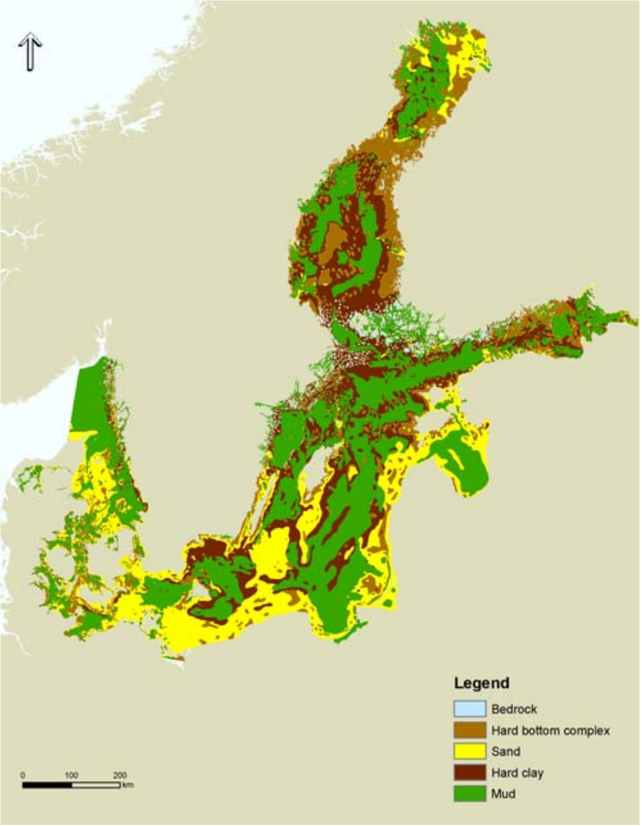

Figure 2a. *Marine seabed sediment split into 5 categories in the Kattegat and Baltic Sea (compiled from sediment information from GEUS, GSF and SGU).*

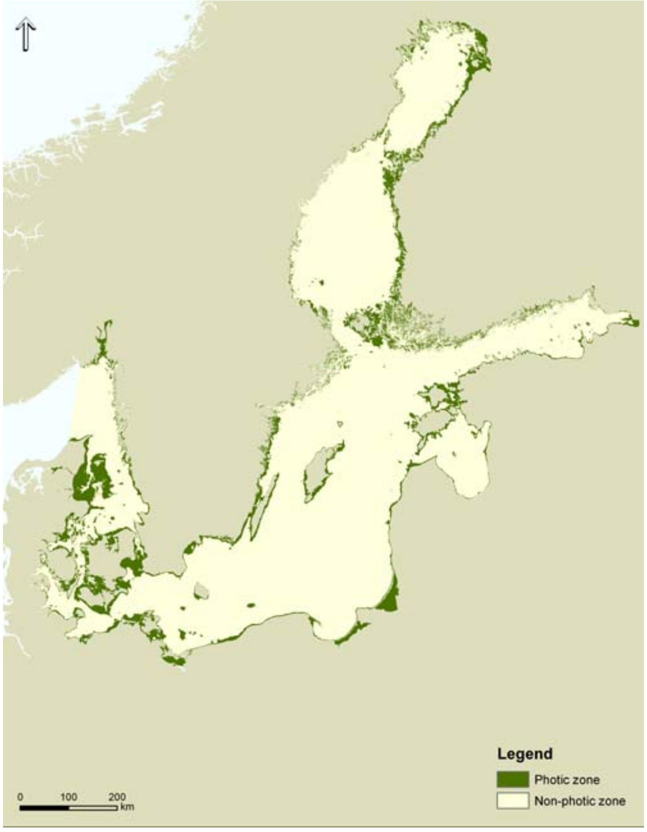

Figure2b*. Model results showing the distribution of where at least 1% available light touches the seabed (the photic zone) and non-photic zone. Data source: DHI and ICES.*

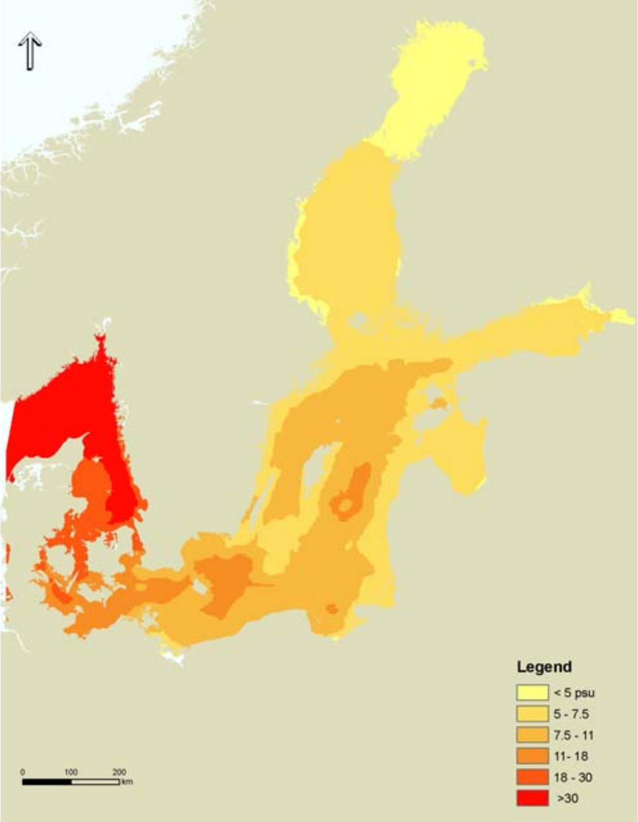

Figure2c. *Model results showing the bottom salinity (psu) field over the Baltic Sea. Data source: NERI/Denmark.*

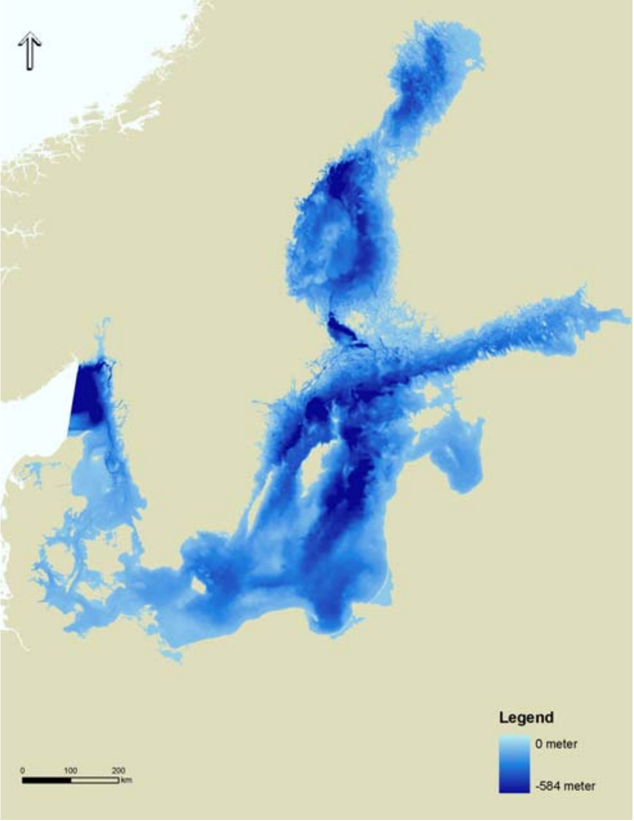

Figure 2d. *Bathymetry map of the Baltic Sea. Source: BALANCE*

3 SEABED TOPOGRAPHIC FEATURES

The topographic features were identified using exclusively bathymetry and sediment distribution. This approach identified the topographic layout and complexity of the seabed and includes bed forms such as deep-water channels or sediment plains. Using these parameters alone makes it difficult to assign significant ecological relevance of to the bed-forms identified, as e.g. depth is not an ecologically relevant entity.

3.1 Approach and data

Topographic and bedform features can be used to visualise the layout of the seabed and to gain insight in the physical and morphological complexity of the seabed. They should not be applied as stand-alone surrogates for broad-scale distribution patterns of species. They are not ecologically relevant units as no information was available which could help to distinguish or justify the ecological relevance of different topographic features.

It was decided to identify bottom topography and bedform features in the Baltic Sea in order to deepen our understanding of the geomorphological parameters, their distribution and diversity. If topographic features are to be applied as a stand-alone characterisation in future nature conservation and environmental protection schemes, then it is essential that our understanding of the ecological relevance of the individual topographic features is enhanced.

The Baltic Sea consists of a number of major basins reaching depths of up to 459m (the Landsort Deep) and has an average depth of 52m. The Baltic Sea is separated from the Kattegat by a number of sills such as at the Gedser (Denmark) – Darss (Germany) or at the Drogden in the Sound between Denmark and Sweden. These sills act as a physical barrier into the Baltic Sea for the relatively heavy saline waters of Kattegat. In Kattegat there are only a few deep areas reaching a maximum depth of 120m, but with an average depth of 23m. The trenches in Skagerrak reach depths of up to 725m (tab. 1 & fig. 3). The bathymetry was use to derive the slope within the Baltic Sea.

