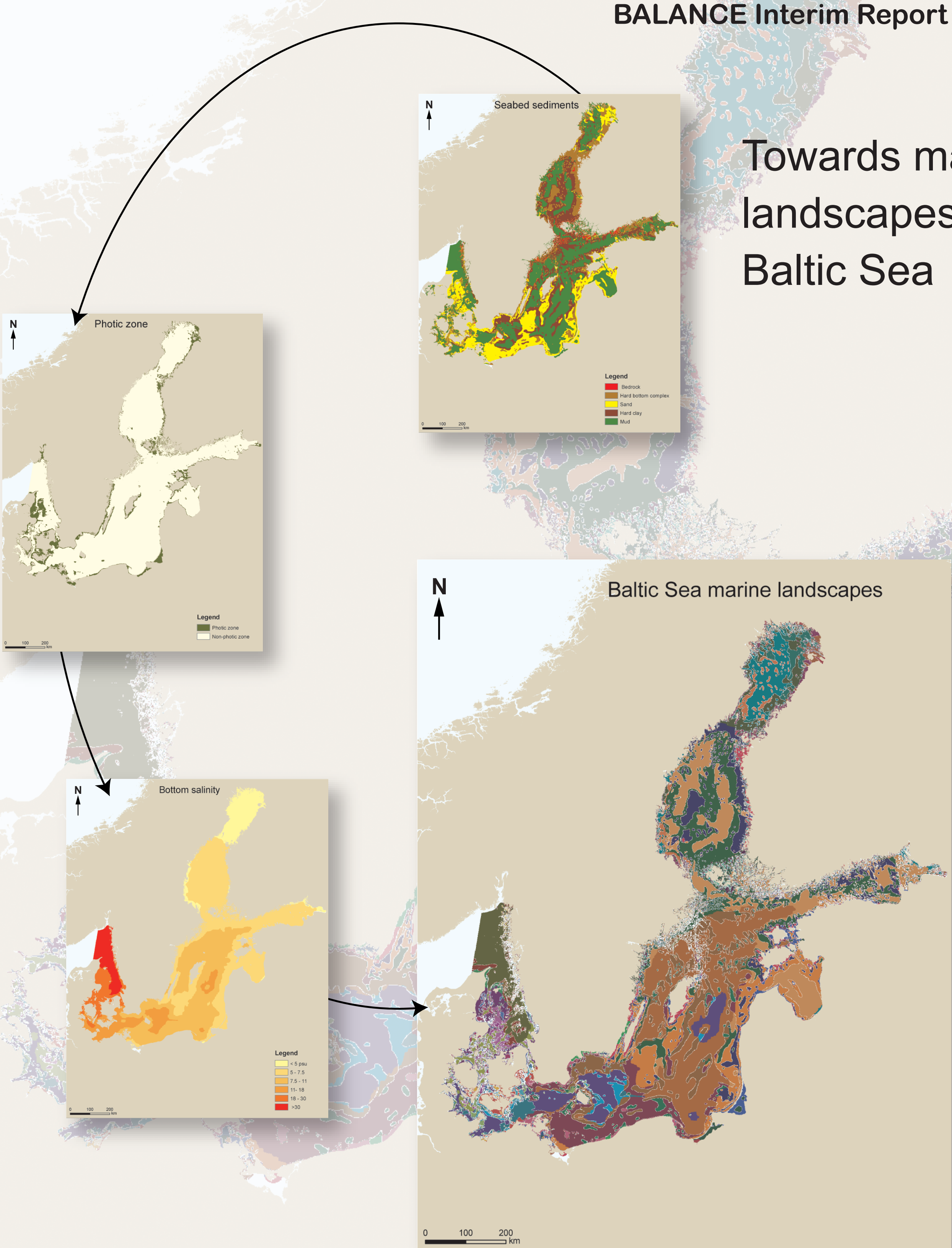
BALANCE Interim Report No. 10

Towards marine landscapes in the Baltic Sea



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CONTENTS

0 PREFACE

This report presents the methodology applied for identifying and mapping the seabed features of the Baltic Sea. The report also summarises some of the potential applications and limitations of applying the marine landscapes approach within the Baltic Sea. Special effort has been put into explaining the reasoning behind the decisions made in order to bridge the gap between different sciences, and thus make the report accessible for non-specialists. The work was undertaken because marine landscape mapping has the potential to support the implementation of a transnational and ecosystem-based approach to the management, including strategic and spatial planning, of the marine environment thus promoting a sustainable development within the Baltic Sea Region[1].

The work is based on extensive transnational cooperation and involves many different scientific disciplines while aiming to bridge the gap to environmental management and policy drivers for the marine ecosystem within the Baltic Sea Region.

The work, while extensive, should only be seen as a first step towards the mapping of marine landscapes of the Baltic Sea, Kattegat and parts of Skagerrak. There are some of the technical aspects, which need further development to fully describe the dynamics of the marine environment. Each map presented is the result of an intensive and arduous data harmonisation and classification e.g. the sediment map took almost a year in production, while reclassifying data from 19 different sediment classifications.

The results, products and recommendations presented in this report represent the experiences of an independent international partnership, and do not represent any national or official viewpoint of the involved research institutes or governmental agencies. The work is part financed by the European development fund BSR INTERREG IIIB Neighbourhood Programme and partly by the involved partners.

More information on the BALANCE project is available at www.balance-eu.org and on the BSR INTERREG IIIB Neighbourhood Programme at www.bsrinterreg.net.

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[1] The Baltic Sea Region is defined by the BSR INTERREG IIIB Neighborhood Programme to include the Baltic Sea, Kattegat and Skagerrak. In the report the use of the term "the Baltic Sea" refers to the delineation of the Helsinki Convention area, including the Baltic Sea and Kattegat rather than writing it explicitly each time.

1 EXECUTIVE SUMMARY

In 2005 a consortium consisting of a total of 27 governmental agencies, research institutes, universities, regional authorities and NGOs in 7 countries surrounding the Baltic Sea and from Norway and U.S.A put forward an application to the BSR INTERREG IIIB Neighbourhood Programme with the aim of developing tools for promoting a transnational and cross-sectoral approach to marine spatial planning within the Baltic Sea. The project was named BALANCE. The tool described here builds upon experiences made in Canada (Roff & Taylor 2000) and initiatives from the UK e.g. the Irish Sea Pilot Project (Vincent et al. 2004) and the UKSeaMap (Connor et al. 2007).

The governmental interest for participating in such as an initiative is based upon current national needs for broad-scale information to help the implementation of national and international obligations. These include implementation of EU directives (e.g. EC Habitats Directive, the EU Water Framework Directive and the proposed EU Marine Strategy Directive) or for finding transnational solutions to initiatives such as the Baltic Sea Action Plan undertaken by the Helsinki Convention. Implementation of these initiatives requires, directly or indirectly, a broad-scale classification and approach to the management of the marine environment. Where possible the development process of the marine landscapes strived to take potential synergies and convergence between these initiatives into account.

1.1 Development of marine landscape maps

The overall goal of this activity was to use available geological, physical, chemical and hydrographic data to identify and map broad-scale marine landscapes for the Baltic Sea based upon transnational and cross-sectoral cooperation. The aim was that the derived marine landscapes should be individually distinct and reflect broad-scale species assemblages within the Baltic Sea. These ecologically relevant marine landscape maps could then be applied as an ecological parameter for broad-scale marine spatial planning, thus contributing to knowledge-based management of our marine environment and the long-term goal of achieving a sustainable development within the Baltic Sea Region. Our approach is to identify three different kinds of broad-scale characterisations of the marine environment, though the focus of the report is on the ecological meaningful entities.

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 bed forms such as deep-water channels or sediment plains. Using these parameters alone makes it difficult to assign any significant ecological relevance of the bed forms identified, as especially depth is not in its own right is not an ecologically relevant entity. However, the topographic approach helps to describe the seabed in a terminology that it is easy to visualise.

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 ecologically relevant, and some of them occur in EU legislation e.g. the Annex 1 in the EC Habitats Directive. There is no a 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 these physiographic features in higher detail and determine their ecological relevance a much-more detailed dataset is needed than what was available for the project. Hopefully, these features will be further developed by national initiatives.

Thirdly, ecologically relevant entities of the Baltic Seabed were identified using environmental parameters which all have an influence upon the distribution of benthic species assemblages. The primary environmental parameters included were sediment, the available light zone and salinity. These parameters are important for determining broad-scale distribution of species in a regional context such as the Baltic Sea. Sediment was split into 5 categories ranging from bedrock to mud each with different ecological relevance. Available light at the seabed was included as it distinguishes between the photic zone where (most) primary production occurs and the non-photic zone. Salinity was split into 6 categories reflecting species distribution throughout the Baltic Sea.

Other environmental parameters were considered, but these were either more relevant for detailed habitat mapping e.g. wave exposure, not relevant for the entire region e.g. ice cover, not significantly influencing 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. Furthermore, the aim was to limit the number of potential combinations to a manageable number. The benthic marine landscapes are the most relevant characterisation for achieving a sustainable management of the marine environment as they do reflect broad-scale species assemblages. This report will mainly focus on these benthic marine landscapes.

As an introduction to each environmental parameter a summary of the conditions in the Baltic Sea is included as well as the degree of influence of specific parameters on marine life – plants, invertebrates and fish. This approach has been found essential in order to bridge the many different technical disciplines involved in the mapping of marine landscape and in order to enhance cross-sectoral understanding. The approach also explains why each layer has been found relevant for inclusion in the mapping of ecological meaningful marine landscapes.

Where relevant the approach strives to build upon existing EU legislation and requirements in order to mould marine landscape mapping into a tool suitable for an ecosystem-based approach to marine spatial planning and management disrespectable of sectoral legislation.

The processes undertaken included:

- Identification of environmental data needed for broad-scale characterisation of the seabed.
- Identification of and accessing available data spanning the Baltic Sea.
- Making of suitable data sharing agreements within and outside the partnership.
- Classification of data into uniform categories and conversion to an agreed GIS format.

- Identification of ecologically relevant categories for each environmental parameter (e.g. photic or non-photic depth) and creation of the data layer in GIS.
- Analysis of the data to produce the classification of the seabed and the coastal zone.
- Initiation of the validation process. This process was difficult due to the lack of access to relevant coherent Baltic-wide biological data.
- Commencement the confidence assessment exemplified for specific subregions. Again this process was difficult due to restricted accessibility to raw and metadata.
- Presentation of the data layers and maps as well as examples of their potential application.

1.2 Potential application and limitations

The purpose of developing the maps was to provide a transnational perspective and overview of the marine landscapes present, their extent and distribution within the Baltic Sea. The potential uses and limitations are summarised below:

- **Implementation of EU Directives:** Support implementation of the EC Habitats Directive, the EU Water Framework Directive, the EU INSPIRE Directive and the proposed EU Marine Strategy Directive. These all, directly or indirectly, require an ecosystem-based approach to the classification and management of the marine environment, including data management.

- **Protecting the marine environment:** The maps will present end users with a better understanding of the extent and distribution of the physical entities of the Baltic Sea. The maps will feed directly into a BALANCE assessment of the representativity of the network of Marine Protected Areas (MPAs) in the Baltic Sea.

- **Marine spatial planning:** The availability of a broad-scale ecologically relevant map for the Baltic Sea can provide sea use planners with an opportunity to incorporate an ecosystem-based approach when making planning decisions on a regional scale taking a layer with the natural values into account, and thus help in an assessment of the potential impact of human activities.

- **Strategic planning:** Marine landscape maps provides a baseline study of the complexity within a region providing field surveyors with a planning tool for areas with limited information.

- **Maritime safety**: Marine landscape maps may be used in regard to maritime safety issues as they provide an indirect ecological input for a region showing the amount and distribution of broad-scale ecological entities and thus provide a basis for sensitivity mapping of areas considered as emergency harbours in case of shipping accidents.

- **HELCOM Baltic Sea Action Plan**: It aims to apply an ecosystem-based approach to the management of the Baltic Sea.

Finally, a word of caution – though fully usable, the marine landscape maps are not better than the data used to develop them. In some regions, especially offshore, raw data points are few and far between and modelled data has been applied. Hence, further refinements need to focus on validation through obtaining new data, continuously improving the maps and lastly, providing a confidence rating of the maps. Similarly, potential end users need to continuously to bridge the gap between the sciences behind the landscape mapping and the future application of the maps.

2 INTRODUCTION

The aim of the report is to deliver the first holistic transnational approach to identifying and mapping seabed features of the Baltic Sea – an approach with the potential to be further developed into a tool for implementing an ecosystem-based and sustainable approach to spatial planning and management of the marine environment in the Baltic Sea. The results presented are based on international and cross-sectoral cooperation with participants from the countries surrounding the Baltic Sea.

2.1 Structure of the report

This report describes a uniform approach to identifying and mapping the marine landscapes of the Baltic Sea using available environmental data from a wide range of databases in the Baltic Sea Region. The origin of each data layer will be described whether it is actual measured field data or derived from ecological modelling. For each variable the data handling procedure and/or model will be described along with its applicability and limitations. As an introduction to each environmental parameter a summary of the conditions in the Baltic Sea is included as well as the degree of influence of specific parameters on marine life – plants, invertebrates and fish. This approach has been found essential in order to bridge the many different technical disciplines involved in the mapping of marine landscape and in order to enhance cross-sectoral understanding. The approach also explains why each layer has been found relevant for inclusion in the mapping of ecological meaningful marine landscapes.

Where relevant and meaningful, the marine landscape approach is related to EU policy documents such as the EC Habitats Directive, the EU Water Framework Directive and the proposed EU Marine Strategy Directive. This approach has been adopted in order to build upon existing EU legislation and shape marine landscape mapping into a tool suitable for a transnational and ecosystem-based approach to marine spatial planning and management.

The BALANCE Data Portal will make the applied data layers available for the wider public as well as being an ideal portal for future sharing of marine information available for the Baltic Sea. Marine data holders interested in sharing or viewing environmental data available for the Baltic Sea region should refer to http://maps.sgu.se/Portal/.

The report does not include biological validation of the identified marine landscapes. However, it does include an example of how well the identified marine landscapes represent major species assemblages. A validation process should continue after the publication of this report based upon data from the national monitoring programmes using the relevant biological dataset.

Finally, the report contains a number of recommendations regarding the applicability and limitations of the maps produced as well as acknowledgements of the people and/or institutions that have helped making the data layers available for the BALANCE project. The report also includes an overview of essential literature and links to selected relevant websites on marine environmental classification.

2.2 Rationale

Since the turn of the century there has been an enhanced focus on the general deterioration of marine environment and the continued increased human exploitation of its resources. This has 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. In order to promote such an ecosystem-based approach to management, broad-scale spatial information linking ecologically relevant information to human activities is needed for the marine environment.

The variety of current needs for broad-scale information is made tangible through various initiatives and legal requirements, such as:

- Implementation of EU directives, such as the EC Habitats Directive, the EU Water Framework Directive, the EU INSPIRE Directive and the proposed EU Marine Strategy Directive, which all, directly or indirectly, requires a broad-scale approach to the management of the marine environment.
- The need for identifying marine protected areas (MPAs) and assessing the ecological coherence and representativity of existing MPA networks, e.g. the Natura 2000 and the Baltic Sea Protected Areas network in the Baltic Sea.
- Delivering ecologically relevant information for promoting marine spatial planning.
- Providing a transnational solution to initiatives such as the Baltic Sea Action Plan undertaken by the Baltic Sea States under the Helsinki Convention.

Meeting these needs creates several political and technical challenges for the countries sharing the Baltic Sea, such as:

- Overcoming the cold war legacy that influenced the region for half a century.
- Enabling access to existing national environmental data.
- Requisition of e.g. biological information for offshore areas where little biological information is available (if it exists at all).
- Overcoming differences in methodology for collecting, storing and classification of marine environmental data.
- Providing relevant transnational and cross-sectoral information for various stakeholders utilising the marine environment, such as fisheries, marine aggregates, wind farms, nature conservation, shipping etc.
- Meeting short-term national commitments and targets, such as those required by various EU Directives or international conventions such as HELCOM etc.

Furthermore, as described by Laffoley et al. (2000) and Connor et al. (2007), more and more countries and the EU Commission (*sensu* the proposed EU Marine Strategy Directive) 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[2].

Thus, given the needs mentioned above and the wish for an improved, cost-effective approach to management of human activities in the marine environment several countries has developed, tested and utilized "the marine landscape concept" in their quest for developing an ecosystem-based approach to management of human activities. The marine landscape concept is based on the use of available physical and hydrographic information in order to yield broad-scale ecological meaningful maps for marine areas with little or no available biological information.

2.3 Origin of marine landscape mapping in the Baltic Sea Region

The concept of marine landscape classification and mapping was originally introduced by Roff & Taylor (2000) in a viewpoint on a Canadian framework for marine nature conservation based on a hierarchical geophysical classification. 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 a the identified marine landscapes. This work was supported by the World Wildlife Fund Canada. Their overall aim was to provide a tool, which could help environmental managers to enhance marine nature conservation schemes and marine spatial planning. The tool should be based on sound ecological principles and apply a more scientific and ecosystem-based approach to marine nature conservation rather than being driven by the more common approach as summarised by Hackman (1993) in his statement that MPAs are designated "*more by opportunity than design, scenery rather than science*".

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 UK has through the initiation of the MESH project (Mapping European Seabed Habitats) cooperated with France, Ireland, Holland and Belgium to improve the classification and mapping of seabed habitats for the north-western European waters. The European Commission supported MESH through the NWE INTERREG IIIB Neighbourhood Programme this project[3].

2.4 Definitions of marine landscapes

The initiatives mentioned above identified three main groups of marine landscapes (Vincent et al. 2004). These are:

[2] The BALANCE project will make a representativity analysis for the Baltic Sea based on the work presented in this report. Please refer to www.balance-eu.org for further information.
[3] More information about BALANCE can be found at http://www.balance-eu.org and about MESH on http://www.searchmesh.org.

- *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 this report three main groups are identified. i) The physiographic marine features of the coast, ii) the topographic features of the seabed and iii) the benthic marine landscapes based on physio-chemical characteristics of the seabed[4]. Pelagic landscapes are not identified, though an example of how it could be done is given in section 9.3.5.

In recognizing similar needs as mentioned above as well as the wish for developing an ecosystem-based approach to the management of the Baltic Sea the countries surrounding the Baltic Sea realised that a transnational and cross-sectoral approach was in order. This resulted in the development of the BALANCE project, which was undertaken by an international partnership consisting of research institutes, governmental agencies, regional authorities and NGOs participating from all the Baltic countries as well as Norway. It was co-financed by the BSR INTERREG IIIB Neighbourhood Programme, and aimed to develop a broad-scale and ecosystem-based approach to the mapping of the unique natural landscapes of the Baltic Sea, Kattegat and parts of the Skagerrak. This resulted in the definition of topographic seabed features, coastal physiographic features and 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. This is described in separate report available at www.balance-eu.org.

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. This report should be seen as the first step towards identifying and mapping the marine landscapes in the Baltic Sea. A process which hopefully will continue in the years to come in order to fill 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. Any future efforts should continue in the spirit of transnational cooperation to truly adopt an ecosystem-based approach to the management of human activities in the Baltic Sea Region.

[4] The term "marine landscapes" applied in this report is identical to the term "seascapes" defined by Roff and Taylor (2000) for the Canadian sea shelf. However, in the UK "seascapes" describes the view over a coastal feature e.g. the White Cliffs of Dover. The term "marine landscapes" has been applied in order to promote the use of a unified terminology in Europe. Any reference to the work done by BALANCE should therefore use the term "marine landscapes".

2.5 Geographic scope - the Baltic Sea

The Baltic Sea region is, seen from, a geological perspective and as a marine ecosystem very young. The Baltic Sea has since the latest glaciation been dominated by shifting freshwater and brackish periods. The melt-off from the Fennoscandian ice-sheet formed 15.000 years ago the Baltic Ice Lake in the area where the brackish Baltic Sea is situated today. It existed until 11.600 cal. BP[5] (Sauramo 1958, Saarnisto & Saarinen 2001) until a connection to the North Sea was established through south-central Sweden due to the retreating ice-margin. This caused a sudden drop of the dammed lake water level by ~25 m, and an intrusion of more saline water into the Baltic Sea Basin (Björck 1995) spelling the beginning of the first brackish period (Andersen & Borns Jr. 1997).

During the Yoldia Sea period brackish conditions lasted just a few hundred years, and were succeeded by some 500 years of fresh-water conditions (Svensson 1991, Andrén et al. 2000, Heinsalu 2001). The rapid glacio-isostatic uplift closed the connection to the North Sea in south-central Sweden, and the Baltic Sea Basin became isolated from the world ocean at around 10.700 cal. BP (Svensson 1991, Björck 1995, Andrén et al. 2000, Heinsalu 2001, Berglund et al. 2005). It was the onset of the freshwater Ancylus Lake. The Ancylus Lake was connected to the North Sea through a river, which today is located in the bottom of the Danish Straits. Further melt-off from the world's ice-sheets caused a raise in the sea level and periodic salt-water intrusions from the North Sea into the Baltic Sea Basin through the Danish straits. These saline water inflows were first restricted to the south-western Baltic Sea Basin.

World ocean levels continued to rise, and finally resulted in the end of the Ancylus Lake and the onset of the brackish Littorina Sea for approximately 8000-7500 years ago (Winterhalter et al. 1981, Björck 1995, Andrén et al. 2000, 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 5000 - 2500 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 (fig. 1).

Today, the Kattegat, the Danish Straits and the Baltic Sea together compose the second-largest brackish area (after the Black Sea) in the world (Segerstråle 1957) with a number of basins varying from almost freshwater in the northern part of the Bothnian Bay to the saline waters of Kattegat with a distinct salinity gradient in the Danish Straits (tab. 1). The total volume of the Baltic Sea including the Danish Straits is approximately 21.700km^3 with a surface area of 415.200km^2 reaching depths of up to 459 m with an average depth of 52 m (Andersen & Pawlak 2006). A volume of approximately a volume of 475km^3 of fresh water passes through the Danish Straits annually. The Baltic Sea is also characterised by an almost total lack of tide (Hällfors et al. 1983), which makes the salinity regime very stabile in often very large areas. Many areas are periodically or permanently stratified, which combined with the intense eutrophication causes large areas to be oxygen depleted (Ærtebjerg et al. 2003).

[5] Calibrated Before Present, which is in 1950 (according to the Christian calender). It relates to the first time radioactive carbon was successfully applied as a tool to date prehistoric geological events.

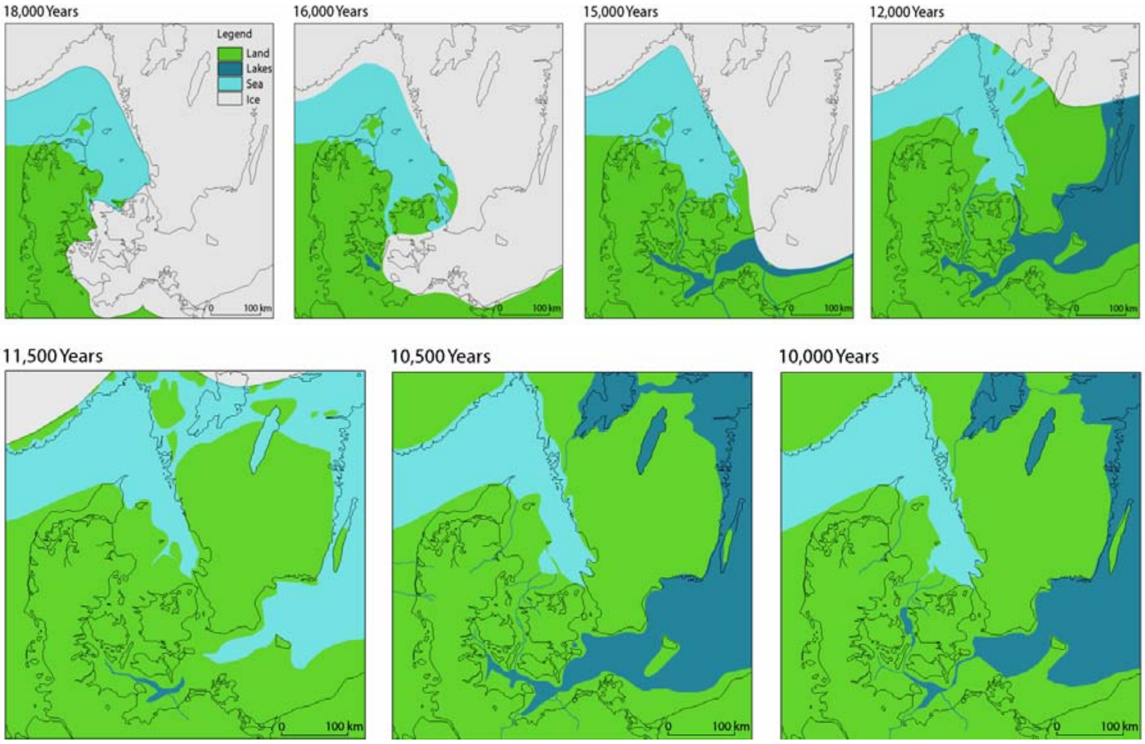

Fig. 1. *Glacial and postglacial maps of the Baltic Sea showing the formation of Yoldia Sea at about 11.500 years ago and the Ancylus Lake at 10.500 years ago (Jensen et al. 2002).*

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 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).

The shallow Kattegat and the Danish Straits form the transition zone between the low saline Baltic water and high saline waters of the North Sea and the Atlantic Sea. Large islands, reefs and sandbanks dominate this area with the remnant river channels forming the deepest part. Numerous large inlets, bays and fjords are located along the coastline (fig. 2). The western Kattegat shores are characterised by a mixed geological composition of mainly sand, gravel and boulders, while bedrock dominates the eastern shores.

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. The Baltic Sea is split into a number of deep basins reaching depths of down to 459 m.

Tab. 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[6]	-	-	-	-
Total Skagerrak	-	-	32-33	725	-

The southern coast of the Baltic Sea is mainly characterised as exposed sandy shore often with lagoons separated from the sea by barriers/ barriers islands. More to the north in the Gulf of Finland and the Archipelago Sea numerous skerries and islands span the Baltic Sea almost bridging the area between Åbo in Finland and the Stockholm Archipelago. To the far north the shore is mostly composed of bedrock interspersed with many small gravelly bays and lagoons. Furthermore, large areas are influenced by massive land rise with the seabed rising up to 9 mm per year in the Quarken area, which creates a unique range of habitats where the sea slowly develops into land.

***Fig. 2**. The Skagerrak, Kattegat and the Baltic Sea as seen from space. The image is used by kind permission of the SeaWiFS Project, NASA/Goddard Space Flight Centre and ORBIMAGE.*

[6] 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.

2.6 Application

Over the last decade some consideration has been given to the potential use and end users of marine landscape maps. Marine landscape mapping can be used as a supporting tool and source of information in environmental management including sustainable governance of large sea areas. An approach which provides a tool for an ecological meaningful regulation of human activities (Connor et al. 2007) and which in regard to environmental protection measures ensures an ecosystem-based approach to management rather than the traditional "*one nation – one approach*". In a semi-enclosed sea, such as the Baltic Sea surrounded by multiple nations with many stakeholders, cross-sectoral and transnational co-operation is essential in the development of marine landscapes. This is partly in order to gain access to relevant and coherent environmental data covering the territorial waters of many nations, partly to enhance the durability through wide acceptance and lastly, but most importantly, for ensuring an ecosystem-based approach to management and environmental protection. It also provides environmental managers with a practical, cost-effective tool to the managing and planning of large off-shore marine areas as physical and oceanographic information typically are available whereas biological data often are very scarce, if available at all.

The main purpose for developing a Baltic marine landscape map is to present a broad-scale, transnational characterisation of the marine environment in the Baltic Sea creating ecosystem-based tools which support various national and international planning and management requirements.

2.6.1 Implementation of EU Directives

All EU Member States are required to implement the EU Water Framework Directive, the EC Habitats Directive, the EU INSPIRE Directive and the proposed EU Marine Strategy Directive. These all require a more holistic or ecosystem-based approach to the management of the marine environment, which should, directly or indirectly, be based upon a broad-scale characterisation of the marine environment as stated in e.g.:

- The EU Water Framework Directive (art. 5.1, Annex II) *"- an analysis of its [river basin district] characteristics".*
- The EC Habitats Directive (art. 3.2, Annex I): *"- shall contribute to the creation of Natura 2000 in proportion to the representation within its territory of the natural habitat types and the habitats of species…".*
- The proposed EU Marine Strategy Directive (art. 7.a, Annex II) *"- an analysis of the essential characteristics and current environmental status of those waters… …and covering the habitat types, the biological components, the physio-chemical characteristics and the hydromorphology".*
- All three directives (WFD art. 5.1, Annex II; pMSD art. 3.1; HD art. 1.c) also require a transnational approach covering entire ecoregion such as the Baltic Sea;

and indirectly,

- The EU INSPIRE Directive which aims to set up the infra-structure for spatial information on e.g. hydrography and protected areas (art. 6A, Annex I) or sea regions, biogeographical regions, habitats and species distribution (art. 6B and 9B, Annex III).

The challenges for the EU Member States are to develop a joint approach promoting synergies and convergence in the implementation of the directives rather than developing several parallel, potentially conflicting characterisations of the marine environment. Marine landscape maps have the potential to be further developed into such a tool.

2.6.2 *Protection of the marine environment*

The marine landscape maps provide a coherent unified ecological map describing the Baltic Sea without regard to e.g. national boundaries. This gives environmental managers a first-time opportunity to gain a holistic overview of national distribution and extent of broad-scale ecologically relevant units and to relate it to a Baltic perspective, thus promoting an ecosystem-based approach to protection of the marine environment. BALANCE intends to apply these maps in a broad-scale assessment of the network of marine protected areas in the Baltic Sea identifying strengths and weaknesses of current protection schemes. Certain inherited limitations of applying the marine landscape map for this purpose are discussed in section 2.7 and by up-coming BALANCE reports available at www.balance-eu.org.

2.6.3 *Marine spatial planning*

The availability of a broad-scale ecological map for the Baltic Sea can provide sea-use planners with an opportunity to incorporate an ecosystem-based approach when making planning decisions on a regional scale taking a layer with the natural values into account, and thus help in an assessment of the potential impact of human activities. E.g. are certain activities that depend on the use of large areas, such as wind farming, unintentionally targeting large proportions of specific ecological units? For more local issues more detailed habitat maps are required. BALANCE is testing this in the Archipelago Sea and is making an overview of habitat mapping activities in 4 pilot areas in the Baltic Sea.

2.6.4 *Strategic planning*

Marine landscape maps can be applied for several strategic purposes as well. These include an application as a baseline study of the complexity within a region, providing field surveyor with a planning tool for areas with limited information. These maps could also provide an informed tool for setting up monitoring programmes, as they would enable a spread of sampling stations across the continuum of ecological units present in a region.

2.6.5 *Maritime safety*

Marine landscape maps may be used in regard to maritime safety issues. They provide input for a region showing the amount and distribution of specific ecological values. If combined with a sensitivity map this would provide valuable information for handling a major shipping catastrophy or oil spill by supplying a baseline for a prioritisation of effort in regard to natural values. E.g. showing the complexity of a near shore area as a sandy beach will be easier to clean than a more complex stony region.

2.6.6 HELCOM Baltic Sea Action Plan

The Baltic Sea Action Plan (BSAP) aims to apply the ecosystem-based approach to the management of the Baltic Sea. The BSAP will set a definition of 'good ecological status' for the Baltic Sea as well as specific environmental targets and necessary measures. It will be difficult to reach these aims without a broad-scale characterisation of the marine environment such as the marine landscapes developed by BALANCE.

2.7 Potential limitations

It is important that end-users are aware of the inherited limitations of the developed marine landscape maps. Some of the considerations made are presented below:

- The resultant map is no better than the information from which it was developed. For some areas data are scarce and/or only available in low resolution with large distances between points with actual data. The map is thus unsuitable for fine-scale planning unless further improved.
- Due to the relative coarseness of the bathymetric data available for the mapping exercise it has not been possible to identify fine-scale topographic features and the resultant map of the topographic and bed-form features present only the most dominant features. Features such as "pockmarks" in the Skagerrak basin have thus not been identified by this approach.
- There are no previously established standards for defining topographic, bed-form and coastal features by GIS. The process and definitions here are developed for the BALANCE project.
- It has not been possible to gain access to all existing data sets for various reasons including military restrictions on e.g. bathymetric data or due to lack of funds for gaining access to certain data sets etc. This influences the "exactness" of the map produced.
- Some of the modelled layers have a grid size of 7km, which can influence e.g. the exact location of a known biogeographic boundary, such as the Drogden Sill in the Sound between Copenhagen (Denmark) and Malmö (Sweden).
- Due to the many different classification schemes for e.g. classifying sediments, it has been necessary to compromise when merging data for the Baltic Sea.
- The lack of accessibility to a relevant and coherent biological dataset of sufficient resolution for benthic biological quality elements covering the Baltic Sea influences the validation process of the map adversely.
- It should be noted that expert judgment (and to some extent availability of data) has been applied in deciding which environmental parameters should be included in the identification of the Baltic Sea marine landscapes. It could be argued that other parameters should have been included or different categories chosen. This will be a challenge for future work.
- For these reasons it is necessary to have a confidence rating of the maps providing the end user with information about the usefulness and inherited limitations of the map and the layers used to develop it. The confidence rating of the maps should be further developed in the coming years.

3 METHODOLOGY

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, such 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).

The challenges in marine landscape mapping are many and the methodology adopted for meeting some of the challenges, if not all, are described below (fig. 3).

3.1 Process adopted

The first challenge was to select the environmental parameters and data sets necessary 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. Basically, the more thematic maps applied in a classification scheme the higher the number of possible combinations. The art in marine landscape mapping is identifying the right balance between including relevant thematic maps and keeping the number of identified landscapes within a manageable limit. Expert judgment was used, with input from a range of scientific disciplines. If more detailed information is desired for a specific regional or local area, a habitat mapping exercise should be conducted.

The next step was to harmonise and standardise the individual data sets and present them in unified formats. The individual data sets were obtained from relevant sources within the Baltic Sea. 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.

One of the more efficient ways to produce a broad-scale benthic marine landscape map from a number of different sources is by using raster map algebra in a GIS. 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 (fig. 3). The quality of data collated also differs from high to low-resolution data. Some of the modelled datasets has 7km resolution while others have ~600 m resolution. All datasets were re-gridded to a 200 × 200 m grid. This process ensures data continuity but it does not increase the output map resolution.

The next 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 expert judgment 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). The justification has been explained for each parameter as these choices have a strong influence on the final classification.

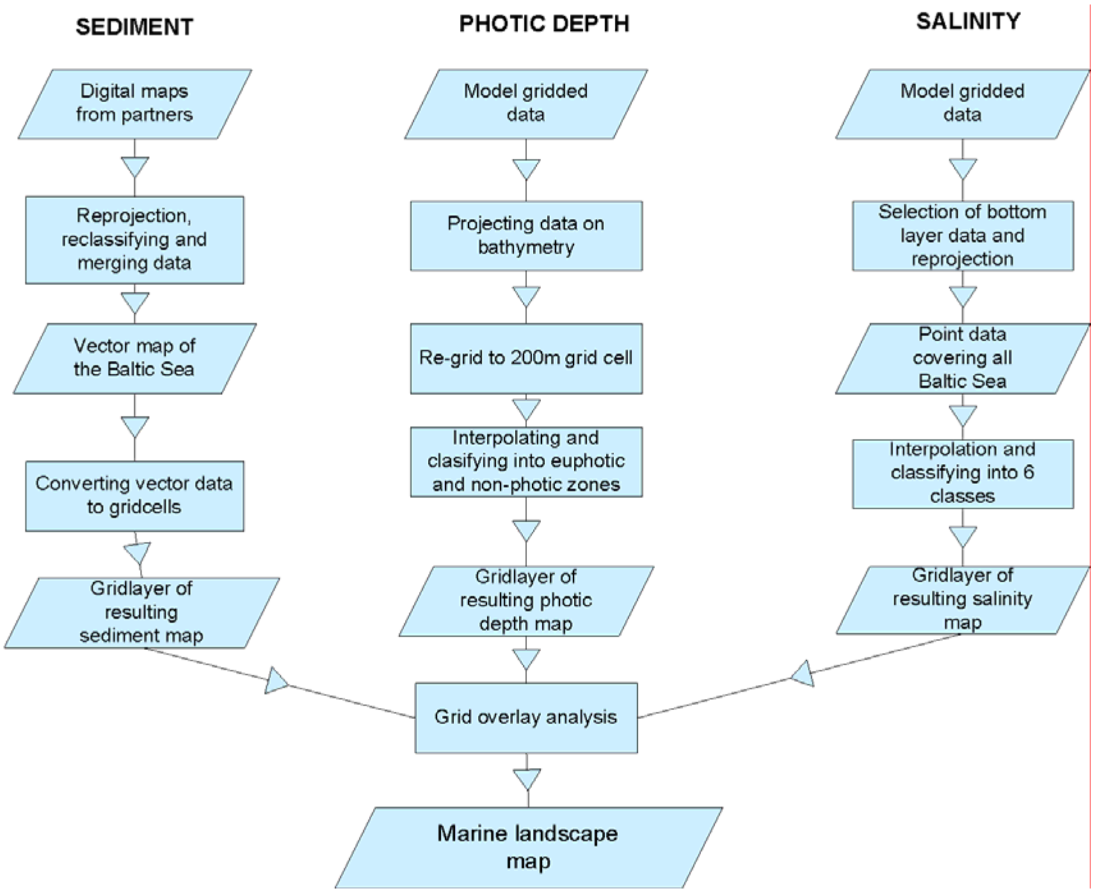

Fig. 3. *Flow chart shows the processing steps of the three datasets used for the production of the benthic marine landscape map.*

3.1.1 Selecting environmental parameters

Our approach is to identify three different kinds of broad-scales characterisations of the marine environment, though the focus of the report is on the ecologically relevant entities – the benthic marine landscapes. This section describes briefly the reasoning behind selecting the specific physical and/or environmental parameters.

