HUMAN USES, PRESSURES AND IMPACTS IN THE EASTERN NORTH SEA

Technical Report from DCE – Danish Centre for Environment and Energy No. 18 2013

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Jesper H. Andersen (editor)[1]
Andy Stock (editor)[2]
Stefan Heinänen[2]
Miia Mannerla[3]
Morten Vinther[4]

[1] Aarhus University, Department of Bioscience
[2] DHI, Denmark
[3] HELCOM Secretariat
[4] National Institute of Aquatic Resources, Technical University of Denmark

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Data sheet

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Authors: Jesper H. Andersen (editor)[1], Andy Stock (editor)[2], Stefan Heinänen[2], Miia Mannerla[3], Morten Vinther[4]

Institutions: [1]Aarhus University, Department of Bioscience, [2]DHI, Denmark, [3]HELCOM Secretariat, [4]National Institute of Aquatic Resources, Technical University of Denmark

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Abstract: This study reports a first attempt to map human activities, pressures and potential cumulative impacts in the eastern parts of the North Sea, including Skagerrak, Kattegat and the northern parts of the Sound. The mapping is based on existing data on human activities in Denmark, Germany, Norway and Sweden. In addition, we have collated maps on ecosystem components, e.g. broad-scale benthic habitats, fish, birds and marine mammal. In order to link human activities and ecosystem component, an online survey was carried out involving exports from the countries involved in the study. The estimated potential impacts were highest in the German Bight, the Sound and in the coastal water of the Kattegat, whilst the lowest impacts were estimated for the western and northern parts of the study area. The results can be used for the initial assessment *sensu* the EU Marine Strategy Framework Directive.

Keywords: Marine Strategy Framework Directive, human activities, pressures, cumulative impacts, ecosystem-based management, North Sea, Skagerrak, Kattegat

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Summary

We report the first ever attempt to map cumulative human pressures and impacts in the eastern parts of the North Sea. Our work is based on the following: (1) Spatial distribution of 33 human activities and types of land- and sea-based pollution, (2) spatial distribution of 28 "ecosystem components" (key species and habitats), (3) systematically collected expert judgment linking negative impacts on ecosystem components to human activities, and (4) the methodology published by Halpern et al. in 2008. We have expanded this methodology, for example allowing some environmental impacts related to e.g. underwater noise, chemical pollution and sediment spills to spread beyond the location of their source.

We present three indices describing the intensity of human uses, the magnitude of the resulting pressures, and the potential for cumulative human impacts (where many pressures overlap with sensitive ecosystem components). The results show significant spatial variations in cumulative human pressures and impacts within the study area, most related to spatial variation in human activities, but some related to variations in the distribution and vulnerability of specific ecosystem components.

This report makes two additional contributions. First, in order to develop the cumulative impact index for our study area, we conducted a detailed online survey about the sensitivity of key species and habitats to different human activities. We present lists of relevant human activities and pressures, the 53 survey respondents' judgment about which human activities cause which pressures as listed in the Marine Strategy Framework Directive Annex III Table 2, and their ranking of these pressures in terms of threats to the North Sea. Second, in Appendices A and B to this report, we present an overview of the more than 60 regionally harmonized data sets describing the spatial distribution of human activities and pollution as well as ecosystem components, some of which have been exclusively prepared for this project.

1 Preface

This report is a product of the HARMONY project and meant as an initial assessment of human uses, pressures and impacts in the eastern North Sea.

HARMONY, or in full ″Development and demonstration of Marine Strategy Framework Directive tools for harmonization of the initial assessment in the eastern parts of the Greater North Sea sub-region″, is a project aimed towards development of informed marine assessments and management tools for the North Sea.

The overall objective of HARMONY, which started in September 2010 and ends in December 2012 is to develop and demonstrate tools for harmonization of the MSFD initial assessment in the eastern parts of the Greater North Sea sub-region. The challenges of the HARMONY project are twofold:

- The first challenge is to establish an overview of ecological information and harmonize it across the eastern parts of the Greater North Sea sub-region and thus support Member States in the implementation of the MSFD.
- The second challenge is to understand and quantify the spatial distribution and intensity of human activities in order to evaluate the trade-off between impacts and safeguarding of marine ecosystems and thus support the implementation of the MSFD.

HARMONY in particular focuses on:

- Developing and testing tools for characterisation and assessment of “environmental status”, including thematic tools for integrated assessment of ″eutrophication status″, ″chemical status″ and ″biodiversity status″.
- Developing and testing tools for characterization of cumulative human pressures and impacts.
- Collaborating and communicating with relevant institutions and organisation and disseminating the results to partners, neighbouring countries and the public.

You can read more about the HARMONY project on:
http://harmony.dmu.dk

2 Introduction

Coasts and seas around the world provide valuable tangible and intangible services to the human population, from individual recreation (e.g. visiting beaches or sailing) to large-scale commercial operations such as deep-sea drilling for oil, shipping and commercial fisheries. In addition, coastal and offshore waters are affected by land based activities (Ban & Alder 2007; Foley et al. 2010). As an example, agricultural fertilizers or industrial pollutants can be washed into rivers and further into the sea.

Human activities and the resulting pressures can have serious effects on the health of ecosystems; in some cases, whole ecosystems have been brought to the edge of collapse (e.g. Jackson et al. 2001). Existing maritime activities have expanded with little coordination, and coastal and offshore waters around the world are being used in new ways (e.g. offshore wind parks). Regime shifts, altered food web structures and other adverse effects (e.g. hazardous substances and contaminations) have been observed especially in coastal environments and in marginal seas (Korpinen et al. 2012).

Recognising the growing needs to manage ecosystems efficiently and sustainably, the *ecosystem approach* to environmental and resource management has emerged from the UN Convention on Biological Diversity (the so-called Malawi Principles)[1]. The objective is to combine human desires and needs with the conservation of a healthy environment. To reach this goal, it is necessary to manage coasts and seas in a comprehensive and integrated way, accounting for the diversity of these ecosystems and the combined effects of multiple stressors. Ecosystem-based Marine Spatial Planning is a well-recognized approach to such integrated management (Foley et al. 2010). Recently, spatial analyses of anthropogenic stressors and their cumulative impacts on the marine ecosystems have been conducted globally and regionally (Halpern et al. 2008, 2009; Selkoe et al. 2009; Ban et al. 2010; Korpinen et al. 2012), in order to provide much-needed information for ecosystem-based management.

The EU Marine Strategy Framework Directive (MSFD; EC 2008) establishes a framework within which Member States shall take the measures to achieve or maintain good environmental status (GES) in the marine environment by 2020. For that purpose marine strategies shall be put in place with the aim of protecting and preserving the marine environment, preventing its deterioration or restoring marine ecosystems in areas where they have been adversely affected. These should also prevent and reduce impacts in order to ensure that there are not significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the European seas.

In order to support this analysis, we have created a collection of spatial data on the major human uses as well as typical coastal and marine habitats and species in the Danish, Swedish, Norwegian and German parts of the North Sea. We have then adjusted the existing approach to map cumulative human

[1] See http://www.fao.org/DOCREP/006/Y4773E/y4773e0e.htm (accessed 02.01.2012)

impacts, described by Halpern et al. (2007, 2008) to the requirements of the MSFD. In this approach, expert judgement is used to combine data on the spatial distribution of anthropogenic stressors (e.g. pollution) with data on the spatial distribution of potentially sensitive "ecosystem components" (e.g. different benthic habitat types) into a spatially explicit "human impact index". This approach has been used in several regional studies in the USA and in Canada (Halpern et al. 2009; Selkoe et al. 2009; Ban et al. 2010) as well as one European initiative, the HELCOM Initial Holistic Assessment (which is not an initial assessment under the MSFD; HELCOM 2010a, 2010b; Korpinen et al. 2012). The approach is here for the first time applied in the North Sea.

In this report, we present:

- Harmonized data on human uses and ecosystem components in the eastern North Sea
- A methodological framework for mapping cumulative human impacts, adjusted to the requirements of the MSFD
- An online expert survey which is the foundation of linking human uses, the resulting pressures and their impacts on key ecosystem components
- A North Sea Human Use Index (NSUI), indicating where in the eastern North Sea multiple human uses (such as shipping and fisheries) occur at high intensities
- A North Sea Pressure Index (NSPI), indicating where in the eastern North Sea multiple anthropogenic pressures occur at high intensity
- A North Sea Impact Index (NSII), indicating where in the eastern North Sea high-intensity pressures and sensitive ecosystem components occur together, and consequently, where big human impacts are likely to occur
- A computer program which allows to easily calculate, change or update the three indices listed above.

3 Methods

3.1 General framework

Halpern et al. (2007, 2008) established a general framework for mapping cumulative human impacts on marine ecosystems. Essentially, the approach (illustrated in *Figure 1*) consists of the following parts:

- Identification of relevant ecosystems and their components, usually representative broad-scale habitats, of the study region, as well as potential anthropogenic stressors. Note that the term stressor may refer both to human activities, such as fisheries, and the pressures they cause, as those listed in the MSFD, Annex III, Table 2 (EC 2008; for example, underwater noise).

- Mapping the spatial distribution of the ecosystem components and anthropogenic stressors, using the same regular grid. Ecosystem components are mapped as presence-absence. The intensity of stressors (e.g. shipping intensity) is log[x+1]-transformed and normalized to the range [0,1]. The log-transformation is applied to avoid an over-dominance of extreme values on the resulting cumulative human impact map and to correct typically skewed frequency distributions.

- Using expert judgement to quantify the sensitivity of the ecosystem components to the stressors. Also these semi-quantitative sensitivity scores range from 0 to 1.

- Summing the products of ecosystem component presence-absence, stressor intensity, and the sensitivity scores

More formally, let $E_1,\dots,E_n$ be n ecosystem components, $U_1,\dots,U_m$ be m human stressors. Furthermore, let for a given location be $p(E)$ the presence (1) or absence (0) of ecosystem component E in this location, $i(U)$ the log-transformed and normalized intensity of stressor U in this location, and $s(E, U)$ the sensitivity score for ecosystem component E and stressor U. Then, the cumulative human impact index for the given location is calculated as

$$\sum_{j=1}^{n}\sum_{k=1}^{m} p(E_j)\, i(U_k)\, s(E_j, U_k)$$

Hence, in a location where three stressors and two ecosystem components occur, the impact index would be the sum of six products (stressor intensity times sensitivity score for each of the six combinations of present ecosystem components and pressures). The impact index is consequently highest in the locations where several ecosystem components occur together with stressors which are at high intensity, and to which the ecosystem components are sensitive according to expert judgement.

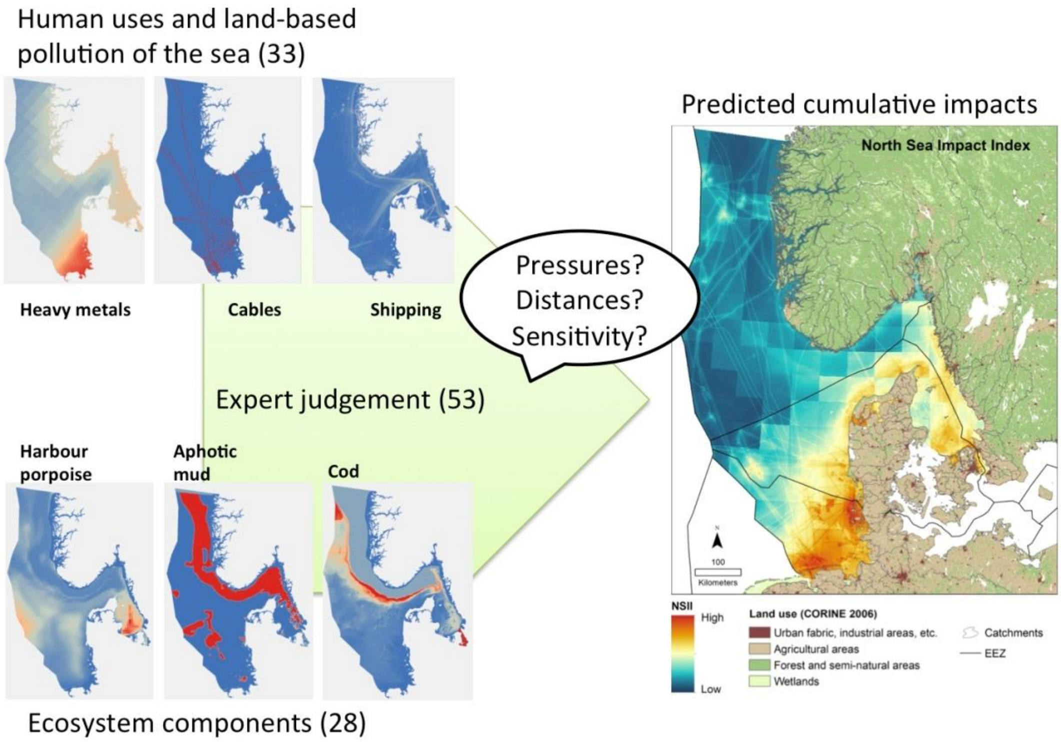


Figure 1. General approach: Expert judgement (involving individual replies by 53 experts) was used to combine data sets on the spatial distribution of 33 human maritime activities and types of land-based pollution (e.g. offshore oil and gas extraction, commercial fisheries using different gear types, and heavy metal pollution from land) with data on the spatial distribution of 28 ecosystem components, for example selected broad-scale seabed habitats, fish and marine mammal species.

We have adjusted this framework to better fit the requirements of the MSFD, and to make the best possible use of the data available for our study area. The most important changes, as compared to the "traditional approach", are:

An explicit distinction of pressures, as described in the MSFD Annex III Table 2, from the human uses of the sea that cause them

The MSFD Annex III Table 2 defines a set of rather abstract pressures to take into account. However, as for all earlier studies, data are not available for pressures (e.g. noise), but for the human activities (e.g. shipping) which cause them. Also management and planning typically occur at the level of human activities rather than pressures (Ban et al. 2010).

Ban et al. (2010) partially solved this problem by assigning one pressure, and a distance over which it would diminish while moving away from its source, to each human activity. Korpinen et al. (2012) used a similar approach, considering human activities as proxies for pressures. However, many human activities cause multiple pressures, which may spread over different distances and affect different ecosystem components. For example, shipping may affect marine mammals by underwater noise and collisions. However, for a collision to occur, the animal and the ship must be exactly in the same location, whereas noise can disturb animals further away. Fish, in contrast, may be less vulnerable to noise and collisions, but can be affected by pollution from the ships. In our framework, each possible combination of human activities, the pressures they cause and potentially sensitive ecosystem components is considered separately.

Formally defined spatial models describing the pressures caused by human activities

Human activities cause pressures, and thus have impacts, at a variety of spatial scales. For example, dredging does destroy the local sea bottom, but resuspended sediment can also lead to smothering of benthic habitats further away. For example, Kutser et al. (2007) used satellite imagery to monitor a sediment plume caused by dredging near a harbour. A 1 km to 3 km wide plume of suspended sediment was observed stretching about 20 km offshore. However, suspended sediment concentrations began to decrease very quickly already close to the dredging activities.

We have defined six distance-based spatial models to describe the spatial extent of the pressures while moving away from locations of the human activities that cause them. The choice of the spatial models for all activity-pressure combinations was based on expert judgement.

Explicit consideration of biological features as described in the MSFD Annex III Table 1

All earlier efforts to map cumulative human impacts on the sea, with the exception of Korpinen et al. (2012), considered exclusively broad-scale habitats (including their biological communities). For example, Ban et al. (2010) included impacts on several benthic and two pelagic habitats (deep and surface waters) in their study.

However, the characteristics listed in the MSFD Annex III Table 1 also include “biological features”, such as seabirds, fish and marine mammals. Korpinen et al. (2012, see also HELCOM 2010a and HELCOM 2010b) included some such features. In HARMONY, we have used state of the art predictive distribution models of key species to map potential human impacts on seabirds, marine mammals, and fish.

Fuzzy ecosystem components

All earlier studies have considered ecosystem components as either present or absent in a given cell. This is a reasonable generalization for e.g. benthic habitats, but of limited use for organisms such as fish, birds and mammals. For example, Korpinen et al. (2012; see also HELCOM 2010a, 2010b) assumed marine mammals to be present within their whole range, and absent everywhere else, without further distinction of their distribution within the range or the importance of different sea areas for these species.

In our framework, we do not use presence-absence maps for ecosystem components, but a continuum of values ranging from 0 to 1, wherever possible. For example, the distribution of seabirds is modelled as the probability of presence, rescaled to the range 0 (corresponding to absence) over 0.5 (intermediate probability of presence) to 1 (highest probability of presence found in the study area). This allows not only more differentiation in whether a certain ecosystem component occurs in a given location, but also avoids the problems inherent in representing vague concepts (e.g. the range of very mobile species) by crisp boundaries.

Figure 2. Conceptual framework for mapping cumulative human impacts, adjusted to the concepts and requirements of the MSFD.

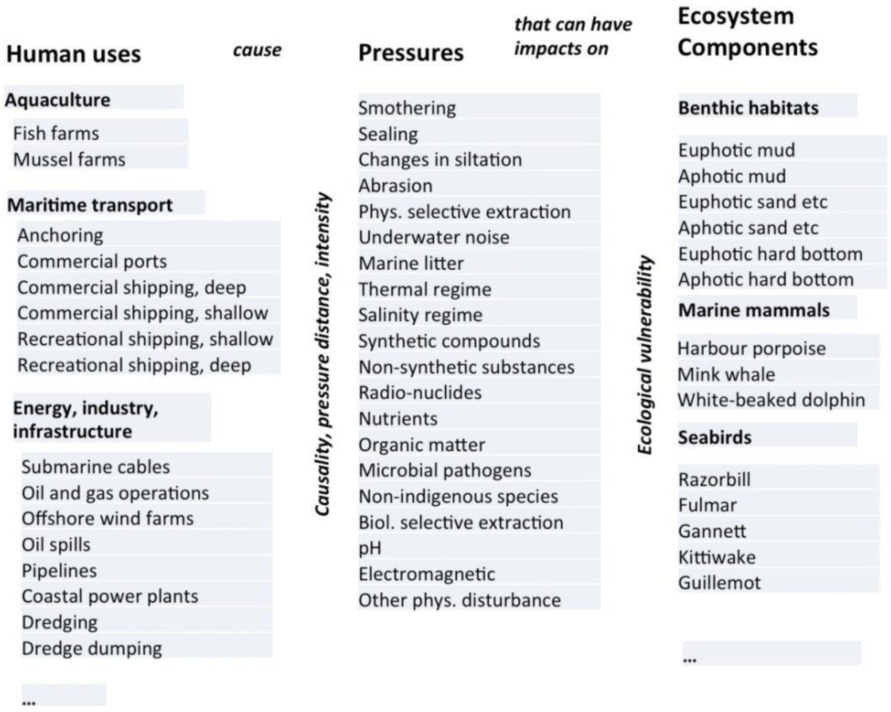


Figure 3. Example: Commercial shipping could affect harbour porpoises e.g. by physical collisions, and by underwater noise. Such relationships and the severity of impacts at a typical intensity of the activity in the study area were modelled based on an online expert survey.

