Analysis of marine protected areas – in the Danish part of the North Sea and the Central Baltic around Bornholm

Part 1: The coherence of the present network of MPAs

DTU Aqua report no. 325-2017

By DTU Aqua, DCE, DHI and GEUS

DTU Aqua
National Institute of Aquatic Resources

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Authors	**DTU Aqua:** Karen Edelvang, Henrik Gislason, Francois Bastardie, Asbjørn Christensen, Josefine Egekvist **AU/DCE:** Karsten Dahl, Cordula Goeke, Ib Krag Petersen, Signe Sveegaard **DHI:** Stefan Heinänen, Anne Lise Middelboe **GEUS:** Zyad Al-Hamdani, Jørn Bo Jensen, Jørgen Leth
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0. Analysis of marine protected areas – extended summary

This report has been written by a team of researchers from DTU Aqua, DCE-BIOS, DHI and GEUS with input and comments from representatives from the Danish Agency for Environmental Protection and the Danish Fish Agency. It presents an analysis of the current network of marine protected areas and the requirements for its potential extension in the two Danish zones; the Danish zone in the North Sea and Skagerrak and the Danish zone in the Central Baltic Sea around Bornholm.

The report presents the scientific input available to evaluate whether the present network of protected areas in the two Danish zones fulfils the requirements of the Marine Strategy Framework Directive (MSFD) article 13(4). Article 13(4) requires that EU member states establish 'coherent and representative networks of marine protected areas, adequately covering the diversity of the constituent ecosystems' as part of their endeavours to achieve Good Environmental Status. The report also analyses locations where additional protection measures may be established, if necessary, by mapping the spatial distribution of ecological and economical value in: (1) the Danish zone in the North Sea and Skagerrak, and (2) the Danish zone around Bornholm. Protection measures in the remaining parts of the North Sea and the Baltic Sea and in the Kattegat, Belt Sea, and Øresund have not been considered.

The report is divided into two parts.

Part 1 describes the main ecological features of the two zones, providing maps of the distribution of habitats and ecological components, outlining their importance and temporal variation and finally discussing the requirements that the present network of protected areas in the two zones, i.e. the Natura 2000 areas, should achieve in order to adequately represent the ecological features identified. Part 1 also provides the information needed to evaluate the coherence criteria outlined in the *Deltares report* (Wolters et al. 2015).

Part 2 contains an evaluation of ecologically and economically important areas, and human activities and pressures. Connectivity simulations are used to identify source areas for larvae and spores of benthic flora and fauna that will settle within the two zones. Ecologically valuable areas are identified using e.g. data on species distributions, benthic communities, connectivity and fish species richness, as well as high level proxies of ecological importance such as primary productivity. Specific coastal habitats (eelgrass beds and shallow brown algae vegetation) have not been included due to data constraints.

The information about the spatial distribution of ecologically and economically important features in the two zones is used to identify areas for protection using two different spatial planning tools, Zonation and Marxan. Although the two tools both produce spatial priorities for protection, the approaches and algorithms they use are very different. Marxan follows a "minimum set framework" to reach feature specific targets, e.g. no less than 20% protection of selected ecological features with minimum costs, whereas Zonation uses a "maximal coverage framework", where the e.g. 20% most ecologically valuable areas are identified. The results from the two models are therefore likely to differ.

Three different themes are investigated both with and without accounting for economic interests. The first theme uses all mapped features to identify the most valuable areas and the areas subject to human pressures. The second theme investigates where spatial closures may be established to protect benthos from fishing impacts, and the third illustrates potential spatial protection measures resulting from MSFD article 13(4).

Closing an area to fishing will displace fishing to other areas, where the ecological impact will increase. Using the output from Marxan, the DISPLACE model is used to predict how fishers are expected to respond to specific spatial closures. DISPLACE predicts where individual fishermen will be fishing if their present fishing ground is closed and estimates the resulting changes in stock abundances, catch, economic value, fuel consumption and benthic impact.

Conclusions from both parts of the report are:

1. The EU seeks to protect the marine environment through a policy framework consisting of a number of directives including the Marine Strategy Framework Directive (MSFD) and the Habitats and Birds Directives. These directives contain obligations to establish marine protected areas (MPAs) exemplified by the Natura 2000 network and by article 13(4) in the MSFD which states that "spatial measures, contributing to coherent and representative networks of marine protected areas" shall be established. No specific definition of coherence is provided, but a review of MPA assessments suggests that a coherent network of MPAs shall ensure representativity and replication of ecological features, sufficient connectivity between sites, and adequacy of size and protection of individual sites.

2. Natura 2000 sites have already been established to fulfil the requirements of the EU Habitats and Birds Directives. These sites are designated to protect the particular habitat types and species mentioned in the Annexes of the Directives. According to the Habitats Directive eight (including marine caves) marine habitats shall be protected by Natura 2000 sites, but no protection is required by the Directive for pelagic habitats, hard bottoms other than reefs and biogenic and bubbling reefs, deeper sand banks, and muddy and flat sandy bottoms permanently covered by seawater. Natura 2000 sites have also been designated to protect particular bird species under the Birds Directive and marine mammal species under the Habitats Directive, but in designating these areas, little attention has so far been given to ensure that the overall diversity of the ecosystems in the two zones is adequately covered. In relation to the requirements of the MSFD, it thus seems that considerations could be given to whether benthic communities and fish assemblages are adequately protected. While the designation of Birds Directive areas for coastal bird species is advanced, the designation of sites to protect offshore species seems less advanced.

3. The available information on geological and biological features and human activities of economic importance relevant for identifying Marine Protected Areas in the two Danish zones was reviewed. Spatial data are available in varying quality and the resolution and coverage change from feature to feature. It was noted that 1) information about the benthos in the two Danish zones was limited, 2) geological survey lines were sparse in some areas, 3) information about the distribution of many seabirds and harbour and grey seals was incomplete or missing and, 4) information on distribution of coastal eelgrass and shallow brown algal vegetation was sparse (for Bornholm). The limited amount of benthos data from the two Danish zones generates a high uncertainty about the spatial distribution and composition of the benthic flora and fauna in these areas. This, together with a lack of information about the spatial distribution and foraging areas of some of the marine mammal populations, and, in those areas where geological survey lines are sparse, the lack of sufficiently spatially resolved seabed information, will constitute the most important gaps in the knowledge necessary for identifying areas to fulfil the requirements of the Marine Strategy Framework Directive (MSFD) Article 13(4). Therefore, in many cases the identification of these areas will need to be based on the extrapolation of geological and ecological information from adjacent areas where samples are available. Sediment data vary in confidence from area to area. Using high resolution mapping will result in sediment maps of high confidence. A better, more confident and more reliable dataset can be produced once high resolution mapping takes place. Spatial information on human activities and pressures is in general of better quality. These include fishing effort and landed value

by major gear types; surface and subsurface seabed abrasion caused by bottom trawls and seines; aggregate extraction; windfarms; oil and gas production and pipelines; cables; military areas and World War 2 munition dump sites.

4. In order to ensure a coherent network of protected areas as required by the MSFD, it is necessary to assess connectivity, adequacy, representativity and replication. These assessments will differ across habitats, species and ecosystem components. Many marine species disperse by means of pelagic eggs from which passively drifting larvae are hatched. Connectivity between subpopulations occupying patches of identical habitat is therefore not only a question of geographical distance and size of adult home range (which is often unknown), but also a question of hydrography such as current direction and speed. To assess representativity and replication, knowledge is required about the presence or absence of particular ecological features in different areas. However, when ecological features are extrapolated from samples collected outside the area of interest, their presence or absence is difficult to establish with absolute certainty. This is a general problem when modelling without having sufficiently dense data coverage.

5. Marine benthic species are often characterized as a series of local populations linked by the exchange of spores or larvae. The connectivity between populations is the basis for their existence, ability to re-establish after disturbance, demographic structure and genetic diversity and thus a key factor to consider in the design of marine protected areas. Simulations with a hydrographic model were used to assess the connectivity between different areas, expressed as the likelihood that offspring could be transported by currents from one area to another. Connectivity was expressed as the “sourciness” of each small area and habitat; where “sourciness” is the probability that larvae produced within the area would be transported to a similar habitat within the two Danish zones, where they could settle. It should be noted that a full analysis of the connectivity between potential MPAs would require the inclusion of habitats and MPA’s in the waters of neighbouring countries and in the Danish waters in the Kattegat, Belt Sea, Øresund and western Baltic Sea. Furthermore, additional connectivity aspects would need to be included, such as the connectivity between potential protected sites.

6. Two different planning tools (Marxan and Zonation) were applied to identify suitable areas for potential additional conservation. Both tools require users to provide weights to balance economic and ecological objectives. However, such weights cannot be provided by science, but must be generated by a political process, where the conservation objectives are identified and the weighting of different ecological and economic objectives is agreed upon. The results of applying the planning tools in this report are therefore meant to illustrate the outcome of potentially relevant management scenarios, but cannot be interpreted as recommending particular solutions. Finally we would like to draw attention to the fact that this report only considers selection of areas for protecting existing biodiversity. It is important to note that there is a distinct discrepancy between modelling the effects of protecting existing biodiversity in habitats that are relatively un-affected by human activities as compared to modelling the restoration of biodiversity in habitats that are heavily affected.

7. Results from three overall management themes are provided to illustrate how suitable areas for protection may be selected. The first theme (1A) illustrates an attempt to identify the most ecologically valuable areas and examine how the addition of economic interests and human pressures may change the overall valuation. In theme 1B for the Baltic exclusively, the robustness of the conclusions based on the selection of ecological layers is investigated. The second theme (2) illustrates an attempt to identify relevant soft bottom areas to be protected from bottom trawls and other fishing gear that cause seabed abrasion. The third theme (3) is an attempt to illustrate the

spatial areas that may be relevant in relation to the requirements of the MSFD article 13(4). In each theme the effect of protecting of 5%, 10% or 20% of the ecological features were considered in the Marxan runs.

8. For the North Sea and Skagerrak, in all three themes, Zonation generally located the highest overall ecological value in areas along the coast of Jutland and in the most south western part of the zone. This result is very much influenced by the modelled connectivity, as revealed by the performance curves produced by the Zonation runs. Adding economic value to the results makes the areas in the Skagerrak and adjacent to the Wadden Sea appear less attractive for protection, because of the high value of the fishery. The exclusion of “no go zones” (estimated unsuitable for conservation such as areas used for aggregate extraction, windfarms, cables, pipelines and oil and gas installations) also changed the ranking of the areas. Marxan provided a similar overall picture as Zonation, but suggested a solution consisting of many smaller closures once economic value was included. Around Bornholm, Zonation identified the areas to the south and south-west of the island as the most ecologically valuable. When economics and human pressures such as fisheries were included and “no go zones” for conservation together with the Polish claim excluded, Zonation also included the area between Christiansø and Bornholm among the valuable areas. Again Marxan provided a very similar overall picture, albeit with much more detail in the particular areas selected. For the Baltic Sea around Bornholm, unprotected eelgrass and less protected brown seaweed habitats are present, but these habitats could not be included due to data deficiencies.

9. In Theme 2, Marxan proposed areas to be closed to bottom trawling in order to protect benthic communities. The DISPLACE model was used to illustrate the overall consequences to the fishery of closing these areas showing how fishing vessels would be displaced to nearby areas, where the ecological impacts of fishing might increase. Often the effect on the fishery will be a short term reduction in profit due to additional steaming, increased fuel consumption and lower catch rates. However, if commercially exploited stocks benefit from the closure and increase in abundance, a positive effect may be seen in the longer term. Provided with information about the areas where the vessels have been fishing in the past and the gear they have been using, the DISPLACE model can predict the areas where they may be fishing after a closure and the resulting changes in landing value, profits, fuel consumption, catch composition etc. The calculations revealed that the 20% target closures suggested by Marxan (avoiding conflicts as best possible) were likely to generate a small reduction in the net present value and catch in the North Sea, and a slightly larger loss in the Baltic Sea, where the affected vessels seemed unable to identify alternative fishing opportunities after they had been displaced from the closed areas. The changes for the fishing sector are much smaller in the 20% target scenario when conflicts are not avoided. The 5% target closures only affected the fisheries marginally. The calculations also indicated that the 20% target closures suggested in the Baltic zone by Marxan would generate only a minor increase in the total benthic biomass within the closed areas. However, the calculations were based on a benthic response model. The parameter values in this model were derived from observations made outside the Baltic. This last result should therefore be interpreted with caution.

10. Natural variations in temperature and salinity generated by changes in meteorological forcing have affected the North Sea and Baltic ecosystems significantly in the recent past, and will most likely continue to do so in the future. Furthermore, global warming has increased the average annual water temperature significantly in both areas, generating well documented changes in relative species composition and distribution due e.g. to influx or increases in abundance of species with a southern affinity, in particular in the North Sea. In the Baltic Sea, salinity has declined due to a reduction in the frequency of saltwater intrusions. This has significantly affected species compositions and ecosystem structure, particularly in transitional areas where salinity and oxygen gradients are large.

Insufficient information is available to predict how future changes will affect the ecosystems in the two Danish zones considered in this report. Should a network of protected areas be implemented, it is therefore important that its functioning is regularly reviewed and that the network is adapted, if necessary, so that its coherence is maintained and it can continue to provide the protection intended.

Overall we conclude that:

- There are important data gaps in the two Danish zones that limit the possibility for describing the spatial distribution of benthic communities, seabirds, marine mammals and, in some areas, habitat types, with sufficient precision.
- Spatial planning tools, such as Marxan and Zonation, can help identify areas with high ecological value and few economic interests. However, the weighting of economic and ecological values cannot be done objectively by science, but necessitates political input. The results of applying the planning tools in this report are therefore meant to illustrate the outcome of potentially relevant management scenarios, but cannot be interpreted as recommending particular solutions.
- A full analysis of the coherence of a potential network of protected areas would require inclusion of information about marine protected areas outside the Danish zones as well as prior selection of a smaller number of potential options for spatial closures than considered here.
- When spatial protection measures are adopted, this will often result in a change in the spatial distribution of human activities and impacts. For fisheries, the available data and models can be used to suggest how fishing vessels may re-allocate their effort to neighbouring areas when an area is closed. This potentially allows estimates of the expected changes in landing value, profits, fuel consumption, catch composition and ecological impact.

1. Introduction

This report has been written by a team of experts from DTU Aqua, DCE-BIOS, DHI and GEUS with comments from representatives from the Danish Agency for Environmental Protection and the Danish Fish Agency. The report presents the final delivery to the Ministry of Foreign Affairs and the Danish Fish Agency in the project ‘Analyse af beskyttede områder i Nordsøen og Den Centrale Østersø’. The project is mainly financed by the European Maritime and Fisheries Fund and Danish government funding. However, part of the study dealing with testing the applicability of using Marxan was financed by the BONUS project BALTSPACE funded jointly by the European Union’s Seventh Programme for research, technological development and demonstration, and the Innovation Fund Denmark.

The report is divided into two separate parts.

The first part of the report presents the scientific input necessary to evaluate whether the present network of protected areas in Danish waters fulfills the requirements of the Marine Strategy Framework Directive (MSFD) article 13(4). The protected areas in question are in two zones (1) the Danish part of the North Sea and Skagerrak, and (2) the Danish part of the Baltic Sea around Bornholm. Article 13(4) requires that EU member states establish ‘*coherent and representative networks of marine protected areas, adequately covering the diversity of the constituent ecosystems’* as part of their endeavors to obtain *Good Environmental Status*. The first part describes the main ecological features of the two zones, provides maps of the distribution of habitats and ecological components, outlines their importance and temporal variation and finally discusses the requirements that the present network of protected areas in the two zones, i.e. the Natura 2000 areas, should achieve in order to adequately represent the ecological features identified. The report also provides the information needed to evaluate the coherence criteria outlined in the *Deltares report* (Wolters et al. 2015). Finally, we discuss how to use this information to determine the coherence of our networks of protected areas.

The second part of the report contains additional material about the identification and importance of biological hotspots; it provides maps of the spatial distribution of economically important human activities in the Danish areas in the North Sea and the Baltic Sea; and finally it delivers output from site selection models and simulations showing how areal closures might affect the spatial redistribution and economic performance of fisheries. The report is meant to provide the knowledge base to identify where additional protected areas, if deemed necessary, may be placed in the two zones, taking both ecological and economic information into account.

And finally, to cite Section 34 of the preamble to the MSFD: *″In view of the dynamic nature of marine ecosystems and their natural variability, and given that the pressures and impacts on them may vary with the evolvement of different patterns of human activity and the impact of climate change, it is essential to recognise that the determination of good environmental status may have to be adapted over time. Accordingly, it is appropriate that programmes of measures for the protection and management of the marine environment be flexible and adaptive and take account of scientific and technological developments. Provision should therefore be made for the updating of marine strategies on a regular basis″.* Therefore, the Marine Strategies shall be updated in steps every six years, cf. MSFD article 17.

2. The policy framework for establishing MPAs

The EU has established a policy framework to protect the marine environment and ensure a sustainable ecosystem-based approach to the management of its marine resources. The main components of this framework are the Habitats and Birds Directives, the Marine Strategy Framework Directive (MSFD), the Common Fisheries Policy (CFP) and the Maritime Spatial Planning Framework Directive (MSPFD). These directives guide the nature protection efforts of the member states and form part of the contribution of the EU to international nature conservation efforts, including regional seas conventions such as HELCOM and OSPAR, the Biological Diversity Convention, the Bonn and Ramsar conventions, and other international agreements and conventions aimed at marine nature protection.

The establishment of Marine Protected Areas (MPAs) constitutes one of the management options available for protecting marine fauna and flora. Many of the directives therefore include obligations to establish MPAs as exemplified by the Natura 2000 initiative of the Habitats and Birds directives and by article 13(4) in the MSFD.

In a report from the Commission to the Council it is stated that MPAs are measures for protecting vulnerable species and habitats by establishing geographically defined marine areas whose primary and clearly stated objective is nature conservation, and that MPAs should be regulated and managed through legal or other effective means to achieve this objective (EC 2015). This definition is in accordance with the IUCN MPA definition (Day et al. 2012) where an MPA is defined as an area where nature conservation is the primary objective.

The overall goal of the Natura 2000 network is to ensure the long-term survival of valuable and threatened species and habitats by establishing the so-called Natura 2000 areas consisting of sites designated according to the Habitat Directive and the Birds Directive. According to Art.4 of the Birds Directive, EU Member States are required to protect the bird species listed in Annex I of the Directive as well as migratory species by designating Special Protection Areas (SPAs). According to Art.3 and 4 of the Habitats Directive, Member States are obliged to propose Sites of Community Importance for the habitat-types listed in Annex I and the species listed in Annex II of the Directive after which the proposed SCI's may be designated as Special Areas of Conservation (SACs).The SPAs and SACs form the Natura 2000 network.

For each Natura 2000 site, the national authority must develop management measures to ensure that favorable conservation status is reached and maintained for the habitat types and species for which the site is designated. Once established the Member States must ensure that the Natura 2000 areas are managed in a sustainable manner and make sure that their distribution and functions are preserved or improved.

However, this requirement does not entail that the Natura 2000 network must be managed as a system of nature reserves from which all human activities must be excluded. Human activities are permitted inside the areas if they do not violate the purpose of their designation, and a range of guidelines are available to assist the Member States in the process of establishing Natura 2000 areas.

2.1 Habitat Directive

Under the Habitats Directive (92/43/EEC, Art. 3 and 4), Member States are obliged to designate Special Areas of Conservation (SACs) to ensure favorable conservation status of a number of habitat types and species throughout their EU range. The Habitats Directive divides the EU into 9 ecologically coherent “biogeographical” regions for which SACs must be selected. The Danish waters cover two biogeographic regions. The Atlantic region includes the North Sea, Skagerrak and Kattegat with connected fjords. The Baltic region covers all other Danish areas.

The selection of SACs by Member States must be based exclusively on the ecological criteria of Annex III of the Habitats Directive. Regarding habitat protection, the Directive mentions three offshore habitat types listed in its Annex I relevant for the designation of MPAs in the Danish area in the North Sea and around Bornholm. The habitats in question include “Sandbanks which are slightly covered by sea water all the time” (1110), “Reefs” (1170), Structures made by leaking gases (1180). Four more habitat types are relevant for inshore waters.

In addition 18 marine species are listed in Annex II of which Common bottlenose dolphin (*Tursiops truncatus*), Harbor porpoise (*Phocaena phocaena*), Grey Seal (*Halichoerus grypus*), Harbor seal (*Phoca vitulina*), Sea Lamprey (*Petromyzon marinus*), River lamprey (*Lampetra fluviatilis*), Common sturgeon (*Acipenser sturio*), Allis shad (*Alosa alosa*), Twaite shad (*Alosa fallax*) and Houting (*Coregonus oxyrhyncus*) are relevant for Denmark.

A further list of species is provided in annexes IV and V of the directive and although the Directive does not require sites to be designated to protect these species, they still need to be protected according to Article 12, 14 and 15 of the Directive. The list includes additional marine mammals: Common dolphin (*Delphinus delphis*), Killer whale (*Orcinus orca*), Long-finned pilot whale (*Globicephala melas*), Risso’s dolphin (*Grampus griseus*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), White-beaked dolphin (*Lagenorhynchus albirostris*), Minke whale (*Balaenoptera acutorostrata*), Fin whale (*Balaenoptera physalus*), and Sperm whale (*Physeter microcephalus*).

2.2 Birds directive

The Birds Directive (2009/147/EC, art. 4) provides a legal framework requiring Member States to protect wild birds in the EU, including their eggs, nests and habitats. The Natura 2000 areas designated under the Birds Directive consist of the so-called Special Protection Areas (SPAs) that are established to protect a number of particularly threatened bird species and all migratory bird species. According to the directive, the selection of SPAs and the delimitation of their boundaries should be carried out exclusively based on ornithological criteria.

Annex I of the directive contains list of the species for which SPAs should be established. For Denmark marine SPAs have been established to protect migratory species such as red-throated diver (*Gavia stellata*), black-throated diver (*Gavia arctica*) and Little Gull (*Hydrocoloeus minutus*). In addition art. 4.2 requires Member States to take measures to protect regularly occurring migratory species not listed in Annex I, bearing in mind the need for protection of their breeding, moulting and wintering areas and staging posts along their migration routes. In Denmark SPAs have thus been established to protect razorbill (*Alca torda*), long-tailed duck (*Clangula hyemalis*), greater scaup (*Aythya marila*), common scoter (*Melanitta nigra*), velvet scoter (*Melanitta fusca*) and eider (*Somateria molissima*).

2.3 OSPAR

In 1998, at a Ministerial Meeting of the OSPAR Commission in Sintra, it was decided that OSPAR should promote the establishment of a network of marine protected areas. In 2003, the OSPAR Ministerial Meeting in Bremen adopted Recommendation 2003/3 on a network of marine protected areas with the purpose of establishing an ecologically coherent network of MPAs in the North-East Atlantic. The marine Natura 2000 areas established by Denmark in the North Sea and Skagerrak have all been adopted as Denmark's contribution to the network of MPAs in the OSPAR Convention area.

2.4 HELCOM

HELCOM Recommendation 35/1 'System of coastal and marine Baltic Sea protected areas (HELCOM MPAs)' that was adopted on 1 April 2014 recommends that the Governments of the Contracting Parties to the Helsinki Convention take all appropriate measures to step up efforts to establish an ecologically coherent and effectively managed network of coastal and marine protected areas in the Baltic Sea. The marine Natura 2000 areas established by Denmark around Bornholm have all been adopted as Denmark's contribution to the network of HELCOM MPAs.

2.5 The Common Fisheries Policy

The Common Fisheries Policy (CFP) provides for the adoption of conservation measures in line with the objectives of the MSFD and the Habitat and Birds Directives. It also allows the establishment of protected areas of biological sensitivity. Art. 22 thus states that "In order to contribute to the conservation of living aquatic resources and marine ecosystems, the Union should endeavour to protect areas that are biologically sensitive, by designating them as protected areas. In such areas, it should be possible to restrict or to prohibit fishing activities. When deciding which areas to designate, particular attention should be paid to those in which there is clear evidence of heavy concentrations of fish below minimum conservation reference size and of spawning grounds, and to areas which are deemed to be bio-geographically sensitive. Account should also be taken of existing conservation areas. In order to facilitate the designation process, Member States should identify suitable areas, including areas that form part of a coherent network...".

2.6 The Convention on Biological Diversity

As a signatory of the UN Convention on Biological Diversity (CBD), Denmark has participated in adopting the 20 global Aichi Targets. Among these, target 11 specifies that at least 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider seascapes (Danish Government 2014).

2.7 MSFD

The Marine Strategy Framework Directive (MSFD) adds further EU requirements for spatial protection measures to those provided by the Birds and Habitat Directives, by requiring measures that contribute to networks of marine protected areas that are coherent, representative and adequate. Article 13(4) states that "Programmes of measures established pursuant to this Article shall include spatial protection measures, contributing to coherent and representative networks of marine protected areas, adequately covering the diversity of the constituent ecosystems, such as special areas of conservation pursuant to the Habitats Directive, special protection areas pursuant to the Birds Directive, and marine protected areas as agreed by the Community or Member States concerned in the framework of international or regional agreements to which they are parties".

According to article 13(5) Member States shall address the competent authorities if the management of human activities is likely to have a significant impact on the marine environment, in particular in the areas addressed in 13(4), so that measures can be taken to maintain or restore the integrity, structure and functioning of the ecosystems.

A report from the Commission to the European Parliament and the Council on progress in establishing marine protected areas in relation to the MSFD (EC 2015), states that MPAs are geographically defined marine areas whose primary and clearly stated objective is nature conservation, and which are regulated and managed through legal or other effective means to achieve this objective.

Annex 1 of EC (2015), refers to Target 11 of the Strategic Plan for Biodiversity 2011-2020 of the Convention on Biological Diversity which requires that “10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures.”

Regarding spatial protection measures, Annex 1 of EC (2015) states that:

“The Marine Strategy Framework Directive as well as the Birds and Habitats Directives all foresee conservation measures outside protected areas in order to ensure the adequate protection of species and habitats, and to maximize the benefits from protected areas. The Marine Strategy Framework Directive talks explicitly about spatial protection measures. The Habitats Directive foresees the establishment of a strict protection regime for species and sub-species listed in Annex IV of the Directive and protection measures for species and sub-species listed in Annex V. Some of these measures are area-based (e.g. temporary or local prohibition of the taking of specimens in the wild and exploitation of certain populations, establishment of a system of licenses for taking specimens or of quotas etc.). The Birds Directive creates a similar structure. Therefore, spatial protection measures are defined following the logic of the MSFD and the Nature Directives, i.e. that spatial protection measures are a wider category than MPAs, and they play a supportive role in nature conservation. Hence, the term "spatial protection measures" is used for:

- area-based conservation measures
- areas that do not meet the criteria of marine protected areas, either because conservation is not their primary objective, or because their objective focuses on a particular activity or sector in order to protect part of the ecosystem.

In this sense, certain fisheries management measures, which have conservation aspects, fall under the definition of spatial protection measures. Such fisheries management measures may include special fishing permits or bans on specific fishing gears for specific areas to protect for example vulnerable marine ecosystems or sea grass meadows or certain conservation measures adopted under Article 7 of the Common Fisheries Policy. Certain measures to be taken under the Maritime Spatial Planning Directive might also be considered as spatial protection measures, as one of the objectives of maritime spatial plans is the “preservation, protection and improvement of the environment.”

Apart from the above, there is so far little official guidance on the interpretation and implementation of article 13(4) of the MSFD. However, a report from Wolters et al. (2015) commissioned by EC/DGENV summarizes the relevant assessment criteria and methodologies for MPA selection from a range of sources and provides additional guidance and criteria for the assessment of the coherence of MPAs in Europe. The report interprets coherence as an overarching concept that combines comparable assessment criteria from different conventions including the Convention on Biological Diversity and the OSPAR, HELCOM and BARCELONA conventions.

2.8 Coherence of an MPA network

As outlined in the report by Wolters *et al.*(2015), ecological coherence is a key concept for an assessment of the MPA network. It describes how well a group of MPAs provides protection for certain chosen features, such as species, habitats, marine landscapes and ecological processes, both individually and as a network. When well planned, and managed as a network, a collection of sites can deliver more benefits than unconnected individual MPAs can provide on their own (e.g. Catchpole 2012).

In practice, ecological coherence can be assessed by using criteria, which describe different characteristics of the network, such as how well certain features are represented within the MPAs and how these protected areas are connected to each other, for example following the method described by Wolters et al.(2015). Wolters et al. (2015) suggest that “coherence” is the over-arching concept that includes the four other criteria often referred to in MPA network assessments (HELCOM 2010, 2016, OSPAR 2013) and mentioned in the CBD Decision IX/20 (CBD, 2008):

Representativity of functions and features of marine biodiversity (depth zones, ecoregions, habitats and species);
Replication of sites and features;
Connectivity between sites and protected features, and
Adequacy of individual MPAs as parts of the network (e.g. MPA size, level of protection).

Each criterion can be further divided into sub-criteria and evaluated through spatial analyses against set targets. There is not yet a common basis for deciding which criteria and targets for coherence and adequacy should be used under the MSFD. This makes it difficult to assess the adequacy, but at the same time it also allows for different approaches. EU, HELCOM, OSPAR and CBD have provided guidance on the choice of targets for assessment criteria (Table 1) under different Directives, recommendations and conventions etc.

This first part of the study sets out the current status of criteria (% of zones included in MPAs) that can be used as a basis to evaluate representativity, replication, connectivity and adequacy for the two zones based on existing available data. In Part 2 and 3 of this study, the collected data is used to analyse hotspots and economic interests.

Table 1 Criteria, sub-criteria and targets for assessing coherence of MPAs compiled from CBD, HELCOM (2010, 2016), OSPAR (2013) and the EU (2016).

	Different criteria, sub-criteria and targets for assessing the coherence or adequacy of MPAs
Representativity	
Marine region	10% (CBD[1], HELCOM[2]), 3% (OSPAR[3])
Eco-region/ subregion	10% (CBD[1], HELCOM[2]), 3% (OSPAR)
Depth zones	10% (CBD[1])
Habitats	20-60% (EU[4])
Species	20-60% (EU[4])
Threatened species	>60% (EU[4])
Replication	
Minimum replication within network – habitats/ species	3 [5]
Connectivity	
Sites and features without known dispersal distance	50% have ≥ 20 connections within 50 km[5]
Sites and features with known dispersal distance	50% of landscape patches have ≥20 connections at the given dispersal distance[5]
Adequacy	
MPA size	80% of marine sites ≥ (30 km^2) [6]
Protection level	10% (more ambitious 30%) of area is Strictly protected[7]

[1]UN Convention on Biological Diversity target 11: https://www.cbd.int/sp/targets/rationale/target-11

[2]HELCOM (2010) Ministerial Declaration, Moscow, http://helcom.fi/Documents/Baltic%20sea%20action%20plan/HELCOM%20Moscow%20Ministerial%20Declaration%20FINAL.pdf

[3]OSPAR (2013) Johnson, D., Ardron, J., Billett, D., Hooper, T.J.E., and Mullier, T. An assessment of the ecological coherence of the OSPAR Network of Marine Protected Areas in 2012. OSPAR Commission publication number 619/2013. ISBN 978-1-909159-52-5. http://www.ospar.org/documents/dbase/publications/p00619/p00619_ecological_coherence_report.pdf

[4]EU (2016) Guideline under Habitats and Bird Directives: https://bd.eionet.europa.eu/activities/Natura_2000/pdfs/sufficiency_criteria.pdf

[5]As proposed by HELCOM (2016) Ecological coherence assessment of the Marine Protected Area network in the Baltic Sea

[6]Recommended size as proposed for HELCOM MPAs, and decision taken by HELCOM STATE AND CONSERVATION 3-2015. https://portal.helcom.fi/meetings/STATE-CONSERVATION%203-2015-276/MeetingDocuments/Outcome%20of%20STATE-CONSERVATION%203-2015.pdf

[7]The fifth World Parks Congress (2003) suggested 10-30% coverage of each habitat type to be strictly protected area https://portals.iucn.org/library/sites/library/files/documents/2005-007.pdf

3. North Sea and Skagerrak

The area under investigation in this chapter represents the Danish part of the North Sea included in the Danish EEZ.

3.1 Overall description of main habitats and ecological components in the North Sea

3.1.1 Geology, sediments and topography

The topography as well as the distribution of different habitat types in the Danish part of the North Sea is strongly governed by the geological development during the Late Quaternary period. Deposits from the last glaciation (the Weichselian) and the previous (the Saalian) glaciations have been the main source for the present seabed sediments.

To the northeast (Little Fisher Bank and Jutland Bank areas) the seabed is characterized by a hummocky topography that distinguishes it from the rest of the Danish North Sea due to the presence of Weichselian glacial deposits in the area of the maximum extension of the ice shield. As the sea level at the end of the glaciation rose more than 50 m, drowning and reworking of the mixed, glacial sediments started and the marine processes formed coastal deposits and offshore sand banks in the area, which today form sand ridges in between ‘islands’ of glacial sediments. The sorting process left the glacially dominated areas with a layer of coarse-grained material dominated by boulders and gravel. The hydrography dominated by tidal influence (until approximately 6,000 years before present) formed widespread lagoonal environments in the Jutland Bank area and has been the source of firm marine clay deposits, the Agger Clay unit. The subsequent sea level rise and the opening of the English Channel caused the hydrographic system to change from tidal-dominated to coastal current dominated today (The Jutland Current). However, deposits from the previous tidal-dominated environment are preserved as relict structures in the present seabed as reefs, sand banks and Holocene clay seabed.

South of the Weichselian dominated area in the northeast, the seabed is more even with a gentle slope to the west. The seabed mainly consists of Weichselian proglacial plains and river valleys dominated by mixed fluvial deposits of sand/clay and gravel. However, the old glacial landscape from the previous Saalian glaciation protrudes above the flat sandy seabed as “bakke-øer”. The internal structure of the “bakke-ø” landscape is complex due to extensive glacio-tectonic deformations, but in general the surfaces are characterized by the presence of mixed sediments with boulders. To the west and in the Skagerrak the seabed sediments become more fine-grained with increasing water depths, mainly dominated by suspension transport and basin infill sediments.

The topography of the Danish part of the North Sea can be broadly described as consisting of relatively shallow areas (<90 m) in the major parts of the western, central and the southern North Sea, with the tail end of the shallow Dogger Bank in the south-western part (Figure 1). The eastern, near coastal areas are generally shallow (<30m) and slopes gradually towards greater depths (~90m) in the central and the western parts. In the northern and north-eastern parts of the North Sea in the Danish area, the depth slopes gently down to 200 m before it reaches the shelf edge or the edge of the Norwegian Trench that extends east along the Norwegian coast into the Skagerrak with depths up to 500 m.

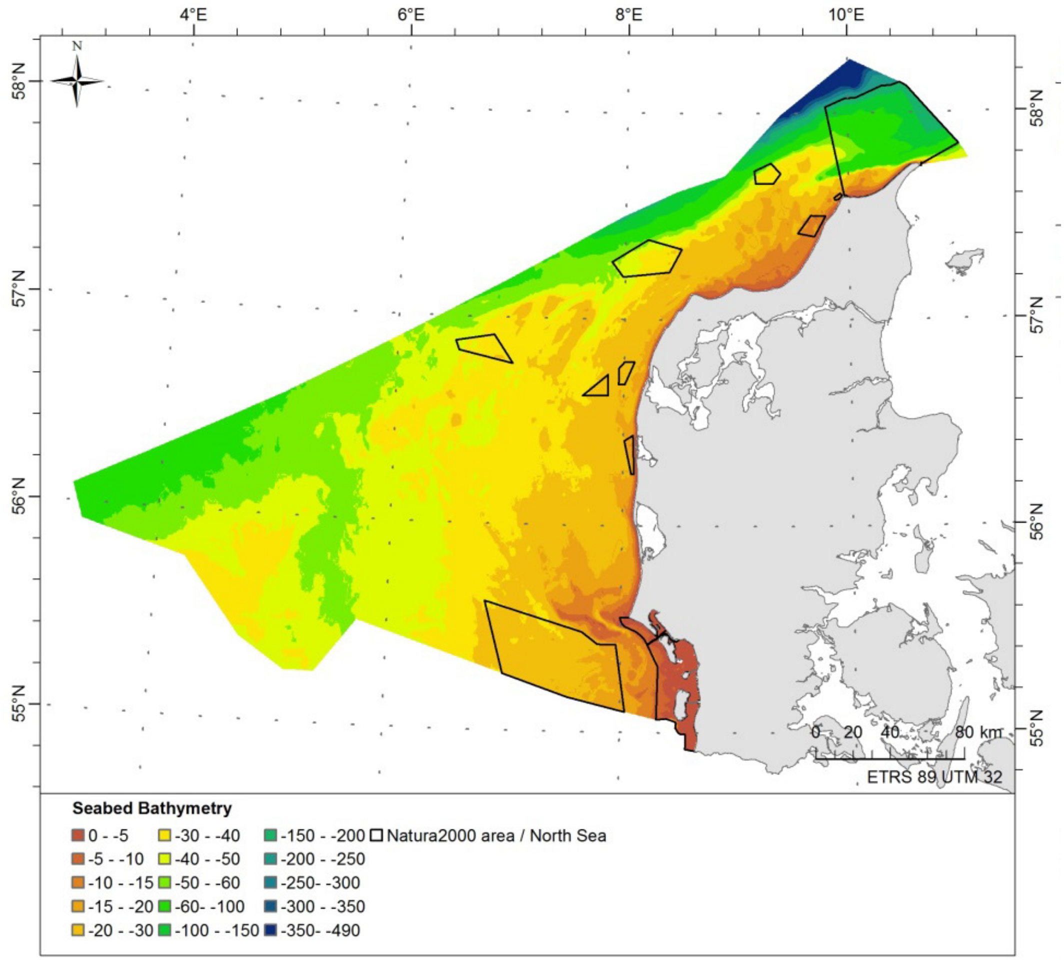


Figure 1 Seabed bathymetry of the North Sea part of the study area.

The substrates are dominated by sand in most parts of the North Sea (Figure 2). The fine-grained sediments of mud and sandy mud or muddy sand can be observed in the western as well as the northern parts of the North Sea and Skagerrak where mud predominates in the deep trenches. In the intermediate areas in Skagerrak, where the depth is between 40 and 80m, the current affects the morphology of the seabed and sand and muddy sand ridges can be observed. Coarse sand sediments are located in the central parts of the North Sea with gravel beds and ridge patches extending southeast to northwest. Till deposits of hard substrate (hard glacial clay, stones and boulders) generally extend across the eastern/ north-eastern North Sea in the area of the maximum extension of the last ice age.

In the shallow southern part, concentrations of boulders may be found locally (such as in the Horns Rev area) where the “bakke-øer” are present. A number of sand banks are found across the North Sea, mainly along the UK coast, eastern Channel, the approaches to the Skagerrak, and the Dogger Bank. The sediment in the deep areas of the Skagerrak consists of fine mud, while hard substrate bottom types may be found in parts of its slopes.

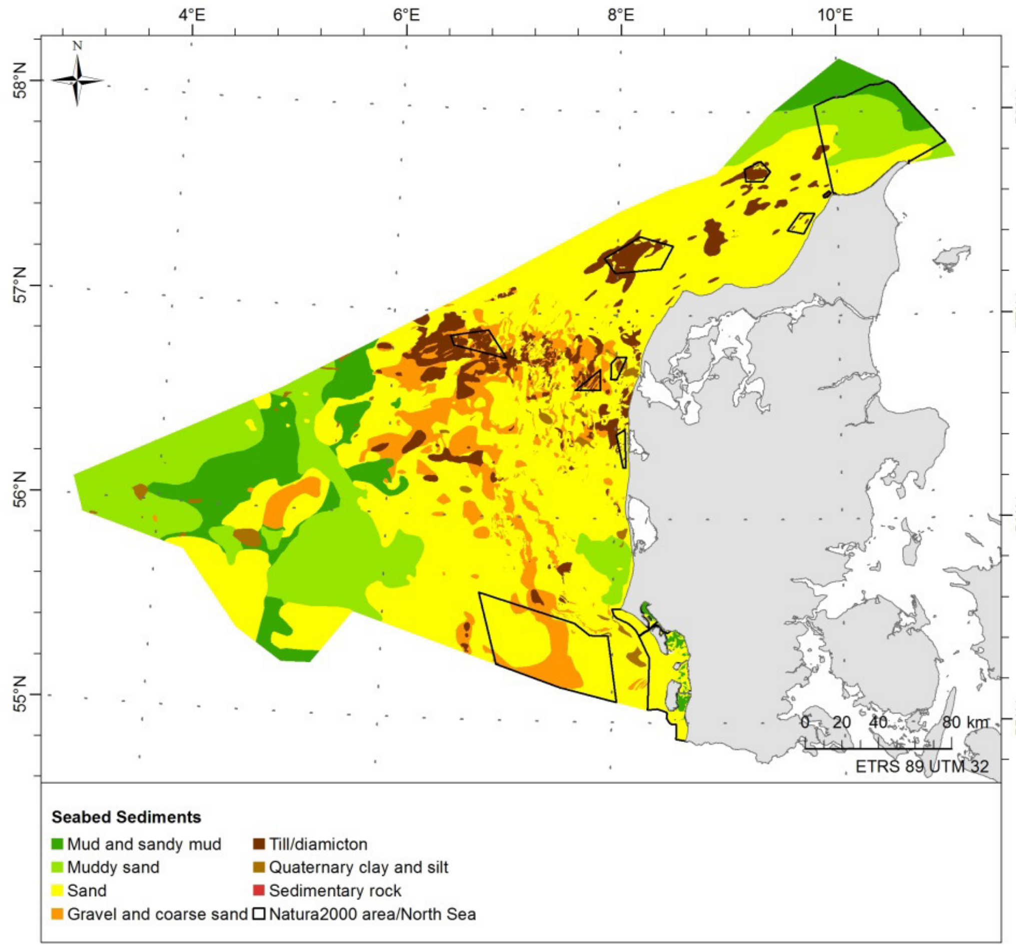


Figure 2 Seabed sediments of the North Sea part of the study area.