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 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. The topographic approach describes the seabed in a terminology that is easy to visualise.

Secondly, identification of the physiographic features was 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 EU legislation e.g. in the EC Habitats Directive. There is no a 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.

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, the photic – non-photic zone (where 1% of available light reaches the seabed) and salinity. These parameters are important for determining broad-scale distribution of species in a regional context such as the Baltic Sea.

Sediment was chosen, as it is fundamental for the distribution of benthic organisms. Sediment was split into 5 categories ranging from bedrock to mud each with different ecological relevance. For example, macroalgae need a hard substrate to be attached, while sea grasses need soft substrate to grow.

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. These two categories thus enable to distinguish between ecological relevant categories of light and provide a division that distinguishes depth between shallow and deeper waters.

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

Other environmental parameters were considered, but these were judged to be either more relevant for detailed habitat mapping e.g. wave exposure, not relevant for the entire region e.g. ice cover, 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 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 benthic marine landscapes are the most relevant characterisation of the marine environment for achieving a sustainable management of the marine environment as it does reflect broad-scale species assemblages. Hence, this report will focus on these benthic marine landscapes.

3.2 GIS data type

Data sets collated from partner institutes and databases came in various shapes and formats, which were not necessarily GIS compatible. Some data sets came in paper format and had to be digitised first, before being converted to ESRI compatible data sets with the right projection and geographic extension. Other types of data sets encountered in the data collation process are:

Vector data: ArcGIS – the GIS platform used in this project – has vector data as the primary data model. Vector data consist of point, line or polygon themes including attribute data to each object (examples could be measurement points with attached measurement data, coastlines with information such as length and polygons defining areas of low oxygen content). These objects can be localized very precisely, but the actual precision depends on the input data source.

Raster data: This data can be either grid data or digital images. Data can be converted from raster to vector format and vice versa, but the quality of the resulting data will be poorer for each conversion.

Grid data: A grid in a GIS is a geographical referenced rectangular array of equally sized, quadratic cells. The size of each cell is given in real world units, e.g. meters. Each cell contains one value (of like salinity etc.) and the whole array is called a grid layer.

Image data: A scanned image (map) can result in a digital image. These can be utilized in a GIS if they are geo-referenced that is real world coordinates given to the pixels. Images have in general three bands (red, green, blue), which combined, can be shown as a colour image. Geo-referenced images can be converted to a grid.

ASCII data: Data from the dynamic models (calculating salinity, current etc.) are delivered as simple ASCII (text) files. This data must be handled in other systems before loading into the GIS for which the statistical system SAS® was applied. The data has coordinate information, which makes it possible to convert the data into a point theme (vector) and further on convert it to a grid theme through interpolation routines.

3.3 Methodology applied for data analysis

Each dataset layer contributing to the production of benthic marine landscape map was carefully analysed before it was merged with datasets of the same kind provided by other partners. Any conflicts arising when these dataset maps were overlaid was dealt with by one of three main approaches:

- The data-providing partners were contacted and the problem presented. If one of the partners had a less confidence in the provided data set and the others had more robust data in their map, then the map with greatest confidence would prevail.
- If the confidence in either maps or data was equal then an expert judgment was used to solve the conflict.
- The resulting marine landscape map was analysed down to the pixel resolution. Whenever an artefact caused by joining layers in the GIS program appeared, they were dealt with in such a way as to preserve the diversity in the marine landscapes, while reducing the occurrence of such artefacts.

The choice of raster data type for GIS analysis rather than vector data sets is due to the ease and speed of algebraic calculations, though it is not possible to add extra information about the data layer in the raster data. Most of the data sets were acquired in raster format that had to be gridded into the right size. A precondition to use raster map algebra is that all data must be in the same grid format with identical grid cell size and location. Thus vector data must be converted to grids and all grids must be reclassified to the same format. Then the layers are combined either by simple addition of the grid values (fig. 4) or by using a weighting function. In this project a combination has been used. All real world values (salinity in psu etc.) have been classified. To preserve all input classes the values have been multiplied by different constants before addition.

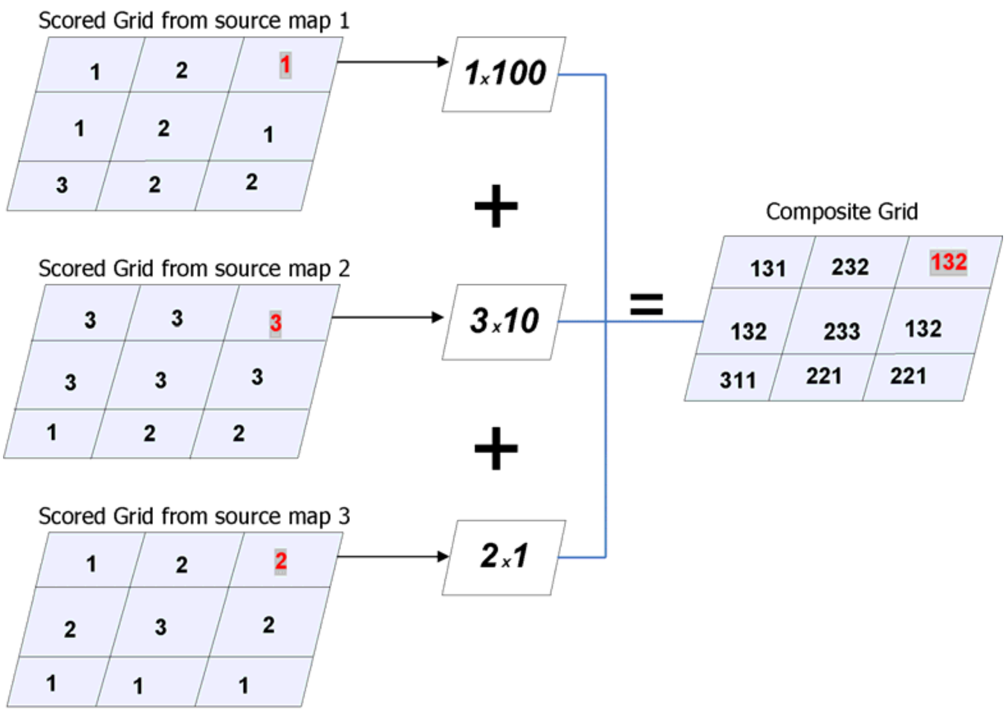

Fig. 4. *Schematic diagram of layers overlaying in marine landscape production using GIS tools. The sum is an algebraic sum and in GIS we multiply layer 1 by 100, layer 2 by 10, and layer 3 by 1 before adding them in the GIS Tool.*

4 SEABED TOPOGRAPHIC FEATURES

This chapter will describe the data applied and approach adopted for identifying the topographic marine landscapes conceptualising the topographic layout of the seabed of the Baltic Sea. The following chapters will identify the coastal physiographic features characterising the transition zone from land to sea (chapter 5), and the benthic features conceptualising the physical and hydrological parameters of the seabed (chapter 6). Together, these three approaches provide a spatial overview of the complexity and geomorphological diversity of the marine environment in the Baltic Sea.

4.1 Topography and bed-form features

Topographic and bed-form 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.

In previous studies, e.g. in the Irish Sea pilot project, the seabed features have been defined using a geomorphological terminology, e.g. plains, reefs and canyons (Golding et al. 2004). In "the National Marine Bioregionalisation of the Australia", the role of the individual geomorphic features is also acknowledged as they "*add information about spatial distribution of benthic marine biot*a". In addition, the current Natura 2000 network is largely connected to geomorphological features. In consequence, it was decided to identify bottom topography and bed-form 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.

4.1.1 Bathymetry and derived slope data

The Baltic Sea consists of a number of major basins reaching depths of up to 459 m (the Landsort Deep) and has an average depth of 52 m. 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 120 m, but with an average depth of 23 m. The trenches in Skagerrak reach depths of up to 725 m (tab. 1 & fig. 5). The bathymetry was use to derive the slope within the Baltic Sea (fig. 6).

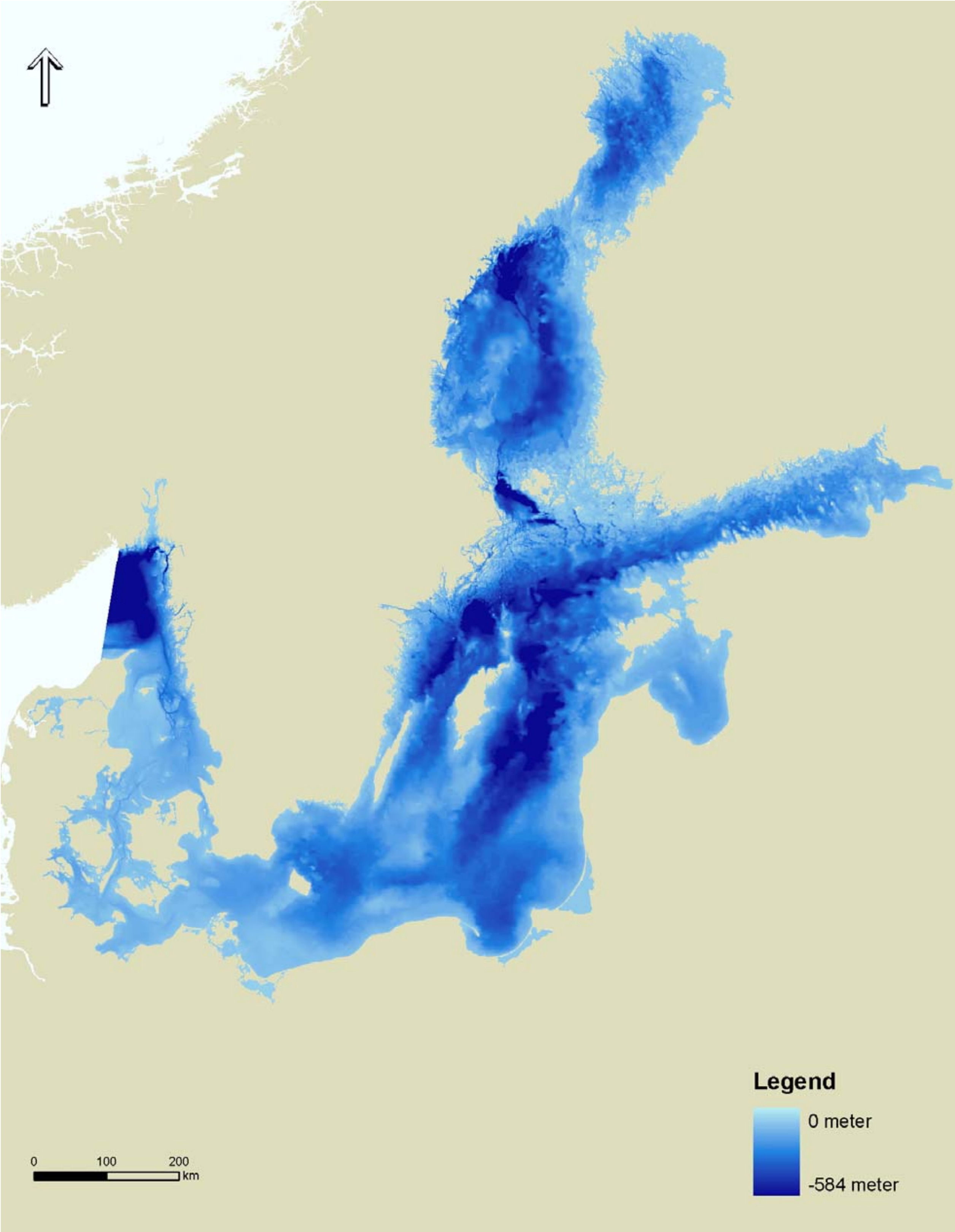

__Fig. 5.__ Bathymetry of the Baltic Sea, Kattegat and Skagerrak. The deepest point in the Baltic sea is –459m whereas the Norwegian Trench in the Skagerrak is deeper.

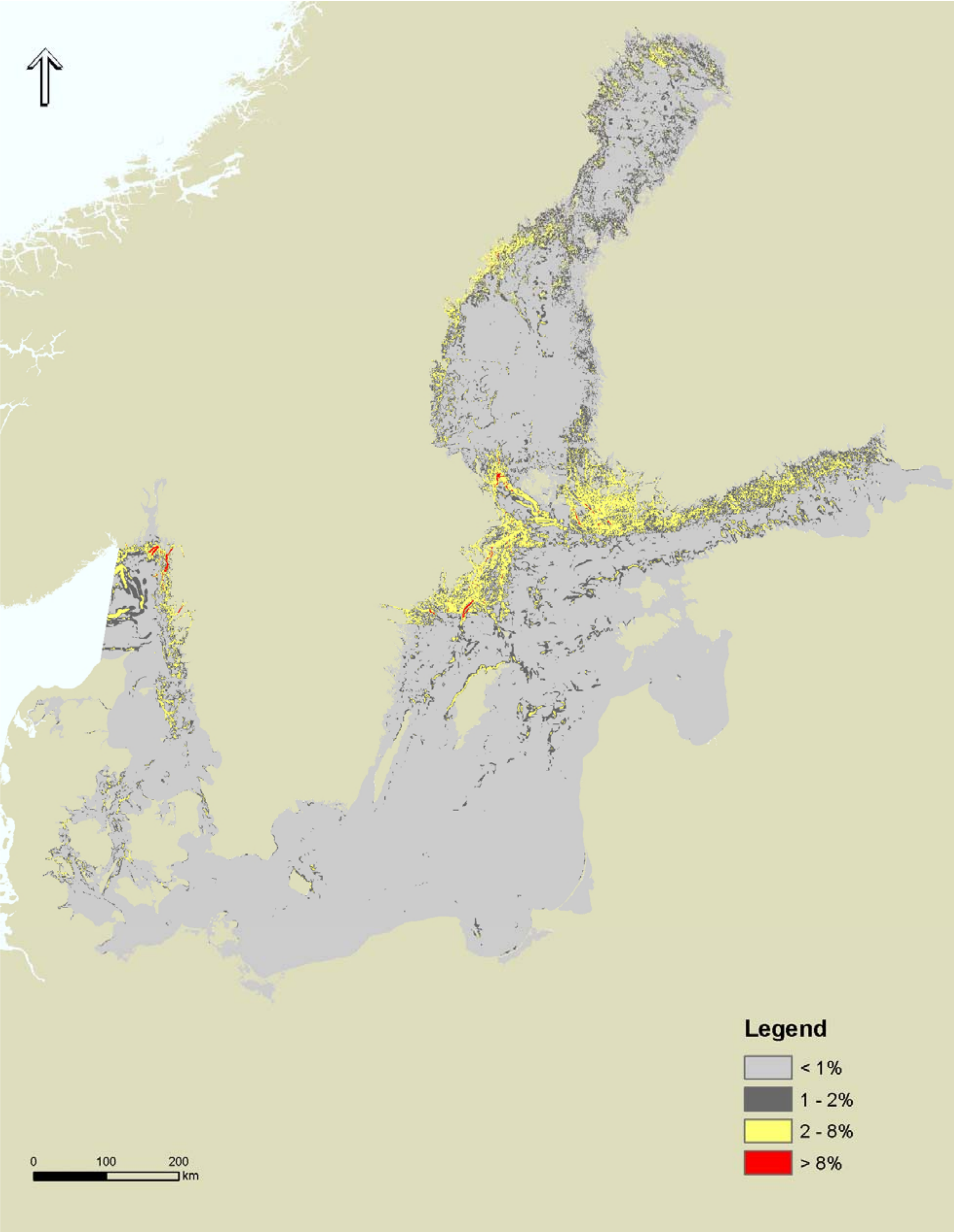

***Fig. 6**. Seabed slope derived from bathymetry map of the Baltic Sea.*

4.2 Topography and bed-form features identified

The following topographic and bed-form features were identified in the Baltic Sea (fig. 7 and tab. 2).

Plains

Plains are large areas with low relief. They are generally uniform and normally located in homogeneous seabed conditions. Two distinct types of plains were identified - fine sediment plains (mud and clay) and coarse sediment plains (hard clay, sand, hard bottom complex). Plains which consist of bedrock and are located within the photic zone are also identified and presented in the map. That they have been considered as "plains" here is due to the low resolution of the bathymetry map.

Basins

A basin is a depression in the seabed, more or less equidimensional in plan view and of variable extent (IHO 2001). Basins are usually a depositional environment of mainly soft sediments composition, though in the Baltic Sea coarse sediment basins do also exist in some areas. Basins have been divided in this project into two categories; mud & clay basins and coarse sediment basins (with various composition of hard clay, sand, hard bottom complex or bedrock).

Troughs (canyon-like features)

Shelf troughs are elongated narrow depressions in the seabed that are steep sided. They have a maximum depth significantly greater than the surrounding seabed. They are usually associated with deep-water currents. Troughs often have a flat bottom, but this feature did not appear in the bed-form analysis conducted in this work due to the rather coarse scale bathymetry. As canyons are more connected to continental slope areas, features showing canyon-like characters are defined here as troughs. Troughs were further divided into mud and clay troughs and coarse sediment troughs (hard clay, sand, hard bottom complex, bedrock).

Valleys and holes

Valleys and holes are depressions in the seabed. Holes are steep-sided small depressions in the seabed, while sea valleys are relatively shallow depressions of which the bottom usually has a continuous gradient. Sea valleys are typically elongated low-lying areas that are surrounded by higher areas. Many rivers that run into the Baltic Sea have a continuation in the seabed as a sea valley. Valleys resemble troughs, but are lower in magnitude. Sea valleys and holes were further subdivided according to the dominating sediments into mud and clay sea valleys and holes as well as coarse sediment sea valleys and holes.

Mounds

Mounds are elevations of the seabed. They include plateaus as well as hills, banks and sills. These features were difficult to differentiate by GIS, mainly due to lack of precise definitions (concerning e.g. extent, height, slope) and low bathymetry map resolution. Therefore it was decided to include all regional scale elevations as one group and name them as mounds. This feature was further subdivided according to sediment type and photic depth into 8 sub-classes (tab. 2). Areas with bedrock outcrops that are elevated from the surrounding flat seabed are referred to in this work as mounds. This type of mound resembles a the Natura 2000 habitat (1180) *Reef* as described by Annex I of the EC Habitats Directive and defined as rock or organic mineralizations that are submerged all times. The presence of rock in this case is an important parameter in reef definition. Erratically placed boulders also form reefs, but were not shown in this work due to lack of detailed substrate information for their probable area of formation. Elevations caused by the presence of hard bottom complex sediments are referred to here as mounds of complex sediments. Submarine moraine formations belong to this group. In some areas these mounds might include large boulders and they can then be regarded as reefs.

Mounds with sand are also identified in the analysis. This type of mound resembles in some circumstances the Natura 2000 habitat (1110) *Sandbanks* as described by Annex I of the EC Habitats Directive. There are also crests of clay and hard clay, which often form sills between basins. These were also grouped together and defined as mounds of clay and hard clay sediments.

Slopes

Slopes are areas where slope exceeds 1%. They are very small group and it was not further classified on the basis of sediments.

Wave/Mega ripples

Wave/Mega ripples occur in sandy bottoms of shallow seas where currents and wave action create a wavy surface. According to the available bottom velocity data, the current velocities in the Baltic Sea are too slow to form such features. Consequently no mega ripple fields were identified within the Baltic Sea. Wave/Mega ripples are included here to enable comparisons with other marine landscape mapping initiatives and to inform future mapping exercises in the Baltic Sea.

Tab. 2: Topographic and bed-form features present in the Baltic Sea.					
GF	**Colour code**	**Topography /BPI**	**Substrata**	**Depth**	**Other criteria**
Troughs		Narrow depression	Mud and clay	Varies	Slope > 4%, longitudinal 2/1
			Coarse (gravel, hard clay, sand, hard bottom composite,		
Basins		Wide depression	Mud and clay	Varies, though often at deeper waters	None
			Coarse (gravel, hard clay, sand, hard bottom composite, rock)		
Mounds		Crest	Clay and hard clay	Non-photic	Raised
				Photic	
			Sand, gravel, cobbles	Non-photic	
				Photic	
			Hard bottom complex, unconsolidated material	Non-photic	
				Photic	
			Bedrock and boulders	Non-photic	
				Photic	
Plains		Flat	Fine sediments, mud and clay	Varies	No slope, may be erosional surface
			Coarse sediments		
			Bedrock	Photic	Photic depth
Valleys and holes		Narrow depression	Mud and clay	Varies	Not trough
			Coarse (gravel, hard clay, sand, hard bottom composite, rock)	Varies	
Slope		Slope	Varies	Varies	Slope ≥1%, not in 2km radius from basin
Wave/Mega ripples	N/A	Crests	Sand. Could not be delineated with the available coarse resolution data sets, not in the Baltic Sea		Moderate to strong currents

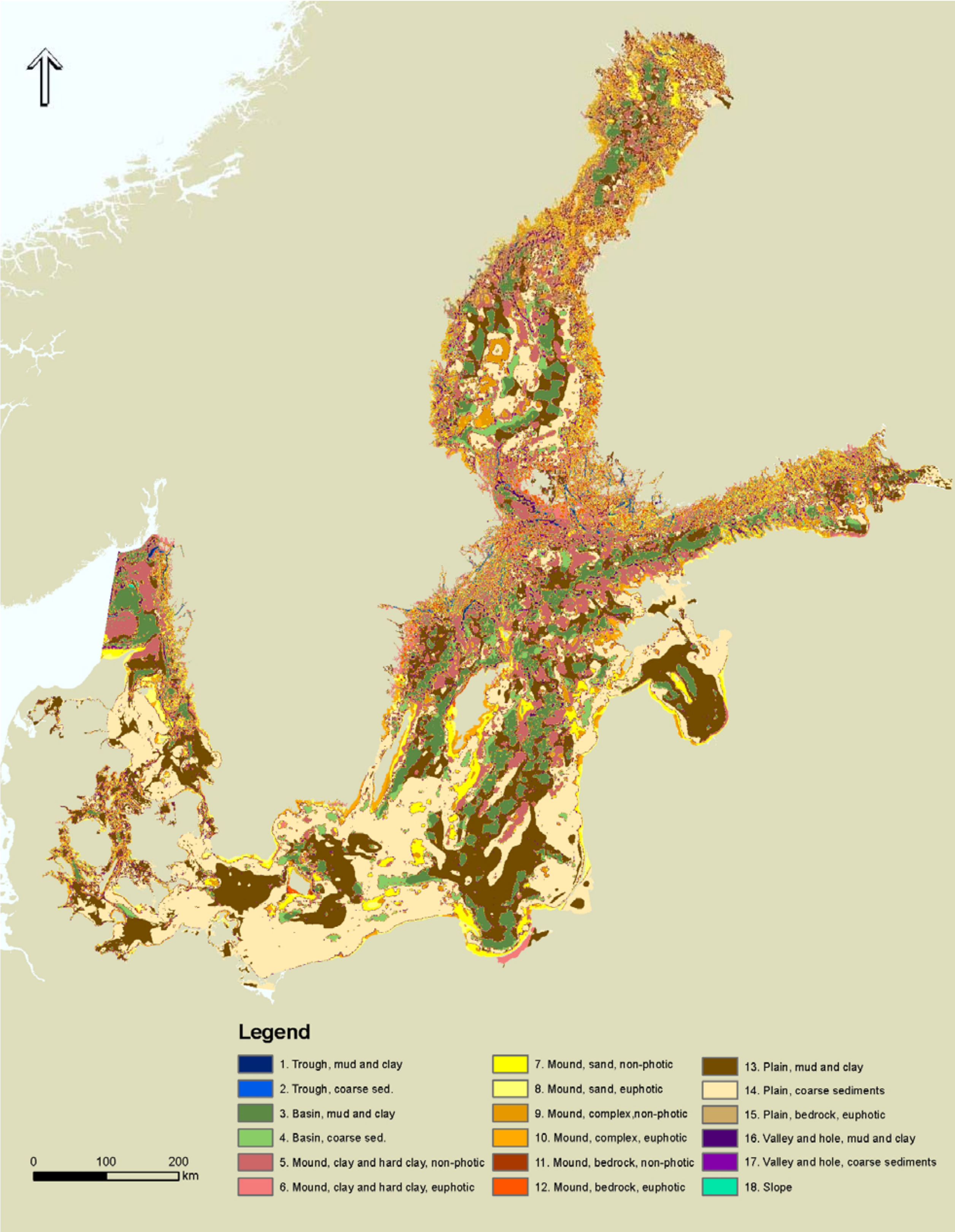

Fig. 7. *Topographic and bed-form features identified in the Baltic Sea.*

5 COASTAL PHYSIOGRAPHIC FEATURES

Coastal physiographic features 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. They 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 ecological units.

5.1 Approach and data

Coastal features cover areas where the seabed and water body are closely interlinked (Golding et al. 2004). Both the seabed and the overlying water are included within the 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. If more detailed results should be desired it would require access to a high-resolution coastline.

5.1.1 Coastline

The coastline in the Baltic Sea is extremely varied ranging from the long exposed sandy shores of Poland over the gently curved bays and inlets in Germany and Denmark to the very complex archipelago regions of Finland and Sweden reflecting the landform processes characterising the region e.g. the land lift in Quarken area. The 1:250 000 coastline used in the work is from the ”Europe Countries” dataset published in ”ESRI Data & Maps”. Originator: AND Data Solutions B.V. and ESRI Inc.

5.2 Coastal physiographic features identified

A total of 5 physiographic features (plus 2 sub-divisions) were identified for the Baltic Sea. These are presented below with their characteristics summarized in the tab. 3 and the distribution in fig. 8.

Estuaries

An estuary is a river mouth where fresh water mixes with water with a higher salinity content. Often sediments from river run-off accumulate in estuaries and form deltas and small islands. In reality the Baltic Sea is one large estuary, but inside the Baltic Sea there are brackish water estuaries with no tidal action. The available salinity data only enables the delineation of the biggest rivers estuaries, such as Neva, Oder, Vistula, Lule and Kemi. Future more detailed mapping efforts of estuaries will depend on the availability of high-resolution salinity data.

Fjords and fjord-like inlets

A fjord is a steep-sided narrow inlet of the sea between steep slopes. They are characteristic features of the glaciated regions. The depths are greater in the upper and middle reaches than on the seaward side (compare to a sound) because there is often a sill (terminal moraines or rocky barrier) near the entrance.

It is known that there exists at least one fjord in the study area, Gullmarsfjorden, which can be seen in the result. However, there are other fjords in the region that are not shown in the resulting map, probably due to the course resolution of bathymetry map and other datasets which are used to define the fjords in GIS. Other enclosed areas are sometimes called fjords without fitting with the in-hand definition; therefore these features are called fjord and fjord-like inlets.

Bays

A bay is an indentation of the sea into the land with a wide opening. It is a water area bordered by land on three sides. There are many bays in the Baltic Sea. However, it is difficult to define them all with GIS. Exact determinations for example on entrance width or maximum depth are difficult to define. On these grounds features like embayment and lagoons are also classified as bay landscapes - bays can be regarded as an umbrella term a coastal feature that are sheltered to some extent. Gulfs, which are in fact large bays, are on the other hand not included to coastal landscapes at this point. The classification of bays is further sub-divided into sheltered bays, lagoons and lagoon-like bays.

According to our definition, bays, sheltered bays and lagoon like bays are very common coastal features throughout the whole Baltic coast. If the lagoon and lagoon like features are considered, then there are in addition to Oder, Vistula and Curonian lagoons lagoon-like bays for instance on the islands of Zealand and Funen. Lagoons, lagoon like features and estuaries can be found in the same geographic location, for example Vistula lagoon is defined as both estuary and lagoon. At present, Limfjorden, that is known to be shallow fjord, is included here in the sheltered bays category. In this work, only broad, regional scale sheltered bays are defined. The archipelagos are very diverse areas and there are lots of small coastal marine landscape groups, which it was not possible to define in regional scale. The marine landscape group archipelago includes also sheltered bays and lagoons inside the area.

Sounds

Sounds are long and relatively wide water bodies that separate land areas. They are shallow in depth and water flows in multiple directions. Probably the best-known sound in the Baltic Sea is the Sound between Denmark and Sweden that is up to 20km wide. This was used as a guideline for the current definition and sounds were defined as narrow water areas where the width of free water does not exceed 20.000 m.

There are few archipelago areas in the Baltic Sea. These are mosaics of small islands where narrow channels occur between land areas. These narrow channels are small sounds. However, they are very small, whereas in this context the aim was to define broad structures. To avoid complications it was decided that archipelagic sounds are included in the coastal features of the archipelago type.

Due to a lack of detail depth and current information, some sounds could not be completely identified by following the given definitions. Therefore, they were identified according to expert judgment and were placed in the physiographic features map.

Archipelago

An archipelago consists of a group of islands in close proximity to each other. It is a broad-scale coastal feature, which is very heterogeneous when examined in detail. An archipelago may include other physiographic types, such as small sounds and lagoons.

There are vast archipelago areas on the Swedish and Finnish coasts with major ones present in the Archipelago Sea, the Stockholm Archipelago, Quarken and the northernmost part of the Bay of Bothnia.

Tab. 3: Coastal physiographic features (CF) identified in the Baltic Sea.

CF	Colour code	Topography & other features	Subclasses	Depth	Salinity	Other criteria/ facts
Estuary		Somewhat sheltered area (Max. 20km wide, land in min. of 4 directions in 15km radius)	No	≤ 30 m	≤ 3.5psu in the north ≤ 6psu in the south	
Fjord and fjordlike inlets		Narrow depression/ trough	No	Varies	Varies	"Terraneous", < 5km wide
Bay		Somewhat sheltered area (Max. 20km wide, land in min. of 4 directions in 15km radius)	Lagoons & lagoon-like bays	≤ 5 m	Varies	
			Sheltered bays	Varies	Varies	Entrance < 1km
			Bay	Varies	Varies	Entrance < 1km
Sounds		Located between land areas, channel	No	Varies	Varies	Outlined manually
Archipelago		> 20 islands in 20km×20km	No	Varies	Varies	

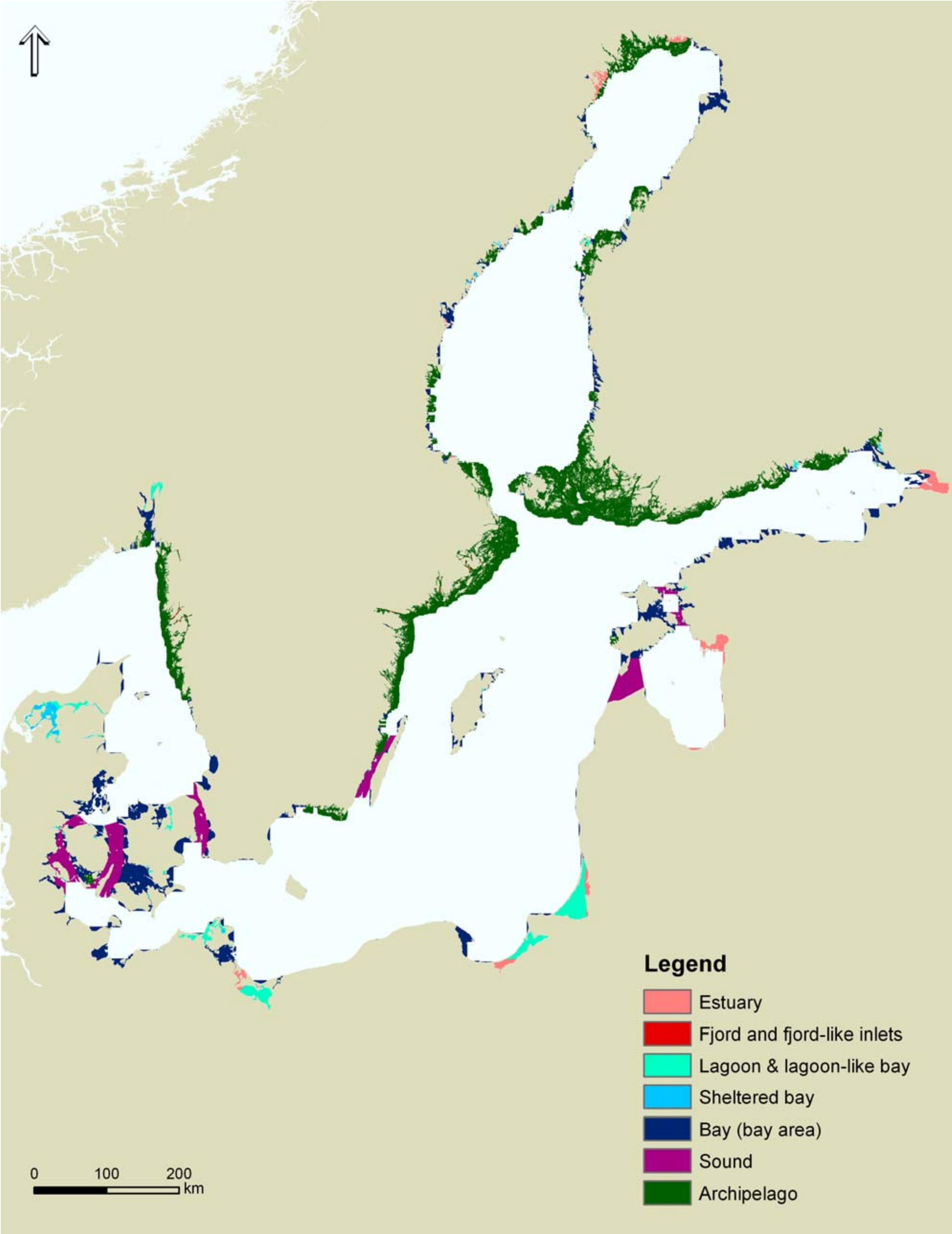

Fig. 8. *Coastal physiographic features identified in the Baltic Sea.*

6 BENTHIC MARINE LANDSCAPES

Mapping topographic and bed-form features of the seabed and coastal physiographic features are only the first steps towards a broad-scale characterisation of the marine environment of the Baltic Sea. Extensive Baltic Sea areas and their ecologically relevant units cannot be identified based on topography and coastline alone. Therefore, a variety of physical and hydrographic parameters were considered based on their influence on shaping the broad-scale distribution of major species assemblages, thus enabling an ecologically meaningful characterisation of the marine ecosystem.

The description of an individual parameter includes a short presentation 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. This is provided as an aid for readers unfamiliar with marine ecology and biology of marine species in order to promote a better understanding for why a specific feature or category has been included in the mapping of the marine landscapes. 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.

It is important when reading the justification of the individual categories to keep in mind that this is a first step towards a broad-scale marine landscape map and that the subdivision of most parameters into ecologically relevant categories are research projects in their own right and thus reaching beyond the scope of BALANCE. Hopefully, it will inspire or provoke scientists towards new research projects making statistical validated ecological categories and at the same time make environmental managers and policy-makers aware of the necessity for public access to environmental data collected to agreed standards.

6.1 Approach and environmental data considered

In order to prepare the marine landscape mapping and modelling a great number of considerations went into identifying and deciding upon the most important data sets to be included in this approach to marine landscape mapping. The challenge was to maintain a balance between input data and the required output – a broad-scale ecologically relevant marine landscape map. The following types of data were considered to be essential and have been included in the marine landscape development in the Kattegat and the Baltic Sea:

I. Surface sediment.
II. Available light (defined as depth where 1% surface light reach the seabed).
III. Salinity at the seabed.

The following types of data were, for various reasons, considered to be secondary for the marine landscape development in the Baltic Sea (see also chapter 7):

I. Temperature.
II. Ice coverage.
III. Wave exposure and wave base.
IV. Current velocity.
V. Oxygen concentration in the bottom water

Where relevant these secondary data sets can be included in the description of the marine landscapes, e.g. ice cover in the Gulf of Finland, in order to fit specific national interests. These secondary data layers are presented separately in chapter 7.

All the above-mentioned data sets were collated for the project, though not all are used in the final analysis due to the following reasons:

I. It was not possible to gain access to standardised region-wide data for all parameters.
II. Some parameters are difficult to utilise at the broad-scale landscape level, and are more applicable on a local scale, e.g. wave exposure in archipelagos.
III. Some parameters are only of major relevance for regional parts of the Baltic Sea, e.g. ice cover.
IV. Some parameters were very difficult to divide into justified ecologically relevant categories e.g. temperature and current velocity.

The following sections will describe how each parameter was considered including a short description of Baltic conditions, ecological relevance for marine life, data source, technical development and justification for selection and categorisation.

6.2 Seabed sediments

In spite of the shallowness, the seabed morphology of the Baltic Sea is very diverse. The Baltic Sea basin underwent several glaciations during the past million years. During that time, the Baltic Sea areas have been repeatedly subjected to glacial erosion and accumulation. However, the main morphological features are of pre-glacial origin. The majority of the most outstanding morphological features consist of various forms of deeps, depressions and trenches, often filled with glacial and postglacial sediments. These sediments smooth smaller depth differences, but the seabed bathymetry follows mainly the surface of bedrock/sedimentary bedrock.

The bedrock has had a great impact on the character and distribution of unconsolidated sediments in the Baltic Sea. It has not only been the major source of material deposited during and after the last glaciation but bedrock has taken part in the distribution and formation of glacial deposits. Land uplift is an ongoing phenomenon in the Baltic Sea basin. Together with transgressions and regressions it has contributed to the distribution of sediments. Sedimentation conditions differ in the southern and northern parts of the basin. The southern Baltic Sea is rather stable, because sea-level fluctuations have been relatively minor for a long time. In the north, however, continuous regression, caused by the uplift, enables the erosion to progress to new seabed regimes (Winterhalter et al. 1981). The land uplift, up to 9 mm/year, leads to the continuous succession of land and simultaneously creates a unique range of habitats. Besides land-uplift and bedrock, factors like water depth, seabed topography, distance from the land, current velocity, grain size, water masses, climate, ice cover, primary production and benthos influences the erosion, transport and accumulation of the sediments.

In the south-western part of the Baltic Sea, the main part of the seabed consists of sand. In the southern and central parts of the Baltic Sea three main bottom types cover large areas. In the deep parts soft bottoms are dominant, sediment thickness reaching up to several tens of meters. Sand bottoms dominate the southern and eastern coastal zones.