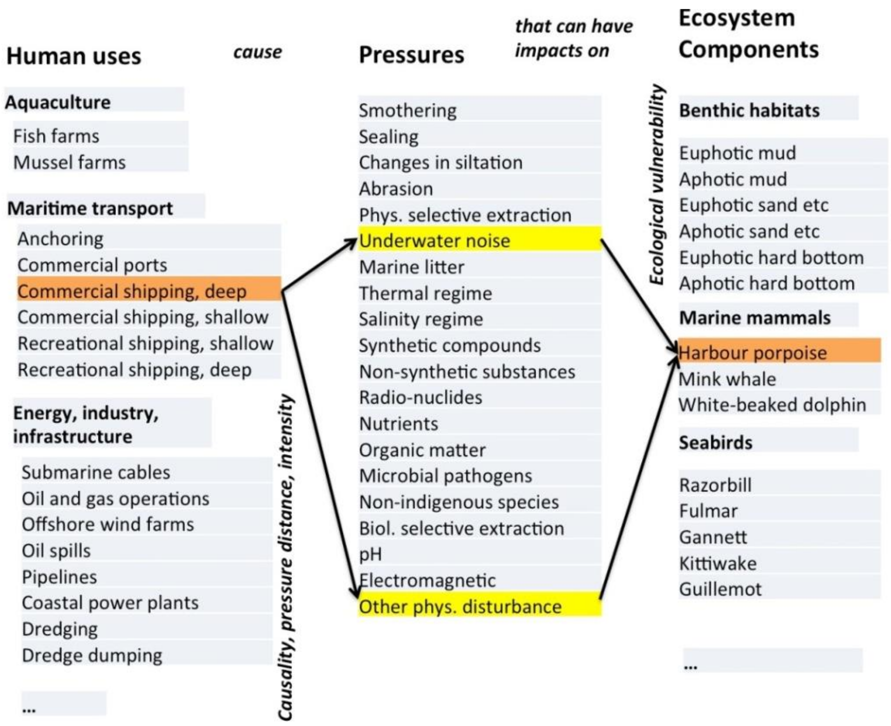


Table 1. Pressures listed in the MSFD (Annex III, Table 2) and additional pressures (*) included in this study. Note that the pressure "Systematic and/or intentional release of substances" is listed in the MSFD, but not included here. Modified from EC (2008).

Pressure	Description
Biological disturbance: Introduction of microbial pathogens	Introduction of microbial pathogens
Biological disturbance: Non-indigenous species	Introduction of non-indigenous species and translocations
Biological disturbance: Selective extraction and by-catch	Selective extraction of species, including incidental non-target catches (e.g. by commercial and recreational fishing)
Hydrological interference: Salinity changes	Significant changes in salinity regime (e.g. by constructions impeding water movements, water abstraction).
Hydrological interference: Thermal changes	Significant changes in thermal regime (e.g. by outfalls from power stations)
Introduction of hazardous substances: Non-synthetic	Introduction of non-synthetic substances and compounds (e.g. heavy metals, hydrocarbons, resulting, for example, from pollution by ships and oil, gas and mineral exploration and exploitation, atmospheric deposition, riverine inputs).
Introduction of hazardous substances: Radio-nuclides	Introduction of radio-nuclides
Introduction of hazardous substances: Synthetic	Introduction of synthetic compounds (e.g. priority substances under Directive 2000/60/EC which are relevant for the marine environment such as pesticides, antifoulants, pharmaceuticals, resulting, for example, from losses from diffuse sources, pollution by ships, atmospheric deposition and biologically active substances
Nutrient & organic matter enrichment: Nutrients	Inputs of fertilisers and other nitrogen – and phosphorus-rich substances (e.g. from point and diffuse sources, including agriculture, aquaculture, atmospheric deposition)
Nutrient & organic matter enrichment: Organic matter	Inputs of organic matter (e.g. sewers, mariculture, riverine inputs)
Others: Changes in pH*	Changes in water pH
Others: Electromagnetic disturbance[1]	Disturbance by electromagnetic radiation of any wavelength, magnetic fields, etc.
Physical damage: Abrasion	Abrasion (e.g. impact on the seabed of commercial fishing, boating, anchoring)
Physical damage: Resource extraction	Selective extraction (e.g. exploration and exploitation of living and non-living resources on seabed and subsoil)
Physical damage: Siltation changes	Changes in siltation (e.g. by outfalls, increased run-off, dredging/disposal of dredge spoil)
Physical disturbance: Other, e.g. collisions*	Other physical disturbance. Examples are collisions, e.g. between whales and ships or birds and wind turbines, or the blocking effect of bridges on birds
Physical disturbance: Marine litter	Marine litter
Physical disturbance: Noise	Underwater noise (e.g. from shipping, underwater acoustic equipment)
Physical loss: Sealing	Sealing (e.g. by permanent constructions)
Physical loss: Smothering	E.g. by man-made structures, disposal of dredge spoil

Software dedicated to the usability of the HARMONY impact mapping framework

Mapping cumulative human impacts involves many data sets on human uses of the sea, the pressures they cause, and ecosystem components. Typically, standard tools (such as ArcGIS and Excel) are used to combine such data.

We have developed dedicated software to implement the conceptual framework described here. For example, once a data set is prepared in a fitting format, it is straightforward to include it in the human use, pressure and impact indices that can be calculated. If better data become available, it takes only a few mouse clicks to update any data layer (however, the data have to be provided in a certain format). Perhaps most importantly, a dedicated and easy-to-use software tool empowers decision-makers to make their own cumulative impact maps, for example assigning own weights to the ecosystem components, or switching on and off human activities, rather than providing one ready-made map of human impacts.

Figure 2 summarizes the conceptual framework used in HARMONY. We have collected data on the spatial distribution of different human activities and ecosystem components. Human activities affect the ecosystem components via pressures. For instance, fish farms may affect some ecosystem components through the pressure "introduction of organic matter". Different activities may cause the same pressure, but at a different level of intensity. Similarly, the same human activity may cause several pressures, which might be relevant for different ecosystem components. *Figure 2* gives an example: Commercial shipping can affect harbour porpoises by causing both noise and physical collisions. In order to link human activities, pressures and ecosystem components, the following questions must be answered:

1. **Causality**: Which human activities cause which pressures, affecting which ecosystem components?

2. **Pressure distance**: How far do the effects of the pressure reach from its source? E.g. the noise caused by shipping can travel relatively far, whereas sealing of the seabed by the foundations of offshore wind turbines is a local pressure.

3. How **vulnerable** are the ecosystem components to different pressures, at the levels caused by the respective human activities? Vulnerability has two parts: **Sensitivity** (for example, how sensitive is a given ecosystem component to underwater noise from shipping?) and **exposure** (do human activities causing noise and the ecosystem component occur sufficiently close to each other for the ecosystem component to be affected?)

The exposure of the ecosystem components to the pressures is based on the spatial distribution of the human activities and the ecosystem components. The answers to all other questions are based on an online expert survey.

3.2 Spatial data and processing

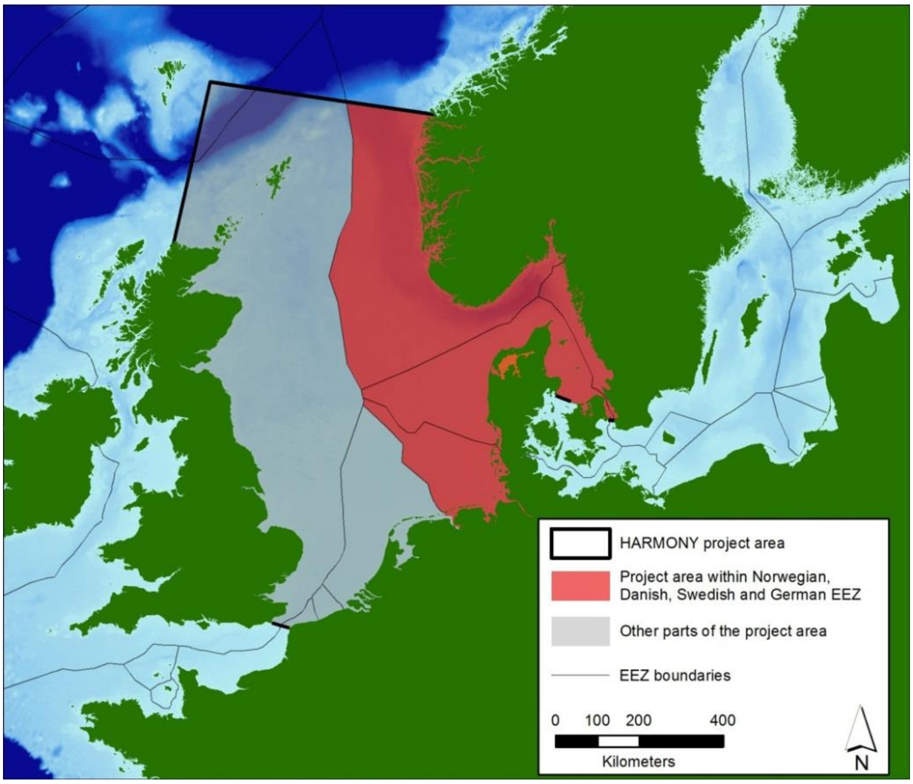
3.2.1 Study area and the HARMONY grid

The HARMONY study area is the North Sea, excluding the English Channel, as shown in *Figure 4*. That being said, because this project was funded by institutions from Denmark, Sweden, Norway and Germany, we have focused on the eastern North Sea falling into the EEZ and territorial waters of these countries. In particular, it was very time-consuming to collect reliable data on human uses of the sea. Wherever possible with reasonable effort, data were collected for the whole North Sea; but many data sets were difficult to obtain or needed further processing, and could thus only be prepared for the waters of the four HARMONY countries. As a consequence, the analyses presented here cover only the Danish, Swedish, Norwegian and German parts of the North Sea. Still, many of the basic data sets prepared within HARMONY, as well as some analyses presented in other HARMONY reports, cover the whole North Sea.

All spatial data used in HARMONY were transferred to a regular grid. To facilitate the use of these data within the framework of the European Union's environmental policies, we have used the EEA's reference grid for Europe at 1 km^2 spatial resolution.[2]

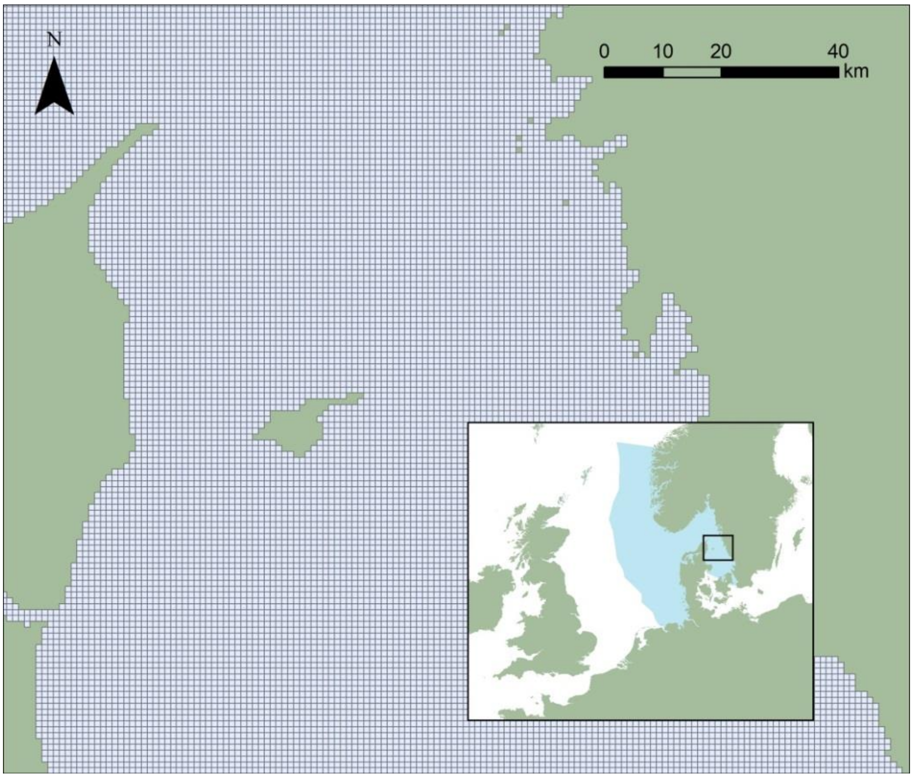
All cells containing no sea areas, according to GSHHS 2.0 shorelines, were removed from this grid, as were cells outside of the study area. A detail of the HARMONY grid is shown in *Figure 5*.

Figure 4. The HARMONY study area.



[2] http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-1

Figure 5. A detail of the HARMONY mapping grid in the central Kattegat.



3.2.2 Ecosystem components

In accordance with Halpern et al. (2007, 2008, 2009), Selkoe et al. (2009), Ban et al. (2010) and Korpinen et al. (2012), we have modelled the combined impacts of anthropogenic stressors on the North Sea as the sum of their impacts on important components of this ecosystem, accounting for potential cross-effects and synergisms only indirectly. As Korpinen et al. (2012), we included both broad-scale habitats and key species, in total 28 ecosystem components:

- Four broad-scale coastal ecosystems (physically complex and very dynamic coastal areas which could not be reasonably covered by the regional scale data used for the other ecosystem components)
- Six benthic habitat types, based on substrate (hard; sand, mixed or coarse; mud) and light availability (euphotic, aphotic)
- Two types of plankton communities (in nutrient-rich waters, in nutrient-poor waters)
- Eight species of fish. Note that because no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass of the different species for these deep areas was estimated as described in *Appendix F*.
- Three species of marine mammals
- Five species of seabirds

The broad-scale coastal ecosystems cover four distinct, very complex coastal seas: The Wadden Sea, the southern Kattegat bays (such as the Limfjord), the western Swedish rocky archipelagos and the Norwegian fjords. These areas are physically very complex and dynamic, and consequently, the regional-sea-scale data describing the other ecosystem components were not available for these areas or must be considered too rough to describe them properly. Consequently, they were included in the analyses as separate ecosystem components.

In contrast to all earlier studies, and with the exception of the four coastal ecosystems and benthic habitats, our analyses are not based on the presence (1) or absence (0) of an ecosystem component in a given cell, but on measures that can take any value in a continuous range from 0 to 1. For example, for the three marine mammal species, we have not used a hypothetical range (assuming presence within this range, and absence outside), but modelled the probability of each species' presence in a given location based on field observations of the species in question, hydrodynamic and biogeochemical data (such as average salinity, current speeds and chlorophyll concentrations). The species included in this study – fish, seabirds and marine mammals – are very mobile; in contrast to presence-absence maps, probabilities of presence represent their spatial distribution much better, being able to distinguish "hotspots" (where the relatively highest impacts on the species would be predicted under given stressors) from areas rarely visited by the species (where predicted impacts on the species would be much lower under the same stressors).

Table 2 gives an overview of the ecosystem components used in this study. They are described in detail in *Appendix A*, as are potentially interesting data sets that were not used in the impact index (for example, sandeel fishing grounds and the abundance of non-assessed sensitive fish species). Spatial distributions of benthic habitats were taken from EUSeaMap[3]. The spatial distribution of all other ecosystem components was modelled within HARMONY.

3.2.3 Stressors

We have identified 47 relevant anthropogenic stressors (human uses of coasts and sea and pollution from land-based sources, which are potential drivers of ecological change) in several workshops, and by a review of the OSPAR QSR 2010 (OSPAR 2010) and the HELCOM Initial Holistic Assessment (HELCOM 2010a, 2010b). Data were available, or could be reasonably modelled, for 33 of the stressors. In many cases, only presence-absence data were available. *Table 3* gives an overview of the stressors that were included in this analysis; *Table 4* lists those that were expected to be important, but could not be included, mostly because no spatial data were available.

Data for other North Sea countries than Denmark, Sweden, Norway and Germany were collected whenever easily possible. However, given that only the four countries listed above provided funding for HARMONY, we were not able to put major efforts in the inclusion of data that were difficult to obtain, to process or to harmonize. Consequently, many of the stressor data

[3] http://jncc.defra.gov.uk/page-5020

compiled in HARMONY cover only the Swedish, Danish, Norwegian and German North Sea.

The data compiled from the different countries had often very different levels of detail. We took special care to combine them in a way that would make them comparable. All included stressor data sets are described in detail in *Appendix B*.

Table 2. Ecosystem components included in the North Sea Impact Index.

Group	Ecosystem components	Spatial distribution described as
Coastal ecosystems	Norwegian fjords and coastal archipelagos Rocky archipelagos of the Swedish west coast Southern Kattegat bays (e.g. the Limfjord and Skälderviken) Wadden Sea	Presence-absence.
Broad-scale benthic habitats and their communities	Euphotic mud Aphotic mud Euphotic sand, coarse and mixed substrate Aphotic sand, coarse and mixed substrate Euphotic hard Aphotic hard	Presence-absence corrected for the number of benthic ecosystem components in each cell. For example, if four benthic habitats exist in a given cell, each of these benthic habitats would have a value of 0.25.
Plankton communities (covering both phyto- and zooplankton)	In nutrient-rich waters In nutrient-poor waters	Fuzzy model of presence-absence: Values range from zero to one based on whether average chlorophyll in the cell is below 0.8 mg m^{-3}, above 4 mg m^{-3}, or in between. These thresholds were taken from Wasmund (2001).
Fish species[4]	Cod (*Gadus morhua*) Haddock (*Melanogrammus aeglefinus*) Norway pout (*Trisopterus esmarkii*) Saithe (*Pollachius virens*) Plaice (*Pleuronectes platessa*) Dab (*Limanda limanda*) Herring (*Clupea harengus*) Rays and skates	Modelled biomass distributions.
Marine mammal species	Harbour porpoise (*Phocoena phocoena*) Minke whale (*Balaenoptera acutorostrata*) White-beaked dolphin (*Lagenorhynchus albirostris*)	Modelled probability of presence.
Seabird species	Razorbill (*Alca torda*) Northern Fulmar (*Fulmarus glacialis*) Northern Gannet (*Morus bassanus*) Black-legged Kittiwake (*Rissa tridactyla*) Common Guillemot (*Uria aalge*)	Modelled probability of presence.

[4] Note that also a data set on sandeel grounds was available (Jensen et al. 2011). However, it could not be included as it did not cover the Kattegat.

Table 3. Human stressors included in the North Sea Impact Index.

Group	Stressors	Spatial distribution described as
Aquaculture	Fish farms	Point locations
	Shellfish farms	Point locations
Fisheries	Fishery for scallops and blue mussels using dredge Pots and traps Set nets Beam trawl with mesh > 80 mm fishing mainly for flatfish Small meshed beam trawl fishing mainly for brown shrimps Trawl and demersal seine with 70-99 mm meshes fishing mainly for Nephrops Trawl and demersal seine with ≥ 100 mm meshes fishing mainly for roundfish Pelagic trawl and seine fishing mainly for herring and mackerel Small meshes trawl fishing mainly for industrial species and Northern shrimp	Fishing efforts in 2009 per ICES Rectangle (1.0 degree longitude by 0.5 degree latitude), as kW days km^{-2}
Industry, energy, population and infrastructure	Offshore wind farms	Turbine locations (points)
	Operational underwater cables	Lines
	Operational oil and gas pipelines	Lines
	Offshore oil and gas installations	Point locations
	Oil spills	Distance-weighted number of detected spills within 25 km radius
	Coastal population	Number of people living within 25 km of the coastline
	Dredging for sand and gravel	Permitted areas (polygons)
	Disposal of dredged materials	Point locations
	Bridges and coastal dams	Lines
	Coastal nuclear power plants	Point locations
	Coastal waste water treatment plants	Point locations
Nutrient enrichment and pollution from land and the atmosphere	Riverine inputs and atmospheric deposition of nutrients	Existing biogeochemical model, own modelling in the Kattegat
	Riverine inputs and atmospheric deposition of heavy metals	Static transport model for monitored and modelled discharges; EMEP data
	Riverine inputs of synthetic compounds	Static transport model based on population in catchments
	Riverine inputs, and atmospheric deposition of radionuclides	Static transport model based on number of nuclear installations per catchment
Shipping and transport	Commercial shipping, deep water	Intensity based on AIS data
	Commercial shipping, shallow water	Intensity based on AIS data
	Major ports	Point locations with gross annual cargo 2005-2009
	Recreational shipping, deep water Recreational shipping, shallow water	Square-Distance-weighted number of marinas within a 20 km radius
Other human activities	Military practice	Areas (polygons)
	Dumped munitions	Point locations

Table 4. Major stressors that could not be included in this study.