3.1.2 Benthic habitats

The EUNIS system is a pan-European classification scheme for habitats intended to provide a biologically relevant classification of seabed habitats. The present classification of EUNIS habitats was part of the EMODNet Phase II-Seabed Habitat project 2013-2016. The project produced a harmonized broad-scale seabed habitat map for major parts of the European waters. The EMODNet sediment map was used for the model production. This map was not upgraded with the 2015 survey data in the North Sea.

The environmental parameters that were used for the modelling of the broad-scale seabed habitats are: biological zone, bathymetry, and oceanographic data such as light, energy and salinity. In the North Sea region light at the seabed, the wavelength/depth, depth to seabed and oceanographic parameters (such as oxygen, temperature and carbon flux) were used to define thresholds for habitats in different bio zones (Infralittoral, circalittoral, bathyal and abyssal deep sea zones). Wave and current energy models were used to define the kinetic energy at the seabed and the required classification thresholds. All these datasets were combined in a GIS platform to produce the final model, which was also translated into EUNIS habitat classification level 3 and level 4, wherever feasible.

The presented benthic habitat map covers the Danish North Sea zone and includes 11 Natura 2000 areas (with Natura2000 numbers 1, 202, 203, 253, 254, 255, 256, 257, 258, 259 and 78

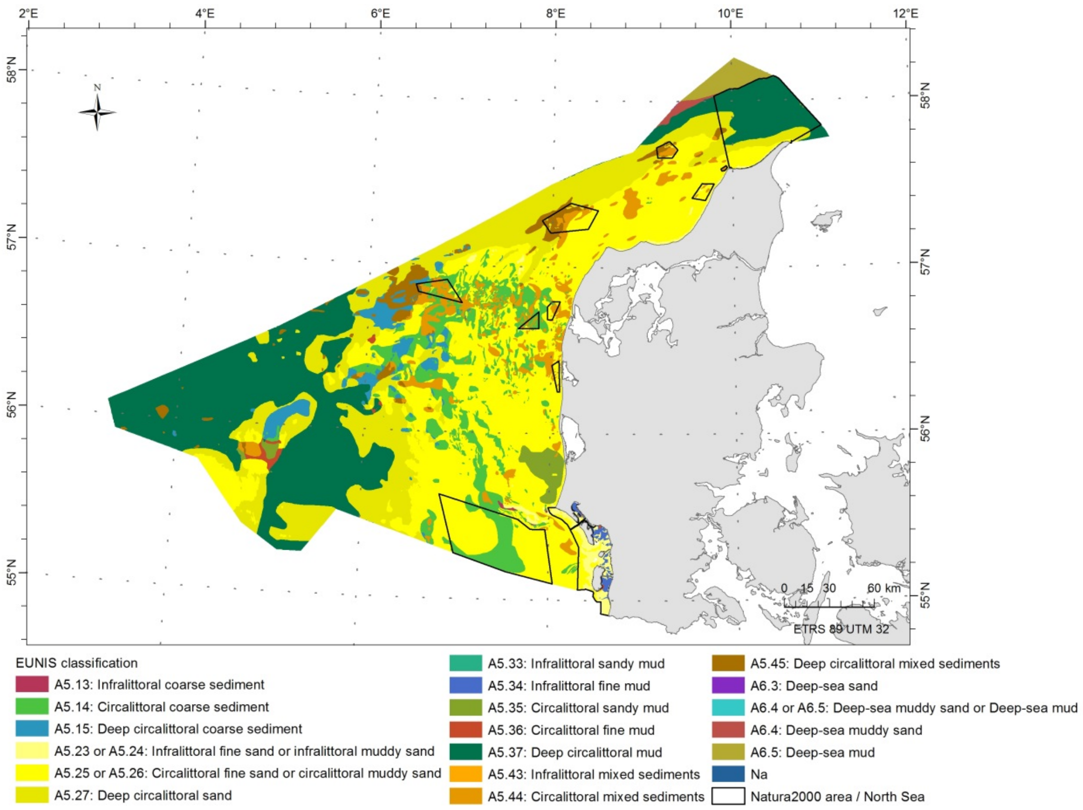


Figure 3 EUNIS habitat classification map for the North Sea study area.

3.1.3 Hydrography

The oceanography of the North Sea is partly determined by the inflow of saline Atlantic water through the northern entrances and, to a lesser degree, through the Channel. These waters mix with river run-off from the major rivers in coastal regions and with the lower-salinity Baltic outflow through the Kattegat. The overall circulation pattern in the North Sea can be described as a large anticlockwise gyre, but this pattern is variable and may be reversed temporally or split into separate northern and southern gyres as a result of wind forcing. Tidal currents are strong and contribute to permanent mixing of surface and bottom water in the southern North Sea, especially in the coastal regions.

The seabed morphology map (Figure 4) as well as the EUNIS habitat map (Figure 3) were used to identify the replication in the habitat types. The seabed morphology map was produced using the available EMODNet 2 bathymetry map, which was based (in the Danish part) on the Geodatastyrelsen depth map, as well as on the EMODNet 2 sediment map of 250m resolution.

The temperature of the surface waters is mainly controlled by local solar heating and atmospheric heat exchange, while temperatures in the deeper waters of the northern North Sea are influenced by the inflow of Atlantic water. The shallow areas in the southern part are therefore subject to large seasonal differences in temperature; thus they are warmer during summer and much colder during winter than the waters in the northern part. Local heating generates vertical stratification of the water column in summer in most parts of the North Sea from April/May to September (e.g. Sharples *et al.*, 2006), but is absent in the shallower waters of the southern North Sea due to strong tidal mixing.

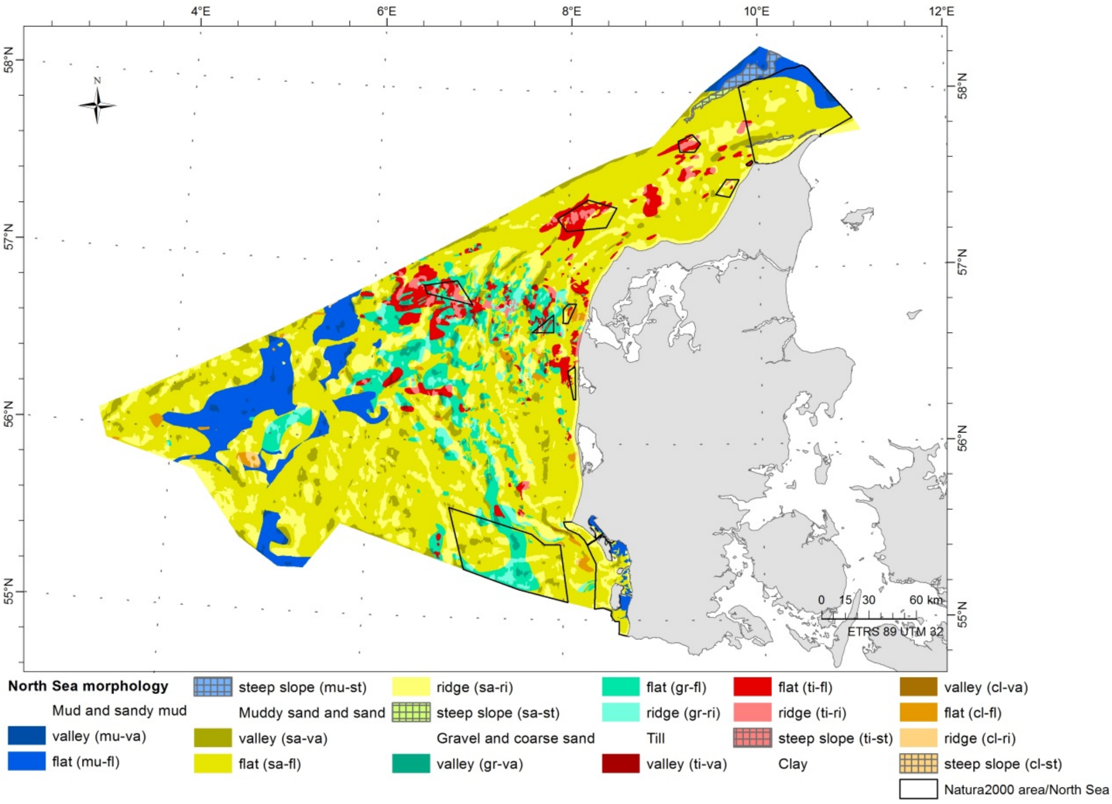


Figure 4 Seabed morphology map of the Danish part of the North Sea.

The inflow from the north and, to a lesser degree, through the English Channel varies over time and is strongly influenced by the so-called North Atlantic Oscillation, reflecting the overall changes in wind forcing and inflow of Atlantic water on decadal time scales (Sündermann & Pohlmann 2016). The North Atlantic Oscillation index, which is a measure of the air pressure gradient between the Azores high and the Iceland low, has undergone both long-term and short-term fluctuations. The index decreased through the mid-part of the last century to a minimum in the 1960s. This coincided with the “Great salinity anomaly” which was a volume of low salinity water formed by an exceptional melting of ice along the east coast of Greenland. The low salinity signal propagated around the northern North Atlantic (Dickson *et al.*, 1988; Blindheim and Skjoldal, 1993) and arrived in the North Sea in the late 1970s, where it produced pronounced minima in both salinity and temperature recordings. Subsequently, the NAO index shifted to high values from the late 1980s through the first part of the 1990s, followed by a marked drop to a strong negative anomaly in the winter of 1995/96. These very marked climatic events were associated with changes in plankton composition (Beaugrand *et al.*, 2002; Beaugrand, 2003; Reid *et al.*, 2003), fish populations, and other biota in the North Sea (Reid and Edwards, 2001; Reid *et al.*, 2001; Edwards *et al.*, 2002; Reid and Beaugrand, 2002).
Besides the inflow of warmer Atlantic water through the northern boundary and through the English Channel, much of the temperature variability is caused by differences in the heat flux from the atmosphere (Larsen *et*

al. 2016). As a result of the global climate change, the North Sea has become warmer over the last two decades. Thus in 2014, the annual mean sea surface temperature was 1.2 °C above average and the warmest on record since the start of the time series in 1969 (Figure 5).

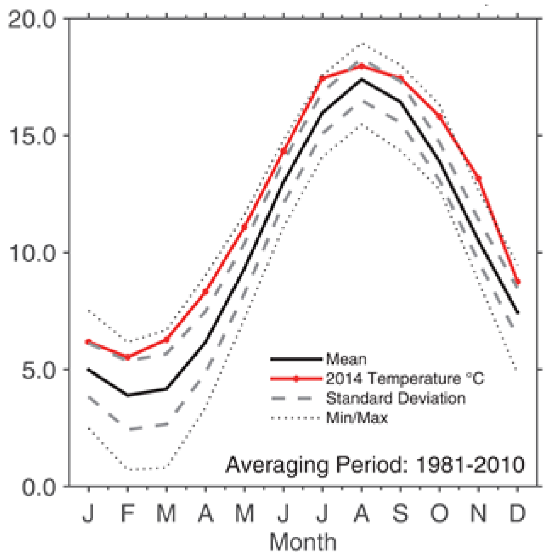


Figure 5 Southern North Sea. Monthly mean sea surface temperature (1981-2010) compared to monthly sea surface temperature in 2014 at Station Helgoland Roads (Source: Larsen et al. 2016).

In addition, the water in the central and southern North Sea has become significantly less clear over the second half of the 20th century. In the regions and seasons investigated by Capuzzo *et al.*(2015) the average Secchi depth decreased by 25% and 75% from before to after 1950. These changes in water clarity were more likely driven by an increase in the concentration of suspended sediments, rather than by changes in phytoplankton abundance. Possible causes include changes in sea-bed communities and in weather patterns, decreased retention of sediments in estuaries, and increased coastal erosion. The predicted future increase in storminess due to climate change may increase the concentration of suspended sediments further leading to decreased clarity and potential changes in primary production.

Due to the significant influence of estuarine water masses and the extensive shallow shelf combined with the presence of tidal currents, the flow patterns and structure of the water column in the different parts of the North Sea is highly complex. This is clearly seen in the Danish part of the North Sea where estuarine and tidal circulations meet creating a diverse and interlinked system of fronts, eddies and up-/down-welling. Most areas in the Danish part of the North Sea can be characterized by one or more frontal processes in the horizontal or in the vertical domain. However, when focusing on fronts for which zones of enhanced biological importance has been documented; the most important frontal areas are those, which due to topographic steering of flow patterns create predictable areas of enhanced concentration of lower and higher trophic levels. A number of frontal systems where water masses of different properties meet are important for biological productivity, either by sustaining a high level of primary production, and/or by aggregating secondary productivity over long periods of time making these areas profitable feeding habitats for top predators. Not only do the fronts vary considerably in time and space depending on wind forcing, current strength, and the physical properties of the different water masses, but they also vary depending on depth.

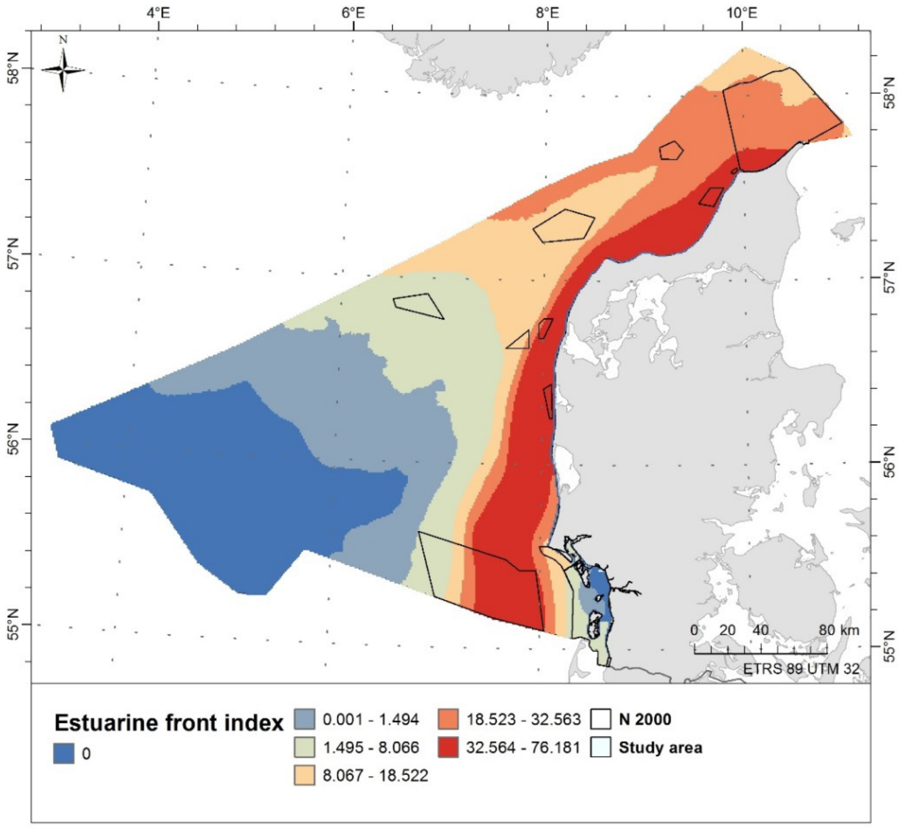


Figure 6 Salinity front in the Danish part of the North Sea. The "Estuarine front" is defined by the frequency of occurrence of salinity 32 - 33.5 during a year. The figure shows the mean of the all years 2011-2016.

In the Danish part of the North Sea, the coastal water generally flows northwards along the coast of Jutland in accordance with the general circulation pattern. Due to the freshwater outflow from the large European rivers entering the south-eastern North Sea, the water along the Jutland coast is generally less saline (< 33.5) than the water further offshore, generating a seasonally persistent salinity front along the coast (Figure 6). The salinity front forms the inner part of the estuarine frontal system with the outer part being marked by the seasonal tidal mixing front.

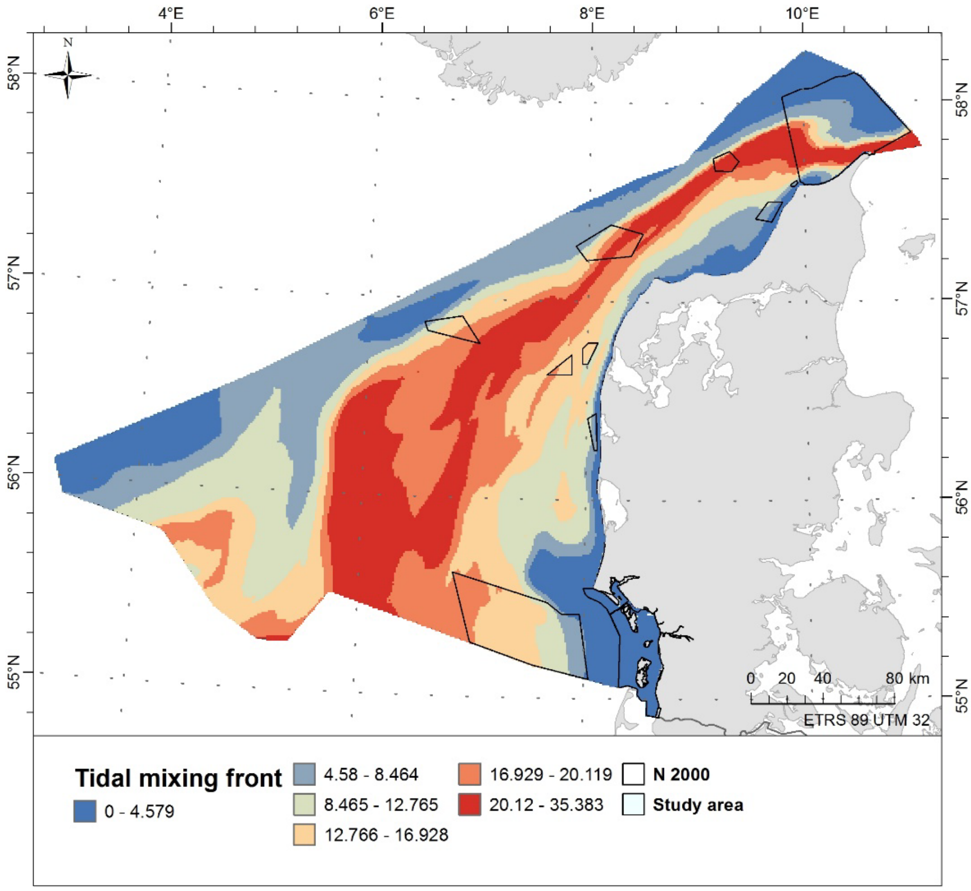


Figure 7 Tidal mixing front in the Danish part of the North Sea. The "Tidal mixing front" is defined by the frequency of a difference between surface and bottom temperature of 2-4˚C in June to September. The figure shows the average for the years 2011-2016.

The interplay between tidal currents, solar heating and shallow offshore areas creates a coherent tidal mixing front west of the salinity front off the coast of Jutland. The geography of the tidal mixing front in the Danish part of the North Sea has been mapped in Figure 7. South of the Skagerrak, the tidal mixing front covers a rather wide zone, which coincides with the trailing edge of the estuarine frontal system described above.

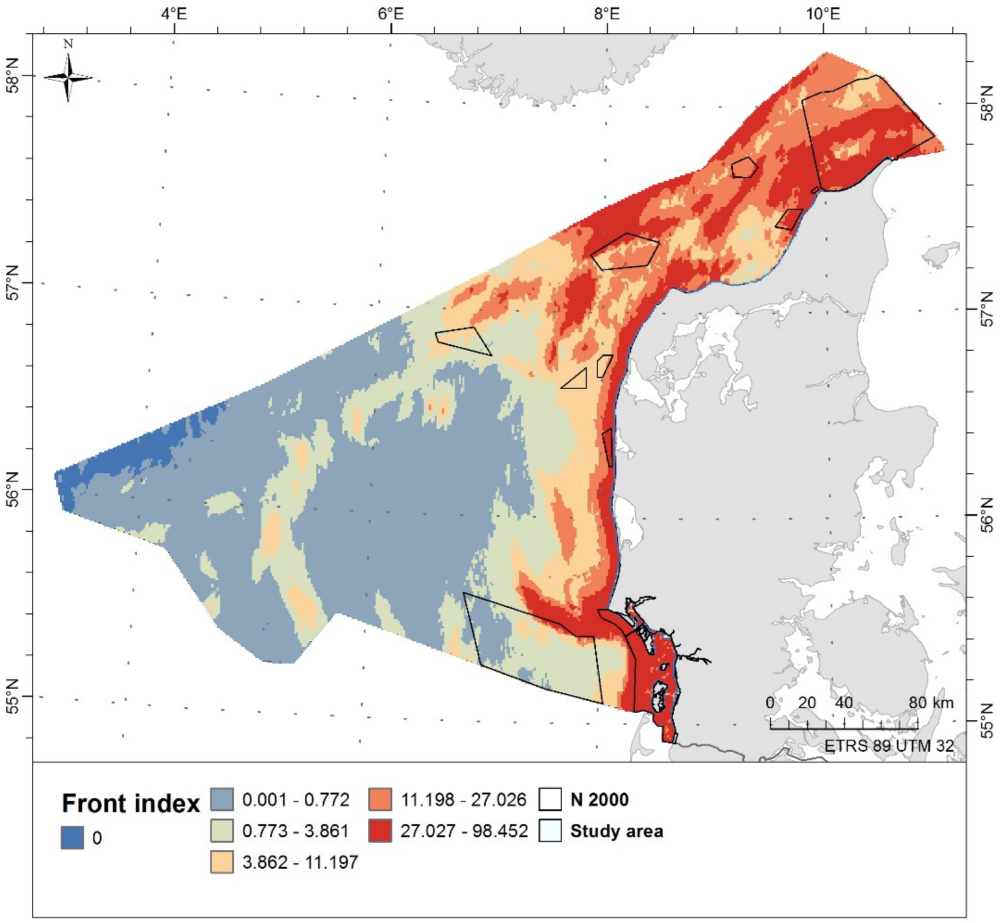


Figure 8 Description of Skagerrak front and other frontal regions based on current gradient and vorticity. The front is defined as the frequency of current gradient and vorticity exceeding the thresholds 0.000015 and 0.00001 respectively combined for each time step at about 20 depths. The figure shows the mean of the years 2011-2016.

In the Skagerrak, the tidal mixing front is narrower and forms part of the Skagerrak frontal system, which is also driven by eddies related to the Skagerrak gyre and the shelf break along the Norwegian Trench (Figure 8). The frontal zone is characterised by enhanced concentrations of phyto- and zooplankton (Nielsen et al. 1993). Schooling fish like sprat *Sprattus sprattus* and predator species occurring in tight aggregations and specialising on schooling fish are observed along the front (Krause et al. 1986, Munk 1993, Stone et al. 1995,). In the Skagerrak region, the front has a profound influence on the distribution of nursery areas for several gadoid fishes (Munk et al. 1999), harbour porpoise *Phocoena phocoena* (Teilmann et al. 2008) and piscivorous seabirds (Stone et al. 1995). Areas of enhanced concentrations of marine mammals and seabirds are also found in smaller zones of high eddy and upwelling activity located north of Skagen, Jyske Rev, Little Fisher Bank and at Horns Rev (Skov & Thomsen 2008, Sveegaard et al 2012, Hammond et al 2013).

3.1.4 Primary production

The inflow from the Atlantic Ocean constitutes the main source of nutrients for the North Sea. New potential production estimated from nutrient budgets ranges from around 30 to 100 g C m^{-2} y^{-1} along the British east coast and in the central area (Heath and Beare, 2008) up to 430 g C m^{-2} y^{-1} in the continental coastal waters of the southern and south-eastern North Sea (German Bight) (Rick *et al.*, 2006), of which river nutrient inputs contribute an estimated 24% (Heath and Beare, 2008). Annual production is scaled to winter nitrate concentrations (van Beusekom and Diel-Christiansen, 1994), and linked to variability in nutrient influx from the Atlantic Ocean (Heath and Beare, 2008). The nutrient cycles in the southern and northern part differ. The water column is mixed in the southern shallow part and has high nutrient concentrations. The central and northern North Sea is stratified and nutrient limited in the surface mixed layer during summer, with a sub-surface increase in production at the thermocline (Weston *et al.* 2015).

The temperature increase of the water has been matched by a long-term increase in phytoplankton biomass (Edwards *et al.*, 2001). Combined analyses of monitoring data derived by the Continuous Plankton Recorder (CPR) Survey and satellite data (SEAWIFS) revealed an increase in chlorophyll a concentration during the 1980s by 13% in the open North Sea and 21% in coastal waters. Phytoplankton biomass increased in coastal waters despite decreasing nutrient levels due to reduced input from land (McQuatters-Gollop and Vermaat 2011, Wiltshire *et al.* 2010). The species composition of the phytoplankton is also changing. A long-term increase in the ratio between diatoms and dinoflagellates since 1990 reflects the increasing sea surface temperature and increasingly windy conditions during summer (Hinder *et al.*, 2012).

Apart from changes in biomass and primary production, changes in the timing of algal blooms may impact higher trophic levels. Edwards and Richardson (2004) showed that especially dinoflagellates reach their seasonal maximum earlier nowadays, whereas the spring and autumn diatom blooms show little change. In general, the timing of the spring bloom in German Bight coastal waters remains remarkably stable (Wiltshire *et al.*, 2008). In the Danish area, modelled primary production varied between 74 and 172 g C m-2 year^{-1} in the DCE model (Figure 9). Modelled primary production was highest in the tidal mixing front zone.

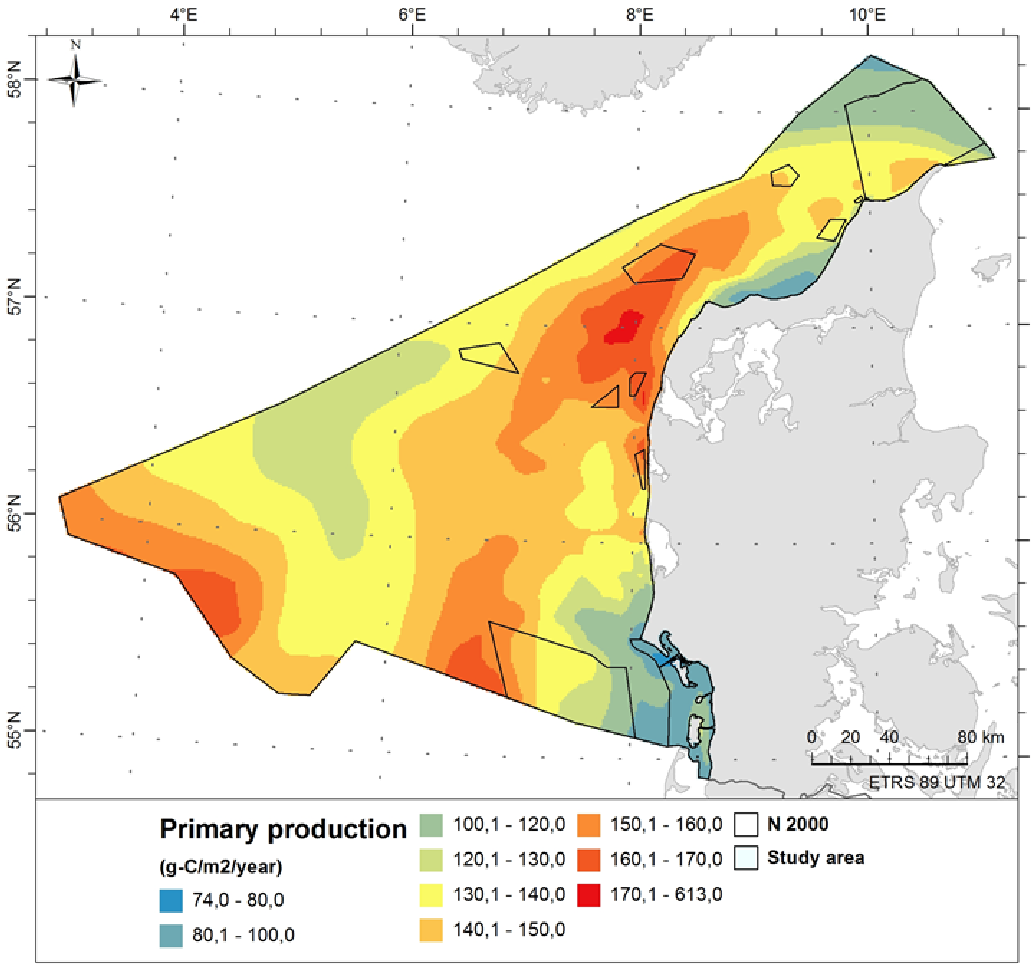


Figure 9 Modelled primary production as yearly average for the years 2009-2013 (g-C/m2/y) (Maar et al. 2016).

3.1.5 Zooplankton

The zooplankton community of the stratified northern part of the North Sea generally consists of north Atlantic species, such as *Calanus finmarchicus* and *Metridia lucens*, while the southern mixed part includes neritic and coastal species such as *Calanus helgolandicus* and *Centropages hamatus*. Climate change has changed the composition of the zooplankton community with knock-on effects on the rest of the food web. There has been a shift in the North Sea from a low-diversity cold water community in the late 1970s to a higher-diversity warmer water community from the 1990s to the present. Beaugrand *et al.* (2002) found a decrease in the abundance of cold water and Arctic zooplankton species and an increase in warmer water ones in the Northeast Atlantic and the North Sea.

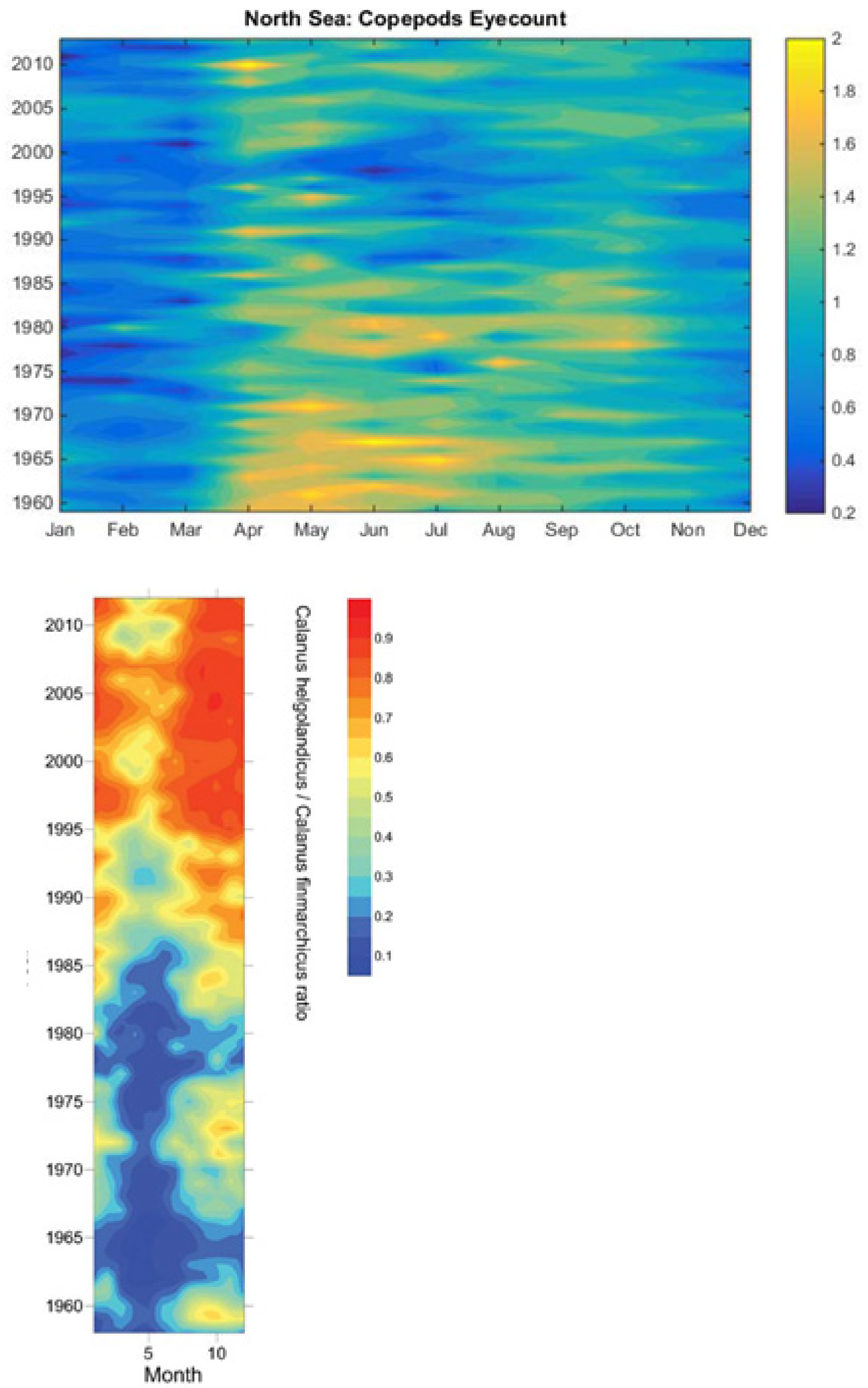


Figure 10 Top: Long term trends in copepod abundance from the Continuous Plankton Recorder survey (log mean density per m3), Bottom: Ratio of abundance between a warm-water copepod species (Calanus helgolandicus) and a cold-water copepod species (C. finmarchicus) per month (from ICES 2016 citing Edwards et al. 2014).

A decreasing abundance of *Calanus finmarchicus* was associated a shift towards the warmer water species *Calanus helgolandicus* (Beaugrand *et al.* 2003) and with a reduction in cod recruitment (ICES 2016) (Figure 10). Corten (2000) showed that the distribution of herring depends on the persistence of suitable food organisms, in particular abundance of *Calanus finmarchicus*, while Sims and Reid (2002) found parallel declines in *Calanus* and basking sharks. Seabirds are also strongly impacted by the abundance of sandeels, which in turn is determined by the abundance of zooplankton and phytoplankton (Frederiksen *et al.*, 2006). Copepod abundance has decreased from 1946 to 2004 over the whole northeast Atlantic (Edwards *et al.* 2006), and pelagic invertebrate larvae (decapods, bivalves and echinoderms) reveal a clear trend in the North Sea towards earlier seasonal peaks in abundance, indicating the effects of a warmer environment, as well as a shift in species composition (Kirby and Beaugrand 2009, Lindley *et al.* 2010).

3.1.6 Soft-bottom communities

A significant part of the energy fixed by the phytoplankton in the North Sea will settle on the seabed and provide food for an abundant benthic invertebrate fauna. Often this fauna is separated into epifauna and infauna. Epifauna live on the sediment surface and may be sampled by bottom trawls and dredges whereas infauna digs into the sediment and must be sampled by sediment corers and grabs. Due to the costs involved in collecting and analyzing the necessary number of benthic samples there are few datasets available to compare the distribution of benthos across the entire North Sea. There have been only two internationally coordinated benthic surveys in the North Sea from which a synoptic picture can be obtained. These surveys took place in 1986 and 2000, respectively. Both of the surveys show that benthic species richness increases from the shallow sandy bottoms in the south to the deeper muddy sediments north of the Dogger Bank.

The species composition in the surveys largely reflects the sediment composition, current regime and depth. In the 1986 survey *Echinocyamus pusillus*, *Pisione remota*, *Glycera lapidum* and *Spisula elliptica* occurred on coarse sediments all over the North Sea, while *Polycirrus medusa* and *Phoxocephalus holbolli* were restricted to coarse sediments in the south and east of the North Sea. On fine sand *Aricidea minuta*, *Bathyporeia elegans* and *Ophelia borealis* occurred all over the North Sea, but *Bathyporeia guilliamsoniana, Fabulina fabula, Urothoe poseidonis* and *Sigalion mathildae* were found only in the southern North Sea on fine sand at depths less than 30 m. Muddy fine sand occur mainly in the southern North Sea at 30-50 m depth and in the western part of the northern North Sea. Typical species were *Eudorella truncatula, Glycinde nordmanni* and *Harpinia antennaria*, and in the southern North Sea *Callianassa subferranea, Nucula nitidosa, Chaeropterus variopedatus* and *Synelmis klatti* (Künitzer *et al.* 1992). In the 2000 survey, species richness of both the infauna and epifauna showed a clear increase from south to north, while the abundance of infauna was highest in the southern and central North Sea and along the Dutch and German coasts.

In the 2000 benthos survey, the spatial distribution of the macrofaunal communities was generally rather similar to that in 1986 (Rees *et al.* 2007). The major divisions in the structure of the communities of the North Sea occurred at the 50 m and 100 m depth contours as before, but in some areas the fauna had changed. These areas included the eastern North Sea, where an increase in abundance of *Phoronida* and *S. bombyx*, and of the bivalves *Fabulina fabula* and *Corbula gibba*, the amphipod *Urothoe poseidonis*, and the brittlestar *Acrocnida* (*Amphiura*) *brachiate* had occurred. Rees *et al.* (2007) found that changes in community structure north of the 50 m depth contour could be related to changes induced by the North Atlantic Oscillation (NAO) which, in positive mode, results in an increase in sea surface temperature and changes in food availability, as described by Reid and Edwards (2001).

Kröncke *et al.* (2013) analyzed a time series of benthos data from the Frisian front in the southern North Sea and found large changes in the structure of the benthos assemblage caused by cold winters and by a general change in environmental conditions related to changes in the NAO and to global warming. Hiddink *et al.* (2015) studied changes in the distribution of 65 North Sea benthic invertebrate species from the1986 and 2000 surveys by examining their geographic, bathymetric and thermal niche shifts. Testing whether species tracked their thermal niche, they found that the distribution of most of the species shifted to the northwest and towards deeper areas as predicted, but less so than both seabed and sea surface temperatures would have suggested. Hiddink *et al.* (2015) therefore concluded that although the temperature increase did affect the distribution of the species, most of them lagged behind the movement of their thermal niche.

Künitzer et al. (1992) used ordination methods to identify indicator species for the macrobenthic assemblages in the eastern North Sea based on the 1986 survey. In the Danish North Sea area, seven faunal assemblages could be identified. The northernmost assemblage was found on coarser sediments and mainly at less than 30m of depth and was characterized by the indicator species *Aonides paucibranchiata*, *Phoxocephalus holbolli* and *Pisione remota* (assemblage 1b, Figure 11). To the south and at similar depths and sediment types this assemblage was replaced by an assemblage (1a) characterized by *Nethphys cirrosa*, *Echinocardium cordatum* and *Urothoe poseidonis.* The stations on fine sand at 30 to 70 m of depth were divided into stations on muddy fine sand south of the Dogger Bank (IIa) characterized by *Nucula nitidosa, Callianassa suibterranea and Eudorella truncatula,* and those on fine sand in the central North Sea (IIb) characterized by *Ophelia borealis* and *Nepthys longosetosa*. At more than 70m an assemblage characterized by *Minuspio cirrifera, Thyasira sp., Aricidea catherina, and Exogone verugera* was found. Species richness generally increased with depth, while biomass generally increased towards the shallower Southern North Sea.

There is generally little macrobenthos data available from the Danish North Sea area. Denmark did not participate in any of the North Sea benthos surveys and has only limited access to the data collected, only the southern part of the Danish area was covered by the 2000 benthos survey, and no systematically collected national Danish data could be identified from the area. The internationally coordinated 1986 survey covered most of the area except the Skagerrak.

In 2015, Denmark re-initiated monitoring of macro-zoobenthos in the open part of the Danish North Sea territory. Ten station grids were visited covering the area. Five station grids were transecting the North Sea area perpendicular to the Jutland coast going to the easternmost part of the Danish North Sea and another five stations following the Jutland coast from the German border to the Skagerrak. At each station grid, 42 individual haps samples were retrieved, each from individual positions. The positions of the stations correspond to the NOVANA monitoring program for water chemistry where the time series going back to the late 1980 ties. Data format is species specific abundance and biomass of macro-zoobenthos larger than 1 mm. Data is reported in Hansen et al. (2016) and shows that the diversity generally is low compared to the Inner Danish Waters such as the Kattegat. However, these data have not yet been compared to community distribution maps based on the 1986 North Sea survey. Another 10 stations have been sampled in 2016 following the same methodology but data have not yet been reported.