Hard bottoms appear north of Poland and near the south-eastern coast of Sweden. Irregular topography with depressions, rather flat regions and areas with shoals characterize the Northern Baltic Sea. Especially in the northern parts of the Baltic Sea basin, where a vast archipelago controls the circulation of free water, active sedimentation conditions can occur even in shallow basins (Winterhalter et al. 1981).

Most of the sediments found on the seabed of the Baltic Sea have been deposited during the last glaciation or after that. These sediments consist of glacial sediments (like till, glaciofluvial formations, and glacial (varved) clays and silts) and post-glacial sediments (fine grained sediments which have been deposited during different lake and marine phases of the Baltic Sea). Coarse-grained sediments, like sand, eroded and deposited by wave action, belong to this group too.

Due to the ongoing changing processes, seabed sediments are composed of different type of sediments ranging from glacial till to recent gyttja. Therefore, the spatial distribution of different sediments types on the seabed is very patchy. The erosion, transportation and accumulation of the sediments on the seabed vary spatially and temporally.

Seabed sediment composition and marine life

The sediment composition of the seabed is considered essential in marine landscape production as it is one of the primary parameters influencing the biogeographic distribution of marine benthic species and a primary component in shaping the physical structure and function of marine habitats (Connor et al. 2003). Areas with various sediment types ranging from mud, sand, gravel and boulders will contain a higher number of species compared to areas with only one or two sediment types (Wennberg et al. 2006).

Most marine macroalgae, such as the brown algae *Fucus vesiculosus* (fig. 9a), are dependent on hard substrate to stay attached to the seabed. Some species, such as the brown algae *Pilayella litoralis* or the red algae *Furcellaria lumbricalis* are able to survive as loose-laying mats often covering large areas of the seabed. A general trend in the distribution of the marine macroalgae in the Baltic Sea is the relatively low number of species along the sandy exposed shores of the south-eastern shores along the Polish and Lithuanian coasts compared to areas of the Swedish coast – regions with a similar salinity regime. Areas with a more varied or mixed composition of substrate tend to have a relatively large number of species when found in a similar salinity of areas with only one sediment type (Nielsen et al. 1995). In more sheltered areas with soft or sandy sediment phanerogams and characeans form large meadows. The marine phanerogam *Zostera marina* (fig. 9b) is common on soft sediments in the more saline parts of the Baltic Sea, while freshwater species such as *Potamogeton* spp., *Myriophyllum* spp., *Chara* spp, and *Phragmites australis* are habitat forming in the more oligohaline parts.

Many marine benthic invertebrate species reproduce by larvae that for some time live and feed in the water masses before settling out of the water and taking up life on the bottom (Ockelmann & Dinesen *submitted*). The larvae are capable of settling preferentially, some in response to specific substrate characteristics, others in response to other cues (Nybakken 2001). Marine benthic species are traditionally divided into two functional groups depending on whether they as adults live attached (sessile fauna) to firm faces, such as plants, algae, boulders, or bed rock, or live freely (motile and sedentary fauna) in or on different types of sediments, of mud, sand, and gravel (Sand-Jensen & Fenchel 2006).

Fig. 9a. *The brown algae* Fucus vesiculosus *is the dominating brown algae on rocky substrate in the Baltic Sea. Photo: Metsähallitus.*

Fig. 9b. *The sea grass* Zostera marina *dominates sheltered areas with sand or softer sediment in the Kattegat and the Baltic Sea. Photo: Peter Bondo Christensen, NERI.*

High diversity of substrates is closely related to high diversity of marine invertebrates Dayton 1994). Several of the sessile fauna belong to classes (and phyla) different from those of the motile and sedentary fauna. Thus, an area with e.g. till covered by finely sorted sand, provide a complex mosaic of different substrates, crevices, and cavities that provide home to many and highly varying life forms and species.

In the same way as kelps and sea grasses occur in the shallow photic zone, larger marine animals occur in dense aggregation, particularly at depths greater than 15 meters. Such 3D structures function as biogenic habitats for a range of other organisms (Tendal & Dinesen 2005). Hence, areas where biogenic substrates overlay the terregenic substrate are often highly diverse in terms of numbers of species, and could be regarded local 'hot spots'.

Fish species are generally not homogenously distributed throughout their geographical range of distribution. For flatfish the preference for a given bottom sediment is believed to be one of the dominant physical parameters accountable for the heterogeneity observed in their distribution. The underlying causes of association are unknown but it seems that differences in food availability in the different sediments is one key parameter, but also the ability to bury oneself in order to avoid predators and reserve energy is important. These relationships have been shown in numerous field studies as well as in laboratory experiments (see Gibson 1994 for review). It has also been found that for a species like plaice (*Pleuronectes platessa*) the ability to bury oneself changes with fish size (Gibson & Robb 1992), indicating that sediment preferences might change with ontogenetic changes. In stocking experiments where artificial breed juvenile turbot (*Psetta maxima*) was released, the mortality caused by bird predation was halved for fish that had experienced a period on natural substrate before release, which was suggested to be a direct effect from increased burying ability and hence lower predation risk (Sparrevohn & Støttrup *in press*). In recent years the deterioration of sediments by drifting mats of filamentous algae, decreasing the availability of nursery habitat for juvenile flatfish, has been receiving increasing attention especially in eutrophied areas (Wennhagen & Pihl 1994, Pihl et al. 2005).

Data sources

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. 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).

Sediment categories

Sediment data were previously used for the mapping and modelling of the benthic marine landscapes (e.g. Roff & Taylor 2000, Laffoley et al. 2000, Roff et al. 2003, Golding et al. 2004), and habitat maps. In order to produce the marine landscapes for the whole Baltic Sea large amounts of seabed sediment data were needed. The existing data, national and international, is numerous, but very diverse. Seabed sediment data has been derived using different field techniques during the past decades. The seabed sediment maps from offshore and coastal areas exist in a wide range of scales from local (1:20.000) to regional (up to 1:1.000.000). Terminology and classifications vary as well, since 9 different Baltic Sea nations (and Norway) have interpreted their own data according to different national classification schemes.

National seabed sediment classification categories needed to be harmonized in order to produce one classification scheme, which had to be as simple as possible, but still takes into account biological importance. The resulting classification scheme consists of five sediment classes, which can be extracted from existing data. The sediment classes applied in the mapping and modelling of the Baltic Sea marine landscapes 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.

The sediment map for the Baltic Sea is presented in fig. 10.

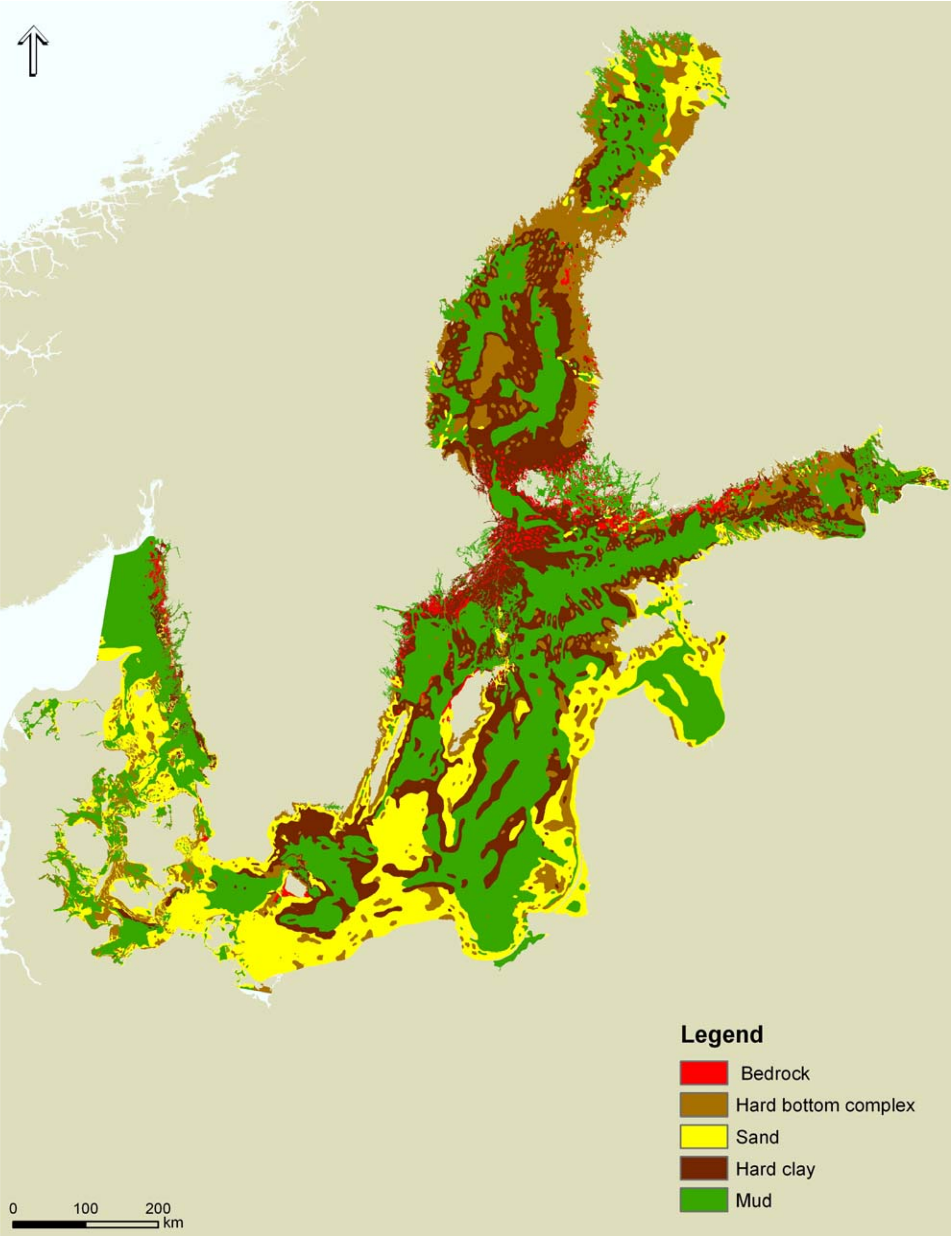

Fig. 10. *Marine seabed sediment split into 5 categories in the Kattegat and Baltic Sea (compiled from sediment information from GEUS, GSF and SGU).*

6.3 Depth zonation

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.

To determine ecological relevant depth intervals, a series of factors was considered:

I. Photic depth[7].

II. Below the photic depth.

III. Halocline.

IV. Water motion.

The environmental parameters used for determining the relevant depth zonation in Kattegat and the Baltic Sea are the photic depth defined as where 1% surface irradiance touches the seabed and non-photic depth below 1% surface irradiance. The other environmental parameters mentioned have also been considered, but these data has either not been available for the Baltic Sea or can be added the description of the individual landscapes depending on end users. Those not included should be considered in future refinements of the map. For that reason and for making the BALANCE efforts available for outside parties a brief description has been included for each of these data. The applied layers, how they have been derived and their ecological relevance are described in the following sections. Be aware that both salinity and temperature not only is important as a vertical structuring parameter, but also on large geographic scales.

6.3.1 Photic zone (light exposed seabed)

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.

Light and marine life

Light is a major parameter in shaping the zonation of biological communities. Light also has photoperiodic and photomorphogenetic effects on many species such as initiating growth and, for a few species, reproductive events (Dring 1994). Marine organisms in the Baltic Sea are thus ultimately depending upon the primary production from a relatively small zone of the sea surface layer.

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[7] As this parameter is used for identifying benthic marine landscapes the use of photic depth is defined as where at least 1% surface irradiance reaches the seabed. The offshore photic surface water layer is thus not represented on the maps or considered further in the text.

Marine plants (seaweeds, phytoplankton and higher plants) grow in conditions that feature exceptionally diverse and dynamic light regimes. The water clarity and hydrodynamic conditions have profound effects on the quantity and quality of the light available for marine plants at specific localities, thus directly influencing the biomass and species composition of the biological communities (fig. 11a and 11b). Light in the form of the day length also influences the initiation of the growth of erect macrothalli in e.g. the brown algae *Scytosiphon lomentaria* (Lüning 1980) or, on rare occasions, the sexual reproduction through e.g. formation tetrasporangia in the red algae *Bonnemaisonia hamifera* (this is coupled to the temperature regime). Macroalgae do not normally, compared to terrestrial plants, have photoperiodic dependent reproduction.

Fig. 11a. *A boulder reef dominated by the brown seaweed* Fucus vesiculosus *in the photic zone at Barskär in the Archipelago Sea. Photo: Metsähallitus.*

Fig. 11b. *Crust-forming red algae are able to live at very low light levels on the border of the photic and non-photic zone. Photo: Peter Bondo Christensen, NERI.*

The non-photic zone covers the largest area of the Baltic Seabed compared to the light exposed seabed. Here, production based on photosynthesis is absent, and the production is based on surplus production produced in the photic zone, and the mainly secondary production of bacteria and animals (Nybakken 2001, Sand-Jensen & Fenchel 2006). Sessile invertebrates feed mainly on capturing particles suspended in the water, whereas motile fauna exhibit a larger variety regarding their mode of feeding, although many are functionally herbivores. Herbivores feed on microalgae in the water and on bottom sediments, or on larger primary producers, such as kelps and eelgrasses. Larger sessile animals and macrophytes are competing for space in the photic zone. This phenomenon is particularly pronounced on hard substrates (Dayton 1994). Many fish species are visual hunters, and may thus avoid areas with poor visibility. However, for most fish, light is not a central determinant of species distributions. There are exceptions such as pikeperch (*Stizostedion lucioperca*) that is adapted to living in highly turbid waters, such as the eutrophicated coastal areas of the Baltic Sea.

Light intervals

Only two intervals based on light regime were used, because they reflect the significant ecological difference between the shallow water depth with the presence of submerged aquatic vegetation, and the deeper waters where fauna (and bacteria) dominate diversity of species, abundance, and biomass. The intervals are:

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

II. The non-photic zone.

Justification of light intervals

The delineation or boundaries between the photic categories are based on the answer to the question – how much light is sufficient to sustain primary production of submerged aquatic vegetation? Several values are available in the literature. A value of 1% of surface irradiance (measured just below the surface) has often been used to define the lower boundary of the photic zone (e.g. Lobban & Harrison 1997) even though some macroalgae such as *Laminaria* spp. are able to grow at light levels of 0.5-1% (Lüning & Dring 1979). The deepest known collected seaweed has been found near the Bahamas at a depth of 268 m at a locality where only 0.0005% of the surface irradiance was available for growth (Littler et al. 1985). No specific information was available for macroalgae in the Baltic Sea.

A conservative approach delineating the light exposed seabed (or photic depth) at 1% of surface irradiance was applied. This was done, even though some species have growth at lower light levels, because it is the minimum irradiance requirement of large structuring algae such as *Laminaria* spp. (at least in the Kattegat). Ideally data on relevant species for the Baltic Sea, such as *Fucus vesiculosus*, should have been included, but such information is unfortunately not available. Furthermore, in order to reflect an ecologically relevant light regime it was decided to use water transparency based on Secchi depth measurements from March to October, because this reflects the (primary) growth season (fig. 12). This approach combined with the relative coarse bathymetry can lead to a situation where some deep-lying reefs are classified as being located in the non-photic zone even though there is occurrence of macroalgae. This is the case for Hobarks Bank, and only future validation will correct such methodological error.

Data source

For the purpose of mapping the photic zone in the Kattegat and Baltic Sea water transparency has been calculated utilizing Secchi disc depth. The data have been collected at the ICES homepage, http://www.ices.dk/Ocean/project/secchi/ (Aarup 2002). The data covers measurements of Secchi disc depth (SD) from the period 1903 to 1998. However, for this study we have only applied data from 1980–1998. Also, only data between March to October have been included to account for the productive period providing approximately 20.000 records. In situations where frequent data are available at the same station, the data have been averaged per station resulting in approximately 2800 records covering most of the Baltic Sea area and Kattegat. These 2800 records have been spatially interpolated and extrapolated to cover the Baltic Sea. With this approach the station locations is weighted equally with the number of measurements. Despite the rich amount of data, the measurements of SD are not evenly distributed and areas in the Baltic Proper, Gulf of Riga and southern Baltic are not well covered.

To identify areas where light is sufficient to support benthic growth a factor of 1.9 × SD has been applied identifying a depth of approximately 1-3% of the light at the surface. This factor is an average of the factors presented by Kratzer et al. (2003), Raymont (1967), Ærtebjerg & Bresta (1984) and Edler (1997) and calculated as (1,7+1,7 +2,3+1,84)/4 =1,9. The results of the estimated depth (1,9 × SD) were interpolated to a 617 × 617 m net. Hence, the SD was translated into an estimated spatial coverage of the bottom exposed to light. In areas with large yearly variations and in areas close to the coast this approach is uncertain. Also, the available data was extrapolated linearly covering all parts of the Baltic Sea. In some areas the data does not support this e.g. the Gulf of Riga where only very limited measured data was available.

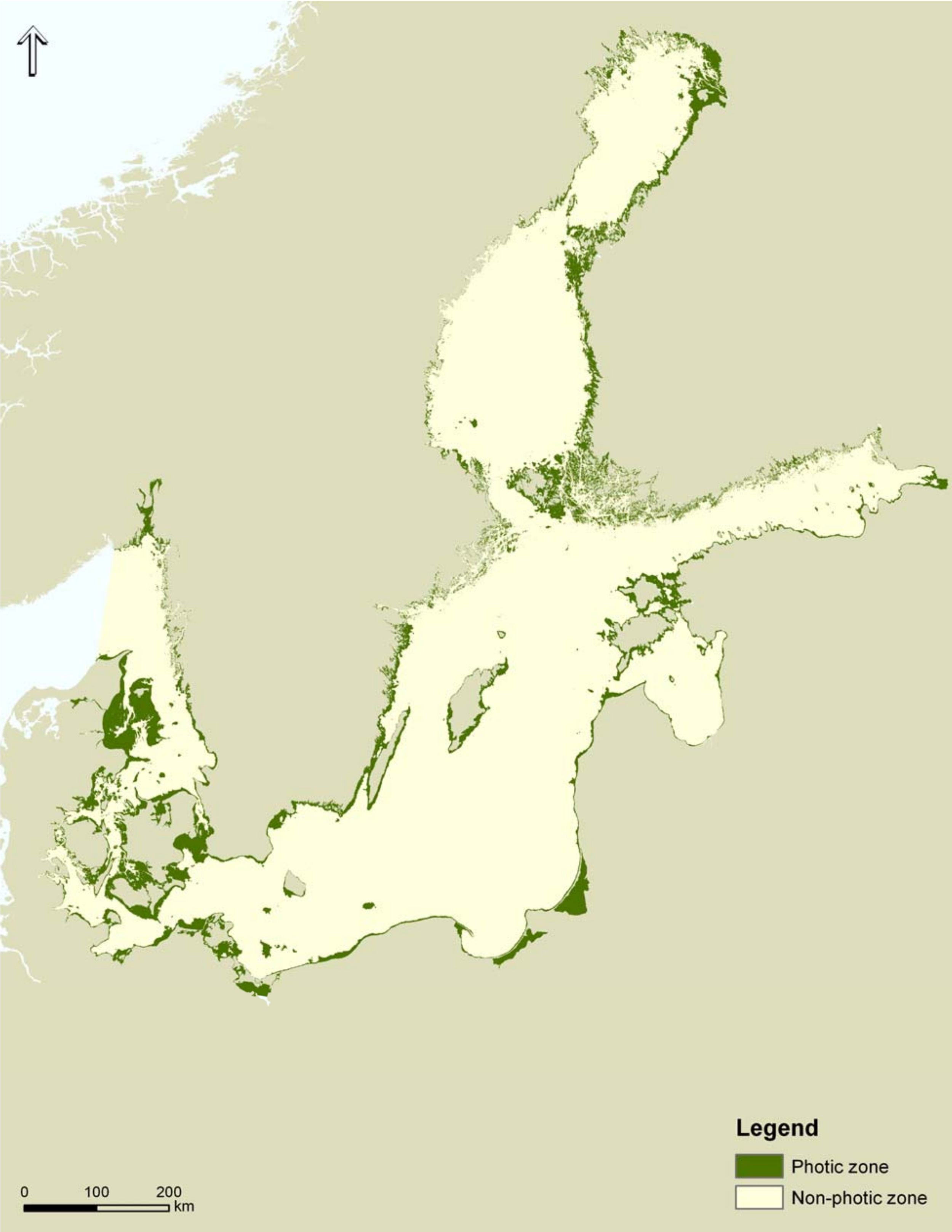

***Fig. 12**. Model results showing the distribution of where at least 1% available light touches the seabed (the photic zone) and non-photic zone in the Baltic Sea based on 1% mean annual irradiance. Data source: DHI Water • Environment • Health and ICES.*

6.4 Salinity

The Kattegat and Baltic Sea is the second largest brackish area in the world (Segerstråle 1957) with a number of basins varying from almost fresh water in the Bothnian Bay through the brackish water of the Baltic Proper to the saline waters of Skagerrak with a distinct salinity gradient in the Danish Straits. 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, see next section), 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 (fig. 15 and fig. 16).

Salinity and marine life

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.

For example, there is a decrease in the number of species of macroalgae along with the salinity gradient from app. 325 in the central Kattegat to less than 50 in the Bothnian Bay with a change in the dominating species from the large kelp, *Laminaria* spp. to *Fucus vesiculosus* and *Fucus radicans* up to the Northern Quark (fig. 13). A total of 422 species of macroalgae has been identified in the Kattegat and Baltic Sea. The proportion of marine species to fresh water species also changes along the salinity gradient (Nielsen et al. 1995).

There is no single or simple explanation of how salinity influences the distribution of macroalgae in Kattegat and the Baltic Sea. Marine macroalgae often have a lower osmotic potential (higher concentration of particles) than the surrounding environment, and the osmotic potential will decrease along with a decrease in salinity. In order to avoid a movement of essential ions out of the cell and a movement of water into the individual cells different physiological and morphological adaptations exist (Lobban & Harrison 1997). These adaptations influence the habitus (how the macroalgae appears to the naked eye) of many marine macroalgae species, which often decrease in the size of the thallus and individual cells (Russel 1985, 1994). In some cases salinity also influences the ability to reproduce sexually and some populations depend solely upon non-sexual reproduction (Breeman 1988). For example, the distributional boundary of *Fucus vesiculosus* in the Baltic Sea might be decided by the salinity tolerance of the gametes (Serrão et al. 1996). In order to summarise – the adaptations or rather lack of adaptations to low salinity, will decide the individual species salinity tolerance and thus its distribution into the Baltic Sea. The salinity tolerance of an individual macroalgae may be further influenced and decrease if exposed to other non-optimal conditions in regard to other environmental parameters.

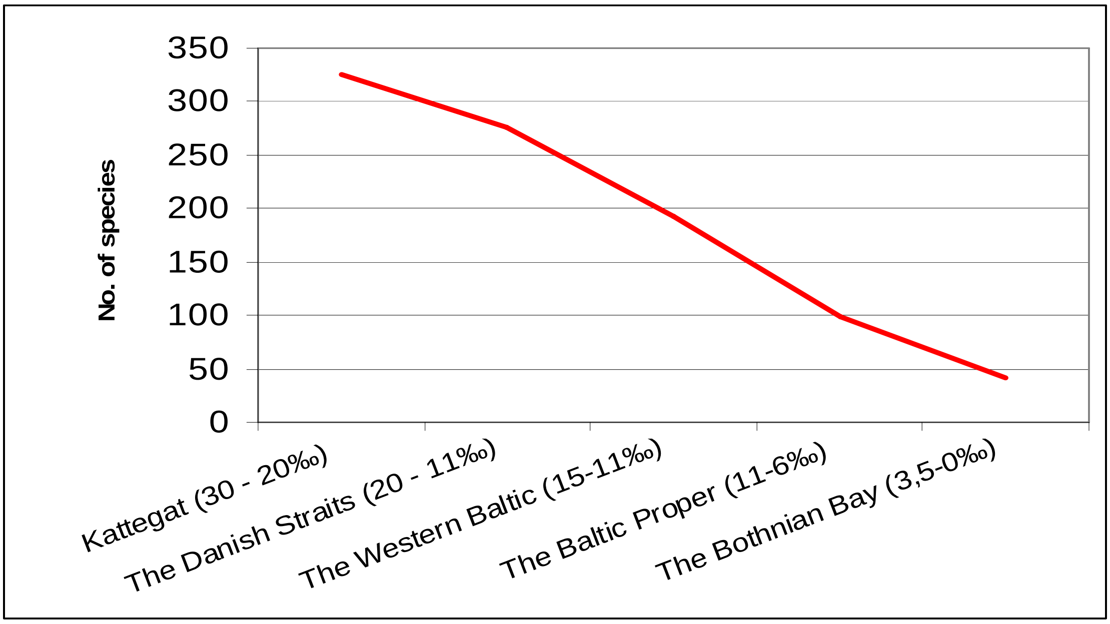

Fig. 13. *Number of species of macroalgae in different regions of the Kattegat and Baltic Sea based on data from Nielsen et al. 1995. Only representative areas with extended coverage of hard substrate have been included. The figure does not take the shift in the proportion of marine vs. fresh water species from the Kattegat through the Danish Straits to the Baltic Sea into account.*

Marine waters are home to the majority of all fauna phyla and classes. Only a few of these are represented in brackish and freshwaters. This phenomenon is reflected in the drastic reduction (greater than 10-fold) of marine species between the Kattegat and the Baltic Sea. The Baltic Sea Region, from the Bothnian Bay in the east to the Skagerrak and the North Sea in the west is home to approximately 3.000 species of marine, benthic invertebrates (Sand-Jensen & Fenchel 2006). The majority of these species have their distribution in the North Sea, Skagerrak, and northern Kattegat at depths from 15 (or 18) meters or deeper. Fewer species are found in shallow waters, and further south, in the Danish Straits and the Sound (except near Knæhagen, a 'larvae trap' north of the island of Ven). In the middle and western parts of the Baltic Sea proper, the majority of species are adapted to a life in brackish water. At a salinity of 6psu we find the lowest fauna diversity of the entire region, of approximately 200 benthic invertebrate species (Remane 1934). In the inner part of the Baltic Sea, most or all species are freshwater species (also ~3000 spp.), and the diversity is rather low as the majority belong to the same class of animals, the insects (Remane 1934, Jansson 1980). As the salinity is reduced through the Baltic system, many (and finally all) of the larger predators become absent, thereby changing the functioning of the food chain. In fact, food chains in the Baltic Sea are often short, and hence highly vulnerable to environmental changes (Sand-Jensen & Fenchel 2006, Ockelmann & Dinesen *submitted*).

One species that is found throughout the entire area is the pinkish bivalve *Macoma balthica*, named after the Baltic Sea (Jansson 1980). In the North Sea, Skagerrak, Kattegat and adjacent fjords, bays and lagoons, this species is restricted to shallow water, at 0–5 (10m) depth. In the Baltic Sea and inner Bothnian Bay where the salinities range between 3–10psu this species may live at depth between 0–40m. Here it dominates the fauna both in numbers and biomass (Remane 1934, Jansson 1970, Sand-Jensen & Fenchel 2006). Salinity affects the growth of this bivalve, with the smallest maximum sizes found at the lowest level of salinity (Remane 1934).

Similarly, a few species of polychaetes, crustaceans, bivalves, gastropods, and cnidarians are found in the Baltic Sea proper at salinities below 8-10psu. Several of these are found also in the fjords adjacent to the Kattegat, but then always in shallow waters between 0 - 10 (or 15) meters depth, where natural disturbance is greatest. The majority of shallow (and brackish) water fauna have great dispersal powers. Following disturbance of such areas, e.g. from trawling or oxygen depletion, recolonisation occurs quickly (Josefson & Hansen 2004). At greater depth, particularly in areas with more species exhibiting low dispersal range or gregarious settlement, re-establishing of the natural fauna is slow, and it may take more than a decade, if at all (Roberts et al. 2004)

Other species substitute each other, e.g. mussels in the Bothnian Bay (living at ≥ 5psu). *Mytilus trossulus* is different from but closely related to the blue mussel *Mytilus edulis*, which is abundant in shallow water in the outer part, including in the Western Baltic Sea (the Arkona Basin), Kattegat, and Skagerrak (Johannesson et al. 1990). Since the Baltic basins are young (≤ 15.000 years), many of the marine species have emigrated from adjacent seas. However, a few marine, brackish, and freshwater species are endemic to the region (i.e. they live in this region only).

Salinity is one of the main parameters determining the geographic distribution of both marine and freshwater fish in the Baltic Sea. All species found in the area are originally adapted to either a marine or a freshwater environment, and the Baltic Sea being an evolutionary young sea, there has been little time to adapt to the current salinity conditions. The cost of living in suboptimal salinity conditions is osmotic stress, leading to an increased metabolism and energy loss. Eggs and juvenile stages are the most vulnerable to osmotic stress, and thus the salinity tolerance of these stages often determines the distribution of the species. Many marine species have pelagic eggs, and in these species the buoyancy of the eggs may limit the distribution into brackish water conditions, since eggs sinking to the bottom will have a very poor survival probability.

Some adaptation to the brackish conditions of the Baltic Sea can be seen. Marine species such as cod *(Gadus morhua*) and turbot (*Psetta maxima*) in the Baltic produce eggs with higher buoyancy and a better tolerance of oligohaline conditions than in marine populations. Freshwater species such as pike (*Esox lucius*), perch (*Perca fluviatilis*) and trout (*Salmo trutta*) may spawn in salinities up to about 6-7psu in the Baltic Sea, which is not possible for freshwater populations. The number of marine fishes decreases sharply towards the inner parts of the Baltic. For example, for flatfishes, fifteen species are found in the Baltic, but only one, the flounder, is distributed throughout the entire area. Turbot is not found north of the Åland islands and plaice and dab (*Limanda limnda*) are restricted to the Baltic proper, whereas sole (*Solea solea*) is not found north/east of Bornholm (Florin 2005). For freshwater species the opposite is true – there is a decline in the number of species towards the south. In the archipelagos of the Baltic Sea, a similar cline may be found, as there is a shift towards a more marine community in the outer parts.

Data sources

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. The depth and spatial location of the stations used to collate data for the model is shown in fig. 14. 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 (fig. 15).

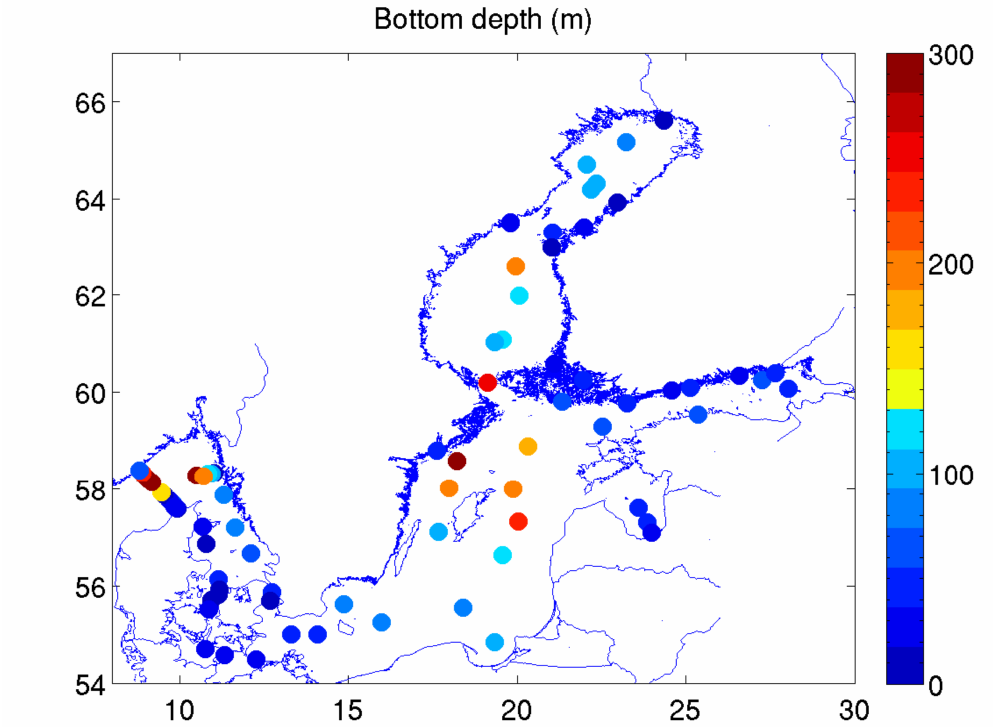

Fig. 14. *Map showing depth (in meters) at the station from Skagerrak to Bothnian Bay used in the assimilation of salinity, temperature and current speed into the model results. Data source: NERI/Denmark.*

Salinity categories

Due to the stratification in especially the Baltic Sea it has been decided to use bottom salinity for the development of the benthic marine landscapes and difference in surface to bottom salinity for the pelagic landscapes. The following 6 categories of annual mean salinity were applied delineating the Kattegat and the Baltic Sea into regions with differences in salinity regime (fig. 15):

I. Oligohaline I (< 5psu).

II. Oligohaline II (5 – 7.5psu).

III. Mesohaline I (7.5 – 11psu).

IV. Mesohaline II (11 – 18psu).

V. Polyhaline (18 – 30psu).

VI. Euhaline (>30psu).

Justification of salinity categories

It was decided to use annual mean bottom and surface salinity for mapping the geographic distribution of major vertical haloclines rather than a minimum or maximum annual salinity. Distributional boundaries of marine organisms usually reflect long-term environmental conditions though the exact boundary is dynamic and it will move back and forth reflecting extreme conditions. Several different approaches were tested for identifying the most ecologically relevant splits between categories. Unfortunately, there exist no 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 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 4 summarises the reasoning behind the specific categories.

Tab. 4: 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.

At some locations in the Bothnian Bay the surface salinity is slightly higher than the bottom salinity. At these locations the variation in density is dominated by temperature, not salinity as elsewhere in the Baltic Sea. Thus, the bottom water in the Bothnian Bay is colder and less saline than the water closer to the surface (*pers. com.* Johan Söderkvist, NERI). This should be further described and included if and when the pelagic marine landscapes are developed for the Baltic Sea.

Data sources

The institutions that kindly made data available for the salinity and temperature modelling (section 4.4.1) are presented in table 5. The raw data is stored in the BED (Baltic Environmental Data) database hosted at the Stockholm University. For a detailed description of the model, please refer to Bendtsen et al. (2007).

Tab. 5: Institutes providing salinity and temperature data for the BALANCE project. The data was stored at the BED database.

Group code	Complete name	Country
IOW	Baltic Sea Research Institute, Warnemünde	Germany
LNUG/LANU	German Oceanographic Data Centre, Hamburg	Germany
CORPI	Coastal Research and Planning Institute, Klaipeda University	Lithuania
EMI	Estonian Marine Institute, Tallinn	Estonia
MIRYB	Morski Instytut Rybacki / Sea Fisheries Institute	Poland
MMCIAE_LA	Institute of Aquatic Ecology, University of Latvia	Latvia
RSHU	Russian State Hydrometeorological University, St. Petersburg	Russia

6.4.1 Stratification

Many areas in the Kattegat and the Baltic Sea are periodically or permanently stratified. The stratification is partly maintained by the large annual input of fresh water from the many rivers in the region as well as the occasional influx of denser more saline water from the Skagerrak over the thresholds in the Danish Straits. In the central Baltic Proper a permanent vertical density gradient (pycnocline) is present at a depth of 50-70m (Håkanson et al. 1984; Persson et al. 1994), while a strong periodic pycnocline is present in Kattegat at a depth of 10–20m (Dahl et al. 2003). The stability of these vertical density gradients is further enhanced by the almost total lack of tides (Hällfors et al. 1983).

Data sources

The location of the strongest density gradient in the Baltic Sea and the Skagerrak area has been estimated applying the results from a 3D model run. The data was originated from the year 2000. In some more dynamic areas the average location might vary between years, but in most areas this is not the case. The applied hydrodynamic model, MIKE 3 HD, is a fully three-dimensional, non-hydrostatic, primitive equation model (Rasmussen 1991). It is based on the Reynolds-averaged Navier-Stokes equations and the conservation of mass, salinity and temperature. To run the hydrodynamic model some external forcings, boundaries, and initial fields are required. The required data and their origin are listed in table 6.

Results

The location of the pycnocline is estimated as the depth with the strongest vertical density gradient. This method allows the same approach to be applied for areas with strong gradients as found in e.g. the Danish Straits and for areas with relatively weak gradients as found in e.g. the Bothnian Bay. However, because the salinity is always increasing from the top-most layers towards the bottom this approach also results in a maximum density gradient even at shallow depths.