Group	Stressors	Reason for exclusion
Fisheries	Recreational fishing	No spatial data available
Industry, energy, population and infrastructure	Marine construction works Coastal engineering and defence Other dredging, e.g. for navigation purposes Changed siltation due to land use (e.g. river dams, deforestation)	No spatial data available No spatial data available Data only for Sweden No spatial data available
Global change	Acidification Ocean warming Increased UV radiation	Global change is outside the scope of the MSFD. No sufficiently accurate spatial data available or requiring major processing efforts.
Nutrient enrichment and pollution from land and the atmosphere	Riverine inputs of organic matter Riverine inputs of specific substances and groups (e.g. PCBs, PAHs)	No data available No data available
Shipping and transport	Anchoring outside harbours	Data available only for parts of the study area
Other human activities	Hunting (seabirds, whaling, sealing)	No spatial data available

Unfortunately, data harmonization often meant that information which was not available for all four HARMONY countries had to be excluded. For example, Sweden provided a data set on regularly dredged shipping lanes, and Denmark provided a very detailed data set on cooling water emissions to the sea. However, as these data were not available for the other HARMONY countries, they could not be included in the analysis. The additive approach to mapping cumulative human impacts, which was also used here, cannot distinguish between "no data" and "the stressor does not occur". Thus, including dredging of shipping lanes in Swedish waters, but not elsewhere, would in our model mean that such dredging and its impacts occur only in Sweden. Consequently, including stressors where data did not cover the whole study area would have meant that the pressure and impact indices presented here would not be comparable across the whole study area any more.

Only the locations at which many human activities occur were available, but no measure of their intensities. For example, we could compile the coordinates of all fish and shellfish farms in the eastern North Sea; but we could not obtain information about the magnitude of the activities, such as the total annual production, of the individual sites.

As in all earlier studies, the stressors represented by intensity (e.g. shipping) rather than presence-absence were log[x+1]-transformed and rescaled so that the maximum was 1. However, before applying the log-transformation, they were first rescaled so that the maximum was 19, as otherwise, the transformation's results would have depended on the maximum value in the data set.

3.2.4 Spatial models

Some human activities only have local effects; others cause pressures that can be transported far away. For example, oil and gas installations can cause local sealing of the seabed; but they also cause pollution, e.g. with discharges of produced water, and noise, which both can spread relatively large distances from their source. Ban et al. (2010) accounted for such effects by letting the intensity of stressors linearly diminish with increasing Euclidean distance from the source. The distances at which the stressors ceased to have an impact were based on a literature survey.

In this study, we have developed this approach further by means of the concept of "pressure distances". In our formal model, the same human activity (e.g. oil and gas extraction) can cause several pressures (e.g. sealing and pollution with non-synthetic substances). Each pressure can be represented by a different spatial model. Furthermore, one human activity can affect ecosystem components via different pressures, and thus over different distances. To give an example, while the impact of deep-water oil and gas extraction on the seabed may be predominantly local, it may affect marine mammals more by noise and pollution, up to several kilometres away.

We have defined six spatial models: A local model and five distance-based models (with pressure distances of 1 km, 5 km, 10 km, 20 km, and 50 km; *Figure 6*). The definition of the local model is described for each data set in *Appendix B*. For example, for cables and pipelines, for fish farms and for shellfish farms, it is simply the presence (1) or absence (0) of such structures in each 1 km^2 cell. For others, it is a value ranging from 0 to 1, depending on a measure of the intensity of the respective activities. As an example, the average annual gross cargo weight (rescaled so that the maximum was 1) handled at the major ports in the study area was used as the "local model value" for the cells containing the ports.

The distance-based spatial models are based on the local models. For example, the value of a cell in the 20 km model for a human activity depends on all cells within a 20 km radius from that location. The cells' local model values are weighted based on their Euclidean distance to the cell in question. For example, imagine a cell with three shellfish farms (the local model value for these cells is 1) within 20 km radius. One shellfish farm is right in the cell in question. The others are in cells 3 km and 10 km away. The value of that cell in the 20 km spatial model for shellfish farms would then be 1 + 17/20 + 10/20. All spatial models were rescaled so that the values ranged again from 0 to 1. This approach works well for stressors represented by points or very small areas (for example fish farms) and relatively straight lines (e.g. underwater cables), but not for stressors represented by large areas (polygons; in this study military areas and sediment extraction sites). Thus, the spatial models for these stressors were prepared in ArcGIS by hand. Also for coastal population, the automatically calculated spatial models were inappropriate (as the complexity of the coastline influences stressor values if calculated as described above), but no new spatial models were calculated because according to the online survey, the effects of population (other than covered by separate pollution data sets) are only local.

The spatial distribution of some other stressors has been modelled explicitly. For example, nitrate concentrations were extracted from a biogeochemical model as a proxy for nutrient enrichment from riverine discharges and atmospheric deposition (*Figure 7*). In such cases, only this one "general spatial model" was used. Fisheries data were only available at the resolution of ICES rectangles. This resolution is by far too coarse to tell where exactly pressures and impacts occur. Consequently, efforts per ICES rectangle were the only spatial model used for the pressures caused by fisheries.

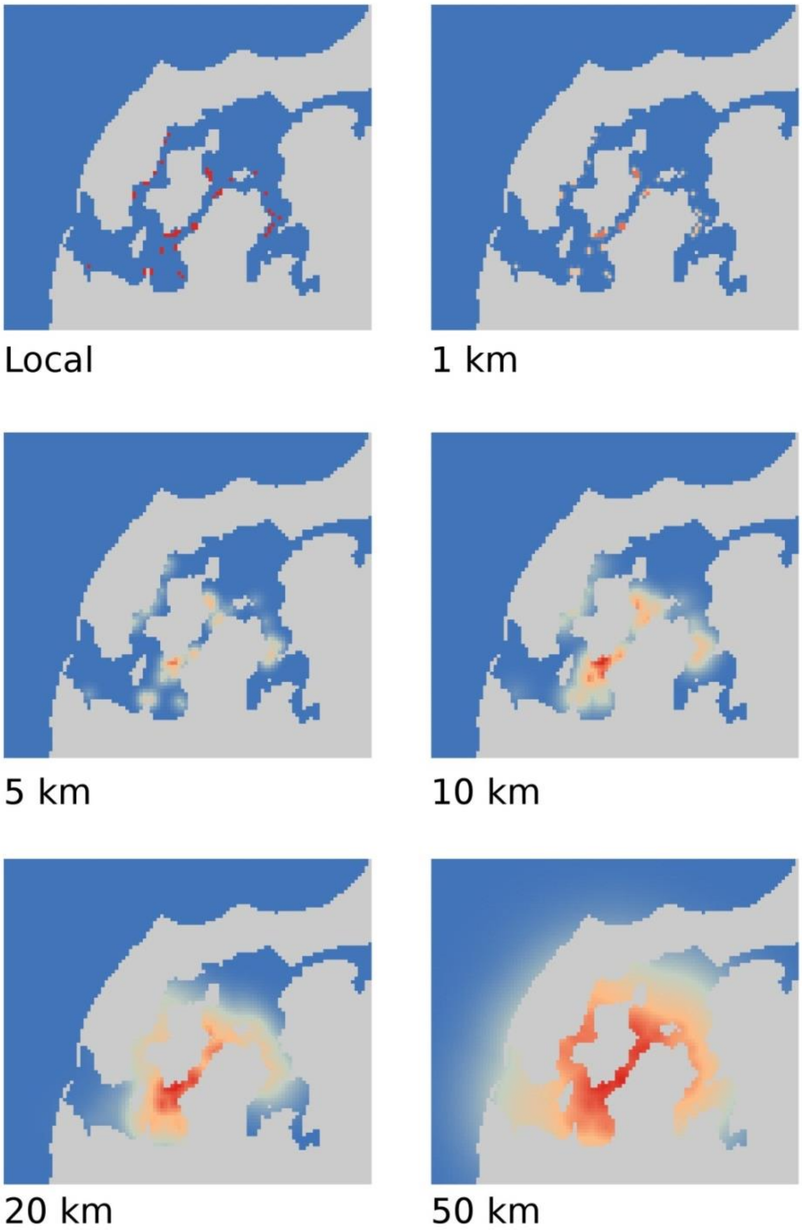
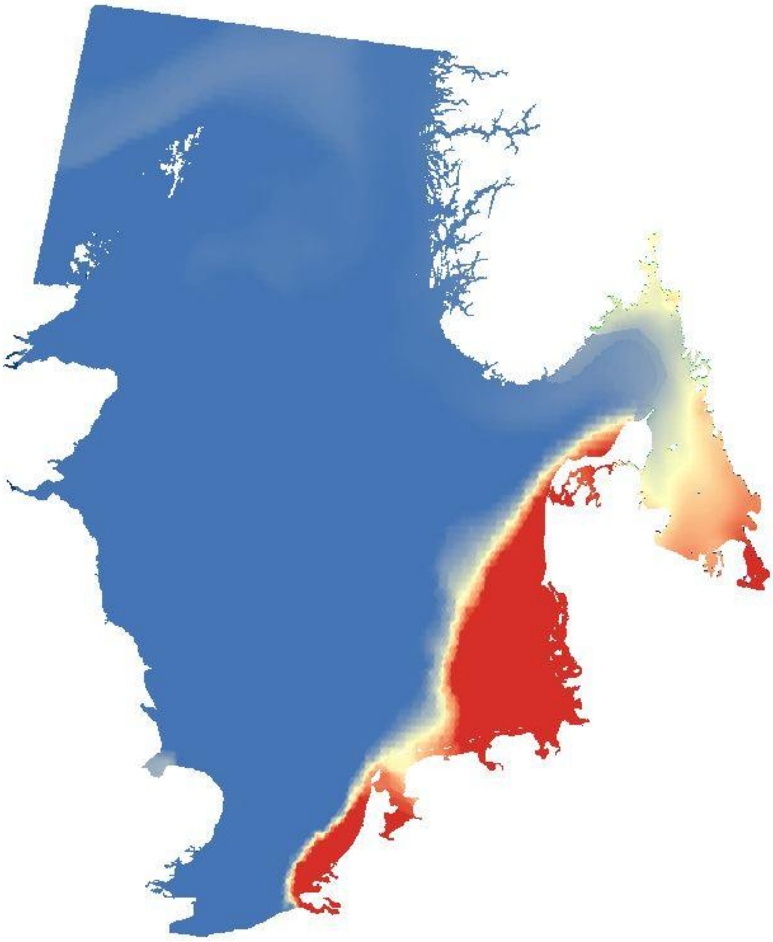


Figure 6. Spatial models for pressures from shellfish farms in the Limfjord. The spatial models for the pressures caused by the different human activities have been chosen based on the expert survey. One human activity can cause several pressures, possibly each with a different own spatial model.

Figure 7. The spatial transport of some stressors, such as riverine discharges and atmospheric deposition of nutrients, has been modelled explicitly (in this example, nitrate concentrations were extracted from the NORWECOM model and merged with data produced within HARMONY for the Kattegat). In such cases, only this one "general" spatial model was used.



3.3 The online expert survey

3.3.1 General approach

In order to map human impacts on the marine environment, it is necessary to quantify the sensitivity of the ecosystem components to the different human stressors. As such studies typically include several hundreds of ecosystem-stressor combinations, a literature review would leave many gaps. Expert workshops have consequently often been held to define the threats to different ecosystems; however, the underlying rationale is not transparent, and it is difficult to update such results with new information. Furthermore, individual rather than group judgement captures the whole range of opinions (Teck et al. 2010) instead of presenting a final compromise which may not be dominated by the most knowledgeable workshop participants. Thus, Halpern et al. (2007) conducted an online expert survey.[5] The respondents were asked to estimate the "ecological vulnerability" of each ecosystem component to each stressor (given that they had knowledge about the particular combination). However, as "ecological vulnerability" is a rather abstract concept, it was subdivided into "vulnerability criteria" as a more tangible and transparent approach. Experts were asked to rate the spatial scale

[5] http://www.nceas.ucsb.edu/~halpern/html/expert_survey.htm

at which the stressors cause impacts (e.g. dredging may affect a whole bay), frequency (how often does it typically occur?), functional impact (species, one trophic level, several trophic levels ecosystem), resistance (does a slight occurrence of the stressor already have an effect?), and resilience (recovery time). Experts were also asked to rate the certainty of their replies. The "ecological vulnerabilities" were then derived by averaging replicate survey responses after bringing them to a numeric scale ranging from zero to four. Korpinen et al. (2012) used an adjusted version of this approach.

According to Teck et al. (2010), there is a growing consensus that ecological vulnerability is a function of exposure, sensitivity, and resilience to stressors.

However, they also describe problems with the approach used by Halpern et al. (2007): For example, the five vulnerability criteria are weighted equally, even if experts find one more important than the others, and uncertainty is addressed only in a qualitative way. Teck and colleagues thus refined the approach as follows. After filling in biographical information, the responding experts were asked to choose one of six sub-regions of the study area (the California Current region). They should then rank the top five stressors in their selected sub-region. The stressors were listed in randomized order to avoid sorting bias. The survey also allowed the addition of stressors to check whether all relevant ones had been captured. In the next part of the survey, 30 hypothetical scenarios with different values for the vulnerability criteria for the different stressors were presented to and rated by the experts. Finally, the experts were asked to revise default scores for the vulnerability criteria, taken by Halpern et al. (2007). The experts could respond to the survey on paper, online, by phone or in-person interview from June to October 2007.

While the approach presented by Teck et al. (2010) has clear advantages, it was not possible to conduct such a comprehensive survey with the resources available in HARMONY. Instead, we modified the approach presented by Halpern et al. (2007, 2008) and adapted by Korpinen et al. (2012) to collect expert opinions on how human activities, the pressures they cause and their impacts on selected parts of the marine environment are interlinked.

3.3.2 The survey instrument

In the HARMONY Online Survey, the experts were first asked to enter biographical information. They could then choose either an ecosystem component (for example harbour porpoises) or a human activity (for example offshore oil and gas extraction). If filling in the survey for an ecosystem component, the experts had to rate the sensitivity of this ecosystem component to the different stressors; for example, the sensitivity of harbour porpoises to commercial shipping, offshore oil and gas extraction, pollution with heavy metals from land-based sources, etc. If filling in the survey for a human activity (including different types of land-based pollution), the experts were rating the sensitivity of the different ecosystem components to this stressor. The questions asked were ultimately the same in both cases. They were just organized in a different way, to allow both experts specialized in ecosystem components (e.g. benthic ecologists or ornithologists) and experts for different sectors (e.g. fishery experts) to use the online survey in the most comfortable way. *Figure 8* shows an example from the survey website.

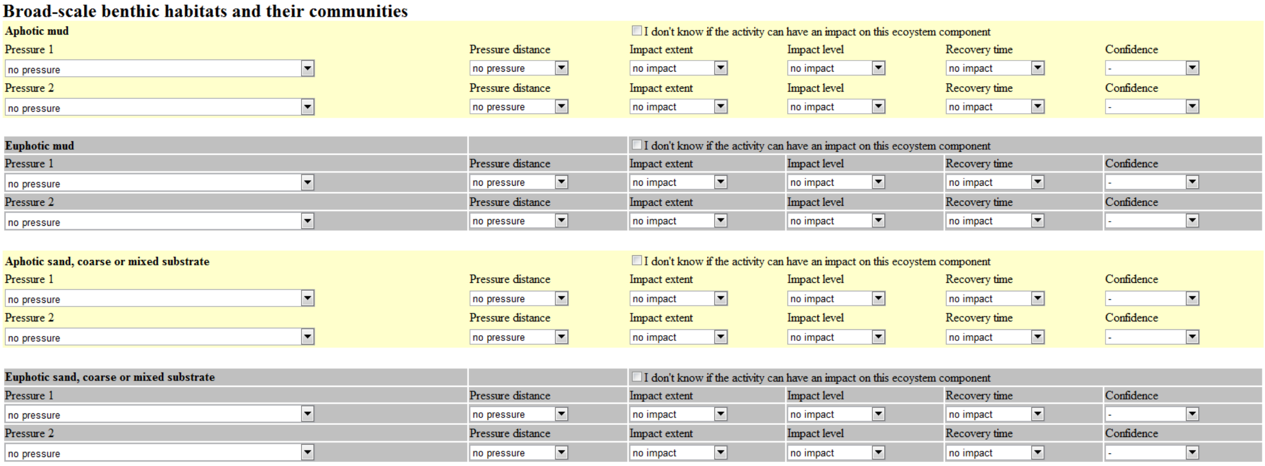


Figure 8. Detail of the HARMONY Online Survey. Here, the impact of a human activity (e.g. fish farms) on different ecosystem components is rated.

In addition to the stressors listed in *Table 3* (which were included in the pressure and impact indices), also the stressors in Table 4 (which were omitted from the spatial analyses mostly because of a lack of data) were included in the online survey, in order to make the resulting data set fit for uses in the future, when more spatial data may become available. Finally, the respondents were asked to name the three pressures (from *Table 1*; without order) which they thought would pose the greatest threat to the North Sea ecosystem in general, and to the ecosystem component for which they were filling in the survey (if responding for a specific ecosystem component).

As Halpern et al. (2007), Teck et al. (2010) and Korpinen et al. (2012), we have asked the experts to rate ecological sensitivity indirectly via several criteria. We have modified the original approach as follows:

1. We first asked the experts to choose one or two of the pressures listed in *Table 1*, in order to link human uses of the sea and other stressors such as pollution with the pressures listed in the MSFD. For human activities causing more than two pressures, the experts were instructed to choose the most important ones for the ecosystem component in question.

2. The experts then had to choose a "pressure distance", corresponding to the spatial models described in section 3.2.4 (see especially *Figure 6*), for each of the pressures they chose.

3. The experts then rated the "impact extent", that is whether the direct and indirect effects of the respective pressure, as caused by the human activity in question, have consequences on the level of individuals, on the whole population or on the community level.

4. The experts next rated the "impact level", ranging from "no impact" over three levels of disturbance to "devastating/lethal".

5. The experts thereafter rated the recovery time for the ecosystem component after the pressure ceases (with a, compared to earlier studies, rather

short maximum of "10 years or more", as the MSFD aims to achieve good environmental status in all European seas by 2020).

6. The experts were finally asked to rate their confidence in their judgement, considering both the general state of scientific knowledge on this ecosystem component-stressor combination and their own experience on the subject.

Table 5 lists the possible reply choices for these criteria, and *Table 6* summarizes the additional information collected in the online survey. We have not included Halpern et al.'s (2007) "spatial scale" (but the related "pressure distance") and the "frequency" of the stressors, as they were already modelled in our spatial stressor data sets.

The complete instructions for the online survey are found in *Appendix C*, *Appendix D* and *Appendix E*.

Table 5. Sensitivity criteria and possible answer choices.