There is a concern whether Künitzer's classification is still valid today in the Danish waters, since it was 1) based on relatively few data and 2) changes must have occurred during the timespan of almost 25 years not least because of changes in human pressure. Therefore, a small exercise was carried out on new data from 2015 and 2016 using the method "Elements of Metacommunity Structure" to see if presence/absence data and species abundance aggregated at station level were randomly distributed according to depth and exposure. Unfortunately, there were no additional information on grain size distribution and carbon content in the dataset. The conclusion was that there is a significant grouping of presence/absence data, but this is not the case for species abundance data.

Based on this analysis it was therefore decided to handle the softbottom community in the North Sea and Skagerrak as consisting of two communities. A community at depths shallower than 50m and and a deep water community below 50m of depth.

Seagrasses and other submerged higher plant species are not present in the open North Sea and Skagerrak. This type of vegetation is only present in the Wadden Sea area, and the fjord areas bordering the open North Sea.

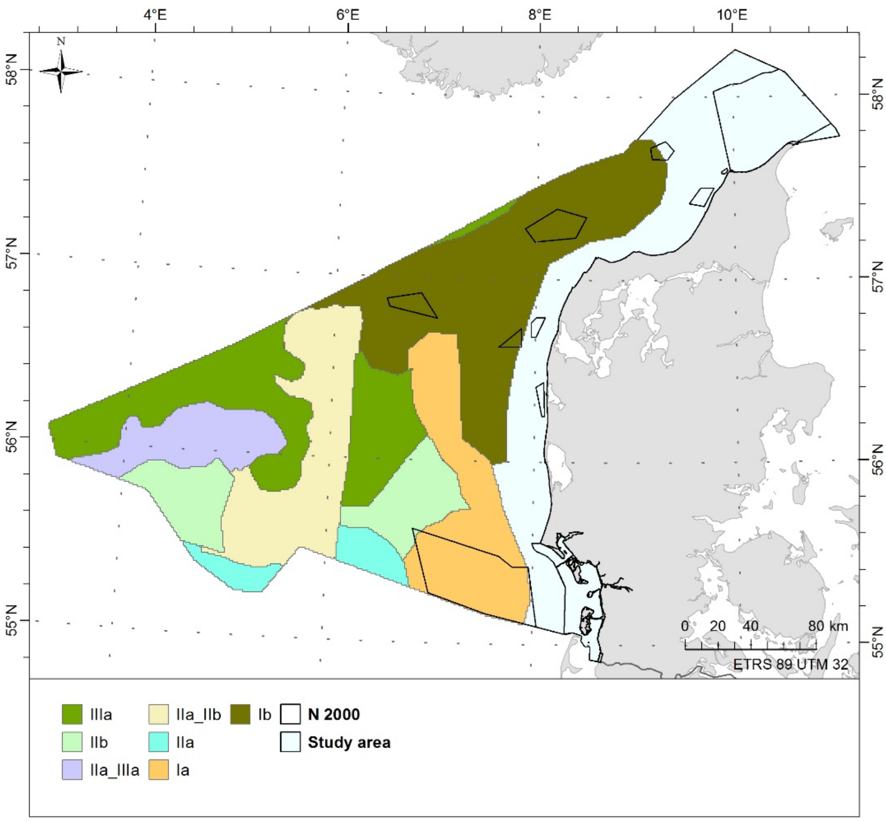


Figure 11 Fauna assemblages. Ia: Nepthys cirrosa, Echinocardium cordatum, Urothoe poseidonis; Ib: Aonides paucibranchiata, Phoxocephalus holboelli, Pisione remota; IIa: Nucula nitidos, Calianassa subterrenea, Eurorella truncata; IIb:Ophelia borealis, Nephtys longosetosa; IIIa: no indicator species (modified from Künitzer et al. (1992)).

3.1.7 Hard bottom communities

Hard bottom communities are strongly associated with a substrate capable of anchoring key species of algal or fauna. Those key species, as well as the substrate, typically make up a distinct habitat for a number of other species. This may be other algae or sessile fauna species growing on the species anchored to the sediment, it may also be pelagic or semi-pelagic fauna species feeding, breeding or hiding among the sessile biota and all together they form specific communities. A special type of reef formed by mussel-beds (biogenic reef) differ in the sense that the mussels themselves are both a key species and at the same time form the substrate on which other species anchor; or the physical structure is used by free moving species to hide.

Hard bottom communities dominate the rocky North Sea coastline off Norway and northern UK, but are also found on reefs located offshore. The substrates hosting hard bottom communities in the Danish part of the North Sea and Skagerrak may be gravel, larger boulders, wrecks or the special chalk formations called “bubbling reefs”. To be able to host a fully developed hard bottom community, the substrate has to lay stable on the seabed. In shallow open waters this means big boulders, whereas gravel is sufficient in deeper areas. Strong physical impact by breaking waves in the coastal zone and frequent burial of migrating sand banks are natural factors that may hinder the development of a mature community structure in shallow areas.

Quantitative information from scientific papers on hard bottom communities in the Skagerrak and North Sea is restricted to one study by Christie et al (2009), who describes the species composition of fauna in macro-algae vegetation in the Skagerrak and documents high individual numbers of some species. Species lists are available from Helgoland in the southeast corner of the North Sea (Harms, 1993 and Reichert & Buchholtz, 2006), and a book on Norwegian fauna by Moen and Svendsen (2014) also covers the North Sea and Skagerrak area. Information on distribution of biomass and numbers of hard bottom species living beneath the photic zone in the Skagerrak and North Sea was not found during a minor literature review.

Information on Danish hard bottom communities on geogenic reefs exists based on two different data sources: 1) dive observations collected as part of the national monitoring program NOVANA at two reef locations Knude Grund and Lønstrup Rødgrund, both located in Skagerrak southwest of Hirtshals and 2) a large number of drop video transects or ROV video points conducted as part of the reef and sand bank mapping exercise in 6 Natura 2000 areas in Skagerrak and the north eastern part of the Danish North Sea (Al-Hamdani et al, 2015).

Based on an evaluation of the collected data, broad scale hard bottom communities and their depth range have been defined. The spatial distribution of those communities are modelled by overlaying the information on the vertical distribution with information on bathymetry as well as the distribution of the geological “till” and “rock” layers presented in Figure 2.

Hard bottom communities in the photic zone typically include macro-algal species. If the light is sufficient, the algal vegetation typically dominates the biomasses in the North Sea and Skagerrak area. Algal dominated communities are mapped and monitored at a few locations in Skagerrak at Lønstrup Rødgrund and Knude Grund. The spatial distribution of algal dominated hard bottom communities is quite small at those two reef locations and is hardly recognisable on the maps (Figure 12) due to scaling and use of average depth within the grid cells. The algal communities on both reef sites are dominated by the large brown species *Laminaria Hyperboria* and *Desmarestia aculeate* together with red filamentous and some red leaf forming algal species.

The lower vertical depth limit of the algal community in Skagerrak is estimated at a maximum depth of 11.5 m in a zone up to 2.5 km from the coast and to a maximum depth of 13.5 m further off-shore, where light conditions are better because of less turbidity. This estimate is based on observations made in the NOVANA program with positive observations and a larger number of mostly deep video transects during a mapping exercise in the Natura 2000 sites. Due to the large horizontal and vertical distribution of observations, a suggestion for a finer graduation is not possible and therefore the upper depth limit of the community is not established. However, reefs are not mapped in shallow waters along the coastline; therefore the upper limit of the specific vegetation community is not important.

Other algal dominated reef areas are likely to exist along the coastal zone of the Danish North Sea (Figure 12). It is assumed that the algal community is more or less the same as in the Skagerrak due to comparable light and salinity conditions; however, there are no data that can confirm our assumption.

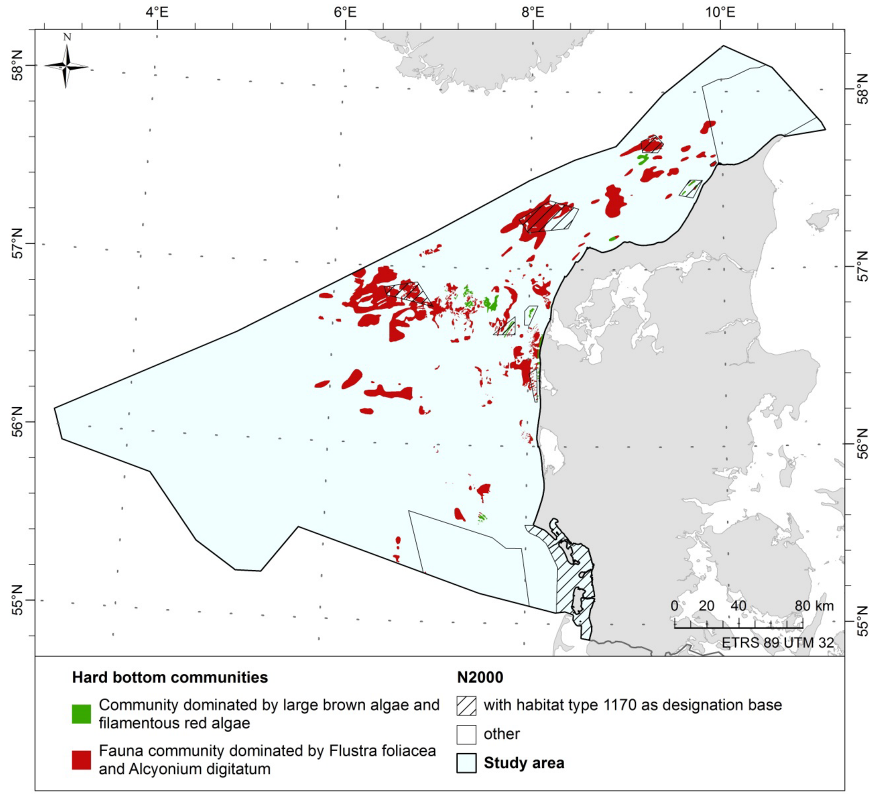


Figure 12 Distribution of broad scale hard bottom communities in the Danish North Sea and Skagerrak. The classification is based on drop-video transects, ROV video points and diver observations and transposed on hard till substrate areas provided by Al-Hamdani et al, 2015. The report is published in 2015, but the data is from 2014. From 2015 onward data are not included in this map.

Hard bottom communities below 11.5 and 13.5m water depth in the Skagerrak and in deeper waters in the North Sea are dominated by the soft coral “Dead man’s finger” (*Alcyonium digitatum*) and the leaf formed bryozoan *Flustra foliacea*. In the upper zone algae might occur as well and associated fauna organism include different types of hydrozoan, sea-urchins, *Cancer pagurus* and other crustaceans as well as sea anemones. A striking observation from video and ROV transects is a high number of large gadoid fish species at reef locations in the Skagerrak and North Sea compared to reefs in the Kattegat, the Belt Sea and western Baltic Sea. Biogenic reefs of blue mussel beds in the Wadden Sea host a community very different from the deep fauna and shallow geogenic reef communities.

Figure 13 Left: Algal community with the brown kelp species *Laminaria hyperborea* and different species of red algae. Right: Fauna community with the leaf formed bryo-zoan Flustra foliacea and the soft coral "dead man's finger" (*Alcionium digitatum*)

3.1.8 Fish

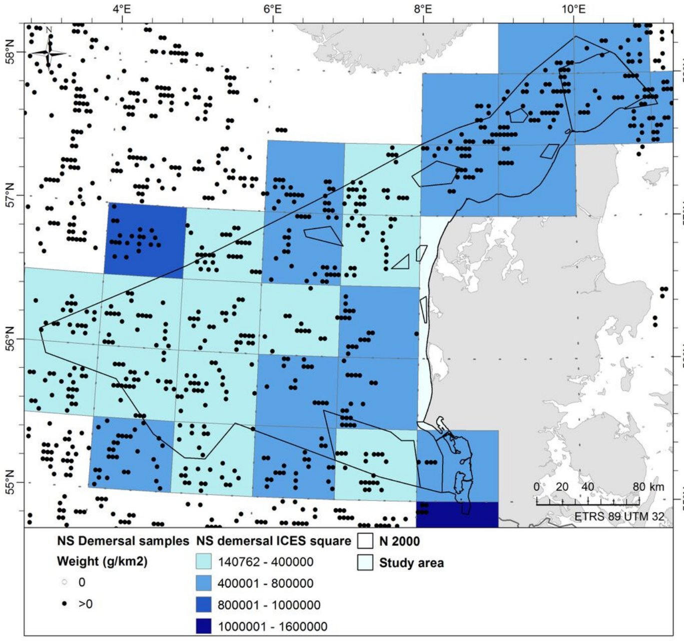
More than 200 different species of fish have been recorded in the North Sea, but many of these are rarely caught. Most species are found in the western North Sea, in the Skagerrak, and along the Norwegian trench where the catches consist of a mixture of deep-water species and species found in shallow water (Heesen *et al.* 2015). The most abundant species such as herring, sandeel, sprat, and Norway pout feed on zooplankton and constitute the link from the primary producers, to fish eating species, and to top predators such as marine mammals, seabirds and sharks. The smaller fish eating species, such as whiting, as well as some migratory species, such as horse mackerel and mackerel, that enter the North Sea during summer, all feed on the plankton eating fishes and on juvenile fish. Others, such as the flatfishes, haddock and grey gurnard, feed on benthos and other prey living on or close to the seabed. The larger species such as cod and saithe include increasingly larger fish in their diet as they grow.

Most fish species produce tiny eggs of approximately one mm in diameter and after hatching the larvae are found drifting in the water column where they feed on zooplankton. The life history of fishes often consists of a migration to a suitable spawning ground, a passive larval drift to the nursery areas, where the juveniles are found and, when the juveniles reach a suitable size, an active migration to join the adult stock in its migrations between feeding and spawning areas (Harden Jones, 1968). Many of the most abundant species follow this pattern, but there are also species which depend on particular bottom habitats, such as reefs (e.g. wrasses), sandy (e.g. sandeel), or muddy sediments (e.g. snake blenny) during much of the juvenile and adult parts of their life. Often the smaller individuals are found in shallower waters than the larger ones.

Comparison of fish species on soft and hard bottom habitats shows that both biomass and number of individuals are significantly higher on hard-bottom habitats. Several fish species are attracted to hard bottom habitats, either because of the substrate for spawning of demersal eggs, or for feeding on benthic hard-bottom species, or shelter from predators and from currents. Algal canopies such as kelp forests forming on these hard-bottom substrates generally increase fish biodiversity further. Typical species of fish in or around hard-bottom habitats belong to the family of wrasses (Labridae), gadoids (Gadidae) or sculpins (Cottidae). Cod has been found to occur in significantly higher numbers close to reefs and artificial reefs, but their occurrence may vary seasonally due to life-history events such as spawning, where they migrate to distinct spawning areas. In the northern Kattegat area, cod, shorthorn sculpin and goldsinny wrasse have been observed to occur in higher densities close to wind turbine foundations (Bergström et al. 2013). This was most obvious for the larger cod (>37 cm).

The fish fauna of the North Sea has undergone large changes that have been linked to changes in environmental parameters and exploitation. In response to the warming of the North Sea many species have shifted their distribution northwards (Perry *et al.* 2005) and to deeper and colder waters (Dulvy *et al.* 2008), while exploitation generally has reduced the abundance of the larger, late maturing species (Daan *et al.* 2005, Sguotti *et al.* 2016). Increased abundance of southern species, such as red mullet, anchovy, and sardine in the survey catches has been linked to increasing water temperatures, although prey releases due to predator removals may also be implicated (Daan *et al.* 2005). The warmer climate and low zooplankton abundance (particularly of *Calanus finmarchicus*) have, together with excessive fishing, been implicated in the decline of North Sea cod before 2007 (Beaugrand et al., 2003; Drinkwater, 2005; Rindorf and Lewy, 2006). ICES(2017) examined the distribution of the major commercially exploited fish species in the North Atlantic and found changes in distribution for 18 out of 21 stocks examined, with the main drivers being changes in environmental conditions (mainly temperature, all species).

Figure 14 shows the distribution of the catch per km^2 swept of demersal and pelagic fish in the Danish North Sea area respectively, based on standardized catch rates per ICES square obtained during the International Bottom Trawl Survey (IBTS), averaged over 2001-2016, and converted to g/km2. Most of the demersal biomass is concentrated in the northernmost part of the area, but there are also local concentrations in both the central and southern part of the area, while for the pelagic species, mainly herring and sprat, the major concentrations are found in the central part of the area. Maps of the average abundance of the individual species accounting for 80% of the biomass observed are shown in Figure 15 to Figure 23 , expressed as N/km^2 per ICES rectangle, the number of individuals caught per km^2 swept in each square by the trawl during the IBTS. In addition, the catch rates from the Danish sandeel fishery are shown in Figure 24 based on VMS positions, landings, and logbook recordings from the Danish industrial Fleet. Herring and mackerel are abundant in the northern and central part of the Danish area, while sprat is found only in the southern part. Among the demersal species, dab is widely distributed, while most of the other species exhibit a peak in abundance in the northernmost area, or are largely absent from the shallow southern part, e.g. saithe.



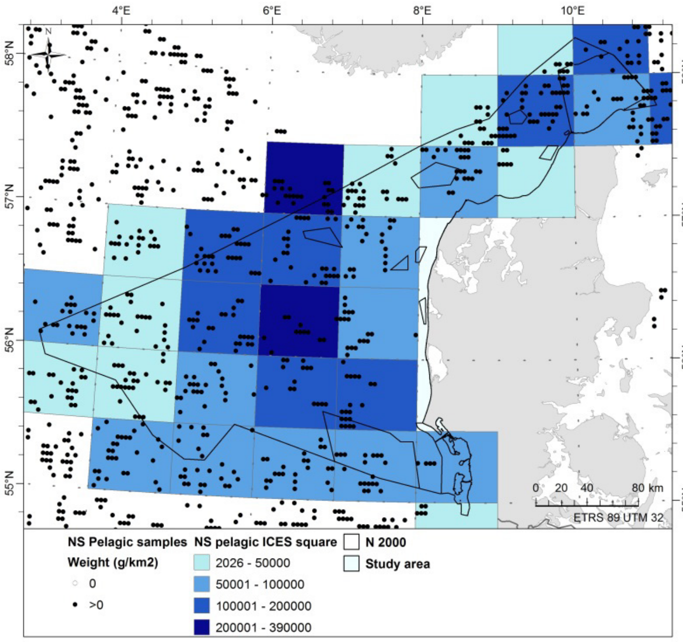


Figure 14 Relative distribution of catch in g per km2 swept (2001-2016) of demersal (top) and pelagic (bottom) fish in the Danish North Sea and Skagerrak. Source: ICES DATRAS survey database

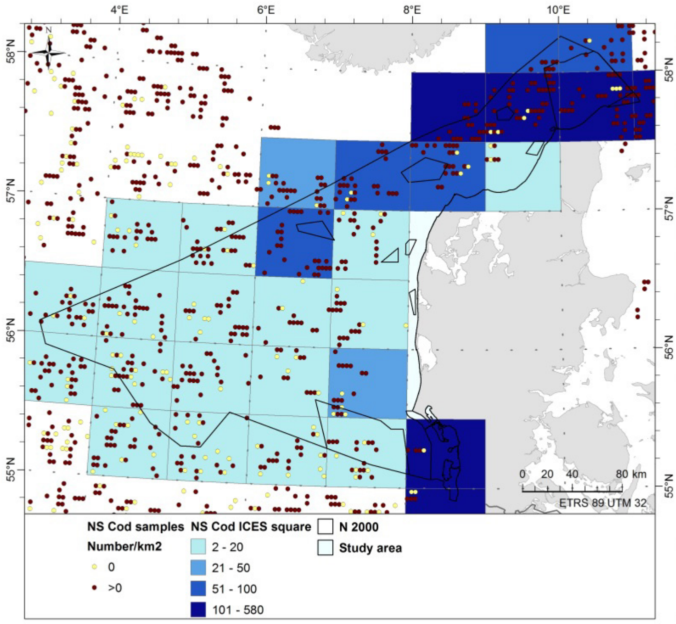


Figure 15 Cod. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

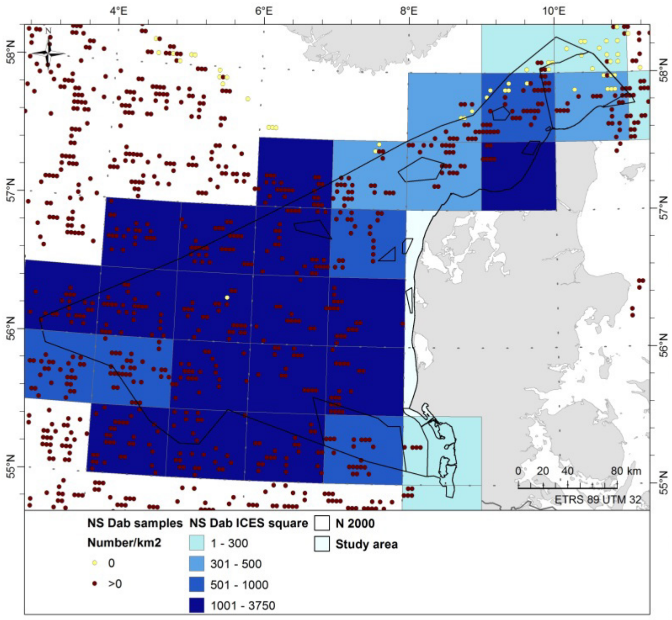


Figure 16 Dab. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

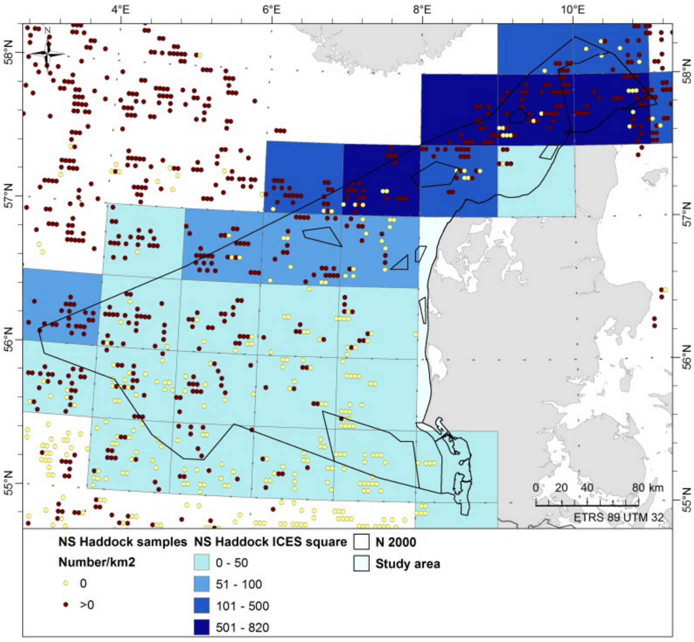


Figure 17 Haddock. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

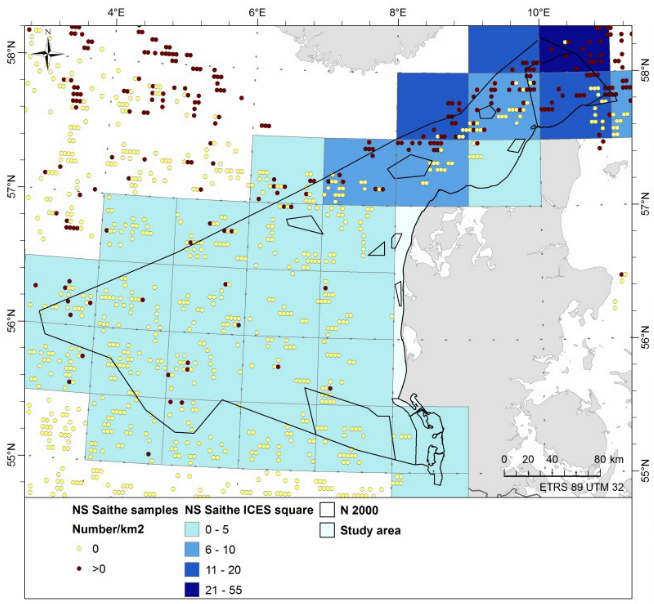


Figure 18 Saithe. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

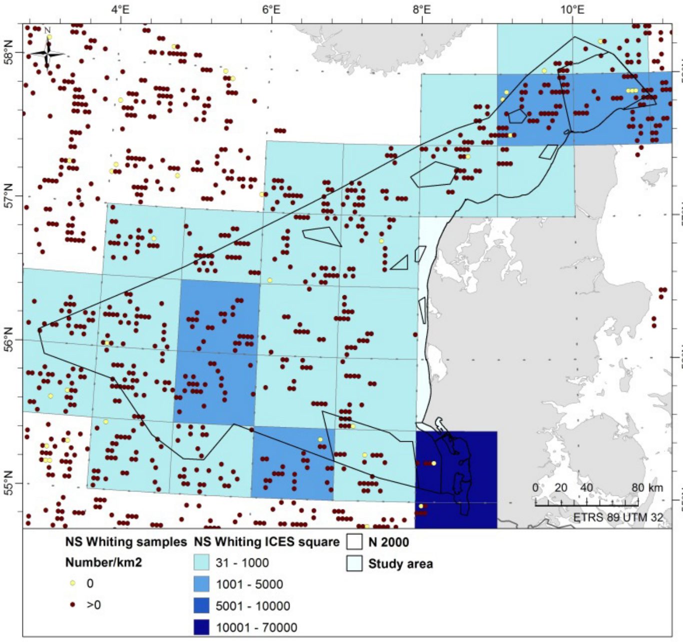


Figure 19 Whiting. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

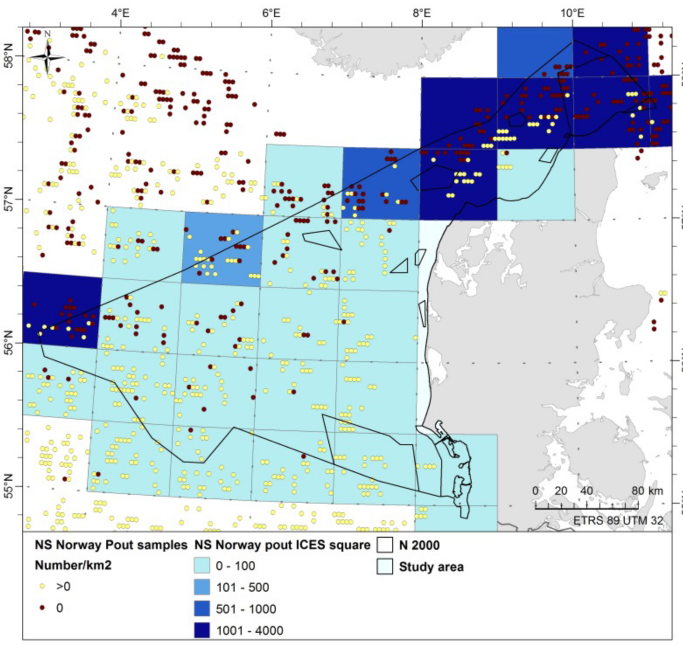


Figure 20 Norway pout. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

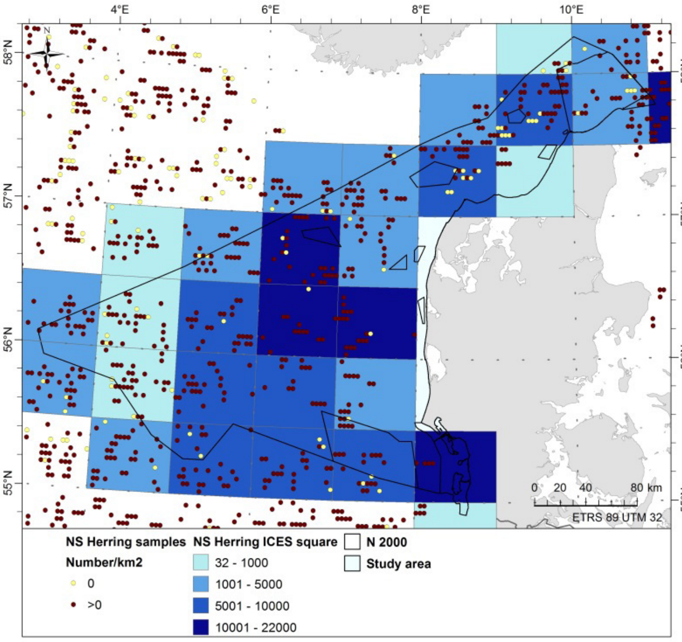


Figure 21 Herring. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

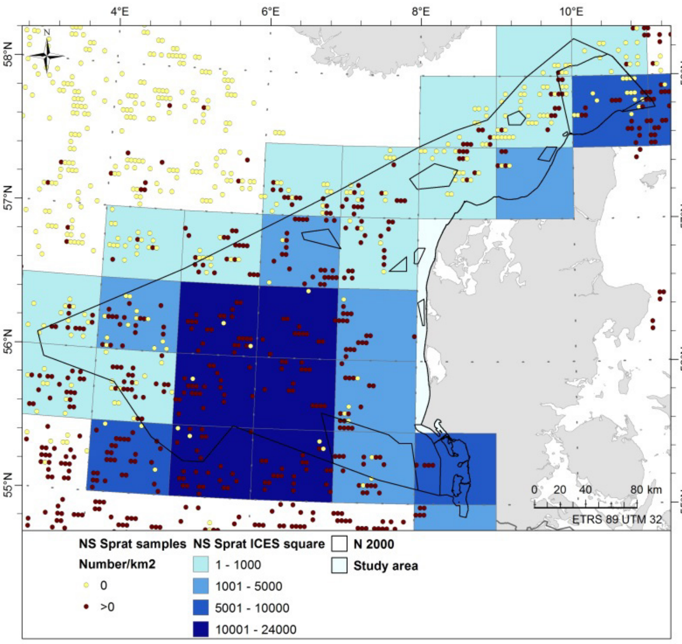


Figure 22 Sprat. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

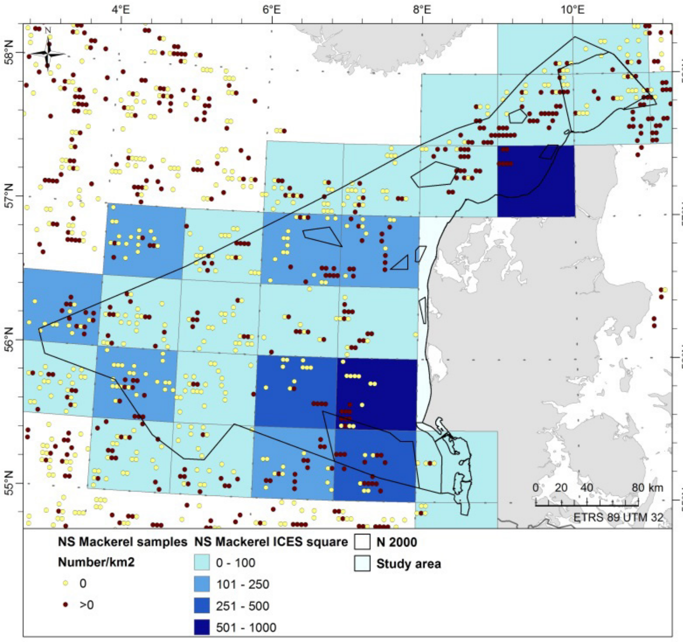


Figure 23 Mackerel. Relative density (average No caught/km2 in quarters 1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence), Source: ICES DATRAS survey database.

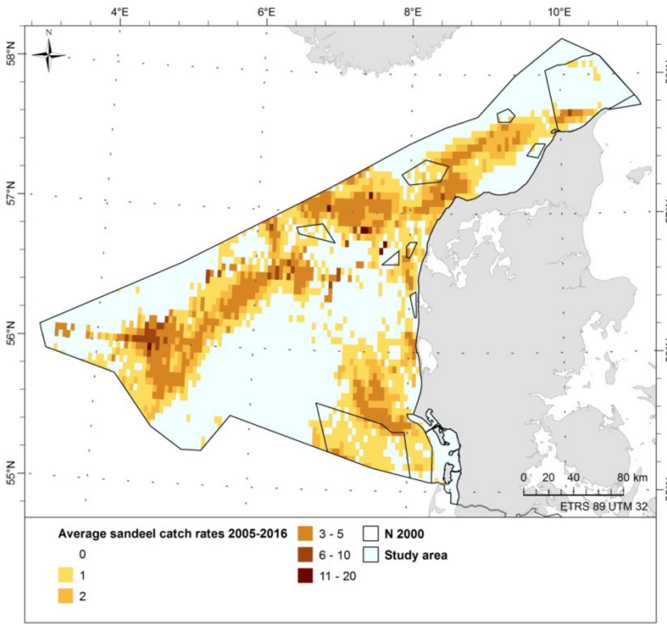


Figure 24 Sandeel. Relative catch per unit of effort in the Danish sandeel fishery (tonnes per standardized unit of effort over the period from 2005 to 2016) (source DTU Aqua).

3.1.9 Seabirds

At least 19 species of seabird breed on the coasts of the Greater North Sea, in particular large numbers of northern gannet *Morus bassanus*, herring gull *Larus argentatus*, lesser black-backed gull *Larus fuscus*, black-legged kittiwake *Rissa tridactyla*, and common guillemot *Uria aalge* (ICES 2016). Most of these species breed in dense colonies along the coast, where they depend on local feeding conditions within tens of kilometers around their colony. Others may cover several hundreds of kilometers during their foraging trips.

Outside the breeding season, some species stay quite close to their breeding grounds whereas others migrate across the North Sea or travel elsewhere, even as far as the Antarctic (ICES 2008).

During the non-breeding season the North Sea is used as a staging and wintering, both by the breeding species and by migratory birds. Immigrants during winter mainly arrive from the north and east. Numbers of some of these migratory species have been declining, possibly due to milder winters, providing the species sufficient food to remain in waters closer to their breeding grounds (ICES 2016). Feeding habits differ from species to species (ICES 2008). Auks and cormorants dive from the surface, gannets and terns use plunge diving, and gulls, kittiwakes and fulmars feed mostly on the surface, while skuas are kleptoparasites (Dunnet *et al.* 1990).

The food resources available to the birds vary accordingly, ranging from plankton to small schooling fish and discards. Because of all these differences, seabirds differ in their response to environmental change and to human activities such as fishing. Some species profit directly from human consumption fisheries, by feeding on either discards or offal, e.g. gulls, kittiwakes and fulmars. The current seasonal distributions, status, and trends of the species are well known and documented. Broadly, the numbers of breeding seabirds increased until about 2000, after which a decline has been observed (ICES 2016). Historically, many species were hunted or had their eggs collected and when this stopped the populations rebounded, but other factors may also have been important. Fulmars may thus have benefitted from the increase in fishing and availability of discards and skuas may have profited directly from the generally increasing abundance of seabirds (Bicknell *et al.* 2013).

In recent years the local breeding success of some of the species has been low. This has been related to local shortages of forage fish. Although the industrial sandeel fishery has been mentioned as the cause of some of the decrease, there is only limited evidence to support a direct link (ICES 2008). The current view is that natural (or perhaps climate-change induced) variation in sandeel recruitment is largely responsible (ICES 2016).

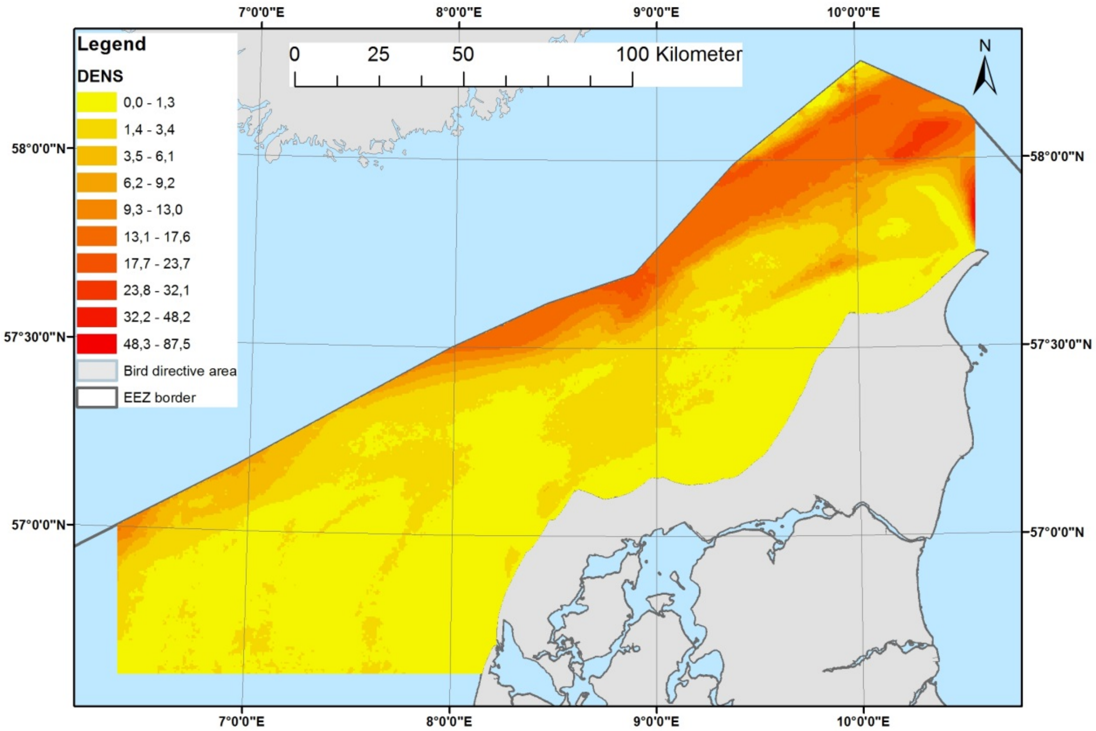


Figure 25. Modelled abundance and distribution of Fulmars in the northern Danish North Sea on 6th August 2006. Total estimation of numbers for the area was 68,175 individuals.

Seabird distributions have been described in a number of publications (Tasker et al. 1987, Skov et al. 1992, Stone et al. 1995, Laursen et al. 1997, Petersen et al. 2006, 2010). Data on seabird distributions in the western part of the Danish North Sea was mainly collected more than 20 years ago. In the area around Horns Reef off Blåvand waterbirds have been monitored intensively in relation to the construction of offshore wind farms in the area (references). The general southern part of the Danish North Sea (including the Birds Directive site nr. 113) has been monitored for birds 10 times since 2002. The northern part of Danish North Sea was surveyed five times in 2006 to 2008, and the central, eastern North Sea from coast of Jutland to approximately the 40 m depth contour was surveyed three times since 2013.

The species presented here are selected either because they are abundantly present in the area, because they listed in Appendix I of the Birds Directive and/or because they appear in numbers of international importance.

In 2006-2007, four aerial surveys of birds were conducted in the northern parts of the Danish North Sea (Figure 26). The surveys were carried out as Distance Sampling line transect surveys (Buckland et al. 2001). Estimated numbers of Fulmar and spatial model of the distribution of the Fulmars was carried out (Petersen 2008, Figure 25). High concentrations of Fulmars were recorded during the late summer and early autumn. The highest densities were recorded in the northern and western parts of the area, where hydrographical conditions create up-welling of nutrient waters. During three surveys in 2007 total numbers of between 18,463 and 86,107 Fulmars was estimated. The distribution of an estimated 68,175 Fulmars in the northern Danish North Sea is illustrated in Figure 25.

Great Skua appears in the study area in varying numbers. Highest numbers are found in the late summer and early autumn (Tasker et al. 1987, Stone et al. 1995, Skov et al. 1995). The species winters primarily off the northwestern coasts of Africa and southwestern Europe as well as marine areas east of Canada (Magnusdottir et al. 2012). During surveys performed in 2011 to 2013 a maximum of 77 Great Skuas were recorded, leading to an estimate of a total of 1,241 individuals. The highest concentrations were the marine areas northwest of Skagen (Figure 26).