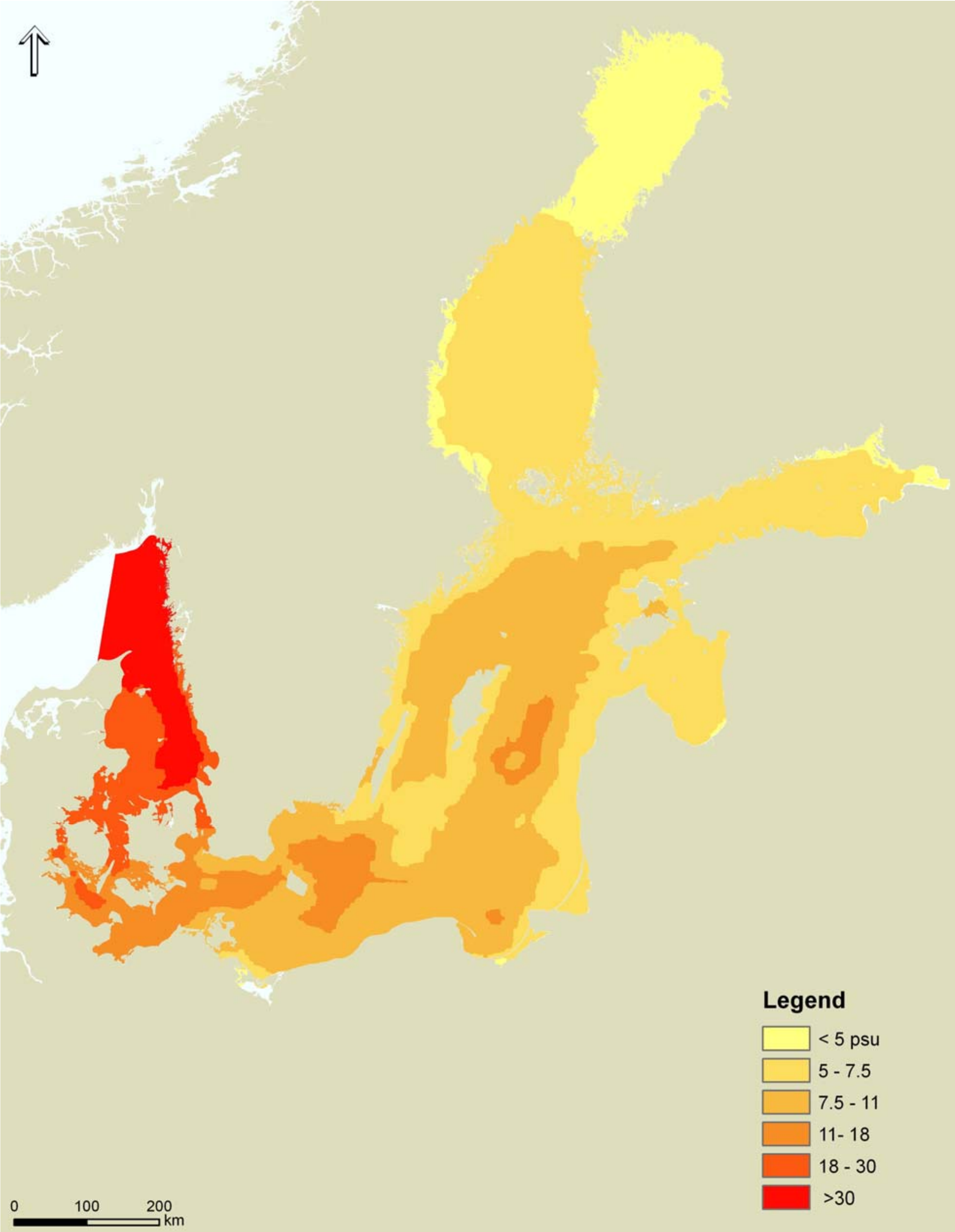

***Fig. 15.** Model results showing the bottom salinity (psu) field over the Baltic Sea. Data source: NERI/Denmark.*

Tab. 6: Required data to run the model.	
HYDRODYNAMIC MODEL	**Data origin**
Open marine boundaries	
Astronomical tides (corrected for actual atmospheric pressure)	
Climatological[8)] values of temperature and salinity distribution in sections (linearly interpolated to cover the entire sections)	ICES[9)] database (on request)
Initial fields	
North Sea and Baltic Sea; Salinity, temperature	ICES database (on request)
Interconnecting Seas; Salinity, temperature	NERI[10)] (MADS database)
Run-off	
Actual monthly values of flow for Danish, Swedish, Norwegian rivers to Skagerrak, Kattegat, and the Belt Sea	NERI SMHI[11)] (on request) IMR[12)] (on request)
Climatological[1)] values for the remaining rivers (Great Britain, Netherlands, Belgium, Germany, Poland, Norway, Russia, Finland, Sweden)	
Air-sea exchange	
Climatological[1)] values of net precipitation	
Actual 3 hours 10 m wind and air pressure fields	HIRLAM
Actual 3 hours 2 m air temperature fields	HIRLAM
Climatological[1)] clearness information	

Also, in some areas different local maxima exist resulting in primary and secondary pycnoclines. The applied approach does not distinguish between the primary and secondary pycnoclines and only the depth with the strongest density gradient is selected.

When evaluating the results the pycnocline in the largest part of the Baltic Sea is located in approximately 40-70m, similar to the figure observed by Pickard & Emery (1990). The applied approach does, however, also include results where the estimated depth of the pycnocline is deeper than 70m and especially in the deeper parts of the Baltic Sea. This is not an indication of a primary pycnocline with large local variation in depth but merely an indication of stronger density gradients located deeper than the primary pycnocline. This is the case in the Bornholm Basin where there is no access through the Stolpe Channel for the more dense (and saline) water mass.

The analysis has only been carried out for the top 120 meters and the model results have a resolution of 9 and 3nautical miles resolution but for this project the data have been interpolated to a 617 × 617 m net including a 617 × 617 m resolved landmask (fig. 16). However, the results in minor fjords and bays are uncertain due to the coarseness of the original data.

[8] 10 years of monthly mean.
[9] International Council for the Exploitation of the Seas, see http://www.ices.dk for further information.
[10] National Environmental Research Institute, see http://www.neri.dk for further information.
[11] Swedish Meteorological and Hydrological Institute, see http://www.smhi.se for further information.
[12] Institute of Marine Research, see http://www.imr.no for further information.

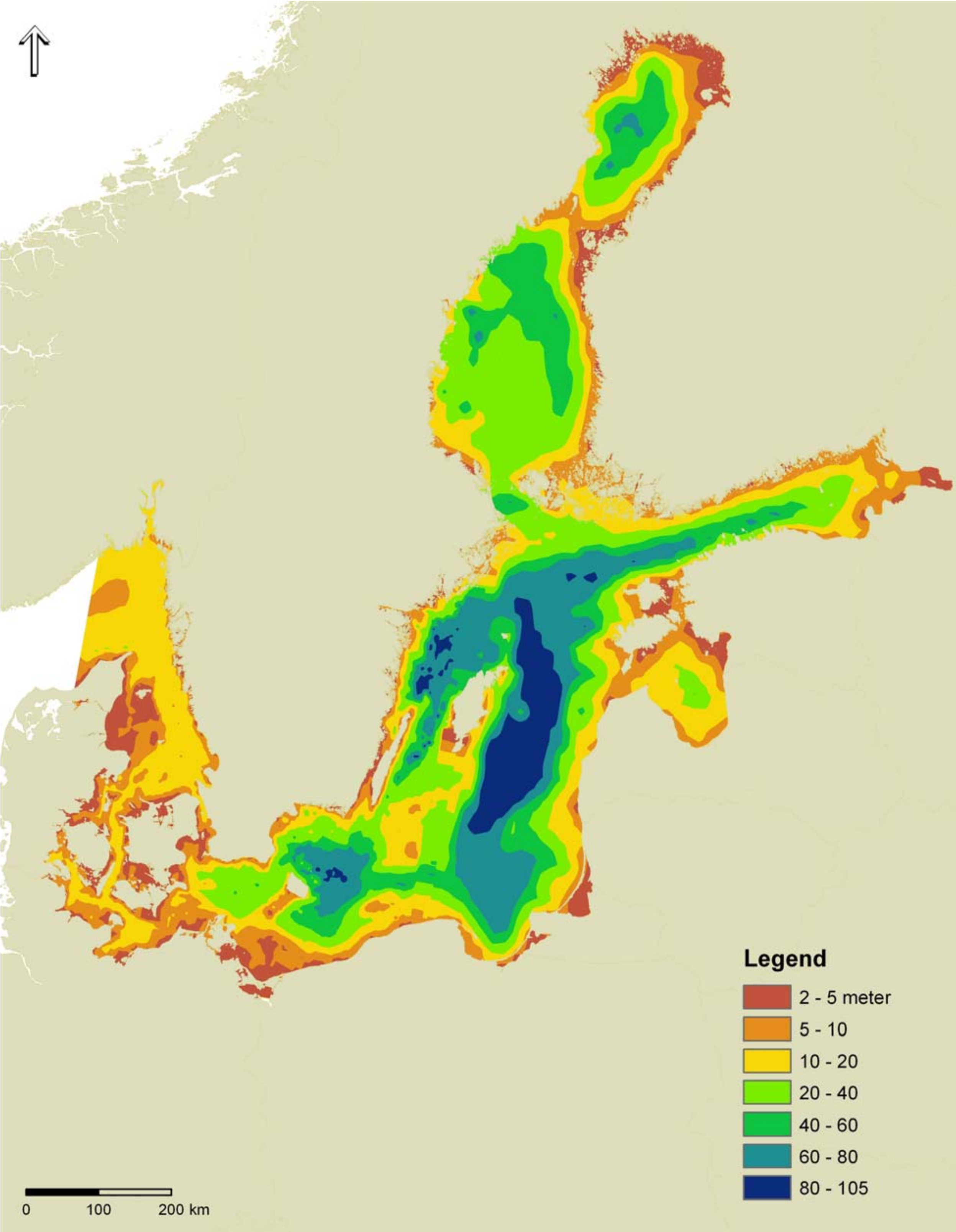

Fig. 16. *Model results showing the most likely depth of the pycnocline in the Baltic Sea. This figure does not indicate whether the stratification is weak or strong, and should be regarded as an estimate of the most likely depth of the strongest density gradient. Data source: DHI Water ● Environment ● Health.*

6.5 Benthic marine landscapes of the Baltic Sea

In the approach described in the previous sections a number of different seabed features have been identified based on the topographic/bed-form analysis (fig. 7) and delineation of coastal physiographic types (fig. 8).

The following section will present the benthic marine landscapes of the Baltic Sea (fig. 17) and include information relevant for the entire ecosystem as well as results inside the EEZ (Exclusive Economic Zone) of each individual country within the Helsinki Convention area (fig. 17-22). The marine landscape map has been delineated using the boundary of the Helsinki Convention area in order to make the marine landscape statistics available and applicable for the work within HELCOM, and thus potentially feed directly into the development of the BSPA and implementation of the proposed Marine Strategy Directive. Therefore, the statistical calculations conducted in this work did not take areas outside the Helsinki Convention area of the Swedish, Norwegian and Danish EEZ into account.

The benthic marine landscapes have been identified based on sediment, salinity and light. These three data sets were overlapped using ArcGis tool.

The statistics and discussion focus mainly on the benthic marine landscapes because of their ecological relevance. These statistics feed directly into an analysis of how representative the network of marine protected areas is within the Baltic Sea. The results of this work will be presented in a separate BALANCE report in late 2007.

A total of 60 benthic marine landscapes were identified based upon sediment composition, light regime and bottom salinity regime (tab. 8). The most common marine landscape present is non-photic mud with a salinity regime of 7.5-11psu, which covers app. 58.640km^2, or 14.3% of the seabed within the Baltic Sea. Together with the landscapes non-photic clay at 5-7.5psu and non-photic mud at 5-7.5psu a total of app. 157.000km^2, or 37.5% of the seabed within the Baltic Sea (tab. 8) is accounted for. These marine landscapes are also present within the Exclusive Economic Zone (EEZ) of most the nations surrounding the Baltic Sea (Denmark and Germany lack one or two respectively, please refer to table 8 for details). The least common marine landscapes are non-photic bedrock at 11-18psu situated at the coast of the island of Bornholm covering only 2.28km^2 and photic hard clay at 11-18psu in the western Baltic Sea covering app. 14km^2 or less than 0.01% of the total seabed area within the Baltic Sea. Please note that these statistics do not take the ecological quality of individual marine landscapes at specific localities into account, and some regions (or landscapes) might be adversely influenced by e.g. oxygen depletion.

Tab. 7 shows how many marine landscapes are present within the EEZ of the Baltic States delineated by the Helsinki Convention area, while tab. 8 shows how large an area of a specific marine landscape is present within the EEZ of the individual Baltic States. Tab. 8 also shows the seabed coverage of each specific marine landscape cover of the seabed compared to the total seabed within the Baltic Sea. For example, of the 60 benthic marine landscapes identified 40 covers less than 1% (and 12 cover between 1-2%) of the total seabed area within the Baltic Sea, while the remaining 8 cover an area of app. 371.700km^2, or 90.7% of the seabed within the Baltic Sea.

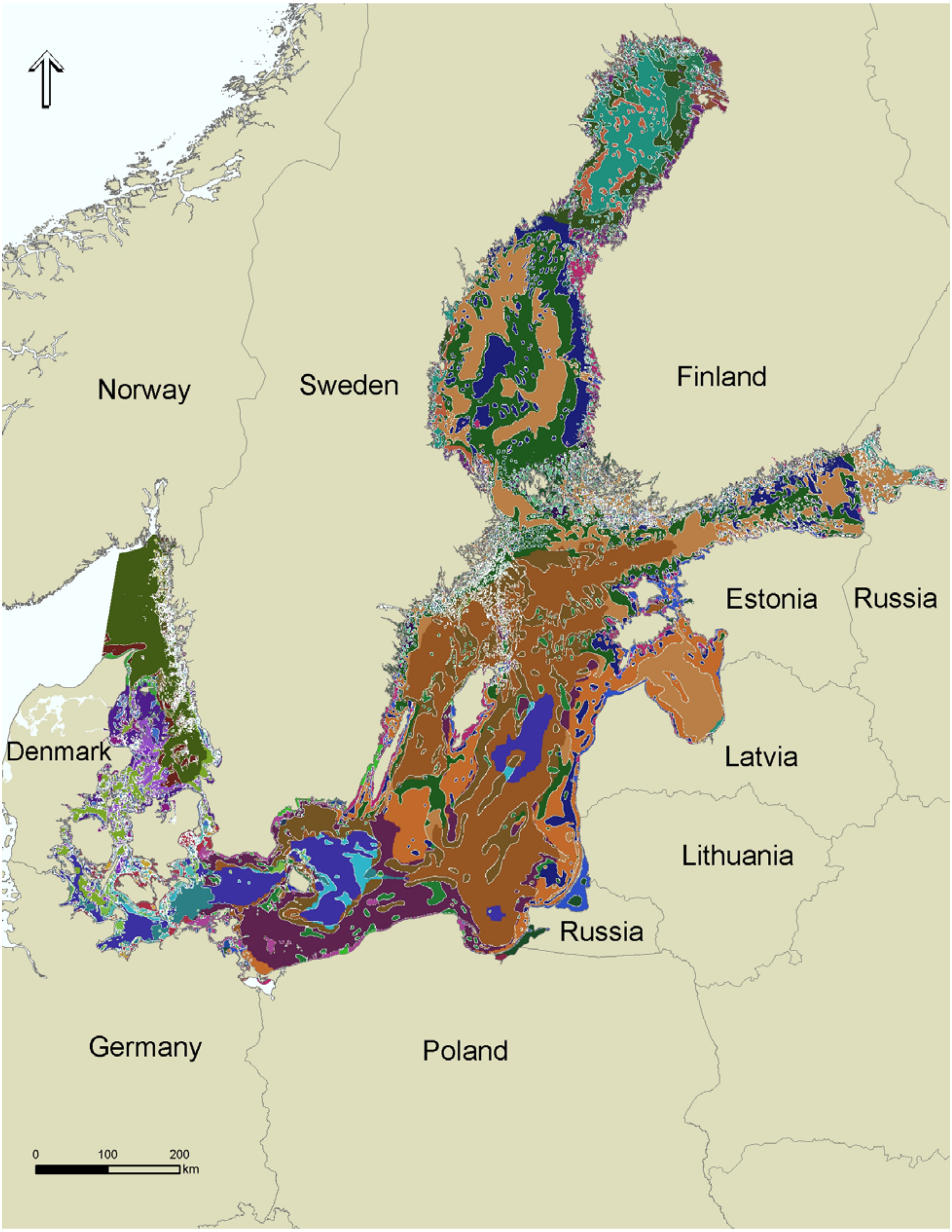

Fig. 17. *Benthic marine landscape map of the Baltic Sea.*

Tab. 8: Baltic Sea marine landscapes and their area (km²) in each country EEZ delineated by the western boundary of the Helsinki Convention area. The "code" relates to a GIS application.													
Marine landscape	**Colour**	**Code (GIS)**	**Sweden**	**Estonia**	**Latvia**	**Russia**	**Poland**	**Germany**	**Denmark**	**Lithuania**	**Finland**	**Total area**	**% of total**
Photic bedrock < 5psu		111	62.24	0	0	96	0	0	0	0	132.52	195.72	0.05
Photic bedrock 5-7.5psu		112	713.80	0	0	0	0	0	0	0	2494.88	3208.68	0.78
Photic bedrock 7.5-11psu		113	66.00	0	0	0	0	0	105.52	0	0	171.52	0.04
Photic bedrock 11-18psu		114	26.64	0	0	0	0	0	21.92	0	0	48.56	0.01
Photic bedrock 18-30psu		115	61.28	0	0	0	0	0	0	0	0	61.28	0.01
Photic bedrock >30psu		116	16.16	0	0	0	0	0	0	0	0	16.16	0.00
Non-photic bedrock < 5psu		121	69.28	0	0	1.92	0	0	0	0	34.24	105.44	0.03
Non-photic bedrock 5-7.5psu		122	1790.40	0	0	1.48	0	0	0	0	2402.96	4194.84	1.02
Non-photic bedrock 7.5-11psu		123	808.88	0	0	0	0	0	131.52	0	0	940.40	0.23
Non-photic bedrock 11-18psu		124	0	0	0	0	0	0	2.28	0	0	2.28	0.00
Non-photic bedrock 18-30psu		125	35.36	0	0	0	0	0	0	0	0	35.36	0.01
Non-photic bedrock >30psu		126	48.52	0	0	0	0	0	0	0	0	48.52	0.01
Photic hard bottom comp. < 5psu		211	1614.08	0	0	123.32	0	0	0	0	2761.88	4499.28	1.10
Photic hard bottom comp. 5-7.5psu		212	1995.24	1541.28	194.76	188.40	55.00	20.96	0	4	2860.24	6855.92	1.67
Photic hard bottom comp. 7.5-11psu		213	697.28	1.48	0	0	230.52	127.88	26.72	0	0	1083.88	0.26
Photic hard bottom comp. 11-18psu		214	31.88	0	0	0	0	477.00	1712.48	0	0	2221.36	0.54
Photic hard bottom comp. 18-30psu		215	76.80	0	0	0	0	0	2157.04	0	0	2233.84	0.55
Photic hard bottom comp. >30psu		216	16.76	0	0	0	0	0	101.44	0	0	118.20	0.03
Non-photic hard bottom comp. < 5psu		221	4911.48	0	0	116.56	0	0	0	0	5255.76	10283.80	2.51
Non-photic hard bottom comp. 5-7.5psu		222	7821.16	2921.68	2031.20	2696.76	72.72	5.48	0	51072	9828.16	25887.88	6.32
Non-photic hard bottom comp. 7.5-11psu		223	1649.20	463.28	497.32	165.44	1922.28	149.48	515.96	8068	49.88	5493.52	1.34
Non-photic hard bottom comp. 11-18psu		224	97.40	0	0	0	28.96	755.68	1159.60	0	0	2041.64	0.50
Non-photic hard bottom comp. 18-30psu		225	18.80	0	0	0	0	6.56	1645.44	0	0	1670.80	0.41
Non-photic hard bottom comp. >30psu		226	157.68	0	0	0	0	0	453.12	0	0	610.80	0.15
Photic sand < 5psu		311	331.00	0	15.44	205.20	0	68.24	0	0	1676.60	2296.48	0.56
Photic sand 5-7.5psu		312	824.68	1809.92	779.08	1084.64	71.04	201.08	0	51912	248.04	5537.60	1.35
Photic sand 7.5-11psu		313	1039.76	184.68	0	0	1009.16	1048.76	144.16	0	0	3426.52	0.84
Photic sand 11-18psu		314	283.20	0	0	0	0	558.64	2158.12	0	0	2999.96	0.73
Photic sand 18-30psu		315	438.36	0	0	0	0	0	5046.20	0	0	5484.56	1.34
Photic sand >30psu		316	20.16	0	0	0	0	0	584.52	0	0	604.68	0.15
Non-photic sand < 5psu		321	2040.64	0	25.24	259.76	0	0	0	0	3488.32	5813.96	1.42

Marine landscape (tab. 8 continued)	Code	Code	Sweden	Estonia	Latvia	Russia	Poland	Germany	Denmark	Lithuania	Finland	Total area	% of total
Non-photic sand 5-7.5psu		322	9427.00	5134.36	6264.12	1590.64	907.60	316.16	0	2361.56	550.56	26552.00	6.48
Non-photic sand 7.5-11psu		323	5120.56	203.40	665.80	786.76	12079.64	3574.68	1396.36	363.00	0	24190.20	5.90
Non-photic sand 11-18psu		324	87.12	0	0	0	223.24	2178.88	1972.52	0	0	4461.76	1.09
Non-photic sand 18-30psu		325	280.96	0	0	0	0	15.04	3321.76	0	0	3617.76	0.88
Non-photic sand >30psu		326	398.84	0	0	0	0	0	1236.56	0	0	1635.40	0.40
Photic hard clay < 5psu		411	316.56	0	0	75.60	0	0	0	0	38.16	430.32	0.10
Photic hard clay 5-7.5psu		412	941.20	321.60	0	43.20	0	0	0	0	1472.44	2778.44	0.68
Photic hard clay 7.5-11psu		413	91.08	4.72	0	0	0	9.40	0	0	0	105.20	0.03
Photic hard clay 11-18psu		414	0	0	0	0	0	0.96	13.12	0	0	14.08	0.00
Photic hard clay 18-30psu		415	174.32	0	0	0	0	0	7.80	0	0	182.12	0.04
Photic hard clay >30psu		416	44.32	0	0	0	0	0	2.52	0	0	46.84	0.01
Non-photic hard clay < 5psu		421	3655.68	0	0	243.56	0	0	0	0	871.76	4771.00	1.16
Non-photic hard clay 5-7.5psu		422	18399.44	4660.08	1185.00	2814.36	2.92	0	0	41.84	20028.72	47132.36	11.50
Non-photic hard clay 7.5-11psu		423	18551.56	2781.88	1686.84	1087.92	3199.96	7.44	1366.88	528.28	1318.12	30528.88	7.45
Non-photic hard clay 11-18psu		424	1022.44	0	95.52	0	314.28	85.24	1664.44	0	0	3181.92	0.78
Non-photic hard clay 18-30psu		425	341.08	0	0	0	0	0	17.60	0	0	358.68	0.09
Non-photic hard clay >30psu		426	325.48	0	0	0	0	0	44.92	0	0	370.40	0.09
Photic mud < 5psu		511	557.40	0	4	154.64	116.56	49.48	0	0	378.28	1256.40	0.31
Photic mud 5-7.5psu		512	742.84	276.60	16.20	711.08	170.84	60.72	0	64.80	2624.36	4667.44	1.14
Photic mud 7.5-11psu		513	109.56	103.56	0	0	10.72	227.92	11.08	0	0	462.84	0.11
Photic mud 11-18psu		514	39.76	0	0	0	0	133.60	543.52	0	0	716.88	0.17
Photic mud 18-30psu		515	223.92	0	0	0	0	0	1347.28	0	0	1571.20	0.38
Photic mud >30psu		516	7.68	0	0	0	0	0	59.36	0	0	67.04	0.02
Non-photic mud < 5psu		521	9105.12	0	119.64	830.64	0	0	0	0	4119.44	14174.84	3.46
Non-photic mud 5-7.5psu		522	14283.32	7635.56	5686.20	5042.12	12	61.52	0	405.88	14822.08	47936.80	11.70
Non-photic mud 7.5-11psu		523	26149.76	7956.08	5944.52	5194.24	7939.44	461.76	788.00	1688.52	2515.36	58637.68	14.31
Non-photic mud 11-18psu		524	4118.76	0	3427.88	77.88	776.32	4082.48	7215.56	0	0	19698.88	4.81
Non-photic mud 18-30psu		525	968.72	0	0	0	0	78.24	4328.16	0	0	5375.12	1.31
Non-photic mud >30psu		526	3729.72	0	0	0	0	0	2983.72	0	0	6713.44	1.64
Total area		**# 60**	**146978.3**	**36000.2**	**28634.8**	**23497.1**	**29131.32**	**14763.3**	**44287.2**	**6564.4**	**79972.8**	**409829.4**	**100**

This kind of information can be valuable for implementing an ecosystem-based approach to management as it shows the rarity and area covered by a specific marine landscape within the EEZ compared to the total occurrence within the Baltic Sea. For example, should rare marine landscapes receive a higher level of attention in regard to protection, as they might be more vulnerable on an ecosystem level compared to the marine landscapes that cover larger areas?

Tab. 8 also provides information that may form the basis for a transnational approach to the protection of the marine environment. An example could be whether each nation should protect a certain proportion of each landscape present within its EEZ or would it make more sense to protect certain proportions within subregions such as the Kattegat focusing on ecological quality rather than the delineation of national EEZs?

Except for the two most rare marine landscapes all of the remaining 58 types are present within the Swedish EZZ reflecting the long and complex coastline of Sweden (tab. 7). Denmark also has a fairly high diversity with 35 marine landscapes present within the Baltic Sea reflecting the change in the salinity regime from Skagen to Bornholm. The number of marine landscapes present within the EEZ of the remaining countries varies from 27 in German waters to 11 along the Lithuanian coast. This variation is partly caused by the more stabile salinity regime and partly by the size of the EEZ. The EEZ of Sweden and Finland cover more than 55% of the total sea area.

Tab. 7: Baltic Sea countries EEZ marine landscapes and the total area at each country.

Country name	No. of marine landscapes	Total area (km^2)	% of total area
Denmark	35	44287	10.8
Estonia	16	36000	8.8
Finland	23	79973	19.5
Germany	27	14763	3.6
Latvia	17	28635	7.0
Lithuania	11	6564	1.6
Poland	19	29131	7.1
Russia	24	23497	5.7
Sweden	58	146978	35.9
Total	**60**	**409829**	**100**

It is important to stress that caution should be applied regarding the "exactness" of the map and the estimated areas covered by the individual marine landscapes, and especially in regard to those covering only small areas as the inherited error in the methodology (e.g. size of grid applied and coarseness of available coastline and/or bathymetry etc.) may influence these proportionally considerably (tab. 8).

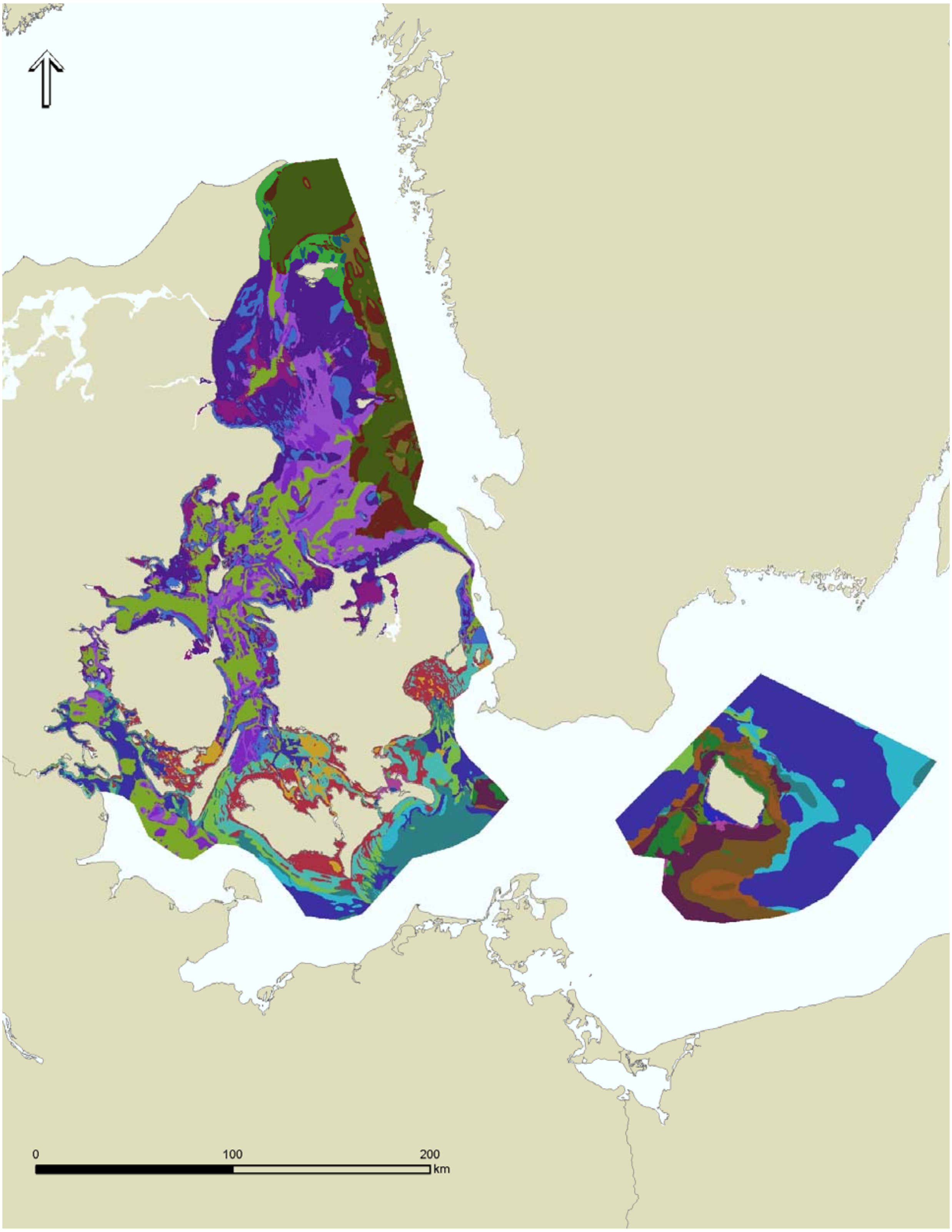

Fig. 18. *Marine landscape map of the Danish EEZ within the Helsinki Convention area.*

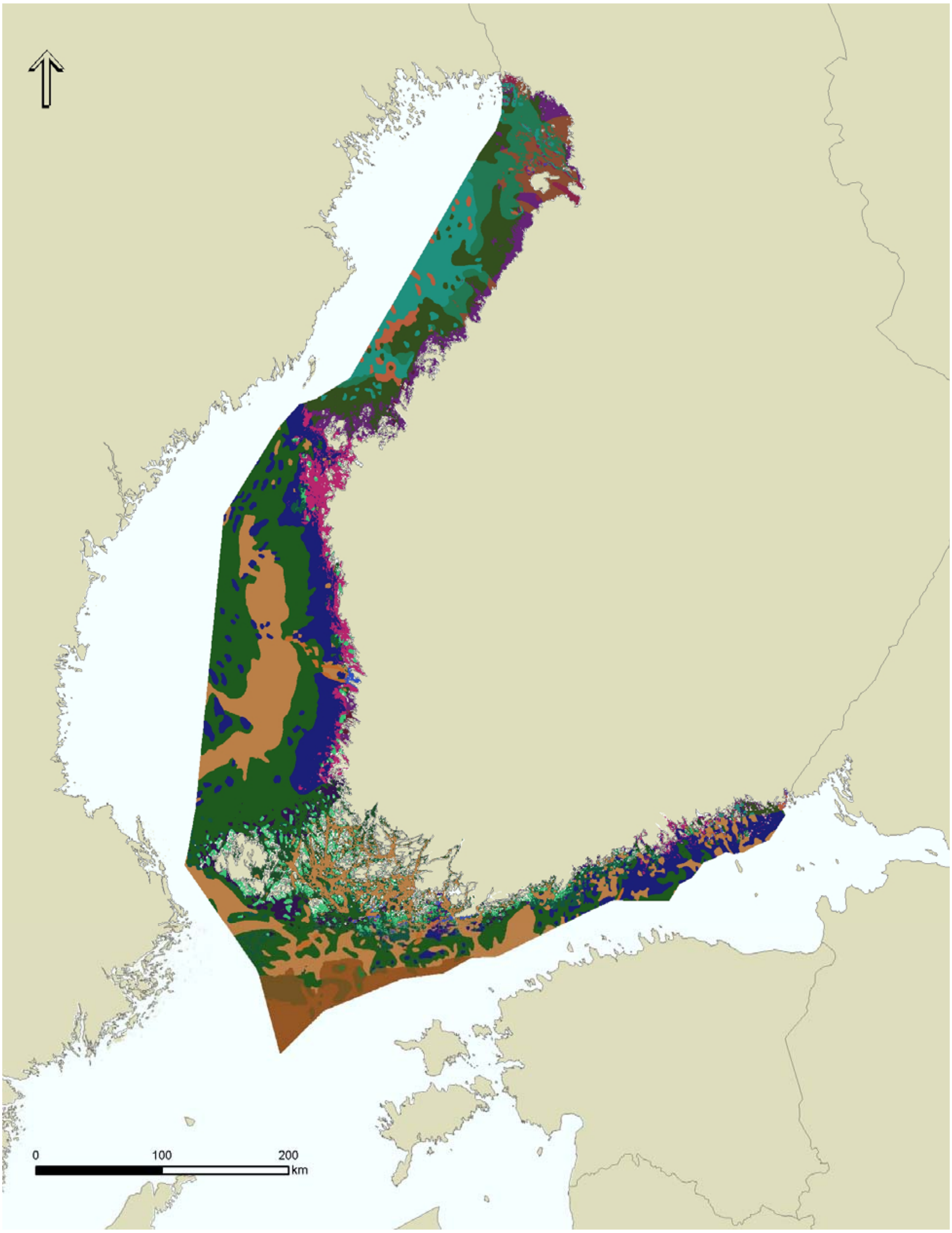

Fig. 19. *Marine landscape map of the Finnish EEZ.*

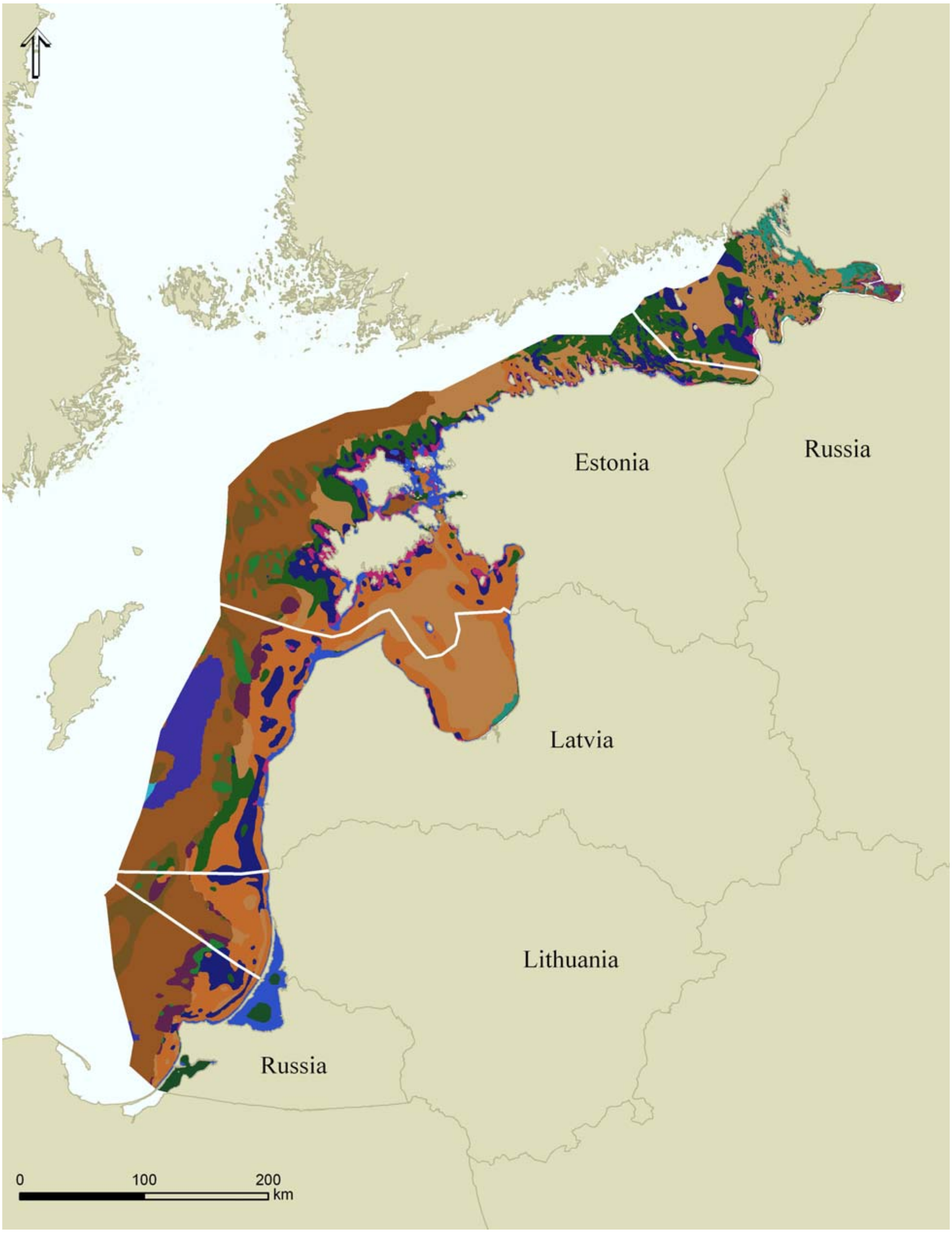

Fig. 20. *Marine landscape map of the Russian, Lithuanian, Latvian and Estonian EEZ.*

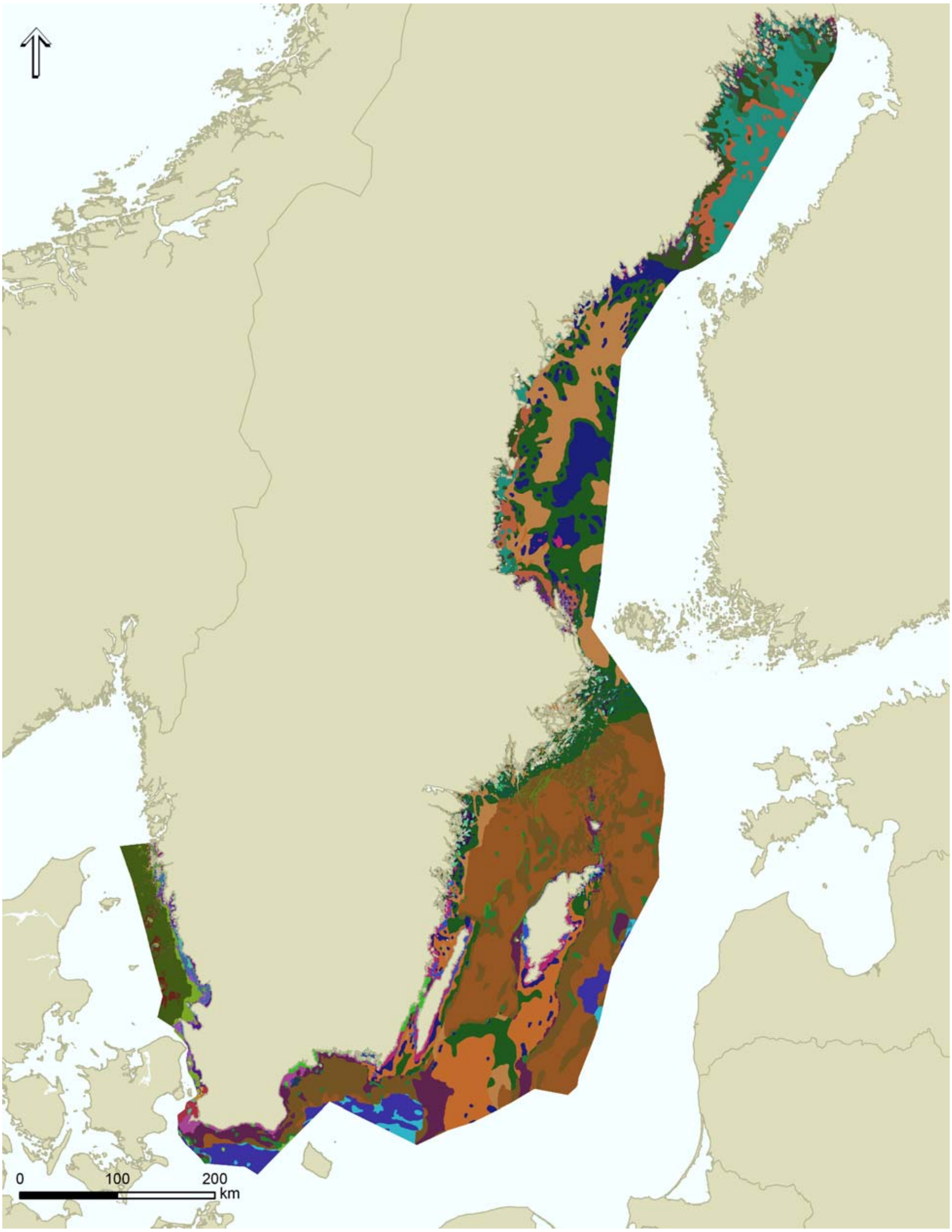

Fig. 21. Marine landscape map of the Swedish EEZ within the Helsinki Convention area.