Criterion	Possible answer choices (numeric values used to calculate sensitivity scores are in brackets)
Pressure	"No pressure" or one of the pressures in *Table 1*
Pressure distance	No impact, 1 km, 5 km, 10 km, 20 km, ≥ 50 km
Impact extent	No impact, individuals (1), population (2), community (3)
Impact level	No impact, minor disturbance (1), medium disturbance (2), major disturbance (3), devastating/lethal (4)
Recovery time	No impact, < 1 year (1), 1-5 years (2), 5-10 years (3), > 10 years (4)
Confidence	Low, medium, high (in addition, it was possible to skip specific combinations of ecosystem components and human activities by choosing an "I don't know" option)

Table 6. Additional data collected in the online survey.

Data	Description
Personal information	Name, Organisation, Country, Type of organisation (government agency, academic institution, private company, NGO, other)
Experience	For each ecosystem component or human activity for which the respondents filled in the survey, they were asked to estimate the number of years that they had research or professional experience related to this theme.
Top ecosystem component threats	If filling in the survey by ecosystem component, the experts were asked to list (without ranking) the three pressures (see *Table 1*) which they thought were the biggest threats to this ecosystem component in the North Sea.
Top ecosystem threats	The experts were also asked to list (without ranking) the three pressures (see *Table 1*) which they thought were the biggest threats to the North Sea ecosystem in general (not any particular ecosystem component).
Comments	Free text comments.

3.3.3 Derivation of pressure distances and sensitivity scores

Cleaning the replies

The replies to the online survey were combined into one table, containing nine columns: user name, human activity, ecosystem component, pressure, pressure distance, impact extent, impact level, recovery time, confidence, and "don't know" (the latter being "true" or "false"). In order to clean up these "raw" replies, all rows where the respondents indicated that they didn't know about this combination of human activity and ecosystem components were removed. Furthermore, all rows for which no confidence was given were removed, because respondents often skipped complete rows without setting any fields or checking the "don't know" field. In the resulting "cleaned" table, each row contained a statement by an expert, indicating that a human activity affected an ecosystem component by causing a certain pressure, together with the pressure distance, impact extent, impact level and recovery time according to the respective expert, as well as her or his confidence.

Which human activities cause which pressures, and over which distances?
Respondents to the online survey could list up to two pressures by which a human activity has an impact on an ecosystem component. They were asked to choose the pressures that they found the most important. Consequently, as the replies about what the most important pressures were can depend on the ecosystem component in question, and the experts may not always agree, all experts together listed several pressures to be caused by most human activities.

While analysing the survey results, it became obvious that experts often disagreed about the pressures related to the disturbance of the seabed other than sealing – for instance, the pressure "abrasion" may be followed by "siltation changes" when the abraded material settles again. For this reason, the pressures "extraction of non-living resources", "siltation changes", "smothering" and "abrasion", about which the survey responses rarely agreed (although the respondents were likely to mean damage by the removal or deposition of sediment in all cases), were combined into one pressure. Furthermore, the online survey included three different stressors on riverine discharges and atmospheric deposition of synthetic substances: PCBs, PAHs, and "other synthetic substances". As there were very few replies on "other synthetic substances", and we could only produce one coarse data set on riverine discharges of synthetic substances in general, the replies on these three stressors were combined into one stressor (riverine discharges of synthetic substances).

It was then counted in all replies how many experts listed a given pressure to be caused by each human activity. Only combinations of pressures and human activities listed independently by at least three experts were included in the further analyses. For each expert, the greatest pressure distance he or she gave for any of these combinations of pressures and human activities (which may depend on the ecosystem components the expert was replying for) was determined as a measure of the expert's opinion on how far the effects of the pressure, as caused by the activity, could reach. The median of these maximum distances, according to the different experts, was used as pressure distance (and spatial model) for this particular combination of human activity and pressure.

For example, 14 experts replied that fish farms cause the pressure nutrient enrichment. One said it would be only local (maximum pressure distance listed by this expert for nutrient enrichment from fish farms for any ecosystem component for which he or she replied). The confidence of this expert was low; note that confidences were given for the whole replies, not only for the pressure distances. Six experts said the pressure would stretch up to 1 km (median confidence: medium); three replied up to 5 km (median confidence: medium), two said up to 10 km (median confidence: high) and two replied up to 50 km or more (median confidence: medium). The median of the pressure distances was assigned to the activity-pressure combinations. In the example the median lies between 1 km and 5 km, requiring a decision on which spatial model to use. Given the higher confidences of the experts who voted for the larger pressure distances, the 5 km spatial model was chosen to represent nutrient enrichment from fish farms. In general, as a high confidence does not guarantee good knowledge, the confidences were only used to make such qualitative decisions, but not to generally weigh the experts' replies.

Calculation of sensitivity scores

Sensitivity scores were calculated for combinations of activities, pressures and ecosystem components; however, only the combinations where several experts found the human activity to cause the pressure, as described above, were included. For each expert who gave his judgement on a combination, an individual sensitivity score was calculated in two ways.

First, an approach similar to that used by Halpern et al. (2007, 2008) and Korpinen et al. (2012) was used. In this approach, the three sensitivity criteria impact extent (e), impact level (l) and recovery time (t) are weighted equally to calculate a sensitivity score s_1 (see *Table 5* for the numbers assigned to the answer choices, and note that e ranges from 1 to 3, but l and t range from 1 to 4):

$$s_1 = \frac{\frac{1}{3}e + \frac{1}{4}l + \frac{1}{4}t}{3}$$

However, in our case, this approach has potential shortcoming: The equal weights for e, l and t mean that, for example given the same recovery time, major disturbances of individuals are considered as important as medium disturbances on the population level and minor disturbances of the whole community. For this reason, we calculated a second set of sensitivity scores:

$$s_2 = \frac{7(e-1) + l + t - 1}{21}$$

This approach generally rates impacts on whole populations higher than impacts on individuals, and impacts on the whole community higher than impacts on populations. More specifically, s_2 ranges from $1/21$ to $7/21$ for impacts on the individual level, from $8/21$ to $14/21$ for impacts on the population level, and from $15/21$ to 1 for impacts affecting the whole community.

The final sensitivity scores s_1 and s_2 for each combination of human activities, pressures and ecosystem components were calculated as the mean of the individual sensitivity scores calculated for all experts who replied on this particular combination. Then, s_1 and s_2 were compared and found to be highly correlated. Furthermore, two versions of the North Sea Impact Index were calculated, one using s_1 and one using s_2, and compared.

3.4 Mapping human uses, pressures and their cumulative impacts

Based on the spatial data on human activities and pollution, pressure distances and sensitivity scores, three different indices were calculated to answer the following questions:

1 Where do many human activities coincide at high intensities?

2 Where do many pressures coincide at high intensities?

3 Where are high cumulative impacts to be expected?

3.4.1 The North Sea Human Use Index (NSUI)

A "North Sea Human Use Index" was calculated based on the "local" spatial models of the human activities listed in *Table 3*. Stressors in the group "Nutrient enrichment and pollution from land and the atmosphere" as well as oil spills were not included in this index, because they are not human activities in a strict sense, and are (with the possible exception of oil spills) not directly coupled to the intensities of human uses of the seas.

For a given cell in the mapping grid, the human use index was calculated as:

$$\sum_{k=1}^{n} i(U_k, M_{local})\, w(U_k)$$

where $U_1 \ldots U_n$ are human activities, $i(U, M)$ is the intensity of human activity U according to the spatial model M in the cell in question, M_{local} is the local spatial model, and $w(U)$ is a weight for U. In other words, the local spatial models of all human activities were simply summed up, with the option of including a weight factor for each activity.

The weights were in this study only used to balance the data sets. As an example, Ban et al. (2010) investigated how the combination of commercial fisheries data into a different number of data layers affected analysis results. Depending on whether the fisheries were represented by individual layers (one layer each for different gear types and target species), grouped by impact category (e.g. several gear types grouped into a "high-bycatch pelagic fisheries" layer), or all commercial fisheries data combined into one pressure layer, they accounted for 75% (all commercial fisheries data as individual pressure layers) down to 12.7% (only one combined commercial fishing layer) of impacts on benthic ecosystems. Accordingly, the relative importance of other stressors varied. We thus calculated and compared human use indices using different weights for the fisheries layers. Furthermore, two stressors – military areas and sediment extraction – were represented by large areas in which the respective activities occur, but without information on the intensity of the activities. These large areas would have been unrealistically dominant compared to stressors represented by intensities rather than presence-absence, and stressors represented by points or lines. To counter this effect, military areas and sediment extraction sites were included with a weight of 0.5.

3.4.2 The North Sea Pressure Index (NSPI)

A North Sea Pressure Index (NSPI) was calculated similar to the NSUI. However, all (also land-based) stressors listed in *Table 3* were included. Furthermore, the different stressors were not necessarily represented by the local spatial model; instead, the greatest pressure distance at which, according to the online survey, the activity caused pressures was used. For example, according in the online survey, experts agreed that offshore oil and gas extraction causes sealing of the seabed, but also causes pollution by e.g. non-synthetic substances. The median pressure distance for "sealing" was local; the median pressure distance for the pollution was 5 km. Consequently, the 5 km spatial model was used for oil and gas extraction in the pressure index.

For a given cell, the pressure index was calculated as:

$$\sum_{k=1}^{n} i\big(U_k, M(U_k)\big)\, w(U_k)$$

where U_k is a human activity, $M(U_k)$ is the spatial model for the greatest median pressure distance for any of the pressures caused by U_k, $i(U_k,m)$ is the intensity of activity U_k according to spatial model m in the cell in question, and $w(U_k)$ is a weight for U_k. As for the human use index, the weight factor was only used to mitigate an imbalance towards fisheries as well as military and sediment extraction areas.

The NSPI as described here corresponds in concept to the Baltic Sea Pressure Index (BSPI) presented by HELCOM (2010a, 2010b) and Korpinen et al. (2012). It is, however, based on more detailed data, calculated at a higher resolution, and uses expert judgement to explicitly consider the spatial scale over which the pressures caused by different human activities diminish from their sources.

3.4.3 The North Sea Impact Index (NSII)

The North Sea Impact Index finally combines the information on where human activities occur and the pressures they cause with the spatial distribution of the ecosystem components and their sensitivity to the pressures. It is calculated by summing up the products of sensitivity (ranging from 0 to 1), the relative intensity of the pressure as caused by the activity (according to a certain spatial model, ranging from 0 to 1), and the fuzzy density for the ecosystem component (e.g. probability of presence, ranging from 0 to 1) for all combinations of human activities, pressures and ecosystem components. For a given cell, the NSII is calculated as:

$$\sum_{i=1}^{l}\sum_{j=1}^{m}\sum_{k=1}^{n} s\big(U_i\,, P_j, E_k\big)\, i\left(U_i, M\big(U_i, P_j\big)\right) d(E_k)\, w_i^U\, w_k^E$$

In this formula, $U_1 \ldots U_l$ are human activities and stressors (see *Table 3*), $P_1 \ldots P_m$ are pressures (see *Table 1*), and $E_1 \ldots E_n$ are ecosystem components (see *Table 2*). The function *s(U,P,E)* is the sensitivity of ecosystem component *E* to pressure *P* caused by the activity *U*. It is zero if *U* does not affect *E* by *P*. The function *i(U, m)* is the relative intensity of a pressure caused by human activity *U* in the cell in question according to spatial model *m*; *M(U,P)* is the spatial model for pressure *P* caused by human activity *U* (the same as used in the pressure index). Finally, *d(E)* is the fuzzy density for ecosystem component *E*, and w^U and w^E are weights for the human activities and ecosystem components.

In simpler words, the NSII is calculated by going through all possible combinations of human activities, pressures and ecosystem components; checking whether the activity has an impact on the ecosystem component via the pressure; if so, multiplying the value of the spatial model which represents the pressure as caused by the activity with the ecosystem component's fuzzy density and its sensitivity to this pressure-activity combination; and summing all products. Note that the sensitivity function *s* summarizes both the intensity of the pressure caused by the human activity, and the ecosystem component's sensitivity.

Again, the weights for human activities were only used to investigate and mitigate the effects of the over-dominance of fisheries, military areas and sediment extraction areas. The weights for ecosystem components were used for two purposes. First, while the spatial distributions of the benthic habitats and the plankton communities were modelled so that in any cell, the sum of all benthic habitats as well as of the plankton communities would be 1, each species of fish, marine mammals and seabirds could have a value of 0 to 1 by itself; in some areas, the sum of e.g. all normalized and rescaled fish biomass distributions was between 3 and 4, leading to a bias towards the species data. To correct for this, all data layers on fish were assigned a weight of 1 divided by the greatest sum of the fish layers found in the whole study area (so that their sum would range from 0 to 1 as well). The data layers describing the distribution of birds and marine mammals were weighted in the same way. Second, in the areas covered by the coastal ecosystems, the values of all other ecosystem components had been set to zero (as most data on ecosystem components were very unreliable in these areas). Consequently, impacts on the coastal ecosystems were systematically underestimated in the index. The weights for coastal ecosystems were used to correct for these errors, and chosen so that the impact index maps showed a smooth transition between the coastal ecosystems and the adjacent sea areas.

The North Sea Impact Index was calculated in a similar, but different way from all earlier studies, because we extended the existing methods by the concept that one human activity can cause different pressures. The main differences are that a) by introducing spatial models, one human activity can affect an ecosystem component by different pressures occurring at different spatial scales. For example, oil and gas installations can affect benthic communities by local sealing and by pollution, the former pressure having only a local impact, while the latter pressure diminishes some kilometres from the installations; and b) different ecosystem components can be affected by the same human activity via different pressures, which can act at different spatial scales.

The experts could list up to two pressures for a given combination of human activities and ecosystem components in the online survey. They were asked to list the two pressures that they thought to be the most important for the combination. As the experts did not always agree on what the most important pressures were, some human activities could affect an ecosystem component by many pressures if all pressures listed by at least one expert were included in the impact index. This would give a greater weight not only to human activities causing many pressures, but also to human activities were the experts' opinions differed widely. To avoid this bias, each human activity could affect an ecosystem component by at most two pressures. If the experts did not agree on only two pressures, the two pressures listed by most experts (and thus found important for the combination of human activity and ecosystem component by most experts) were included in the impact index. Furthermore, combinations of human activities, pressures and ecosystem components listed by only one expert were only considered if this expert's confidence was high. For example, for the effects of beam trawl fisheries with mesh size ≥ 80 mm, five experts replied that it would affect dab by the pressure "extraction of living resources" (all with high confidence); three replied that it would also affect dab by "smothering and siltation changes" (median confidence: medium); and one replied that it would affect dab by causing "organic matter enrichment" (confidence: medium). Thus, as described above, the impacts of this type of fisheries on dab were included in the impact index with the two pressures "extraction of living resources" and "smothering and siltation changes", each with their own pressure distances and sensitivity scores, If no expert had listed "smothering and siltation changes", impacts on dab from "organic matter enrichment" caused by beam trawl fisheries would nevertheless not be included in the impact index, as this combination was listed by only one expert and with only medium confidence.

3.4.4 The human impact mapping tool

The work presented here had a very ambitious objective: Building a comprehensive spatial model of human impacts on the eastern North Sea. We have collected or prepared data on the spatial distribution of 28 ecosystem components and 33 human stressors. Given this comprehensive scope, not all data were available or could be prepared with the desirable accuracy. For some potentially important stressors (such as recreational fishing), no spatial data were available at all. Some of the data became only available at a late stage of this project. Consequently, we put a special focus on making our results easy to update once new or better data become available. While we used standard GIS software (ESRI ArcGIS 10) to prepare all spatial data sets and for the layout of most maps shown in this report, a dedicated software tool (screenshot in *Figure 9*) was developed for the calculation of the indices.

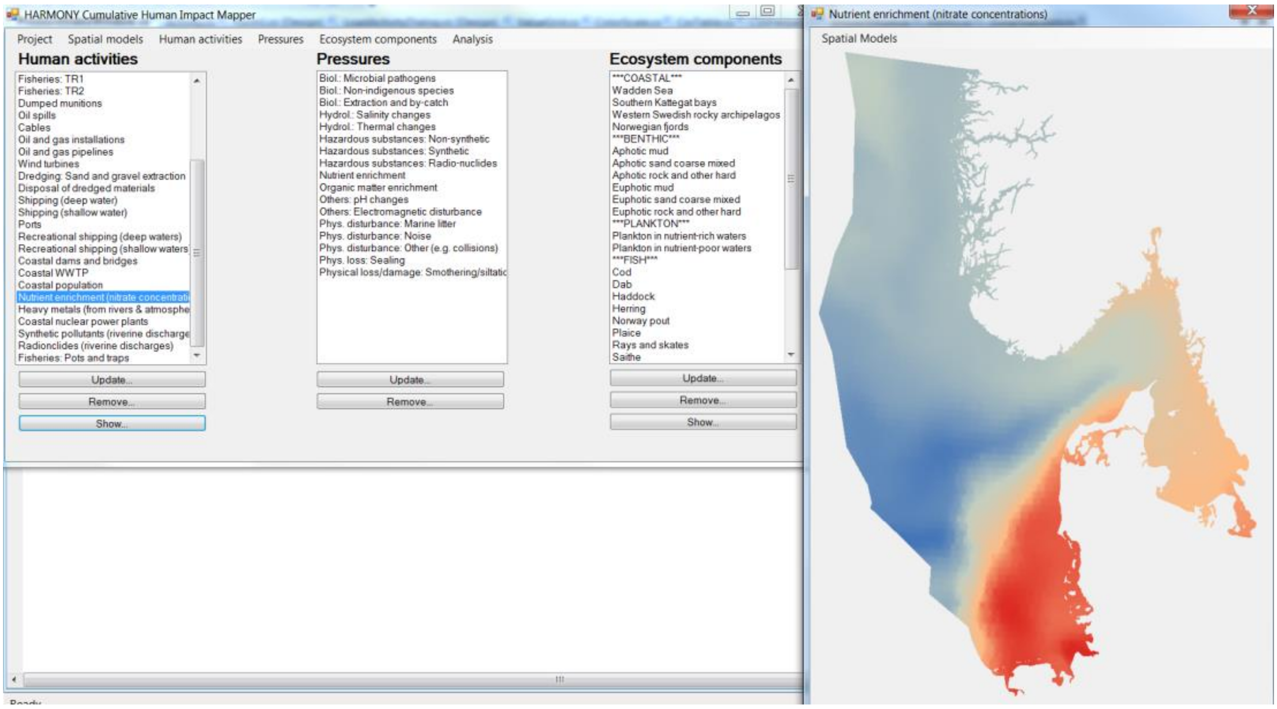


Figure 9. Screenshot of the HARMONY human impact mapping tool.

The tool currently uses comma separated value (CSV) files for all inputs and outputs. After setting up a new project, defining a mapping grid (by means of a CSV file containing the grid cells' IDs and centre coordinates), it allows to add ecosystem components and human activities by loading CSV files containing cell IDs and the respective values. Human activities and ecosystem components can be updated, for example if better data should become available, with a few mouse clicks.

Once all required data are loaded, the spatial models can be defined and calculated. It is possible to automatically calculate the human use, pressure and impact indices. The outputs are, again, CSV files containing cell IDs, centre coordinates, and index values. Also a very simple map is automatically saved for each calculated index to allow a quick check of results.

However, the impact mapping tool is not an official HARMONY deliverable, but was developed to make the work done within this project simpler and easy to update. Thus, some potentially useful functions (especially for visualizations, e.g. changing colour scales) have not yet been integrated in the user interface, and no quality assured stable version has been prepared. However, the tool can already now be used to speed up similar human impact mapping efforts, and as a decision support tool (for example, different impact indices can easily be calculated and visualized, switching on and off human activities and ecosystem components, or assigning different weights). Information on access to the tool will later be provided on the HARMONY website (see Page 2). Until then, please contact the editors.