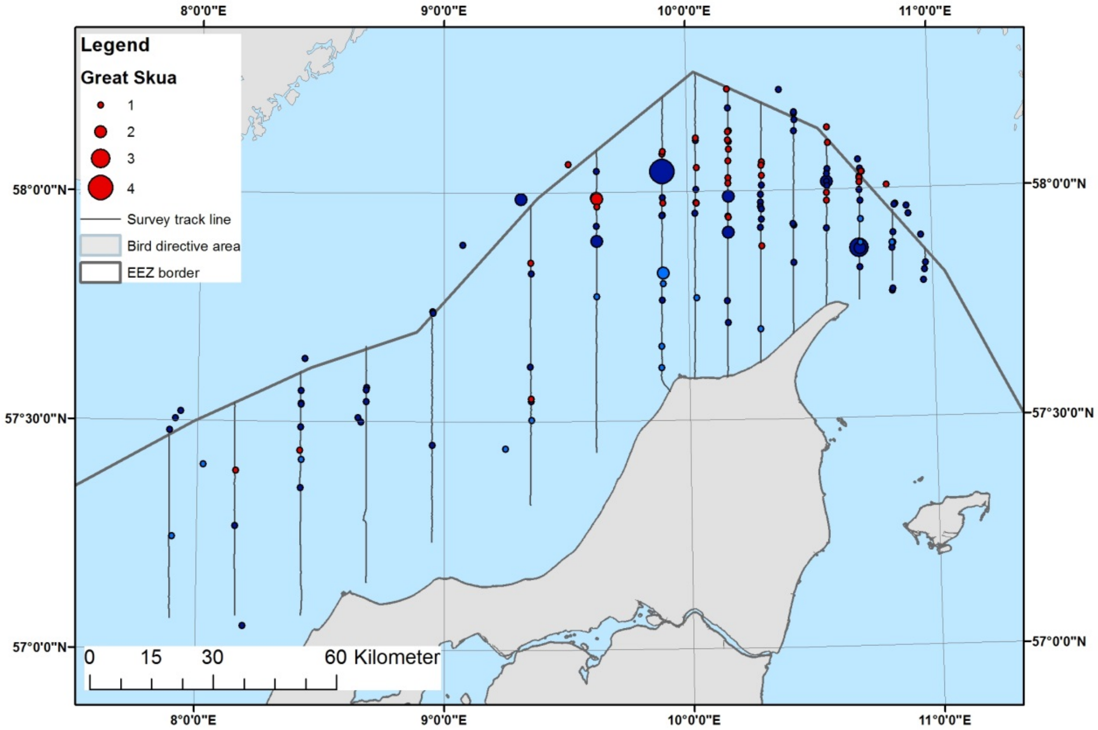


Figure 26. The spatial distribution of Great Skuas as observed during three surveys conducted in Skagerrak i the late summers of 2011-2013 (2011: Yellow, 2012: Red and 2013: Blue).

The distribution of divers in the Danish part of the North Sea was surveyed in April/May of 2016. A total of 171 individuals were recorded, of which 18.7 % were observed within the Birds Directive No. 113, southern Danish North Sea (Figure 27). The majority of the birds were Red-throated Divers. The western part of Danish North Sea was not covered. The distribution of the divers has been described to be associated with the saline fronts of the study area (Skov et al. 2001).

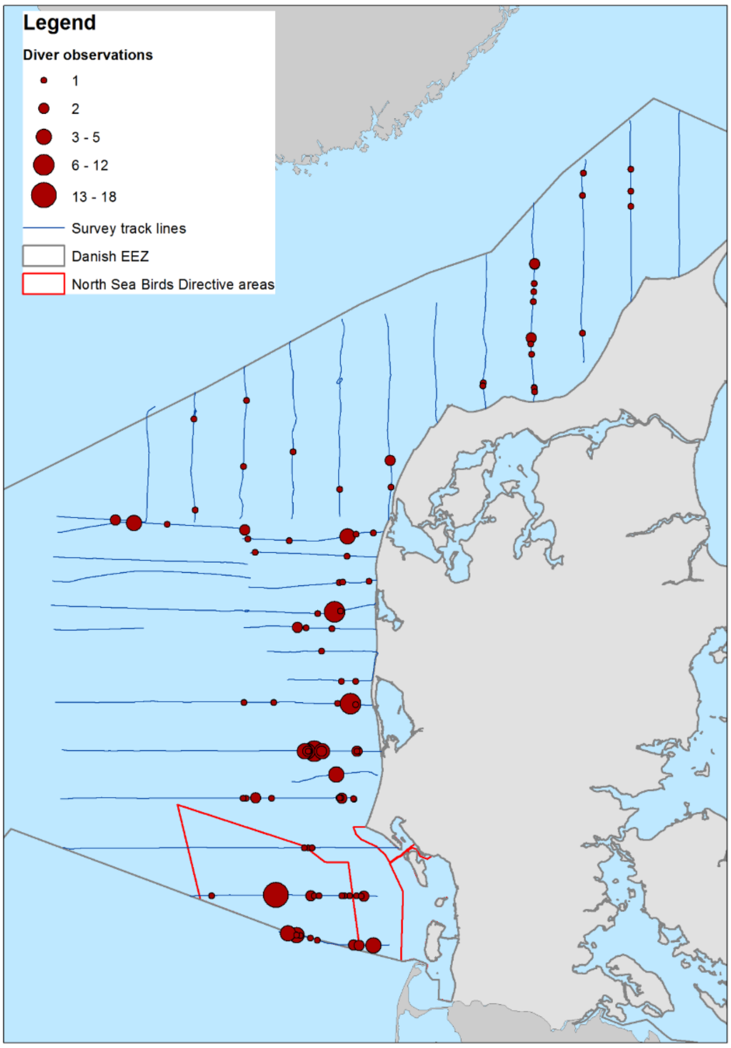


Figure 27. The spatial distribution of a total of 171 Red-throated/Black-throated Divers recorded during aerial surveys in the eastern parts of the Danish North Sea in April/May 2016.

The distribution of Common Scoters is primarily confined to near-shore areas in the eastern parts of the Danish North Sea. The majority of the birds are found off the southern parts, including Horns Reef (Figure 28), but shallow parts of the eastern North Sea, out to distances of almost 50 km from the coast hold concentrations of Common Scoters (Figure 29). Common Scoters feed intensively on the invasive American Razor Clam (*Ensis sp.*). The numbers of Common Scoters wintering in the Danish part of the North Sea seems to have increased since the early 1990-ies, with Horns Rev as the most important single site.

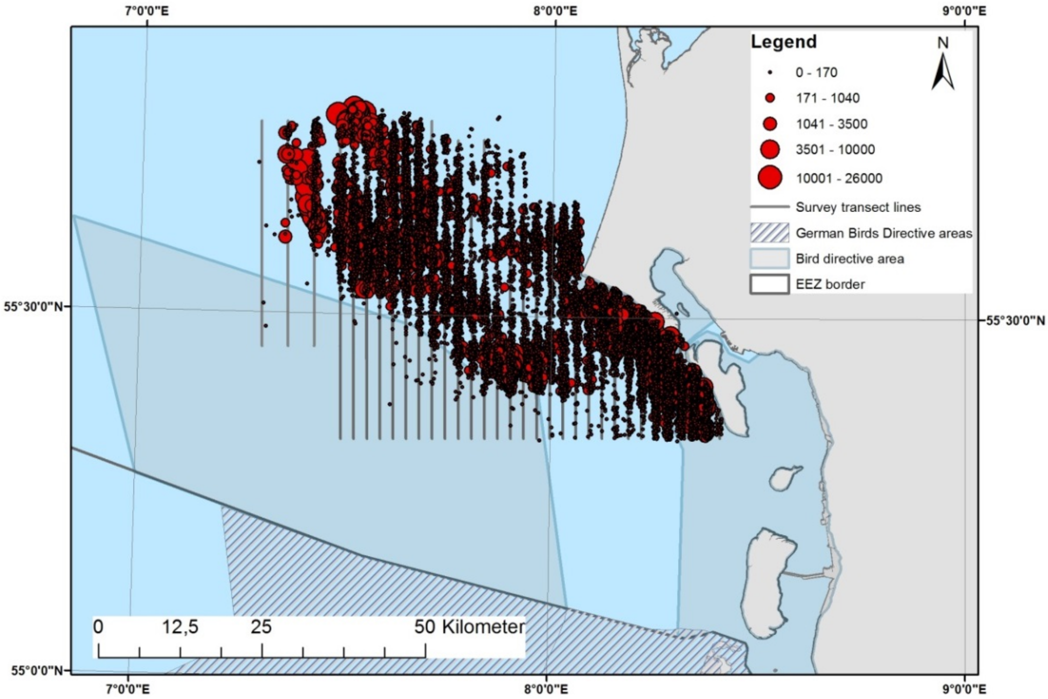


Figure 28. The spatial distribution of approximately 1.9 million observed Common Scoters at Horns Rev, cumulated across 50 surveys over a period from 1999 till 2011. Survey tracks and relevant Birds Directive areas are indicated, both on the Danish and German side of the border.

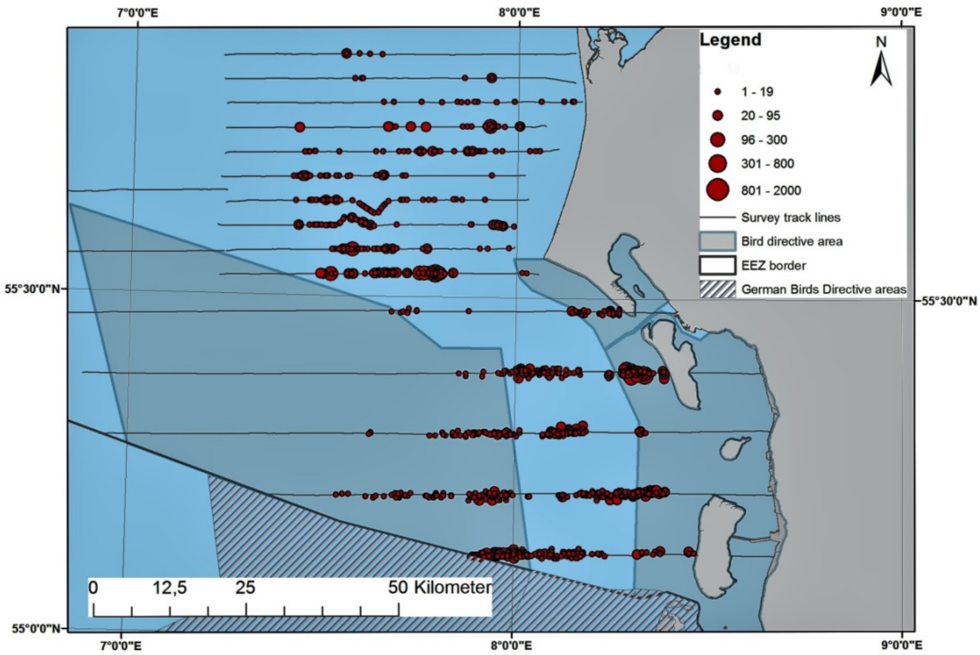


Figure 29. The spatial distribution of 14,354 Common Scoters observed in the southern part of the Danish North Sea during surveys of mid-winter waterbirds in 2013. Survey tracks and relevant Birds Directive areas are indicated, both on the Danish and German side of the border.

3.1.10 Marine Mammals

The marine mammals in the North Sea consist of two species of seal: grey seal *Halichoerus grypus* and harbour seal *Phoca vitulina*, and four species of cetaceans that occur commonly or are resident: harbour porpoise *Phocoena phocoena*, white-beaked dolphin *Lagenorhynchus albirostris*, bottlenose dolphin *Tursiops truncatus*, and minke whale *Balaenoptera acutorostrata*. In addition, there are at least five less common species that occur regularly: short-beaked common dolphin *Delphinus delphis*, Atlantic white-sided dolphin *Lagenorhynchus acutus*, long-finned pilot whale *Globicephala melas*, killer whale *Orcinus orca*, and Risso's dolphin *Grampus griseus* (ICES 2016).

Over the past century both seal species have both undergone large population changes. In the 1970s, the abundance of harbor seal reached an all-time low, but after it was nationally protected it subsequently increased steadily at an annual rate of 4%. This increase was, however, interrupted by major outbreaks of the phocine distemper virus (PDV) in 1988 and 2002. Declines in the harbor seal population have occurred over the last 15 years in the northwestern North Sea. The reasons for these recent declines are unknown, although they are thought to be different in different areas. Grey seals occur predominantly along the British coasts of the North Sea and have been increasing at an annual rate of up to 10% (ICES 2015).

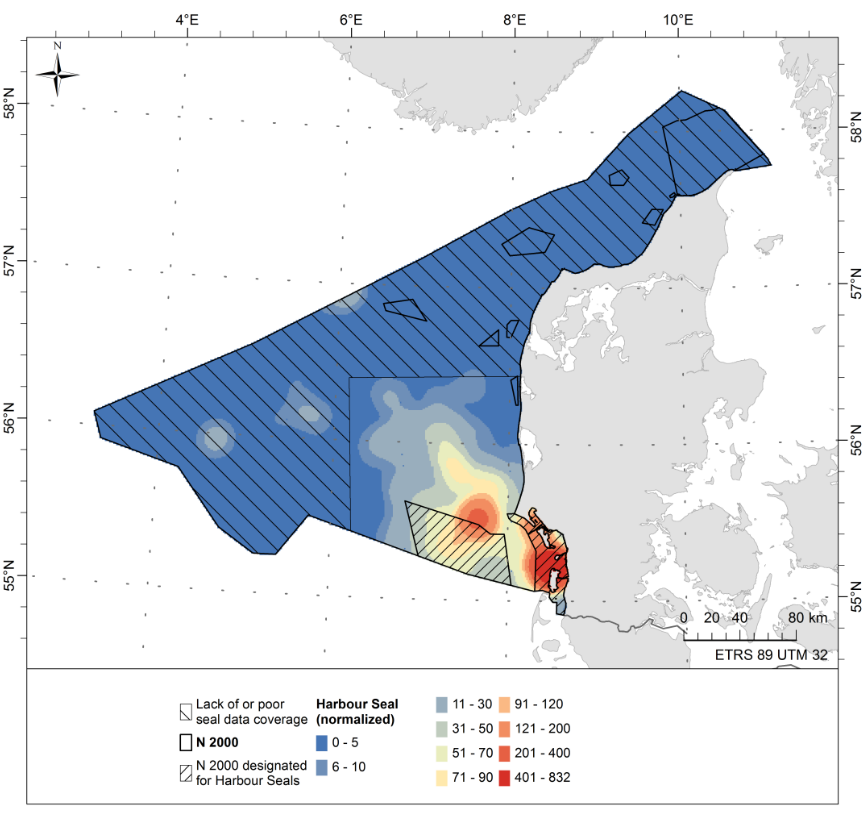


Figure 30 Distribution of 21 satellite tracked harbour seals displayed as Kernel Density Estimates with values normalized to 1 mill. (2002-2005). Shaded area indicates areas with lack of or poor coverage of seal distribution data.

Both seal species are found in the Danish part of the North Sea and Skagerrak, where they breed and haul out in larger numbers in the Wadden Sea as well as in the western part of Limfjorden. Single seals or smaller groups are also seen resting along the western coast of Jutland including Skagen Gren. Data on abundance are available from annual counts of seals at haul outs during breeding and molding. Data on distribution at sea (including hot-spots and potential foraging areas) is only available for the harbour seals residing in the Wadden Sea. Here, 21 harbour seals were tracked with Argos satellite transmitters or GPS/GSM transmitters in 2002 – 2005 (The transmission period: 5-213 days). The data were filtered to one position per animal per day was extracted. For all positions, kernel densities with a radius 20 km were calculated (Figure 30). The combined dataset was normalized to sum up to the value 1 mill. The 21 harbour seals moved up to 321 km away from the tagging site in the Wadden Sea, but did not distribute evenly but spend most time in or near the Wadden Sea and at Horns Reef northwest of the Wadden Sea. 80% of all locations were observed within 112 km of the tagging site. It should be noted that the telemetry data are rather old and that 21 individuals may not be representative for the entire population.

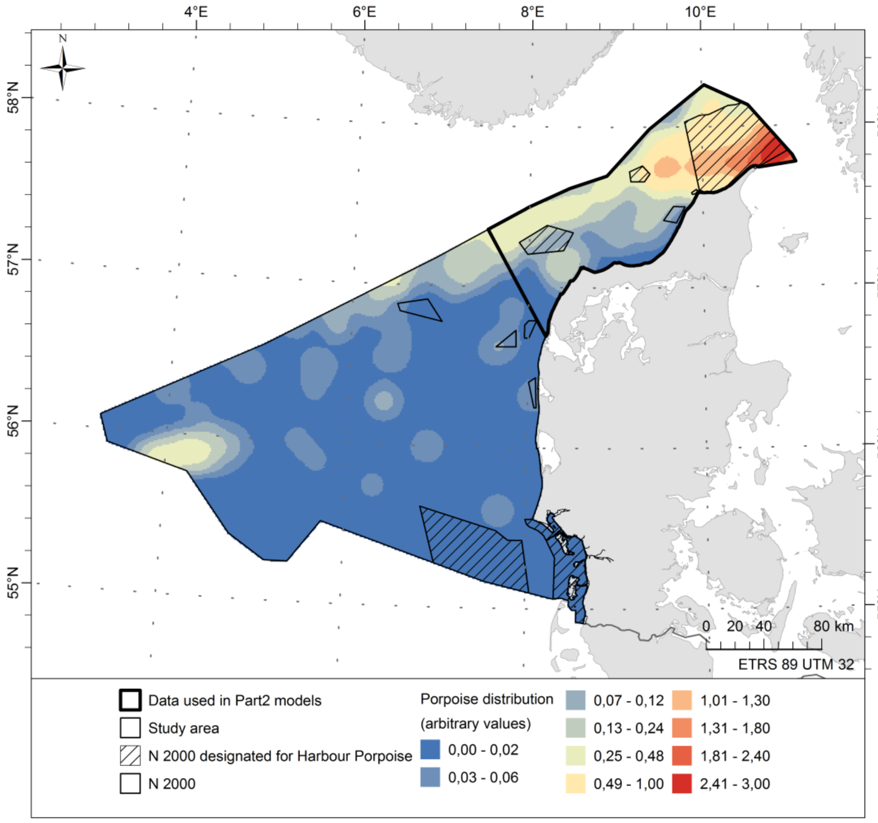


Figure 31. The relative harbour porpoise distribution derived from Kernel density estimates (KDE) calculated from satellite tracking data from harbour porpoises tagged in Danish waters 1997-2016 in Skagerrak. SACs designated for harbour porpoises as well as the area in which the telemetry data are used in the part 2 modelling is indicated. The dataset was normalized to sum up to the value 1 mio.

Several other groups or subpopulations of harbour seals are known to inhabit the Danish North Sea and Skagerrak e.g., seas from the Western part of Limfjorden. Their main activities are believed to be foraging, socializing and resting along the coastline of Jutland. However, there are no telemetry data to illustrate the distribution of these animals. Thus the current distribution as illustrated in Figure 30 is only representative for the southeastern part of the Danish North Sea and work is in progress to try and add aerial survey data to our current knowledge within this project. There is no available information on grey seal distribution in the North Sea and this species is therefore not included in the North Sea part of this project.

The harbour porpoises residing in the North Sea, Skagerrak and the Northern Kattegat belong to a genetically distinct population separate from the porpoises in the inner Danish waters (e.g. Sveegaard et al. 2015).There was no significant change in the abundance of harbor porpoise between the surveys in 1994, 2005 and 2016 (Hammond et al. 2017) although the center of summer distribution moved southwards, possibly in response to changes in availability of prey from 1994 to 2005 (Hammond et al. 2013). The distribution results from the SCANS-III survey in 2016 are not yet available. In the Danish part of the North Sea and Skagerrak, harbour porpoises are the most abundant cetacean and the only species included in the Danish Special Areas of Conservation network. Data on distribution in this area derives from two different sources 1) In Skagerrak, kernel density estimates (KDE) calculated from satellite tracking data from harbour porpoises tagged in Danish waters (all year, 1997-2016) (Figure 31) and 2) in the North Sea, seasonal habitat-based density models based on visual aerial surveys (For Denmark only summer distribution is reliable) (Gilles et al. 2016).

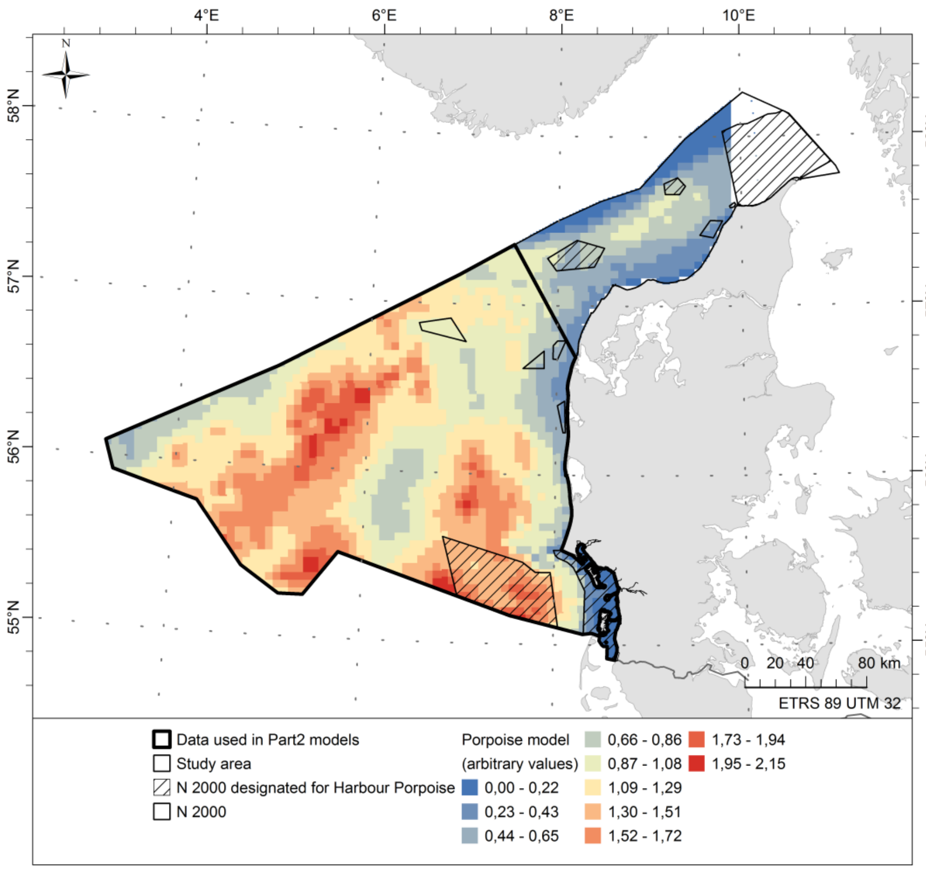


Figure 32 The relative harbour porpoise distribution derived from seasonal habitat-based density models based on aerial porpoise survey data in the North Sea (Gilles et al. 2016). SACs designated for harbour porpoises as well as the area in which the model data is used in the part 2 modelling are indicated. The dataset was normalized to sum up to the value 1 mio.

Each of the two datasets was normalized to sum up to the value 1 mill. None of the two dataset covers the entire North Sea study area and thus they are used separately with the satellite telemetry data covering Skagerrak (Figure 31) and the density model covering the North Sea (Figure 32). The two data sets show that harbour porpoises do not distribute evenly, but aggregate at the tip of Jutland and along the Norwegian Trench in Skagerrak as well as in several larger areas in the central and southern Danish North Sea.

Minke whales and white-beaked dolphins are found mainly in the northern North Sea (ICES 2015), but distribution models based on aerial surveys has suggested that the north-western part of the Danish North Sea may be a preferred habitat for both species and that the waters along the Norwegian Trench as well as the central Danish North Sea may be preferred habitats for minke whales (Figure 34).

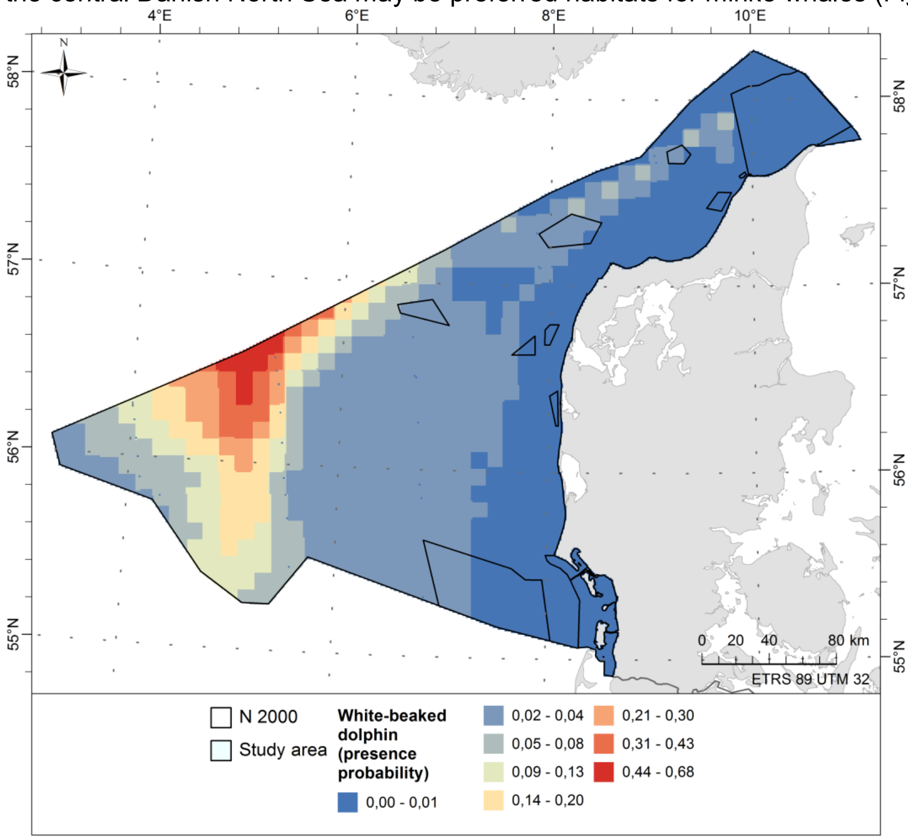


Figure 33 Probability of presence of white-beaked dolphins modelled using Multivariate additive regression splines (MARS) based on species observations (SCANS aerial surveys in 1994 and 2005 (2016 not included), both surveys were combined) and environmental predictors. The data was modelled and provided by HARMONY.

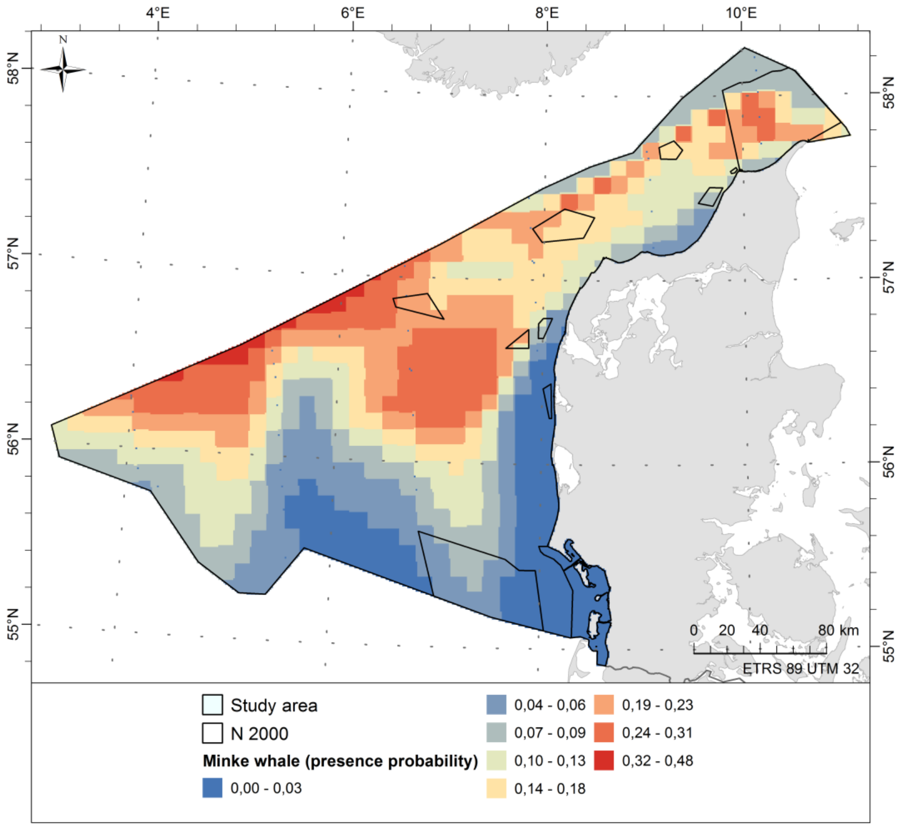


Figure 34 Probability of presence of minke whales modelled using Multivariate additive regression splines (MARS) based on species observations (SCANS aerial surveys in 1994 and 2005, both surveys were combined) and environmental predictors. The data was modelled and provided by HARMONY.

3.2 The present MPA network

The Natura 2000 sites are designated to fulfil obligations set by either the EC Birds Directive or the EC Habitats Directive with regard to specific species or habitats. The sites cover a total area of 12,679 km^2.

3.2.1 Habitats directive Annex I habitats

Eleven Natura 2000 areas (excluding those in the closed Ringkøbing Fjord, Stadil Fjord and Vest Stadil Fjord, Nissum Fjord and the Limfjord) are designated to protect habitats under annex I in the Habitat Directive. The spatial distribution of the different habitats being part of the designations is shown in Figure 1 and the sizes of both the Natura 2000 areas and the specific habitats within the MPA's are given in table 2. The habitat types "Estuaries" (EU code 1130), "Mudflats and sandflats not covered by seawater at low tide" (EU code 1140) (in short "Mud and sand flats"), "Coastal lagoons" (EU code 1150) and "Large shallow inlets and bays" (EU code 1160) are present in the North Sea and all are found within the Natura 2000 area in the Wadden Sea (table 3).

The habitat type "Sandbanks which are slightly covered by sea water all the time" (EU code 1110) (in short "sandbanks") is included as justification for designation in five Natura 2000 sites (table 2). The habitat "Reef" (EU code 1170) is part of the designation in seven of the eleven Natura 2000 areas. In the Wadden Sea, reefs are made up of beds of blue mussels (biogenic reefs), however, a definition of biogenic reefs in Natura 2000 areas is still under consideration in Denmark, therefore it is still not possible to estimate the present biogenic reef area for this particular Natura 2000 site. A new estimate shows that 16.6% of the reef areas are included in the joint North Sea and Skagerrak area excluding the biogenic mussel reefs in the Wadden Sea.

The reef areas with vegetation-dominated communities are in general small (Figure 12). Two broad scale hard bottom communities highly associated with “reef” have been classified based on the existing data. The present MPA network is estimated to include 11.9% of the shallow community “large brown algae and filamentous red algae” estimated for the total North Sea and Skagerrak area and 15.9% of the deeper epifaunal “Alcyonium and Flustra dominated community”. These estimates are subject to a high degree of uncertainty for several reasons. First of all there are uncertainties in the estimation of the total reef areas in the North Sea and Skagerrak, especially the areas outside the Natura 2000 areas and secondly bathymetric data used for the depth contours that distinguish the two broad scale habitats from each other, and to allocate them to specific areas, are sparse over almost the entire area.

Reefs are likely to exist in the Natura-2000 areas “Skagens gren og Skagerrak”, “Sandbanker ud for Tyborøn”, “Sandbanker ud for Thorsminde” and “Sydlige Nordsø” as “till” is present as surface sediment. However it is not at the moment part of the designation for those specific sites. The deeper fauna dominated reef areas extend far beyond the borders of the four Natura 2000 area “Jyske Rev”, “Store Rev”, “Gule Rev” and “Thyborøn Stenvolde”.

Submarine structures made by leaking gases (EU code 1180) (known as bubbling reefs) are present in two or more Natura 2000 sites in the North Sea and Skagerrak. The areas of bubbling reefs are small (Table 3), but several may be present within a location. Bubbling reefs are quantified by number and presented as points on maps. The zone where bubbling reefs occur is a band extending from the south-eastern part of the Kattegat to L.S and north-westward, past Jutland and out in the Skagerrak. One visually confirmed bubbling reef formation and one identified as likely are mapped outside the present Natura-2000 sites as well as a few more possible structures. Overall, most of today’s known bubbling reef structures in the Skagerrak are located within the present Natura-2000 area. The biota associated with deep bubbling reefs is more or less the same as biota on deep reefs.

Table 2 Annex 1 marine habitat types and their size within the ten Natura 2000 areas including benthic habitats designated by 2017. The habitat type "bubbling reef" is given as number of observations of structures or group of structures. The number in bracket indicates structures not visually confirmed (sources: Nicolaisen(2010), Al-Hamdani et al. (2015), and Seabed Habitat, EMODNet report(2016).

Natura 2000 site	Natura 2000 size (km^2)	Habitat types beeing part of the present designation.	Cover of habitats (km^2) (or number observed*) being part of the designation
Skagen Gren og Skagerrak (1)	2703	Sandbanks (1110)	501[8]
Knude Grund (203)	7.5	Reefs (1170)	5.2
Lønstrup Rødgrund (202)	93.2	Reefs (1170)	56.6
Sandbanke ud for Thyborøn (219)	63.3	Sandbanks (1110)	15.5
Sandbanke ud for Thorsminde (220)	63.5	Sandbanks (1110)	17.1
Thyborøn Stenvolde (H247)	78.0	Reefs (1170)	36.5
Jyske Rev og Lille Fiskebanke (248)	241.9	Reefs (1170)	153.8
Store rev (249)	108.9	Reefs (1170)	66.1
		Bubbling reef (1180)	5 (+4)*
Gule Rev (250)	472.6	Reefs (1170)	309.6
Vadehavet (89)	1511.6	Sandbanks (1110)	448.2
		Estuaries (1130)	0.3
		Mud and sand flats (1140)	409.4
		Coastal lagoons (1150)	3.5
		Large shallow inlets and bays (1160)	242.8
		Reefs (1170)	Biogenic reefs present but waiting accepted definition before areal calculation can be done
Sydlige Nordsø (240)	2,473.2	Sandbanks (1110)	Awaiting the result of the 2017 mapping

8 This is a primary result from existing data. We are awaiting the 2017 habitat mapping to get more information.

Table 3 Estimated areal distribution of six marine annex 1 habitats in total for the North Sea and Skagerrak (excluding Ringkøbing Fjord, and other closed fjord area) and mapped within Natura 2000 sites and the ratio of habitat presents within MPA's compared to likely area within this water body by 2017. Information on bubbling reefs is given for number of structures or group of structures observed and not for areas and the percentage cover by MPA's.

Habitat type	Area mapped within Natura 2000 Sites (km^2)	Total mapped and estimated area for the North Sea and Skagerrak (km2)	Percentage covered by MPA
Sandbanks (1110)	1271	7892	14[9]
Estuaries" (1130)	0.3	0.3	100
Mud and sand flats (1140)	409	409	100
Coastal lagoons (1150)	3.5	3.5	100
Large shallow inlets and bays (1160)			100
Reefs (1170)	590	3554	17
"Bubbling reef" (1180)	6 obs[10].	8 obs.	75

3.2.2 Habitats directive Annex II species

Of the eleven sites, five are designated for harbour porpoises (7111 km^2 in total), two are designated for harbour seal (6678 km^2 in total) and two for grey seals (3826 km^2 in total) (Table 8).

Table 4 Natura 2000 areas and the species they are designated to protect under the Habitat Directives Annex II.

Natura 2000 site	Natura 2000 size (km^2)	Species
Skagen Gren	2703	Harbour porpoise (1351)
Store Rev	108.4	Harbour porpoise (1351)
Gule Rev	470.6	Harbour porpoise (1351)
Vadehavet	1511.6	Harbour porpoise (1351)
		Harbour seal (1365)
		Grey seal (1364)
Sydlige Nordsø	2463	Harbour porpoise (1351)
		Harbour seal (1365)
		Grey seal (1364)

The only species for which the percentage of the species covered by the Natura 2000 sites can be calculated is harbour porpoise (Table 5). Here, the five designated areas cover 12.4% of the porpoises occupying the Danish part of North Sea and Skagerrak. Harbour seals haul out in the western part of Limfjorden and in the Wadden Sea. It is assumed, that the harbour seals in the western part of Limfjorden utilize the North Sea adjacent to the Limfjord mouth. Data on distribution of harbour seals from Limfjorden is however lacking and the species cover cannot be calculated. In the last decade, grey seals have been observed in the Wadden Sea and in Limfjorden. In 2015, 167 grey seals were counted in the Danish

[9] Including sands banks at at more than 20m water depth.

[10] 9 in total: (6 verified & 3 archived), as well as 3 potential (not counted) in StoreRev:1 verified in Kundegrund; 2 outside the Natura2000 area (named Boblerev1 & Boblerev2).

Wadden Sea (Hansen 2016) and 21 were counted in the western part of Limfjorden (DCE unpublished data). There are, however, no distribution data available so the species cover cannot be calculated.

Table 5 List displaying of marine mammal species inhabiting the North Sea and Skagerrak listed Habitat Directives Annex II, the number and size of Natura 2000 sites they are protected in as well as the percentage of the species covered by the Natura 2000 areas.

Species	Species code	Number of Natura 2000 sites	Natura 2000 size (km^2)	Species cover (%)
Harbour porpoise	1351	5	7256.6	12.4
Grey seal	1364	2	3974.6	Unknown
Harbour seal	1365	2	3974.6	Unknown

3.2.3 Birds directive

Two SPAs (special protection areas) designated under the Birds Directive are found in the marine parts of Danish North Sea, excluding the closed fiords of western Jutland."Vadehavet", SPA No. 57 the Danish Waddensee and Limfjorden, covers an area of 1,136.2 km^2, consisting mainly of tidal and near-shore marine areas. SPA No. 113 Sydlige Nordsø, in the southern Danish North Sea is an offshore site, covering an area of 2,473.2 km2 (Figure 35, Table 6 and Table 7).

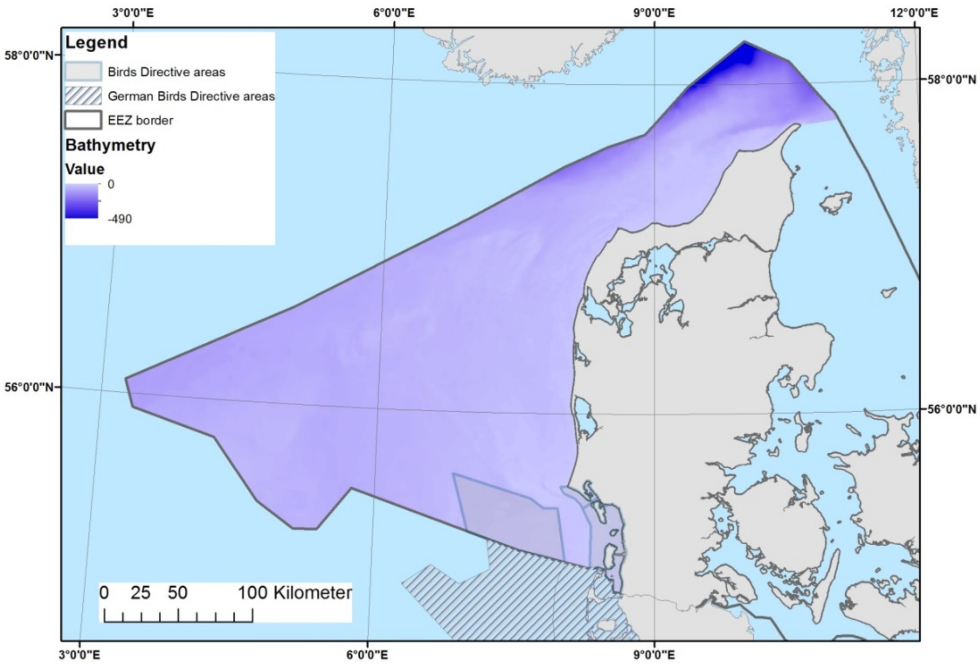


Figure 35 The Danish North Sea with indication of the two Birds Directive areas (blue line) designated in this region. The neighboring German Birds Directive areas are also shown (shaded area).

Table 6 List of designated species for the Bird Directive area No. 57, the Danish Waddensee, with details on designation status and criteria.

Annex 1 species according to art.4, par. 1	Other species, according to art. 4, par. 2	Breeding	Migrating
Barnacle Goose			International importance
White-tailed Sea Eagle			National importance
Hen Harrier			National importance
Peregine			National importance
Avocet		Breeding	International importance
Kentish Plover		Breeding	National importance
Golden Plover			International importance
Bar-tailed Godwit			International importance
Little Gull			National importance
Gull-billed Tern		Breeding	
Sandwich Tern		Breeding	
Common Tern		Breeding	
Arctic Tern		Breeding	
Little Tern		Breeding	
Short-eared Owl		Breeding	
Bluethroat		Breeding	
	Pink-footed Goose		International importance
	Greylag Goose		International importance
	Light-bellied Brent		International importance
	Dark-bellied Brent		International importance
	Shellduck		International importance
	Wigeon		International importance
	Teal		International importance
	Pintail		International importance
	Shoveler		International importance
	Common Eider		International importance
	Common Scoter		International importance
	Oystercatcher		International importance
	Grey Plover		International importance
	Knot		International importance
	Sanderling		International importance
	Dunlin		International importance
	Curlew		International importance
	Redshank		International importance
	Greenshank		International importance

Table 7 List of designated species for the Bird Directive area No. 113, Southern Danish North Sea, with details on designation status and criteria.