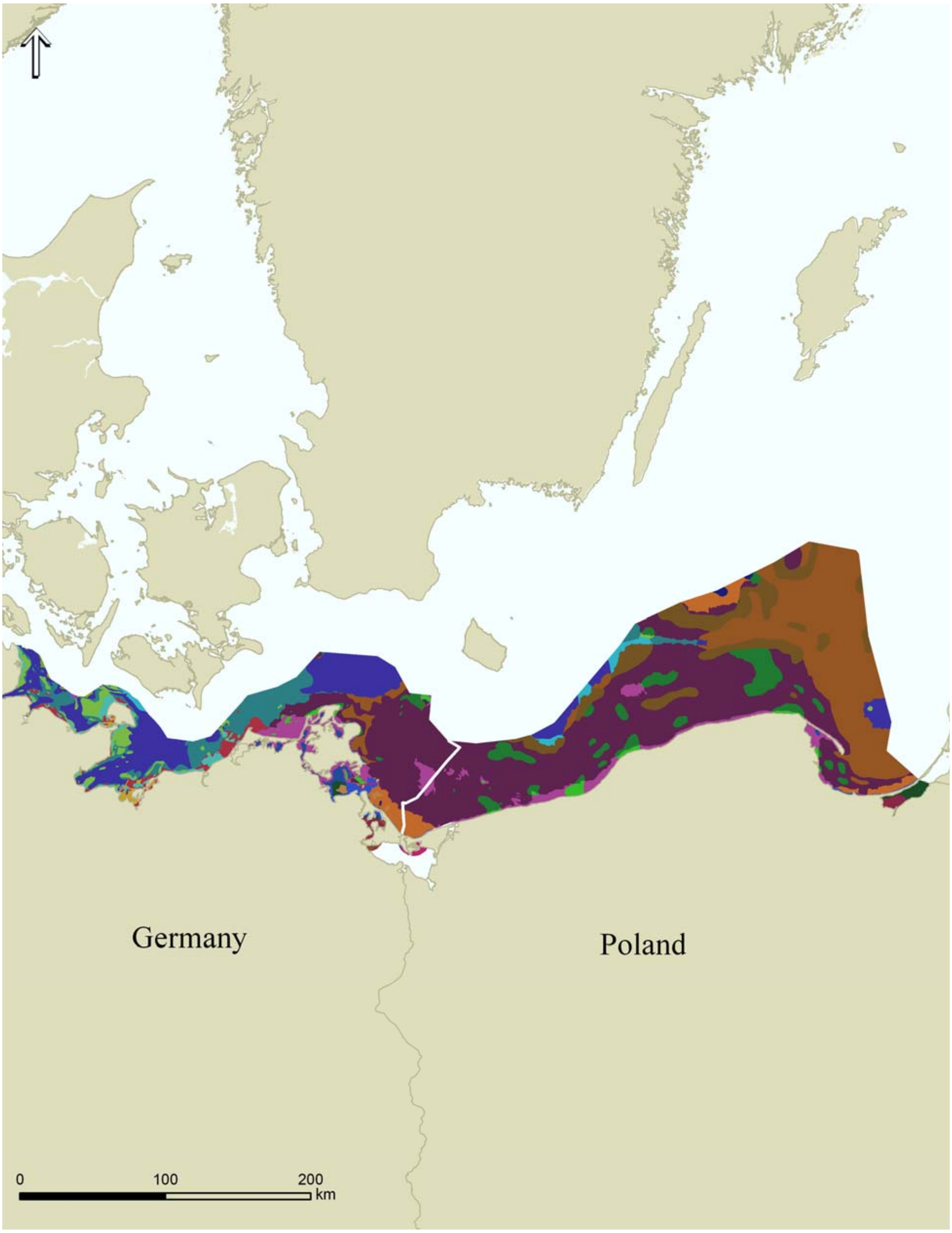

Fig. 22. *Marine landscape map of the Polish and German EEZ.*

7 SECONDARY PHYSICAL DATASETS

The “secondary” physio-chemical data layers that were under consideration during the process, but for various reasons were not included among the primary data sets are presented below. It was decided to include a fairly detailed description of each data set partly as a response to potential criticism of why this data was not included among the primary data sets and partly to provide any future initiatives with a starting point for each feature (data access issues, justification of intervals etc.).

7.1 Temperature

The surface temperature of the sea varies in general with latitude from 28°C at the tropics to 0°C at the poles though temperature may vary greatly in specific regions depending on major currents. Secondly, it also varies seasonally with the largest changes occurring at mid-latitudes – such as the latitudes where the Kattegat and the Baltic Sea are situated. Temperature also varies vertically and stratification is common in coastal and estuarine waters. Sharp temperature boundaries (horizontally and vertically) are called thermoclines. A stratification caused by temperature can be further enhanced by differences in density between surface and bottom waters due to variation in salinity and is then defined as a pycnocline.

The Baltic Sea region is mainly boreal with a small arctic region, which implies seasonality in radiation and hence, light and temperature. Because of waters physical characteristics, it exhibits less temperature variation than air does. However, the entire water mass is influenced by changes in water temperature. The largest annual variation is usually found in the upper few meters, where temperature may change from ≤ 0°C with ice formation in the winter months to ~30°C in the summer. Temperature was not included as a primary data set in the characterisation of the benthic marine landscapes. BALANCE was not able to justify temperature specific categories with an ecological influence relevant for benthic marine landscape mapping in the Baltic Sea, as the benthic species present has to be able to survive the large annual variation in temperature described above. However, at a European scale such categories could be developed and justified by using e.g. distribution patterns of marine plants or invertebrates.

Temperature and marine life

Temperature has been considered, as it is one of the important physical parameters influencing marine life. Due to the physical properties of water the daily and even annual temperature regime in a specific region is relatively stable and provides marine organisms with predictable temperature conditions compared with conditions in terrestrial environments. Temperature influences the growth, reproduction and lethal tolerance of marine organisms and ultimately the overall geographic distribution of marine species.

For example, the temperature tolerances of different species of macroalgae are at least partly responsible for most geographic boundaries of macroalgae on a global scale (van den Hoek 1984, Breemann 1988). The distribution of some species in Kattegat and the Baltic Sea might be hindered because of a narrow temperature tolerance rather than lack of substrate or a lack of tolerance towards low salinity. The distribution of the red algae *Lomentaria articulata* (Yarish et al. 1986) and the brown algae *Saccorhiza polyschides* (van den Hoek 1984) in Kattegat could be caused by the low winter temperatures, while *Saccorhiza dermatodea* (van den Hoek 1984) might be limited by the high summer temperatures. Other species, such as *Fucus vesiculosus*, are able to survive extreme temperatures down to -40°C for several months (Gessner 1970). Temperature also influences the growth rate and reproduction of many marine macroalgae and in e.g. the brown algae *Ectocarpus siliculosus* the development of various types of sexual and asexual organs is temperature dependent (van den Hoek et al. 1995).

Only few boreal marine animals can survive periods of temperatures below 0°C (or above 30°C). Those who can are all adapted to a life in the intertidal zone. In both intertidal and subtidal animals, temperature influences on the physiological processes, with lower temperature leading to e.g. reduced rates of growth (Nybakken 2001, Sand-Jensen & Fenchel 2006). The seasonality in temperature (and stratification) is reflected in both somatic growth and the reproduction of almost all of the organisms in the area. This is closely linked to the seasonality of the primary production, which again depends on incoming light (and associated temperatures), summer stratification, and availability of nutrients (Ærtebjerg et al. 2003).

Fish are strongly dependent on temperature, as the ambient temperature controls their physiology. Different species have different temperature optima, as do different life stages of the same species. Many fish, such as the freshwater species perch (*Perca fluviatilis*), pike (*Esox lucius*) and pikeperch (*Stizostedion lucioperca*), have a distinct preference for high temperatures. Other species, such as cod (*Gadus morhua*) and herring (*Clupea harengus*) have lower temperature optima, as do salmonids and also the relict species four-horned sculpin (*Triglopsis quadricornis*). In general, juveniles have higher temperature optima than adults of the same species.

In order to regulate their metabolism many fish undertake seasonal migrations, both horizontal and vertical, to stay in water masses with favourable temperature conditions. These movements include spawning migrations, to areas, which allow the eggs and juvenile stages to grow in warmer waters than preferred by the adults, often to shallow coastal areas. For many species, the adult stages can usually be found in deeper areas than the juveniles, at least during the warm season of the year. It has been suggested that the species specific depth preference observed is connected to the temperature, since more shallow areas are general warmer during the summer period compared to deeper areas. Juveniles from species like flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and turbot (*Psetta maxima*) are general found in very shallow areas and have high optimum temperatures (≈ 20°C) for growth (Fonds et al. 1992). In addition a decrease in optimum temperature for growth with increasing size has been identified in species like turbot, which corresponded to the findings of larger individuals in deeper areas than smaller individuals. Some of the flatfish species living in the Baltic has been observed to bring the energy intake to an end when temperature drops below a certain level, e.g. turbot begins to reduce its energy intake at temperatures lower than 10°C and stops eating at temperatures below 7°C.

Temperature categories

Averaged fields of temperature are presented for the plant growth season from April – September. However, in order to provide future work with a starting point it was decided to present the model and derived data. These should be considered especially for pelagic landscape development (fig. 23). For details on the model and the data sources, please refer to Bendtsen et al. (2007). The institutions that made data available for the temperature modelling is presented in table 5. The data is stored in the BED database.

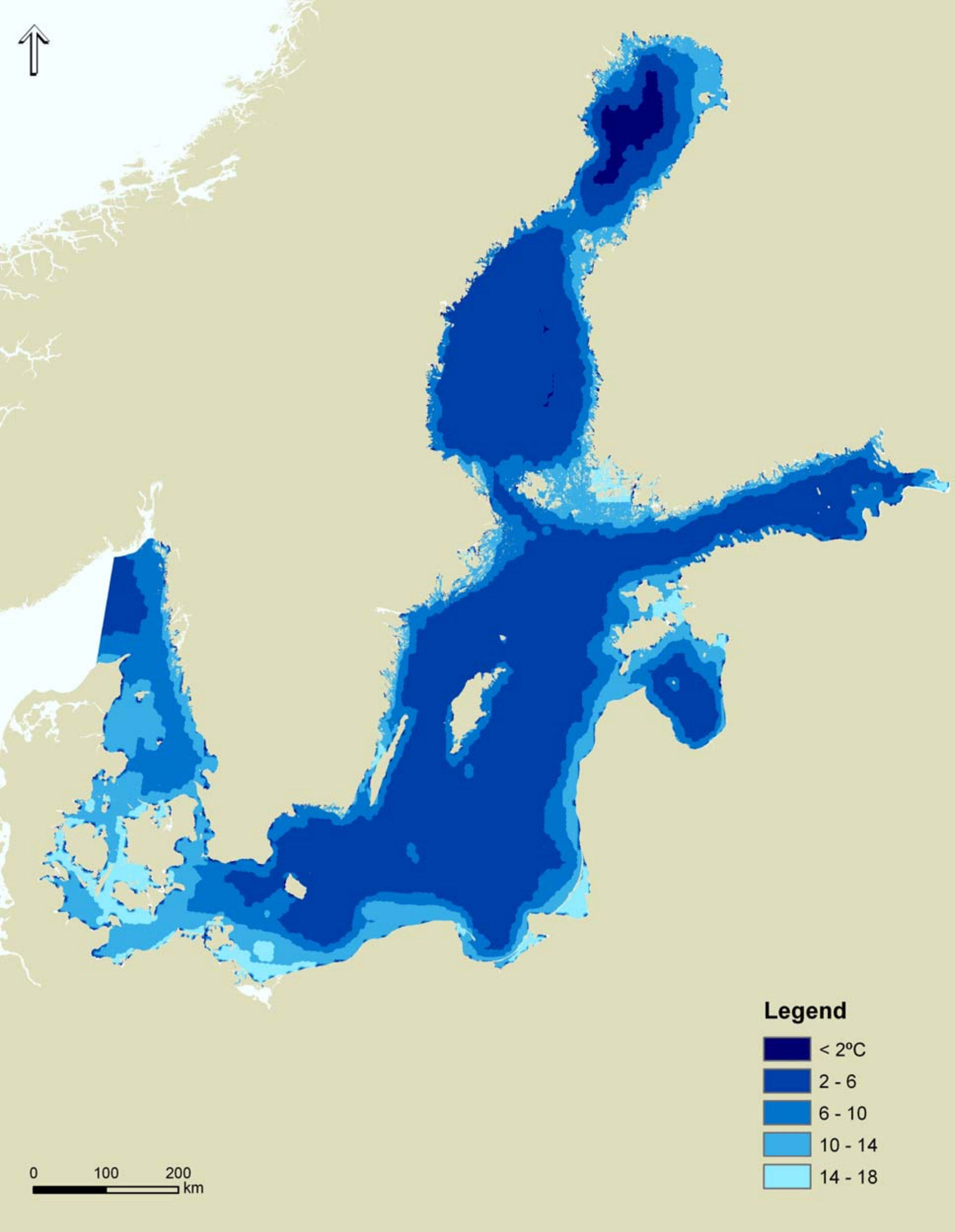

Fig. 23. *Model results showing the average bottom temperature in the Baltic region in the plant growth season from April to September. Map developed by: NERI/Denmark.*

7.2 Ice cover

Large parts of the Baltic Sea are covered by sea ice for extended periods of the year though especially in the northern part. In the very cold winters even the inner Danish waters freezes over. Ice cover was not included as a primary parameter as it is not of major relevance for the geographic distribution of species within the Baltic Sea compared to e.g. sediment, light and salinity. Though not included in the base map of the marine landscapes ice cover has been presented to enable end users to include it as a descriptive parameter for their area of interest.

Ice cover and marine life

Ice cover influences marine organisms by the potential destructive scouring of the substrate in a zone close to the water surface on which sessile organisms are attached. Ice cover also influences marine organisms indirectly through shading of available light for primary production or through access to oxygen through exchange with the atmosphere.

Ice cover influences the growth of marine plants in several ways. Firstly, ice cover will shorten the period available for growth as it affect the annual available irradiance reaching the marine plants, though it may be argued that the low temperature in itself will keep any growth at a minimum. Secondly, ice cover will on more exposed shores be fairly unstable resulting in the scouring of the substrate in near surface zone. This will typically result in a flora consisting mainly of opportunistic species, such as the green algae *Enteromopha intestinalis*. Temperatures below freezing are normally lethal for most marine plants though some adaptations exists to handle low temperatures, including increasing the concentration salts in the cytoplasm or development of antifreeze compounds. For example, *Fucus vesiculosus* is able to survive at temperatures as low as -40°C (Gessner 1970).

Ice cover categories

Ice cover occurs annually in large areas of the Baltic Sea, and has thus a major influence on both species in coastal or shallow waters and anthropogenic activities. 3 categories for ice cover have been identified. The categories are:

I. 0–90 days of ice cover.

II. 90–150 days of ice cover.

III. >150 days of ice cover.

There is no scientific or ecological justification for the chosen categories except that these categories often are applied when presenting ice cover in the Baltic Sea (fig. 24). Therefore, ice cover was not included as a primary data layer.

Data sources

The data for the ice cover was acquired from Metria/Sweden as a shape file for the Swedish part of the Bothnian Bay, and from Leppäranta et al. (1988) where a ice cover map was published for the period 1963/64-1979/1980. This map was digitised and combined, by GIS, with the map produced by Metria/Sweden for the Swedish east coast.

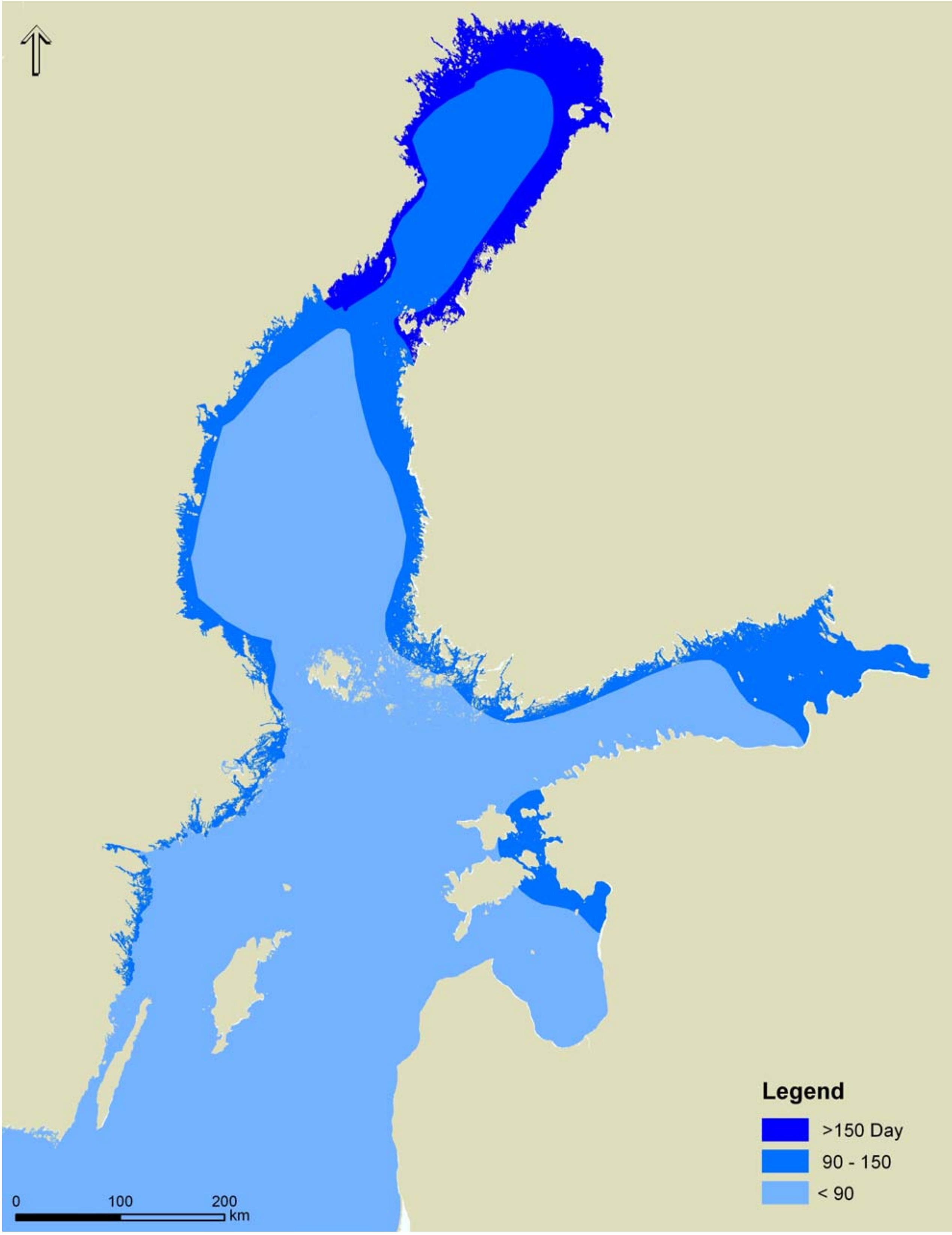

Fig. 24. *Average ice cover within the Baltic Sea region. Data sources: Metria/Sweden and Leppäranta et al. (1988).*

7.3 Water motion

Water motion, whether it is wind driven or caused by currents, it is influencing the structure of marine habitats and the life of marine organisms. Waves influence the near-shore area and the wave-base cause turbulence in shallow offshore areas. This turbulence is important for e.g. breaking up and mixing stratified waters, which often are found in shallow estuarine areas such as the Kattegat or the Baltic Proper. The physical characteristics of waves (height, period, length) will depend on the velocity and duration of the wind and the distance of open water of which the wind has blown (defined as fetch). Furthermore, waves almost always tend to approach a shore perpendicularly no matter what their direction was at sea. If waves approach obliquely, one end will reach shallow water first decreasing its speed compared to the part of the wave in deeper water thus curving the wave front swinging it around perpendicular to the shore (Lobban & Harrison 1997). Water motion caused by wave action creates a much more dynamic and unpredictable environment compared to the often more predictable water motion caused by currents. In any circumstances, water motion is the driving factor for erosion and sedimentation processes, but also the transport of marine organisms from one region to another. Water movement caused by tidal currents is of minor importance in the Baltic Sea and is not further elaborated upon even though minor tidal currents do exist in the Kattegat.

During the course of this work various aspects of water motion and their relevance for marine landscape mapping in the Baltic Sea was considered. These included:

I. Wave exposure and wave base

II. Current velocity

Water motion is important for the structuring and functioning of many marine habitats and should be considered in future refinements of the maps. Therefore, each parameter is briefly presented in the following sections.

These parameters were not included as primary data layers in the final identification of the marine landscapes for the Baltic Sea. For the wave exposure and wave base the explanation is that the ecological influence operates at a local scale, and is thus more relevant for detailed mapping of coastal habitats. This is especially true for large parts of the Baltic Sea, with its often complex shoreline. For the current velocity, the modelled results showed that these all were in the "low" category of other initiatives such as e.g. UKSeaMap (Connor et al. 2007). For this reason, combined with the lack of information for categorising current velocities into ecologically relevant categories, current velocities were not included as a primary data layer. However, if relevant for an end-user the data can be included in the application of the individual landscapes.

Water motion and marine life

Water motion will provide the organisms with oxygen, nutrients and prey, but at the same time influence their mortality at all stages of their growth from the settling of spores and larvae to the involuntary movement of adult specimens or even the destruction from the force of large waves. For example, large storm driven waves can scour substrate of existing mature biological communities enabling colonisation of more opportunistic species much the same way seasonal fires or storm can clear areas of patches of fallen trees in some terrestrial habitats. The destructive potential of large waves results largely from their direct hydrodynamic forces, which is further increased by their ability to move sand, gravel and even rocks up 20 cm in diameter even at depths below 20 meters (Seymour et al. 1989). Productivity is normally very high on locations with a lot of water motion or wave exposure due to several parameters. Firstly, wave action will constantly move algae fronds ensuring that no fronds are permanently shaded maximizing available area for trapping light. Secondly, constant water motion will increase the availability of nutrients and/or provide food particles for e.g. filter feeders such as mussels (fig. 19a). Thirdly, grazing of macroalgae will be smaller compared to areas with less wave exposure allowing the macroalgae to invest less effort on structural or chemical defences and more on growth (Leigh et al. 1987).

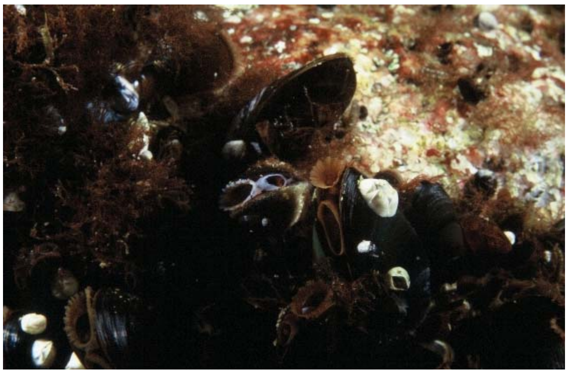

Fig. 19a. *Mussels on exposed shores often have a high productivity. Photo: Metsähallitus.*

Fig. 19b. *Charaphyceae are dependent on soft sediment and are only found at sheltered localities. Photo: Metsähallitus.*

Water motion is essential for providing marine macroalgae with nutrients and for enhancing dispersal of spores and zygotes. Water motion also affects macroalgae morphology, just as the macroalgae morphology can influence how the water force affects the individual specimen. For example, macroalgae communities present at localities with high wave exposure may consist of large kelps, short bushy or turfy algae or crusts each with different survival strategies. Water motion can also influence the morphology or physical appearance of individual specimens to some extent and e.g. some macroalgae may grow very large in periods of relative calm only to be pruned back in more severe weather conditions (Lobban & Harrison 1997). Severe weather conditions may also cause an increased mortality to macroalgae allowing them to drift if they are attached to smaller stones risking being swept ashore or out to deeper waters below the photic zone. It may also cause the macroalgae to be ripped off the substrate allowing for an endless cycle of succession. Different species thus occupy different ecological niches according to their ecological requirements (fig. 19b).

Organisms that live in marine sediments face numerous challenges. Except in shallowest areas, where there is sufficient light to allow photosynthesis at the bottom, most sedimentary organisms are dependent on phytoplankton and other organic material sinking down from the surface water above. The spatial coupling of production from most marine benthic environment makes these environments fundamentally different from those of terrestrial and fresh water benthos. With increasing water depth, the amount of material reaching the bottom decreases; most deep-sea sedimentary environments are thought to be food limited.

To take advantage of whatever food is present, some organisms (suspended feeders) are able to remove suspended particles from near bottom water; others (deposit feeders) rely on particles that have settled onto the bottom. The mobility of many benthic organisms is very limited; many are sessile, and others have limited mobility within sediments. As a result, many benthic species rely completely on the water above them to supply food.

Water also supplies oxygen, a basic requirement for most organisms residing in sediments. As organisms respire and use up oxygen, sediments can quickly become anoxic (particularly when large amounts of organic matter sink from surface waters) and therefore inhospitable for the majority of species. Water flow and circulation can provide the oxygen needed for maintaining life for benthos habitats.

Many species have a complex relationship with the sedimentary environment. Generally speaking, suspension feeders tend to be most abundant in a high-energy environment, and deposit feeders are most abundant in depositional areas with fine grained, muddy sediments. But contrasting these environments in terms of how they determine infaunal pattern is complex because many important variables vary with flow regime. High-energy environments are typically sandy, with strong bottom flows and horizontal flux of food and perhaps settling larvae. Sediment grain size is large, and organic content and microbial content tend to be low. High energy regimes produced by waves and strong currents move sediments and some organisms. Low energy environments are often muddy, with weak flows and low horizontal but greater vertical flux of food, fine sediments, and larvae (Snelgrove 1999).

Water motion is a strong indirect determinant of the distribution of fish at local spatial scales. Differences in wave exposure gives rise to habitat heterogeneity, as water motions may for example affect the sediment and vegetation type. Wave exposure also strongly affects the temperature of surface waters, which is another major descriptor of fish habitats. The degree of wave exposure is particularly variable in archipelago areas, and is thus a central variable in modelling fish habitats in these environments.

7.3.1 Wave exposure and wave base

Wave exposure is one of the major parameters in structuring the coastal environment in the Baltic (Kautsky & van der Maarel 1990). Wave exposure is defined as the long-term wave condition that affects the zonation of littoral species as described by Lewis (1964).

Wave exposure may be estimated in many ways and the method chosen was the Simplified Wave Model (SWM), which is fully described by Isæus (2004). The method is called ”simplified” since it uses the shoreline and not the bathymetry as input for describing the coastal shape. This is an adaptation to the fact that detailed bathymetry data is often poor, or restricted, and is therefore usually not available for larger areas such as a national coastline or for an entire regional sea. The method also uses fetch, adjusted for refraction/diffraction patterns, and wind speed from 16 directions. A nested-grids technique is used to ensure long distance effects on the local wave exposure regime. The resulting grids have a resolution of 25 m.

The calculated exposure values were proved ecologically relevant in scientific studies (Eriksson & Sandström 2004, Sandström & Eriksson 2005) as well as in research and development projects on environmental management (Isæus et al. 2007, Wennberg et al. 2006.). SWM has also been compared to three other methods (FWM, STWAVE, Norsk

Standard) and was found to be the method, which provides the most ecologically relevant results (*pers. com.* Trine Bekkby).

SWM has been used for wave exposure calculations of the entire Swedish, Norwegian and Finnish coasts, and the values are comparable between the shores. The extended use of the same method is for describing the physical environment facilitates for the implementation of common habitat classification systems, such as EUNIS (fig. 25). The continuous wave exposure values have been classified in eight classes according to the descriptions in EUNIS. In BALANCE SWM was used for several habitat-modelling projects in pilot area 1 and 3 (references will be made available on the www.balance-eu.org by the end of 2007).

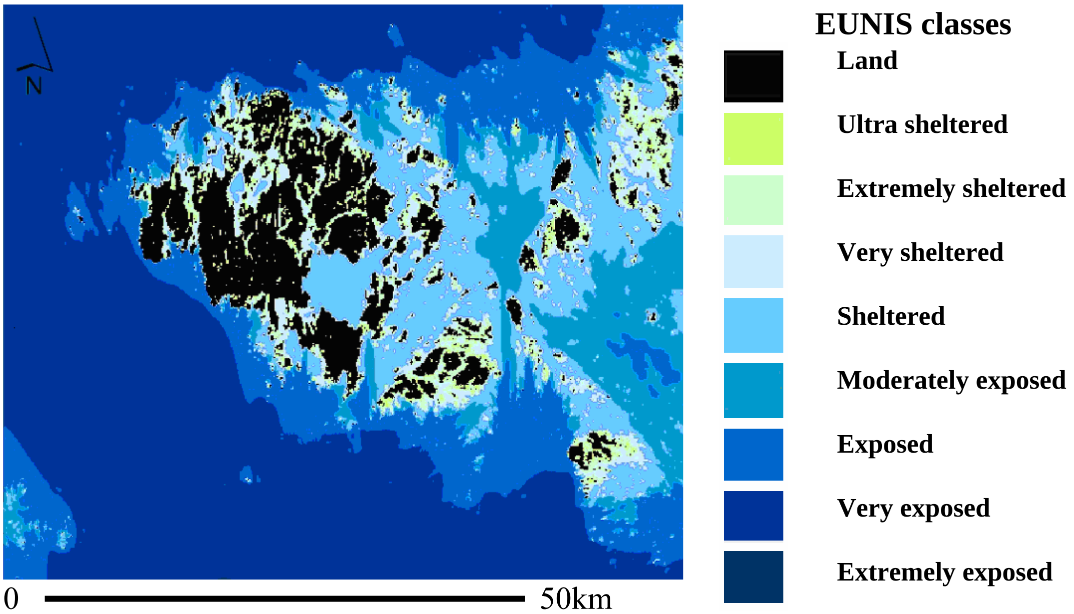

Fig. 25. *A coast with many inlets and bays with small islands will provide many ecological niches with differences in wave exposure. Wave exposure calculated using SWM around Åland (Isæus 2004).*

7.3.2 *Current velocity*

Currents in the sea can be generated by many different parameters, among which are:

I. Tidal motion

II. Wind stress

III. Density difference due to differences in salinity or temperature

IV. Seismic activity and motion of the earth

In near shore regions, the wave-induced *along shore* currents are the dominating currents, whereas in offshore regions, a combination of tidal and meteorological forces is the dominating current generating parameters.

Near the sea bottom the friction of the current flow forms a turbulent layer, termed boundary layer, over the seabed. The thickness of this layer ranges from few meters up to several tens of meters. Within this layer the current speed increases nonlinearly with the height above the seabed, being zero at the seabed and maximum at the top of the layer. The variation of the current speed with height above the seabed is called *current velocity profile*.

Current velocity categories

The EU-CIS Working Group 2.4 categories current speed into three classes (Vincent et al 2002):

I. Weak, for current speed of less than 1 knot.

II. Moderate, for current speed between 1 and 3 knots.

III. Strong, when the current speed is above 3 knots.

It was not possible to identify any biological data in the Baltic Sea, which could be applied in a justification of the ecological relevance of these classes. Subsequent work should aim to clarify the ecological relevance of these classes. Likewise it might be worth considering whether the application of a minimum and/or maximum current is more ecological relevant than the mean annual current velocity as illustrated by NERI below as the mean annual current velocity is within category I for the Baltic Sea and thus not relevant for inclusion in the development of the benthic marine landscape map.

Current velocity model

Fig. 26 shows the mean bottom current velocity derived the model described in Bendtsen et al. (2007). The model results were based on monthly averaged values from January 2003 and for one year. The bottom velocities show the largest values in the Danish Straits as well as the Kattegat and in the southern entrance to the Bothnian Sea.

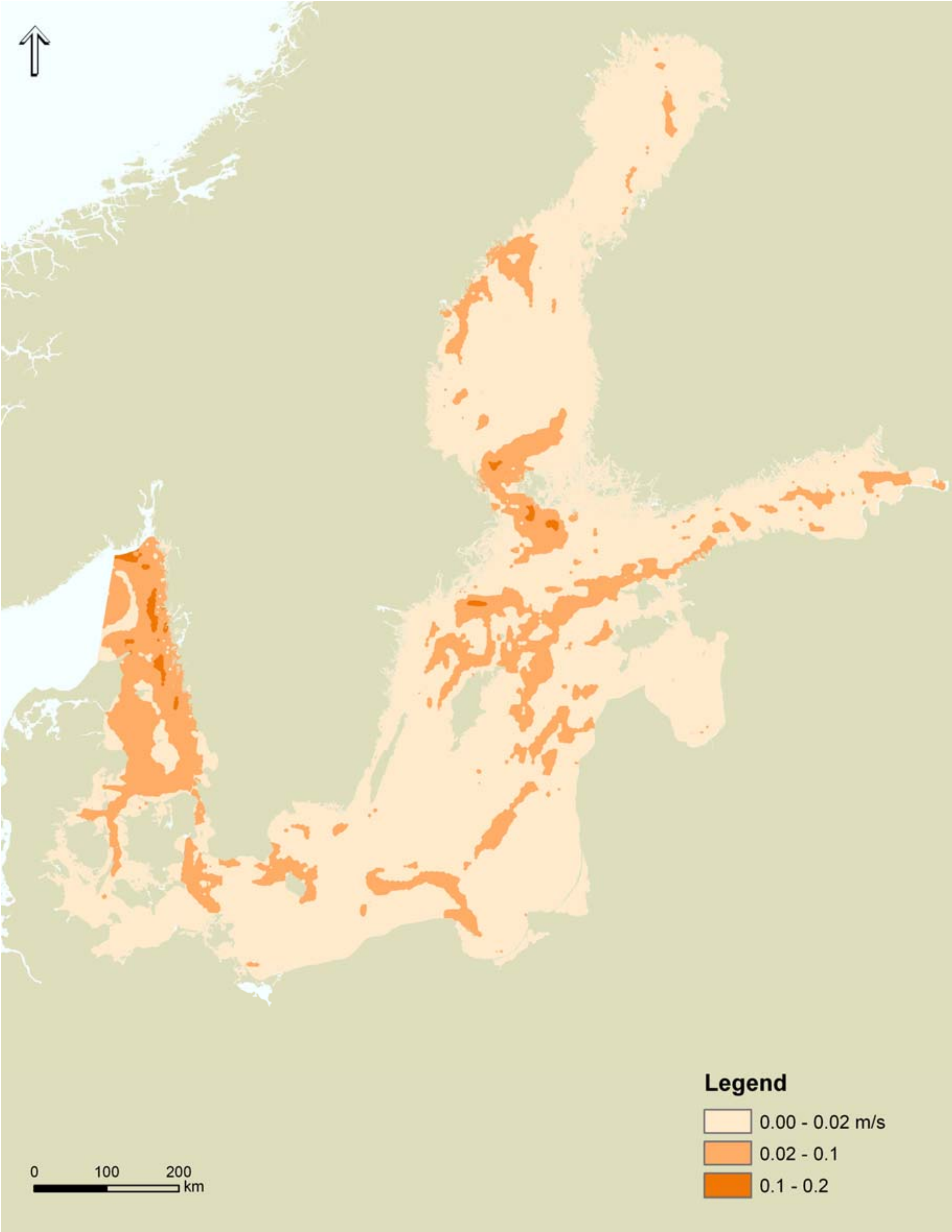

Fig. 26. *Model results showing the annual mean bottom current velocity (m/s). Data source, NERI/Denmark.*

7.4 Oxygen concentration

Regions of the Baltic Sea have since the 1800´s changed from an oligotrophic clear-water marine ecosystem into a eutrophic marine environment. The enrichment with nutrients causes an increased primary production through the excessive growth of filamentous algae and/or phytoplankton. This in turn gives rise to an increased rate of oxygen consumption from both the living plants and from the decaying processes of the increased amount of dead organic matter deposition at the seabed. The decay processes cause decreased oxygen concentrations and an increased frequency of oxygen depletion. However, oxygen deficiency or even permanent depletion occurs only in stratified water columns where the stratification prevents oxygen rich surface waters from mixing with the bottom waters (Ærtebjerg et al. 2003).