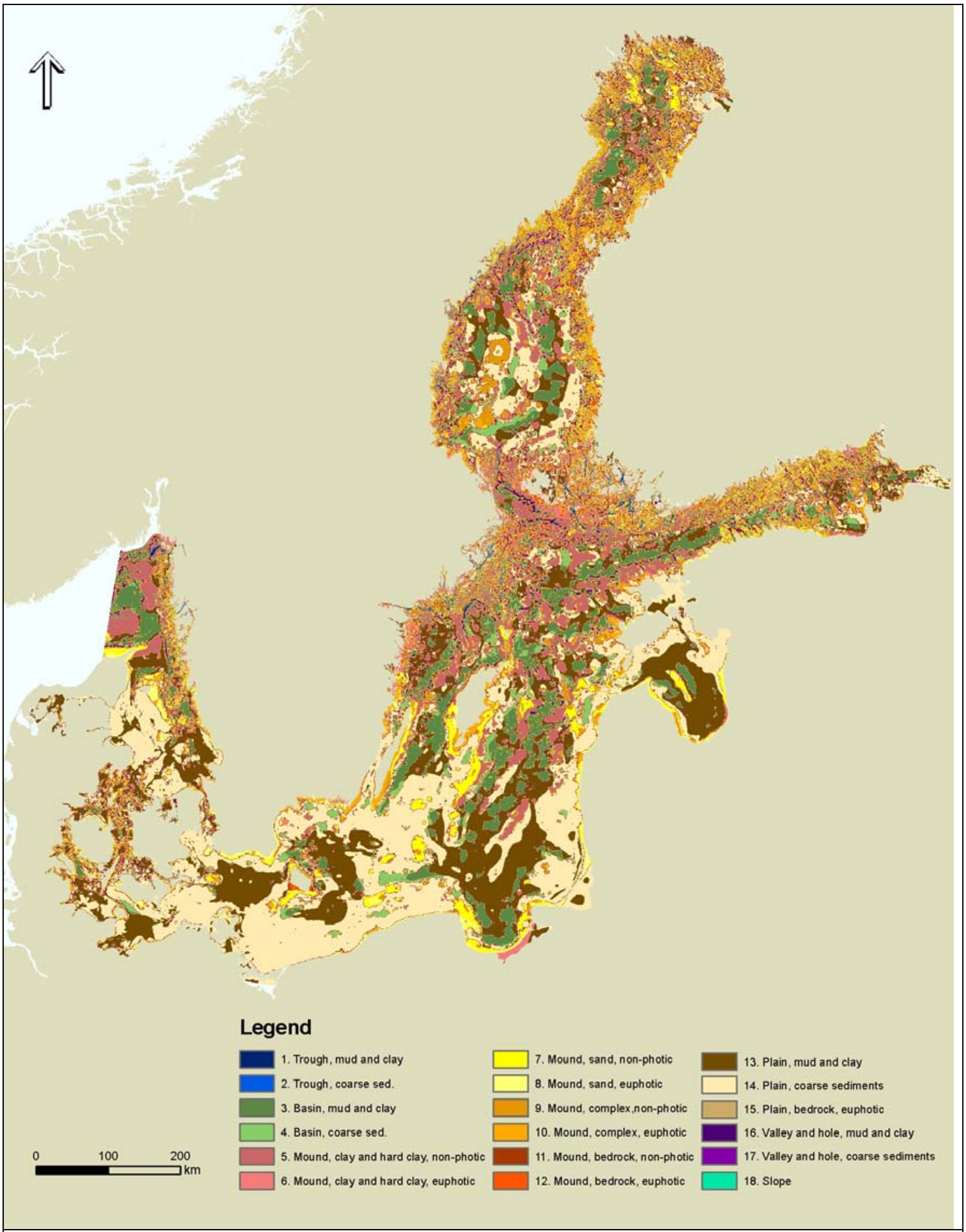

Figure. 3*. Topographic and bed-form features identified in the Baltic Sea.*

4 COASTAL PHYSIOGRAPHIC FEATURES

The physiographic features were identified based only upon the geographic layout of the shoreline. They can be used to characterise the transition zone from land to sea, and can be used to illustrate the physiographic complexity of the near-shore environment in the Baltic Sea. The features are to some extent ecological relevant, and some of them occur in EU legislation e.g. in the EC Habitats Directive. There is no truly objective approach for identifying these features and in e.g. the EC Habitats Directive the marine habitats are identified at very different scales or level of classification. These features have been included as they shape the coastline, and are important for coastal spatial planning. In order to identify physiographic features in higher detail and determine their ecological relevance datasets of higher resolution is needed than what was available for the project.

Coastal physiographic features represent the area of the sea with the highest concentration of human activities and interests. They should not be applied as stand-alone surrogates for broad-scale distribution of species assemblages as they are not, at this point, ecological relevant units.

4.1 Approach and data

Coastal features cover areas where the seabed and water body are closely interlinked (Golding et al. 2004). The seabed as well as the overlying water mass is included within this marine landscape. Coastal features (estuaries, lagoons, sounds, bays, archipelago, and fjords) are identified by coastline, bathymetry and salinity. Marine landscapes aim to describe regional scale features of the Baltic Sea. Therefore, only the largest and most apparent features are distinguished from the result.

In total 7 features were identified. The approach presented by BALANCE should only be considered as a first step towards identifying these features. If more detailed results should be desired it would require access to a high-resolution coastline. Furthermore, a more ecological relevant classification could be developed if hydro-morphological modelling was applied as well.

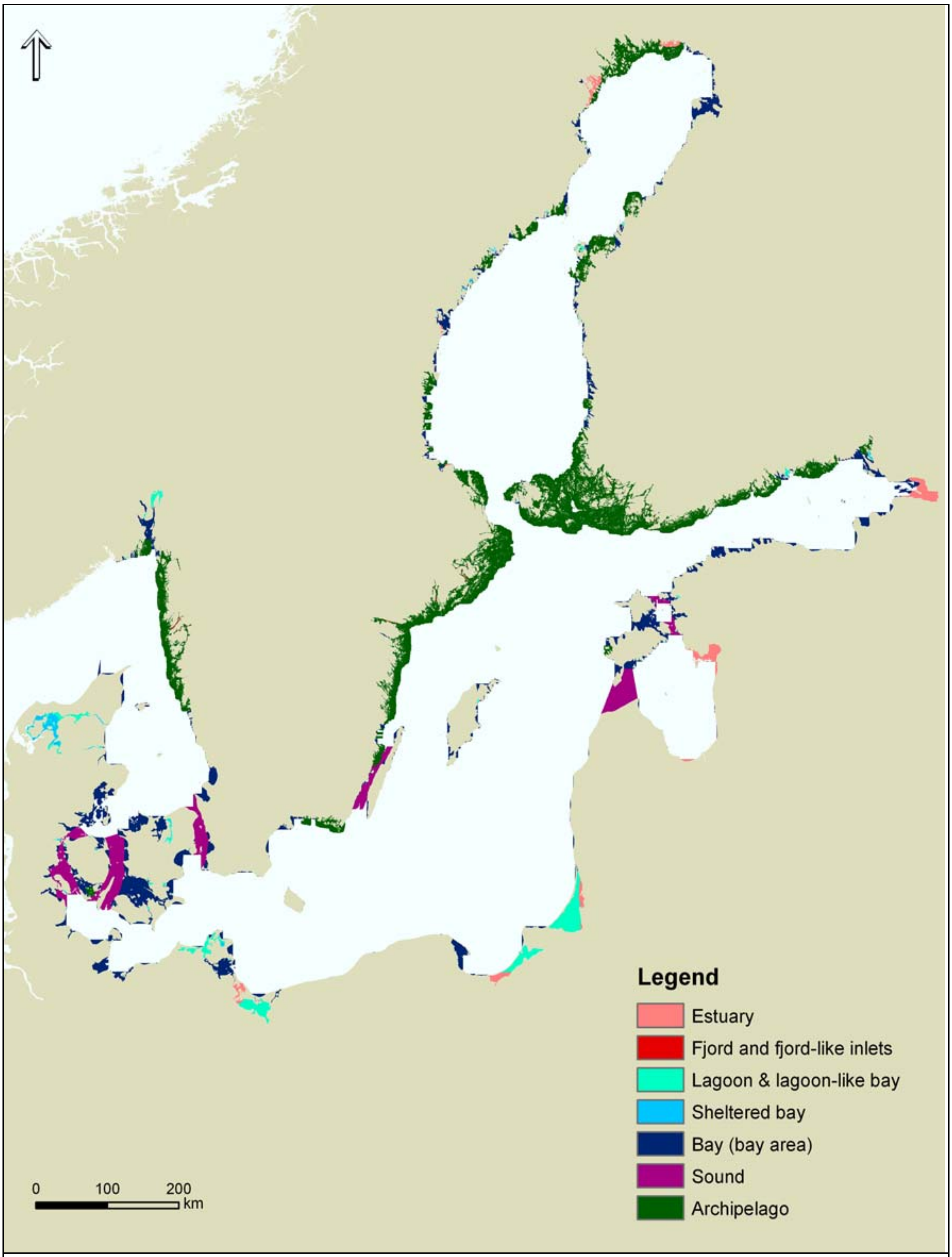

Figure 4. *Coastal physiographic features identified in the Baltic Sea.*

5 BENTHIC MARINE LANDSCAPES

One of the aims with developing marine landscapes for the Baltic Sea, were to provide input to the assessment of the network of marine protected areas in the Baltic Sea performed elsewhere in BALANCE. In order to achieve this goal, it was important to deliver a broad-scale ecological relevant map covering the entire Baltic Sea marine region. The benthic marine landscapes illustrate the BALANCE approach to delivering such a map. It is important to note that while this map is not better than the data available, it has been showed that the individual marine landscapes is different from each other in regard to the communities found within them (Al-Hamdani et. Al. 2007; Reijonen et. Al. 2008)

5.1 Approach and data

A variety of environmental (i.e. physical and hydrographic) parameters have an influence on shaping the broad-scale distribution of major species assemblages, thus enabling an ecologically meaningful characterisation of the marine ecosystem.