Species	Breeding	Migrating
Red-throated Diver		National importance
Black-throated Diver		National importance
Little Gull		International importance

3.3 Habitats and species not covered by the present MPA network

Soft bottom communities

Soft bottom habitats with sandy or muddy sediments are present in the North Sea and Skagerrak but not included in the present MPA network as a target for protection. According to the benthos surveys and later interpretation, there seem to be several different communities present depending on sediment grain size and water depth. However, at present robust, up-to-date data on benthos communities are still lacking from the North Sea and the deeper parts of the Skagerrak.

Pelagic habitats

No pelagic habitats such as upwelling areas are currently protected in the existing network of MPAs. The pelagic habitats in the Danish zone of the North Sea are described by the estuarine (salinity) fronts, tidal mixing fronts, and the Skagerrak front. In total, 22% of the total front areas (defined by the upper 10% percentile) are situated in present MPAs. Note, however, that although they are inside MPAs they are not traditionally mapped or part of the designated habitats protected in the MPAs. Defining the pelagic habitats requires good 3D hydrodynamic modelling. Here state-of-the-art hydrodynamic modelling (MIKE 3FM) of the North Sea is used as the data basis, resulting in moderate uncertainty in data.

3.4 Status of the present MPA network for each biotic feature and habitat

In this chapter, the status of the present MPA network is described with reference to representativity, replication and adequacy. In part 2 of the project, we will use more advanced tools (Zonation and Marxan) developed to define hotspots and analyze the network of MPAs. Furthermore, connectivity will be assessed using IBM modeling. Therefore, connectivity is not assessed in this first part.

3.4.1 Representativity

Representativity aims to ensure that the MPA network protects relevant biogeographic areas and physical features, reflecting the whole range of habitats, important biological communities and levels of biodiversity. Representativity considers different types of area coverage, in order to describe how the network covers different features such as habitats or species or the factors related to their existence and status as geological, physical and hydrographic features. Here we assess the status by describing how much of the total area, benthic and pelagic habitats and species is protected in the current network (Table 8). MPAs cover 15% of the Danish North Sea zone, including the Skagerrak (total 58,755 km2).

The proportion of reefs in MPAs (16.6%) from Figure 12 was calculated from the mapping interpretation of the Natura 2000 sites, where substrate types 3 and 4 were considered as potential reefs, and for the unmapped areas, from the seabed sediment map (including H1, H253, H254 and H255). No consideration was given to the depth of these reefs. The photic or non-photic hard bottom percentages were calculated from the EUNIS habitats - infralittoral and circalittoral or deep circalittoral mixed sediments used in the EMODNet sediment classification. This mixed-sediment class comprises all the hard-bottom substrate and is therefore not directly comparable with the figures for hard bottom in Table 8. The photic hard bottom is 19.8% and the non-photic hard bottom is 13.5%.

The certainty in estimating these parameters varies from low to high depending on data availability and quality. For some Natura 2000 areas moderate to high quality data exist, while in most of the North Sea the data is sparse. The same uncertainty and data reliability issue can be seen where maps of high uncertainty are obtained for areas with large data gaps and no survey lines or sampling points. So area H1, H78 and H255 are of high uncertainty while the rest of the Natura2000 areas are of moderate (H254, H253) or high certainty such as area H202, H203, H259, H258, H257 and H256. The Topographic Position Index "TPI" method was used with the bathymetric data to compute the Slope Position grid of 6 categories, reflecting different seabed shapes and morphology, where each cell in the bathymetry raster was compared with the neighboring cells at a chosen radius of 10km. The sediment grid was simplified and combined with the Slope Position grid to produce the morphological features such as sand ridges, mud valley, etc. The photic-non photic classification was described in the previous chapter.

The sandbank percentage was calculated from the morphology map (the combined bathymetry and sediment map) and it represents the sand ridges in the area without depth consideration. The Natura 2000 areas with large areas of sand ridges are H1 and H255 and they are not mapped properly yet, so the uncertainty in sand ridges estimation is high. Sand ridges are a geomorphological term given to a sand elevation structure. Sandbanks are a Habitat Directive term given to sand ridges or banks in water depths 20m.

Benthos
There are no recent benthos data from the soft bottom communities available for the North Sea. Data from 1986 from Künitzer were considered not to represent the current situation adequately.

Fish
The fish species in the Danish zone of the North Sea are not presently explicitly protected by MPAs but they are managed in accordance with the objectives of the CFP (Table 9).

Table 8 Status of representativity estimating how large a part (%) of marine benthic and pelagic habitats and species populations is protected by the current MPA network in the Danish zone of the North Sea.

	Current status (%)	Uncertainty in data (low, moderate or high)
DK part of NS		
Area covered by MPAs	15	high
Habitats - Habitat directive		
Reefs	15.7	
Sandbanks	13.8	(High in H1 & H255) Low in the rest of Natura2000 areas
Bubbling reefs	No number available	
Mud and sand flats	100	low
Shallow bays and inlets	100	low
Estuaries	100	low
Coastal lagoons (prioritized)	100[11]	low
Habitats not Habitat Directive		
Deeper sand flats	0	Not relevant
Deeper sand banks	0	Not relevant
Muddy soft bottom	0	Not relevant
Pelagic habitats		
Pelagic fronts (Estuarine-, Tidal mixing- and Skagerrak fronts)	0	Moderate
Specific communities		
Algae dominated hard bottom communities	11.9	High
Non-photic hard bottom fauna communities	15.9[12]	High
Species		
Harbour porpoise	12.4	Moderate
Fish see Table 9		
Birds see Table 10		

[11]Concerns only the Wadden Sea

[12]The number represents a mean of the individual communities

Table 9 Important fish species and species listed in Annex II and V in the Danish part of the North Sea. None of them are protected in the current network of MPAs. Data from IBTS survey 2001-2016. Note that catches of Annex II and V species are very low.

Ecological feature	Species name	Percentage estimated to be within existing Natura 2000
Demersal fish biomass		20.9
Pelagic Fish biomass		11.5
Cod abundance	Gadus morhua	33.1
Dab abundance	Limanda limanda	6.5
Haddock abundance	Melanogrammus aeglefinus	22.5
Herring abundance	Clupea harengus	12.3
Mackerel abundance	Scomber scombrus	11.5
Saithe abundance	Pollachius virens	56.7
Sprat abundance	Sprattus sprattus	15.4
Whiting abundance	Merlangius merlangus	18.8
Sandeel	Ammodytes spp.	8.1
Annex II species		
River lamprey	Lampetra fluviatilis	0
Sea lamprey	Petromyzon marinus	0
Houting	Coregonus oxyrhyncus	NR[13]
Sturgeon	Acipenser sturio	NR[13]
Annex V species		
Allis shad	Alosa alosa	33.3
Twaite shad	Alosa fallax	5.9

Birds

The Danish SPAs cover high percentages of near-shore and tidal bird species (Table 10).Near-shore and tidal bird species found in the Danish Waddensee Bird Directive area Nr. 57 contribute significantly to this. The breeding bird species designated for the area are generally well covered by SPA designations in Denmark. This is also the case for migratory near-shore and tidal species of dabbling ducks, geese and waders.

[13]Not recorded in the IBTS survey 2001-2016

Table 10 For selected species of birds and for the entire survey area, the total number of individuals observed during the 2008 national waterbird survey is given (Total N observed). The percentage of those birds encountered within any of the Danish EU Birds Directive areas (SPA) is given (% in SPA), and likewise the percentage of each species encountered within a Birds Directive area to which the species is on the list of designated species for the area (% in designation SPA).

Species	Total N observed	% in SPA	% in designation SPA
Red-throated Diver/Black-throated Diver	598	18	0
Great Crested Grebe	5,591	46	-
Cormorant	24,223	59	11
Mute Swan	54,362	80	70
Bewick's Swan	554	20	20
Whoopers Swan	41,854	44	36
Greylag Goose	87,229	59	32
White-fronted Goose	6,383	66	0
Tundra Bean Goose	3,497	0	0
Bean Goose	6,513	45	44
Pink-footed Goose	23,760	34	34
Light-bellied Brent Goose	5,309	82	79
Dark-bellied Brent Goose	2,630	79	32
Barnacle Goose	56,457	74	60
Shellduck	32,360	93	71
Mallard	135,893	70	-
Teal	14,647	77	29
Pintail	4,780	91	80
Wigeon	62,076	74	37
Pochard	17,248	54	17
Tufted Duck	162,247	53	38
Greater Scaup	15,363	60	42
Goldeneye	64,977	64	47
Long-tailed Duck	2,509	15	0
Common Eider	138,534	51	42
Common Scoter	136,187	77	74
Velvet Scoter	601	74	46
Smew	2,078	82	49
Goosander	13,846	67	30
Red-breasted Merganser	9,565	57	41
Coot	187,170	69	44
Razorbill/Guillemot	4,584	9	0

The present SPA designations cover low percentages of Red-throated and Black-throated Diver. Data from surveys in April/May 2016 showed that 18.7 % of Red-throated and Black-throated Divers recorded in the eastern part of Danish North Sea were recorded within the Birds Directive area designated for the species (see Figure 27). Common Scoters are well represented within Danish Bird Directive areas, with 74 %

recorded within areas to which the species is on the designation list. A large proportion of the remaining 26 % were recorded in the Horns Reef area off Blåvand.

Other areas of the Danish North Sea, not covered by the present Birds Directive network, are known to hold concentration of marine bird species of international importance. This is the case for Fulmar and Great Skua in the late summer (see Figure 25, Figure 26). Areas with nationally important concentrations of Razorbill and Guillemot have been described for the northern part of the Danish North Sea (Skov et al. 1992, Laursen et al. 1997). These areas are not covered by the present Birds Directive network. For these four species it is estimated that between 0 and 2 % of the total national numbers of these species are covered by the existing Danish Birds Directive network. This particular area is also of importance to Common Guillemot in the late summer.

On the basis of the national monitoring of waterbirds in Denmark in 2008 the percentage presence of bird species within the SPA's was estimated. The data covered both offshore areas, nearshore areas as well as selected inland wetlands. The total numbers of observed birds comprise the basis for a calculation of the percentages present in a SPA as well as the percentage present in a SPA for which the species is on the designation list. The numbers only relate to birds in winter (Table 10).

Marine mammals
The only species for which the percentage covered by the Natura 2000 areas can be calculated is harbour porpoise. Here, the five designated areas cover 12.4% of the porpoises occupying the Danish zone of North Sea and Skagerrak. The distribution data are based on year round satellite tracking of porpoises in the Skagerrak. These data have proven to give a reliable representation of the porpoise distribution. In the North Sea, however, the distribution is modelled based on merely two aerial surveys in July 1994 and July 2005. The model used here (Gilles et al 2016) did not include the 2016 data. The uncertainty of the combined dataset as well as the methods is assessed to be Moderate (Low for telemetry data in the Skagerrak and High for aerial surveys in the North Sea).

3.4.2 Replication
Replication aims to ensure the protection of the same feature across multiple sites in the MPA network ensuring natural variability of all features. Replication considers the number of replicas of a conservation feature in the study area for example habitat or species. Habitat types listed in Table 11 within the Natura 2000 sites were identified and their spatial extension was calculated. High reliability data was obtained from inside the Natura 2000 sites where mapping projects were conducted previously. This can be applied to most of the Natura 2000 sites except for the two large sites 1 and 255.

Table 11 Overview of replication of marine benthic and pelagic habitats and fauna communities for which data was available.

	Status
DK part of NS	
Habitats - Habitat directive	
Reefs	6
Sandbanks	11
"Bubbling reefs"	
"Mud and sand flats"	
Shallow bays and inlets	
Estuaries	
Coastal lagoons (prioritized)	
Habitats - not Habitat directive	
Deeper sand flats	
Deeper sand banks	
Muddy soft bottom	
Pelagic habitats	
Pelagic Fronts	10
Specific communities	
Photic hard bottom communities	
Non-photic hard bottom communities	

4. Baltic Sea

The area under investigation in this chapter represents the Danish part of the Baltic Sea included in the Danish EEZ and covers the zone surrounding Bornholm.

4.1 Overall description of main habitats and ecological components in the Baltic Sea

The Baltic is one of the world's largest brackish water bodies (Snoeijs-Leijonmalm *et al.* 2017). It is connected to the Kattegat and North Sea by the Øresund and Danish Belts, and receives freshwater from more than 200 large and small rivers. The topography of the Baltic is characterized by large shallow areas that are less than 25 m in depth interspersed by a number of deep basins. The Gulf of Bothnia and the Gulf of Riga are shallow internal fjords, while the deep basins in the central and south western part of the Baltic are up to 460 m deep. The western and northern parts of the Baltic have rocky bottoms and extended archipelagos, while the bottom in the central, southern, and eastern parts consist of till deposits in combination with muddy or sandy sediments.

The Baltic Sea has undergone large changes since the last ice-age. Eight thousand years ago it was gradually transformed from a freshwater lake to the present brackish sea. Numerous ecological niches are therefore still available for immigration (Bonsdorff 2006) and new non-indigenous species frequently enter the Baltic, often aided by shipping or other human activities. Today approximately 130 non-indigenous species have established themselves in the area (Snoeijs-Leijonmalm 2017). The non-indigenous species may be considered as aliens in the system, but add positively to the functional richness of the ecosystems in the Baltic.

4.1.1 Geology, sediments and topography

Geologically, Bornholm is a domino-shaped island formed as an elevated bedrock-block with a subsurface dominated by Pre-Quaternary hard bedrock and sandy and clayey deposits. In some of the offshore areas southwest of Bornholm, the Pre-Quaternary outcrops at the seabed with no or just a thin cover of Quaternary sediments. The Baltic Sea surrounding Bornholm has been exposed to several glaciation periods with only thin patchy deposits preserved. From the end of the last (Weichselian) glaciation until today, the land/sea configuration has been influenced by isostasy and eustasy and two lake stages whose influences are reflected in the present seabed sediments.

The areas of glacial till deposits in the shallow part, Adler Grund, southwest of Bornholm and to the northwest are dominated by large areas of coarse-grained, mixed sediments with boulders. Plenty of channels cutting into the Pre-Quaternary and/or the glacial surfaces yield evidence of the presence of meltwater deposits. The huge sand bank called Rønne Banke southwest of Bornholm is composed partly of Pre-Quaternary and partly of postglacial marine sandy deposits. The area is characterized by the presence of terraces indicating fossil coastal development in the early postglacial period. The dominance of sand is interrupted by outcrops of glacial deposits with scattered boulders.

One of the characteristic seabed features in this part of the Baltic Sea is the presence of Quaternary clay and silt deposited during the two lake stages, The Baltic Ice Lake and the Ancylus Lake stages. These deposits are composed of firm clays occasionally with a content of scattered centimeter to decimeter scale dropstones. In some areas this seabed type has a thin lag of drop stones on top of the clay due to erosion. At water depths of more than 30-40m the seabed sediments gradually become finer into silt and fine, muddy sand. Muddy sediments dominate the seabed below 40 m.

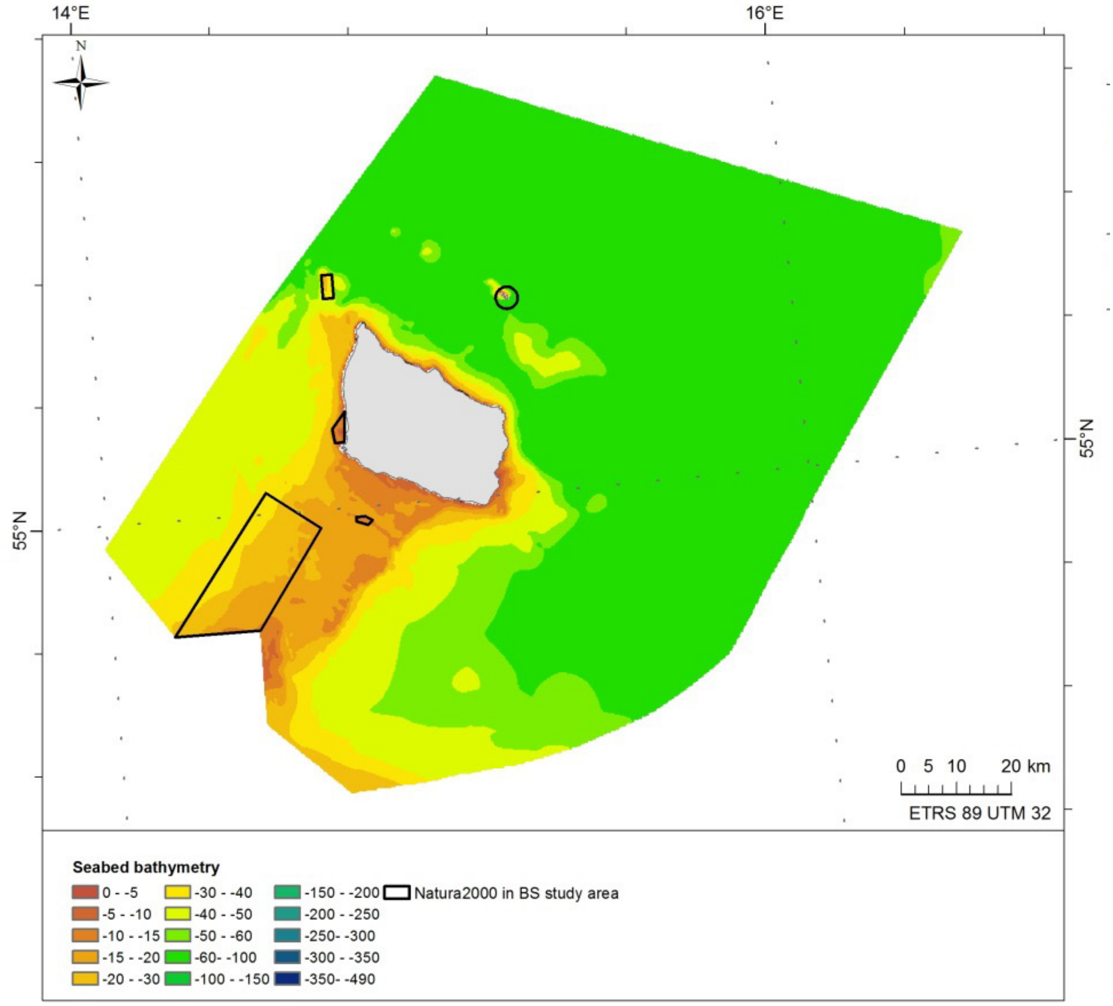


Figure 36 Bathymetry of the study area.

The area North-east of Bornholm is dominated by a deep basin named Bornholm Basin with water depths of more than 70 m. The geological structure in the basin consists of bedrock incised by a complex system of channels and the deeper basin is partly filled in by depositional fans with a structure similar to so-called ‘contourites’ known from the deep oceans. It indicates that the depositional systems reflect a system of the mixture of inflowing, heavy salty bottom water and outflow of brackish lighter surface waters. The deposits in the Bornholm Basin are a combination of sand and sandy mud sediments at the inflow and muddy sediments in the deeper parts, deposited from suspended material.

As shown in Figure 36 the area is characterized by a shallow area in the western-southwestern region with a depth of about 15m and dominated by hard substrate and a deep area in the northern region with a depth of more than 70m dominated by mud and silt as shown in Figure 37.

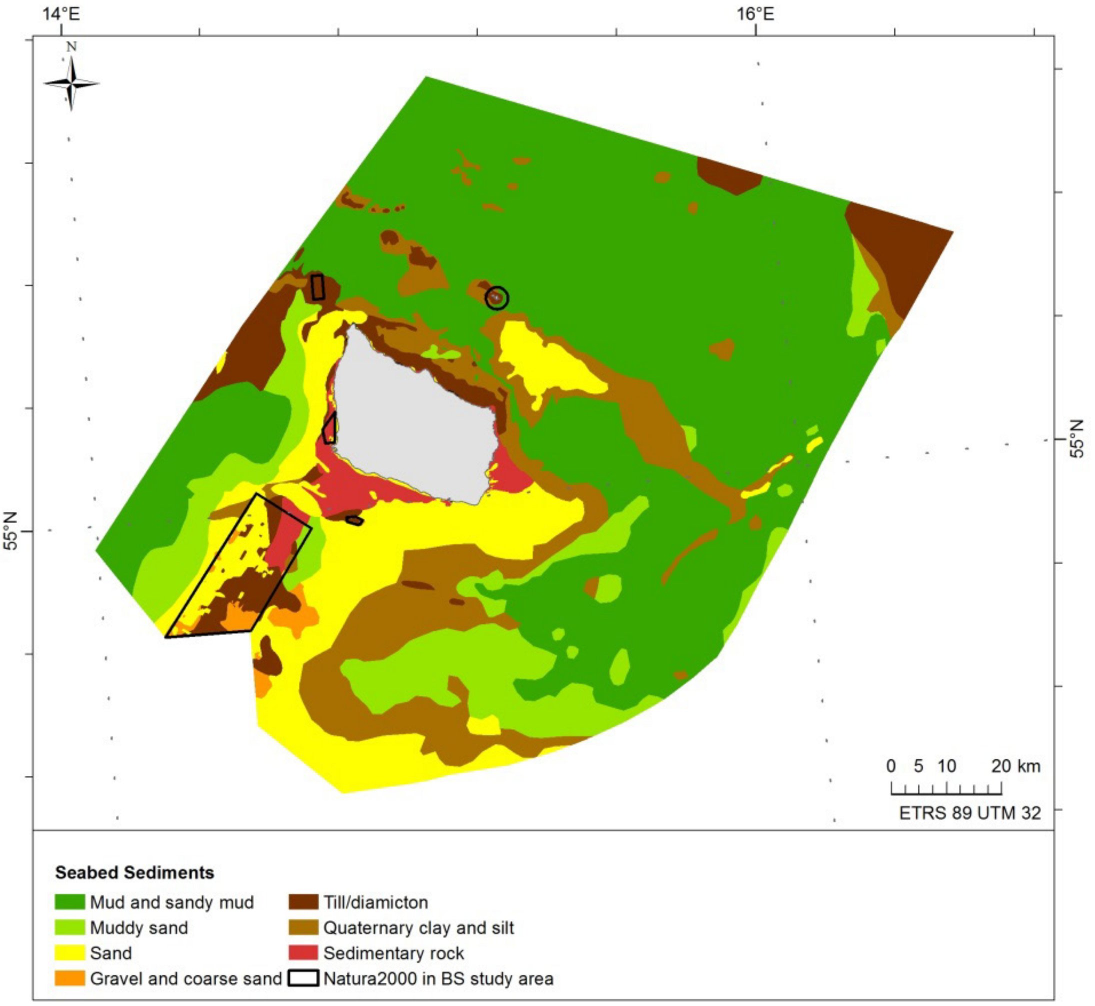


Figure 37 Map of the seabed sediments.

4.1.2 Benthic habitats

The benthic habitat map of the Central Baltic Sea around Bornholm Island was originally produced in the EMODNet Phase II project. The area includes five Natura 2000 sites (H209, H210, H211, H212 and H261) plus a terrestrial underwater cave area H184.

The environmental parameters used for modelling the North Sea region were also adopted for modelling the Baltic Sea broad-scale habitat map. However, the data sources and thresholds were different. The Secchi disc depth was used to model the light percentage at the seabed. The salinity at the seabed was used as a factor for defining the biozones, and the wave exposure was used for defining the energy thresholds. Three biozones were modelled, the Infralittoral, the Shallow Circalittoral and the Deep Circalittoral zones. As described above the southwestern and eastern areas offshore of Bornholm are composed of infralittoral and circalittoral sedimentary rock outcrops with a total area of 240km². These habitats were classified according to their energy thresholds into sheltered, moderately sheltered and exposed habitats as shown in Figure **38**. The sedimentary rock habitat type occurs in two Natura 2000 sites (H211 & H261) with a total area of about 4.7km².

In calculating the areal percentages of habitats inside the Natura 2000 areas, they were also divided into two biozones, the photic and the non-photic zone. The photic zone is analogues to the Infralittoral zone defined by the EUNIS classification with 1% light reaching the seabed, while the non-photic zone is covered by the shallow and deep circalittoral zones combined. Sandbank percentage was calculated from the morphology map in areas where sand ridges were delineated. All of the Natura 2000 areas were have been mapped, so the reliability of the habitat distribution inside the sites is high, but in the region outside the Natura2000 sites, there are very few survey lines and large data gaps exist, which result in the calculation of areal percentages having high uncertainties.

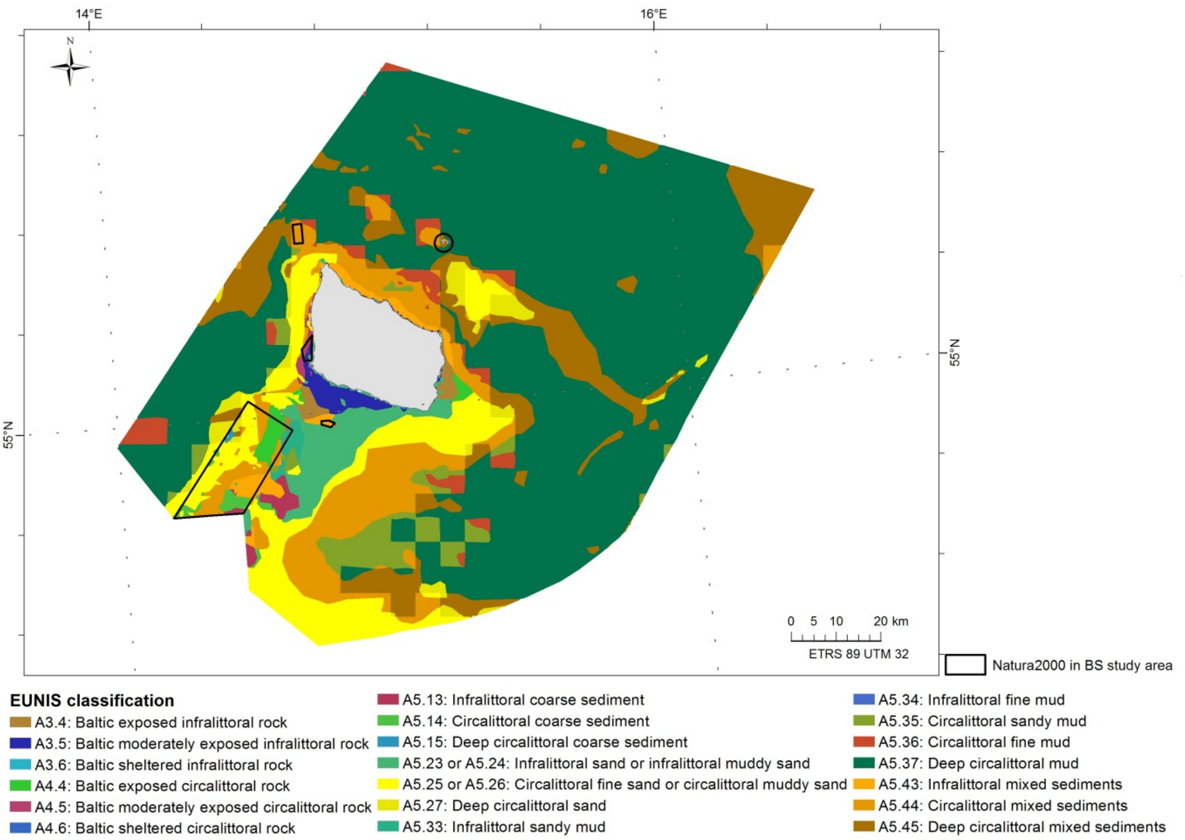


Figure 38 EUNIS habitats in the Baltic Sea.

As in the North Sea study area, a morphology map (Figure 39) was produced from the bathymetric and the sediment maps, following the same procedure as described in the North Sea part of the report. However, in the Central Baltic Sea area sedimentary rock outcrops (EUNIS habitat A3.4, 5, 6 and A4.4, 5, 6) were also identified and delineated.

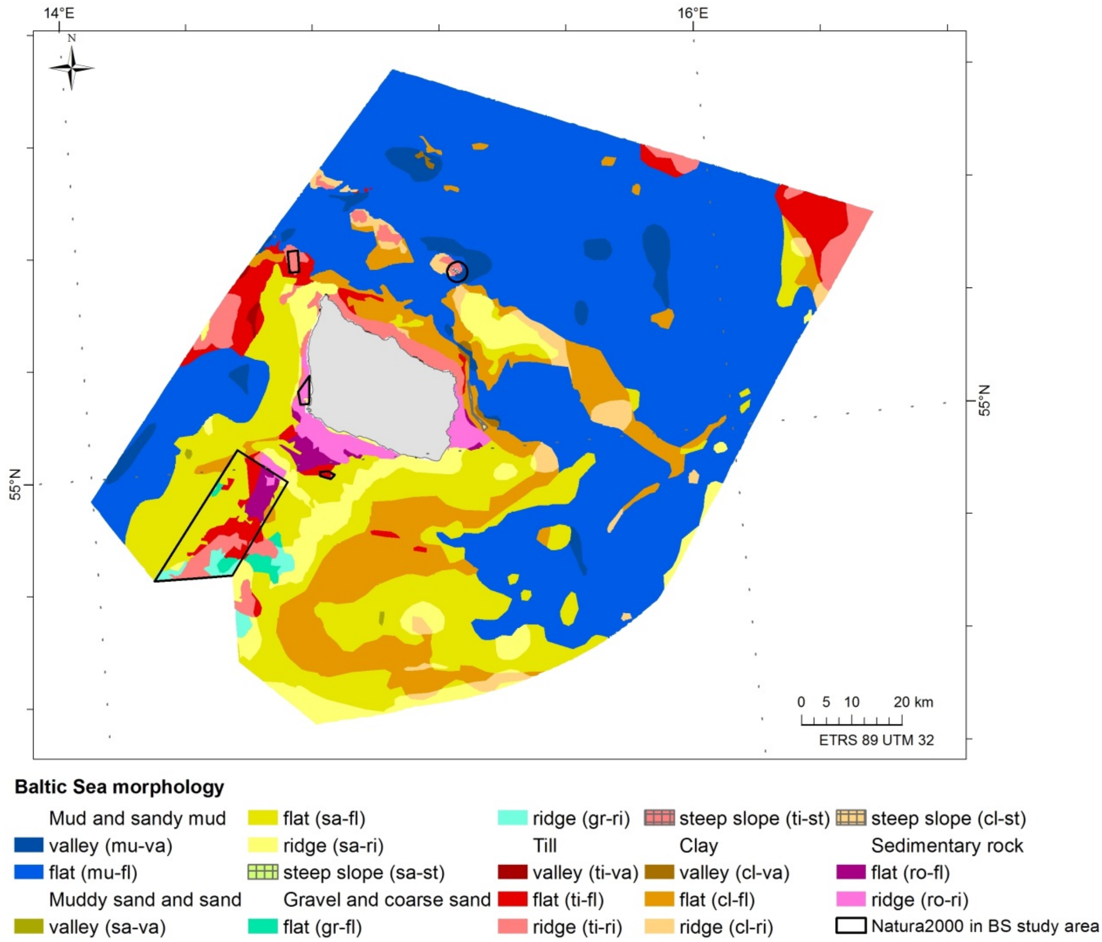


Figure 39 Sea bed morphology in the Baltic Basin.

4.1.3 Hydrography

The Baltic Sea is an intra-continental brackish water basin with a total area of 375,000 km^2 excluding the Danish Straits. The Baltic Sea is characterized by a closed basin circulation with pronounced vertical salinity gradients (Voss et al. 2005). The connection with the Kattegat through the Sound and the Danish straits generates a salinity gradient from the southwestern to the northeastern Baltic Sea and a water exchange characterized by the inflow of heavy saline water near the bottom and an outwards flowing surface current of lighter brackish water. Most of the salty inflowing water settles in the deeper basins, giving rise to a pronounced vertical salinity gradient. The bottom water slowly mixes with the overlying low saline waters generating a surface layer of brackish water. In the Bornholm Basin, the separation between the saline bottom water and the brackish surface water occurs at 40-50 m of depth (Ojaveer 2017). In the deeper parts of the basins, the oxygen content of the inflowing saline bottom water is gradually depleted, resulting in hypoxic or anoxic conditions. Infrequent storm related inflows are important for providing new saltwater and oxygen to the bottom waters in these areas. Previously the inflows used to happen every four to five years, but since the 1970’s they have become much less frequent. The four latest major inflows happened in 1983, 1993, 2003 and 2014.

The currents in the Baltic are mainly wind driven and result in a general anti-clockwise circulation of water northeastwards along the eastern coasts and southwestwards along the western. Although tides are generally weak, tidal currents do occur in some of the narrow passages in the southwestern part of the Baltic. During summer a thermocline develops at 15 to 30m, separating warm surface water from the colder more nutrient rich water below, but wind-induced upwelling, where colder and more nutrient rich water is brought to the surface, can occur locally (Lehman & Myrberg 2008). In the Danish waters around Bornholm, fronts and eddies mainly develop in the areas shallower than 50 m (Figure 40).This area to the west of Bornholm is the region with the highest density of harbour porpoise *Phocoena phocoena* in this part of the Baltic Sea (Amundin 2015).

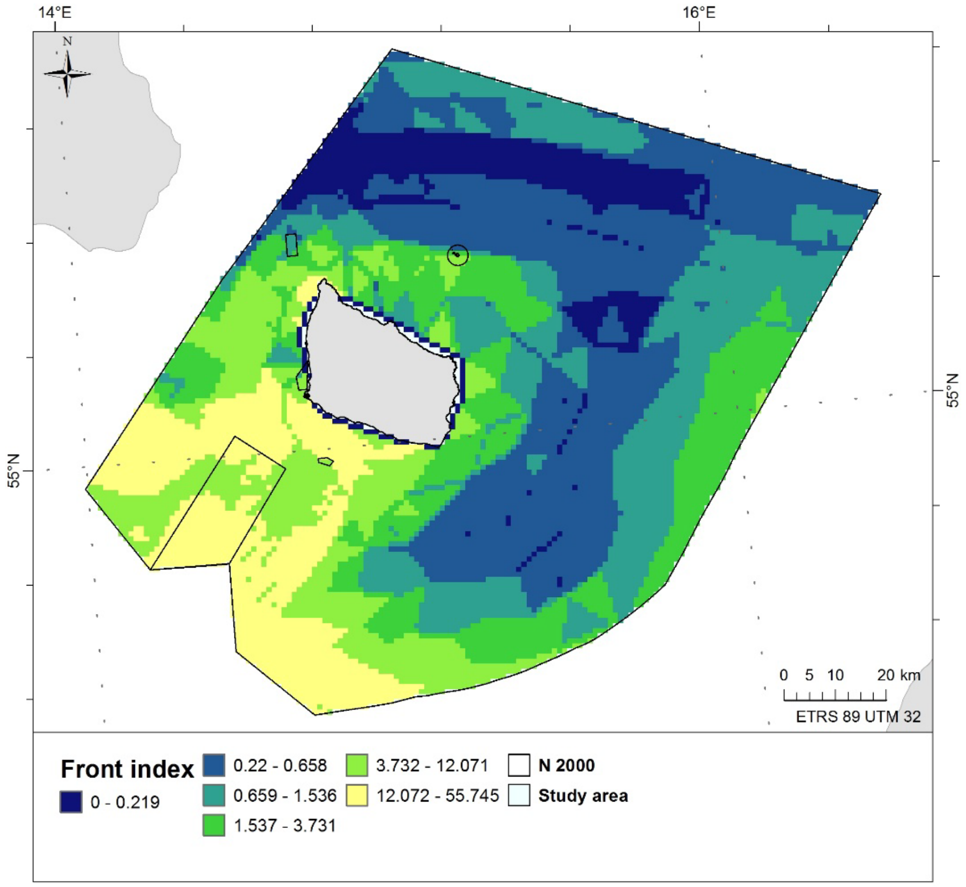


Figure 40 Frontal area based on current gradient and vorticity. The fronts are defined as high frequency of current gradient and vorticity exceeding the thresholds 0.000015 and 0.00001 respectively combined for each time step at about 20 depths. The figure shows the average of the years 2002-2007.

A recent warming trend in the surface waters is evident in the Baltic and the annual mean sea-surface temperature has increased by up to 1 °C per decade over the period from 1990 to 2008, with the greatest increase occurring in the northern Bothnian Bay, the Gulf of Finland, the Gulf of Riga, and the northern Baltic Proper. Although the increases in the northern areas are affected by the recent decline in the extent and duration of sea ice, warming is still evident during all seasons, with the greatest increase occurring in summer. The least warming of surface waters (0.3–0.5 °C per decade) occurred north-east of Bornholm Island up to and along the Swedish coast, probably owing to an increase in the frequency of coastal upwelling.

During the period 1952-2015 surface salinity in the Bornholm Basin has been stable with an average of 7.6 and without temporal trend (Feistel et al. 2008; Nausch et al. 2016), hence the effects of increased precipitation seems to be counteracted by increased evaporation driven by higher temperatures.

The environmental conditions and variability in the central Baltic Sea depends on several large-scale atmospheric circulation patterns such as the Arctic Oscillation and North Atlantic Oscillation, strength and frequency of major Baltic inflows, the integrated river runoff draining into the Baltic Sea, and the relative vorticity of geostrophic wind over the Baltic Sea (Dippner et al. 2012). The new multivariate Baltic Sea Environmental Index has been shown to explain the variability in hydrographic conditions as well as in zooplankton composition (Dippner et al. 2012).

Photosynthetic benthic marine organisms are restricted to areas which receives sunlight in sufficient quantities. This is naturally related to depth and water transparency. The photosynthetic available radiation (PAR) was therefore calculated based on modelled Secchi depth and water depth. Areas with PAR intensity exceeding 1% of surface insolation are located along the cost of Bornholm and the shallow areas southwest of Bornholm (Figure 41).

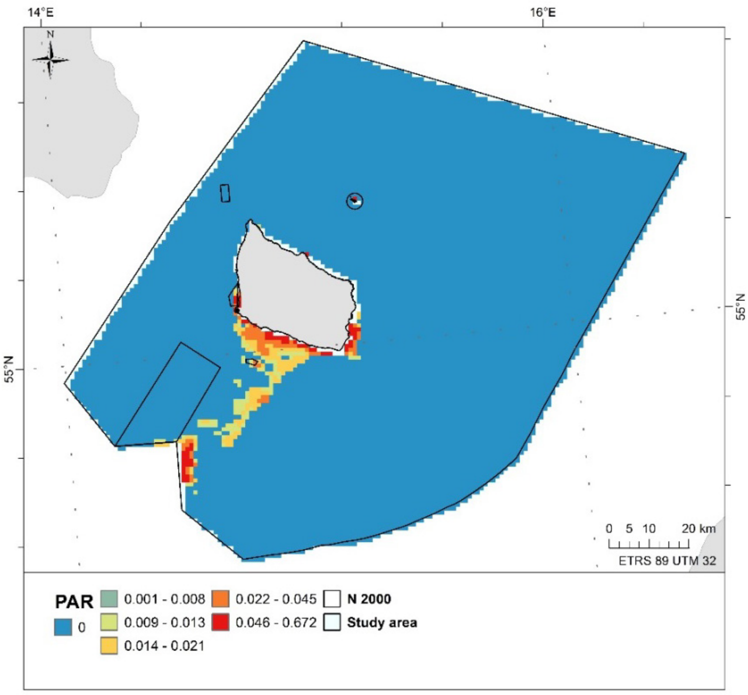


Figure 41 Photosynthetic available radiation (PAR).

4.1.4 Primary production

The phytoplankton species composition in the Baltic Sea depends on salinity, availability of nutrients and light, and accordingly the composition changes gradually from the southwest to the northeast. Primary production generally exhibits large seasonal and inter-annual variability (Helcom 2002, Figure 42). Typically, the spring bloom starts in February/March in the southwestern Baltic, and 2-to-3 months later in the Gulf of Bothnia. In the southwestern part the spring bloom is normally dominated by diatoms, whereas dinoflagellates dominate in the central and northern parts. In the Arkona Sea (west of Bornholm) the spring bloom is dominated by diatoms and the mixotrophic ciliate *Mesodinium rubrum*, while in the Bornholm Basin (east of Bornholm) dinoflagellates and diatoms irregularly alternate in spring bloom dominance along with *Mesodinium rubrum* (Wasmund et al. 2004-2016).

In summer, the proportion of diatoms is higher in the western, higher saline, parts of the Baltic Sea, whereas bloom forming cyano-bacteria normally represents the main phytoplankton group during summer in the eastern and northern parts. Potentially harmful, diazotrophic (N-fixing) species, like *Nodularia spumigena* and *Aphanizomenon* spp. are especially adapted to the conditions in the Baltic proper, but have rarely been observed in the Kattegat and the northern Gulf of Bothnia (Kahru et al. 1994; Wasmund 1997).