Oxygen depletion has here been considered as a quality parameter due to its linkage to eutrophication, and thus not included as a primary parameter.

Oxygen depletion and marine life

Oxygen concentration has been considered not only as an important chemical parameter for shaping the marine environment, but also as a qualitative parameter as access to sufficient concentrations of oxygen is a primary requirement of higher organisms. The oxygen concentration close to the seabed in stratified waters depends on two processes, which vary both spatially and temporally. These are the consumption rate (depending on the amount of available organic matter and the temperature) and the oxygen supply rate, which is mainly dependent on the wind-driven mixing of water layers of different density (Ærtebjerg et al. 2003). Oxygen depletion for any extended periods of time will cause the death of benthic organisms, but also more mobile species such as fish will die if unable to escape the oxygen-depleted area (fig. 27a and 27b). The lowest oxygen concentrations occur in late August to October when bacteria via an oxygen-consuming process decompose organic matter. In the Kattegat, the Danish Straits and the Western Baltic Sea oxygen depletion is a seasonal phenomenon, while in the deeper basin in the Baltic proper it is of a permanent character.

Marine plants do not necessarily suffer adverse effect because of the lack of oxygen in the surrounding water though several parameters related to oxygen depletion may in combination have severe effects on e.g. the sea grass *Zostera marina* (fig. 9b). It has been hypothesised that the combined exposure to anoxia, sulphide and extreme temperature might have been behind the disappearance of sea grass on several sites in the Kattegat during the warm summers of 1992 to 1994 (Ærtebjerg et al. 2003). Similarly, marine macroalgae is more likely to suffer from the causes behind the oxygen depletion, such as high chlorophyll concentration in the water column, and thus the availability of light and nutrients (Dahl et al. 2001).

In august 2002 the estimated oxygen depleted area in the Kattegat, Danish Straits and Western Baltic waters alone covered 9.173km^2 with less than 2 mg O_2/l and 20.585km^2 with less than 4 mg O_2/l (Ærtebjerg et al. 2003). This serious event resulted in the death of estimated 371.000 tons of marine invertebrates (Hansen et al. 2003). At the same time oxygen depletion in the Baltic Proper covered large areas of the deep basins.

Oxygen intervals

It was decided to use information on available oxygen in the period from August to October as this represents the period with the lowest oxygen concentrations available to marine life. Furthermore, it was decided to use the following categories for the oxygen concentration:

I. Below 2 mg O_2/l (hypoxic, available for the Kattegat, the Danish Straits and the Baltic Sea). 2 mg O_2/l roughly equals 1,5 ml O_2/l.

II. 2-4 mg O_2/l (only available for the Kattegat and the Danish Straits). 4 mg O_2/l roughly equals 3 ml O_2/l.

The example presented here is based upon Danish data from the Kattegat. Traditionally oxygen content has in Denmark been expressed as mg O_2/l since the 1970´s, and not as ml O_2/l, as it is done in other countries within the Helsinki Convention area.

After the deadline for this report BALANCE was able to initiate the development of oxygen maps for the entire Helsinki Convention area. These maps will be presented as ml O_2/l, and the methodology and application of these maps will be presented in separate BALANCE reports (e.g. Hansen et al. 2007) and made available for initiatives such as HELCOM BIO.

Fig. 27a. *A dead star fish in a "cloud" of hydrogen sulphide (H_2S) released from the sediment in a period of oxygen depletion. Photo: Peter Bondo Christensen, NERI.*

Fig. 27b. *Even mobile species such as fish cannot escape the often-large areas with low or no oxygen, Kattegat. Photo: Christen Jensen, The Danish Ministry of Environment.*

Oxygen levels below 4 mg O_2/l adversely influence many higher organisms. For the Kattegat and the Danish Straits oxygen depletion is defined as 0-2 mg O_2/l and oxygen deficiency between 2-4 mg O_2/l (Ærtebjerg et al. 2003). In the Baltic Sea the only available data is for areas with 2 mg O_2/l oxygen or less. In order to be able to illustrate the value of oxygen depletion maps in regard to the application of marine landscape maps it was decided to show a region in Kattegat and the western Baltic Sea for which data was available (fig. 28).

Data sources

The data from the Kattegat example and the model was provided and developed by NERI, Denmark. The data is stored in the MADS database at NERI.

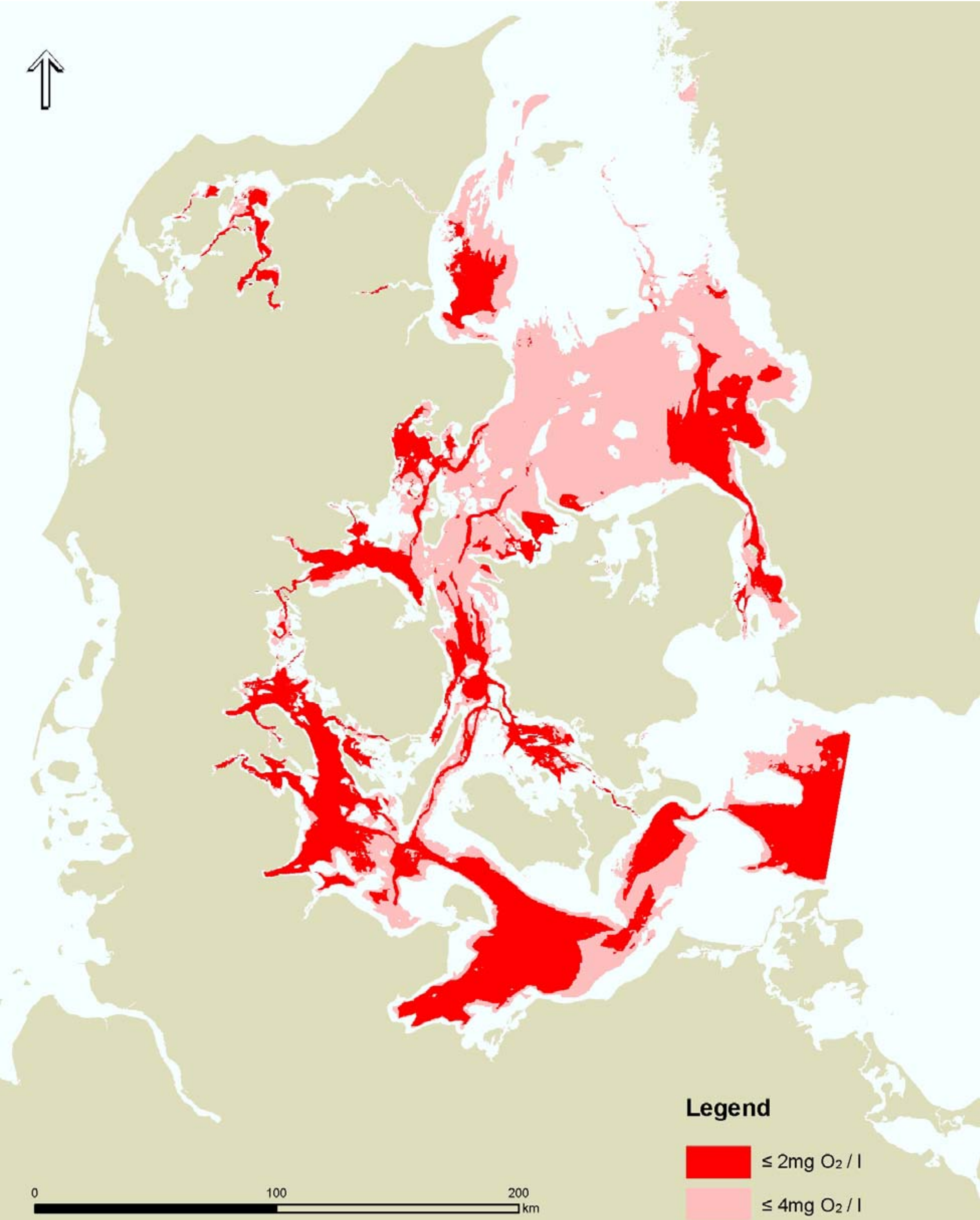

Fig. 28. *Model results showing the maximum oxygen depleted area in the Kattegat and western Baltic Sea over a 10-years period. Data source: NERI/Denmark.*

8 REPRESENTING SPECIES ASSEMBLAGES

The benthic marine landscape map for the Baltic Sea was constructed by combining three physical data sets using a GIS platform. These layers were characterised into different classes based on ecological criteria justified by expert judgement as previously described. Therefore, each of the 60 marine landscapes developed by combining these layers is assumed to reflect the broad-scale ecological requirements of the benthic species assemblages that may exist in the specific physical and geological environment defined by the individual landscape. It is important to realise that it is not the distribution of specific habitat types or individual species, which are discussed here. It is rather an attempt to predict broad-scale assemblages of benthic biota, which may or may not be related to the individual benthic marine landscape. The survey described below aim to test whether it is possible to distinguish between the species present within closely related benthic marine landscapes.

It should be mentioned that it was not possible to identify any data sets or existing research, which could be used for justifying the ecological relevance for either the topographic landscapes or the physiographic landscapes identified.

A test area was chosen at random in the central Kattegat in order to test the robustness of how well the benthic marine landscape map in representing broad-scale species assemblages (fig. 29). Several marine landscapes are present within the test area and a good coverage of biological as well surface sediment samples were available. The specific purpose of this example was to relate the fauna community structure on soft bottoms and diversity to physical properties of the marine landscape. It was decided to conduct the example within a fairly small area with compatible salinity and below the photic depth in which the similarity of the marine landscapes might be higher than comparing species assemblages on e.g. photic bedrock landscapes with non-photic soft bottom landscapes, as they most likely will be different.

Ideally, this exercise should be carried out for different regions thus covering the entire benthic landscape map. This would require a more complete biological investigation and classification for the various regions covered by the produced marine landscapes at different physical and geological conditions, before a scientific conclusion could be made regarding how well the benthic marine landscapes can be used as a proxy for broad-scale species assemblages. This was not been feasible within the timescale of the BALANCE project. Hopefully, this can be done at either the national level based on national monitoring data, as part of implementing the EU Marine Strategy Directive or perhaps as part of the continued work within HELCOM. This section simply aims to exemplify how it can be done.

A detailed description of the methods applied and statistics are presented in two BALANCE Interim Reports available at www.balance-eu.org (Dahl et al. 2007, Dinesen et al. 2007, in press).

8.1 Justification of the identified benthic landscapes

The area chosen are within BALANCE pilot area 1 in the Kattegat (fig. 29). This area was chosen for several reasons:

I. Detailed biological information was available (fig. 29).

II. A geophysical investigation was performed on this area and multi-beam bathymetry and side-scan backscatter data is available for use.

III. The marine landscapes present are closely related.

Although the area is not large and contains only few marine landscapes it is considered a good test area for exemplifying how broad-scale marine landscapes can be related to biological information.

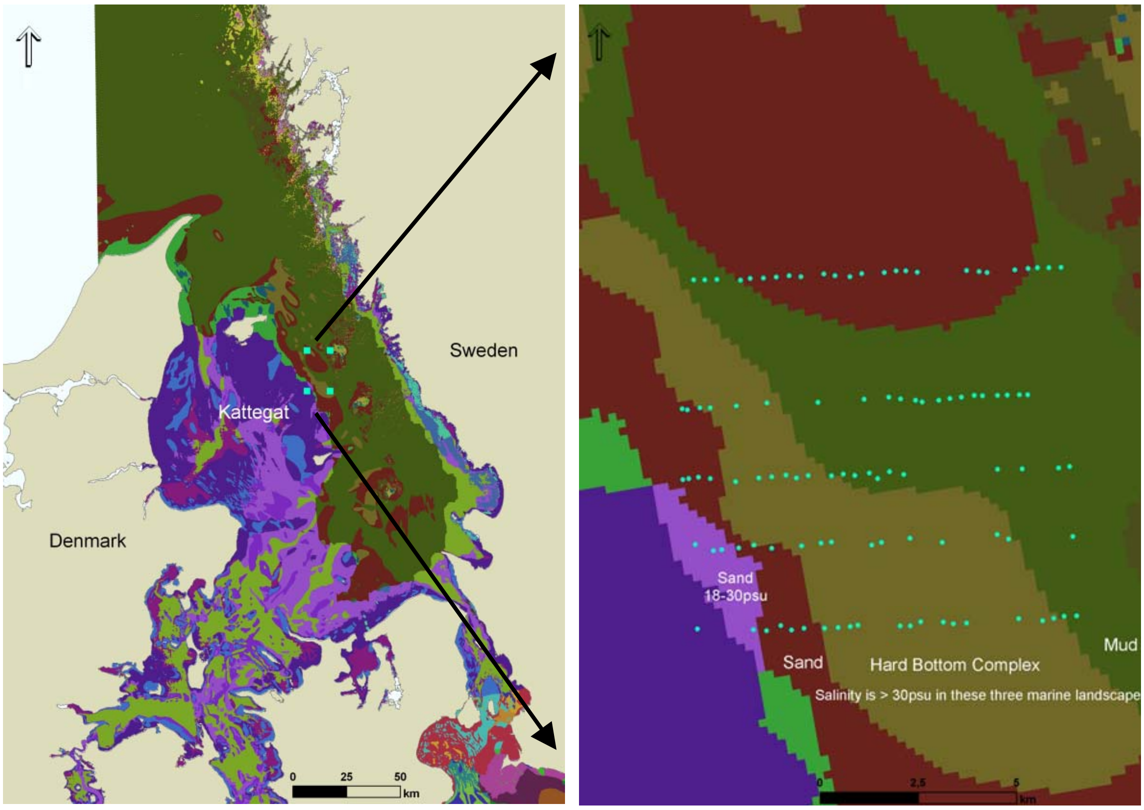

Fig. 29. *Location of the area chosen for biological sampling (bounded by squares).) Zoom in diagram where blue circles represent the 106 sample positions.*

8.2 Materials and methodology

The study area was located in the middle of pilot area 1 in the Kattegat between the islands Anholt and Læsø delimited by the following positions: 5701.600 N; 1130.000 E and 5705.200 N; 1140. 000 E. The macrofauna was sampled on the 25th and 26th April 2006 by R/V Gunnar Thorson on 106 stations located along 5 East – West transects delimited by the positions 5701.600 N; 1130.000 E and 5705.200 N; 1140. 000E.

This area has a varied topography with various sediment plains situated between 20 and 30m of depth intersected by narrow troughs (or channels) extending up to 80m deeper into the seabed (fig. 5). In one instance, a hole extended down to almost 130m. The sea bottom within this area comprises a mixture of hard substrates and sediments of varying composition, and five benthic marine landscapes are present (fig. 29b). Of these it was possible to obtain sufficient macrofauna samples from the non-photic sand at >30psu, the non-photic hard bottom complex at >30psu and non-photic mud at >30psu. The detailed sampling methodology is described in Dahl et al. (2007).

8.2.1 Results

Fauna data were matched with a sediment analysis station-by-station and sample-by-sample. The specific depth was extracted from the existing maps using the logged positions (fig. 30d). The samples covered a depth range from 12 to 90m and a composition of sediment ranging from almost pure silt/clay to almost pure sand. The sampling methodology, grab sampling, did not allow for sampling in areas with hard substratum. The deepest location in the study area was not sampled and the deepest location attempted sampled was surprisingly classified as "potential hard substrate". There is a cluster of samples at depth around 25-30m that corresponds to the depth of the sediment plains in the area whereas the deeper samples come from the troughs or their slopes. The sediment composition of the sampled stations showed a group of stations with more than 50 percent of medium sand, and another group of stations with a mixture of coarse and fine sand whereas there were relatively few stations where the sediment was dominated by the silt/clay-fraction and these were generally located deeper than 50m. The percentage of organic material, the ignition loss, ranged from less than 1% to 12% with most observations around 1%. The percentage of ignition loss showed a clear positive relationship with water depth. Medium and coarse sand dominate on the shallow plains whereas fine sand occurs at shallow as well as deep stations. The silt and clay dominated at the bottom and slopes of the troughs where the highest percentage of organic material was also found (ignition loss).

8.2.2 The fauna community

The species richness of the fauna community was high within the study area with polychaetes, molluscs, echinoderms and crustaceans as the dominant taxa. The molluscs contribute with most of the biomass of the fauna community and the polychaetes the most abundant and most species rich taxa. The average biomass was 160g wet weight per m^2 and the total abundance was 822 individuals per m^2. Both figures are somewhat lower than found in other studies in the Kattegat area. Altogether there were registered more than 179 species in the 109 samples. Average number of species per sample ($143cm^2$) was 7.8.

The total species richness as well as the richness per sample was comparable to other locations in the Kattegat. The fauna community sampled at 18 surveillance stations covering the entire Kattegat with and a total number of 95 samples showed that one sample on average contained 8.4 species and the total richness of the entire area was app. 160 species. This was despite the fact that these stations covered types of habitats not found within the test area.

The highest biomass of invertebrate macrofauna was generally found on the shallow plain although this result is somewhat biased by a few numbers of very large individuals of molluscs, echinoderms and polychaetes (fig. 30a-c). The species richness also tended to be higher on the sediment plains compared with the troughs, whereas there was no pattern of the total abundance related to the depth.

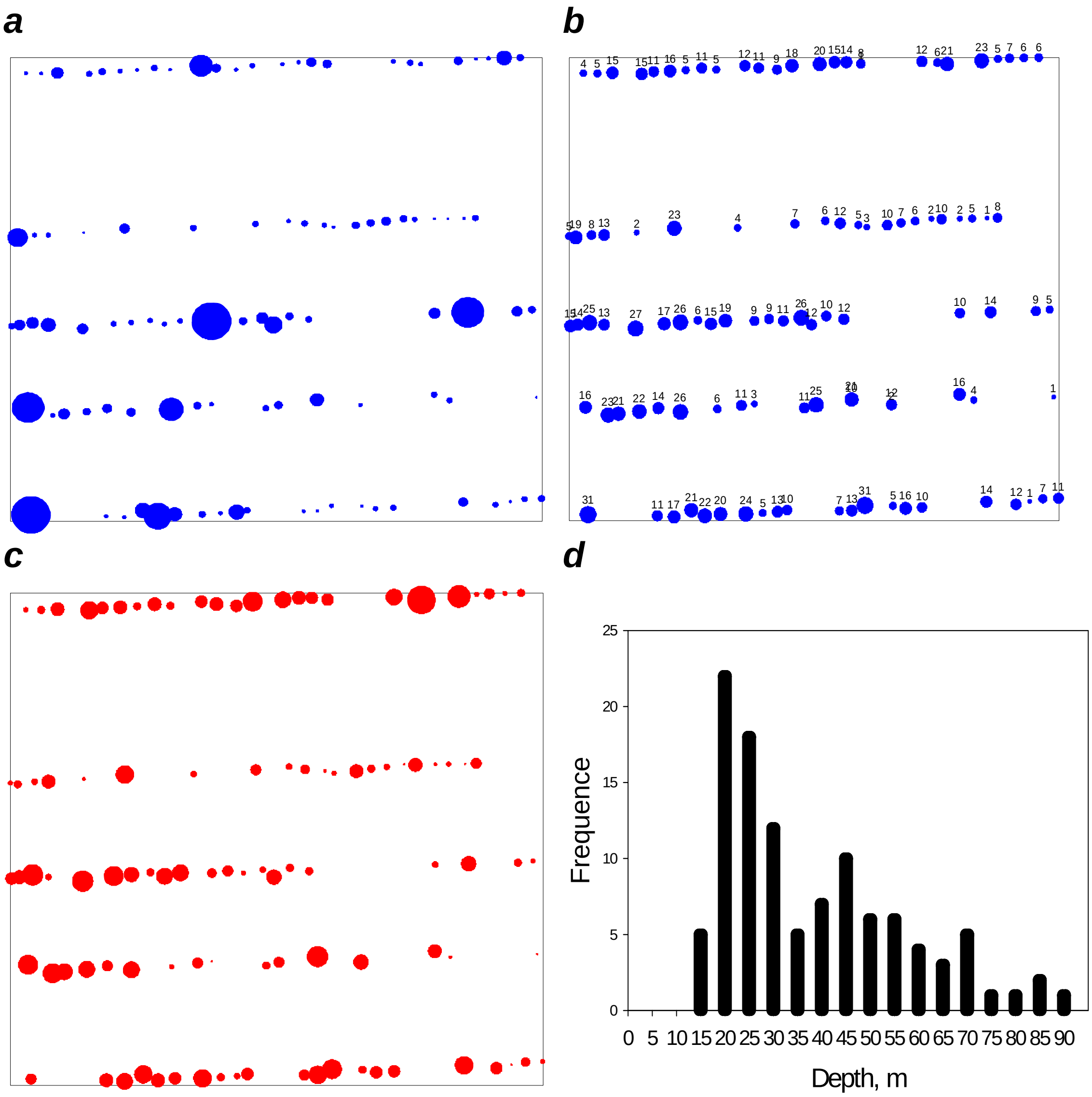

Fig. 30. *Distributional patterns of the fauna community in terms of a) biomass (square root transformation) b) number of individuals per 143 cm², c) number of species per 143 cm², and d) depth distribution of sampled stations.*

8.2.3 Community analyses

A more detailed analysis matching the spatial patterns of the fauna community with the physical properties of the marine landscapes is described in Dinesen et al. (*in prep*.). It was found that the best correlation between the similarity of the fauna communities and the physical parameters was obtained with a combination of station depth, ignition loss, and fine sand. Including additional parameters did not improve the correlations.

For most of the environmental parameters in the study area there was a more or less continuous change of the fauna community composition along the environmental gradients and there were no clear "thresholds". However, grouping of stations according to depth gave a very distinct separation and the fraction of silt/clay and the ignition loss show a correlation with depth by splitting the data in two groups: deeper or shallower than 28m. Within the group of stations deeper than 28m the fauna communities can be grouped secondly according to the sediment composition, where the fraction of medium sand gave the best separation if the criteria were set to be more or less than 50% medium sand. The group of shallow stations can also be grouped according to the sand fraction of the sediment. Medium and fine sand separated the communities equally well and resulted in almost the same community when analysed with SIMPER. For simplicity medium sand was chosen as the secondary criteria for the shallow stations and their 4 habitats could be distinguished by only two parameters.

Thus the fauna community may be related to 4 significant distinguishable habitats: I) stations deeper than 28m with coarse or fine sand, II) stations deeper than 28m with more than 50% medium sand, III) stations less than 28 m with more than 50% medium sand, and IV) stations shallower than 28m with a sediment composition of coarse and fine sand or silt/clay. By analysing community composition with ANOSIM on the stations grouped by the above depth and sediment criteria revealed significant differences between all combinations of the above groups with P values <1.4%. The characteristic species of each of these communities were following analysed by the SIMPER procedure in the software package PRIMER (please refer to Dinesen et al. 2007, in prep. for further details).

With such detailed information it is possible to classify different marine habitats and their associated characteristic species. Most importantly, the information obtained through this study indicates that the depth of the halocline is an important environmental parameter, which should be included in a future improvement of the marine landscape map in the Kattegat area.

8.3 Distinctive marine landscapes?

The 4 habitats identified are defined by slightly different ecological boundaries than the benthic marine landscapes present, partly because of the more detailed sediment information available and partly because of the influence of the halocline on the benthic communities. The challenge that remains is to evaluate whether there is a significant difference between the identified benthic marine landscapes based on the invertebrate macrofauna sampled.

Most of the sampling stations were situated within three marine landscapes, i) non-photic hard bottom complex at >30psu, ii) non-photic sand at >30psu and, iii) non-photic mud at >30psu (fig. 29). In order to analyse whether any significant differences exist between the three marine landscapes the benthic samples were analysed in PRIMER using the ANOSIM routine. The results revealed significant differences between all combinations of the above marine mentioned benthic marine landscapes with P values ~1%. An MDS plot of the clustering of the stations is presented below (fig. 31).

Thus, there were three significant distinguishable fauna communities corresponding to each of the three benthic marine landscapes. The fauna data collected in the test area also resemble the fauna communities known from other part the central Kattegat and thereby allows for comparisons to other areas of Kattegat (Dinesen et al. 2007 *in prep.*).

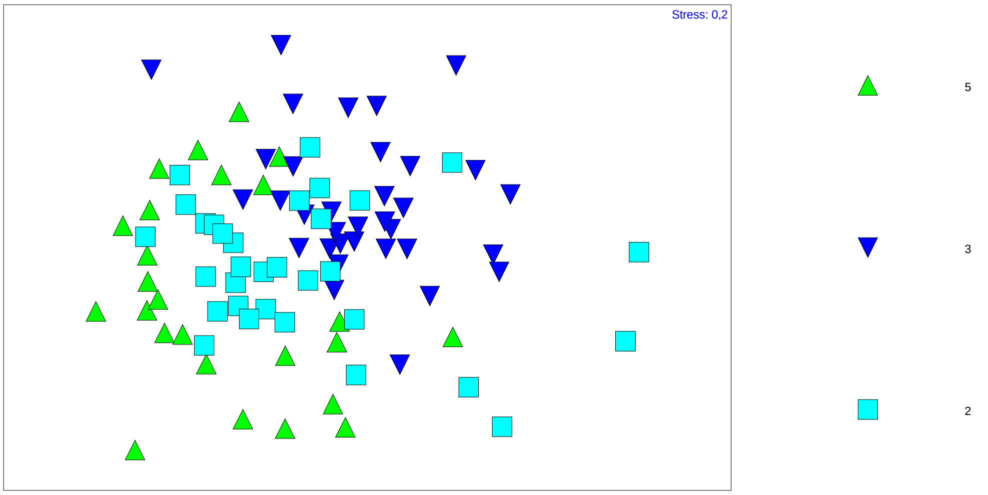

Fig. 31. *MDS plot (multi dimensional scaling) showing the clustering of stations in the test area 1 based on Bray Curtis similarity (presence/absence). The relative position of the stations in the plot scales with the similarity between stations. The green triangle is the non-photic mud, the blue triangle is non-photic sand and the turquoise square is non-photic hard bottom complex that includes boulders and coarse sand.*

The characteristic species of each of these marine landscapes were analysed by the SIMPER procedure in the software package PRIMER (tab. 11). This procedure ranks the species of each of these communities according to their contribution to the overall Bray Curtis similarity within the predefined communities and dissimilarity between communities. The very rare species were not included in this analysis.

Tab. 11: Characteristic species of each of the four types of habitats only the important species, which together contribute to more than 90 percent of the similarity within the community. Species of each community is listed in rank order according to their specific contribution to the similarity. Species highlighted in black indicate species, which only occur in one community.

Non-photic hard bottom com-	Non-photic sand >30psu	Non-photic mud >30psu
Amphiura filiformis	*Amphiura filiformis*	*Amphiura filiformis*
Thyasira flexuosa	*Thyasira flexuosa*	***Amphiura chiajei***
Nephtys hombergii	***Phoronis muelleri***	*Thyasira flexuosa*
Diplocirrus glaucus	***Scoloplos armiger***	***Ophiura albida***
Owenia fusiformis	*Spiophanes bombyx*	***Abra nitida***
Glycera alba	***Magelona alleni***	***Laonice bahusiensis***
Nemertea	*Nephtys hombergii*	***Ampelisca tenuicornis***
Diastylis lucifera	*Nemertea*	*Calianassa subterranea*
Spiophanes bombyx	***Prionospio fallax***	***Pholoe baltica***
	Magelona filiformis	
	Chaetozone setosa	
	Lucina borealis	
	Echinocardium cordatum	
	Spio filicornis	
	Calianassa subterranea	
	Echinocyamus pusillus	
	Glycinde nordmanni	
	Montacuta ferruginosa	

The species associated with the three marine landscapes sampled in this field survey are not necessarily restricted to only one of the three marine landscapes, and are most likely present within several marine landscapes. Furthermore, any single benthic marine landscape will to some extent contain a large number of different marine habitats e.g. due to the coarseness of the sediment map or the fine-scale complexity of the seabed might enable mud habitats to be present within an area delineated as non-photic bedrock. Only detailed mapping surveys will be able to identify the extent of such overlap. It is important to keep this in mind when adding information on e.g. oxygen depletion (section 9.3.2) as the species within one marine landscape are not necessarily under threat just because one marine landscape is almost completely influenced by oxygen depletion.

In order to summarize, it is well known that the individual species show preferences for sediment composition, water depth and salinity, and that the community composition in the Kattegat area changes according to these parameters - in particular salinity, as there are more species in the high saline environments. However, in the Kattegat the physical parameters of depth and salinity are strongly inter-correlated because of the stratification extending over the entire area. The sediment composition is also to some extent correlated with depth as the sandy habitats predominantly occur in the shallow areas in the western part of the Kattegat. In contrast, the stations in the test area were, with a few exceptions, located below the halocline and therefore all almost permanently had salinity of >30. Thus this area offered the opportunity to test the influence of sediment and depth independently of salinity. It was possible to distinguish four communities based on criteria of sediment composition and water depth and these communities matched the communities found on similar habitats outside the pilot area. This suggests that mapping of the communities may be extended outside the pilot area although the local salinity must be taken into consideration.

While this approach is inconclusive for the entirety of the benthic marine landscape map it indicates that even closely related marine landscapes represent significantly different species assemblages. These species assemblages may be mapped to higher levels of details for other purposes, and thus start the process of associating marine habitats the coarser marine landscapes.

Furthermore, it is assumed that the difference between benthic marine landscapes with a more distinct difference in salinity, available light (non-photic – photic) or between various sediments (e.g. mud and bedrock) must be even more significant. While incomplete for the entire landscape map it does add a certain amount of creditability to the map, though similar exercises should be done nationally for the various Baltic regions based on data from the national monitoring programmes.

Therefore, in conclusion, of this first attempt to map the benthic marine landscapes of the Baltic Sea it appears that even closely related marine landscapes do represent significantly different species assemblages.

9 DISCUSSION

An improved and informed understanding of the many competing uses of the sea requires better information and understanding of maritime activities (social, economical or recreational) and the impact they have on the environment in which they occur. The overall objective of BALANCE is to enhance awareness on applying broad-scale ecologically relevant maps for informed marine spatial planning. These maps present the BALANCE efforts to produce a tool for implementing an ecosystem-based approach to our management of the Baltic Sea keeping the long-term goal of sustainable development in sight. The marine landscape maps presented here should thus be seen as the first transnational attempt to develop broad-scale coherent ecologically relevant maps for the Baltic Sea. The experiences made during this process presented in order to provide guidance for future marine spatial planning.

9.1 Marine information

One of the primary experiences made through the development of the Baltic marine landscape maps was that though data exist within the public domain the information is not always available or accessible at a transnational level within the Baltic EU Member States. Another experience was how available data could be used to develop informed management strategies of the human activities occurring in the marine ecosystem.

Many of the Baltic States have large amounts of data for the marine environment, though there is great variation in the availability of existing environmental information for the Baltic Sea. Furthermore, gaining access to coherent Baltic-wide individual data sets is very difficult, if not impossible for especially biological information. In general, even though this information has been collected with public funds (national or EU funds) it was not readily available for a transnational initiative such as BALANCE for various reasons. These reasons included:

- data not having been collected to uniform standards,
- not being held in suitable formats,
- public organisations that did "not have the manpower" to provide e.g. existing GIS shape files,
- military restrictions to sharing data with non-national organisations e.g. usable bathymetry or detailed coastlines for broad-scale habitat mapping,
- the need to maintain secrecy until results are published within scientific journals, technical difficulties in gaining access to closed, but in theory public databases etc.

In general, these justifications appeared to cover a wish to avoid placing data in the public domain. Furthermore, some data had to be purchased or licensed from publicly funded organisations (using project and/or national public funds).

Likewise, some data are collected and held by private sector for various purposes such as environmental assessments or for e.g. fisheries related purposes. This information is also often difficult to gain access to in a usable resolution due to a general distrust between sectors or because the information is considered to be *commercial-in-confidence* or because of the lack of a central database hosting this data. This could be argued to oppose a wider public interest.

Biological information collected and presented according to unified standards that cover the Baltic Sea has not been available for the project, (if such exists at all for benthic organisms). This has made a coherent approach to the validation very difficult as well made it impossible to apply statistical methods in defining biological relevant categories for each environmental parameter considered. A unified, transnational approach to field sampling and public access to the results are necessary for future improvement of the maps.

Potentially, this lack of transparency and data availability leads to unnecessary duplication of survey efforts and thus results in an inappropriate use of public funds. It also results in a non-optimal utilisation of information by only taking a proportion of existing data in account and hinders a sustainable, informed management of the marine ecosystem in which all human activities and interest are taken into proper consideration. The argument, that it ought to be in the public interest that information collected with public funds (EU or national) should not be withheld or charged for, appears strong indeed. Hopefully, the effort set up in order to implement the EU INSPIRE Directive will provide the tools to overcome these problems.

9.2 Marine landscape mapping

BALANCE has demonstrated that it is possible to identify and map marine landscapes characterising an entire ecoregion (*sensu* the proposed EU Marine Strategy Directive). However, it is important that end-users realise that the marine landscapes maps produced should only be considered as a first step towards a broad-scale characterisation and mapping of the Baltic Sea, not necessarily a final truth nor a true representation of what is actually present at a specific location. Thus, a continued improvement of the maps is necessary. However, as shown for other European seas, the basic concept is sound and fully applicable as a broad-scale characterisation of the Baltic marine ecosystem.

It could be argued that other or different environmental parameters should have been included or a different categorisation and/or justification should have been applied in the development of the maps. These are valid arguments and only future work on describing; refining and validating the individual landscapes will show how these elements might be adjusted. Any improving and refining of the marine landscape maps should, if at all possible, be done with data covering the Baltic Sea. This could be a specific number of Baltic-wide habitat maps of key and/or habitat forming species or e.g. improved coverage of surface sediment maps. Therefore, as new survey data become available this should be included in a continued refinement of the maps. This could be part of the 6-year reporting cycle required from the EU Member States by the EU Water Framework Directive, and/or as a standardised requirement for implementing the proposed EU Marine Strategy Directive potentially coordinated by an international body or organisation.

As more relevant information become available it could help describing the ecological relevance of the identified marine landscapes and thus help refining the maps. It would also enable a process identifying the sensitivity of individual landscapes to various anthropogenic activities providing an informed baseline for marine spatial planning. Such information would help to produce a confidence rating of the produced landscape maps and the environmental data layers included for developing the landscape maps.

Lastly, it is important that other transnational initiatives make further investigations further into how well different marine landscapes reflect large-scale species assemblages using the methodology previously described. This could be based upon data from the national monitoring programmes, as part of implementing e.g. the proposed EU Marine Strategy Directive or perhaps as part of the continued work within the Helsinki Convention.

If high-resolution data is made available, it will enable a more detailed mapping of the physiographic features and provide a better overview of the distribution of these types within the Baltic Sea. Hopefully, it will also enable more consideration on how to define and characterise these physiographic types by objective criteria. Likewise, detailed biological mapping is required to clarify the ecological relevance and characterisation of both of the topographic and physiographic landscape types. Hopefully, future work will provide solutions/hierarchical classifications merging the various broad-scale characterisations into a single seamless broad-scale map.

Another major task for future improvement of the available marine landscape maps would be the development of pelagic landscape maps covering the Baltic Sea based on 3D modelling and the ecological requirements of key pelagic species such as key fish species (e.g. cod), plankton or marine mammals. Such endeavour could be part of another transnational project.

It is important that any future improvements continue the spirit in which the marine landscapes were developed and seek to apply an ecosystem-based approach based on transnational and cross-sectoral co-operation covering the Baltic Sea. If the usual *one nation – one approach* is chosen for e.g. the implementation of the proposed EU Marine Strategy Directive, it will be very difficult to obtain a true ecosystem-based approach to management of the marine environment as comparisons and standardisation between data and maps will be near impossible, if at all sensible.

9.3 Application of the marine landscape maps

In the approach applied for the mapping of marine landscapes of the Baltic Sea three types of seabed features were identified. These are: the topographic/bed form features map, the physiographic features map, and the benthic features map. An overlap between the maps are caused by the fact that the topographic/bed-form features as well as the coastal physiographic features are identified based on their physical shape, while the seabed features mostly are identified by their physio-chemical characteristics. All three types are valid characterisations of the marine ecosystem.

The topographic features are characterising and conceptualising vast areas of the sea normally only illustrated by coarse Navigational Charts, and are providing helpful strategic information as well as visualising on the overall topographic layout of the seabed. The coastal physiographic features characterise the coastal zone. This map represents the region of the sea with the highest concentration of human activities and interests, and which is thus highly relevant as a basic layer for integrated coastal management. The seabed features identified by their physio-chemical characteristics are important for providing an overview of the potential distribution and diversity of marine natural values, and if correctly applied, can contribute towards a sustainable development.

The potential uses and applications of the marine landscape maps are many (see also section 2.6). The intention with these examples is only to provide food for thoughts for potential users and is not in any way exhaustive or meant to show the full picture and relation to e.g. implementation of policy documents. It will be up to the EU Member States, and neighbouring countries such as Russia, to develop the full application of this type of information of the marine environment, though some examples will be available from other BALANCE products. Though advice has been given throughout the report on how improvements could be made, the maps presented by BALANCE are fully developed and usable in their current form.

The marine landscape maps might be used in connection with human activities and their impact or as a measure for environmental assessments of e.g. the representativity of marine protected areas within an ecoregion. Several EU Directives (EC Habitats Directive, EU Water Framework Directive and the proposed EU Marine Strategy Directive) and regional initiatives (e.g. the Baltic Sea Action Plan) require spatial information of the marine environment. Marine landscape maps provide such transnational information covering the marine ecosystems and where possible care should be taken to identify synergies and promote convergence between EU Directives and the utilisation of the maps. This could include requirements or needs in regard to data, characterisation needs, sensitivity, impact and status assessments etc.