The primary environmental parameters included for the developing the benthic marine landscapes were sediment, the photic – non-photic zone (where 1% of available light reaches the seabed) and salinity as they are important for determining broad-scale distribution of species in a regional Baltic Sea context.

The individual parameters are presented here with examples of how the parameter may influence the distribution of the marine organisms in the Baltic Sea. A justification of the chosen categories is also included. Similarly, each description includes a more technical presentation of data, their origin, descriptions of the models used and limitations/opportunities of the marine landscape mapping process.

5.2 Seabed sediments

Sediment was chosen, as it is fundamental for the distribution of benthic organisms. For example, macroalgae need a hard substrate to be attached, while sea grasses need soft substrate to grow. There was no readily available sediment map covering the Baltic Sea. Such a map was therefore created for the development of the benthic marine landscapes. The Baltic nations have traditionally classified sediments according to their own national classes. A major task in combing maps was to harmonise sediments classes to the BALANCE classifying system and transfer them to ArcGis vector format – a total of 19 classifications were harmonised. The first step of recalibration was to predict the surficial material for each sediment category in all maps, and then reclassify these predicted materials into the BALANCE substrate class. For detailed information on the harmonisation process and origin of the individual data including a comparison to the EUNIS classification, please refer to Erlandsson & Lindeberg (2007), Kotilainen et al. (2007) and Reijonen & Kotilainen (2007).

National seabed sediment classification categories were harmonized in order to produce one classification scheme, which had to be as simple as possible, but still take into account biological importance. The resulting classification scheme consisting of five sediment classes are applied in the mapping and modelling of the Baltic Sea marine landscapes. These are:

I. Bedrock.

II. Hard bottom complex, includes patchy hard surfaces and coarse sand (sometimes also clay) to boulders.

III. Sand including fine to coarse sand (with gravel exposures).

IV. Hard clay sometimes/often/possibly exposed or covered with a thin layer of sand/gravel.

V. Mud including gyttja-clay to gyttja-silt.

5.3 Available light

Depth or bathymetry in itself is not an ecological structuring feature, but it is likely to prove useful as a surrogate to describe vertical zonation from the littoral zone to the deepest trenches in the Skagerrak. Depth is difficult to use as it reflects the ecological importance of a series of independent physical environmental features, their often-complex interaction, and how they shape the marine environment for living organisms.

The environmental parameter used for determining the relevant depth zonation in Kattegat and the Baltic Sea is the photic depth. Light or rather irradiance is, strictly speaking, a measure of the amount of energy falling on a flat surface. From an ecological point of view, available light is one of the primary physical parameters influencing and structuring the biological communities in the marine environment, as it is the driving force behind the primary production by providing the energy for the photosynthesis – energy that ultimately is transferred to other organisms not capable of photosynthesis. The depth of the photic zone is traditionally defined, for benthic plants, as the depth where 1% of the surface irradiance (as measured just below the water surface) is available for photosynthesis.

Available light at the seabed was included and divided into two categories – the photic and non-photic zones. It is used to distinguish the zone where primary production occurs from the zone where no (or little) primary production occurs. The two categories reflect the significant ecological difference between the shallow water with the presence of submerged aquatic vegetation, and the deeper waters where fauna (and bacteria) dominate diversity of species, abundance, and biomass.

The categories are:

I. The photic zone (where at least 1% of the available light touches the seabed).

II. The non-photic zone.

5.4 Salinity

Salinity has been included as it is one of the primary physical parameters structuring the distribution of habitats, the associated species and their abundance within the Baltic Sea. A general trend is the profound decrease in the number of marine invertebrates, plant and fish species along the salinity gradient from the Kattegat to the Baltic Sea, while the number of fresh water species increase in the Gulf of Bothnia and the Gulf of Finland. The proportion of marine species to fresh water species also changes along the salinity gradient (Nielsen et al. 1995).

The Baltic Sea is characterised by some fairly stable salinity gradients ranging from > 30psu in the northern Kattegat to almost fresh water in the Bothnian Bay. As the salt concentration influences marine life in a number of different ways, salinity was split into 6 categories reflecting the distribution of structuring species.

The comprehensive analysis of the salinity distribution within the Skagerrak, Kattegat and Baltic Sea was made on salinity data from an extensive number of field stations ranging from the Bothnian Bay to the Baltic Proper including the Gulf of Finland and the Bay of Riga. Data was also included from stations in the German Bight, Danish Straits, Kattegat and Skagerrak. These provided the input to a three-dimensional primitive equation model based on the COHERENS model (Luyten et al. 1999), which was used for quantifying transports and distributions of salinity, temperature and additional tracers. For more detailed information on the origin of data and description of the model, please refer to Bendtsen et al. (2007). This analysis provided the description of the bottom (and surface) salinity conditions in the Baltic Sea.

Salinity also varies vertically and stratification between a low salinity surface layer and a bottom layer with higher salinity is common in the Baltic Sea. Rather sharp salinity boundaries are called haloclines, which combined with temperature boundaries (thermoclines), define an often very robust boundary between a high salinity cool bottom layer and a low salinity warmer surface layer called a pycnocline. Haloclines occur both horizontally and vertically.

Unfortunately, there exist no relevant coherent species data covering the Baltic Sea Region, which could have been linked to the salinity map through a multivariate analysis. Instead it was decided to focus on known requirements of certain key species such as large brown algae e.g. at what salinity does *Fucus vesiculosus* become the dominant marine macroalgae. The choice of these organisms was decided using expert judgement partly supported by significant amounts of scientific data on e.g. the critical life requirements of the Baltic cod (*Gadus morhua*) and partly based on pragmatism such as adapting it to the categories defined by the EU Water Framework Directive. Table 2 summarises the reasoning behind the 6 specific categories.

Table 2: Categories for sea bottom salinity and their justification based on expert judgment.

Category	Salinity range	Justification
Oligohaline I	< 5psu	This picks up the biogeographic boundary in the Quarken area. This region has a higher content of fresh water species.
Oligohaline II	5 – 7.5psu	7.5psu equals roughly the area where *Fucus serratus* has its distributional boundary (Öland, SE) making *Fucus vesiculosus* the dominating sublittoral brown algae. This category also has the lowest number of species and is thus the most vulnerable part of the Baltic Sea.
Mesohaline I	7.5 – 11psu	11psu is the minimum requirement enabling cod (*Gadus morhua*) eggs to float. As cod is an important commercial species for the Baltic Sea Region this interval was chosen in order to increase applicability of the marine landscapes for environmental management. It also helps to separate offshore environment from coastal areas in large parts of the Baltic proper.
Mesohaline II	11 – 18psu	18psu is the minimum requirement (roughly) for sexual reproduction or limiting distribution of many marine macroalgae, e.g. *Laminaria digitata* and *Ascophyllum nodosum,* and of e.g. Echinoderms. Picks up the biogeographic boundary in the Sound. 18psu is also the boundary in the EU Water Framework Directive further increasing the applicability of the marine landscape maps.
Polyhaline	18 – 30psu	Most marine species are able to survive within this interval. It is also an interval defined by the EU Water Framework Directive.
Euhaline	> 30psu	Requirement of truly stenohaline species separating the marine parts of the Skagerrak and North Sea from the fresh water influenced water masses of the Kattegat and Baltic Sea region.