4 Results

4.1 Online survey

4.1.1 Replies and comments

Of approximately 200 invited experts, 92 registered their personal information on the online survey site. Of these, replies for at least one human activity or ecosystem component were received from 51 user accounts. Two pairs of experts replied to the online survey using one account (two names listed in the personal information; the teams were treated as one expert in the analyses of the survey replies). Thus, the results presented here include the opinions of 53 experts: 18 from Denmark, 15 from Sweden, 6 from Norway, 3 from Germany, and 11 from other countries (invited by international organizations which work with parts of the HARMONY study area, such as HELCOM). Most respondents came from environment-related government agencies (21) and academic institutions (19); 5 came from private companies, 4 from other institutions such as international organizations, and 4 provided no information on their affiliations.

The experts submitted a total of 156 "reply sheets", each describing either one human activity (65) or one ecosystem component (91). For some human activities (e.g. fish farms) and ecosystem components (e.g. benthic habitats), many replies were received; for others (especially minke whales, white-beaked dolphins and the seabirds) only few experts submitted replies. Still, they are in parts well covered because most experts filling in the survey by ecosystem component gave their judgement on many human activities, and the experts responding for human activities covered most ecosystem components in their replies.

The comments to the online survey were mostly explanatory, telling why the respondent had made some choices. The comments were useful to spot a few minor misunderstandings, but in general indicated that the respondents had understood what was expected from them very well.

Some respondents gave constructive critical comments. Most importantly, they pointed out:

- A distinction of phyto- and zooplankton would have been useful, as they react differently to some stressors.

- Indirect effects, for instance the impacts of fisheries on birds depending on the target species as food, could not be expressed. However, many of the experts included indirect effects in their replies (for example, replying that fisheries would have effects on fish-eating seabird populations by the extraction of living resources, in spite of not being a direct effect).

- Several experts missed biological pressures (for instance "genetic contamination", "changes of species composition" without non-native species). Indeed, the pressures listed in the MSFD concentrate on different physical impacts on the seabed.

- The survey took too much time to fill in and there were too many aspects to keep in mind.

- One respondent questioned the value of the online survey in general, stating that it would be too complex to yield any reliable results, and there was a high risk of accidentally choosing the wrong replies from the lists. However, the impacts of the latter problem are diminished by excluding impacts which were not individually described by at least two experts, and using the medians of the experts' opinions on pressure distances, impact extents, impact levels and recovery times.

- Only two experts made use of the option to add additional human activities (increased exposure of euphotic sandy bottoms to nutrients from different human activities, and construction of recreational boating facilities in the archipelagos of the Swedish west coast). Thus, in general, the human activities included in the online survey (*Table 3*, *Table 4*) can be said to cover the most important human stressors in the North Sea region.

Table 7. Top threats to the North Sea according to the online survey. The respondents were asked to list up to three pressures (without order), which they thought to be the most important threats to the North Sea ecosystem in general. 42 experts or teams of experts filled in this part of the online survey.

Rank	Pressure	Expert "votes"
1	Selective extraction of species, including bycatch	31
2	Nutrient enrichment	19
3	Changes in thermal regime	13
4	Introduction of synthetic compounds	8
	Abrasion	
	Introduction of non-synthetic substances and compounds	
	Changes in pH[6]	
	Selective extraction of non-living resources, e.g. sediment	
5	Introduction of non-indigenous species	6
6	Marine litter	5
7	Organic matter enrichment	4
8	Other physical disturbance, e.g. collisions[7]	3
9	Smothering	2
10	Underwater noise	1
	Sealing	
	Changes in siltation	

4.1.2 Top threats to the North Sea ecosystem

In total, 40 individual experts and the two teams of two experts (whose replies were counted only once each) listed pressures which in their opinion were the top three threats to the North Sea ecosystem in general (some of these respondents listed only one or two top threats). The most often listed pressures were by far the selective extraction of living resources and bycatch (31 "votes"), and nutrient enrichment (19 "votes"). "Thermal changes", with 13 "votes" on rank 3, is likely referring to climate change rather than to

[6] Not listed in the MSFD.

local changes, e.g. from cooling water discharges. *Table 7* shows the complete results. Note that physical disturbance of the seabed (abrasion, extraction of non-living resources, smothering, siltation changes and sealing) would be on rank 2 if counted as one pressure, rather than four different pressures; however, it is possible that some respondents erroneously chose "Extraction of non-living resources" when in fact meaning the extraction of living resources such as fisheries.

4.1.3 Human activities, pressures and pressure distances

Table 8 summarizes the experts' replies on which human activities cause which pressures, and over which distances the pressures diminish from their source. The table only includes pressure-cause combinations that were independently found in the replies of at least three experts. The pressure distances listed in this table were used to choose the spatial models for calculating the NSPI and the NSII. Note that the results presented here and the NSII do not distinguish pressure distances for the different ecosystem components, because too few replies were received to confidently establish separate sets of pressure distances for each ecosystem component. For example, once it was determined that the pressure distance for noise from offshore wind farms was 1 km, this pressure distance was used for impacts of noise caused by wind farms for all ecosystem components.

4.2 North Sea Human Use Index (NSUI)

The North Sea Human Use Index (NSUI) gives an overview of the spatial distribution of the intensity of human uses in the eastern North Sea. A high NSUI indicates that many human activities occur at high intensities in the respective locations. In contrast, a low NSUI indicates that few human activities, and at low or moderate intensities, occur in the respective locations. Note that no pollution data (nutrients, hazardous substances, oil spills) are included in the NSUI, as these stressors do not directly mark the locations of human uses of the sea.

As fisheries are represented by nine data layers, they have the potential to contribute much more to the NSUI than other human uses represented by only one data layer (e.g. commercial shipping or military practice), as described by Ban et al. (2010). *Figure 10* shows the NSUI with different weights assigned to the nine included data sets on fisheries: Counting them as on data layer (weights 1/9), like four data layers (weights 4/9), or as nine individual data layers (weights 1) changes the NSUI substantially. Given that most experts responding to our online survey ranked the extraction of living resources and by-catch as a top threat to the North Sea ecosystem in comparison to other pressures, a weight of 4/9 (that is, giving all fisheries combined the potential to have four times greater impacts than e.g. commercial shipping or offshore wind farms) may be a good choice for general purposes. The NSUI using these weights of 4/9 is shown in *Figure 11*.

As the NSUI does not consider pollution or pressure distances, the highest index values are found only in small patches. The index' broad-scale spatial pattern is dominated by high levels of fisheries in the German Bight, the western and north-western Danish EEZ, and northern Kattegat. Also some areas with intensive commercial shipping clearly show in the map, for example around Skagen (the northernmost tip of Denmark) and in parts of the Kattegat. In addition, some coastal areas (in particular the archipelagos around and to the north of Göteborg, the Sound and the Limfjord) have much recreational shipping (and coastal recreation in general), which stands out in the NSUI.

Table 8. Pressures, the human activities that cause them, and the distances at which the pressures diminish from their source according to the online expert survey. Note that the number of experts who replied that a certain pressure would be caused by an activity depends on e.g. the number of experts that replied on this particular activity and the ecosystem components they replied for. Thus, a high number of experts saying that a given pressure is caused by a certain activity do not imply that this activity is in general a more important cause of the pressure than an activity listed by fewer experts.

Pressure (no. of causes)	**Caused by (human activities)**[7]	**Experts**	**Pressure distance (median)**[8]
Sealing (9)	*Marine construction works*	*10*	*Local*
	Coastal dams and bridges	7	Local
	Coastal engineering and defence	*7*	*Local*
	Wind farms	7	Local
	Dredge disposal	6	Local
	Pipelines	6	Local
	Ports	5	Local
	Cables	4	Local
	Oil and gas extraction	3	Local
Smothering, siltation changes, resource extraction, abrasion (28)	Dredging	29	1 km
	Fisheries: Dredge	21	Local
	Increased sedimentation from land	*20*	*10 km*
	Fisheries: Beam trawl with mesh > 80 mm	20	local (*)
	Anchoring (outside harbours)	*17*	*Local*
	Dredge disposal	15	1 km
	Marine construction works	*16*	*1 km*
	Fisheries; Trawl and demersal seine, 70-99 mm	14	local (*)
	Fisheries; Trawl and demersal seine, ≥ 100 mm	14	local (*)
	Decreased sedimentation from land	13	5 km
	Coastal engineering and defence	12	1 km
	Fisheries: Small-meshed beam trawl	10	local (*)
	Coastal population	9	Local
	Offshore wind farms	9	Local
	Fisheries: Small mesh trawls for industrial species and Northern shrimp	9	local (*)
	Coastal dams and bridges	8	1 km
	Oil and gas extraction	8	1 km
	Fisheries: Pots and traps	7	local (*)
	Oil and gas pipelines	6	Local
	Fisheries: Set nets	6	local (*)
	Fish farms	6	5 km

7 Human activities in *italics* could not be included in the pressure and impact indices.
8 A star in brackets (*) means that a general spatial model was used for this stressor.

Pressure (no. of causes)	Caused by (human activities)[9]	Experts	Pressure distance (median)[10]
Smothering, siltation changes, resource extraction, abrasion (28)	Commercial shipping in shallow waters	6	1 km
	Recreational shipping in shallow waters	4	Local
	Oil spills	4	20 km (*)
	Ports	4	1 km
	Military practice	3	1 km
	Underwater cables	3	Local
	Hunting	*3*	*1 km*
Underwater noise (14)	Offshore wind farms	15	1 km
	Marine construction works	*13*	*1 km*
	Recreational shipping in shallow waters	10	1 km
	Military practice	9	10 km
	Commercial shipping in deep waters	9	5 km
	Commercial shipping in shallow waters	9	5 km
	Recreational shipping in deep waters	8	1 km
	Major ports	7	5 km
	Oil and gas extraction	5	1 km
	Recreational fishing	*4*	*1 km*
	Hunting	*3*	*Local*
	Fisheries: Beam trawl with mesh > 80 mm	3	1 km (*)
	Coastal dams and bridges	3	Local
	Fisheries: Pelagic trawl and seiners	3	1 km (*)
Marine litter (9)	Coastal population	15	Local
	Recreational shipping in deep waters	10	10 km
	Recreational shipping in shallow waters	9	20 km
	Commercial shipping in shallow waters	8	≥ 50 km
	Commercial shipping in deep waters	6	≥ 50 km
	Fisheries: Set nets	4	Local
	Anchoring (outside harbours)	*3*	*1 km*
	Recreational fishing	*3*	*Local*
Other physical disturbance, e.g. collisions (8); not listed in the MSFD	Offshore wind farms	11	Local
	Marine construction works	*7*	*Local*
	Coastal dams and bridges	4	Local
	Coastal population	3	Local
	Commercial shipping in shallow waters	4	Local
	Commercial shipping in deep waters	3	Local
	Coastal engineering and defence	*3*	*1 km*
	Oil and gas pipelines	3	Local
Changes in salinity regime (1)	Coastal dams and bridges	7	≥ 50 km
Changes in thermal regime (2)	*Ocean warming*	*28*	*≥ 50 km*
	Coastal nuclear power plants	15	1 km

[9] Human activities in *italics* could not be included in the pressure and impact indices.
[10] A star in brackets (*) means that a general spatial model was used for this stressor.

Pressure (no. of causes)	Caused by (human activities)[11]	Experts	Pressure distance (median)[12]
Introduction of synthetic compounds (8)	Riverine discharges of synthetic substances and compounds	14	≥ 50 km (*)
	Coastal Waste Water Treatment Plants	8	20 km
	Dredge disposal	6	1 km
	Major ports	6	5 km
	Oil and gas extraction	5	5 km
	Dumped munitions	5	local
	Commercial shipping in deep waters	3	20 km
	Commercial shipping in shallow waters	3	20 km
Introduction of non-synthetic substances and compounds (10)	Oil spills	34	≥ 50 km (*)
	Riverine discharges and atmospheric deposition of heavy metals	20	20 km (*)
	Oil and gas extraction	16	10 km
	Major ports	8	10 km
	Oil and gas pipelines	6	10 km
	Dumped munitions	5	1 km
	Commercial shipping in shallow waters	5	10 km
	Dredge disposal	4	1 km
	Commercial shipping in deep waters	3	20 km
	Military practice	3	Local
Introduction of radio-nuclides (2)	Riverine discharges of radio-nuclides	12	≥ 50 km (*)
	Coastal nuclear power plants	6	10 km
Nutrient enrichment (7)	Riverine discharges and atmospheric deposition of nutrients	28	≥ 50 km (*)
	Coastal waste water treatment plants	22	10 km
	Fish farms	17	1 km
	Fisheries: Dredge	6	1 km (*)
	Dredging	6	Local
	Shellfish farms	5	5 km
	Dredge disposal	4	1 km
Organic matter enrichment (8)	*Riverine discharges of organic matter*	*26*	*20 km*
	Fish farms	14	1 km
	Shellfish farms	13	Local
	Coastal waste water treatment plants	6	10 km
	Dredge disposal	6	1 km
	Increased sedimentation from land	*5*	*5 km*
	Dredging	3	1 km
	Riverine discharges of nutrients	3	≥ 50 km (*)
Introduction of microbial pathogens (3)	Fish farms	10	20 km
	Shellfish farms	4	1 km
	Coastal waste water treatment plants	4	10 km

[11] Human activities in *italics* could not be included in the pressure and impact indices.
[12] A star in brackets (*) means that a general spatial model was used for this stressor.

Pressure (no. of causes)	Caused by (human activities)[13]	Experts	Pressure distance (median)[14]
Introduction of non-indigenous species (6)	Major ports	9	5 km
	Commercial shipping in shallow waters	8	20 km
	Commercial shipping in deep waters	7	≥ 50 km
	Ocean warming	6	≥ 50 km
	Fish farms	5	≥ 50 km
	Shellfish farms	4	≥ 50 km
Selective extraction of species and by-catch (11)	All commercial fisheries included in this study	10…26	local (note: some experts included in-direct effects further away) (*)
	Recreational fishing	*18*	*Local*
	Hunting	*9*	*Local*
Electromagnetic disturbance (3); not in the MSFD	Submarine cables	8	Local
	Global changes in UV radiation	7	≥ 50 km
	Offshore wind farms	3	Local
Changes in pH (1); not in the MSFD	*Acidification*	*21*	≥ *50 km*

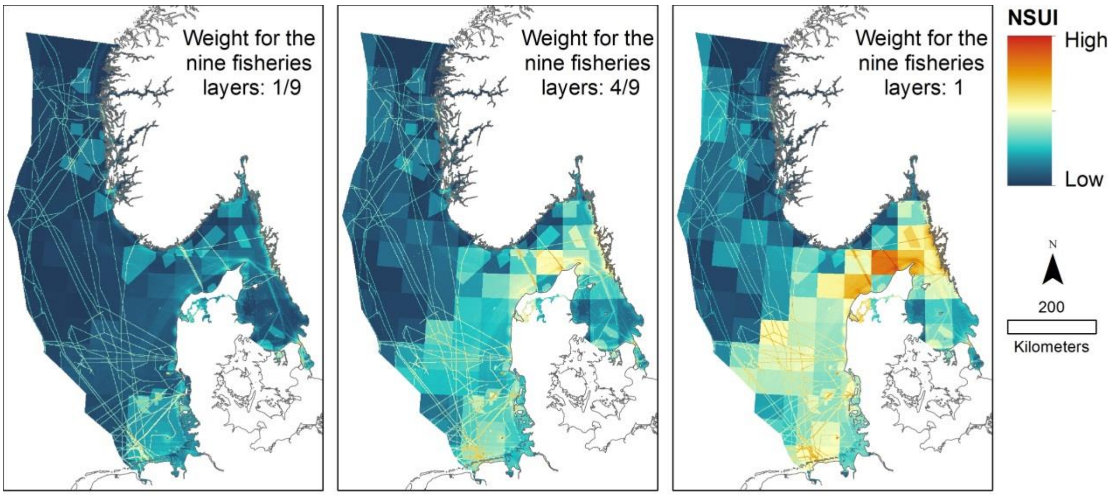


Figure 10. The North Sea Human Use Index with different weights for the fisheries. Left: Counted like one human use layer (such as commercial shipping and wind farms); middle: Counted like four human use layers (i.e. having the potential to make four times greater contributions to the index than e.g. commercial shipping); right: Each of the nine fisheries data sets counted as one human use layer (i.e. having the potential to make nine times greater contributions to the index than e.g. commercial shipping).

In contrast, while a few ICES squares, the area north of Bergen and some clusters of offshore oil and gas installations stand out, the human use index is generally low in the Norwegian EEZ. This must be interpreted while keeping in mind that fishing efforts by the Norwegian fleet could not be included in this study.

[13] Human activities in *italics* could not be included in the pressure and impact indices.
[14] A star in brackets (*) means that a general spatial model was used for this stressor.

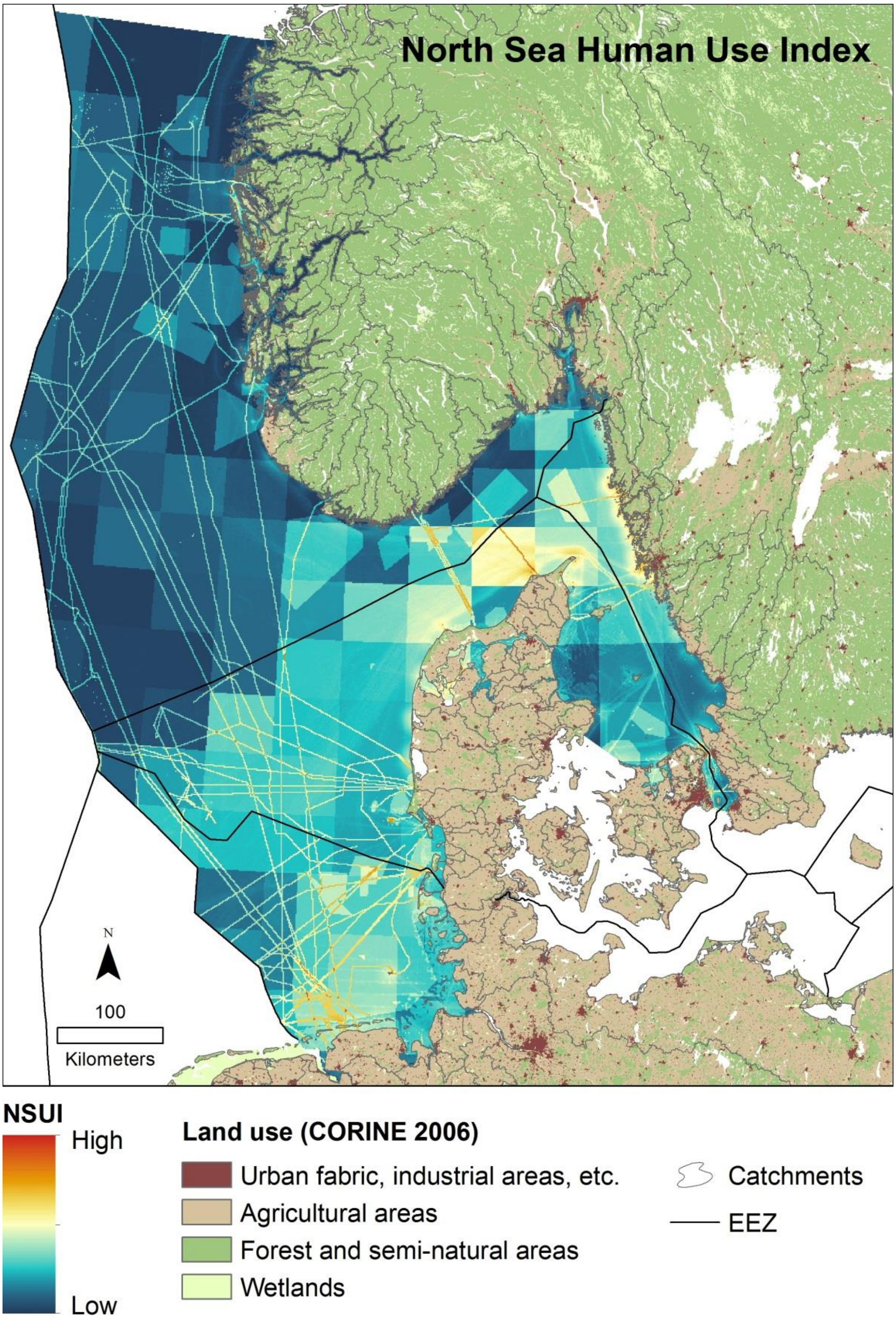


Figure11. The North Sea Human Use Index (with a weight of 4/9 for each of the nine fisheries layers).