The maps can also be used to provide information on the proportion and composition of existing protection schemes e.g. how well are the existing network of marine protected areas representing the marine landscapes identified for Baltic Sea. Other BALANCE activities will provide such information on a Baltic Sea scale.

In order to fully exploit ecological maps for marine spatial planning it is necessary that socio-economic data covering leisure activities, commercial fishing, marine aggregates, shipping, offshore wind farms etc. are made available in compatible data formats. This merging of interests would provide an informed base for a discussion on how large a proportion of a national or regional natural resource/landscape is actually impacted by specific anthropogenic activities. Of course this would require the various sectors to realise that mutual benefits arise from cross-sectoral cooperation rather than the existing "*one sector – one spatial approach*".

However, no matter for what purpose the maps are applied some caution is necessary as the marine landscape maps only show certain aspects of the marine environment. E.g. they do not take the distribution of e.g. birds, fish or marine mammals into account. Likewise, the grid size used for the modelled data and the scarceness of data in most offshore areas means that the maps are not suitable for fine-scale management. For this detailed habitat maps based upon high-resolution information is required.

Together, the three types presented here provide a broad-scale spatial overview of the complexity and diversity of the marine environment in the Baltic Sea and provide environmental managers and planners with valuable information for implementing an ecosystem-based approach to management. Any utilisation of a single map will only provide “part of the picture” and therefore, proper caution should be exercised if any of the approaches are applied alone.

9.3.1 Application example I – complexity of the Baltic Sea

The following two maps illustrate the complexity of a specific area (grid cell) based on the number of benthic marine landscapes present within a 50km grid (fig. 32) or within a 20km grid (fig. 33). The map can tentatively be applied to identify potential hotspots with the presence of a high complexity as well as areas with a lower complexity of marine landscapes within the Baltic Sea. This information provides environmental managers with a tool to identify potential important areas that might need further investigation or for strategic planning of field surveys, thus contributing with an ecosystem-based perspective.

The maps show that certain areas in the Baltic Sea host a high complexity of up to 20 marine landscapes within a 50km grid (or 19 within a 20km grid), while most areas contain between 1-10 within a 50km grid. The “hotspot” areas include the Swedish west coast, the Danish Straits and the Sound at the entrance of the Baltic Sea, around the northern part of the island of Gotland and the Gulf of Finland. In general, coastal areas appear to host a greater number of marine landscapes in comparison to off-shore regions, though this may in part be due to better data coverage in coastal areas, partly because of a higher sediment complexity in smaller areas near the coast and partly because of the physical parameters chosen for the development of the benthic marine landscapes.

Some caution should be applied when using the map. Firstly, if two adjacent grids have the same colour or number of marine landscapes present within them, this does not necessarily mean that the marine landscapes are identical in the two adjacent grids. Large areas (or several adjacent grids) with the same colour or similar number of marine landscapes do merely illustrate that the diversity in the region is low, but not necessarily identical from grid to grid. In order to get an indication of the level of complexity present within a region comparison should be made between fig. 32 and fig. 33, but also with fig. 17.

Secondly, a grid with a high diversity (orange to red) usually reflects a high sediment complexity as well as a salinity boundary present in the region/grid. This is the case in e.g. along the Finnish coast in the Gulf of Finland or at the “known” biogeographic boundary in the southern part of the Sound between Denmark and Sweden (fig. 33). As these “hotspots” basically are determined by the categories chosen to delineate each environmental parameter it is important that anyone using the maps is aware of and in agreement with the justification for the categorisation applied in the approach described in this report. A change in the categories would obviously change the distribution or delineation of the marine landscapes and thus the location of the hotspot. Hence, the maps should only be cited as indicative and used for initiating further surveys, not as the final truth.

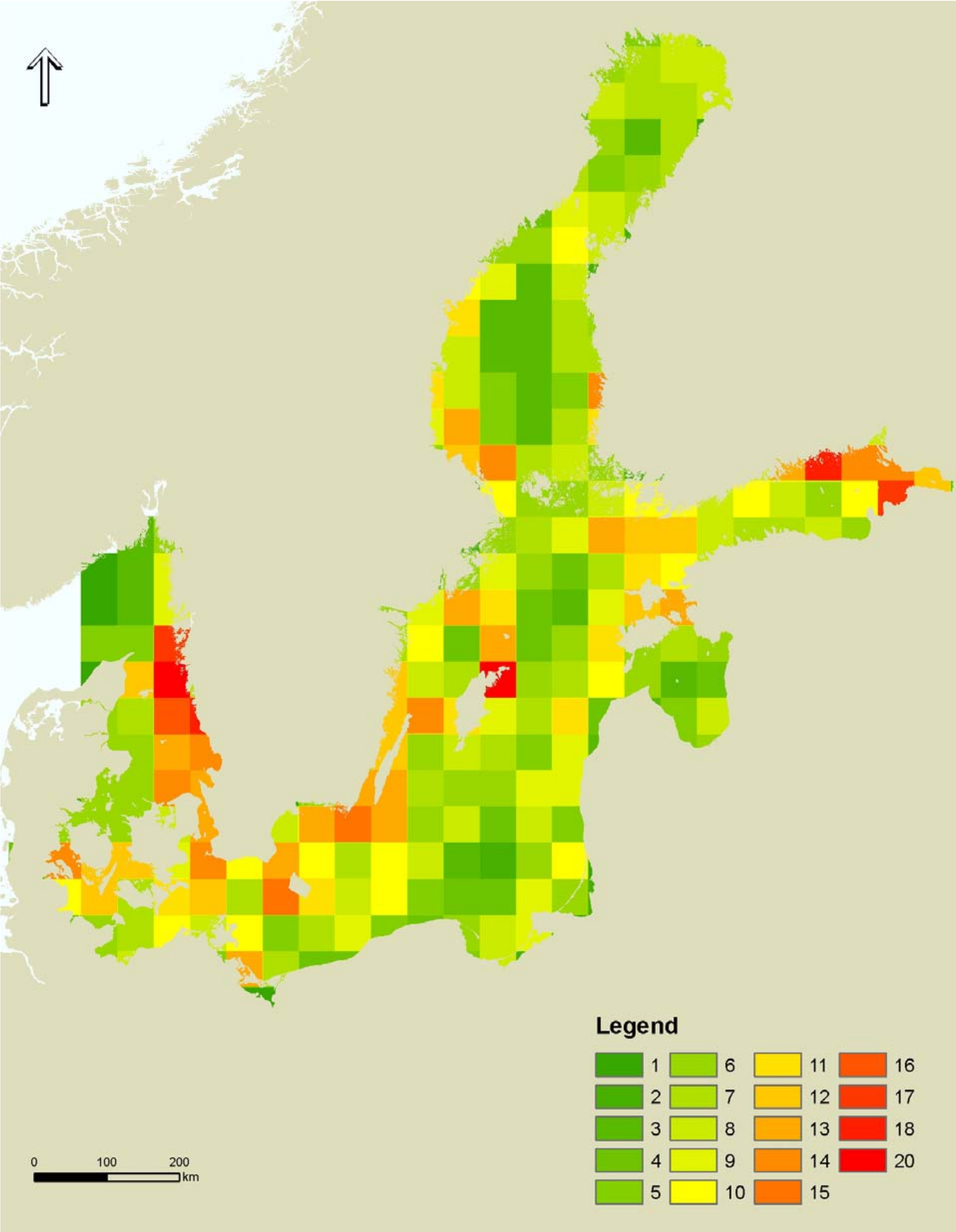

Fig. 32. *Map showing the number of benthic marine landscapes within a 50km grid.*

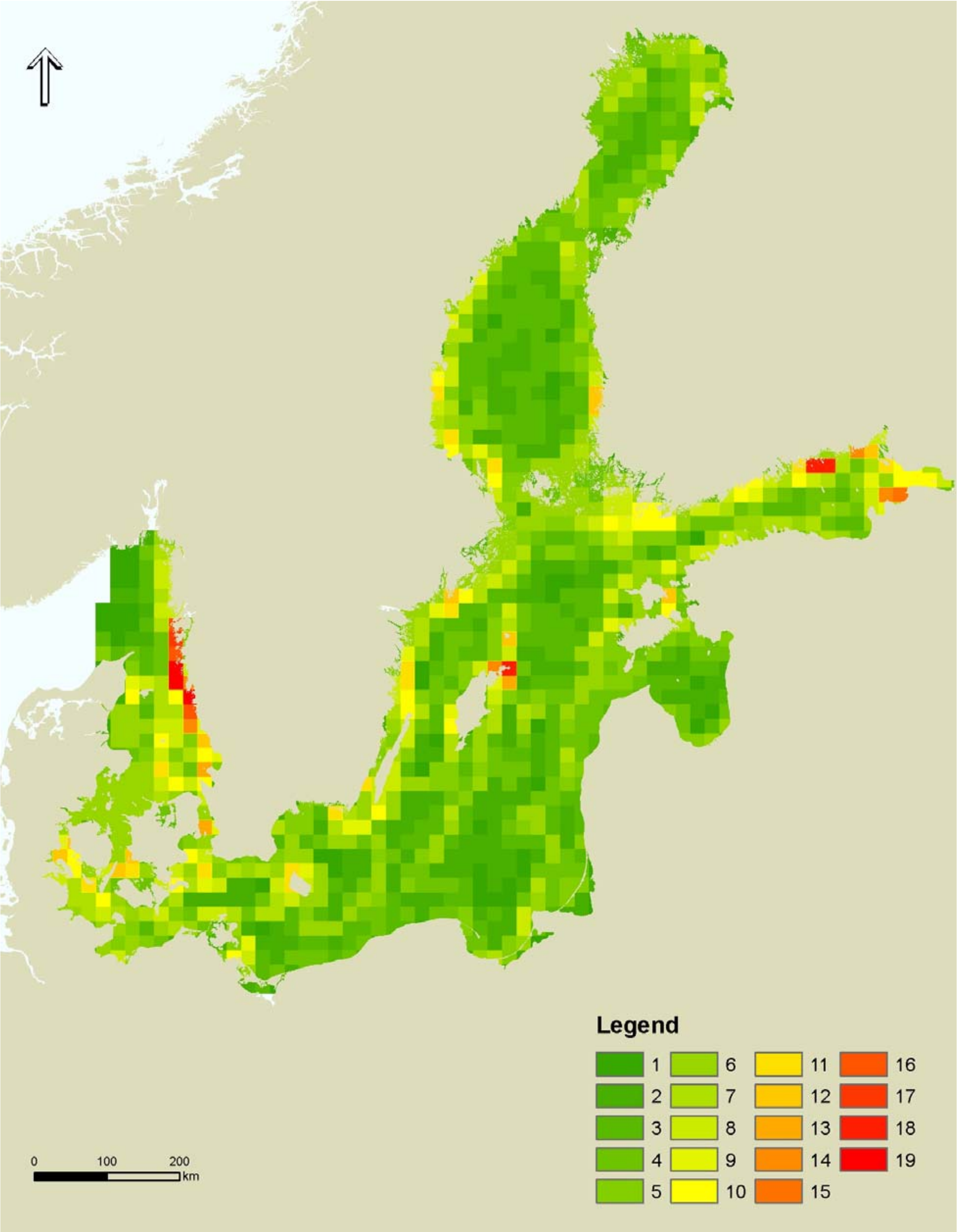

Fig. 33. *Map showing the number of benthic marine landscapes within a 20km grid.*

9.3.2 Application example II – oxygen depletion

The second example illustrates how marine landscapes can be applied in regard to oxygen depletion within the Baltic Sea. The region chosen includes only the Kattegat and western Baltic Sea as delineated by fig. 34. A similar example will be available in an up-coming BALANCE Interim Report (late 2007) for the Helsinki Convention area.

37 benthic marine landscapes are present within the western Baltic Sea and the Kattegat with an overlay of the area influenced by oxygen depletion defined as the maximum during a 10-year period (fig. 34). Tab. 12 shows the area of the individual landscapes influenced of oxygen depletion. The maximum extent of oxygen depletion shown occurred during late summer 2002 in the Danish waters (Hansen et al. 2003). For many of the marine landscapes only a small proportion is influenced by oxygen depletion and is thus under minor threat. All of these are within the photic zone. More importantly, very large proportions of the non-photic soft substrate are influenced by oxygen depletion e.g. non-photic mud from 30 to 7.5psu of which 90% are influenced by oxygen depletion (or 21% of the total area).

When such large proportions of an ecological entity are influenced by oxygen depletion the consequences for the marine ecosystem will most likely be severe as it influences the both the abundance and quality of marine life (tab. 12, red box). During the oxygen depletion in 2002 it was estimated that 371.000 tons of marine invertebrates died in the Kattegat and Danish Straits. No figures are available for the vertebrates e.g. fish.

Besides influencing the total biomass, changes in species richness will also occur following a series of repeated oxygen depletion incidents. Time series of fauna data from the Kattegat area shows that the communities undergo temporal changes in the entire area over the time scale of few years as well as long time changes. A 50% reduction in the species richness over the past 13 years observed in the soft bottom communities in the Kattegat area is an example of long time changes (Hansen et al. 2003).

Merging broad-scale information with the benthic marine landscape map thus provides valuable information on the proportion of an area, which is influenced by an environmental pressure or anthropogenic activity. In the oxygen depletion example the information will form an important basis for any protection measures of the 10% of the specific marine landscape (e.g. non-photic mud at 18-30psu) not influenced by oxygen depletion. The argument that care should be taken to actively manage and protect such an area from other anthropogenic impacts, e.g. physical disturbance, as it may provide a very important donor area for supplying the larvae needed to re-colonise the oxygen depleted areas appears very strong. Such efforts should also take into account dispersal mechanisms of marine organisms in order to limit habitat fragmentation (Martin & Nilsson, *in prep*.).

Another application of the area-based information that is obtained through merging benthic marine landscape map with environmental information is to set informed environmental targets for management plans or environmental strategies covering entire ecosystems rather than the more traditional "*one nation – one approach*". For example, how large a proportion of the marine landscapes or areas of individual marine landscapes within a subregion (*sensu* the proposed EU Marine Strategy Directive) can be affected by oxygen depletion without adversely influencing specific environmental targets? If an ecosystem-based approach to our management of the marine environment were desired such targets would need to inform national implementation strategies as well as operate both at the Helsinki Convention area and/or regional (e.g. the Kattegat) level to help inform status and enhance transnational understanding and cooperation. This is especially true for the Baltic Sea with its many nations and extensive eutrophication problems.

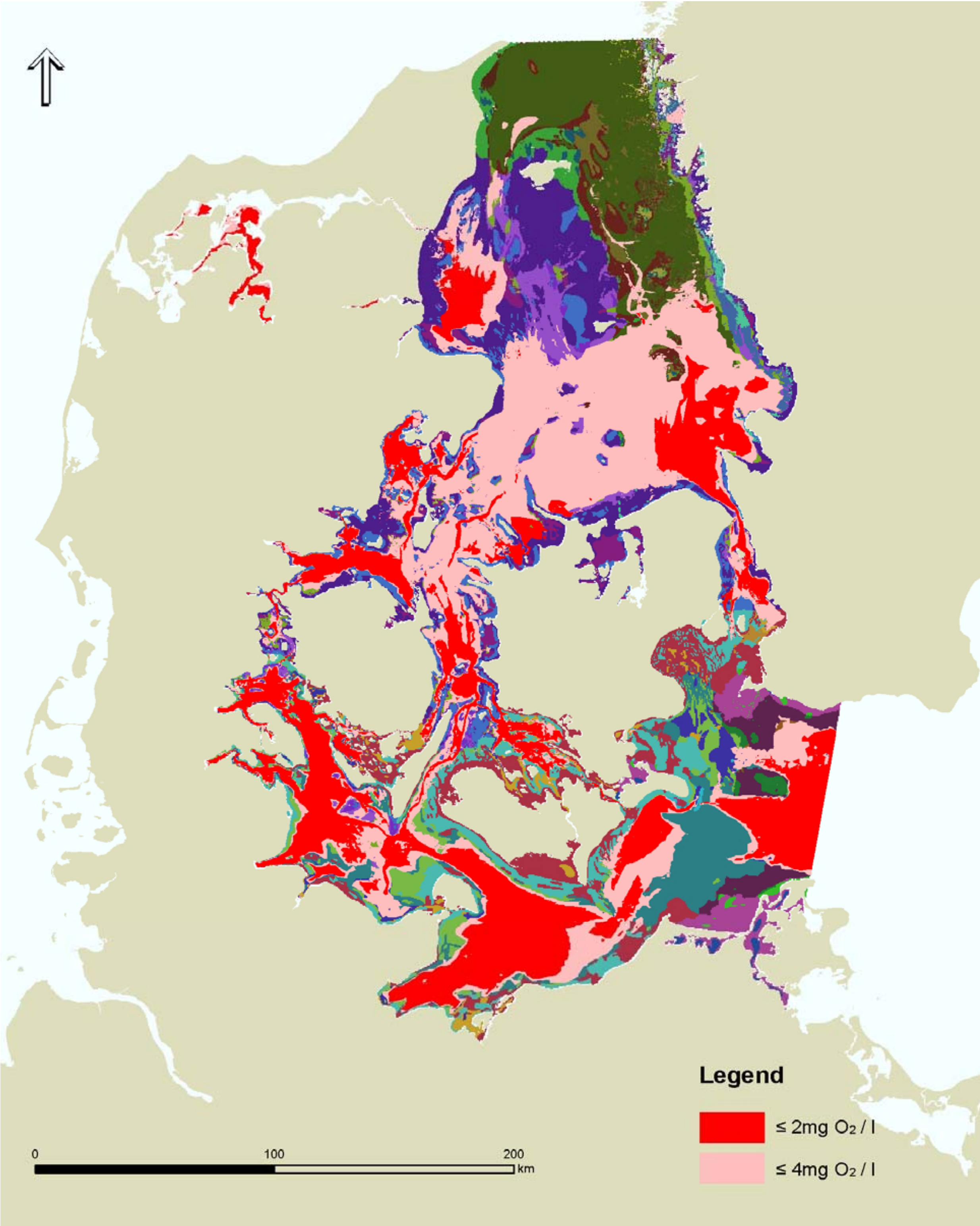

Fig. 34. *Benthic marine landscapes influenced by oxygen depletion over a 10-year period in the Kattegat and the western Baltic Sea. Area shows the oxygen content of <2mg O_2/l and 2-4 mg O_2/l. Data source: NERI/Denmark.*

Tab. 12: Proportion of marine landscapes influenced by oxygen depletion in the Kattegat and the western Baltic Sea. The red box indicates a group of marine landscapes severely influenced by oxygen depletion. Please refer to fig. 34 for the specific geographic area covered in this table[13].

Marine landscape	Total area cov-eredkm^2	Area (km^2) with <2mgO$_2$/l	% with <2 mg O$_2$/l	Area (km^2) with 2-4 mg O$_2$/l	% with 2-4 mgO$_2$/l	Area influ-enced	% of total area covered
Photic bedrock 7.5-11psu	1.12	0.00	0.00	0.00	0.00	0.00	0.00
Photic bedrock 11-18psu	46.08	0.00	0.00	0.00	0.00	0.00	0.00
Photic bedrock 18-30psu	55.52	0.32	0.58	1.92	3.46	2.24	4.03
Photic bedrock >30psu	14.24	0.00	0.00	0.00	0.00	0.00	0.00
Non-photic bedrock 18-30psu	34.40	3.36	9.77	6.08	17.67	9.44	27.44
Non-photic bedrock >30psu	38.88	0.00	0.00	0.00	0.00	0.00	0.00
Photic hard bottom comp. 7.5-11psu	85.44	0.00	0.00	0.00	0.00	0.00	0.00
Photic hard bottom comp. 11-18psu	2219.20	37.92	1.71	80.00	3.60	117.92	5.31
Photic hard bottom comp. 18-30psu	2230.08	72.64	3.26	311.52	13.97	384.16	17.23
Photic hard bottom comp. >30psu	115.84	0.00	0.00	0.00	0.00	0.00	0.00
Non-photic hard bottom comp. 7.5-11psu	172.64	0.80	0.46	2.56	1.48	3.36	1.95
Non-photic hard bottom comp. 11-18psu	1756.16	302.88	17.25	431.68	24.58	734.56	41.83
Non-photic hard bottom comp. 18-30psu	1667.68	345.12	20.69	1006.40	60.35	1351.52	81.04
Non-photic hard bottom comp. >30psu	613.60	0.80	0.13	168.32	27.43	169.12	27.56
Photic sand 7.5-11psu	976.96	0.00	0.00	0.00	0.00	0.00	0.00
Photic sand 11-18psu	2976.80	7.04	0.24	42.40	1.42	49.44	1.66
Photic sand 18-30psu	5454.08	267.84	4.91	636.32	11.67	904.16	16.58
Photic sand >30psu	604.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-photic sand 7.5-11psu	1016.16	93.92	9.24	100.00	9.84	193.92	19.08
Non-photic sand 11-18psu	3948.32	722.24	18.29	1090.72	27.62	1812.96	45.92
Non-photic sand 18-30psu	3627.52	409.76	11.30	2054.88	56.65	2464.64	67.94
Non-photic sand >30psu	1630.88	71.84	4.40	756.48	46.38	828.32	50.79
Photic hard clay 11-18psu	14.08	3.36	23.86	1.44	10.23	4.80	34.09
Photic hard clay 18-30psu	176.64	0.00	0.00	5.92	3.35	5.92	3.35
Photic hard clay >30psu	46.88	0.00	0.00	0.00	0.00	0.00	0.00
Non-photic hard clay 7.5-11psu	18.40	10.88	59.13	4.96	26.96	15.84	86.09
Non-photic hard clay 11-18psu	472.96	398.88	84.34	40.16	8.49	439.04	92.83
Non-photic hard clay 18-30psu	360.16	2.56	0.71	78.40	21.77	80.96	22.48
Non-photic hard clay >30psu	373.28	4.48	1.20	45.60	12.22	50.08	13.42
Photic mud 7.5-11psu	96.32	0.00	0.00	0.00	0.00	0.00	0.00
Photic mud 11-18psu	714.88	136.80	19.14	94.08	13.16	230.88	32.30
Photic mud 18-30psu	1552.64	251.68	16.21	323.52	20.84	575.20	37.05
Photic mud >30psu	68.32	0.16	0.23	0.64	0.94	0.80	1.17
Non-photic mud 7.5-11psu	244.16	75.20	30.80	155.20	63.56	230.40	94.36
Non-photic mud 11-18psu	5107.52	3960.80	77.55	691.04	13.53	4651.84	91.08
Non-photic mud 18-30psu	5368.32	2413.76	44.96	2371.68	44.18	4785.44	89.14
Non-photic mud >30psu	6629.28	772.16	11.65	1899.52	28.65	2671.68	40.30
Sum	**50529.44**	**10367.20**	**20.52**	**12401.44**	**24.54**	**22768.64**	**45.06**

13 A species might occur in several benthic marine landscapes due to the complexity of the seabed and is thus not necessarly under threat just because a single landscape is under severe threat from oxygen depletion. Similar, no temporal considaration e.g. how fast is a landscape recolonise after an oxygen depletion event, has been done in this example. Such considerations should of course be included in a management scheme.

9.3.3 *Application example III – protecting the marine environment*

A broad-scale classification of the marine environment such as the benthic marine landscapes provides an overview of the distribution and total area of these ecologically relevant entities within ecoregion. This information is valuable when assessing current management and protection schemes for the marine environment in order to identify the strengths and weaknesses of existing networks of marine protected areas. The following example will illustrate this for the part of the Danish EZZ present within the Helsinki Convention area by comparing the coverage of the network of marine protected areas designated under the EC Habitats Directive with the map of the benthic marine landscapes. The geographic area considered is shown in fig. 35 and the area of individual landscapes within and outside the Danish Natura 2000 network is shown in tab. 13.

Before making the comparison it is important to be aware of some of the conditions for making such an assessment:

- There is no direct link between the classification of Natura 2000 habitats for which the Natura 2000 network is designated and the classification of benthic marine landscapes;
- areas protected under the EU Birds Directive, which are part of the of the Danish Natura 2000 network, are not included. The seabed in these areas is generally not protected under existing management practices unless the seabed integrity is essential for the birds for which a site is designated;
- only habitats for which a site is designated is protected within a Natura 2000 site. If a habitat is not mentioned in the Annex 1 of the EC Habitats Directive it is not protected even if it is present within a designated site;
- in Denmark the Natura 2000 network also includes Baltic Sea Protected Areas, and there is no parallel network of marine protected areas;
- the assessment is only based upon the distribution of the benthic marine landscapes and do not take any other considerations into account, e.g. more detailed local information, for which a site might be designated, and lastly,
- such an assessment would be even stronger if based on habitat maps based on high-resolution information.

A total of 11.92% or 5.279km^2 of the Danish EEZ within the Helsinki Convention area is designated under the EC Habitats Directive as marine protected areas. Of the 35 benthic marine landscapes only five are not present at all within the network of protected areas, while the remaining 30 is represented from up to 100% to less than 1% within the Natura 2000 network. Of these, 10 occur inside a designated site with more than 20% of their total area. In general, benthic marine landscapes within the photic zone have a higher representation than benthic marine landscapes in the non-photic zone, and sand within the photic zone appears to be the best represented sediment class.

Tab. 13 shows that marine landscapes, which to some extent are similar to or can be related to the habitats mentioned in Annex 1 of the EC Habitats Directive, are well represented within the Danish part of the marine Natura 2000 network. This is especially true for e.g. sand in the photic zone or the hard bottom complexes in which some of the reefs can be found. However, it is important to be aware that hard bottom complex include other substrates than boulders and the area can therefore not be directly related to the total estimated reef area in the Danish waters.

While there is no doubt that the Danish part of the Natura 2000 network is adequate for implementing the EC Habitats Directive for the Danish part of the Helsinki Convention area the EC Habitats Directive appears less than adequate for protecting a representative part of the marine environment. For example, though mud in the non-photic zone covers a total of 12.331km^2 of the 44.287km^2 in the Danish part of the Helsinki Convention area only 322km^2 or 2.1% of the non-photic "muddy" landscapes are within a protected area. The explanation is that there is no habitat identified in the EC Habitats Directive Annex 1 for the large offshore areas containing the majority of non-photic mud habitats. Similarly, for sand in the non-photic zone, which covers a total 7.927km^2 only 294km^2 or 3.7% is within a protected area. The explanation is partly the limitation in the definition of sandbanks that state that it only includes sandbanks slightly covered by water (down to 20 m) and partly that not all parts of a sandy seabed form sandbanks, and hence is not protected under the EC Habitats Directive.

If this information is compared to the oxygen content information (tab. 12) it is apparent that the benthic marine landscapes most likely to be influenced by oxygen depletion are also those without any formal protection. As mentioned previously, it was estimated that during the oxygen depletion in 2002 that 371.000 tons of marine invertebrates died in the Kattegat and the Danish Straits, while a 50% reduction in species richness has occurred in the infauna communities (Hansen et al. 2003). The argument that a national network of protected areas ought to protect the small part of a highly vulnerable ecological entity not adversely affected by e.g. oxygen depletion from any other negative impacts appears strong. Such protection might help the marine ecosystem to maintain resilience towards broad-scale ecological catastrophes such as extensive oxygen depletion by securing a sanctuary for healthy donor populations /communities of e.g. marine invertebrates. It could therefore be argued that the existing management practices and protection schemes solely based on implementation of the Natura 2000 Directives do not provide a sufficient tool for halting the loss of marine biodiversity by 2010.

However, if the aim of a network of marine protected areas is to help halting the loss of marine biodiversity by 2010 then several options exists based upon the information provided by broad-scale ecologically relevant maps. A first step could be to expand the current management scheme to include all habitats present within a Nature 2000 site besides the EC Habitats Directive Annex 1 habitats for which a site is designated. This could be further expanded to include seabed habitats within international bird areas after which an assessment could identify any gaps left within the network of marine protected areas. The network of marine protected areas could then be adjusted accordingly as part of the implementation process of the proposed EU Marine Strategy Directive. The benthic marine landscape map could thus be used to inform environmental management of where adjustments to existing network of marine protected areas could occur. As shown with the oxygen depletion map it is important that other environmental parameters and anthropogenic activities and impacts are taken into account when designating new areas or adjusting existing boundaries.

This example should not be seen as a criticism in the implementation of the marine Natura 2000 network, except to point out the limitations of the number of marine habitats included in the Annex 1 of the EC Habitats Directive. It should rather provide food for thought for a revision of the overall approach applied to protection of the marine environment in European waters. The proposed EU Marine Strategy Directive might provide a first opportunity for improving the existing approach to the protection and human exploitation of the marine environment unless a throughout revision is made of the EC Habitats Directive.

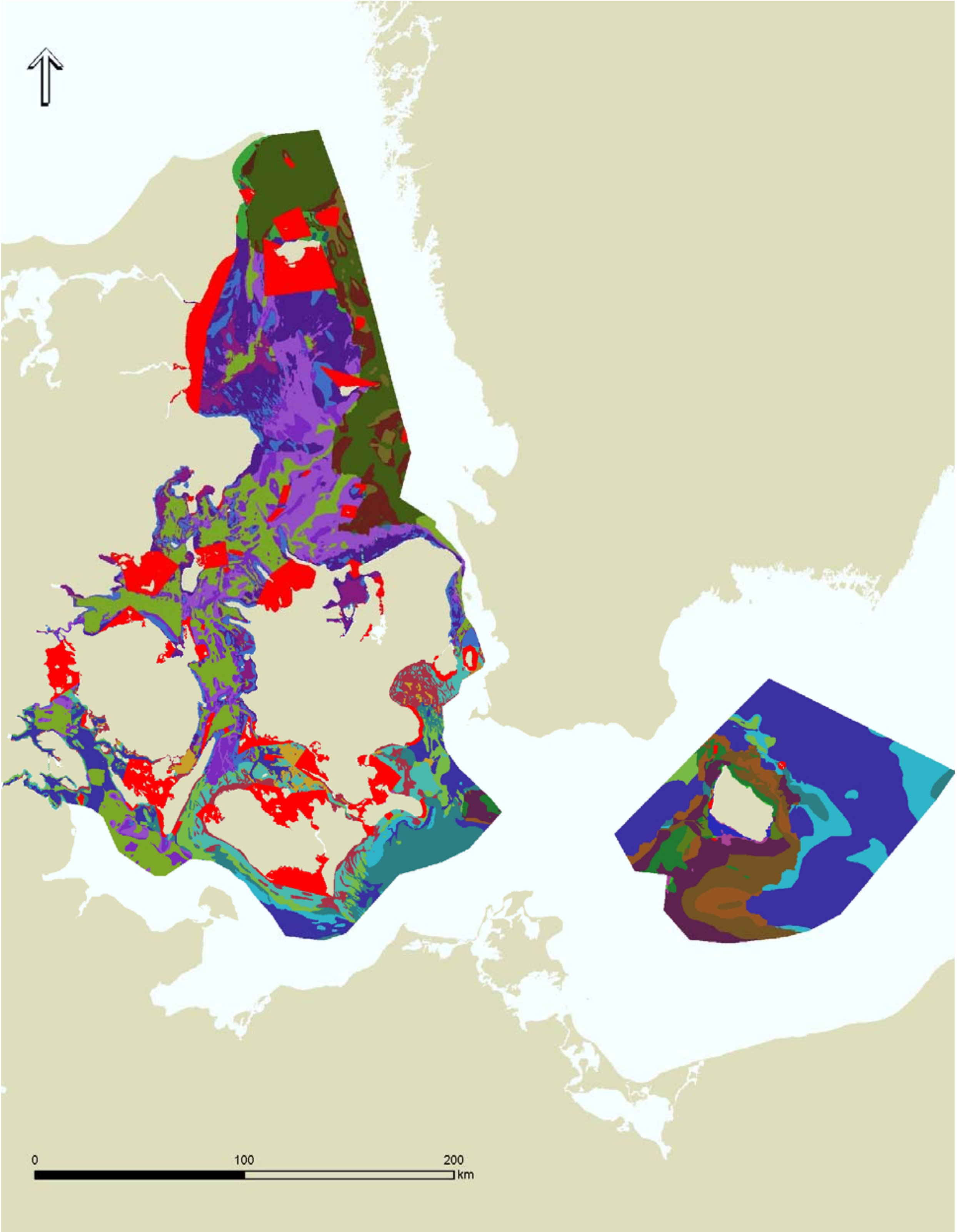

***Fig. 35**. Natura 2000 sites (red colour) designated under the EC Habitats Directive within the Danish EZZ in the Helsinki Convention area. Data source: SNS/Denmark.*

Tab. 13: Area of marine landscapes present within of the Danish EEZ present within the Helsinki Convention area and marine landscape proportion within a Natura 2000 site as designated under the Habitats Directive. The red box indicates an example of a group of marine landscapes currently overlooked in the existing protection schemes. Please refer to fig. 35 for a graphic presentation.

Marine landscape	Colour code	GIS code	Area (km^2) of the marine landscapes in the Danish EEZ in the HELCOM Region	Area (km^2) within a Natura 2000 site (Habitats Directive)	% within a Natura 2000 site
Photic bedrock 7.5-11psu		113	105.52	4.80	4.55
Photic bedrock 11-18psu		114	21.92	4.36	19.89
Non-photic bedrock 7.5-11psu		123	131.52	2.68	2.04
Non-photic bedrock 11-18psu		124	2.28	0	0.00
Photic hard bottom comp. 7.5-11psu		213	26.72	4.64	17.37
Photic hard bottom comp. 11-18psu		214	1712.48	342.92	20.02
Photic hard bottom comp. 18-30psu		215	2157.04	511.36	23.71
Photic hard bottom comp. >30psu		216	101.44	58.56	57.73
Non-photic hard bottom comp. 7.5-11psu		223	515.96	9.12	1.77
Non-photic hard bottom comp. 11-18psu		224	1159.60	28.76	2.48
Non-photic hard bottom comp. 18-30psu		225	1645.44	78.48	4.77
Non-photic hard bottom comp. >30psu		226	453.12	75.04	16.56
Photic sand 7.5-11psu		313	144.16	73.08	50.69
Photic sand 11-18psu		314	2158.12	1015.40	47.05
Photic sand 18-30psu		315	5046.20	1710.40	33.89
Photic sand >30psu		316	584.52	256.04	43.80
Non-photic sand 7.5-11psu		323	1396.36	1.72	0.12
Non-photic sand 11-18psu		324	1972.52	46.32	2.35
Non-photic sand 18-30psu		325	3321.76	165.44	4.98
Non-photic sand >30psu		326	1236.56	80.52	6.51
Photic hard clay 11-18psu		414	13.12	0	0.00
Photic hard clay 18-30psu		415	7.80	0	0.00
Photic hard clay >30psu		416	2.52	2.36	93.65
Non-photic hard clay 7.5-11psu		423	1366.88	0	0.00
Non-photic hard clay 11-18psu		424	1664.44	5.28	0.32
Non-photic hard clay 18-30psu		425	17.60	0	0.00
Non-photic hard clay >30psu		426	44.92	5.32	11.84
Photic mud 7.5-11psu		513	11.08	11.08	100.00
Photic mud 11-18psu		514	543.52	193.56	35.61
Photic mud 18-30psu		515	1347.28	265.00	19.67
Photic mud >30psu		516	59.36	4.92	8.29
Non-photic mud 7.5-11psu		523	788.00	0	0.00
Non-photic mud 11-18psu		524	7215.56	56.84	0.79
Non-photic mud 18-30psu		525	4328.16	245.84	5.68
Non-photic mud >30psu		526	2983.72	19.28	0.65
Sum		**#35**	**44287.2**	**5279.12**	**11.92**

9.3.4 Application example IV – marine aggregates and offshore wind-farms

The fourth example is illustrating how benthic marine landscapes can be applied in regard to important offshore anthropogenic activities. The example include both marine aggregate extraction[14] and offshore wind-farms[15] in order to illustrate that anthropogenic activities should not be handled as stand-alone activities, but as part of a wide range of anthropogenic activities and environmental pressures occurring in the marine environment.

The example includes data on marine aggregate extraction sites and existing and potential offshore wind-farms from the Danish EEZ delineated by the Helsinki Convention area to the north and by the available oxygen to the east (section 7.4). No data on marine aggregates extraction sites nor on offshore wind farms were included from the German or Swedish EEZ though this will not influence the illustrative value of the example. If sufficient data were available broad-scale integrated spatial planning and management could be done for an entire ecoregion.

The area of the individual landscapes influenced by these anthropogenic activities is presented in fig. 36 and tab. 14. For many of the marine landscapes only a small proportion, if any, is influenced by these offshore anthropogenic activities. More specifically, only a few of the marine landscapes are targeted by these activities, such as e.g. Non-photic sand at 7,5-11psu. Thus, individual anthropogenic activities do not, in a marine landscape context, appear to put the marine environment under a significant threat, except for the local adverse disturbance or, in the case of marine aggregates, the damage caused by the exploitation of the natural resource.

However, if an ecosystem-based approach to the management of the marine environment in Kattegat is desirable, then individual anthropogenic, or sectoral activities, should be compared not only with the ecologically relevant marine landscape or habitat maps, but also with environmental pressures, such as eutrophication or the effects hereof e.g. oxygen depletion (which influence 45% of the total area in the example). In the example it becomes apparent (visually) that the marine aggregate and the offshore wind-farming are focussed (with 68%, tab. 14) on the more shallow areas with little or no oxygen depletion, thus increasing the pressure and impact on specific elements of the marine ecosystem that are already under pressure.

Each individual anthropogenic activity is of little spatial extent if compared to the entire Danish marine area. However, if these anthropogenic activities are added with an environmental pressure such as the oxygen depletion, it becomes apparent that it is the sum of activities and pressures that should be considered when making environmental assessments, not the impact of each sector separately. This would be even more apparent if more anthropogenic activities were added such as e.g. fisheries for Norwegian lobster (*Nephros norvegicus*), fish or mussel farms, cables, shipping, dumping of dredge material etc. For example, the non-photic sand at 7,5-11psu covers a total of 145,24km^2 of which 50,27 km^2 is proposed as an offshore wind-farm while 35,98 km^2 is influenced by oxygen

[14] The information was provided by the Danish Forest and Nature Agency.