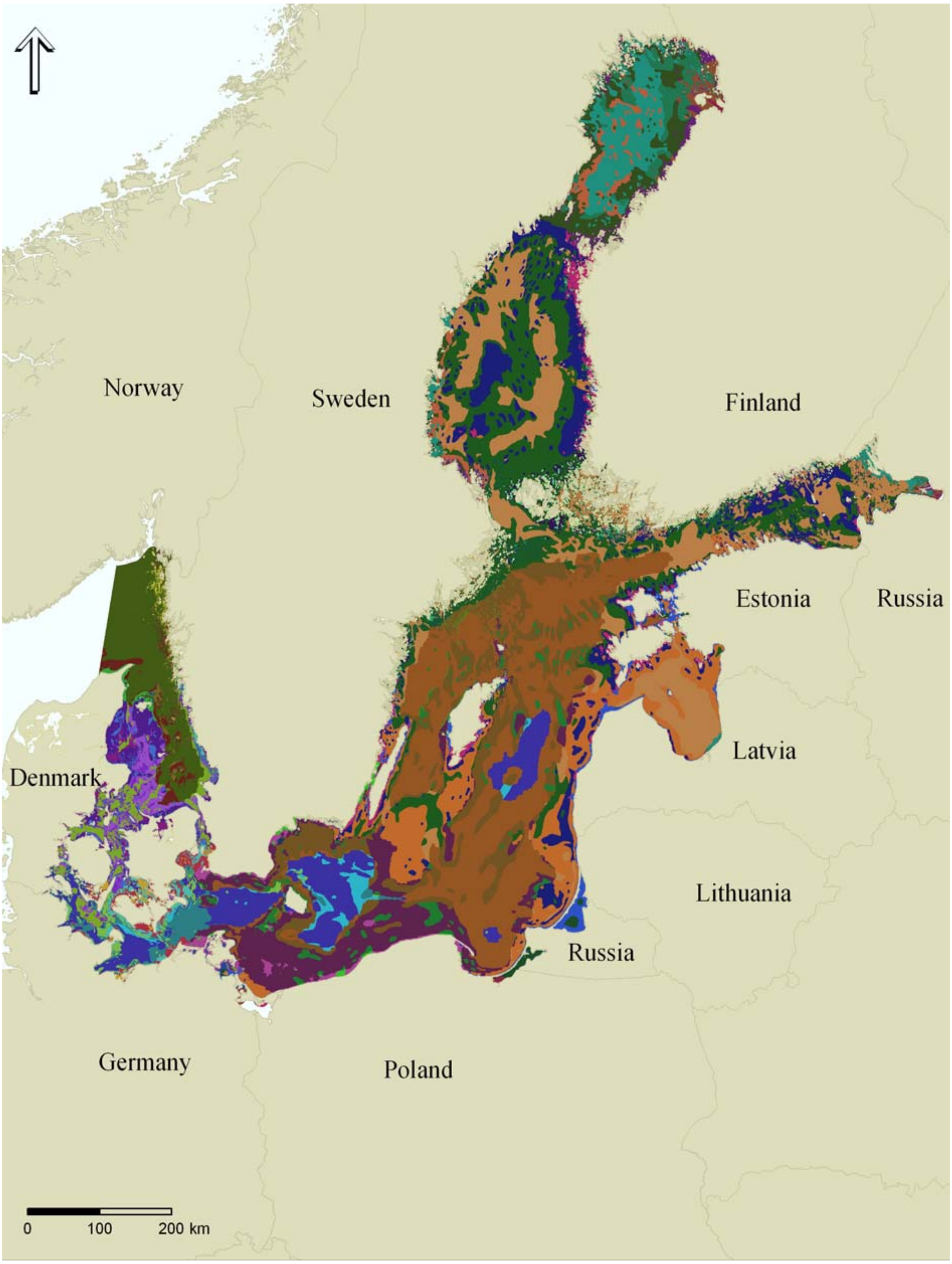

Figure 5. *Benthic marine landscape map of the Baltic Sea. Source: BALANCE.*

5.5 Secondary physical datasets

Other environmental parameters were considered their relevance in the regional context assessed. Some were either more relevant for detailed habitat mapping e.g. wave exposure, not a significant influence on the species distribution in the Baltic Sea e.g. temperature or lastly, of only minor importance compared to other geographic areas, such as tidal currents. Environmental parameters such as oxygen concentration were considered as an expression for the environmental pressure and thus not suitable for a primary description. Furthermore, the aim was to limit the number of potential combinations within a manageable number.

The “secondary” physio-chemical data layers that have been prepared during the project are:

I. Average bottom temperature
II. Average ice cover
III. Bottom current velocity
IV. Oxygen depletion

It was decided not to include these layers among the primary data sets. However, they will provide any future initiatives with a starting point for each feature (data access issues, justification of intervals etc.). A fairly detailed description of each layer can be found in Al-Hamdani & Reker (2007).

5.5.1 Recommended actions: Baltic-wide benthic landscape map

The development of Baltic-wide broad-scale benthic landscapes succeeded in establishing the first delineation of individually distinct coarse-scale regions reflecting broad-scale species assemblages. The results underline that marine landscape maps covering entire eco-regions are potentially strong tools providing a basis for a broad-scale spatial approach to the planning and management of the marine environment. The approach presented here is fully applicable for an ecologically relevant characterisation of the Baltic Sea. However, end users might find it necessary to validate and further refine and improve the maps. Such validations and refinements are necessary in order to fully exploit the potential application of the maps and for linking them to the implementation of national legislation, EU Directives and other policy documents such as the Baltic Sea Action Plan and the EU Maritime Policy.

Validation could be made either by carrying out an independent classification based entirely on a statistical approach or based on a classification with fuzzy logic acceptance criteria. The future success of producing marine landscape maps with a higher accuracy and precision and with information on ecological significance and sensitivity depends on access and availability of existing data as well as a transnational and cross-sectoral approach to this spanning the Baltic Sea. As such, the work presented in this report should be seen as a first step towards the broad-scale mapping of the marine landscapes in the Baltic Sea to be further developed by EU Member States for implementing EU maritime policy and legislation.

6 HABITAT MAPPING AND MODELLING

Mapping and modelling of marine habitats in the Baltic Sea region varies in approach between the different types of habitats, between specific areas, and between countries. The challenges of marine habitat mapping and modelling are numerous. Methodologies adopted by BALANCE for meeting some of them are described below. The use of different approaches often reflects genuine difference in physical or ecological structure, or both. Although in some cases differences in approach reflect spatial and qualitative difference in available data and lack of a common classification system of marine benthic and pelagic habitats in the Baltic Sea region. Despite these differences a large degree of harmonisation has been achieved in the methods applied in the BALANCE pilot areas. To some extent this has secured the comparability of results and facilitated a transnational and cross-sector approach.

Habitat mapping and modelling have been performed within four pilot areas (figure 6) governed by the following aims:

- Identify data of possible use for mapping and modelling of marine habitats in the Baltic Sea area, including of marine Natura 2000 Annex I habitats and/or the marine habitats of selected species.
- Agree on approaches to mapping and modelling of selected marine Natura 2000 Annex I habitats and/or of the habitats of selected species.
- Develop models to demonstrate the usefulness of data and various methods for mapping and modelling of selected marine habitats in the Baltic Sea area.

***Figure 6**. Skagerrak, Kattegat and the Baltic Sea with the four pilot areas. The image is used by kind permission of the SeaWiFS Project, NASA/Goddard Space Flight Centre and ORBIMAGE.*

In total 16 case studies (table 2) on predictive modelling of spatial distribution of marine habitat were carried out on selected species within the four pilot areas (fig. 6):

1) Kattegat-Skagerrak; 2) Bornholm Deep; 3) Archipelago Sea and 4) Coastal areas of Estonia, Latvia and Lithuania.

The studies included benthic habitat-forming kelps, bladder wrack, and other macro algae, submerged plants, reef-forming mussels and habitat-structuring lobsters. Essential fish habitats were modelled for the ecological and economical important species plaice, flounder, sole, pike, perch, pike-perch, roach, and cod. The latter habitats were modelled specifically for juvenile or spawning stages.

Several of the case studies are rather comprehensive, thus detailed descriptions of those studies are being published as separate Balance Interim reports (see www.BALANCE-eu.org).

Classification systems (e.g. EUNIS) provide classes with discrete boundaries that can be perceived by managers and policy makers. Yet a full Baltic classification system has not yet been developed, and the existing systems have not been found to apply very well to the Baltic Sea region. The classification system developed in UK waters is difficult to apply to the Baltic Sea due to the significant differences in prevailing environmental conditions (tide, salinity, age/geo-history) as well as different approaches to sampling marine information in the 10 countries composing the Baltic Sea Region.

Table 2. Pilot studies of mapping and modelling of marine benthic and pelagic habitats in the Baltic Sea region in the BALANCE pilot areas 1, 2, 3, and 4.

Marine habitats	Mapping and GIS analyses	Spatial predictive models
Pilot Area 1: Kattegat - Skagerrak	3.1 Mapping of seabed and habitats in the Norwegian Rauøfjorden-Hvaler	4.1 Spatial prediction of *Laminaria hyperborea* in the Norwegian Skagerrak
	3.2 Mapping of NATURA 2000 habitats in Kattegat using acoustic and ground truth methods	4.2 Spatial prediction of *Nephrops norvegicus* in the Swedish Skagerrak
	3.3 Mapping of hard bottom and sandy habitats and modelling seaweed forest on hard substrate in Kattegat, Danish waters	4.3 Spatial prediction of nursery grounds for juvenile flatfish in the Danish Kattegat
	3.4 Mapping of soft bottom fauna between Læsø and Anholt islands, Danish waters	▨
Pilot Area 2: Bornholm deep	▨	4.4 3D-modelling of pelagic habitats of cod and sprat spawned eggs and adults
Pilot Area 3: Baltic Archipelago Sea	3.5 Mapping of NATURA 2000 habitats in Swedish and Finnish waters	4.5 Spatial prediction of *Fucus vesciculosus*, *Zostera marina*, and *Mytilus edulis* in the Finnish Archipelago
	3.6 Mapping of EUNIS habitats in Finnish waters	4.6 Spatial prediction of fish habitats in the Swedish Archipelago
Pilot Area 4: Coastal areas of Estonia, Latvia and Lithuania	3.7 Mapping of EUNIS habitats in Lithuanian waters	4.7 Modelling of species habitats in Estonian waters
	3.8 Wave impact on coastal habitat along the Latvian Baltic Proper coast	4.8 Spatial prediction of *Furcellaria lumbricalis* in Lithuanian coastal waters

6.1 Data used for mapping and modelling

A variety of data were used in mapping and modelling of marine habitats. Some were based on analogue information, which had to be digitalised, while others already existed in a digital format. All data were geo-referenced which allowed extensive use of GIS tools.

6.1.1 Data format (GIS)

Throughout all studies of benthic habitats, the GIS software packages of ArcGIS were used as standard. Within the pilot areas case studies were carried out involving data from a single country. However, in pilot area 3 a time-consuming effort has been put into the harmonising of data and results between Sweden and Finland to create cross-border maps of the benthic habitats studied.

Temporal variation has exclusively been considered in pilot area 2 in the modelling of the pelagic habitat of adult cod spawning and of the spawn. However, temporal scale can be added to all the habitat models if and when time series data become available.

6.1.2 Data for mapping and predictive modelling

Mapping and modelling was performed on the basis of point or transect measurements in the form of vector data and as interpolated or modelled surfaces in the form of raster data. Raster data may include areas of missing or invalid data, as an example a land mask or mask defining area of low coverage.