In addition to human uses of the sea, *Figure 11* shows land use in broad classes as well as main river catchments around the study area, because agricultural lands and urban areas are related to discharges of nutrients and pollutants into the sea. The German and Danish catchments draining into the North Sea are dominated by agricultural lands (and, which is not visible in the map, have a somewhat higher population density); most of the Norwegian and Swedish catchments draining into the study area are dominated by forests and other natural or semi-natural landscapes. Note that some large catchments, especially in the south, are not completely visible in *Figure 11*, and that high levels of nutrients and hazardous substances enter the Kattegat as outflow from the Baltic Sea (the latter may be underestimated in the pressure and impact indices presented in the following sections). Also major urban centres (such as Hamburg, Malmö, Copenhagen, Göteborg, Oslo) are visible.

4.3 North Sea Pressure Index (NSPI)

The North Sea Pressure Index (NSPI) gives an indication of where many pressures are likely to occur at high intensities, It is based on the same human stressor data sets as the NSUI, but there are two major differences between the NSPI and the NSUI: First, the NSPI also considers the pollution stressors included in this study, which are not strongly spatially linked to a human use of the sea (riverine discharges and atmospheric deposition of heavy metals, of nutrients, riverine discharges of synthetic substances, of radio-nuclides, and oil spills). Second, while the NSUI shows where human uses of the sea occur, the NSPI considers the distances up to which the human activities cause pressures, according to expert judgement. For each human activity, the greatest distance up to which it causes a pressure (see *Table 8*) was used. The pressure distances used in the NSPI are also listed in *Table 9*.

The NSPI is, as the NSUI, sensitive to the number of data sets representing different human uses and stressors. *Figure 12* shows the NSPI with different weights for the nine fisheries layers included in this study, based on the same reasoning as for the NSUI.

Figure 13 shows the NSPI with weights of 4/9 for all fisheries layers, avoiding their over-dominance, but still accounting for the high impacts of fisheries on the North Sea ecosystem.

The NSPI map is dominated by the human stressors that occur at large spatial scales (fisheries, nutrient enrichment and hazardous substances from rivers and the atmosphere), and the human activities that cause pressures spreading over large distances from their source (e.g. aquaculture) according to the expert judgement. Nearly everywhere, the pressure index is higher in coastal than in offshore waters.

The pressures from fisheries show the same spatial pattern as in the NSUI: They are highest in the German Bight, much of the Danish part of the study area and the Kattegat. The same areas have relatively high levels of nutrient enrichment and pollution from terrestrial sources (compare e.g. the modelled nitrate concentrations in *Figure 7*). One large area with high pressure index values stands out in the German Bight: In the Wadden Sea around Sylt, high levels of pollutants and nutrients coincide with fisheries as well as two major coastal dams (the Hindenburg Dam and the Romø Dam), shellfish farms and coastal recreation.

Table 9. Spatial models used in the NSPI.

Group	Human activity/stressor	Spatial model for NSPI
Aquaculture	Fish farms	50 km
	Shellfish farms	50 km
Fisheries	All nine commercial fisheries included in the NSPI	ICES rectangles
Industry, energy, population and infrastructure	Offshore wind farms	1 km
	Operational underwater cables	Local
	Operational oil and gas pipelines	10 km
	Offshore oil and gas extraction	10 km
	Oil spills	Modelled "oil spill impact risk"
	Coastal population	Local
	Dredging for sand and gravel	1 km
	Disposal of dredged materials	1 km
	Bridges and coastal dams	50 km
	Coastal nuclear power plants	10 km
	Coastal waste water treatment plants	20 km
Nutrient enrichment and pollution from land and the atmosphere	Riverine inputs and atmospheric deposition of nutrients	Modelled nitrate concentrations
	Riverine inputs and atmospheric deposition of heavy metals	"Artificial plume" model
	Riverine inputs of synthetic compounds	"Artificial plume" model
	Riverine inputs of radio-nuclides	"Artificial plume" model
Shipping and transport	Major ports	5 km
	Commercial shipping in deep water	50 km
	Commercial shipping in shallow water	50 km
	Recreational shipping in deep water	10 km
	Recreational shipping in shallow water	20 km
Other human activities	Military practice	10 km
	Dumped munitions	1 km

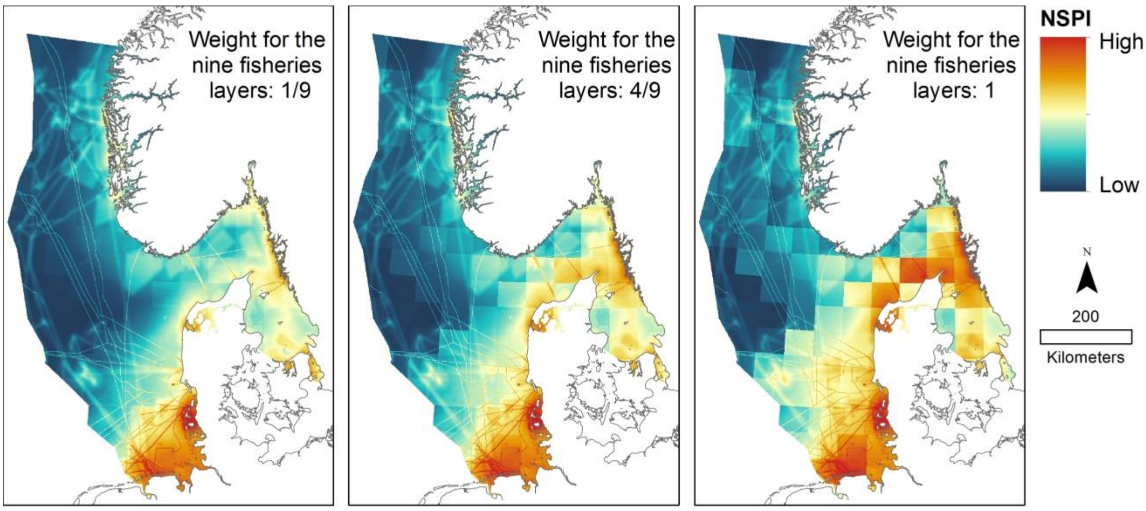


Figure 12. The North Sea Pressure Index with different weights for the fisheries. Left: All fisheries together counted as one pressure layer (such as oil spills, commercial shipping and wind farms); middle: Counted like four pressure layers (i.e. having the potential to make four times greater contributions to the index than e.g. oil spills); right: Each of the nine fisheries data sets counted as one pressure layer (i.e. having the potential to make nine times greater contributions to the index than e.g. oil spills).

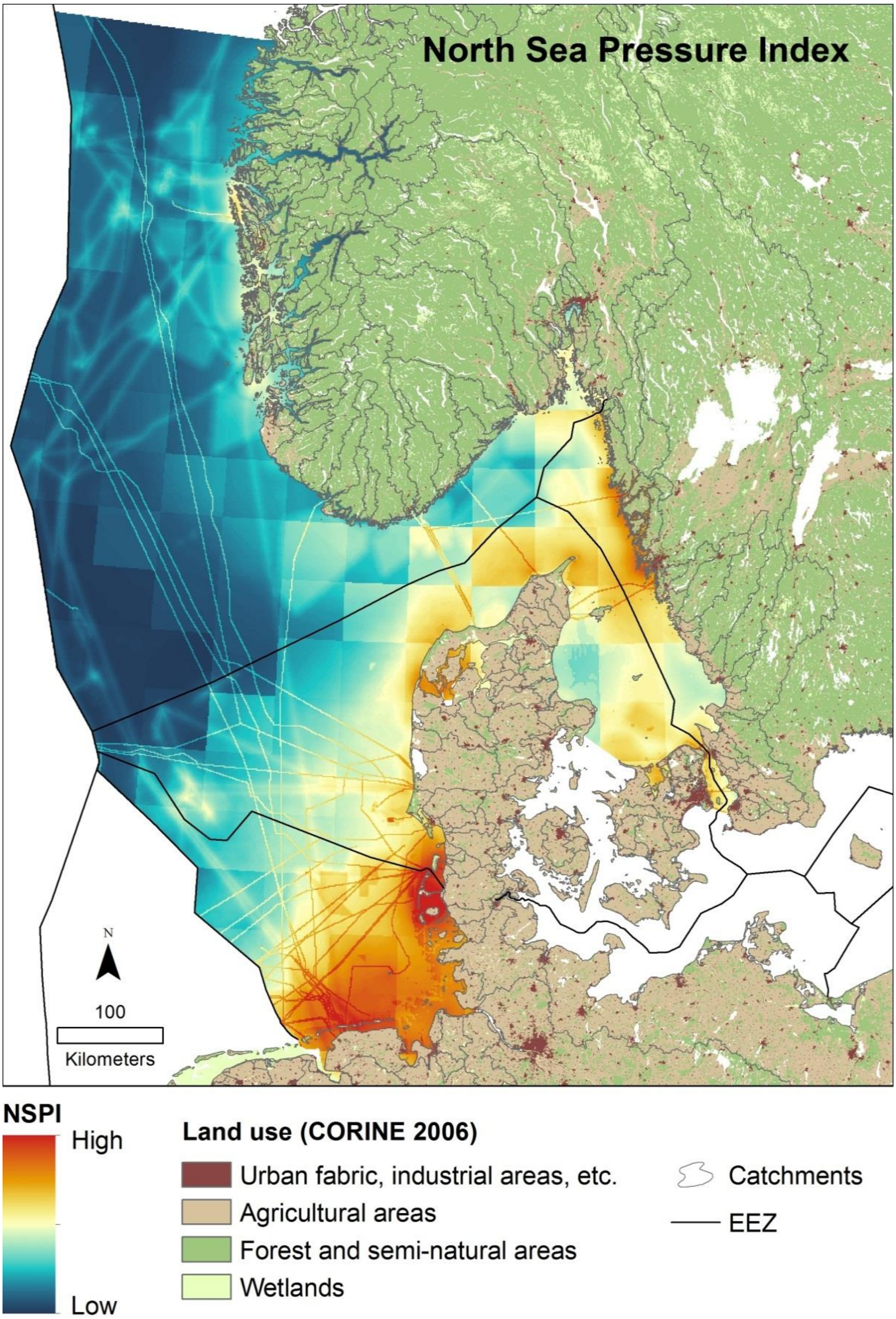


Figure 13. The North Sea Pressure Index.

In the central Kattegat, the pressure index is high due to fisheries, pollution and nutrient enrichment (although less than in the German Bight), shipping and a high frequency of oil spills. Also some coastal areas in the Kattegat region have a high pressure index. Although the modelled pollution and nutrient levels were rather moderate along the Swedish west coast north of Gothenburg, this area is used intensively for shellfish farms, maritime transport (including major ports at Göteborg and the Preemraff refinery), and coastal recreation.

In the western Limfjord, a big proportion of the high pressure index is attributable to nutrient enrichment, pollution, mussel farming and dredge fisheries, together with some recreational shipping. Also in the Isefjord and the Sound, modelled nutrient and pollution levels are high, and these areas are intensively used for recreation and many activities with more local effects, such as military practice (in the Isefjord) and the disposal of dredged materials (in the Sound). Fishery efforts are comparatively low in the Sound, but maritime transport contributes strongly to the NSPI.

As the NSUI, the NSPI is relatively low in the Norwegian North Sea. A moderately high index value is reached in a rather small part of the central Oslofjord (two military practice areas and several human activities at rather moderate intensities), north of Bergen (where moderate fisheries coincide with an important commercial shipping route, frequent oil spills and comparatively high modelled atmospheric deposition of heavy metals), and in some areas with oil and gas operations, Again, it is important to remember that efforts by the Norwegian fishing fleet are not included in the underlying fisheries data sets.

The NSPI is based on the locations where different human stressors occur, and how far away from their source the pressures caused by human activities typically diminish. It does not consider how sensitive local ecosystems are to the stressors; for example, although oil spills are likely to cause more damage than recreational shipping to coastal areas, these two stressors are weighted similarly in the NSPI. Consequently, areas with a high NSPI can still be healthy if the local ecosystem is not sensitive to the pressures occurring there. Similarly, the local ecosystem can be in a very bad state in spite of a low NSPI if it is very sensitive to a few pressures that occur in that respective location.

4.4 The North Sea Impact Index (NSII)

The North Sea Impact Index (NSII) is based on the same data sets on human uses of the sea and pollution as the NSPI, but in addition considers the spatial distribution and sensitivity of the ecosystem components to different stressors. A high NSII indicates that high levels of impacts can be expected, because many pressures and sensitive ecosystem components occur together in the same location. A low NSII, in contrast, indicates that few anthropogenic pressures occur in this location, or that the ecosystem components found in this location are not sensitive to the pressures they are exposed to.

Also the NSII is sensitive to the number of data sets representing different human stressors. *Figure 14* shows the NSII with different weights for the nine fisheries layers included in this study (left to right), and with sensitivity scores calculated in two different ways (top and bottom; see Section 3.3.3). The sensitivity scores s_1 and s_2 were positively correlated (R^2 = 0.80) and, as *Figure 14* shows, the choice of the method to calculate them had only minor influence on the NSII. Thus, and because we found it reasonable to consistently rate impacts on the community level higher than impacts on the population level, and impacts on the population level higher than impacts affecting only individuals, we will use the second set of sensitivity scores (s_2) in all further maps and discussions.

Again, the weights for the nine data layers on fisheries strongly influence the impact index in much of the study area, as each included data set can potentially add a value from 0 to 1 to the impact index in any location. Because the expert survey indicated that the selective extraction of species and by-catch are the greatest threat to the North Sea ecosystem, we found a higher weighting of the fisheries reasonable. At the same time, we wanted to avoid a complete dominance of the index by fisheries, and thus used the "medium" version of the NSII with a weight of 4/9 for each fisheries layer (as in the NSUI and NSPI) for all further analyses. *Figure 15* shows the NSII with these weights.

Figure 16 shows separate indices for the five groups of ecosystem components included in this study.

The broad patterns of the NSII resemble the NSPI. This could be expected, as impacts only occur where pressures occur; and the more human activities and pressures occur at higher intensities in a given location (as indicated by the NSPI), the more likely it is that one or more of the ecosystem components found there are sensitive (resulting in a high NSII). The NSII is high in the German Bight, along the west coast of northern Germany and Denmark, and most of the Kattegat, including the Limfjord. Along the Swedish coast, the predicted impacts decrease towards the Norwegian boundary. The NSII is, as the NSPI, generally lower in the Norwegian coastal and offshore waters than in the other countries'; again, some ICES rectangles and areas used for offshore oil and gas extraction stand out, reaching intermediate index values, and it must be considered that the efforts of the Norwegian fishing fleet had to be excluded from the index.

Considering the five groups of ecosystem components (*Figure 16*), the impact index for benthic broad-scale habitats is generally following the NSII. Demersal fisheries and, locally, benthic structures such as cables and pipelines are obvious causes for the high values in the German Bight and the Kattegat. The highest impact index values for fish are found in German and western Danish offshore waters, along the southern boundary of the Norwegian trench, in parts of the Kattegat and a small hotspot close to the northwestern boundary of the study area. These areas have relatively high predicted biomasses of several fish species. The impact index for plankton follows closely the concentration of nutrients; also areas where oil spills are common show as an important stressor in the map. The highest impacts on birds are predicted in the German Bight, the southern Kattegat, and south of the Oslofjord. The latter area has high probabilities of presence of all five bird species included in this study; Guillemot and Kittiwake have high probabilities of presence in the other listed areas. In contrast, according to our models, e.g. Gannets are most likely to be found in areas where the NSPI is low, leading to the question of whether this is a natural pattern or if the pressures, some of which may have been present since decades, have led to the birds' displacement from high pressure areas. The impact index for marine mammals is highest in the southern Kattegat, where harbour porpoises are the most abundant.

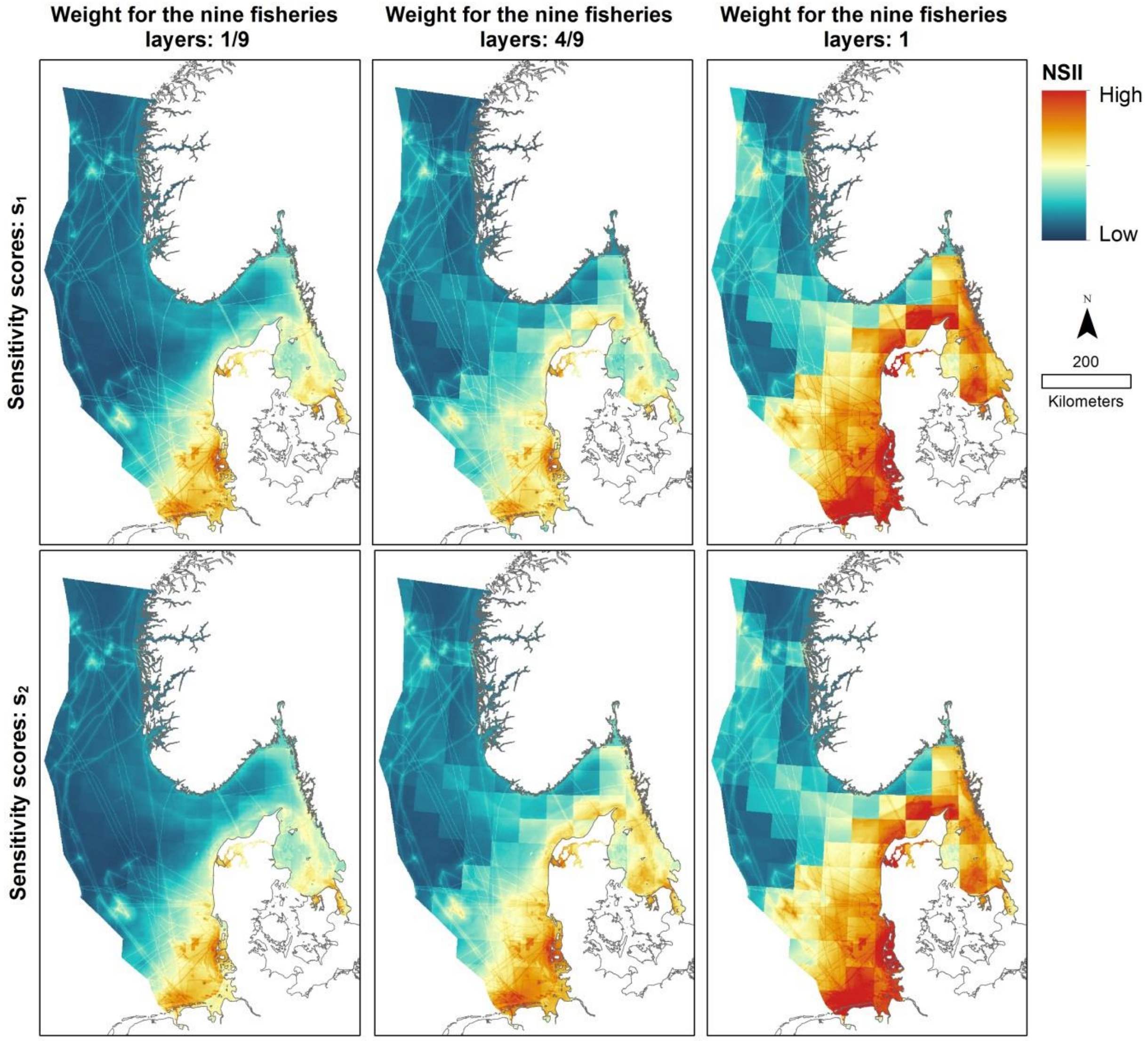


Figure 14. The North Sea Impact Index with different weights for the fisheries and sensitivity scores calculated in two ways. Top row: Sensitivity scores s1, that is the "classic" approach; bottom row: sensitivity scores s2, resulting in large weights for impacts at the community level, medium weights for impacts at the population level, and small weights for impacts on individuals. Left: All fisheries together counted as one pressure layer (such as oil spills, commercial shipping and wind farms); middle: Counted like four pressure layers (i.e. having the potential to make four times greater contributions to the index than e.g. oil spills); right: Each of the nine fisheries data sets counted as one pressure layer (i.e. having the potential to make nine times greater contributions to the index than e.g. oil spills).