[15] The area included for the potential offshore wind-farms have been set to 44 km^2 after contact with the Danish Energy Authority. The specific area for each potential wind-farm has not defined nor has it at this point in time been decided if these wind-farms will be established at all. The area of the existing offshore wind-farms was based on delineating the area around the individual windmills on the web GIS at the Danish Energy Authority at www.ens.dk.

depletion. Thus a total of 76 km^2 or more than 50% of a specific marine landscape is under pressure[16].

It could be argued that the economic expenses of extracting marine aggregates or establishing offshore wind-farms increase with depth, and that some sectors are unjustly required to pay for a problem concerning the society as a whole. Such considerations could be handled as part of a socio-economic analysis defining the economic costs of each human activity compared to the impact on the marine environment, thus taking multiple anthropogenic activities and environmental pressures into account. Similar the environmental benefits should also be included in such an analysis. For example, what would the consequences for the marine ecosystem, the long-term sustainable development and the general economy if too large a proportion of a specific marine landscape is exploited or is under severe environmental pressure? Would the loss of a too large proportion of a marine landscape or habitat influence important fisheries and thus local communities/economy adversely due to loss of e.g. juvenile habitat or forage area?

Likewise, it could also be argued that e.g. the establishment of an offshore wind-farm does not necessarily impact adversely on the marine environment. For example, the structural foundations could be shaped to provide cave-forming hard substrata and thus provide a habitat for cave depending species in a sea area, such as the Kattegat, where these habitats previously has been targeted by marine aggregate extraction for harbour jetties and coastal defence. These areas or habitats might also function as a sanctuary for some species if access is limited to the management of the wind-farm. In general, such cross-sectoral synergies should be an important element of marine spatial planning, as it will help to enhance sectoral understanding and minimise potential stakeholder conflicts.

Similarly, old extraction sites could, besides being restored, be utilised for other purposes such as the establishment of e.g. a mussel or fish farm in the area (depending on the specific environmental requirements of such farms) or for storing of dredge materials. If these activities were undertaken with long-term spatial planning in mind, it would probably result in less anthropogenic pressure upon the marine environment. Only a true integrated, cross-sectoral approach to offshore management can answer such questions.

Basically, if a sustainable development of the marine environment is desired, then all anthropogenic activities need to be handled as part of a holistic, integrated offshore spatial planning taking natural values and environmental pressures into account. The impact of one or two anthropogenic activities might not adversely influence the ecosystem, and it is the sum of all occurring anthropogenic activities and environmental pressures, that push ecological thresholds to the point of a continued, irreversible degradation of the marine ecosystem.

In conclusion, while the examples on application of ecological maps outlined above are fairly simple and without all the considerations necessary for proper spatial planning and management of the marine environment, they still remain illustrative of an important point - integrated offshore planning based on ecologically relevant information, environmental pressures and anthropogenic activities is a major challenge the EU Member States must face if an ecosystem-based and long-term sustainable approach to the management of our marine natural resources is desired.

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[16] The sum is less than the two figures added, because ~11km^2 of the wind-farm area is oxygen depleted.

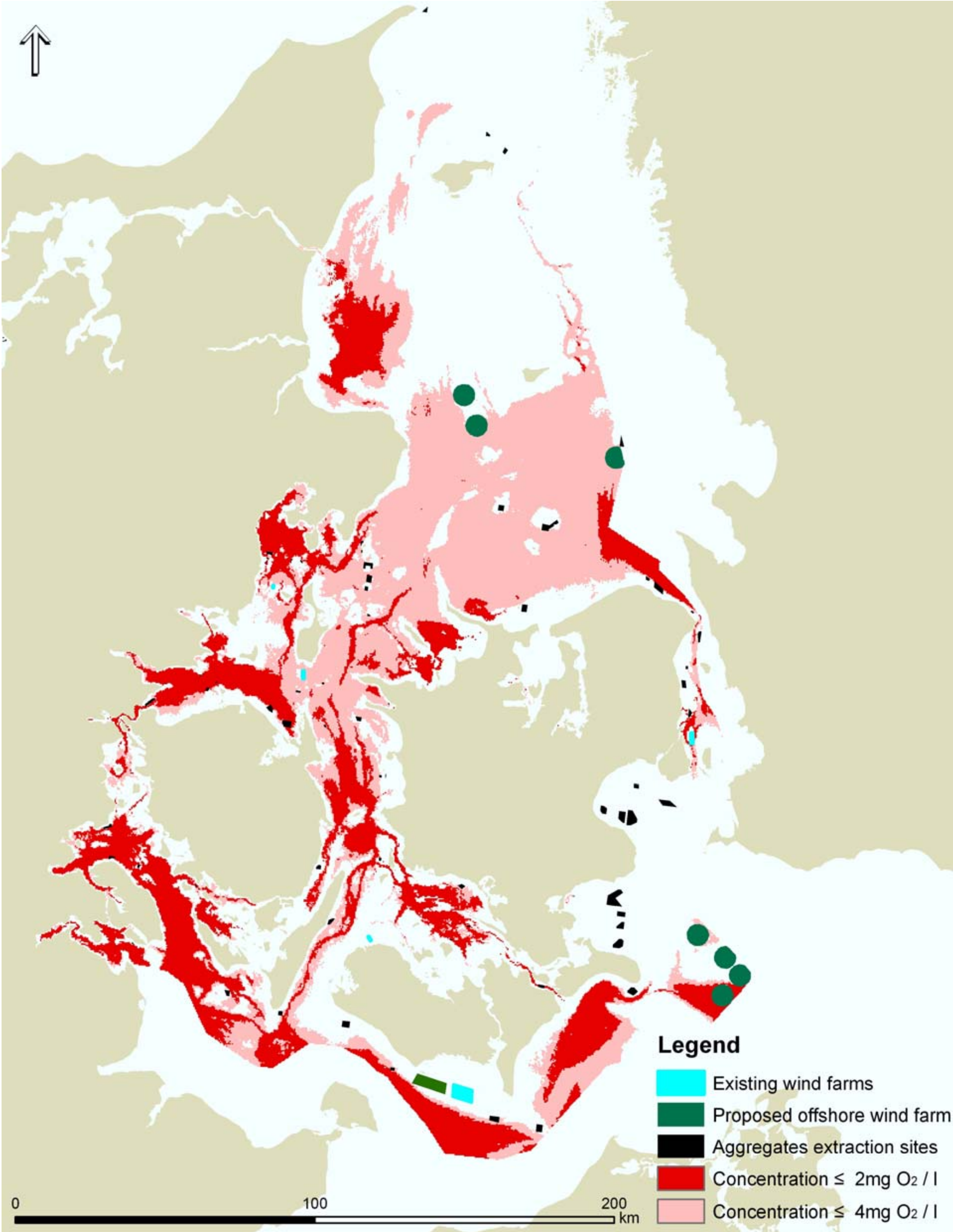

Fig. 36. *Offshore wind-farms and marine aggregate site with the Danish EZZ within the Helsinki Convention area. Data source: The Danish Forest and Nature Agency and the Danish Energy Authority.*

Tab. 14: Area of marine landscapes present within of the Danish EEZ and within the Helsinki Convention area showing marine landscape proportion within an existing / potential offshore wind-farm and/or a marine aggregates site. Please refer to fig. 36 for a graphic presentation and for a delineation of the area.

Marine landscape	Area (km^2) of the marine landscapes	Area (km^2) within a proposed / existing offshore wind-farms	Area (km^2) within a marine aggregate site	Area (km^2) of the marine landscapes influenced by oxygen depletion	% of wind-farm / marine aggregate sites within an area not influenced by oxygen depletion
Photic hard bottom comp. 11-18psu	1711,6	45,30	16,26	101,38	99,22
Photic hard bottom comp. 18-30psu	2156,6	2,64	14,98	371,86	88,60
Photic hard bottom comp. >30psu	101,44	0,00	2,07	0,11	100
Non-photic hard bottom comp. 7.5-11psu	61	38,84	0	0,99	98,64
Non-photic hard bottom comp. 11-18psu	962,36	1,83	3,64	416,93	92,87
Non-photic hard bottom comp. 18-30psu	1645,32	26,81	7,61	1345,19	27,76
Non-photic hard bottom comp. >30psu	453,12	1,02	0,16	158,91	8,59
Photic sand 7.5-11psu	75,64	0,00	0	0	100
Photic sand 11-18psu	2156,64	20,63	59,84	20,43	99,04
Photic sand 18-30psu	5045,2	0,16	31,01	849,36	95,70
Photic sand >30psu	584,48	0,00	1,55	0,16	100,00
Non-photic sand 7.5-11psu	145,24	50,27	0	35,98	79,51
Non-photic sand 11-18psu	1721,68	12,91	21,04	826,18	45,98
Non-photic sand 18-30psu	3321,72	61,38	11,34	2267,03	64,96
Non-photic sand >30psu	1236,56	5,21	0,42	658,36	13,86
Photic hard clay 11-18psu	13,12	0,00	1,22	4,85	100
Photic hard clay 18-30psu	7,8	0,00	0	0,04	100
Photic hard clay >30psu	2,52	0,00	0	0	100
Non-photic hard clay 7.5-11psu	2,56	0,00	0	0,04	100
Non-photic hard clay 11-18psu	366,92	1,60	0	333,4	81,22
Non-photic hard clay 18-30psu	17,6	0,00	0	17,52	100
Non-photic hard clay >30psu	44,92	0,00	0	30,54	100
Photic mud 7.5-11psu	11,04	0,00	0	0	100
Photic mud 11-18psu	542,96	0,04	2,06	202,3	43,82
Photic mud 18-30psu	1347,28	0,16	5,73	546,39	66,57
Photic mud >30psu	59,36	0,00	0	0	100
Non-photic mud 7.5-11psu	16,56	8,45	0	16,32	0
Non-photic mud 11-18psu	1654,64	58,10	0,35	1302,8	35,34
Non-photic mud 18-30psu	4328,16	0,00	6,64	4099,88	9,19
Non-photic mud >30psu	2983,72	30,98	0,53	1156,79	2,91
Sum	**32.777,76**	**366,33**	**186,45**	**14763,74**	**68,02**

9.3.5 Application example V – pelagic marine landscapes

Besides the development of benthic marine landscapes BALANCE have also considered how ecologically relevant pelagic marine landscapes of the Baltic Sea could be modelled using a similar, though different, approach from the mapping of the benthic marine landscapes. An important difference is that pelagic landscapes have greater temporal variation than the more stable benthic marine landscapes – a factor that end users should be aware of when mapping pelagic marine landscape and applying the resultant maps.

The central assumption of the pelagic marine landscapes is that hydrographical information (for which there is generally better broad-scale coverage than biological information) can be used *in lieu* of biological information to classify pelagic marine habitats and to set marine nature conservation priorities. Justifications for this assumption are the very strong ecological/physiological relationships, which exist between hydrographic parameters and the physiological performance of species determining their preferred or essential habitats. The example presented here is called the cod reproductive volume and is based upon this relationship.

The Bornholm Basin east of the island of Bornholm in the western Baltic Sea is the most important spawning area of the Baltic cod (fig. 37). The ecological/physiological relationship in this area is well investigated. The cod eggs required a minimum of 2 ml O_2/l in order to survive, and a salinity of more than 11psu in order to float. Such conditions are present in the Bornholm Deep in a water layer based between approximately 55-65 m of depth. Above this depth is a water body consisting of water with lower salinity content, while the oxygen content below can be lower than 2 ml O_2/l. In contrast to the benthic marine landscapes the temporal variation of pelagic marine landscapes is very distinct over a fairly short time-scale e.g. the cod reproductive volume illustrated at the 1st of April over three consecutive years (fig. 37).

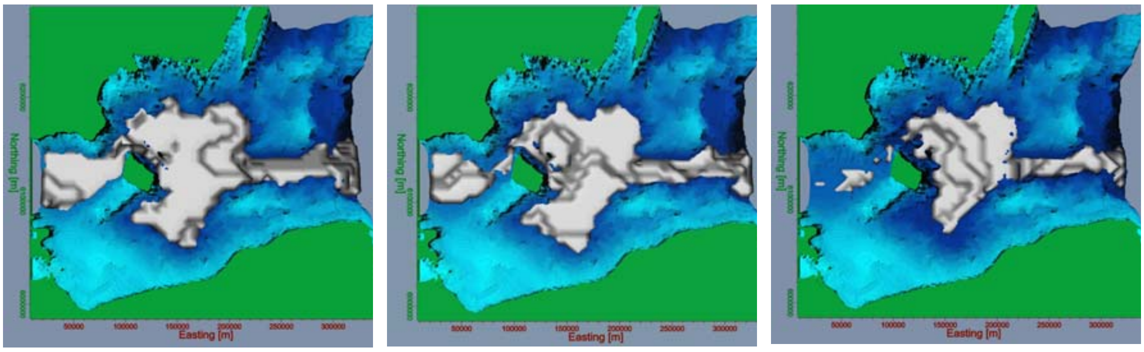

Fig. 37. *3D-model of the cod reproductive volume from the same date of three consecutive years a) ¼ 2003, b) 1/4 2004 and c) 1/4 2005. Please notice the distinctive temporal variation. Source DIFRES.*

This sort of modelling of the marine environment is obviously valuable for an informed management of fisheries. E.g. the size of the cohorts of juveniles can be directly related to the size of the available suitable water volume in which eggs can survive, which thus influences the available fish stock in the coming years. As the volume of specific marine landscapes shows extensive temporal variation (fig. 37), environmental or fisheries management should take the natural variation into account.

However, information such as the "cod reproductive volume" could also be utilized for implementing EU legislation such as the EU Water Framework Directive and the up-coming EU Marine Strategy Directive. These both require an overall characterisation of the marine environment as well as an ecosystem-based approach to the management of the marine environment. If the pelagic landscape maps were expanded to cover entire basins or even entire ecoregions it would enable a uniform approach to the implementation of the EU Directives with a strong link to fisheries management. It would also enable a stronger link between various sectoral monitoring initiatives e.g. fisheries and environmental monitoring, and thus hopefully increase stakeholder understanding. An example could be to link the distributional patterns of fronts and fish movements with the wide-ranging species mentioned in the EC Habitats Directive. Besides increasing cross-sectoral co-operation and understanding, it would also provide a cost-effective solution to marine monitoring. Similarly, characterising the pelagic environment on the basis of the ecological requirements of key species would enable e.g. environmental status assessments taking fisheries, environmental data and management requirements into account.

Pelagic marine landscape maps can also be used in regard to monitoring of climatic change and its consequences for the marine environment. For example, if the primary production in the water column increases due to an increase in water temperature (and continued nutrient enrichment), then it will lower the oxygen content in the lower part of the water column. This would put pressure on e.g. the "cod reproductive volume" from the bottom and decrease the overall suitable volume available for cod eggs. Similarly, if the precipitation increases in the Baltic region the run-off of freshwater to the Baltic Sea will increase making it even harder for saline, oxygen rich water to move over the thresholds in the western Baltic Sea into the Arkona Deep and Bornholm Deep. This will put pressure upon the "cod reproductive volume" from the top of the water column. Together these two climate-related pressures will assumedly decrease the total available water volume in which cod eggs can survive and thus influence the long-term survival of the Baltic cod.

A pelagic marine landscape map showing the temporal variation of different water masses defined by ecological requirements of key species would provide a strong tool for monitoring, understanding and adapting management responses to the natural temporal variation of the marine environment.

Any mapping exercises of pelagic marine landscapes would thus benefit from the use of a continuously running model reflecting the natural variation and dynamic processes of the marine environment rather than an instantaneous 2D representation. For the Baltic Sea area hydrodynamic models are being run and these could be further developed taking ecological considerations into account when describing the physical environment. This would enable an ecosystem-based approach to the management of the Baltic Sea, but require enhanced data sharing, further technical development as well as an international coordinating and responsible body. Hopefully, such efforts will be made possible as part of implementing the proposed EU Marine Strategy Direcitive.

The approach described should be futher expanded to cover the water column for the entire Helsinki Convention area. The example summarized above is described in detail in a separate BALANCE report, which also describes models of adult cod habitats as well as sprat habitats. The report will be available late 2007 at www.balance-eu.org.

10 CONCLUSION & RECOMMENDATIONS

In conclusion, marine landscape maps covering entire ecoregions are potentially a strong tool providing a basis for a broad-scale spatial approach to the planning and management of the marine environment. The approach presented here is a fully applicable and usable ecologically relevant characterisation of the Baltic Sea. However, end users might find it necessary to continue the refinement and improvement of the maps. Such 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. The future success of producing marine landscape maps with a higher accuracy and precision depends on access and availability of existing data as well as a transnational and cross-sectoral approach 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.

The following recommendations are directed at policymakers, scientists and environmental managers for the future refinement and application of ecologically relevant marine landscape maps. The long-term goal of using these maps is to support a sustainable development in the Baltic Sea Region through an informed transnational approach to the management of the marine ecosystem. The recommendations could be carried out as part of implementing the proposed Marine Strategy Directive, by a potential BALANCE II and/or by the individual EU Member State or the HELCOM Contracting Parties.

10.1 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 organisa-

tion 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.

10.2 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.

10.3 International co-operation

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. When it comes to implementing an ecosystem-based approach to the management of the Baltic Sea, the Baltic States should pursue coherence, transparency, efficiency and transnational cooperation. This could be achieved through launching strategic projects or development of long-term planning strategies ideally spanning a 6-year reporting cycle matching key EU requirements.

19. 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.

20. Multiple human activities (socio-economic information) should be combined with broad-scale ecological relevant maps and environmental pressures in order to provide an informed base for an ecosystem-based approach to marine spatial planning and management rather than the traditional "*one sector – one spatial approach*".

10.4 Application

21. The marine landscape approach includes i) identification of the topographic features conceptualising the topographic layout of the seabed, ii) identification of the coastal physiographic features characterising the transition zone from land to sea,

and lastly iii) the seabed features identified by their physio-chemical characteristics. Together, the three types provide a broad-scale spatial overview of the complexity and diversity of the marine environment and provide valuable information for implementing an ecosystem-based approach to management. Any utilisation of a single map will only provide "part of the picture" and therefore, caution should be exercised if any of the approaches is applied alone.

22. The marine landscape approach should be adapted as a key tool for broad-scale characterisation of the marine environment to be utilised in an ecosystem-based approach to marine spatial planning, management and marine nature conservation. Where relevant it should complement obligations under the EC Habitats Directive, EU Water Framework Directive and the proposed EU Marine Strategy Directive.

23. Synergies between EU Directives/initiatives require spatial information of the marine environment to be identified and fed directly into the future refinements of the marine landscape maps. Similarly, convergence should be promoted in the utilisation of the maps. This could include needs in regard to data, characterisation, sensitivity, impact and status assessments etc.

24. The marine landscape maps could be applied in bridging the gap from national, subregional to ecosystem-wide environmental targets and provides a basis for environmental assessments covering the Baltic Sea.

25. Ecologically relevant maps combined with georeferenced information on environmental pressures and anthropogenic activities should be included in an ecosystem-based approach to integrated offshore management.

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12 REFERENCES

Aarup, T. (2002): Transparency of the North Sea and Baltic Sea – a Secchi Depth data mining study. *Oceanologia* 44(3):323-337.

Andersen, B.G. & H.W. Borns Jr. (1997): *The ice age world.* Scandinavian University Press. Oslo. 228 pp.

Andersen, J.H. & J.T. Pawlak (2006): *Nutrients and eutrophication in the Baltic Sea: Effects/causes/solutions*. Nordic Council and Baltic Sea Parliamentary Conference. 32 pp.

Anonymous (1992): Directive 92/43/EEC of 21 May 1992 on the Conservation of natural habitats and of wild fauna and flora.

Anonymous (1998): Environment of the Baltic Sea area 1994-1998. *Baltic Sea Environment Proceedings* 82B.

Anonymous (2000): Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a Framework for Community action in the field of water policy.

Anonymous (2006): Directive of the European Parliament and of the Council establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). PE-CONS 3685/2006.

Anonymous (2006): Proposal for a Directive of the European Parliament and of the Council establishing a Framework for Community Action in the field of Marine Environmental Policy (Marine Strategy Directive). Brussels, 11 December 2006.

Bendtsen, J., Söderkvist, J., Dahl, K., Hansen, J.L.S. & Reker, J. (2007): Model simulations of blue corridors in the Baltic Sea. *BALANCE Interim Report no.* 9. Available at http://www.balance-eu.org

Bergstrøm, S. & Carlsson (1994): River run-off to the Baltic Sea: 1950-1990. *Ambio* 23 (4-5):280-287.

Björck, S. (1995): A review of the history of the Baltic Sea, 13.0–8.0 ka BP. *Quatern. Int.* 27:19-40.

Breeman, A.M. (1988): Relative importance of temperature and other factors in determining geographic boundaries of seaweeds: experimental and phonological evidence. *Helgol. Meersunters.* 42:199-241.

Connor, D.W., J.H. Allen, N. Golding, L.M. Lieberknecht, K.O. Northern & J.B. Reker (2003): The National Marine Habitat Classification for Britain and Ireland, Version 03.02 Copyright JNCC, Peterborough ISBN 1 86107 546 4. Available at http://www.jncc.gov.uk/MarineHabitatClassification

Connor, D.W., N. Golding, P. Robinson, D. Todd & E. Verling (2007): *UKSeaMap: The mapping of marine seabed and water column features of UK seas*. Consultation report. Joint Nature Conservation Committee, Peterborough.

Dahl, K., J. Hansen, S. Helmig, R. Nielsen & H.S. Larsen (2001): Naturkvalitet på stenrev – Hvilke indikatorer kan vi bruge? Danmarks Miljøundersøgelser. 130 s. *Faglig rapport fra DMU nr. 52.*

Dahl, K., S. Lundsteen & S. Helmig (2003): Stenrev – havbundens oaser. Miljøbiblioteket 2. Gads Forlag. 104 p. Available at http://www.dmu.dk/1_viden/2_Publikationer/3_miljobib/rapporter/MB02.pdf

Dahl, K, J. Hansen & J. Leth (2007): The Kattegat - 18/7 – 18/8 and 21/11 – 23/11 2006. *BALANCE Interim Report No. 7*. Available at www.balance-eu.org/Publications

Day, J.C. & J.C. Roff (2000): Planning for Representative Marine Protected Areas: A framework for Canada´s Oceans. *Report prepared for World Wildlife Fund Canada, Toronto*.

Dayton, P.K. (1994): Community landscape: Scale and stability in hard bottom marine communities. In Aquatic Ecology: Scales, Patterns and Processes. Giller, P.S., A.G. Hildrew & D.G. Rafaelli (eds.), Blackwell Press.

Dinesen, G.E. (Ed.) (*in prep.*): Mapping and modelling of marine habitats in the Baltic Sea region. *BALANCE Interim Report No. 20*. Available in October 2007 at www.balance-eu.org.

Dring, M. (1994): *The biology of marine plants*. Cambridge University Press. 199 pp.

Edler, L. (1997): In: Report of the ICES/HELCOM Workshop on Quality Assurance of Pelagic Biological Measurements in the Baltic Sea. ICES CM 1997/E, 5.

Eriksson, B.K. & A. Sandström (2004): Effects of boating activities on aquatic vegetation in the Stockholm archipelago, Baltic Sea. *Estuarine, Coastal and Shelf Science* 61(2):339-349.

Erlandsson, C. & G. Lindeberg (2007): Harmonising marine geological data with EUNIS classification. *BALANCE Interim Report No.* 13.

Florin, A. (2005): Flatfishes in the Baltic Sea – a review of biology and fishery with a focus on Swedish conditions. Finfo 2005:14, 58 pp.

Gessner, F. (1970): *Temperature: plants.* In O. Kinne (ed). *Marine Ecology* (vol. 1, pt. 1, pp.363-406). New York: Wiley.

Gibson, R.N. (1994): Impact of habitat quality on the recruitment of juvenile flatfish. *Neth. J. Sea Research*. 32(2):191-206.

Gibson, R.,N. & L. Robb (1992): The relationship between body size, sediment and grain size and the burying ability of juvenile plaice, *Pleuronectes platessa L. Jour. Fish Biol.* 40:771-778.

Golding, N., M.A. Vincent & D.W. Connor (2004): Irish Sea Pilot – Report on the development of a Marine Landscape classification for the Irish Sea. *JNCC report No. 346.*

Hansen, J.L.S., A.B. Josefson & T.M. Pedersen (2004): Genindvandring af bundfauna efter iltsvindet 2002 i de indre danske farvande. Danmarks Miljøundersøgelser. - *Faglig rapport fra DMU* 506. 61 pp. Available at: http://www2.dmu.dk/1_Viden/2_Publikationer/3_Fagrapporter/rapporter/fr506.pdf

Hansen, J.L.S. (2005): Biodiversitet på sedimentbund i de indre danske farvande. In: Ærtebjerg et al. 2005: Marine Områder 2004 - Tilstand og udvikling i miljø og naturkvaliteten. *Faglig rapport fra DMU nr. 551.*

Hansen, I.S, N. Keul, J.T. Sørensen, A. Erichsen and J.H. Andersen (2007). Baltic Sea Oxygen Maps 2000-2006. BALANCE Interim Report no. 17. Available at www.balance-eu.org.

Hällfors, G., E. Leskinen & Å. Niemi (1983): Hydrography, chlorophyll and nutrients at Tvärminne Storfjärd, Gulf of Finland, in 1979/80. *Sci. Reps*. Walter and Andree de Nottbeck Foundation, Helsinki 4:1-19.

Hoek, C. van den (1984): World-wide lattudinal and longitudinal seaweed distribution patterns and their possible causes, as illustrated by the distribution of the Rhodophytan genera. *Helgol. Meersunters*. 38:227-257.

Hoek, C. van den, D.G. Mann & H.M. Jahns (1995): *Algae – An introduction to phycology*. Cambridge University Press. 623 pp.

Håkanson, L., I. Kulinski, & H. Kvarnäs (1984): Vattendynamik och bottendynamik i kustzonen. SNV PM 1905. Statens Naturvårdsverk, Solna.

IHO (2001): Standardization of Undersea Feature Names: Guidelines Proposal form Terminology. International Hydrographic Organization and International Oceanographic commission. Monaco. 40 pp.

ISO 19115 (2003): Geographic information—Metadata.

Isæus, M. (2004): Factors structuring *Fucus* communities at open and complex coastlines in the Baltic Sea. Dept. of Botany. Stockholm, Sweden, Stockholm University**.** 40 pp.

Isæus, M., I. Carlén, C. Wibjörn & S. Hallén (2007): Svenska högarna. Marinbiologisk kartläggning och naturvärdesbedömning. Stockholm Administrative County Board**:** 50.

Jansson, B.O. (1980): Natural systems of the Baltic Sea. *Ambio* 9:128-136.

Jensen, J.B., A. Kuipers & W. Lemke (2002): BALKAT, the Baltic Sea without frontiers. GEOLOGI - Nyt fra GEUS 4/2002 , 20 pp.

Johannesson, K., N. Kautsky & M. Tedengren (1990): Genotypic and phenotypic differences between Baltic and North Sea populations of Mytilus edulis evaluated through reciprocal transplantations. II. Genetic variation. *Mar. Ecol. Prog. Ser.* 59(3):211-219.

Josefson, A.B. & J. Hansen (2004): Species richness of benthic macrofauna in Danish estuaries and coastal areas. *Glo. Ecol. and Biogeo.* 13:273-288.

Kautsky, H. & E. van der Maarel (1990): Multivariate approaches to the variation in phytobenthic communities and environmental vectors in the Baltic Sea. *Mar. Ecol Prog. Ser*. 60:169-184.

Kotilainen, A., A. Reijonen, J. Leth, G. Lindeberg, A. Elhammer & D. Ryabchuk (2007): Draft guidelines for intercalibration of geological data. *BALANCE Interim Report. No*. 20.

Kratzer, S., B. Håkansson & C. Sahlin (2003): Assessing Secchi and Photic Zone Depth in the Baltic Sea from Satellite Data. *Ambio* 32(8):577-585.

Laffoley, D.d'A., J. Baxter, T. Bins, M. Bradley, D.W. Connor, M. Hill, M.L. Tasker & M.A. Vincent (2000): An implementation framework for conservation, protection and management of nationally important marine wildlife in the UK. Prepared by the statutory nature conservation agencies, EHS and JNCC for the DETR working group on the Review of Marine Nature Conservation. Peterborough, *English Science Report* 394.

Leigh Jr., E.G., R.T. Paine, J.F. Quinn & T.H. Suchanek (1987): Wave energy and intertidal productivity. *Proc. Natl. Acad. Sci*. USA 84:1314-18.

Leppäranta, M., E. Palosuo, H. Grönvall, S. Kalliosaari, A. Seinä & J. Peltola (1988): Itämeren jäätalven vaiheet / Isvinters faser i Östersjön / Phases of the ice season in the Baltic Sea. Finnish *Marine Research No*. 254, Supplement 2. (it covers years 1963/64 - 1979/1980).

Lewis, J.R. (1964): *The ecology of rocky shores*. The English Universities Press, London.

Littler, M., D.S. Littler, S.M. Blai & J.N. Norris (1985): Deepest known plant life discovered on an uncharted seamount. *Science* 227:57-9.

Lobban, C.S. & P.J. Harrison (1997): *Seaweed ecology and physiology*. Cambridge University Press. 366 pp.

Lüning, K. (1980): Control of algal life-history by day length and temperature. In: J.H. Price, D.E.G. Irvine & W.F. Farnham (Eds.): *The shore environments. Vol. 2: Ecosystems*. (pp. 915-45). New York: Academic Press.

Lüning, K. & M. Dring (1979): Continuous underwater light measurements near Helgoland (North Sea) and its significance for characteristic light limits in the sublittoral region. *Helgol. Meersunters.* 32:403-24.

Luyten, P.J., J.E. Jones, R. Proctor, A. Tabor, P. Tett & K. Wild-Allen (1999): COHERENS – A coupled hydrodynamical-ecological model for regional and shelf seas: user documentation. MUMM report. Management Unit of the Mathematical Models of the North Sea. Belgium. 911 pp.

Martin, G. & P. Nilsson (Eds.) (*in prep*.). A practical guide on application of the blue corridor concept on MPAs for biodiversity conservation in the Baltic Sea. *BALANCE Interim Report No. 17*. Available October 2007 at www.balance-eu.org.

Nielsen, R., Aa. Kristiansen, L. Mathiesen & H. Mathiesen (1995): Distributional index of the benthic macroalgae of the Baltic Sea area. *Acta Bot. Fenn.* 155:1-51.

Nybakken, J.W. (2001): Marine Biology – An Ecological Approach (5^{th} ed). Benjamin Cummings, San Francisco. 516 pp.

Ockelmann, K.W. & G. Dinensen (*submitted*): Marine invertebrates in the Baltic and North Sea – life histories, dispersal, food webs and habitat requirements.

Persson, J., L. Håkansson & M. Wallin (1994): Ett geografiskt informationssystem för kustvatten – planering baserat på sjökortsinformation. *TemaNord Raport* 1994:667.

Pickard, G.L. & W.J. Emery (1990): *Descriptive physical oceanography, an introduction.* 5th edition. Antony Rowe Ltd, Chippenham, UK.

Pihl, L., J. Modin & Wennhage (2005): Relating plaice (*Pleuronectes platessa*) recruitment to deteriorating habitat quality: effects of macroalgal blooms in coastal nursery grounds. *Can. J. Fish. Aquat. Sci*. 62(5):1184-1193.

Rasmussen, E.B. (1991): A finite difference scheme for three dimensional modelling of fluid dynamics. *Proceedings of IAHR*, Madrid, Spain, C339-348.

Raymont, J.E.G. (1967): *Plankton and Productivity in the Oceans*. Pergamon Press, Oxford.

Reijonen, A. & A. Kotilainen (2007): Intercalibration of sediment data from the Archipelago Sea. *BALANCE Interim Report No*. 14.

Remane, A. (1934): Die Brackwasserfauna. - *Verh. Dt. Zool. Ges*. 34-74.

Roberts, D., C. Davies, A. Mitchell, H. Moore, B. Picton, A. Portig, J. Preston, M. Service, D. Smyth, D. Strong & S. Vize (2004): Strangford Loch ecological change investigation.

Roff, J.C. & M.E. Taylor (2000): National frameworks for marine conservation – hierarchal geophysical approach. *Aquatic Con.: Mar. Freshw. Ecosys.* 10:209-223.

Roff, J.C., M.E. Taylor & J. Laughren (2003): Geophysical approach to classification, delineation and monitoring of marine habitats and their communities. *Aquatic Con.: Mar. Freshw. Ecosyst.* 13:77-90.

Russel, G. (1985): Recent evolutionary changes in the algae of the Baltic Sea. *Br. Phycol. J.* 20:87-104.

Russel, G. (1994): A Baltic variant of *Pilayella littoralis* (Algae, Fucophyceae). *Ann. Bot. Fennica* 31:127-138.

Sand-Jensen, K. & T. Fenchel (eds.) (2006): *Havet*. Naturen i Danmark. Gyldendal, Copenhagen, 516 pp.

Sandström, A. & Eriksson, B. K. (2005): Boating activities influences the recruitment of near-shore fishes in a Baltic Sea archipelago area.. *Ambio* 34(2): 125-130.

Sauramo, M. (1958): Die Geschichte der Ostsee. *Annales Academiae Scientarium Fennicae*, A III 51:1-522.

Segerstråle, S.G. (1957): The Baltic Sea. In: J.W. Hedgpeth (ed.). Treatise on Marine Ecology and Paleocology I. *Ecology. Geol. Soc. Am. Mem*. 67:751-800.

Serrão, E. A., L. Kautsky & S.H. Brawley (1996): Distributional success of the marine seaweed *Fucus vesiculosus* L. in the brackish Baltic Sea correlates with osmotic capabilities of gametes. *Oecologia* 107:1-12.

Seymour, R.J., M.J. Tegner, P.K. Dayton & P.E. Parnell (1989): Storm wave induced mortality of giant kelp, *Macrocystis pyrifera*, in southern California. *Estuarine, Coastal and Shelf Science* 28:277-92.

Snelgrove, P.V.R. (1999): Getting to the bottom of marine biodiversity: Sedimentary habitats. *BioScience* 49:129-138.

Sparrevohn, C.R. & J.G. Støttrup (*in press):* Post-release survival and feeding in reared turbot. *J. Sea Research - in press*.

Svensson, N.-O. (1991): Late Weichselian and early Holocene shore displacement in the central Baltic Sea. *Quatern. Int.* 9:7-26.

Stepputtis, D. (2006): *Distribution patterns of Baltic sprat (Sprattus sprattus L.) - causes and consequences*. Ph.D thesis, Univ. Kiel.

Tendal, O.S. & G.E. Dinesen (2005): Biogenic sediments, substrates and habitats of the Faroese shelf and slope. *Fróðskaparrit* 41:224-242.

Vincent, M.A., S.M. Atkins, C.M. Lumb, N. Golding, L.M. Lieberknecht & M. Webster (2004): Marine nature conservation and sustainable development – the Irish Sea Pilot. Report to Defra by the Joint Nature Conservation Committee, Peterborough.

Wennberg, S., C. Lindblad, J. Albertsson, U. Bergström, M. Isæus, M. Kilnäs, A. Mattisson & A. Sandman (2006): Sammanställning och Analys av Kustnära Undervattenmiljö (SAKU). Stockholm, *Naturvårdsverket Rapport* nr. 5591. 99 pp.

Wennhage, H. & L. Pihl (1994): Substratum selection by juvenile plaice (*Pleuronectes platessa* L.): Impact of benthic microalgae and filamentous macroalgae. *Neth. J. Sea Research* 32:343-351.

Winterhalter, B., T. Flodén, H. Ignatius, S. Axberg & L. Niemistö (1981): Geology of the Baltic Sea. Teoksessa: Voipio, A. (Ed.) The Baltic Sea. Elsevier *Oceanography Series* 30:1-121.

Yarish, C., A.M. Breeman & C. van den Hoek (1986): Survival strategies and temperature responses of seaweeds belonging to different biogeographic distribution groups. *Bot. Mar.* 29:215-230.

Ærtebjerg, G. & A.M. Bresta (eds.) (1984): *Guidelines for the Measurement of Phytoplankton Primary Production*. Baltic Marine Biologists Publication, 1. 2nd edition.

Ærtebjerg, G., J.H. Andersen & O.S. Hansen (Eds.) (2003): *Nutrients and Eutrophication in the Danish Marine Waters. A Challenge for Science and Management*. National Environmental Research Institute. 126 pp.

Ærtebjerg, G., J. Carstensen, P. Axe, J.-N. Druon & A. Stips (2003): The 2002 Oxygen Depletion Event in the Kattegat, Belt Sea and Western Baltic. Thematic Report (HELCOM 2003). Helsinki Commission. *Baltic Sea Environment Proceedings 90*. 64 pp. Available at: http://www2.dmu.dk/1_viden/2_Publikationer/3_Ovrige/rapporter/Helcom2003_BaltSeaEnvironProcNo90.pdf

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About the BALANCE project:

This report is a product of the BSR INTERREG IIIB project "BALANCE".

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 will be 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.

The BALANCE partnership is composed of the following institutions based in 10 countries: The Danish Forest and Nature Agency (Lead), The Geological Survey of Denmark and Greenland, The National Environmental Research Institute/University of Aarhus, The Danish Institute for Fisheries Research, WWF Denmark, WWF Germany, Institute of Aquatic Ecology at University of Latvia, Estonian Marine Institute at University of Tartu, Coastal Research and Planning Institute at Klaipeda University, Metsähallitus Natural Heritage Service, The Finnish Environment Institute, The Geological Survey of Finland, WWF Finland, The Swedish Environmental Protection Agency, The National Board of Fisheries – Department of Research and Development, The Geological Survey of Sweden, County Administrative Board of Stockholm, Department of Marine Ecology at Gothenburg University and WWF Sweden. The following institutes contribute as consultants to the partnership: The Geological Survey of Norway, Norwegian Institute for Water Research, DHI Water & Environment, The Leibniz Institute of Marine Sciences, The Sea Fisheries Institute, The Finnish Game and Fisheries Research Institute, Metria Miljöanalys and The Nature Conservancy.

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