The parameters applied in the BALANCE habitat mapping and modelling are:

- Bathymetry
- Substrate
- Oceanographic parameters: Light and wave exposure
- Water chemistry: Salinity, temperature and oxygen

6.2 Development of multi-criteria evaluation (MCE) models

Baltic-wide landscape maps and regional maps of NATURA 2000 habitats in Pilot area 3 were developed by GIS-based multi-criteria evaluations (MCE) using the Raster Calculator routine of Spatial Analyst in ArcGIS and the Map Modeller routine in Erdas Imagine. Selection of data layers for the MCE models was based on expert judgements in both studies. Each data layer in the classification was given the same weight and all acceptance criteria were defined as hard classifiers (i.e. criteria defined numerically with precise cut-off values). The development of the Baltic-wide broad-scale landscape maps has been presented in the chapters 3, 4 and 5. The NATURA 2000 habitat models of Pilot area 3 used the following data layers:

- Bathymetry: Nautical chart, topographic maps (1.25.000)
- Coastline: ortophoto (1m), Landsat ETM (25m) basic map (1:10.000), Esker Island database (vector)

- Substrate and soil: 1:50.000
- Wave exposure: 25m model
- Secchi depth: national wq database
- Coastal exploitation: 1:10.000
- Archipelago zone (50m)
- Slope: from depth model (25m)
- Photic depth: modelled from land coverage in 5km radius and secchi depth.

Table 3. Data and analyses used for MCE-modelling of NATURA 2000 Annex I habitats and EUNIS habitats in the Baltic Sea region.

Habitat	Analyses	Data
1110 Sublittoral sandbanks	Ground-thruthing MCE	Acoustic: Multibeam Depth, substrate, slope
1130 Estuaries	MCE	Depth, freshwater flow, not exposed coast, presence of reeds
1150 Coastal lagoons	MCE	Depth, size, lack of freshwater inflow
1150 Gloes	MCE	Depth, size, lack of freshwater inflow
1160 Large, shallow inlets & bays	MCE	Depth, size, lack of freshwater inflow, geometry
1170 Reefs	Ground-thruthing MCE	Acoustic: multibeam, interferometric and side-scan sonar Depth, exposure substrate, slope
1610 Baltic Esker Islands	MCE	Depth, substrate, slope with submergence
1620 Boreal Baltic & small islands	MCE	Depth, exposure, location in archipelago (outer zone)

Table 4: The criteria used to delineate potential Annex I habitats in Pilot area 3

Habitat	Depth	Size	Exposure to wave action	Substrate	Freshwater flow	Other
1110 Sandbanks	<= 30m			Sand >= 70%		Elevated from surrounding seafloor
1130 Estuaries	<= 3m at the mouth				At least 1 river with >= $1km^2$ watershed[1]; >=2 m^3/s^2 flow	Not on an open coast Reed beds present
1150 Lagoons	Max <=6m	< 30 ha			No river inflow	
1160 Large Bays	<20% of area >15m (6m) deep	>= 20ha (>= 100ha)			No river inflow	Wider than long at least 1:1
1170 Reefs	<= 6m <= photic depth		Sheltered and higher (algal zonation)	Hard substrate		Elevated from surrounding seafloor
1610 Esker Islands	<= 10m <= photic depth			Sand or moraine (>= 50% of cover)		Submerged part elevated from the surrounding seafloor
1620 Boreal Islets	<=6m[1] <= photic depth		Sheltered and higher			In outer archipelago zone

6.2.1 *Evaluation of MCE models of NATURA 2000 habitats*

The multi-criteria evaluation (MCE-model) of NATURA 2000 habitats in the archipelago sea between Sweden and Finland proved the potential for using MCE models with existing GIS data on key habitat drivers at a somewhat smaller scale (BALANCE Interim Report no. 30). However, the results show that MCE are very sensitive to the quality of existing GIS data. Basic landscape data that outlines water and land have sufficient quality, as they are available in very detailed resolution (scale 1:20.000) that is needed to identify small habitats like small islands and lagoons, although maps in scale 1:50.000 may well suite the purpose for most habitat modelling. Similarly, the data on wave exposure and land cover also have sufficient quality to be used in MCE modelling of NATURA 2000 habitat. However, better data on water flow from small rivers are wanted, as well as data on water quality. The main datasets missing to produce high-quality detailed habitat maps for the region are high resolution maps of the sediment characteristics and depth (e.g. from multibeam surveys). Besides resolution, the current depth and substrate data available has two major problems; a) There are quite large areas with very limited or no information available due to military restrictions and b) the shallow areas of 0 – 6m are not well outlined. A separation between large shallow inlets and bays and long narrow inlets are not done. Additionally, the mapped habitats give no information about the vegetation cover in the areas.

6.2.2 Recommendations

To enhance the overview for management use in Pilot area 3 the achieved results could be complemented with models showing:

- Vegetation cover in shallow soft bottoms
- Vegetation cover around islands
- Shallow hard bottoms with zoned vegetation
- Deeper hard bottoms with zoned vegetation
- Deeper soft bottoms separated into sandy/muddy areas without oxygen depletion
- Areas with high values for fish

6.3 Development of predictive habitat models

In the BALANCE context, predictive modelling covers statistical analyses correlating biological data with physical, oceanographic, and chemical data. Models were built for areas for which environmental data were available for the major part of the area. Response samples of species and habitats were both given as presence-absence and abundance/density. Environmental predictors were selected with known and potential structuring effect, such as depth, substrate, wave exposure, and salinity. A subset of the environmental predictors explaining most of the variance of the response variable was used to predict the species/habitat distribution.

The main method used for spatial modelling was Generalised Additive Models (GAM) based on known key variables in relation to the distribution of habitat-building species and essential fish habitat. GAM has proven a useful technique to incorporate non-linear relationships commonly found between animals and abiotic habitat features into statistical prediction models. For reasons of comparability Generalised Linear Models (GLM) and GAM were used as a basis for all predictive modelling in BALANCE. GLM and GAM are the most widely used statistical models in the fields of ecological modelling biodiversity and conservation. GAM, which is a semi-parametric extension of GLM, has been successfully applied in habitat modelling in terrestrial as well as marine studies, due to its flexibility in resolving complex responses between species and environmental data. In addition, GAM was chosen due to its characteristic smoothed coarse-scale modelled distributions which fitted the coarse-scale focus of BALANCE well. In order to ease trans-national collaboration on the application of GLM/GAM all WP2 partners used the software package GRASP (Generalized Regression Analysis and Spatial Prediction). Detailed descriptions of the applied models can be found in the BALANCE Interim Reports.

The modelling results were transferred to a GIS, and a suite of routines were used for comparison and evaluation of resulting maps in ArcGIS, as well as for merging the results of different habitats models and maps into a single, coherent map of the included habitats.

6.3.1 Data requirements

The predictive habitat modelling activities of BALANCE have high-lighted some general requirements for the GIS datasets to be used in predictive spatial modelling of marine habitats in the Baltic Sea.

Firstly, it is clear that predictive modelling should be preceded by the design of a conceptual model outlining the potential regulating mechanisms before conducting a survey or utilising data from older surveys. This will enable a better and more conservative selection of environmental variables concentrating initially on the potentially most important ones.

Secondly, it is important that the sampling design comprises large or entire parts of the environmental gradient that governs the distribution of the target species, habitat or assemblage in question. Many of the datasets collected in the Baltic monitoring programs do not meet this criterion. They are often, instead, targeted against the core areas of the distribution of the species. When producing habitat maps over large geographical areas, it is important to keep in mind that there may be regional differences in the species-environment relationship. If the statistical models are based only on a smaller, restricted area, biases may occur when applying the models to larger areas, especially if the environmental variables used as predictors are not primary drivers for the distribution of the target species. A trade-off in this respect is the tendency for the strength of the model predictions to decrease with increasing prediction area, thus demanding more precise and accurate descriptions when increasing prediction area.

Thirdly, it is important that the coverage of samples is relatively even and not too restricted to certain habitats. The latter is potentially a problem for some organism types that are only possible to sample in certain habitats. For example, many biological sampling methods are restricted either to soft or to hard bottom substrates. It may therefore be difficult to cover the potential distribution of species that are not closely associated with a certain bottom type.

Fourthly, it is, especially when considering the objectives of BALANCE project and the requirements of the work package 3 (connectivity and coherence) and work package 4 (MPA selection and network development), important that the explanation models can be used for predicting habitat distributions over larger spatial scales. This condition does not only affect the requirements of the field data but also, equally important, demands high resolution maps of the environmental variables that cover the whole areas of interest.

6.3.2 Predictors: Results and discussion

As mentioned above a common feature in the design of habitat models in BALANCE has been the application of conceptual models and model calibration using all available knowledge of the ecological requirements of the modelled species. This allowed for the careful selection of a few variables with known structuring functions in relation to the species habitats. Although the case studies gave satisfactory results in terms of coarse-scale predictions of species distributions they indicated that some of the selected variables act as true habitat drivers while others play a minor role in shaping the habitat of the modelled species. In addition, the results of the case studies pointed at the needs for additional predictor variables, especially at the smaller scale, to establish more comprehensive habitat models.

Currently, a lack of high-resolution maps of for example bathymetry, surface sediments, hydrography, and in the case of young fishes, vegetation coverage, is limiting the production of accurate habitat maps. For bathymetry, this deficiency may be alleviated for example by opening access to classified maps, and by easing restrictions on collection and usage of bathymetric data. For other environmental variables, and for bathymetry in some areas, additional high-resolution mapping is needed. Development of new techniques, such as remote sensing for identification of coastal habitat characteristics, as well as GIS-modelling techniques similar to those used within this BALANCE report, may provide efficient tools for producing high-resolution maps at reasonable costs.

The modelling of *Laminaria* in Pilot area 1 indicated that the significance of seabed curvature in the model reflect the importance of substrate, as curvature indicates presence of submarine elevations (here rocky bottom) vs. level bottom. The precision of benthic habitat models in this region is expected to increase as fine-scale substrate information becomes available. The surprisingly low significance of the two parameters slope and exposure appeared to be a bias, as field data failed to cover the whole gradient in the region.