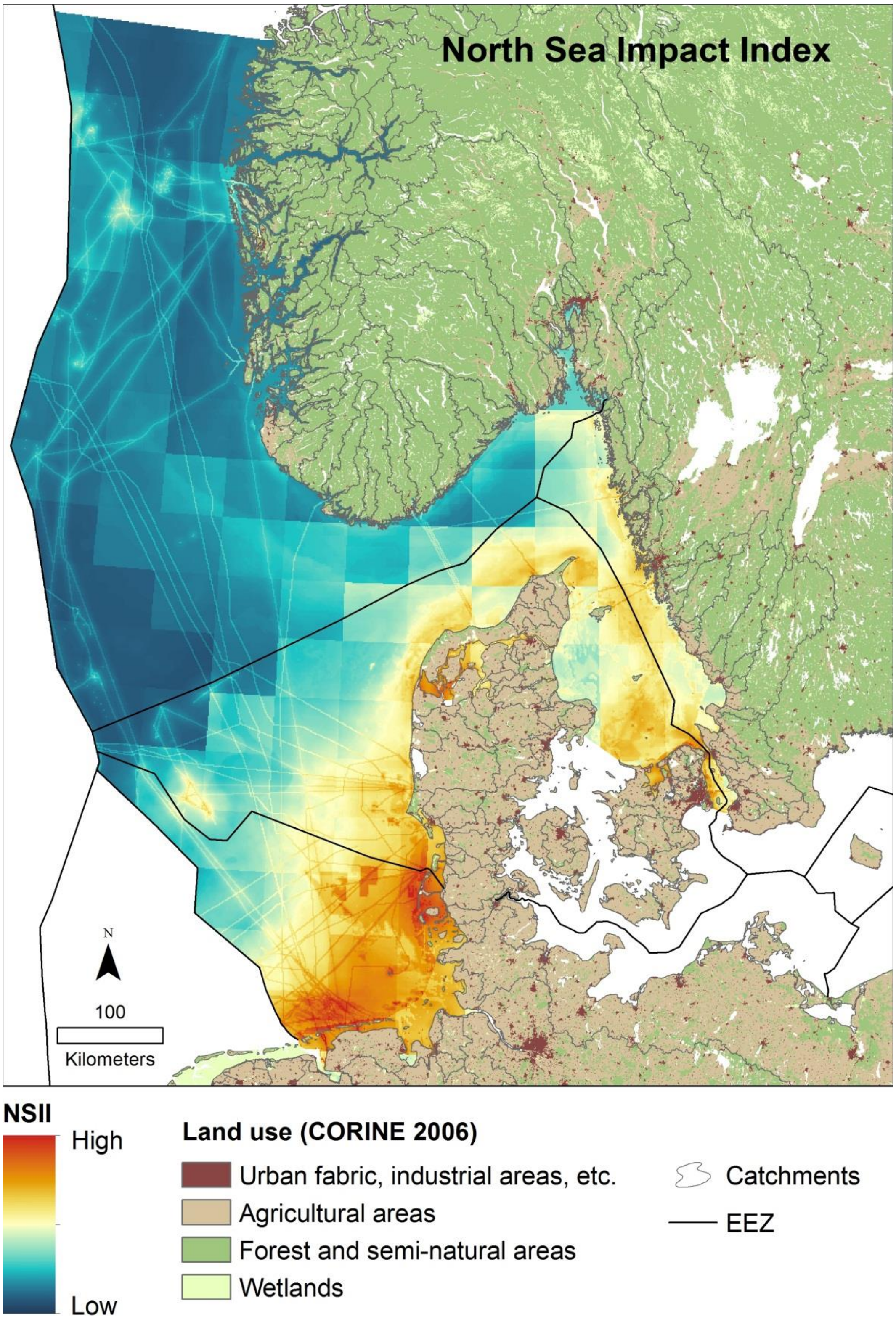


Figure 15. The North Sea Impact Index (with a weight of 4/9 for the nine fisheries layers), and the sensitivity scores emphasizing community-level impacts.

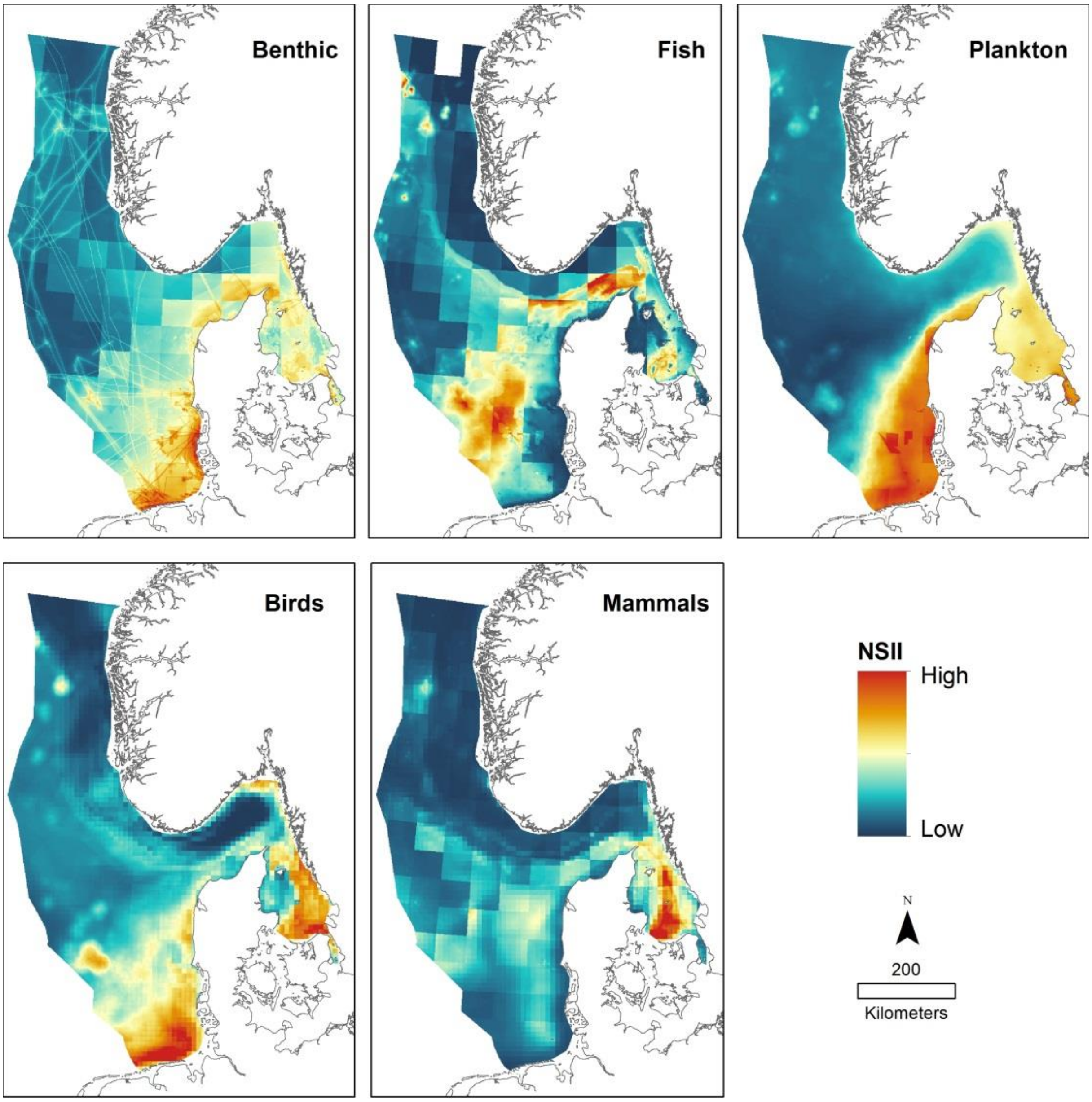


Figure 16. Separate impact indices for the five main groups of ecosystem components included in the NSII. Note that the impact indices for the five groups are relative; i.e. in each of the maps, blue areas have the lowest index values within this group, whereas red areas have the highest index values within this group. Direct comparisons between groups are not possible. For example, a fully red area in the index for fish does not necessarily indicate the same level of impact as a similarly red area in the index for mammals.

4.5 Comparison to results from HELCOM HOLAS in the Kattegat

The pressure and impact indices calculated for the Baltic Sea (BSPI and BSII; HELCOM 2010a, 2010b, Korpinen et al. 2012) and the respective indices calculated for the eastern North Sea (NSPI and NSII) in this project overlap in the Kattegat.

Figure 17 shows a comparison. Both pressure indices are high in the Sound (location *e* in the maps) and the northern Kattegat (*a*); the BSPI is higher along the Danish coast right north of the Limfjord. Furthermore, the BSPI shows the most intensive fisheries to occur just north of the Sound, whereas the NSPI shows comparatively low fishing efforts in this area. This difference may have been caused by the use of fisheries data from different years, and by distinguishing different gear types. The NSPI is much higher than the BSPI in the Isefjord and the Limfjord (*d* and *c*).

While the NSII and the BSII are similar in some areas (a, e), the NSII is much higher in the Limfjord (c), the Isefjord (d) and the central southern Kattegat (b). One likely reason for these differences is the inclusion of different data sets on human stressors and on ecosystem components. For example, the Limfjord is the site of intensive dredge fisheries and mussel farming, and is surrounded by agricultural lands; also the Isefjord suffers from e.g. land-based nutrient enrichment and pollution. The high NSII just north of the Isefjord (b), where the BSII is low, is probably caused by the different choice of ecosystem component layers for the eastern North Sea: In the Baltic Sea, 8 of the included 14 ecosystem components were benthic, 2 pelagic, 2 related to mammals, 1 to birds and 1 to fish. In addition, the ecosystem components were represented by presence-absence (e.g. the range of harbour porpoises, meaning that "hot spots" could not be distinguished from areas with low numbers). Indeed, according to Korpinen et al. (2012), only a medium number of ecosystem components were modelled to be present in this area, which could explain the relatively low BSII. In contrast, the NSII considers the spatial distribution and sensitivities of 6 benthic habitats, 2 plankton communities, 8 fish species, 5 seabird species and 3 marine mammal species, many of which were modelled on a continuous scale (e.g. biomass distributions or probability of presence); in addition to the broad-scale habitats and plankton communities, which are found everywhere, many of the fish and seabird species, as well as harbour porpoises, are predicted to occur at high densities in this area. Furthermore, the NSII was explicitly corrected to "even out" the differences between the number and characteristics of the data sets describing the ecosystem components, resulting in a comparable weighting of the five included groups. Indeed, in the area marked with "b" in *Figure 17*, the North Sea models predict high impacts on all groups of ecosystem components (see *Figure 16*). The NSII including all groups is consequently also high.

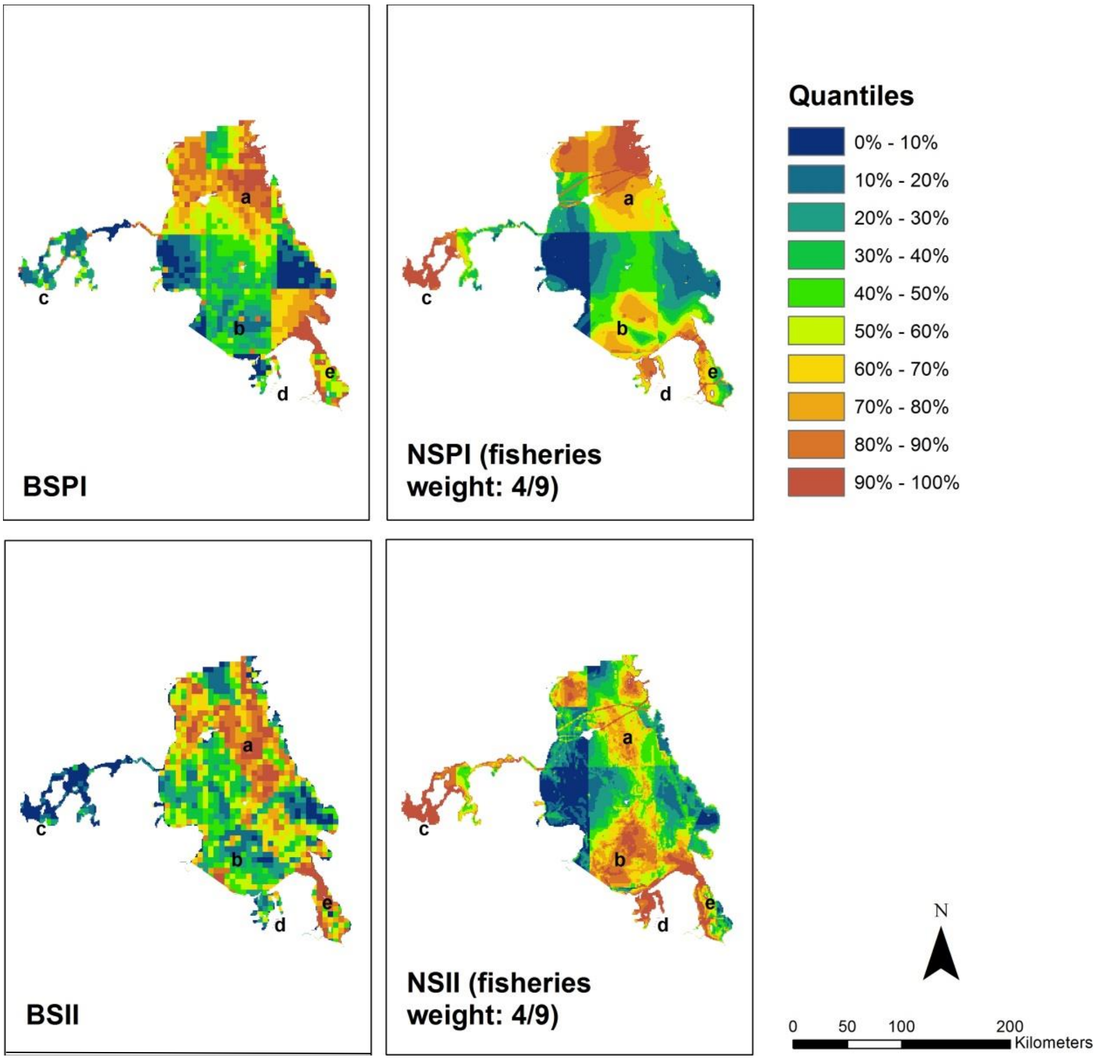


Figure 17. Comparison between the pressure and impact indices calculated for the North Sea (NSPI, NSII) in this project and for the Baltic Sea by Korpinen et al. (2012; BSPI, BSII).

5 Discussion

5.1 Data availability and gaps

Much of the efforts to produce the North Sea Impact Index went into the collection and production of data on human stressors and ecosystem components. Concerning ecosystem components, broad-scale benthic habitats were readily available from EUSeaMap. Survey data were available for key species of fish, marine mammals and seabirds. However, the surveys of marine mammals and seabirds used to predict their spatial distributions were rather old, covering the period from 1995-2004 for seabirds and the years 1995 and 2004 for marine mammals. The maps of the spatial distribution of fish have a major gap off the Norwegian coast, as no survey data were available for this area. The gap filling with only one value for each species, as described in *Appendix F*, is far from being an optimal solution.

As indicated by comments on the online survey, the NSII would have benefitted from a more detailed classification of plankton; unfortunately, no maps on the spatial distribution of phyto- and especially zooplankton covering our whole study area were available. Data on most ecosystem components were unreliable in coastal areas, which could however be mitigated by the separate mapping of impacts on broad-scale "coastal ecosystems" such as the Wadden Sea. It should be noted that these coastal ecosystems were based on administrative and data set boundaries rather than ecological boundaries. In summary, most of the data on ecosystem components presented in this report could be improved given access to better source data, time and money. At the same time, the use of fuzzy measures (for example, predicted probabilities of presence) of the spatial distribution of most ecosystem components helped to mitigate some inaccuracies.

Data on human uses of the sea were collected from external sources, mostly from government agencies. Some of these data were very difficult to obtain, in spite of HARMONY being supported by government agencies from all four countries for which the pressure and the impact indices were developed. Some basic data sets were not available from official and quality-assured sources in one or more countries; for example, Norwegian industrial ports and leisure harbours had to be extracted from a private database, with no information on data quality available. In a few cases, institutions denied the sharing of existing data, sometimes even of data that had already been published in reports or nautical charts. In all four countries involved in HARMONY, but especially in Germany, data were spread over many institutions. It was often very time-consuming to find out who exactly was responsible when searching for national data on a given theme.

Many of the available data sets contained only basic information. For example, it was straightforward to obtain the locations of shellfish farms, but impossible to receive information about the intensity of the farming (e.g. mean annual production) and potential impacts (e.g. measurements of introduced nutrients). In some cases, such data were simply not collected at all or at least not in a centralized data set; in others, laws prohibited the publication of business-related information. If detailed data were available, this was often not the case in all four countries included in this study. Thus, in order to make the data from different countries comparable, national data sets often had to be generalized to a "greatest common denominator", which in many cases was rather small.

Two problems limit the usefulness of the fisheries data included in this study. First, we were not able to obtain data from the Norwegian fleet in time for this project's completion, which is likely to have caused an underestimation of the impacts of fisheries in Norwegian waters. Second, the resolution at which fisheries data were available (ICES rectangles) was too coarse to tell exactly where impacts occur. For example, most areas protected from some or all kinds of fishing are somewhat smaller than ICES rectangles. Low levels or absence of fisheries in such a protected area would decrease the value for the whole ICES rectangle in which the area is located, but not show with the area's boundaries on the map. If fishing were intense in the ICES rectangle outside the protected area, such important effects would not be visible in the pressure and impact indices at all.

Several stressors could not be included in this work because no data were available (see *Table 4*). Many of these stressors, such as anchoring outside harbours and marine construction works, could add considerable local impacts to the maps of pressures and impacts presented here; an inclusion of stressors related to global change, although not desired with regard to the MSFD, could have the potential to considerably change pressure and impact patterns throughout the study area. For example, Crain et al. (2009) list ocean acidification, climate change and ocean warming in general (with effects on all scales, for example the dispersal of larvae) and salinity changes (which may, among other causes, be related to climate change) among the top threats to global coastal and marine ecosystems. While some stressors related to global change may be less important in the North Sea than in some other seas, these global change stressors occur at wide spatial scales, potentially affecting species and communities across the whole North Sea. Also in our online survey, the responding experts rated thermal changes to be an important threat to the North Sea ecosystem (see *Table 7*).