During summer, colony-forming cyano-bacteria such as, *Aphanizomenon flos-aquae* and *Nodularia spumigena,* capable of binding nitrogen from the atmosphere, often dominate phytoplankton biomass in the Baltic Proper and Bornholm Basin. In some years – especially in warm summers – cyano-bacteria blooms may reach into the Danish Straits in the Kattegat. Cyano-bacteria blooms continue until the early autumn, and even up to October in some years (Ojaveer 2017). Mass occurrences of blue-green algae often consist of several species. Since 1992 the toxin-producing species *Nodularia spumigena* has become more abundant compared to the non-toxic *Aphanizomenon flos-aquae* in the Arkona Basin west of Bornholm. In the Arkona and Bornholm Basins modelled primary production varied between 111 and 194 g C m-2 $year^{-1}$ in the DCE model.

The Danish zone around Bornholm is part of the Arkona and Bornholm seas, and is probably influenced by wind driven upwelling in Swedish coastal waters, seen as a gradient in modelled summer (Jun-Sep) (Figure 44) phytoplankton biomass (mean 2000 and 2007)compared to the yearly average (Figure 43).

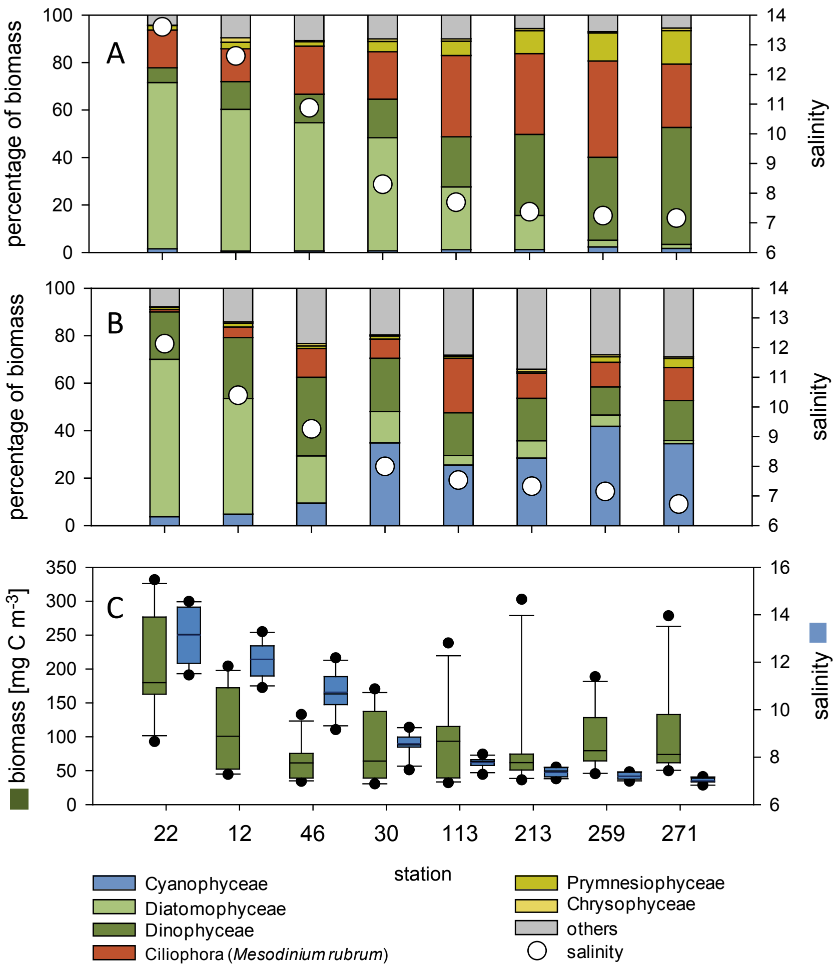


Figure 42 Seasonal variation of phytoplankton biomass (determined in integrated samples of 0-10 m depth), split into main taxonomical groups, along the large marine gradient of the Baltic Sea. Fig. A: Spring season: Data represent mean values from 1998-2008. Fig. B: Summer season: Data represent mean values from 1998-2008. Fig. C: Biomass (green) and surface salinity (blue) data based on yearly means, excluding winter values, for the time period 1998-2008. Stations: 22 – Mecklenburg Bight (inner part), 12 – BMP M02, Mecklenburg Bight (outer part), 46 – Kadett Channel, 30 – BMP K08, Darss Sill, 113 – Arkona Basin, 213 – BMP K02, Bornholm Basin, 259 – BMP K01, southern Baltic Proper, 271 –BMP J01, Eastern Gotland Basin. (from FEHY 2013 based on data from the German HELCOM monitoring programme covering different periods between 1998-2008).

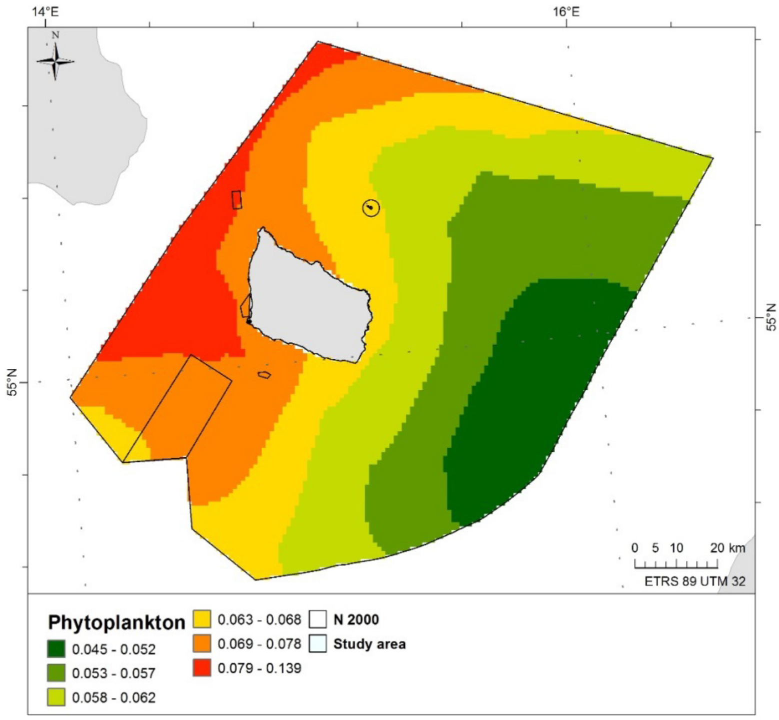


Figure 43 Modelled summer (Jun-Sep) phytoplankton biomass (g c m^{-3}) in the upper 10 layers for 2000 and 2007.

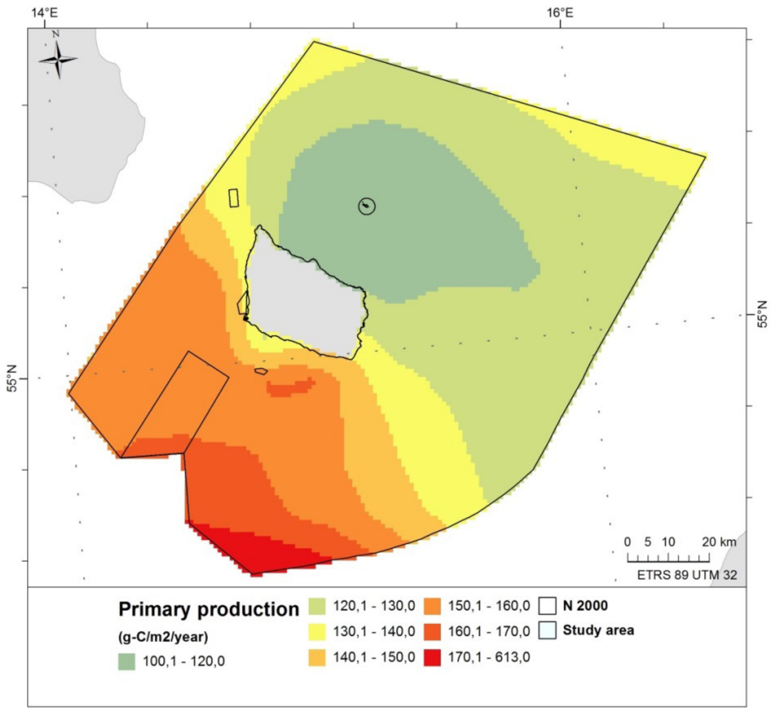


Figure 44 Modelled primary production as yearly average for the years 2009-2013 (g-C/m2/y) (from Maar et al. 2016)

4.1.5 Zooplankton

The zooplankton community in the Baltic is relatively species poor compared to the North Sea. The seasonal succession of the main species in the central Baltic is very similar from year to year. It starts with increasing abundance of rotifers in spring and early summer, followed by increases in small cladocerans (e.g. *Bosmina*) and copepods (e.g. *Acartia*) around mid-summer, while the more marine copepods (e.g. *Pseudocalanus* and *Temora*) peak in late summer and autumn (Hernroth and Ackefors 1979). However the timing of the abundance peaks of the groups may change from year to year. Copepods are important as food items for larval and juvenile fish.

Mysids are common in the Baltic Sea, both in the coastal zone and in the open sea. The open sea species, *Mysis mixta* and *Mysis relicta* remain close to the seafloor during the day and ascend into the water column during night. They are omnivorous, feeding on detritus along with living and dead particles on and in the sediment during the day and on phytoplankton and zooplankton in the water column during night (Viherluoto et al. 2000). Mysids constitute important food items for the larger herring (*Clupea harengus*) (Aneer 1980). Changes in the species composition of the zooplankton have been linked to changes in salinity and temperature. In the shallower northern areas of the Baltic Sea a decline in copepods and an increase in species of fresh-water origin, e.g. cladocerans has been related to a reduction in salinity caused by increased river runoff (Viitasalo et al., 1995; Vuorinen et al., 1998; Ojaveer et al., 1998).

In the deep basins of the central Baltic the abundance and biomass of the marine *Pseudocalanus spp.* has declined since the 1980s, whereas the abundance of *Temora longicornis* and *Acartia spp*. has increased. The decrease in *Pseudocalanus spp.* was correlated with the decrease in deep-water salinity, resulting from the reduced frequency of inflow events (Möllmann et al., 2000, 2003). Recent investigations indicate that the combination of low salinity and oxygen conditions in the halocline of the deep basins might have a detrimental effect on the viability of *Pseudocalanus spp*. eggs and nauplii (Schmidt et al., 2003). The increase in *Acartia spp*. and *Temora longicornis* during the 1990s is correlated with temperature (Möllmann et al., 2000, 2003), and is a result of the persistently strong positive state of the NAO (Alheit et al., 2005; Möllmann et al., 2005). More generally Möllmann et al. (2009) described a regime shift in the pelagic ecosystem of the Central Baltic Sea during the late 1980s and early 1990s. The timing of the Baltic regime shift was in accordance with similar events detected in many North Pacific and North Atlantic marine ecosystems and involved a range of hydroclimatic, nutrient, phyto- and zooplankton, and fish related factors.

4.1.6 Soft-bottom communities

The number of macrozoobenthos species follows the general decline in species richness with salinity from the southwestern to the northeastern part of the Baltic. Richness is high in the southwestern part of the Baltic, where a high number of marine species is found. The strong vertical gradients in salinity and oxygen content also affect the distribution of benthic species. Shallow-water soft bottom communities have higher habitat diversity and thus more species than the deeper hypoxic communities (e.g. Andersen et al. 1978). Often a few species dominate. Among the 51 non-indigenous zoobenthos species in the Baltic Sea approximately a third originate from marine waters and the rest from inland waters (48 % from the Black, Caspian and Azov Seas and 19 % freshwater species) (Zettler et al. 2014).

In Baltic proper, the fauna is dominated by the polychaete *Bylgides sarsi*, the bivalve *Macoma balthica*, the amphipods *Monoporeia affinis* and *Pontoporeia femorata*, and their predator, the up to 9 cm large isopod *Saduria entomon* (Laine 2003). Many of the species living in deep waters are able to tolerate low oxygen levels (e.g. the isopod *Saduria entomon* and the bivalve *Macoma balthica*), but only a few species are well adapted to these conditions (e.g. the polychaete *Bylgides sarsi*). None of the animals can survive without oxygen. In the open sea areas of the southwestern sub-basins the communities are markedly different, with dominance of fully marine species, including species such as the bivalves *Arctica islandica* and *Astarte borealis* and numerous species of polychaete.

Higher diversity of invertebrates and fish is often found in the coastal zone in habitats with a high biomass of the macrophyte seaweed (*Fucus vesiculosus*) and eelgrass (*Zostera marina*), which form important habitats and nursery grounds for many animals (Snoeijs-Leijonmalm 2017). The distribution of seaweed and seagrass has changed over time, in some cases in response to eutrophication (Helcom 2009). Eelgrass beds were observed around Ertholmene and south and southwest of Bornholm from 1890 to 1912 in five areas. The old data show that eelgrass could be found down to 10m depth outside Øleå, south of Bornholm and to 5m at other locations. New investigations of eelgrass in the period 2008 to 2013 at Franks Reef found eelgrass down to 2m in 2008, 3.3m in 2012, and 3.8m in 2013. Eelgrass coverage varied between 5 and 25% on the investigated transects. No information on the current extent and position of eelgrass beds is available (see figure 45).

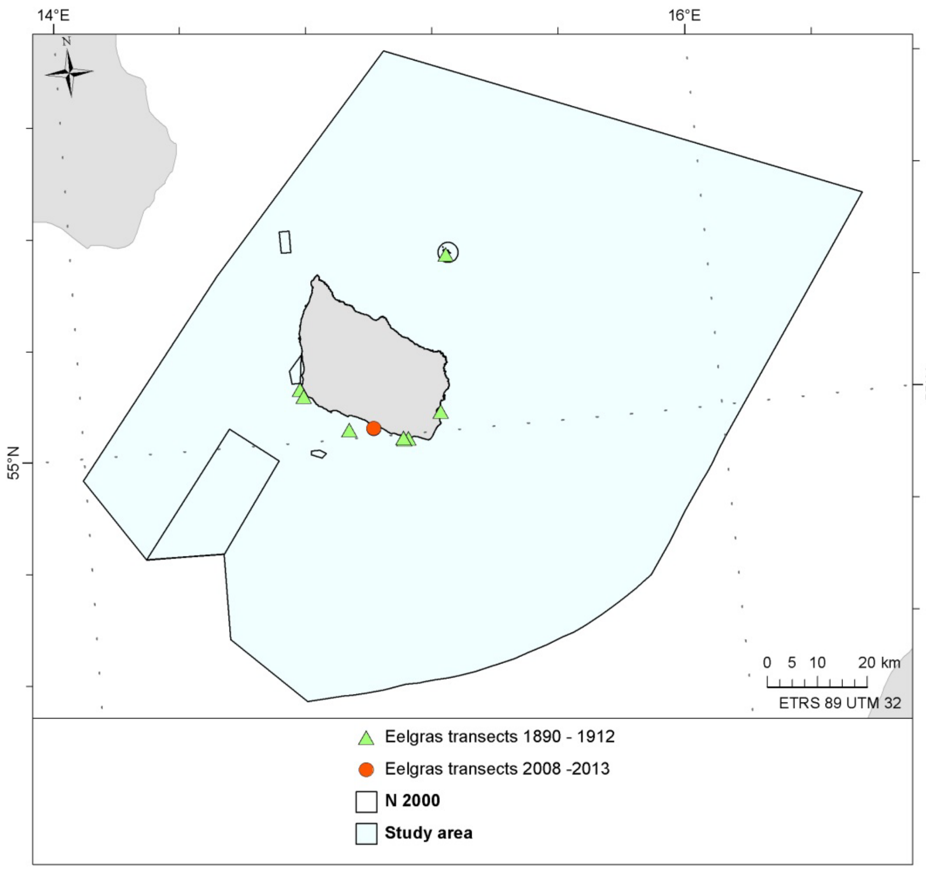


Figure 45 Eelgrass observations at NOVANA transects

Gogina *et al*.(2016) used hierarchal clustering of benthos samples to subdivide the Baltic soft-bottom macrobenthos into a number communities and characteristic species. Using either the abundance or biomass per species and more than 17,000 samples collected in the period from 2000 to 2014 at 7,000 different locations throughout the Baltic, combined with temperature, salinity, and bottom current data, they identified 10 and 17 communities, respectively. Unfortunately, there are few macrobenthos data from the Danish zone and those are taken on the deeper As a result, the benthos classification in this area is based on the predictions from their model. Another problem is that the mapped hard bottom areas were incorporated in the model. The predictions showed three communities based on the environmental covariates and abundance (Figure 46) and four communities based on biomass in the Danish zone around Bornholm (Figure 47).

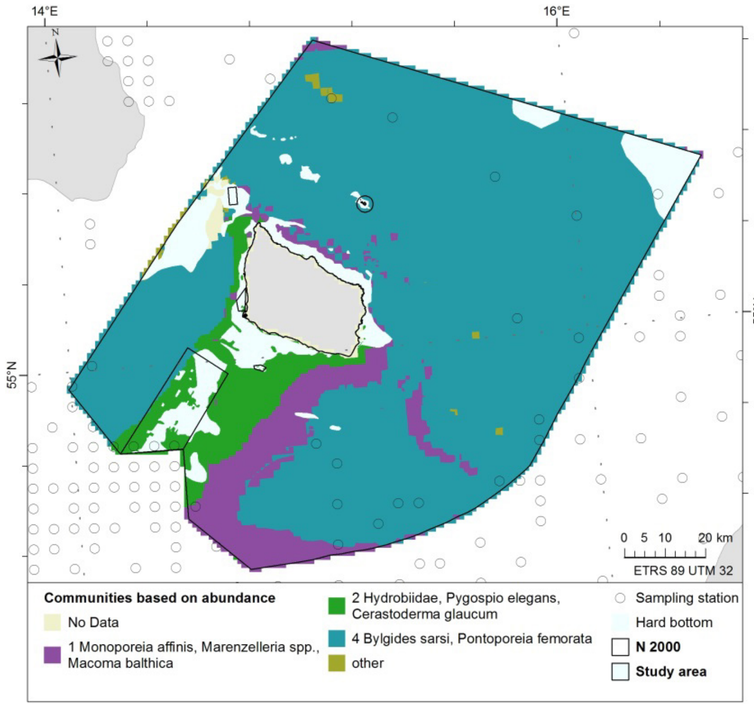


Figure 46 Modelled invertebrate communities on sandy and muddy soft bottom sediments based on abundance from Gogina et al. (2016) and on the seabed sediment map provided by GEUS. Sampling stations are shown as grey circles.

To the southwest of Bornholm and close to the island, the main borders of two community predictions overlapped, producing a community dominated by mud snails *Hydrobiidae*, the polychaete *Pygospio elegans* and the cockle *Cerastoderma glaucum* (abundance), plus the polychaete *Hediste diversicolor* and the clam *Mya arenaria* (biomass) on the sandy part of the bottom at less than 30m depth. To the east, north and west this was replaced by a community typified by the crustacean *Monoporeia affinis*, the bivalve *Macoma balthica*, the invasive polychaete *Marenzelleria ssp*. (based on abundance) or by the crustaceans *Saduria entomon* and *Pontoporeia femorata* and the priapulid worm *Halicryptus spinulosus* (based on biomass) on bottoms of sandy mud. Further east and at greater depths and on muddy (hypoxic) bottoms the community is characterised by *Bylgides sarsi* and *Pontoporeia femorata* (only abundance).

The fourth community was only identifiable in the analysis based on biomass and consisted of a community characterized by the crustacean *Diastylis sp*., the bivalves *Astarte spp*, *Mya truncata*, and *Abra alba*, the ascidian *Dendrodoa grossularia*, the polychaetes *Lagis koreni* and *Trochochaeta multisetosa* and the nemertean *Lineus ruber*. This community was found to the west of Bornholm on muddy sediments. Gogina et al.(2016) warns that their predicted communities are based on interpolation of data collected mostly during spring and summer, a somewhat arbitrarily chosen cut-off level of cluster similarity, and a random forest classification model that ignores the effects of some of the important co-variates, such as oxygen and temperature.

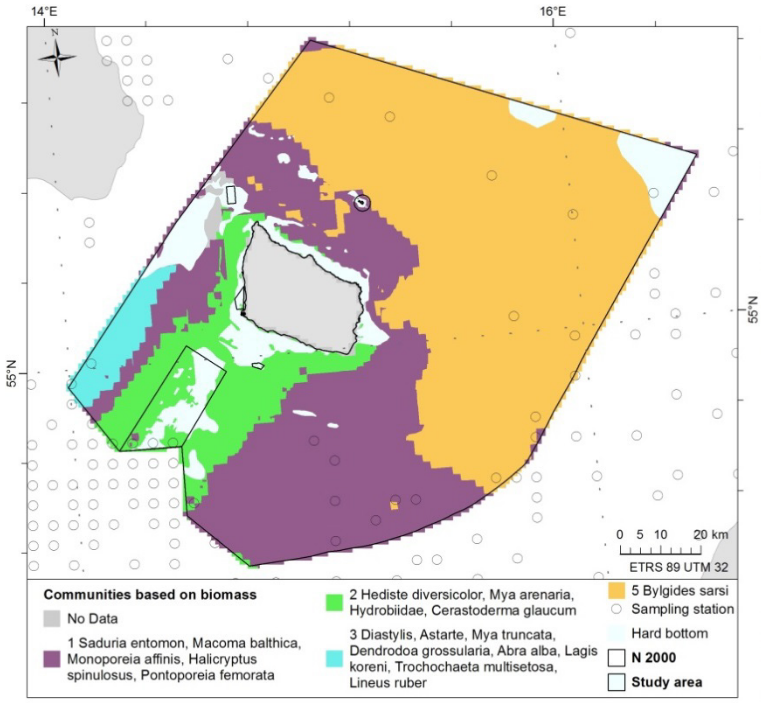


Figure 47 Modelled invertebrate communities on sandy and muddy soft bottom sediments based on biomasses from Gogina et al.(2016). Sampling stations are shown as grey circles and the border of Danish waters is indicated with a line.

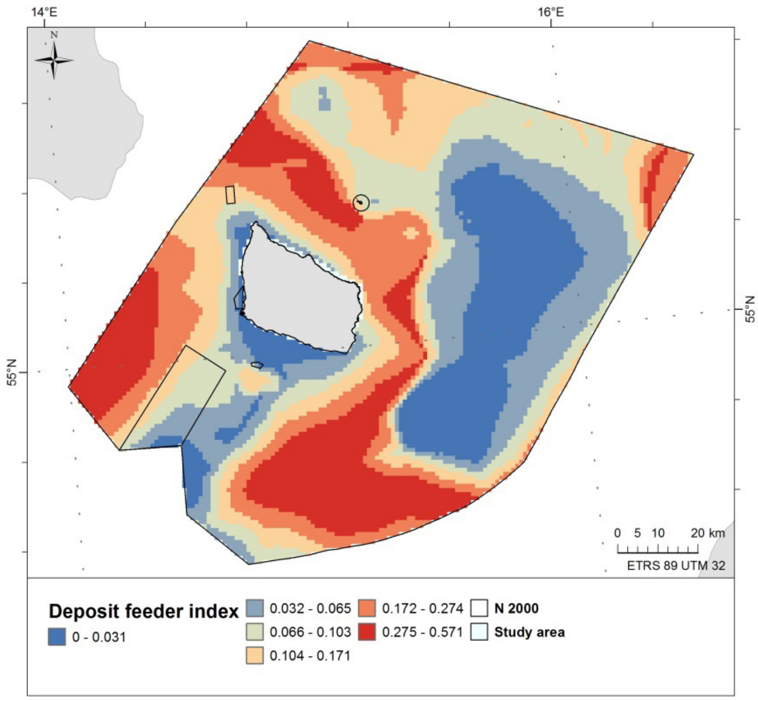


Figure 48 Modelled deposit feeder index based on bottom phytoplankton and detritus carbon, bed shears stress and oxygen concentration.

The benthic habitats can also more broadly be divided into deposit feeder habitats and filter feeder (or suspension feeder) habitats. The deposit feeder habitat can be categorized as areas where organic material can settle and where oxygen is available whereas the filter feeder habitats should in addition to available organic material also so have a relatively strong bottom current. A deposit feeder index was calculated based on summing modelled phytoplankton carbon and detritus carbon at the bottom (based on an DHI eutrophication model, mean values during the whole year 2002-2007) in areas with low bed sheer stress and without oxygen deficiency (Figure 48). The filter feeder index was calculated based on modelled bottom current speed multiplied with modelled bottom phytoplankton carbon (mean values during 2002-2007) (Figure 49).

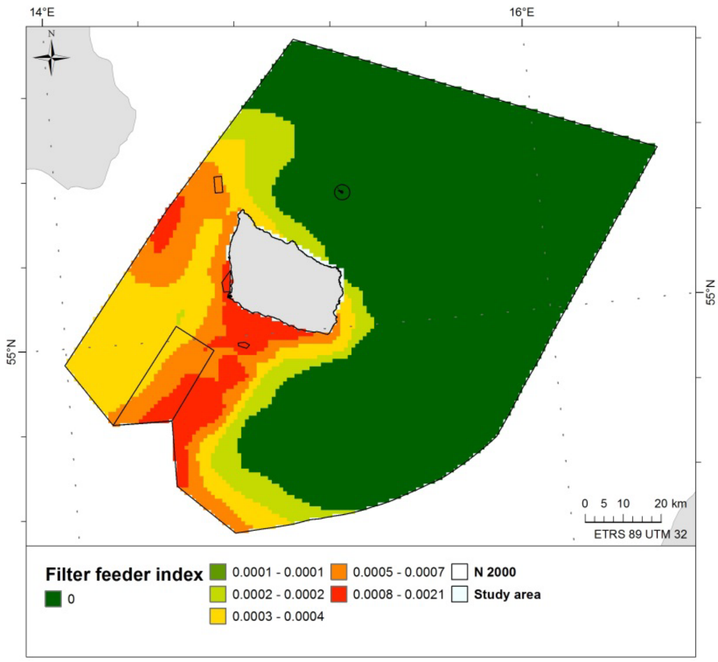


Figure 49 Modelled filter feeder index based on bottom current speed and bottom phytoplankton carbon

4.1.7 Hard bottom communities

Hard bottom communities as well as key structuring species are strongly associated with a hard stable substrate capable of anchoring key species of algae or fauna. Hard bottom communities dominate the rocky coast along the Swedish east coast and the coast of Finland. Scattered boulders and gravel beds exists along the coastline from Estonia and along the southern boundary as far as the Danish Straits. Baltic offshore reefs of boulders and bedrock exist as well. A large part of the western, northern and eastern coastline of Bornholm is dominated by bedrock extending out to sea, which is also the case around Ertholmene.

The decrease in salinity from the Kattegat to the Bothnian Bay has a major impact on the hard bottom biodiversity as shown by Nielsen et al (1995) and Ojaveer (2010), and more specifically for Danish waters in Dahl et al (1991) and Middelboe et al. (1997) for macrophytes. The changes are most profound in the Kattegat, the Belt Sea area and the western Baltic Sea. The changes in salinity also influence the community structure. Lack of predator control of the two blue mussel species *Mytilus edulis* and *Mytilus trossolus* by the common sea star (*Asterias rubens*) sets in from the southern Belt sea area and at lower salinities. This changes the balance in biomasses between primarily and secondary producers in the benthic community within the photic zone, compared to higher salinity regimes.

Information from the national monitoring program (NOVANA) on hard bottom communities on geogenic reefs exists from the waters around Bornholm. Dive observations of fauna and flora cover have been collected at several reef sites and different depth. Based on evaluation of the collected data, broad-scale hard-bottom communities and their depth ranges have been defined. The spatial distributions of those communities are modelled by overlaying the information on the vertical distribution with information on bathymetry as well as the distribution of the geological “till” and “rock” layers presented in figure 37.

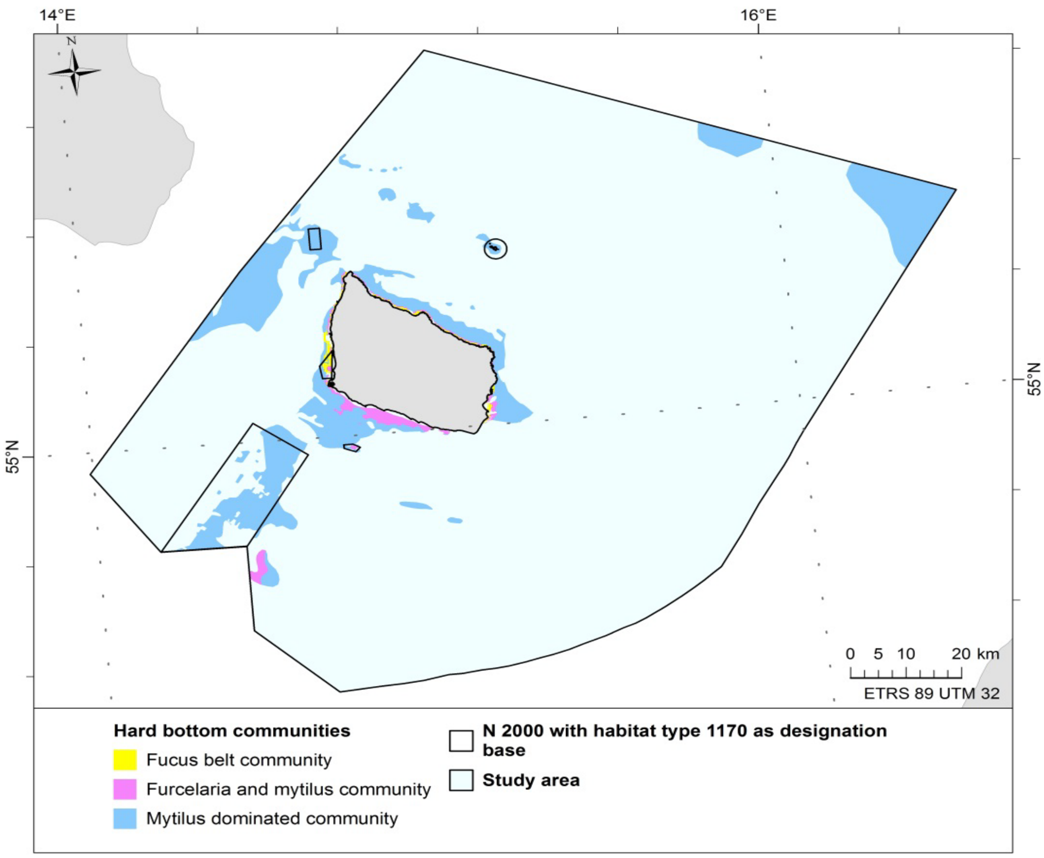


Figure 50 Hard bottom communities in the Baltic

A *Fucus* belt has been recorded in shallow waters on N-E Bornholm and at the Ertholmene. This belt consists of the large perennial brown algae *Fucus serratus* and *Fucus vesiculosus* with more than 10% cover. As the two species in general are large, this will be reflected in high biomasses. There was typically an understory of red algal species mixed with *Mytilus*. The fucus belt was observed from the shoreline to 5m depth at Ertholmene, to 7 m depth from stations covering the stretch from Sandvig to Nexø (extrapolated to Due Odde) and only in very shallow water 0-1m W and S-W of Bornholm. Below the *Fucus* belt but still in the photic zone a community dominated by the red algae *Furcelaria lumbricalis* (>25% cover) and *Mytilus* (>50% cover) exists around Bornholm. This community was not observed at Ertholmene. The community was

common from the *Fucus* belt to 13m depth on the North-Eastern and Eastern coast of Bornholm and down to 12m west and south-west of the island. As light becomes sparse *Mytilus* completely dominates the hard bottom benthos and this was also the case at Ertholmene just below the *Fucus* belt.
Figure 50 shows the spatial distribution of the three communities on hard bottom areas in Danish waters around Bornholm. The resolution of the depth is around 500m and therefore likely to be very uncertain not least along the rocky shoreline.

A blue mussel suitability index was modelled in the MOPODECO project (Dahl et al. 2012, Figure 51), and the patterns are similar to the outlined Mytilus community mapped above (Figure 50).

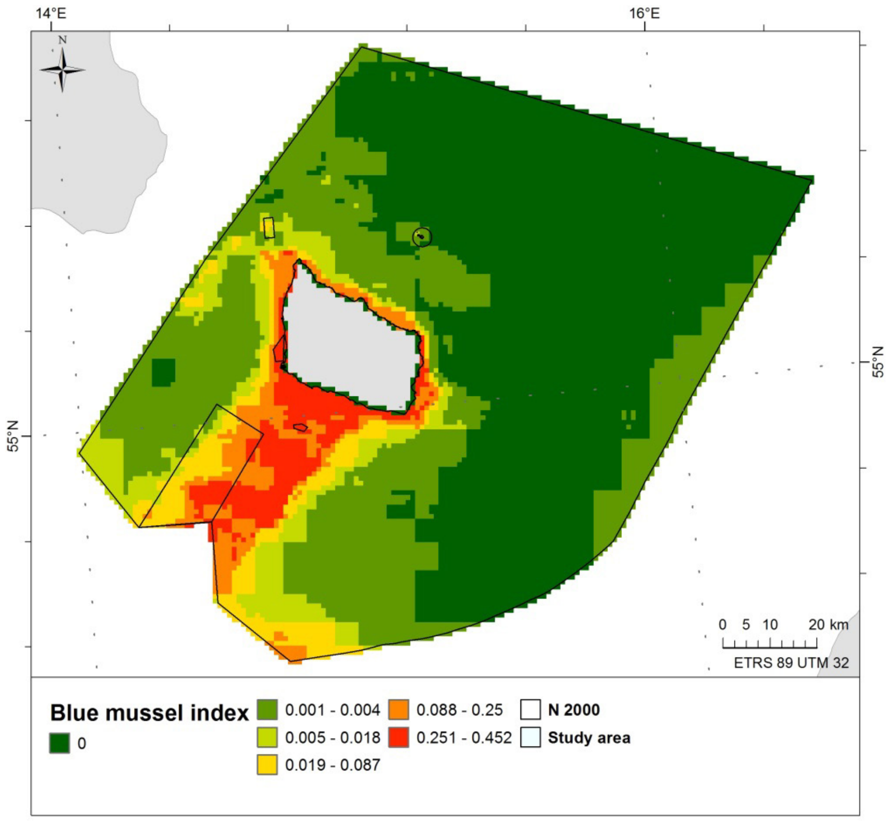


Figure 51 Blue mussel index

4.1.8 Fish

The fish fauna of the Baltic Sea consists of a mix of marine and freshwater species. More than 70% of the species are of marine origin, approximately 20% of freshwater origin and the rest of the species migrate between freshwater and marine water at different stages of their life (Helcom 2013). In the central and southern Baltic the fish fauna is dominated by three interacting species; herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and cod (*Gadus morhua*). Herring and sprat feed mostly on zooplankton while the larger cod feed on herring, sprat and younger cod. Herring and sprat in the central Baltic prey on cod eggs, and sprat are cannibalistic on their own eggs. This creates a complex system of interactions where the outcome sometimes is difficult to predict.

In the southern Baltic, additional marine species such as mackerel (*Scomber scombrus*), whiting (*Merlangius merlangus*) and plaice (*Pleuronectes platessa*) can be found, while in northern Baltic freshwater species such as perch (*Perca fluviatilis*), roach (*Rutilus rutilus*), and smelt (*Osmerus eperlanus*) are abundant. Salmon (*Salmo salar*) occurs throughout the Baltic, but is much less abundant than cod. Most salmon in the Baltic are nowadays produced in hatcheries in the rivers and streams in the central and northern Baltic, and few wild salmon remain. The three-spined stickleback (*Gasterosteus aculeatus*) usually lives amongst the macrophytes in the coastal area, but may also form large pelagic shoals in the open sea where they feed on small zooplankton. Flounder (*Platichthys flesus*) inhabits most areas of the Baltic, but is subdivided into a number of different populations.

Over the last 40 years, the dynamics of the fish stocks of the Baltic Sea have been strongly affected by natural variations in saltwater inflow, eutrophication and fishing. Climate-driven changes in the salinity, temperature, and oxygen content of the water affect the recruitment of cod, and the growth and recruitment of herring and sprat. The reduction in salinity and oxygen and the increase in temperature caused by the high NAO index in the 1990s resulted in a reduction of the growth rate of herring, and sprat growth declined during the 1980s and 1990s, probably due to changes in zooplankton composition and abundance (Rönkkonen et al., 2004; Möllmann et al., 2005) and as a result of increases in food competition (Casini et al., 2006).

Cod eggs can only survive if the salinity is over 11psu and the oxygen is above 2 $ml*L^{-1}$. Cod used to spawn in spring and early summer in the four southernmost deep basins. However, after its abundance was reduced due to heavy exploitation, spawning became restricted to the Bornholm and Arkona basins and gradually shifted to summer and early autumn. After a long period of low recruitment, reproductive success increased again after 2003, leading to a five-fold increase in the biomass of juvenile cod in the central Baltic Sea from 2003 to 2013. This happened despite a lack of major inflows of saline water, a condition previously believed to negatively influence its recruitment success (Eero *et al.* 2015). The increase in cod recruitment coincided with low abundance of fish prey and benthos, and resulted in much reduced individual growth.

Herring and sprat feed on zooplankton and are able to influence zooplankton production. At least in late summer and autumn, predation pressure by herring, sprat and mysids has been estimated to exceed zooplankton production (Hansson et al. 1990; Rudstam et al. 1992). The effects of diminishing cod stocks may even cascade through herring, sprat and zooplankton to coastal fish, because in some areas, the open sea predation by zooplanktivores may affect the coastal zooplankton (Ljunggren et al. 2010). However, climate related variables have also been found to be important for coastal fish communities. Olsson et al. (2012) concluded that local temperature and regional salinity were the most significant variables in relation to observed changes in coastal fish community composition in the Baltic, while local nutrient concentration played a lesser role.

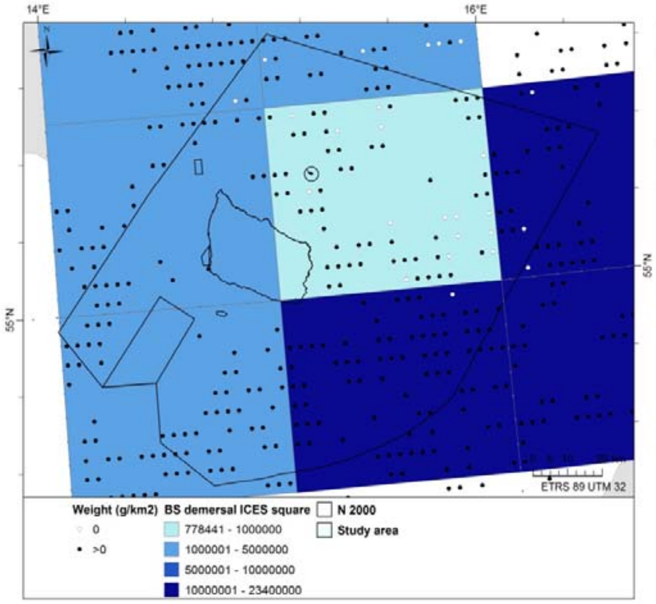


Figure 52 Demersal fish. Average catch per area swept (g/km2 from BITS survey in quarters1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence). Source: ICES DATRAS survey data.

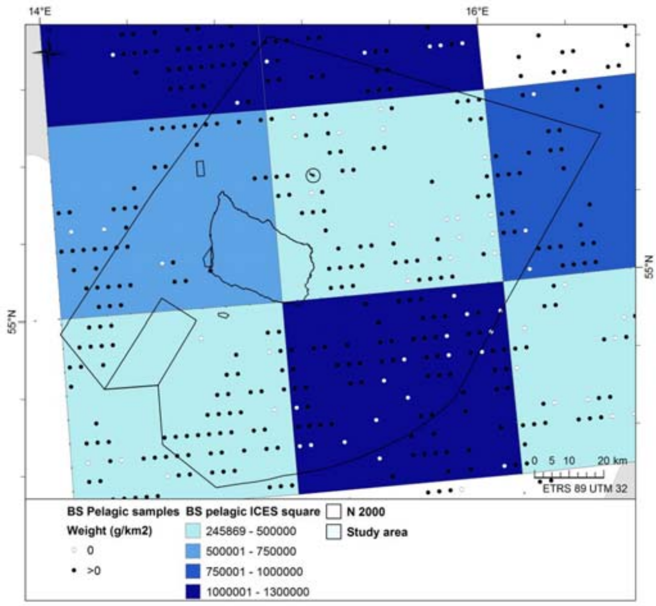


Figure 53 Pelagic fish species. Average catch per area swept (g/km2 from BITS survey in quarters1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence). Source: ICES DATRAS survey data.