Modelling of lobster habitat in Pilot area 1 showed that backscatter data on bottom substrates is a useful predictor variable when modelling this species, as it describes the bottom characteristic that is most important to the lobster distribution. However, the study suggested that the habitat model could be strengthened by adding data on local currents which relate directly to food supply for the species. It was further clear that for the model to accurately describe the variation of lobsters, it is necessary to cover the whole range of the environmental variables.

Modelling of the habitat to juvenile flatfish in Pilot area 1 indicated sampling problems; as trawling is not usable on several types of substrates, e.g. it does not sample efficiently in sea weed or eel grass beds, areas with patches of stones, or in muddy areas. Hence, potentially essential fish habitats may be not included in the final map. Another striking result was the fact that the three predictors showed great variability between response variables (species).

The 3-dimensional GIS study of suitable fish spawning areas in Pilot area 2 did not include spatial modelling. However, modelling was evaluated as a potential important supplement to be used to evaluate if environmental variables are randomly related to the spawning locations or if they present significant habitat choices. (BALANCE Interim Report no. 20).

In Pilot area 3 water depth turned out as the most important factor in all models. Other important factors were distance to sandy shores and either exposure or the density of shoreline. For *Mytilus* the distance to submerged and emergent rocks was also significant, whereas aspect explained a large amount of deviance in the algae model. The results from this case study also demonstrated that explanatory and predictive power may show different results. The *Mytilus* model got the highest score for explaining variance in the response variable as well as the lowest Generalized Cross Validation score, while the deviance explained by the angiosperm model was fairly low. However, the ROC plots showed that the models with best predictive capability were in fact the algae and angiosperm models, falling into the category 'excellent and 'outstanding', respectively.

The fish models in Pilot area 3 showed that the predictor variables chosen were important components when determining the habitats of the fish species, and that GIS-modelling could develop into an indispensable tool in large-scale mapping of essential fish habitats. Two of the predictor variables, wave exposure and the visibility proxy, which were completely GIS-derived and may be considered as indirect variables, displayed the strongest explanatory power. For future modelling work it was suggested to use an alternative approach to attaining large-scale maps of turbidity by applying satellite imagery. A separate study showed that turbidity can be accurately interpreted from SPOT 5 images at a resolution of only 10m. In addition, including vegetation coverage as a predictor variable would most likely increase the predictive power of the models. Producing high-resolution, large scale GIS-layers of vegetation coverage would therefore constitute an important step towards increasing the precision of many fish habitat models.

The *Fucus* model in Pilot area 4 (Estonia) underlined the need for using key habitat drivers as predictor variables, and the problems associated with obtaining these data at a suitable scale. The Fucellaria model in Pilot area 4 (Latvian) had relatively low predictive power caused by small-scale environmental heterogeneity. Point measurements of the depth at the observation sites (input data) do not provide information on local conditions of exposure (sheltered or not) caused by seabed elevations. This effect may also be captured by data at a finer spatial resolution of sediment data and using polygon based data for statistical model rather than point observations. (BALANCE Interim Report no. 23).

6.3.3 Model selection

The Akaike information criterion (AIC) has proven useful in selection of models and model complexes predicting habitat distribution in the Baltic Sea region. AIC estimates the Kullback-Liebler information lost by approximating full reality with the fitted model. This model selection approach involves terms representing lack of fit and a bias correction factor related to model complexity. AIC has a second order derivative, AICc, which contains a bias correction term for small samples size, and should be used when the number of free parameters, p, > n/40 (where n is sample size). AIC has the advantage over maximizing fit, such as adjusted R^2 that do not consider model complexity, and thus always favours fuller models, while neglecting the principles of parsimony. In comparison with AIC, the commonly used null hypothesis tests, such as the likelihood ratio tests, compare pairs of nested models. The latter method has drawbacks, among others it cannot be used to quantify relative support among competing models.

6.3.4 Validation and ground truthing

Within the framework of MCE modelling and habitat classification in BALANCE it has not been possible to carry out validation, nor ground truthing of the model results. Both statistical and GIS-based validations of the Baltic-wide marine landscapes are planned in the near future. A wide range of validation techniques were applied for the habitat prediction models to evaluate the explanatory and predictive power of the models. There has been a rapid increase in available methods for species distribution modelling, and there is yet no consensus among the scientific community on how to best describe the potential and limitations of a model. Many authors recommend the use of separate data sets when building and evaluating models, although such an approach runs the risk of comparing sampling occasions or methods rather than model results. In BALANCE the predictions were not assessed by using independent samples. Whether or not new data has been used in validation, components of accuracy and level of generalization need to be specified to aid comparisons with different models and assess model usefulness in different situations. It is not enough to specify only e.g. overall accuracy or sensitivity if end-users/managers are to draw appropriate conclusions about the usefulness and limitations of a model.

6.4 Classification of marine habitats

Geographical information systems offer a number of ways to analyse and synthesise spatial data into classes that are meaningful from the viewpoint of a habitat classification system. The approach presented here would be applicable to any hierarchical classification system where data is available on the factors determining classes. At present the Environment Agency's EUNIS classification of marine habitats is the only available classification system for the Baltic. The Baltic classification in the EUNIS classification has been achieved using the classification system of HELCOM for red-listed biotopes.

An attempt at mapping habitats in an area where substrate data is available in the Archipelago Sea (Pilot Area 3) was made in order to assess the applicability of the EUNIS system for the Baltic Sea (BALANCE Interim Report no. 31). The results indicated that Baltic classes do not follow the hierarchical structure of the classification very well and are somewhat inconsistent to what is included on each level. Improvements to the classification are surely needed regarding marine habitats in the Baltic Sea. The current system is, however, the best available today. The classes used for BALANCE purposes follow as closely as possible the EUNIS classes on level 2, 3 and 4.

The main aims of the habitat classification in Pilot Area 3 were to combine available GIS data layers to produce habitat maps at EUNIS level 2 and to integrate results from previous modelling exercises on mussels, algae and angiosperms to complete maps at EUNIS level 3. The analysis of EUNIS classification level 2 and 3 habitats used four sets of GIS layers:

I. Substrate data classified according to the BALANCE substrate classification, which corresponds fairly well to the substrate classes used in the EUNIS classification.
II. The photic layer derived from a model where the Secchi depth is predicted based on the level to which an area is enclosed.
III. Wave exposure data classified into 3 categories (sheltered, moderately exposed and exposed), first using the cut-off values derived from an analysis of the distribution of lichens and algae on shores and then combining these seven classes into 3.
IV. Raster layers (5m cell size) with probability of presence of *Mytilus trossulus*, algae and angiosperms.

Data were combined in GIS using multi-criteria evaluations following the same standards as for the Baltic-wide landscape maps. The first two layers (substrate and photic depth) were combined in a GIS overlay analysis to produce maps of EUNIS level 2. The same approach, also including the third dataset (wave exposure), was used for those level 3 habitats that do not include biotic information (Table 5). It was recognised that a combination of the original GIS analysis and additional layers achieved by habitat modelling techniques could be used to complete the maps on level 3. Habitat modelling enables mapping those classes that cannot be done using GIS analysis of abiotic data layers alone. The biological data required for the models, including observations of mussels, algae and angiosperms, was only available for a very small part of the study area. This 100 km^2 area was used as an example area in an attempt to develop and demonstrate the approach. Table 5 describes the data needed for making a map of the habitat classes in the current EUNIS marine habitat classification that are found in the study area.

Table 5: EUNIS Habitats in the Archipelago Sea

Level 2		Level 3		Level 4	
A3	Infralittoral rock and other hard substrata	A3.4	Baltic exposed infralittoral rock		
		A3.5	Baltic moderately exposed infralittoral rock		
		A3.6	Baltic sheltered infralittoral rock		
A4	Circalittoral rock and other hard substrata	A4.4	Baltic exposed circalittoral rock		
		A4.5	Baltic moderately exposed circalittoral rock		
		A4.6	Baltic sheltered circalittoral rock		
A5	Sublittoral sediment	A5.1	Sublittoral coarse sediment	A5.11	Infralittoral coarse sediment in reduced salinity
				A5.13	Circalittoral coarse sediment
				A5.14	Deep circalittoral coarse sediment
		A5.2	Sublittoral sand	A5.21	Sublittoral sand in low or reduced salinity
				A5.27	Deep circalittoral sand
		A5.3	Sublittoral mud	A5.31	Sublittoral mud in low or reduced salinity
				A5.37	Deep circalittoral mud
		A5.4	Sublittoral mixed sediments	A5.41	Sublittoral mixed sediment in low or reduced salinity
				A5.45	Deep mided sediments
		A5.5	Sublittoral macrophyte dominated sediments	A5.52	Kelp and seaweed communities on sublittoral sediment
				A5.54	Angiosperm communitites in reduced salinity
		A5.6	Sublittoral biogenic reefs	A5.62	Sublittoral mussel beds on sediment
		A5.7	Features of sublittoral sediments	A5.72	Organically enriched or anoxic sublittoral habitats

Can be achieved using existing abiotic GIS layers	Requires habitat models made from biological data overlaid with the habitats from abiotic GIS data	Requires a spatial model of organic enrichment and anoxia overlaid with the habitats from abiotic GIS data

6.4.1 *Evaluation of marine habitat classification*

Presently, the Baltic Sea area is poorly represented in the EUNIS system. The Baltic classes do not follow the hierarchical structure of the classification very well and are somewhat inconsistent to what is included on each level. Improvements to the classification are surely needed. The Baltic has several gradients that do not play a significant role in the truly marine environment from where EUNIS originates. The most obvious differences are the lack of tides, the salinity gradient, benthic substrate complexity, and the enclosed nature of the sea.

The lack of tides means there is a narrow or no intertidal zone (<0.5m). However, some of the species found in the intertidal zone on marine shores, form a similar communities sub-tidally in the Baltic Sea. This is currently not laid out in the existing EUNIS hierarchy. In the Archipelago Sea salinity changes from almost freshwater in the innermost archipelago and near river mouths to approximately 5-7 psu where it joins the Baltic Proper. On the scale of the whole Baltic Sea Region, including the Baltic Sea, Kattegat and Skagerrak, the salinity gradient is much larger, from 0 to 34 psu. The enclosed nature limits fetch and consequently wave exposure. Although wave exposure in the Baltic may be small compared to Atlantic shores, the variation within the Baltic plays an important role in structuring communities.

In general, the modelled layers satisfy the needs for large scale planning of the coastal sea. All maps show the potential occurrence of the habitats and can be used to derive habitat complexity maps estimate the proportion of protected versus unprotected areas of the habitats and can be used as a first selection of areas of interest for more detailed surveys. The Natura 2000 habitats do not cover deeper habitats or shallow hard bottom habitats that may have high nature value.

In the future there is a need to re-calibrate wave exposure specifically for the Baltic Sea area. There is also a need to create true classes based on the flora and fauna communities and the special abiotic factors at play in the Baltic Sea area, to be incorporated into the hierarchical structure of EUNIS.

6.5 Application of habitat maps for management

Splitting nature into man-made categories is not the most accurate representation of nature, but often necessary for management purposes. The maps produced using this methodology, will give a basic view of the types of habitats that are found in an area. The ecological considerations related to these habitats can be inferred from existing knowledge. In nature habitats are never static, and the habitats depicted in the maps may have seasonal or multi-annual cycles (e.g. annual algae, bottom fauna on soft bottoms), but if these are acknowledged and included in decision making, the maps can be a good addition to the sustainable management of marine areas and to marine conservation.

It is important that end users are aware of the inherited limitations of the developed marine habitat maps:

- The resultant maps are no better than the information on which they were developed. For some areas data are scarce and/or only available in low resolution with large distances between points with actual data. The maps are thus not suitable for fine scale planning unless further improved.
- Due to the relatively coarseness of most of the data available for the mapping and modelling exercises it has not been possible to identify fine-scale features and the resultant maps only present the most dominant features.
- The maps should be regarded as beta-versions, which need further refinement and validation before they are applied in spatial planning. Most important is the validation of the MCE-based habitat maps and correction for auto-correlation in the habitat prediction models as well as ground-truthing of all maps.

Despite these limitations the results of the habitat mapping and modelling were very encouraging and successfully demonstrated the potential to develop basin-wide coarse-scale maps of benthic and pelagic habitat maps on the basis of few key variables. The Baltic-wide models of topographic and benthic landscapes represent highly needed datasets for the implementation of the EU Habitats Directive in the Baltic Sea. These maps are also expected to become highly valuable for the succesful launch of ecosystem-based management in the region, which will require a basemap on structural habitat entities. At the sub-regional level the modelling results are expected to provide a useful tool in developing integrated solutions for nature conservation and sustainable fisheries, coastal development, transport and other sea uses. As an example the modelling of Norwegian lobster habitat in Skagerrak may be used in the management of the lobster fishery for information on where important lobster habitat can be found. Similarly, the 3-dimensional modelling of spawning areas to Baltic cod and sprat can be used in the characterization of the spatial and temporal variability of eastern Baltic cod spawning habitats in the light of implemented closed areas to ensure undisturbed spawning. The usefulness of the BALANCE models and the examples for habitat modelling applications they provide is stressed by the high demand for detailed maps of essential fish habitats, marine mammals and other top predators. The habitat maps developed during BALANCE are already used by several regional authorities, e.g. in fisheries restoration and management plans and in the design and zonation of forthcoming MPAs.

6.6 A stepwise approach to mapping of marine habitats in the Baltic Sea area

1. GIS analyses and mapping of the NATURA 2000 Annex I habitats that equal landscapes, as well as analyses and mapping of other marine landscapes.

2. Detection of remaining NATURA 2000 Annex I habitats by acoustic and other methods.

3. Sampling of acoustic data of fine grain (multibeam and back scatter, resolution of 1-10cm) and validation using samples, UW video/photographs, and/or diving observations.

4. Sampling and collation of additional variables, essential for NATURA 2000 Annex I habitats. For the OSPAR, HELCOM and essential top predator habitats variables driving ecological significance will be necessary.

5. Predictive modelling of habitats, particularly on habitat-building species of structural importance and species of high ecological significance. Validation of models.

6. Integration of habitat model results and existing marine landscapes in GIS to create a habitat classification system for the Baltic Sea region, with classes of discrete boundaries.

7. Predictive modelling of spatial and temporal variation of each classified habitat.

Application for planning of MPA network, incl. of the NATURA 2000 network:

8. Apply in GIS to create areas of appropriate size and numbers, as well as blue corridors.

9. Use the above data to evaluate the best possible solutions of a marine protected areas network of habitats and corridors, which maintain ecological functioning.

Application for management and evaluation of ecological status of MPA network, incl. of the NATURA 2000 network:

10. Assess the resilience and sensitivity of each classified habitat in relation to major sea uses.

6.7 Recommendations

The following recommendations are directed at policymakers, scientists and environmental managers for the future refinement of the modelling and mapping of marine habitats with the long-term goal of a supporting a sustainable development in the Baltic Sea Region through an informed trans-national approach to the management of the marine ecosystem.

6.7.1 Data and methodology

The following recommendations and demands are listed in regard to marine information issues within the Baltic Sea region:

1. Geo-morphological data of land features, e.g. the coast line, exists and are accessible at both fine and coarse scales. These data are highly useful for mapping of several Natura 2000 Annex I habitats.

2. Data models on a range of environmental variables, such as light attenuation, oxygen levels, salinity, temperature, are available and should be used when improving models for mapping the distribution of species habitats.

3. Bathymetric data exists at a fine scale from multiple areas, but are often not accessible due to e.g. military restrictions. Effort should be made to retrieve data from the areas, where they do exist. In areas where data are lacking, new data should be collected. Coarse scale data, e.g. from nautical charts, have proven highly valuable for mapping of Natura 2000 Annex I habitats and for modelling and mapping of habitats of several marine species.

4. Substrate data exists at a coarse scale (grid size of 1-2km) from most areas, while fine scale data (grid cell of 10-50cm) exists only from a few areas. Effort should be made to collect such data covering the entire Baltic Sea areas. When available, these data have proven highly useful for mapping and modelling of most plants and animal species.

5. GIS-analysis is appropriate for mapping of Natura 2000 “habitats” using physiographic and geological features.

6. Predictive modelling, e.g. GAM, is a cost-effective way of developing fine scale, large extent distribution maps of marine habitats of species and species assemblages.

7. It is highly important that the biological data cover the entire range and extent of the environmental variables.

8. At present, modelling of habitats in time requires detailed knowledge of the limits of environmental variables at the species level.

6.8 Confidence of the habitat maps

The following recommendations are proposed in regard to marine landscapes and habitat mapping issues within the Baltic Sea region:

1. The maps of Baltic-wide benthic marine landscapes and some of the selected Natura 2000 Annex I habitats have not yet been fully validated. The majority of the maps of species habitats from the predictive modelling have been validated, however, it is recommended to test the predictive power of the models on independent data and to take account of auto-correlation effects. All maps need further ground-truthing prior to application for management using data from the national monitoring programmes unavailable for the BALANCE purposes.

2. The current habitat maps are not to be regarded as all inclusive and full coverage, but rather pieces of the Baltic Sea marine patchwork. Also, the maps are products that demonstrate the value of using different methods for mapping of marine habitats.

6.9 Application for nature conservation

Habitat maps are a pre-requisite for nature conservation management. While Natura 2000 Annex I habitats are legal entities they are defined using geomorphological criteria as well as defined at different hierarchical levels,. Thus, maps of species distribution or habitats of structuring species are needed to evaluate ecosystem functioning of the Natura 2000 network at sea. Development of Baltic-wide habitat maps of ecological relevance requires a co-ordinated approach. The following recommendations are made in regard to nature conservation issues within the Baltic Sea area:

1. Harmonisation of habitat characteristics of both Natura 2000 Annex I habitats and of species habitats, and their relation to marine landscapes. If a classification system is developed, it should be coherent with systems of adjacent seas, e.g. the EUNIS system.

2. Development of guidelines for a common approach to modelling and mapping of marine habitats. The guidelines should be in line with those developed for adjacent seas, e.g. as part of the MESH project.

3. To increase the cost-efficiency, harmonisation of data collection and monitoring methods should be made to the extent possible without loosing valuable information needed for other purposes. Supplementary surveys should be made for the specific purpose of mapping of marine habitats and ecosystem function.

4. Within the framework of BALANCE it was not possible to integrate information and models of key processes and ecological significance into the characterisation of Baltic marine landscapes. Therefore, the marine landscape classifications should be seen as qualitative and future studies will be needed to resolve the linkages between landscapes and ecological functioning.

6.10 Application for marine spatial planning

The following recommendations are made in regard to marine spatial planning issues within the Baltic Sea:

1. Habitat maps should be included as a basic layer to marine spatial planning thus contributing with ecological relevant information to the planning process. If such spatial ecological information is not included, then it marine spatial planning will be limited in its contribution to a long-term sustainable development . Thus, full coverage habitat maps should be developed for the entire Baltic Sea area. This could be done in a patchwork approach, where new, validated and ground truth maps are added to the master-map as they become available.