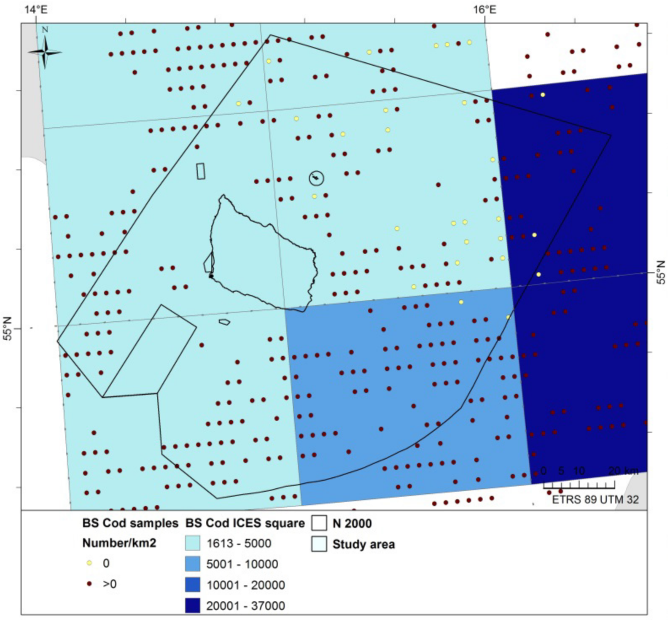


Figure 54 Cod. Average density (No/km2 from BITS survey in quarters1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence)

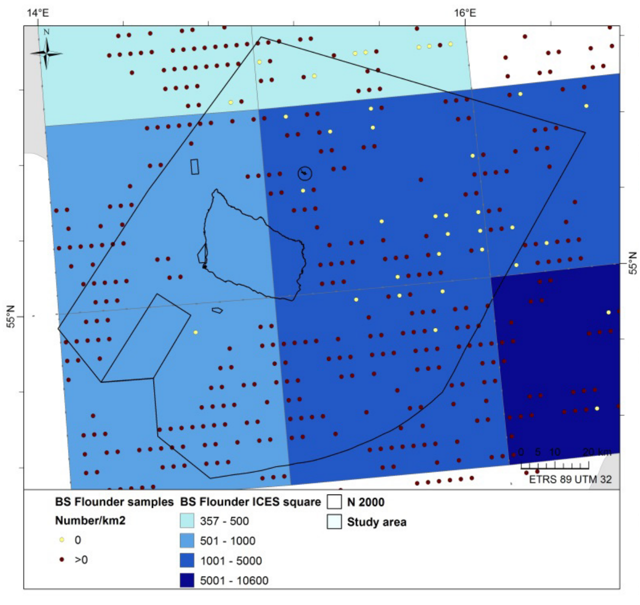


Figure 55 Flounder. Average density (No/km2 from BITS survey in quarters1 and 3 over the period from 2001 to 2016) and sampling positions (circles; filled circles indicate presence, open circles absence)

In the Danish zone around Bornholm cod and flounder dominate the biomass of demersal fish caught by the bottom trawl. The biomass of demersal fish species seems to be concentrated in a patch southeast of the island (Figure 52) while pelagic biomass is more dispersed and is found to both the southeast and north (Figure 53).

Cod constitute more than 80% of the total fish biomass caught and abundance of cod has a highly aggregated spatial pattern, while flounder is much more dispersed to the north, east and southeast of the island (Figure 54 and Figure 55).

4.1.9 Birds

The Baltic study region is partly covered by the national Danish monitoring program, NOVANA. The marine area west of Bornholm has been surveyed for wintering birds every third winter since the initiation of the NOVANA monitoring program. These surveys have been conducted as line-transect samples. The most abundant wintering waterbird in the study region was Long-tailed Duck (Clangula hyemalis). In 2004 around 47,300 Long-tailed Ducks winter in Danish marine areas, of which 27,500 was estimated for the Rønne Banke and Adler Grund areas (Figure 56). These areas are thus the main area the Long-tailed Ducks wintering in Denmark (Laursen et al. 1997, Petersen et al. 2006, 2010, Petersen & Nielsen 2011). A severe decline in the Baltic population of Long-tailed Duck was reported to have occurred between 1992 and 2007 (Skov et al. 2011). For the mid-winter survey of 2008 a total of 8,776 Long-tailed Ducks was estimated for the marine areas west of Bornholm (Figure 57). Densities in 2008 were much lower than in 2004.

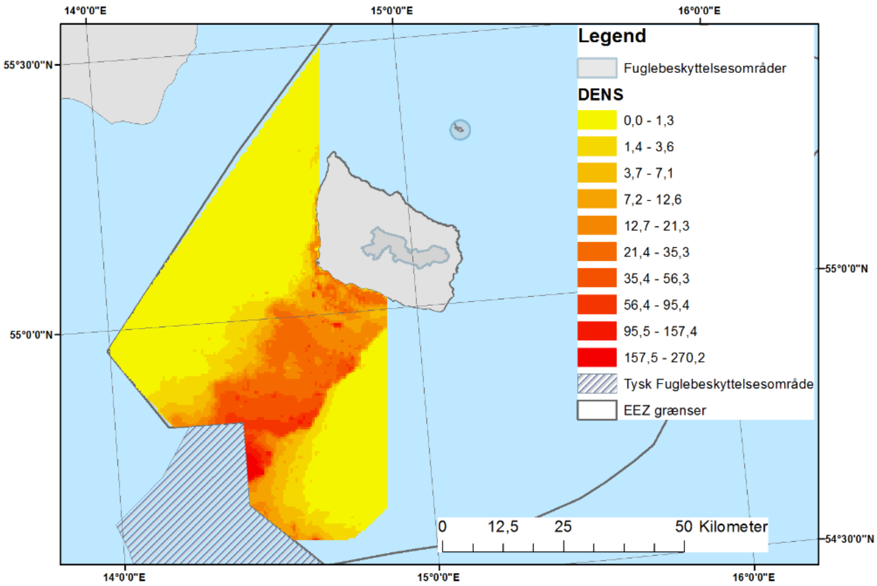


Figure 56 Spatial distribution of 27,556 Long-Tailed Ducks in the waters west of Bornholm in the winter of 2004.

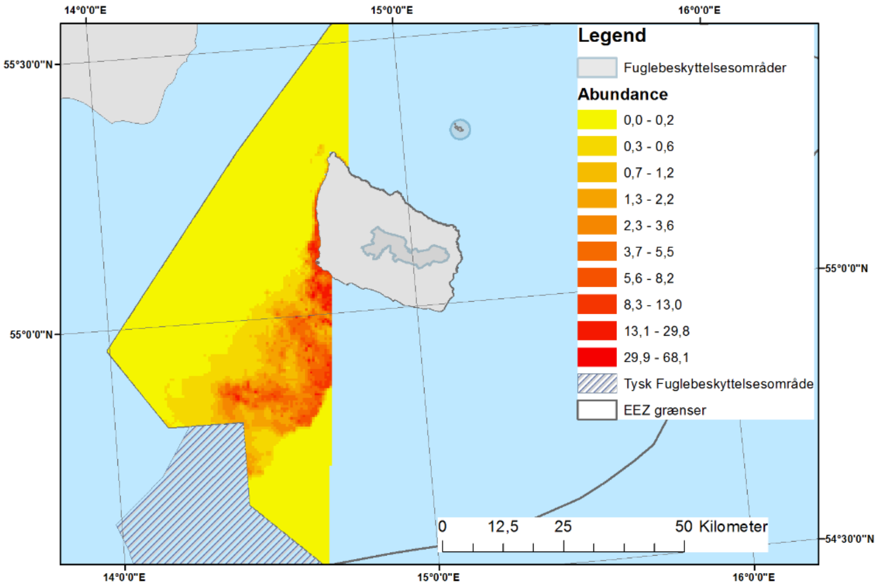


Figure 57 Spatial distribution of 8,776 Long-Tailed Ducks in the waters west of Bornholm in the winter of 2008.

The total abundance of Long-tailed Ducks for the area was not estimated for the 2013 and 2016 data. Therefore, a plot of observed flocks is presented instead. Experience from previous estimates of total numbers for this area showed that the ratio between observed numbers and estimated totals was between 10.2 and 16.5. During the 2013 mid-winter survey a total of 2.377 Long-tailed Ducks were recorded in the Rønne Banke area (Figure 58). Using the above ratio a tentative total number of between 24,000 and 39,000 could be estimated.

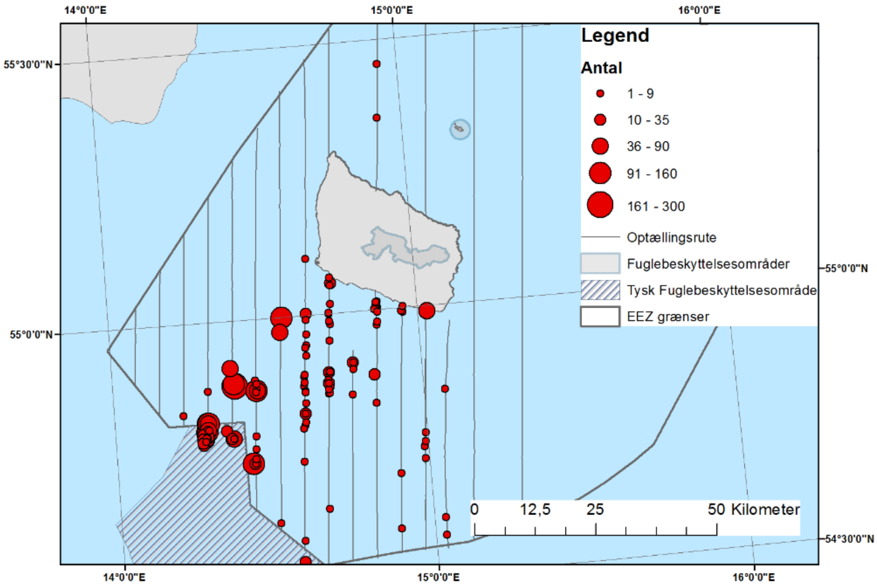


Figure 58 Spatial distribution of 2,377 observed Long-tailed Ducks on Rønne Banke and Adlers Grund in the winter of 2013.

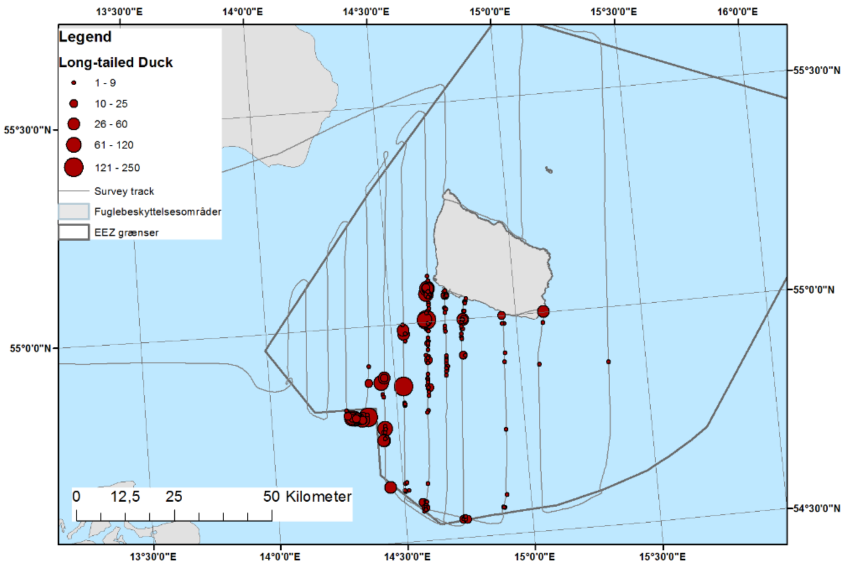


Figure 59 Spatial distribution of 2,724 observed Long-tailed Ducks on Rønne Banke and Adlers Grund in the winter of 2016

During the 2016 mid-winter survey a total of 2.724 Long-tailed Ducks were recorded in the Rønne Banke area (see Figure 59). Using the above ratio a tentative total number of between 28,000 and 45,000 could be estimated. Long-tailed Ducks in this area are mainly found where water depths are 14-24 m (Figure 60, Petersen et al. 2006).

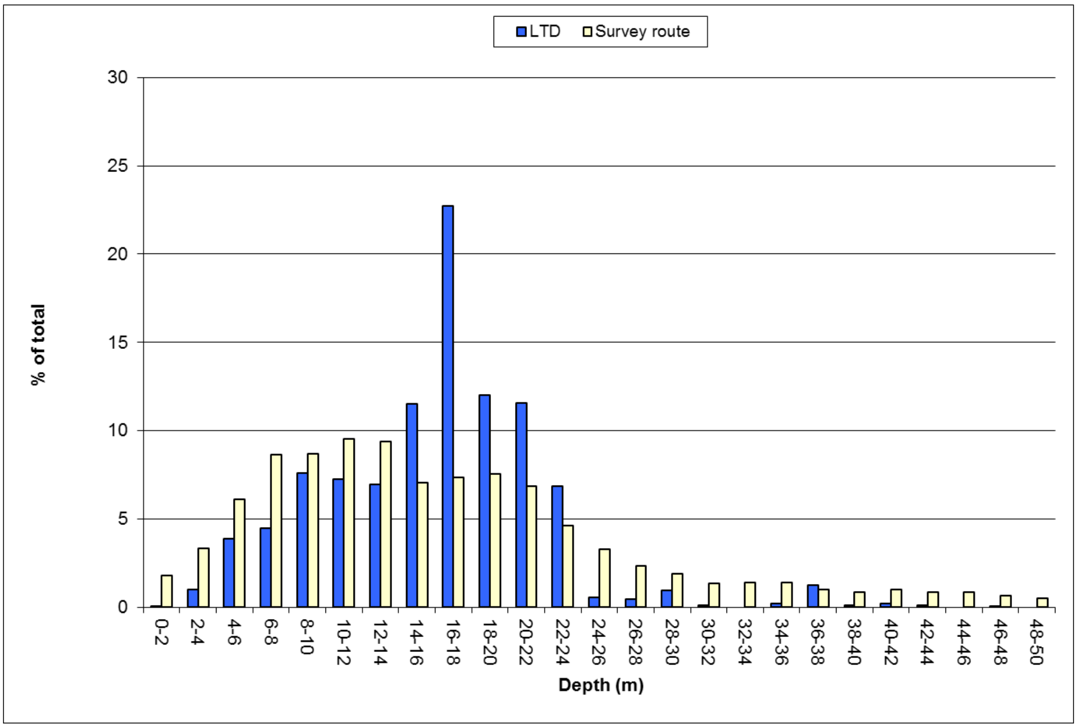


Figure 60 The depth frequency distribution in 2 m intervals of 3,694 nonflying long-tailed ducks observed during line transect surveys in Danish waters. The corresponding depth frequency distribution for the survey track line is also given.

4.1.10 Marine mammals

The marine mammals in the Baltic Sea consist of two species of seal: grey seal *Halichoerus grypus* and harbour seal *Phoca vitulina*; and one species of cetacean that occurs commonly or is resident: harbour porpoise *Phocoena phocoena*. Other species are observed in the western part of the Baltic Sea on rare occasions, such as minke whale *Balaenoptera acutorostrata*.

Based on molecular data and satellite telemetry, the harbour seals in the Baltic Sea have been split into two management units or sub-populations, between which there is at least partial reproductive isolation:

1) Kalmarsund (between Øland and the Swedish mainland) and
2) the southwestern Baltic (along the southern Danish and Swedish coasts) (Goodman et al. 1998, Härkönen 2006; Olsen et al. 2014).

There are, however, no harbour seal haul-outs in the Danish zone around Bornholm and the seals from the two known sub-populations do not inhabit these waters regularly. Consequently, harbour seals are not further assessed here.

The Baltic grey seal is a genetically separate population found in the Baltic Proper, the Bothnian Sea and the Gulf of Finland (Graves et al. 2009, Fietz et al. 2016) and it is the most abundant seal species in the Baltic. Approx. 100 years ago the grey seal population consisted of 80-100,000 individuals but in the 1970s it was down to about 4,000 (Harding and Härkönen 1999). The latest assessment based on visual counts of seals estimated that the population was above 40.000 seals (HELCOM 2015). In the Danish part of the Baltic, the number of grey seals has increased considerably over the last decade: In 2002-2005 only 0-12 individuals were counted here. These numbers increased to 67 and 41 in 2009 and 2010, respectively and reached 301 in 2014 and 850 in 2015. Of the 850 grey seals counted in 2015, 567 were observed at Ertholmene near Bornholm (Hansen 2016). Ertholmene is the only grey seal haul-out in the Danish Baltic Sea around Bornholm. This colony is at present the largest of the Danish grey seal colonies and from 2011 to 2014, 33-99% of all observed grey seals in Denmark were counted here. However, grey seals move over long distances in the Baltic Sea and only a few breed on the Danish coast. Therefore, the majority of animals may be migrating between breeding sites in the northen Baltic Sea and feeding sites in the western Baltic. In the Baltic Sea, grey seal prey mainly on herring, but also on sprat, common whitefish, freshwater cyprinids, gobies and flounder (Lundström et al. 2007).

Data on grey seal distribution at sea (including hot-spots and potential foraging areas) in the area is available for 19 grey seals in the Baltic tagged with Argos satellite transmitters or GPS/GSM transmitters (2009-2015). The seals were tagged in various resting places including Rødsand, Falsterbo in Sweden and Vitsten. For all datasets one position per animal per day was extracted, regardless of how long the individual transmitters had sent signals. For all positions, Kernel Densities Estimates with a radius 20 km were calculated (Figure 61). The combined dataset was normalized to sum up to the value 10^6. It should be noted that the telemetry data are only based on 19 individuals and may not be representative for the entire population. Consequently, some important pelagic foraging sites may be missing from the map.

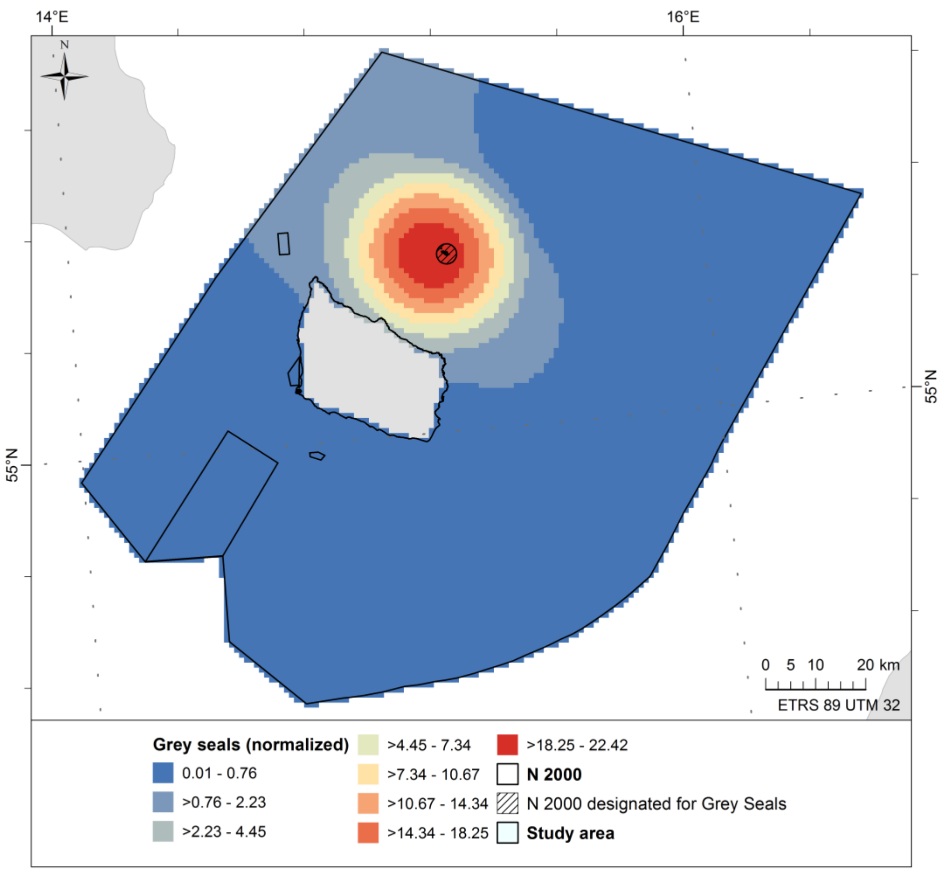


Figure 61 Distribution of 19 satellite tracked grey seals displayed as Kernel Density Estimates with values normalized to 1 mill. (2009-2015).

The harbour porpoises inhabiting the Danish Baltic Sea around Bornholm are understood to be a mix of two populations: one residing in the Kattegat, the Belt Sea, the Sound and the western Baltic (called the Belt Sea population) and one residing in the Baltic Proper (Wiemann et al. 2010, Galatius et al. 2012, Sveegaard et al. 2015). The abundance of the Belt Sea population has been relatively stable over the last two decades (Hammond et al. 2017), while the Baltic population is listed as “critically endangered” by the International Union for Conservation of Nature (IUCN) and the abundance was recently estimated to be approx. 500 individuals (Amundin 2016).

Information on harbour porpoise distribution is available from the SAMBAH project (Amundin 2016). Here, 300 acoustic data loggers were deployed for two years (2011-2013) recording porpoise echolocation click sounds. Based on these detections, a density model for two seasons (summer and winter) was created covering the Baltic Sea. For this project, the model was delimited to the Danish zone around Bornholm. In general, the abundance in this area is low and the models predict very low densities in the area east of Bornholm (Figure 62). The porpoises that do use the area, aggregate in the southwestern part of the area near the Polish zone in the summer period. In the winter, they occupy an area further north between Bornholm and the Swedish zone.

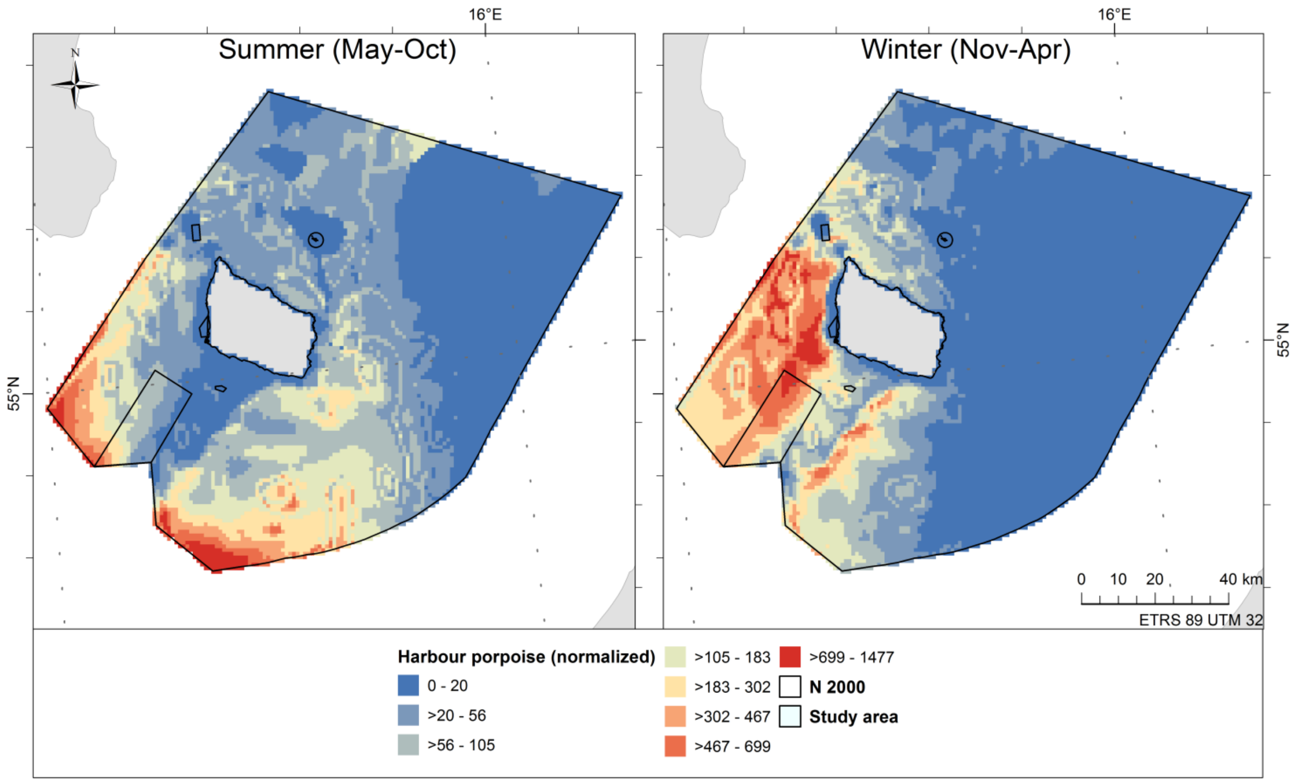


Figure 62 The relative harbour porpoise distribution based on a spatial density model derived from two years (2011-2013) of passive acoustic recordings in the Baltic (300 CPODs distributed in an even grid, SAMBAH.org). Left panel is summer distribution and right panel is winter distribution. For this project, the mean raster value per grid cell was calculated and afterwards normalized to sum up to 1 mill.

4.2 The present MPA network

In 2017, six Natura 2000 sites make up the protected areas in the Danish zone around Bornholm. The sites are designated to fulfil obligations set by either the EC Bird Directive or by the EC Habitats Directive with regard to specific species or habitats or a combination of both Directives. The six sites cover in total 353km^2.

In addition, an area has been closed to cod fishing to protect the spawning aggregations of cod over the Bornholm Deep from May to November each year (see figure from the DISPLACE chapter).

4.2.1 Birds directive

In the Baltic area, only one marine area has been designated as a Bird Directive area (SPA). SPA nr. 79, Ertholmene, covers the islands of Ertholmene east of Bornholm and a narrow radius of sea around these. The total area of the SPA is 12.7 km^2. The site is designated for two species of breeding birds are, namely Razorbill and Common Guillemot.

There are no SPAs in the study region designated for migratory/staging birds. German marine areas bordering the southwestern parts of Danish Rønne Banke have been designated as Birds Directive areas (Figure 63).

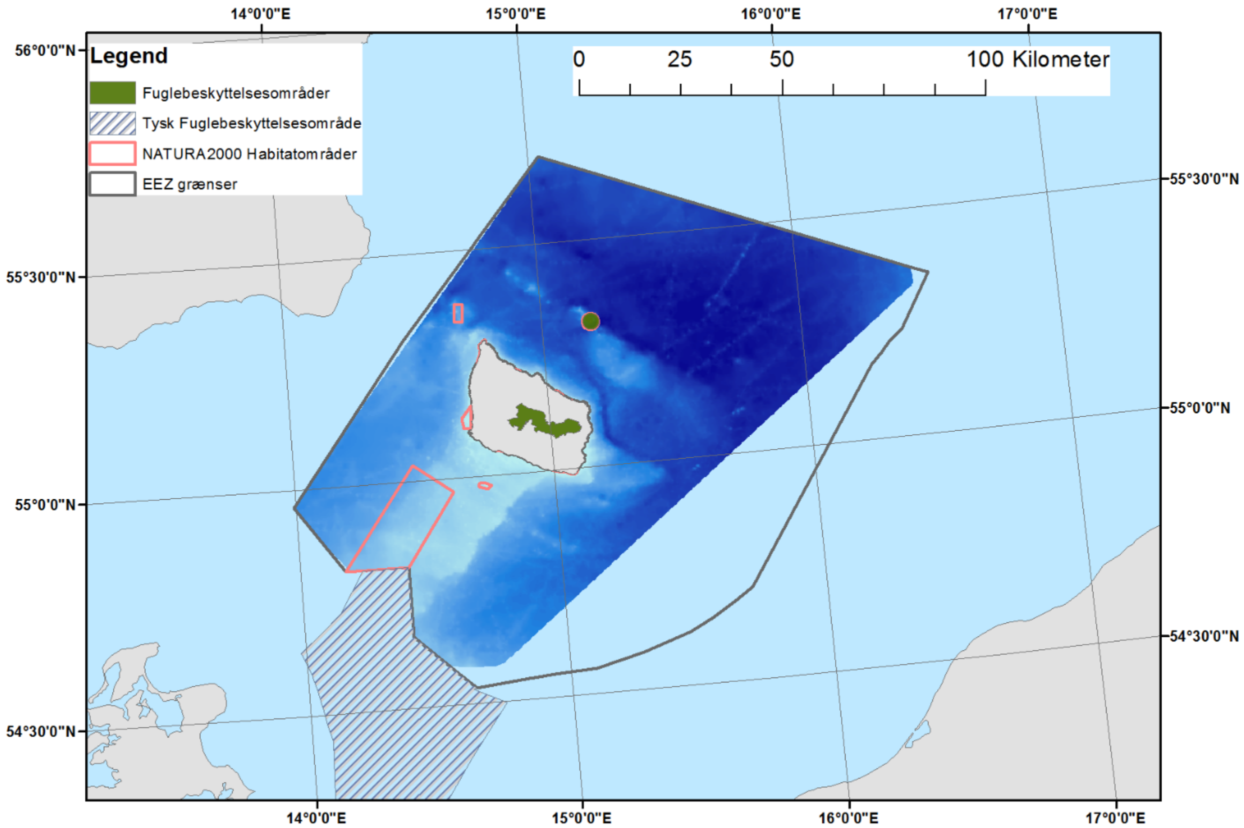


Figure 63 The Baltic zone with Danish Birds Directive areas (green) and Habitat Directive Areas indicated (red). Neighboring German Birds Directive areas are also indicated (shaded).

4.2.2 Habitats directive Annex I habitats

The six Natura 2000 sites are all habitat sites (SACs) and are all designated for the protection of Annex I habitats under the Habitats Directive. The sizes of both the Natura 2000 areas and the specific habitats within the MPAs are given in table Table 12 and Table 13. Only three habitat types are present in the waters around Bornholm. “Sandbanks which are slightly covered by sea water all the time” (EU code 1110 and in short “sandbanks”) “Reef” (EU code 1170) and “Submerged or partially submerged sea caves” (EU code 8330).

“Reef” is part of the designation in five of the six Natura 2000 areas. The area classified as reef within the five Natura 2000 areas is given in Table 12. Biogenic reef areas are not mapped although large biomasses of blue mussels Mytilus edulis and/or Mytilus trossolus are observed in monitoring stations on hard bottom. In those cases the habitat is simply referred to as reef. There is no evidence that blue mussels form biogenic reefs in the open waters around Bornholm on softer sediments, as is the case in some other Danish marine waters. Overall it is estimated that approximately 17% of the reef areas in Danish waters around Bornholm are located within Natura 2000 areas. Three broad-scale hard bottom communities highly associated with “reef” have been classified based on the existing data. The present MPA net covers approximately 15% of the shallow “fucus community”, 4% of the “Furcelaria-Mytilus community” and 18% of the deeper “Mytilus community”.

"Sandbanks" are designated in two Natura 2000 sites (Table 12), in the Danish Baltic Sea, as more careful mapping was able to document sandbanks in the Natura 2000 area "Bakkebræt og Bakkegrund" and "Adler Grund og Rønne Banke" (Jensen *et al.* GEUS report 2012). Overall, it is estimated that 0.8 % of sandbank areas in Danish waters around Bornholm are located within Natura 2000 areas. So far no broad scale communities for sandbanks have been identified for the area (Table 13).

The habitat "Cave" is located within the cliffs of Hammer. One cave is well known within the Natura 2000 area that mostly covers terrestrial habitats.

Table 12 Annex 1 marine habitat types and their size within the six Natura 2000 areas designated in 2017. (*)Indicates that most of the area is terrestrial.

Natura 2000 site	Natura 2000 size (km^2	Habitat types	Habitat cover (km^2) or number observed*
Hammeren og Slotslyngen (184)	5,49*	"caves" (8330)	1 pc may be a few more
Ertholmene (189)	12,7	Reefs (1170)	4,5
Davids Banke (209)	8,38	Reefs (1170)	8,4
Hvidodde Rev (211)	7,89	Reefs (1170)	7,2 (sedimentary rock)
Bakkebræt og Bakkegrund (212)	2,99	Sandbanks (1110) Reefs (1170)	0.06 2.4
Adler Grund og Rønne banke (252)	319,10	Sandbanks (1110) Reefs (1170)	4,6 109,1 (till) + 40,2 (sedimentary rock)

Table 13 Estimated areal distribution of six marine annex 1 habitats in total for the Danish area around Bornholm, mapped within Natura 2000 sites and the protected ratio within this water body in 2017. Information on "cave" is given for the identified structure observed (*) and not for areas in km2. Data from Al-Hamdani et al. 2015 and Jensen et al. 2012).

Habitat type	Area mapped within Natura 2000 sites (km^2)	Total mapped and estimated area for the Danish waters around Bornholm (km2)	Percentage covered by MPA
Sandbanks (1110)	5.7	683.3	0.8
Reefs (1170)	171.7	777.6	16.5[14]
"Caves" (8330)	1*		100

4.2.3 Habitats directive Annex II species

Of the five Natura 2000 areas in the Danish zone around Bornholm, one - Ertholmene (12.7 km^2) - is designated for grey seals (Table 14). No other Natura 2000 areas are designated for marine mammals.

[14]Moraine only - no sedimentary bed rock.

Table 14 Natura 2000 areas and the species they are designated to protect under the Habitat Directives Annex II, the number and size of Natura 2000 sites they are protected in as well as the percentage of the species covered by the Natura 2000 areas.

Species	Species number	Number of Natura 2000 sites	Natura 2000 size (km2)	Species cover (%)
Harbour porpoise	1351	0	0	0
Grey seal	1364	1	12.7	3.2

4.3 Habitats and species not covered by the present MPA network

Three benthic fauna communities based on abundance and four based on biomasses are identified on habitats formed by low saline soft sandy or muddy soft sediment in the Danish zone around Bornholm. None of these habitats is covered by the present MPA network. In addition, communities associated with eelgrass beds in shallow waters have been monitored south and south-east of Bornholm. In general, one may say that the benthic communities are shaped by the sediment composition together with salinity, light and exposure. The biological components of the physical habitats are affected by long- term effects of eutrophication, affecting oxygen and food conditions. Riemann et al (2015) demonstrated large scale changes in benthic biomasses and the balance between filter and deposit feeders in Danish coastal waters as a result of decreasing nutrient load and similar changes might take place in the Baltic Sea.

Sandy fauna community in shallow water

The community is characterized by mud snails Hydrobiidae, the polychaete Pygospio elegans and the cockle Cerastoderma glaucum (abundance) plus the polychaete Hediste diversicolor and the clam Mya arenaria (biomass) on the sandy part of the bottom at less than 30m depth. This community often coexists with hard bottom habitats as sandy patches in between gravel, larger boulders or patches of bedrock. The community is expected to be present within all or most of the existing Natura 2000 areas in the waters around Bornholm.

Sandy mud bottom community

This community is typified by the crustacean *Monoporeia affinis*, the bivalve Macoma balthica, the invasive polychaete *Marenzelleria spor*, by the crustaceans *Saduria entomo*, *Pontoporeia femorata* and the priapulid worm *Halicryptus spinulosus* (only biomass). There is no overlap between this community and the borders of the present Natura 2000 network.

Muddy community in deep hypoxic water

This community is characterised by *Bylgides sarsi* and *Pontoporeia femorata* (only abundance) Bylgides can cope better with hypoxic conditions than most species in the Baltic and the community is symptomatic of the severe oxygen conditions in the deep parts of the Baltic. The restoration of these deep anoxic parts of the Baltic is less a management issue within the area and more a question of regulation of eutrophication in the Baltic Sea as a whole.

Muddy bottom community

This community is characterized by selected species from the “Muddy community in deep hypoxic water”. The community is characterized by the crustacean *Diastylis sp*., the bivalves *Astarte spp*, *Mya truncata*, and *Abra alba*, the ascidian *Dendrodoa grossularia*, the polychaetes *Lagis koreni* and *Trochochaeta multisetosa* and the nemertean *Lineus ruber*. There is no overlap between this community and the existing borders of the Natura 2000 network.

Seagrass community in shallow waters
Seagrass beds are an important habitat for many species. They are present along the coast of Bornholm (Figure 45); however insufficient knowledge is available to evaluate their extent.

Fish
Cod spawn in the Bornholm Deep during summer and autumn. To protect the spawning aggregations an area has been closed to fishing from May to October. However, analysis of survivors in the year 2000 suggested that most of the cod larvae originated from fish spawning outside the area (Huwer et al. 2014) and subsequent work has shown that the relationship between spawning locations and areas producing good cod larval survival is variable, making spatial protection measures difficult to design.

Birds
The Rønne Banke and Adler Grund areas west and southwest of Bornholm have wintering populations of Long-tailed Ducks of both national and international importance. Of the existing Bird Directive areas in Denmark only one has Long-tailed Duck on the designation list, namely Nr. 72, Marstal Bugt og den sydlige del af Langeland.

Rønne Banke and Amrum Bank can be classified as an internationally important site on the basis of regular occurrence of more than 20,000 waterbirds. This is a criterion first used in relation to the Ramsar Convention, later also the Birds Directive. The percentage of Long-tailed Ducks presently occurring within Birds Directive areas for which the species is on the designation list is presently less than 5%, for example in 2008 data it was 0% (Figure 56).

Marine mammals
Harbour porpoise is not included in the current network, apart from a population d-status in Adler Grund and Rønne Banke. D-status means that the species may be present within the area, but no management is required. The distribution of porpoises in the Baltic was only recently examined during the SAMBAH project (Amundin 2016) and the Danish Environmental Protection Agency is currently reviewing whether further areas should be designated for porpoises in the Danish Baltic (Pers. comm. Marie-Louise Krawack, 30/5-2016).

4.4 Status of the present MPA network for each biotic feature and habitat

In this chapter, the status of the present MPA network is described with reference to representativity, replication and adequacy. In Part 2 and 3 of the project, we will use more advanced tools (Zonation and Marxan) developed to define hotspots and analyze the network of MPAs. Furthermore, connectivity will be assessed using IBM modeling.

4.4.1 Representativity

Representativity aims at ensuring that the MPA network protects relevant biogeographical areas and physical features, reflecting the whole range of habitats, important biological communities and levels of biodiversity. Representativity considers different types of area coverage in order to describe how the network covers different features, such as habitats or species or the factors related to their existence and status as geological, physical and hydrographic factors (Table 16).

MPAs in the Danish part of the Baltic Sea
The six sites of MPAs cover 3% (353 km^2) of the Danish zone of the Baltic Sea (11,565 km^2).

Hydrodynamic features

No pelagic habitats such as upwelling areas are protected in the existing network of MPAs. 12% of the upwelling zones and 3% of the areas with sufficient light for benthic primary producers (PAR[15] > 1%) are situated within the present MPA network.

Benthos

The hard bottom communities are protected via the Habitat Directive. Approximately 15% of the modelled *Fucus* dominated hard bottoms, 4% of *Furcellaria-Mytilus* dominated hard bottoms, 18% of the *Mytilus* areas and 17% of the Filter feeder/ Mytilus areas are situated within MPAs.

Fish

Table 15 shows the proportion of the biomass of demersal and pelagic fish species and the proportion of the abundance of cod and flounder that are found inside the MPA borders. None of the present MPAs are established to protect fish. Although they avoid hypoxic or anoxic areas, cod cannot be assumed to be associated with particular bottom habitats, while flounder is found mainly on sandy or muddy bottoms. Note that the surveys do not cover hard ground such as found in the Adler ground Natura 2000 area, and that the temporary spatial measure to protect spawning cod has not been included REGULATION (EU) 2016/1139). The uncertainty in the data is regarded as moderate to high.

Table 15 Proportion of fish biomass of demersal and pelagic fish relevant for the area.

Ecological feature	Species name	% of feature in the Danish area inside Natura 2000 areas
Demersal fish biomass		2.3
Pelagic Fish biomass		0.4
Cod abundance	Gadus morhua	3.1
Flounder abundance	Platichthys flesus	0.5

Birds

For the breeding population of Razorbills and Common Guillemots the percentage of the Danish breeding population is well targeted by the Bird Directive area Nr. 79, Ertholmene. Almost 100% of the Danish breeding populations of these two species are found within this single SPA. Only a low percentage of wintering Long-tailed Ducks are seen in Danish SPAs outside the Baltic zone). In the example of the 2008 mid-winter data, no birds were seen outside the Baltic Zone (Table 10).

[15] Photosynthetic Available Radiation

Table 16 Status of representativity estimating how large a part (%) of marine benthic and pelagic habitats and species populations is protected by the current MPA network in the Danish part of the Baltic Sea.