2. Further, BALANCE focused on the establishment of landscape maps covering mainly benthic habitats. A future coherent landscape map would also include the identification of pelagic marine landscape maps.

3. In relation to sectoral development planning it is important to stress the need to transfer the habitat and landscape maps to sensitivity maps displaying the degree of resilience and vulnerability of the habitats and landscapes in relation to potential perturbations associated with each sectoral use of the sea.

7 SUMMARY AND CONCLUSIONS

The mapping and modelling efforts of the BALANCE project should be seen as a step towards developing ecological relevant maps spanning the entire Baltic Sea Region. The last 2½ year has shown that it is possible to develop a regional wide marine landscape map through intensive transnational cooperation. This process has no doubt been helped through the timing of the BALANCE project, the amount of effort it has been possible to put into solving the task as well as no such approach has been done previously for the region. A process which hopefully will continue in the years to come either as part of implementing e.g. the Baltic Sea Action Plan or the EC Marine Strategy Framework Directive, or as part of national initiatives. This would enable us to fill the gaps in our knowledge as new or more data are made available increasing the confidence and testing the ecological validity of the produced marine landscape maps.

Similarly, BALANCE has shown that there is a lot of individual high-quality habitat mapping initiatives going on throughout the Baltic Sea Region. These include both efforts related to commercial fish species as well as to the environmental sector such as EC Habitats Directive Annex 1 habitats. However, compared to the marine landscape development most, if not all, of the countries surrounding the Baltic Sea has developed their own approach to mapping and modelling of marine habitats e.g. *1170 Reefs*. This means that there will be challenges for the future in regard to the harmonisation and classification of these maps at a regional sea scale even though initiatives such as BALANCE has contributed to an agreement on which environmental parameters should be included in marine habitat mapping.

In general, there are many challenges to be met if ecological relevant maps are to be produced for larger marine areas, such as the Baltic Sea Marine Region. Some recommendations are presented below.

7.1 Marine information

The following recommendations are made concerning marine information issues within the Baltic Sea:

1. All marine environmental data collected with public funds, EU and national, should be held electronically with Baltic-wide agreed formats and standards and placed in easily accessible public domains within specified timescales. This data should be available for an international Baltic-wide marine information system through an automated harvesting process enabling an ecosystem-based approach to reporting requirements under e.g. the EU Water Framework Directive, EC Habitats Directive and the proposed Marine Strategy Directive. A relevant international forum could form the basis for such a hub through co-operation with national data responsible agencies. This could be regulated through Government Agency contract obligations. Public funds made available to universities, research institutes and other organisations should be subject to these conditions. It could build upon the existing HELCOM Indicator Database or through the databases established during the implementation of the EU INSPIRE Directive.

2. EU structural funds, such as BSR INTERREG IVB, co-financing national and/or international activities within the Baltic Sea should require that any data collected or data layers produced during an EU funded project should be published in usable formats (e.g. GIS shape files) before the end of a project through the above recommended data portal. No data layers should only be kept in the individual organisation receiving such funding, but made available in usable formats for and distributed by e.g. regional seas conventions.

3. All marine environmental data collected by private bodies for e.g. Environmental Impact Assessments could be placed within the public domain within specified timescales if and when it does not jeopardise specific commercial interests.

4. The establishment of a standardised transnational web-based electronic map or chart data portal within the public domain extending seamlessly across the Baltic Sea and Kattegat. It should enable an easy overview of the extent and coverage of marine information in coastal and offshore areas. The BALANCE Data Portal could be further developed for such purposes, but this would require support from relevant national public authorities.

5. A Baltic-wide marine information network based on harmonisation of environmental data and their origin (who, what, where, when etc.) should be established. Consideration should be given to whether a relevant international organisation could be form a central Baltic hub for such a portal.

6. In order to meet these recommendations a data management plan should be developed and implemented by a relevant transnational organisation.

7.2 Marine landscape mapping

The following recommendations are made concerning broad-scale mapping issues within the Baltic Sea:

7. The methodology behind the marine landscapes should be further developed and refined as part of the implementation of the above mentioned EU Directives.

8. The future refinement should continue to apply a transnational and cross-sectoral approach spanning relevant scientific disciplines.

9. A process, either through specific projects or through statuary obligations, collecting Baltic-wide biological data focusing on key species and/or habitats should be established and the results placed in the public domain. Such information is vital for refining the marine landscape maps and for making ecosystem-wide environmental assessments. This includes improving validation and providing background information for a statistically verified justification of the categorisation of the environmental parameters.

10. The identification of habitats associated with each type of marine landscape should be encouraged in order to perform a proper validation of the produced maps.

11. Tools, which improve accuracy and precision of the individual modelled environmental data layers, should be developed. It would increase the confidence rating of the resultant marine landscape map.

12. The development of Baltic Sea-wide datasets on environmental pressures, such as annually updated oxygen concentration maps, should be encouraged.

13. A sensitivity map associated with the individual marine landscapes should be developed.

14. The development of a coherent pelagic marine landscape map for the Baltic Sea should be strongly encouraged. Such an endeavour should include 3D ecological modelling of all major coastal and offshore water volumes and show the temporal variation characteristics of the pelagic environment. The categorization of each environmental parameter chosen should be related to ecological requirements of e.g. key species.

15. Future use and refinement of the marine landscape maps should strive to promote synergies and converge requirements under the proposed EU Marine Strategy Directive, the EU Water Framework Directive and EC Habitats Directive. The usual *one nation – one approach* is not desirable as it acts against the entire purpose of a broad-scale ecosystem-based characterisation of an ecoregion.

16. Future refinements of the marine landscape maps should build upon transnational cooperation and coordination for the Baltic Sea. They should build upon harmonisation and standardisation of individual data layers for the Baltic Sea followed up by a unified approach to the identification process.

17. Future refinements and application should not only depend on available EU funding, but also be part of enhanced transnational cooperation on fulfilling statuary obligations between responsible national governmental agencies.

18. Institutions and personnel developing broad-scale ecological maps for one region should be encouraged to co-operate with similar initiatives in adjacent ecoregions to ensure a coherent European approach to the characterisation of the marine environment. This could include a coherent and compatible list of marine landscapes identified so far within the territorial waters of EU Member States.

7.3 Marine habitats

19. A European standard for marine biological surveys on littoral and sublittoral hard bottom is currently under development. However, national monitoring programs are still likely to continue without major changes in order not to loose comparability with earlier data series. Efforts should be made to enable a use of the European standard, while maintaining, to the extent possible, the time series.

20. Baltic Sea wide habitat maps should be modelled. It should be possible to model several species since they are included the national datasets. These in-

clude the brown alga *Fucus vesiculosus*, the red alga *Furcellaria lumbricalis*, the phanerogam *Zostera marina*, the blue mussel *Mytilus edulis* and charophytes. All which are important habitat building species that equally could be modelled as habitats. The general distribution of phytobenthic species could also be modelled.

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- The BALANCE partnership is grateful for the support received from partners in the MESH project in methodology on how to map and classify marine landscapes of the Baltic Sea as well as marine institutes and data holders in the Baltic Region who kindly has provide access to relevant environmental data.

9 REFERENCES

In this report we have decided not to include a complete reference list. For a more comprehensively coverage of the issues discussed we refer to literature references in the following BALANCE Work Package 2 Interim Reports, which also can be downloaded from www.BALANCE-eu.org.

BALANCE Interim Report no. 32: Guidelines for harmonisation of marine data
BALANCE Interim Report no. 31: Marine landscapes and benthic habitats in the Archipelago Sea
BALANCE Interim Report no. 30: Mapping of Natura 2000 areas in Baltic Sea archipelago areas
BALANCE Interim Report no. 29: Essential fish habitats and fish migration patterns in the Northern Baltic Sea
BALANCE Interim Report no. 27: Mapping and modelling of marine habitats in the Baltic Sea
BALANCE Interim Report no. 23: The modelling of *Furcellaria lumbricalis* habitats along the Latvian coast
BALANCE Interim Report no. 21: Mapping of marine habitats in the Kattegat
BALANCE Interim Report no. 20: Pelagic habitat mapping: A tool for area-based fisheries management in the Baltic Sea
BALANCE Interim Report no. 17: Baltic Sea oxygen maps
BALANCE Interim Report no. 15: Biodiversity on boulder reefs in the Kattegat
BALANCE Interim Report no. 14: Intercalibration of sediment data from the Archipelago Sea
BALANCE Interim Report no. 13: Harmonizing marine geological data with the EUNIS habitat classification
BALANCE Interim Report no. 12: Evaluation of satellite imagery as a tool to characterise shallow marine habitats in the Baltic Sea
BALANCE Interim Report no. 11: Fish habitat modelling in a Baltic Sea archipelago region
BALANCE Interim Report no. 10: Towards marine landscapes in the Baltic Sea
BALANCE Interim Report no. 5: Evaluation of remote sensing methods as a tool to characterise shallow marine habitats.
BALANCE Interim Report no. 3: Feasibility of hyperspectral remote sensing for mapping benthic macroalgae cover in turbid coastal waters of the Baltic Sea.

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About the BALANCE project:

The BALANCE project aims to provide a transnational marine management template based on zoning, which can assist stakeholders in planning and implementing effective management solutions for sustainable use and protection of our valuable marine landscapes and unique natural heritage.

The template is based on data sharing, mapping of marine landscapes and habitats, development of the blue corridor concept, information on key stakeholder interests and development of a cross-sectoral and transnational Baltic zoning approach.

BALANCE thus provides a transnational solution to a transnational problem.

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For more information on BALANCE, please see www.balance-eu.org and for the BSR INTERREG Neighbourhood Programme, please see www.bsrinterreg.net.

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