	Current status (%)	Uncertainty (low, moderate or high)
DK part of the Baltic around Bornholm		
Area covered by MPA's	3.1	
Habitats – habitat directive		
Reefs (mapped as till)	16.5	Low inside Natura2000 and high outside
Sandbanks	0.84	Low inside Natura2000 and high outside
Caves	100	low
Benthic habitats not covered by HD		
Shallow sandflats (see below for communities)	0	Not relevant
Shallow Coastal bedrock (see below for communities	0	Not relevant
Pelagic habitats/ features		
Pelagic Fronts/ upwelling habitats	0	Not relevant
PAR > 1%	0	Not relevant
Benthic fauna index		
Deposit feeder	0	Not relevant
Filter feeder	17	Moderate
Mytilus index	17	Moderate
Specific communities		High
Fucus dominated hard bottom community	15.4	High
Furcellaria-Mytilus hard bottom community	3.7	High
Mytilus hard bottom community (mostly Non-photic)	18.1	Moderate
Sandy fauna community on more shallow water	0	Moderate
Sandy mud bottom community	0	Moderate
Muddy community on deeper hypoxic water	0	Moderate
Muddy bottom community	0	Moderate
Eelgrass community	0	
Species		Moderate
Grey Seal	3.2	
Fish see Table 15		
Birds see Table 10		

Marine mammals
Grey seal is the only species for which the percentage covered by the Natura 2000 sites can be calculated, since no Natura 2000 sites are designated for porpoises in the waters around Bornholm. Here, the designated area, Ertholmene, cover 3.2% of the grey seals occupying the Danish waters around Bornholm. The distribution data is based on year round satellite tracking data of 19 grey seals in the Baltic. Telemetry data give an accurate illustration of the individual movements of each seal and their preferred areas. However, since Ertholmene may hold up to 1000 grey seals and only 19 seals have been tagged, the uncertainty of the data as well as the method is assessed to be moderate.

4.4.2 Replication
Replication aims to ensure the protection of the same feature across multiple sites in the MPA network, ensuring natural variability of all features. Replication considers the number of replicas of a conservation feature in the study area, for example habitat or species.

Benthic habitats listed in Table 17 were delineated for the study area in the Central Baltic Sea. The number of each habitat inside the 6 Natura 2000 areas was given in the table. The morphology map (
Figure 39) and the EUNIS habitat map in Figure 38 is used to identify the required habitat types.

Sandbanks were calculated from the morphology map sand ridges class. They exist in Natura 2000 areas H261 and in H211 only and with small spatial extent as compared to the large sandbank areas in the southern and southeastern part of the study area. Inside the previously mapped Natura 2000 areas, the reefs are identified as substrate 3 and substrate 4, outside these areas the reef is identified by the EUNIS habitat class “mixed sediments”.

An overview of key habitats and faunal communities is given in Table 17. Most of the habitats listed in Table 17 have a replication number of minimum 3 Natura 2000 areas/habitat types.

Table 17 Overview of replication of marine benthic and pelagic habitats and fauna communities.

	Status
Benthic habitats	
Reefs	5
Sandbanks	2
Cave	1
Pelagic habitats not in Habitat Directive	
Pelagic Fronts/ upwelling habitats	2
PAR > 1%	4
Benthic fauna index	
Deposit feeder	0
Filter feeder	3
Mytilus index	3

5. References part 1

Al-Hamdani, Z., Skar, S., Jensen, J.B., Rödel, L.G., Pjetursson, B., Bennike, O., Jensen, G.C.O., Rasmussen, M.B., Dahl, K., Rømer, J.K., Göke, C., Bruhn, B. & Lundsteen, S. 2015: Marin habitatkortlægning i Skagerrak og Nordsøen 2015. Udført for Naturstyrelsen. Danmarks og Grønlands Geologiske Undersøgelse.

Alheit, J., Möllmann, C., Dutz, J., Kornilovs, G., Löwe, P., Mohrholz, V., and Wasmund, N. 2005. Synchronous ecological regime shifts in the central Baltic and the North Sea in the late 1980s. ICES Journal of Marine Science, 62(7): 1205-1215.

Amundin, M. 2015. SAMBAH. LIFE08 NAT/S/000261 FINAL Report. Kolmårdens Djurpark. 77 pp.

Amundin, M., 2016, SAMBAH Final report LIFE08 NAT/S/000261: Kolmårdens Djurpark AB, Vildmarksvägen, SE-618 92 Kolmården, Sweden.

Andersen A-B, Lassig J, Parkkonen L, Sandler H (1978) Long-term fluctuations of the soft bottom macrofauna in the deep areas of the Gulf of Bothnia 1954-1974; with special reference to Pontoporeia affinis Lindström (Amphipoda). Finn Mar Res 244:137-144.

Aneer G (1980) Estimates of feeding pressure on pelagic and benthic organisms by Baltic herring (Clupea harengus v. membras L.). Ophelia 1:65–275

Beaugrand, G. 2003. Long-term changes in copepod abundance and diversity in the north-east Atlantic in relation to fluctuations in the hydroclimatic environment. Fisheries Oceanography, 12: 270–283.

Beaugrand, G., Brander, K. M., Lindley, J. A., Souissi, S., and Reid, P. C. 2003. Plankton effect on cod recruitment in the North Sea. Nature, 426: 661–664.

Beaugrand, G., Reid, P. C., Ibañes, F., Lindley, J. A., and Edwards, M. 2002. Reorganization of North Atlantic marine copepod biodiversity and climate. Science, 296: 1692–1694.

Bergstrom L., Sundqvist F., Bergstrom U. 2013. Effects of an offshore wind farm on temporal and spatial patterns in the demersal fish community. Marine Ecology Progress Series 485: 199-210.

Bicknell, A. W., Oro, D., Camphuysen, K. C., & Votier, S. C. (2013). Potential consequences of discard reform for seabird communities. Journal of Applied Ecology, 50(3), 649-658.

Blindheim, J., and Skjoldal, H-R. 1993. Effects of climatic changes on the biomass yield of the Barents Sea, Norwegian Sea, and West Greenland Large Marine Ecosystems. In Large Marine Ecosystems: Stress, mitigation and sustainability, pp. 185–198. Ed. by K. Sherman, L. M. Alexander, and B. D. Gold. AAAS Press, Washington DC, USA.

Bonsdorff E (2006) Zoobenthic diversity-gradients in the Baltic Sea: continuous post-glacial succession in a stressed ecosystem. Journal of Experimental Marine Biology and Ecology 333:383–391

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L. (2001): Introduction to distance sampling, estimating abundance of biological populations. Oxford University Press 2001, 432 pp.

Capuzzo, E., Stephens, D., Silva, T., Barry, J., & Forster, R. M. (2015). Decrease in water clarity of the southern and central North Sea during the 20th century. Global change biology, 21(6), 2206-2214.

Casini, M., Cardinale, M., and Hjelm, J. 2006. Inter-annual variation in herring Clupea harengus and sprat Sprattus sprattus condition in the central Baltic Sea: what gives the tune? Oikos 112:639 651.

Catchpole R, 2012. Ecological Coherence Definitions in Policy and Practise. Final Report. Aspen International, Leeds, UK. Downloaded from http://www.snh.gov.uk/docs/B1028804.pdf

Cederwall H, Elmgren R (1980) Biomass increase of benthic macrofauna demonstrates eutrophication of the Baltic Sea. Ophelia Supplement 1:287–304

Center for Miljø og Energi, 148 s. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi nr. 208 http://dce2.au.dk/pub/SR208.pdf

Christie H, Norderhaug KM, Fredriksen S. 2009. Macrophytes as habitat for fauna. Marine Ecology Progress Series 396:221-233

Corten, A. 2000. A possible adaptation of herring feeding migrations to a change in timing of the Calanus finmarchicus season in the eastern North Sea. ICES Journal of Marine Science, 57: 1261–1270.
Dahl, K., et al. (2012), MOPODECO: Modeling of the Potential coverage of habitat-forming species and Development of tools to evaluate the Conservation status of the marine Annex I habitats, Nordic Council of Ministers, Copenhagen K.
http://dx.doi.org/10.6027/tn2012-532
Dahl, K., Hansen, J., Helmig, S., Nielsen, R., and Larsen, H. S. (2001) Naturkvalitet på stenrev, hvilke indikatorer kan vi bruge ? . Danmarks Miljøundersøgelser. Faglig rapport fra DMU nr. 352.
Danish Government, 2014. Danish Nature Policy – Our shared Nature. Ministry of the Environment. Danish Nature Agency 2014/2015:25. Downloaded 1/5/2017 from: www.naturstyrelsen.dk/media/137410/danish-nature-policy.pdf
Day J, Dudley N, Hockings M, Holmes G, Laffoley D, Stolton S, Wells S, 2012. Guidelines for applying the IUCN Protected Area Management Categories to Marine Protected Areas. Gland, Switzerland: IUCN. 36pp.
Dickson, R. R., Meincke, J., Malmberg, S-Aa., and Lee, A. J. 1988. The Great Salinity Anomaly in the northern North Atlantic 1968–1982. Progress in Oceanography, 20: 103–151.
Dippner JW, Kornilovs G & K Junker (2012) A Multivariate Baltic Sea Environmental Index. Ambio 41(7): 699–708.
Drinkwater, K. F. 2005. The response of Atlantic cod (Gadus morhua) to future climate change. ICES Journal of Marine Science, 62: 1327–1337.
Dulvy, N. K., Rogers, S. I., Jennings, S., Stelzenmüller, V., Dye, S. R., & Skjoldal, H. R. (2008). Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. Journal of Applied Ecology, 45(4), 1029-1039.
Dunnet, G. M., Furness, R. W., Tasker, M. L., and Becker, P. H. 1990. Seabird ecology in the North Sea. Netherlands Journal of Sea Research, 26: 387–425.
Daan, N., Gislason, H., Pope, J. G., and Rice, J. C. 2005. Changes in the North Sea fish community: evidence of indirect effects of fishing? ICES Journal of Marine Science, 62(2): 177–188. doi: 10.1016/j.icesjms.2004.08.020.
EC, 2015. Report from the Commission to the European Parliament and the Council on the progress in establishning marine protected areas (as required by Article 21 of the Marine Strategy Framework Directive 2008/56/EC. Brussels, 1.10.2015 COM(2015) 481 final.
Edwards M, Helaouet P, Johns DG, Batten S, Beaugrand G, Chiba S, Hall J, Head E, Hosie G, Kitchener J, Koubbi P, Kreiner A, Melrose C, Pinkerton M, Richardson AJ, Robinson K, Takahashi K, Verheye HM, Ward P, Wootton M., 2014. Global Marine Ecological Status Report: results from the global CPR survey 2012/2013. SAHFOS Tech Rep 10:1–37
Edwards, M., Beaugrand, G., Reid, P. C., Rowden, A. A., and Jones, M. B. 2002. Ocean climate anomalies and the ecology of the North Sea. Marine Ecology Progress Series, 239: 1–10 pp.
Edwards, M., Johns, D.G., Leterme, S.C., Svendsen, E., Richardson, A.J., 2006. Regional climate change and harmful algal blooms in the northeast Atlantic. Limnol. Oceanogr. 51 (2), 820–829.
Edwards, M., Reid, P., Planque, B., 2001. Long-termand regional variability of phytoplankton biomass in the Northeast Atlantic (1960–1995). ICES J. Mar. Sci. 58, 39–49.
Edwards, M., Richardson, A.J., 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature 430 (7002), 881–884.
Eero M, Hjelm J,Behrens J,Buchmann K,Cardinale M,Casini M,Gasyukov P,Holmgren N,Horbowy J,Hüssy K,Kirkegaard E, Kornilovs G, Krumme U, Köster FW, Oeberst R, Plikshs M, Radtke K, Raid T, Schmidt J, Tomczak MT, Vinther M, Zimmermann C, and Storr-Paulsen M (2015) Eastern Baltic cod in distress: biological changes and challenges for stock assessment. ICES Journal of Marine Science, 72: 2180–218
Elmgren R (1989) Man’s impact on the ecosystem of the Baltic Sea: energy flows today and at the turn of the century. Ambio 18:326–332

Emeis, K. C., van Beusekom, J., Callies, U., Ebinghaus, R., Kannen, A., Kraus, G., ... & Möllmann, C. (2015). The North Sea—A shelf sea in the Anthropocene. Journal of Marine Systems, 141, 18-33.
Feistal R, Nausch G & N Wasmund (Eds.) (2008) State and Evolution of the Baltic Sea 1952-2005. – John Wiley & Sons, Inc., Hoboken, New Jersey, p. 625-667
Fietz, K.; Galatius, Anders; Frie, A.K.; Teilmann, Jonas; Dietz, Rune; Klimova, A; Jensen, L F; Graves, J.A.; Hall, A.; McConnell, Bernie; Hoffman, J.; Gilbert, M T P; Olsen, M. T. 2016. Grey seals in Europe: Divided by climate and culling – reunited by conservation. Molecular Ecology 25: 4097-4112
Finni T, Kononen K, Olsonen R, Wallström K (2001) The history of cyanobacterial blooms in the Baltic Sea. AMBIO 30:168–172
Frederiksen, M., Edwards, M., Richardson, A. J., Halliday, N. C., and Wanless, S. 2006. From plankton to top predators: bottom-up control of a marine food web across four trophic levels. Journal of Animal Ecology, 1–10.
Galatius, A., Kinze, C.C. and Teilmann, J. (2012). Population structure of harbour porpoises in the greater Baltic region: Evidence of separation based on geometric morphometric comparisons. Journal of the Marine Biological Association of the United Kingdom 92(8): 1669-1676
Gogina, M., Nygård, H., Blomqvist, M., Daunys, D., Josefson, A. B., Kotta, J., Maximov, A., Warzocha, J., Yermakov, V., Gräwe, U., and Zettler, M. L. 2016. The Baltic Sea scale inventory of benthic faunal communities. ICES Journal of Marine Science, 73(4):1196-1213 doi: 10.1093/icesjms/fsv265.
Goodman, S. 1998. Patterns of extensive genetic differentiation and variation among European harbour seals (Phoca vitulina vitulina) revealed using microsatellite DNA polymorphisms. Molecular Biology and Evolution 15: 104-118
Graves JA, Helyar A, Biuw M, Jussi M, Jussi I et al. (2009). Microsatellite and mtDNA analysis of the population structure of grey seals (Halichoerus grypus) from three breeding areas in the Baltic Sea. Conservation Genetics 10: 59-68. doi:10.1007/s10592-008-9517-1
Gravesen, P.G., Leth, J.L. & Jensen, J .B., 2009: Nordsøen – Havbundsdata og kortlægning. GEUS rapport 2009/48.
Hammond PS, Lacey C, Gilles A, Viquerat S, Börjesson P, Herr H, Macleod K , Ridoux V, Santos MB, Scheidat M, Teilmann J, Vingada J, Øien N. 2017. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. Final report. 39 pp.
Hammond, P. S, Macleod, K., Berggren, P., Borchers, D., Burt, L., Cañadas, A., Desportes, G., Donovan, G. P., Gilles, A., Gillespie, D., Gordon, J., Hiby, L., Kuklik, I., Leaper, R; Lehnert, K., Leopold, M., Lovell, P., Øien, N., Paxton, C. G., Ridoux, V., Rogan, E., Samarra, F., Scheidat, M., Sequeira, M., Siebert, U., Skov, H., Swift, R., Tasker, M. L., Teilmann, J., Van Canneyt, O., and Vázquez, J. A. 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164:107–122.
Hansen, J.W. (red.) 2016: Marine områder 2015. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 148 s. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi nr. 208, http://dce2.au.dk/pub/SR208.pdf
Hansen, J.W. (red.) 2016: Marine områder 2015. NOVANA. Aarhus Universitet, DCE – Nationalt
Hansson S, Larsson U, Johansson S (1990) Selective predation by herring and mysids, and zooplankton community structure in a Baltic Sea coastal area. J Plankton Res 12:1099-1116.
Harden Jones, F. R. (1968). Fish migration. Edward Arnold.
Harding KC and Härkönen TJ. 1999. Development in the Baltic grey seal (Halichoerus grypus) and ringed seal (Phoca hispida) populations during the 20th century. Ambio 28: 619-627
Harms J. 1993. Check list of species (algae, invertebrates and vertebrates) found in the vicinity of the island of helgoland (North Sea, German Bight) GÇö a review of recent records. Helgolænder Meeresuntersuchungen 47:1-34
Heath, M. R., & Beare, D. J. (2008). New primary production in northwest European shelf seas, 1960–2003. Marine Ecology Progress Series, 363, 183-203.

Heeesen, H.J.L., Daan, N. and Ellis, J.R. 2015. Fish atlas of the Celtic Sea, North Sea and Baltic Sea. Wageningen Academic Publishers, KNNV Publishing, The Netherlands.
HELCOM 2002. Environment of the Baltic Sea area 1994-1998. Balt. Sea Environ. Proc. No. 82 B., 215 pp., Helsinki Commission, Helsinki, Finland. Accessible at www.helcom.fi.
HELCOM 2009. Eutrophication in the Baltic Sea – an integrated thematic assessment of the effects of nutrient enrichment in the Baltic Sea region. Baltic Sea Environment Proceedings, 115B. 1–148. Helsinki Commission, Helsinki, Finland. Available at www.helcom.fi.
HELCOM 2010 Ecosystem Health of the Baltic Sea 2003–2007: HELCOM Initial Holistic Assessment. Balt. Sea Environ. Proc. No. 122. Available at www.helcom.fi.
HELCOM 2013 HELCOM Red List of Baltic Sea species in danger of becoming extinct. HELCOM BSEP140. Available at www.helcom.fi.
HELCOM. 2003. The Baltic Marine Environment 1999-2002. Baltic Sea Environment Proceedings No. 87. Helsinki Commission, Helsinki, Finland. Available at www.helcom.fi.
HELCOM. 2015. Core indicator report - Population trends and abundance of seals. Available at: http://helcom.fi/Pages/search.aspx?k=seal%20monitoring
Hernroth L, Ackefors H (1979) The zooplankton of the Baltic Proper. A long-term investigation of the fauna, its biology and ecology. Report of the Fishery Board of Sweden, Institute of Marine Research 2:1–59
Hinder, S.L., et al., 2012. Changes in marine dinoflagellate and diatom abundance under climate change. Nat. Clim. Chang. 2 (4), 271–275.
Hislop, J. R. (1996). Changes in North Sea gadoid stocks. ICES Journal of Marine Science: Journal du Conseil, 53(6), 1146-1156.
Huwer B, Hinrichsen HH, Bötcher U, Voss R, and Köster F (2014). Characteristics of juvenile survivors reveal spatio-temporal differences in early life stage survival of Baltic cod. Mar. Ecol, Prog. Ser. 511:165-180.
Härkönen, T., 2006, "Populationsinventeringar av knubbsäl i Kalmarsund", (Eds: Naturhistoriska Riksmuseet i Stockholm, Miljögiftgruppen).
ICES (2015) Report of the Working Group on Marine Mammal Ecology (WGMME), 9–12 February 2015, London, UK. ICES CM 2015/ACOM:25. 114 pp.
ICES (2016) Report of the ICES Advisory Committee 2016. Greater North Sea Ecosystem Overview. ICES Advice, 2016. Book 6.
ICES (2017). Report of the Working Group on Fish Distribution Shifts (WKFISHDISH), 22–25 November 2016, ICES HQ, Copenhagen, Denmark. ICES CM 2016/ACOM: 55. 197pp.
ICES. 2016. Interim Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB), 18-22 April 2016, Helsinki, Finland. ICES CM 2016/SSGIEA:08. 27 pp.
Jensen, J.B., Nicolaisen, J.F., Al-Hamdani, Z., Nørgaard-Pedersen, N., Addington, L.G., Christensen, L., Lomholt, S., Schmedes, M. 2012. Marin råstof- og naturtypekortlægning i Kattegat og vestlige Østersø 2011. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2012.
Kirby RR, Beaugrand G, Lindley JA (2008) Climate-induced effects on the meroplankton and the benthic-pelagic ecology of the North Sea. Limnology and Oceanography, 53, 1805–1815.
Kirby, R. R. & Beaugrand, G. (2009) Trophic amplification of climate warming. Proc. R. Soc. B 276, 4095–4103.
Krause, G., Budeus, G, Gerdes, D., Schaumann, K. & K. Hesse 1986. Frontal systems in the German Bight and their physical and biological effects. Pp 119-141 in: Nihoul, J.C.J. (ED.). Marine Interfaces Ecohydrodynamics. Elsevier Oceanography Series 42, Elsevier, Amsterdam.
Kröncke, I., Reiss, H., & Dippner, J. W. (2013). Effects of cold winters and regime shifts on macrofauna communities in shallow coastal regions. Estuarine, Coastal and Shelf Science, 119, 79-90.
Künitzer, A. et al. 1992. The benthic infauna of the North Sea: species distribution and assemblages. ICES Journal of Marine Science, 49: 127–143.
Laine AO, 2003. Distribution of soft-bottom macrofauna in the deep open Baltic Sea in relation to environmental variability. Estuarine, Coastal and Shelf Science 57:87–97

Larsen, K. M. H., Gonzalez-Pola, C., Fratantoni, P., Beszczynska-Möller, A., and Hughes, S. L. (Eds.) 2016. ICES Report on Ocean Climate 2014. ICES Cooperative Research Report No. 329. 139 pp.
Laursen, K., Pihl, S., Durinck, J., Hansen, M., Skov, H., Frikke, J. & Danielsen, F. (1997). Numbers and distribution of waterbirds in Denmark 1987-1989. - Danish Review of Game Biology 14 (1): 1-184.
Laursen, K., Pihl, S., Durinck, J., Hansen, M., Skov, H., Frikke, J. & Danielsen, F. (1997). Numbers and distribution of waterbirds in Denmark 1987-1989. - Danish Review of Game Biology 14 (1): 1-184.
Lehmann A, Myrberg K, 2008. Upwelling in the Baltic Sea. Journal of Marine Systems 74:S3–S12.
Lehmann, A., Krauss,W., and Hinrichsen, H. H. 2002. Effects of remote and local atmospheric forcing on circulation and upwelling in the Baltic Sea. Tellus, 54: 299–316.
Lindley JA, Beaugrand G, Luczak C, Dewarumez JM, Kirby RR (2010) Warm-water decapods and the trophic amplification of climate in the North Sea. Biology Letters, 6, 773–776.
Ljunggren L, Sandström A, Bergström U, Mattila J, Lappalainen A, Johansson G, Sundblad G, Casini M, Kaljuste O, Eriksson BK, 2010. Recruitment failure of coastal predatory fish in the Baltic Sea coincident with an offshore ecosystem regime shift. ICES J Mar Sci 67:1587-1595
Lundström, K., Bergenius, M., Aho, T., Lunneryd, S.G. 2014. Födeval hos vikaresäl i Bottenviken:. Aqua reports 2014:1
Magnusdottir, E., Leat, E.H.K., Bourgeon, S., Strøm, H., Petersen, A., Phillips, A.P., Hanssen, S.A., Bustnes, J.O., Hersteinsson, P. & Furness, R.W. 2012. Wintering areas of Great Skuas Stercorarius skua breeding in Scotland, Iceland and Norway. - Bird Study 59(1):1-9.
McQuatters-Gollop, A., Vermaat, J.E. (2011) Covariance among North Sea ecosystem state indicators during the past 50 years — contrasts between coastal and open waters. J. Sea Res. 65 (2), 284–292.
Mendel, B., Sonntag, N., Wahl, J., Schwemmer, P., Dries, H., Guse, N., Müller, S. and Garthe, S. 2008. Artensteckbriefe von See- und Wasservögeln der deutschen Nord- und Ostsee: Verbreitung, Ökologie und Empfindlichkeiten gegenüber Eingriffen in ihren marinen Lebensraum. Landwirtschaftsverlag. 438 pp.
Middelboe AL, Sand-Jensen K, Brodersen KP.1997. Patterns of macroalgal distributions in the Kattegat-Baltic region. Phycologia 36 (3):208-219
Moen, F. and Svensen, E. 2014, Dyreliv i havet. Nordeuropøisk marin fauna. 6. udgave. Kom forlag
Munk P. 1993. Differential growth of larval sprat (Sprattus sprattus) across a tidal front in the eastern North Sea. Marine Ecology Progress Series 99: 17-29.
Munk, P., Larsson, P.O., Danielsen, D.S. & Moksness, E. 1999. Variability in frontal zone formation and distribution of gadoid fish larvae at the shelf break in the northeastern North Sea. Mar. Ecol. Prog. Ser. 177: 221-233.
Munk, P., Wright, P. J., and Pihl, N. J. 2002. Distribution of the early larval stages of cod, plaice and lesser sandeel across haline fronts in the North Sea. Estuarine, Coastal and Shelf Science, 55: 139-149.
Möllmann C, Diekmann R, Muller-Karulis B, Kornilovs G, Plikshs M, Axe P, 2009. Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central Baltic Sea RID C-4788-2011. Global Change Biology, 15, 1377–1393.
Möllmann C, Kornilovs G, and Sidrevicz L, 2000. Long-term dynamics of the main mesozooplanktnon species in the central Baltic Sea. J. Plankt. Res. 22(11):2015 2038.
Möllmann C, Kornilovs G, Fetter M, and Köster FW, 2005. Climate, zooplankton and pelagic fish growth in the Central Baltic Sea. ICES Journal of Marine Science, 62:1270 1280.
Möllmann C, Kornilovs G, Fetter M, Köster FW, and Hinrichsen H-H, 2003. The marine copepod, Pseudocalanus elongatus, as a mediator between climate variability and fisheries in the Central Baltic Sea. Fisheries Oceanography 12 (4-5):360 368.
Maar, M., Markager, S.S., Madsen, K.S., Windolf, J., Lyngsgaard, M.M., Andersen, H.E., Møller, E.F., 2016. The importance of local versus external nutrient loads for Chl a and primary production in the Western Baltic Sea. Ecol Model, 320:258-272

Nausch G, Naumann M, Umlauf L, Mohrholz V, Siegel H, DE Schulz-Bull (2016): Hydrographic-hydrochemical assessment of the Baltic Sea 2015. Meereswiss. Ber, Warnemünde, 101, doi: 10.12754/msr-2016-0101
Nicolaisen J.F. (Redaktør). 2010. Marin råstof- og naturtypekortlægning in Nordsøen 2010. Report delivered to Naturstyrelsen/Denmark.
Nielsen R, Kristiansen AA, Mathiesen L, Mathiesen H.1995. Distributional index of the bentic macroalgae of the Baltic Sea area. Acta botanica fennica, The Baltic Marine Biologists Publication No.18 vol. 155:1-51
Nielsen R, Kristiansen AA, Mathiesen L, Mathiesen H.1995. Distributional index of the bentic macroalgae of the Baltic Sea area. Acta botanica fennica, The Baltic Marine Biologists Publication No.18 vol. 155:1-51
Nielsen, T.G., Løkkegaard, B., Richardson, K., Pedersen, F.B., Hansen, L. 1993. Structure of plankton communities in the Dogger Bank area (North Sea) during a stratified situation. Mar. Ecol. Prog. Ser. 95: 115-131.
Ojaveer E, 2017. Ecosystems and Living Resources of the Baltic Sea. Their assessment and management. Springer International Publishing AG. 291 pp.
Ojaveer E, Lumberg A, and Ojaveer H, 1998. Highlights of zooplankton dynamics in Estonian waters (Baltic Sea). ICES Journal of Marine Science, 55: 748-755.
Ojaveer H, Jaanus A, MacKenzie BR, Martin G, Olenin S, Radziejewska T, Telesh I, Zettler ML, Zaiko A. 2010. Status of Biodiversity in the Baltic Sea. Plos One 5:
Olsen, M.T., Andersen, L.W., Dietz, R., Teilmann, J., Härkönen, T. and Siegismund, H.R. 2014. Integrating genetic data and population viability analyses for the identification of harbour seal (Phoca vitulina) populations and management units. Molecular Ecology 23, 815–831
Olsson J, Bergström L, and Gårdmark A, 2012. Abiotic drivers of coastal fish community change during four decades in the Baltic Sea. ICES Journal of Marine Science, 69: 961–970.
Peperzak, L. (2003) Climate change and harmful algal blooms in the North Sea. Acta Oecol. 24, 139–S144.
Perry, A. L., Low, P. J., Ellis, J. R., & Reynolds, J. D. (2005). Climate change and distribution shifts in marine fishes. science, 308(5730), 1912-1915.
Petersen, I.K. & Nielsen, R.D. 2011. Abundance and distribution of selected waterbird species in Danish marine areas. Report commissioned by Vattenfall A/S. National Environmental Research Institute, Aarhus University, Denmark. 62 pp.
Petersen, I.K. 2008. Antal og fordeling af vandfugle i den nordlige danske del af Nordsøen. – upubliceret notat, rekvireret af By- og Landskabsstyrelsen.
Petersen, I.K., Nielsen, R.D., Pihl, S., Clausen, P., Therkildsen, O., Christensen, T.K., Kahlert, J. & Hounisen, J.P. (2010). Landsdækkende optælling af vandfugle i Danmark, vinteren 2007/2008. - Danmarks Miljøundersøgelser, Aarhus Universitet. Arbejdsrapport fra DMU, No. 261. 78 pp.
Petersen, I.K., Nielsen, R.D., Pihl, S., Clausen, P., Therkildsen, O., Christensen, T.K., Kahlert, J. & Hounisen, J.P. (2010). Landsdækkende optælling af vandfugle i Danmark, vinteren 2007/2008. - Danmarks Miljøundersøgelser, Aarhus Universitet. Arbejdsrapport fra DMU, No. 261. 78 pp.
Petersen, I.K., Pihl, S., Hounisen, J.P., Holm, T.E., Therkildsen, O. & Christensen, T.K. (2006). Landsdækkende optællinger af vandfugle, januar og februar 2004. - Danmarks Miljøundersøgelser. Faglig rapport fra DMU, No. 606. 76 pp.
Petersen, I.K., Pihl, S., Hounisen, J.P., Holm, T.E., Therkildsen, O. & Christensen, T.K. (2006): Landsdækkende optællinger af vandfugle, januar og februar 2004. Danmarks Miljøundersøgelser. 76 pp. – Faglig rapport fra DMU nr. 606. http://www.dmu.dk/Pub/FR606.pdf
Rees, H. L., Eggleton, J. D., Rachor, E., and Vanden Berghe, E. (Eds.) 2007 Structure and dynamics of the North Sea benthos. ICES Cooperative Research Report No. 288. 258 pp.
Regulation (EU) 2016/1139 of the European Parliament and of the Council of 6 July 2016 establishing a multiannual plan for the stocks of cod,
Reichert K, Buchholz F. 2006. Changes in the macrozoobenthos of the intertidal zone at Helgoland (German Bight, North Sea): a survey of 1984 repeated in 2002. Helgoland Marine Research 60:213-223

Reid, P. C., and Beaugrand, G. 2002. Interregional biological responses in the North Atlantic to hydrometeorological forcing. In Changing states of the Large Marine Ecosystems of the North Atlantic, pp. 27–48. Ed. By K. Sherman and H-R. Skjoldal. Elsevier Science, Amsterdam.
Reid, P. C., and Edwards, M. (2001) Long-term changes in the fishery, pelagos and benthos of the North Sea. Senckenbergiana Maritima, 31: 107–115.
Reid, P. C., Borges, M. F., and Svendsen, E. 2001. A regime shift in the North Sea circa 1988 linked to changes in the North Sea horse mackerel fishery. Fisheries Research, 50: 163–171.
Reid, P. C., Edwards, M., Beaugrand, G., Skogen, M., and Stevens, D. 2003. Periodic changes in the zooplankton of the North Sea during the twentieth century linked to oceanic inflow. Fisheries Oceanography, 12: 260–269.
Rick, H. J., Rick, S., Tillmann, U., Brockmann, U., Gärtner, U., Dürselen, C., & Sündermann, J. (2006). Primary productivity in the German Bight (1994–1996). Estuaries and coasts, 29(1), 4-23.
Riemann B, Carstensen J, Dahl K, Fossing H, Hansen JW, Jakobsen HH, Josefson AB, Krause-Jensen D, Markager S, Staehr P.A, Timmermann K, Windolf J., Andersen JH (2015) Recovery of Danish Coastal Ecosystems After Reductions in Nutrient Loading: A Holistic Ecosystem Approach. Estuaries and Coasts 39:82-97
Rindorf, A., and Lewy, P. 2006. Warm, windy winters drive cod north and homing of spawners keeps them there. Journal of Applied Ecology, 43: 445–453.
Rudstam LG, Hansson S, Johansson S, Larsson U (1992) Dynamics of planktivory in a coastal area of the northern Baltic Sea. Mar Ecol Prog Ser 80:159-170.
Rönkkönen, S., Ojaveer, E., Raid, T., and Viitasalo, M. 2004. Long-term changes in Baltic herring (Clupea harengus membras) growth in the Gulf of Finland. Can. J. Fish. Aquat. Sci. 61(2):219 229.
Schmidt, J., Möllmann, C., Temming, A., Herrmann, J-P., Floeter, J., Sell, A., and St. John, M. A. 2003. Unusual water mass advection affected central Baltic key species 2: Pseudocalanus and the winter inflow. GLOBEC International Newsletter, 9: 28-29.
Seabed Habitats. EMODnet Thematic Lot n° 3. EMODnet Phase 2 – Final report. 2016. http://www.emodnet-seabedhabitats.eu/pdf/seabed_habitats_final_report_v3.pdf
Sguotti, C., Lynam, C. P., García
and sharks in the North Sea: 112 years of change. Global change biology, 22(8), 2729-2743.
Sharples, J., Ross, O., Scott, B. E., Greenstreet, S., and Fraser, H. 2006. Inter-annual variability in the timing of stratification and the spring bloom in a temperate shelf sea. Continental Shelf Research, 26: 733–751.
Sims, D.W. and Reid, P. C. (2002). Congruent trends in long-term zooplankton decline in the Northeast Atlantic and basking shark (Cetorhinus maximus) fishery catches off west Ireland. Fisheries Oceanography 11:1, 59-63.
Skov, H. & E. Prins. 2001: Impact of estuarine fronts on the dispersal of piscivorous birds in the German Bight. Marine Ecology Progress Series 214: 279–287.
Skov, H. & Prins, E. 2001. Impact of estuarine fronts on the distribution of piscivorous birds in the German Bight. – Mar Ecol Prog Ser 214: 279-287.
Skov, H. & Thomsen, F. 2008. Resolving fine-scale spatio-temporal dynamics in the harbour porpoise Phocoena phocoena. Marine Ecology Progress Series 373: 173-186.
Skov, H., Durinck, J. & Danielsen, F. (1992): Udbredelse og antal af Lomvie Uria aalge I SkagerrakSkagerrak I sensommerperioden. – Dansk Orn. Foren. Tidsskr. 86: 169-176.
Skov, H., Durinck, J., Leopold, M. & Tasker, M. (1995). Important bird areas for seabirds in the North Sea. BirdLife International, Cambridge.
Skov, H., Heinänen, S., Žydelis, R., Bellebaum, J., Bzoma, S., Dagys, M., Durinck, J., Garthe, S., Gennady Grishanov, G., Hario, M., Kieckbusch, J.J., Kube, J. Kuresoo, A., Larsson, K., Luigujoe, L., Meissner, W., Nehls, H.W., Nilsson, L., Petersen, I.K., Roos, M.M., Pihl, S., Sonntag, N., Stock, A. Stipniece A. and Wahl. J. 2011. Waterbird populations and pressures in the Baltic Sea. TemaNord2011:550,Nordic Counsil of Ministers, Copenhagen, Denmark.

Snoeijs-Leijonmalm P, Schubert H, and Radziejewska T (Eds.) 2017. Biological Oceanography of the Baltic Sea. Springer Science+Business Media Dordrecht 2017. 683 pp.
Snoijs-Leijonmalm P, 2017 Patterns of Biodiversity. In Snoeijs-Leijonmalm, P., Schubert, H. and Radziejewska (Eds.) Biological Oceanography of the Baltic Sea. Springer Science+Business Media Dordrecht 2017. 683 pp.
Stone, C.J. et al. 1995. An atlas of seabird distribution in north-west European waters. Joint Nature Conservation Committee. Peterborough, 326 pages.
Stone, C.J., Webb, A., Bsrton, C., Ratcliffe, N., Reed, T.C., Tasker,M.L., Camphuysen, C.J. & Pienkowski, M.W. (1995): An Atlas of Seabird Distribution in north-west European waters. – Joint Nature Conservation Committee and Nederlands Instituut voor Onderzoek der Zee. 326 pp.
Sveegaard S, Nabe-Nielsen J, Stæhr K-J, Jensen TF, Mouritsen KN, Teilmann J. 2012. Spatial interactions between marine predators and their prey: herring abundance as a driver for the distributions of mackerel and harbour porpoise. Marine Ecology - Progress Series. 468:245-253.
Sveegaard, S., Galatius, A., Dietz, R., Kyhn, A., Koblitz, J.C., Amundin, M., Nabe-Nielsen, J., Sinding M.H., Andersen L.W., Teilmann, J. 2015. Defining management units for cetaceans by combining genetics, morphology, acoustics and satellite tracking. Global Ecology and Conservation 3: 839–850
Sveegaard, S., Galatius, A., Dietz, R., Kyhn, L. A., Koblitz, J. C., Amundin, M., Nabe-Nielsen, J., Sinding, M.H.S., Andersen, L.W., Teilmann, J. (2015). Defining management units for cetaceans by combining genetics, morphlogy, acoustics and satellite tracking. Global Ecology and Conservation, 3: 839-850.
Sündermann, J. & Pohlmann, T. 2016. Hydrography – Description of North Sea Physics. Ch. 1.4 in: Quante and F. Colijn (eds.), 2016 North Sea Region Climate Change Assessment, Regional Climate Studies, DOI 10.1007/978-3-319-39745-0_1
Tasker, M.L., Webb, A., Hall, A.J., Pienkowski, M.W. & Langslow, D.R. 1987: Seabirds in the North Sea. – Nature Conservancy Council, UK. Report, 336 pp.
van Beusekom, J., & Diel-Christiansen, S. (1994). A synthesis of phyto and zooplankton dynamics in the North Sea environment. Godalming: World Wildlife Fund.
van Leeuwen, S., Tett, P., Mills, D., van der Molen, J. (2015). Stratified and non-stratified areas in the North Sea: Long-term variability and biological and policy implications. Journal of Geophysical Research: Oceans 120(7): 4670–4686
Viitasalo M, Blenckner T, Gårdmark A, Kaartokallio H, Kautsky L, Kuosa H, Lindegren M, Norkko A, Olli K, and Wikner J. 2017. Environmental Impacts - Marine Ecosystems. In. Bolle H-J, Menenti M, Sebastiano al Vesuvio S, and Ichtiaque Rasool S (2015) Second Assessment of Climate Change for the Baltic Sea Basin. Springer, 501 pp.
Viitasalo, M., Vuorinen, I., and Saesmaa, S. 1995. Mesozooplankton dynamics in the northern Baltic Sea: implications of variations in hydrography and climate. J. Plankton Res. 17:1857 1878.
Vuorinen, I., Hänninen, J., Viitasalo, M., Helminen, U., and Kuosa, H. 1998. Proportion of copepod biomass declines together with decreasing salinity in the Baltic Sea. ICES Journal of Marine Science, 55: 767-774.
Wahl,J. 2011. Waterbird Populations and Pressures in the Baltic Sea – Nordic Council of Ministers, TemaNord 2011:550 ISBN 978-92-893-2249-2.
Wasmund N, Siegel H, 2008. Phytoplankton. In: Feistel R, Nausch G, Wasmund N (eds) State and evolution of the Baltic Sea, 1952–2005. Wiley, Hoboken, pp 441–481.
Weston, K., Fernand, L., Mills, D. K., Delahunty, R., & Brown, J. (2005). Primary production in the deep chlorophyll maximum of the central North Sea. Journal of Plankton Research, 27(9), 909-922.
Wiemann, A., Andersen, L.W., Berggren, P., Siebert, U., Benke, H., Teilmann, J., Lockyer, C., Pawliczka, I., Skora, K., Roos, A., Lyrholm, T., Paulus, K.B., Ketmaier, V. & Tiedemann, R. (2010). Mitochondrial Control Region and microsatellite analyses on harbour porpoise (Phocoena phocoena) unravel population differentiation in the Baltic Sea and adjacent waters. Conservation Genetics 11: 195–211.
Wiltshire, K. H., Kraberg, A., Bartsch, I., Boersma, M., Franke, H. D., Freund, J., ... , & Wichels, A., (2010) Helgoland roads, North Sea: 45 years of change. Estuaries and Coasts, 33(2), 295-310.

Wiltshire, K.H., et al., (2008) Resilience of North Sea phytoplankton spring bloom dynamics: an analysis of long-term data at Helgoland Roads. Limnol. Oceanogr. 53, 1294–1302.
Wolters HA, Galparso I, Castro R, Korpinen S, Nurmi M, Tsangaris C, Reizopoulo S, van der MeulenM, Schipper CA, Roeleveld G, Uriarte A and Uyarra MC, 2015. Proposal for an assessment method of the ecological coherence of networks of marine protected areas in Europe. Reference 1208917-000-ZKS-0018, 31 March 2015, final. 123pp.
Zettler ML, Karlsson A, Kontula T, Gruszka P, Laine AO et al. 2014. Biodiversity gradient in the Baltic Sea: a comprehensive inventory of macrozoobenthos data. Helgoland Marine Research 68:49–57.

DTU Aqua
National Institute of Aquatic Resources
Technical University of Denmark

Kemitorvet
2800 Kgs. Lyngby
Denmark
Tel: + 45 35 88 33 00
aqua@aqua.dtu.dk

www.aqua.dtu.dk