While acknowledging the problems with the completeness and accuracy of our data, we have presented the to our knowledge only comprehensive collection of data on human uses and key ecosystem components of the eastern North Sea. In the process of creating the North Sea Impact Index, we have encountered and pointed out data gaps. Most of the included data sets could be improved, given sufficient resources. For example, existing methods allow mapping the distribution of fishing efforts within ICES squares based on VMS (Vessel Monitoring System) and EU logbook data (e.g. Fock 2008; Pedersen et al. 2009). We hope that the data basis for comprehensive analyses like the NSPI and NSII will continue to improve, e.g. driven by the requirements of the MSFD Initial Assessments in all EU Member States. The cumulative impact mapping software prepared in HARMONY makes updating of the indices presented in this report straightforward, once improved or additional data become available. It also allows the relatively fast and simple creation of national maps of human pressures and impacts, making use of the best available data at the national level (while sacrificing the possibility to compare pressures and impacts across boundaries).

At the same time, building an information basis for ecosystem-based environmental management at the level of the European regional seas may require more than improving national data sets. We often found data from different countries to be difficult to combine (for example, the Swedish data set on leisure harbours was more detailed than the other countries', leading to a potential over-estimation of pressures and impacts from recreational shipping along the Swedish coast). Data sets missing in at least one country had to be completely excluded from this study (for example, spatial data on the dredging of shipping lanes were available only for Sweden).

5.2 Critical review of the applied methods

The methods applied in this study are adapted from earlier, peer-reviewed work (Halpern et al. 2007, 2008, 2009; Selkoe et al. 2009; Ban et al. 2010; Korpinen et al. 2012). While the basic approach remained essentially unchanged, the later studies have improved the methods of the earlier ones; also we have presented some improvements such as the introduction of fuzzy models of the spatial distribution of ecosystem components. Still, important uncertainties remain and must be understood in order to make the maps presented here useful for communication and decision-making; ignoring uncertainties may lead to misinformed and unfavourable decisions (Agumya & Hunter 2002; Couclelis 2003).

Data on stressors and ecosystem components may be inaccurate. As an example, we used the number of people living in river catchments as a proxy for the discharges of synthetic pollutants from these rivers into the sea. While, in the absence of measured concentrations of synthetic pollutants at the river mouths or biogeochemical modelling results, this may be a reasonable solution, it is a crude generalization.

Availability of input data. Some important stressors and ecosystem components had to be omitted from the analyses because spatial data were not available and impossible to prepare with the resources available for this work.

Selection and detail of included data sets. Human stressors and ecosystem components for which many data layers are available can be over-represented in the pressure and impact indices. As an example, Ban et al. (2010) investigated how the combination of commercial fisheries data into a different number of pressure layers affected analysis results. Of the 38 pressures considered in that study, 25 were fishing-related. Depending on whether data on commercial fisheries were included as individual pressure layers (one layer each for different gear types and target species), grouped by impact category (e.g. several gear types grouped into a "high-bycatch pelagic fisheries" layer), or all commercial fisheries data combined into one pressure layer, they accounted for 75% (all commercial fisheries data as individual pressure layers) down to 12.7% (only one combined commercial fishing layer) of impacts on benthic ecosystems. Accordingly, the relative importance of other pressure types varied.

To mitigate this effect, we have explicitly adjusted the weights of the ecosystem components to compensate for different types and numbers of data layers for the five broad groups (benthic habitats, plankton, fish, seabirds, marine mammals) included in the indices. We have also demonstrated the effects of the number of layers into which fisheries are classified (e.g. *Figure 14*). While this is no final solution to the problem, the possibility to easily re-make the indices with changed weights for any data layer by using the HARMONY cumulative impact mapping software will allow to explore this problem further.

Last but not least, considering pressures resulting from global climate change could have a strong influence on the pressure and impact indices.

Reliability of expert judgement. While we could involve the opinions of more than 50 experts, many combinations of human stressors and ecosystem components were covered by only few replies. Also the method with which the experts' replies were translated into sensitivity is reasonable but not perfect (Teck et al. 2010). We have proposed another (also imperfect) method for this purpose and compared how this influenced the impact index; it did not change major patterns (*Figure 14*). Also a basic Monte Carlo Simulation conducted by Halpern et al. (2008) showed a low sensitivity of their global map of human impacts on marine ecosystems to the results of the expert judgement. A similar sensitivity analysis was conducted for the NSII in spring 2012, demonstrating that the large-scale (but not local) patterns of the NSII were surprisingly little affected by errors of the sensitivity scores.

The impacts of multiple pressures are not always additive (Crain et al. 2009; Ban & Alder 2007); they can as well be antagonistic or synergistic. Furthermore, a linear relationship between pressure intensity and impact was assumed, whereas in reality, thresholds may exist but are often unknown (Halpern et al. 2008).

The dynamics and complexity of coastal and marine ecosystems are not sufficiently covered. For example, our data on the spatial distribution of fish consider only biomass, and thus emphasize adult life stages, while e.g. pressures on spawning areas may be of ecological importance, too. Furthermore, indirect effects (e.g. the consequences of the local depletion of fish stocks on the birds feeding on them) are not covered sufficiently. While the North American studies (Halpern et al. 2008, 2009; Selkoe et al 2009; Ban et al. 2010) based their cumulative impact maps exclusively on broad-scale habitats (e.g. "pelagic surface waters") and their communities, this study (and to a lesser extent Korpinen et al. 2012) based the impact index partially on the spatial distribution of individual species. If this level of detail is required, it becomes especially important to investigate ways to better model the interlinkages of ecosystem components in the future. The way in which we calculated the sensitivity scores emphasizes community impacts, but can only mitigate this problem in part.

We miss a historical baseline, and past anthropogenic impacts cannot be properly accounted for (i.e., the most sensitive ecosystem components may already be gone from areas with high levels of pressures, and only more resilient ones remain both in reality and thus in our models, many of which are based on recent observations).

Pressures with mostly local impacts (e.g. dredging) are hardly visible in the pressure and impact maps, although they may have devastating impacts where they occur.

In spite of these unresolved problems, this report presents a step forward in cumulative impact mapping. It describes the first published effort to use fuzzy representations of the spatial distribution of ecosystem components to map cumulative human impacts, leading to a better representation of the real world and in general reduced uncertainties. For example, areas with high uncertainty about an ecosystem component can have small to intermediate values rather than having to decide between presence and absence, with the risk of being "completely wrong". The approach presented here is (after Ban et al. 2010) only the second one to explicitly consider the distances over which pressures travel from their sources before they diminish, and the first one to allow different ecosystem components to be affected by the same human activity by different pressures and over different distances. It is also the only study where a human activity can affect an ecosystem component by more than one pressure. For example, offshore wind turbines can locally lead to the complete loss of natural benthic habitat due to sealing, but can also cause impacts due to noise (from vibrations). The latter impacts can be minor, but stretch over a larger distance. While making the model more realistic, allowing multiple pressures per combination of a human activity and an ecosystem component greatly increases complexity (especially of the expert survey). Making use of this possibility to its full extent would require many more expert replies (partially because the pressures listed in the MSFD are sometimes overlapping, e.g. abrasion and siltation changes). While the strong linking of this project with the MSFD justifies the use of this set of pressures, similar initiatives with other objectives should carefully weigh the benefits (a gain in the model's realism and higher relevance with regard to the MSFD) against the costs of the resulting additional complexity.

The cumulative impact mapping software (the first of its kind), which will be developed further to support additional types of analyses, allows easy updating of the different indices presented here, for example if better data become available. It also facilitates data exploration: Instead of confronting decision-makers with one map of cumulative human impacts (which they may believe in or not), it allows them to calculate own indices, for example to explore the effects of turning on and off particular human activities, pressures and ecosystem components. Still, this is only a first step towards making maps of cumulative human impacts, with all their assumptions, more useful to planners and decision-makers.

Acknowledgements

We want to thank the many people and institutions which have provided data on human uses of the North Sea as well as the members of the HARMONY project team who were not directly contributing to this report, helped with discussions and often data. But most importantly, we want to express our gratitude to the respondents of our online survey, who used their valuable time to support our project.

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Appendix A - Ecosystem component data layers

List of the ecosystem components

Broad-scale benthic habitats
Broad-scale coastal ecosystems
Plankton communities
…in nutrient-rich waters
…nutrient-poor waters

Fish

Biomass distribution of:
- Cod (*Gadus morhua*)
- Dab (*Limanda limanda*)
- Haddock (*Melanogrammus aeglefinus*)
- Herring (*Clupea harengus*)
- Norway Pout (*Trisopterus esmarkii*)
- Plaice (*Pleuronectes platessa*)
- Saithe (*Pollachius virens*)
- Rays and skates

Not included in the impact index:

- *Large rays and skates*
- *Whiting (Merlangius merlangus)*
- *Sandeel (Ammodytes marinus) fishing grounds*
- *Abundance of sensitive non-assessed fish species*
- *Large Fish Indicator (LFI)*
- *Size spectrum height*
- *Size spectrum slope*
- *Species evenness*
- *Species richness*

Birds

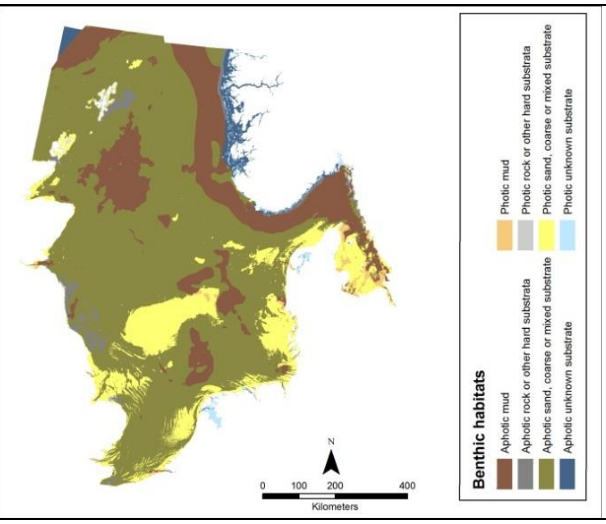
Probability of presence:
- Fulmar (*Fulmarus glacialis*)
- Gannet (*Morus bassanus*)
- Guillemot (*Uria aalge*)
- Kittiwake (*Rissa tridactyla*)
- Razorbill (*Alca torda*)

Mammals

Probability of presence:
- Harbour porpoise (Phocoena phocoena)
- Minke whale (*Balaenoptera acutorostrata*)
- White-beaked dolphin (*Lagenorhynchus albirostris*)

Broad-scale benthic habitats

Broad-scale benthic habitats for the North Sea provided by the EUSeaMap project. They were generalized into six broad classes for the HARMONY project based on substrate and light availability.



Data sources

- EUSeaMap (http://jncc.defra.gov.uk/page-5020)

Spatial extent	North Sea

Lineage and data quality

Data quality varies throughout the North Sea region depending on the quality of the data on which the original habitat map is based. See the EUSeaMap report (http://jncc.defra.gov.uk/page-5020) for a detailed description of data quality and uncertainties.

The original data contain seven substrate types, six biological zones, as well as several salinity and energy classes, resulting in more than 50 combinations occurring in the North Sea region at the finest level of detail. Within HARMONY, the data have been generalized based on substrate and light availability, distinguishing only six broad classes (substrate: mud; sand, coarse or mixed; rock and other hard; light: aphotic; euphotic).

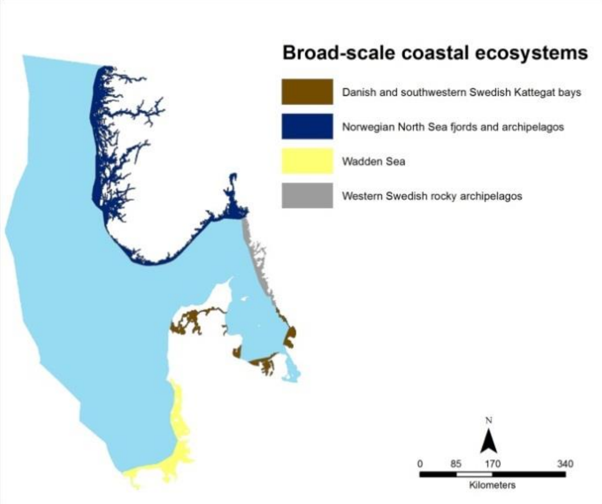
The data cover the whole North Sea region, however there are some gaps. First, relatively large areas – especially off the Norwegian coast – have the substrate type “seabed”, which means that the substrate is unknown. Second, in some areas close to the coastline there are spots without any data, e.g. most of the Danish Limfjord.

For the North Sea impact index, the benthic habitats were summarized on the 1 km grid as follows. In each cell *c*, the density of benthic habitat *h* was set to *p(h) / n(c)*, where *p(h)* is presence or absence (1 or 0) of *h* and *n(c)* is the number of benthic habitats (1…6) present in *c*. For example, in a cell containing euphotic rock, aphotic rock and aphotic mud, the density of each of the three benthic habitats would be set to 1/3, and that of all other benthic habitats to 0. However, in some cells no information on substrate was available, but it was known whether it contained aphotic bottoms, euphotic bottoms or both. In these cases, the densities of the three aphotic or, respectively, euphotic benthic habitats were set to 1/3 each. Similarly, in cells without any information on benthic habitats, the densities of all 6 benthic habitats were set to 1/6. Finally, in the areas covered by broad-scale coastal ecosystems (for which data on benthic habitats were mostly missing), the densities of all six benthic habitats were set to 0.

Scale or resolution	Habitats originally modelled at about 250 m resolution (smallest representable habitat patch size). However, some source data were much coarser.
Time period covered	N/A. Date of publication is February 2011
Data access	Contact the HARMONY Team. For the original data, see “Data sources”. Conditions of use: http://jncc.defra.gov.uk/plugins/newmapper/EUSeaMap_webGIS_Terms_&_Conditions_and_Privacy__Privacy_Policy_(WEB).pdf.
Additional information sources	The EUSeaMap project report can be downloaded from the EUSeaMap website (see “Data sources”).

Broad-scale coastal ecosystems

Four broad-scale coastal ecosystems were defined:
The Wadden Sea. Western Swedish rocky archipelagos, Danish and south-western Swedish Kattegat bays (such as the Limfjord and Skäldervik), and Norwegian Fjords. They represent areas where other biological data such as modelled species distributions were unreliable, and were thus analysed separately.



Data sources

Baselines:

- Norway: Statens Kartverk (via WMS); http://www.statkart.no/nor/Land/Kart_og_produkter/Grenser/Sjogrenser/
- Germany, Denmark and Sweden: EEA maritime boundaries; http://www.eea.europa.eu/data-and-maps/data/maritime-boundaries

Spatial extent	Eastern North Sea

Lineage and data quality

The four broad-scale coastal ecosystems were primarily defined because the data used for the open sea were not available or very unreliable for these morphologically complex coastal seas.

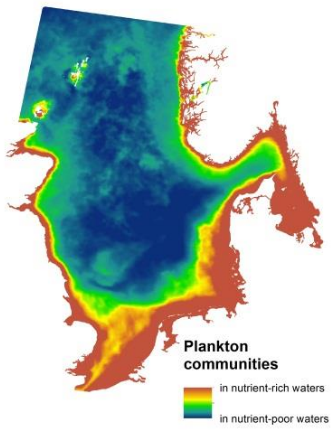
The broad-scale coastal ecosystems were first delineated following the baselines. Their seaward boundaries were then checked against the data coverage of the ecosystem components for offshore waters, many of which had major data gaps in coastal waters. In a few cases, the data gaps extended some kilometres seaward of the baselines. In these cases, the areas of the coastal ecosystems were extended accordingly to allow a full coverage of the HARMONY study area.

For the impact index, all cells within or intersecting a given coastal ecosystem were assigned a value of 1, and all others a value of 0. Note that the values of all other ecosystem components were set to 0 within the coastal ecosystems.

Scale or resolution	1 km
Time period covered	n/a
Data access	Contact the HARMONY team. The baselines are available online (see "Data sources").
Additional information sources	None

Plankton communities (in nutrient-rich and nutrient-poor waters)

Nutrient-rich and nutrient-poor waters were used as a proxy for the spatial distribution of plankton communities, because no other spatial data on phytoplankton and zooplankton were available.



Data sources

- Annual chlorophyll concentrations from 2003-2010. MODIS L3 standard product at 4 km resolution. http://oceancolor.gsfc.nasa.gov/ (follow the link to L3 Browser).

Spatial extent	North Sea

Lineage and data quality

Global annual averages for 2003-2010 of marine chlorophyll concentrations were downloaded as MODIS Aqua L3 product at 4 km resolution in HDF format. Physical values and geographic coordinates for the North Sea were extracted using SeaDAS 6.2.0 and interpolated (inverse distance weighted) to 1 km rasters. Values for the eight years were averaged.

Wasmund et al. (2001) suggest the following thresholds for classifying trophic state based on chlorophyll (chl): Oligotrophic < 0.8 mg m^{-3}, mesotrophic 0.8-4 mg m^{-3}, eutrophic 4-10 mg m^{-3}, poly/hypertrophic > 10 mg m^{-3}. Accordingly, the densities of nutrient-rich waters were set to 1 for chl ≥ 4 mg m^{-3}, to 0 for chl ≤ 0.8 mg m^{-3}, and ranging linearly from 0 to 1 for values in between. The densities of nutrient-poor waters have been set to $1 - d_r$, where d_r is the density of nutrient-rich waters in this location.

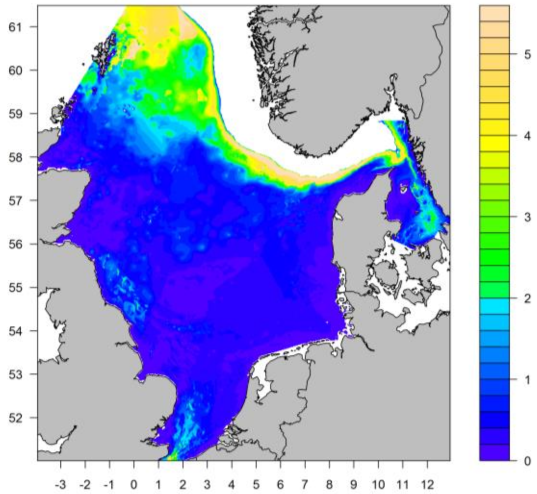
Finally, for the index calculations, the densities for plankton communities in nutrient-rich as well as nutrient-poor waters were set to 0 in areas covered by the broad-scale coastal ecosystems.

Scale or resolution	1 km (original chlorophyll data: 4 km)
Time period covered	2003-2010
Data access	Contact the HARMONY team. Original data: Public domain, see “Data sources”.
Additional information sources	None.

Biomass distribution of Cod (*Gadus morhua*)

Biomass distribution of cod was predicted from observations of catch rates from scientific surveys. For quarters 1 and 3 separately, caught biomass per unit effort local (proxy for densities) were estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from the model parameters and maps of bottom substrate and water depth. An average "annual" biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

Cod has been chosen to represent the group of large gadoids. The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS, BTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys.

Lineage and data quality

Cod has a high commercial value, is widely distributed in the Greater North Sea, has a high growth rate and obtains a relatively large body size. This makes the species vulnerable to almost all demersal fisheries in the area, which has resulted in a too high fishing mortality for almost fifty years. Cod has a preference for habitats with coarse sediments but is found on almost all sediments and depths in the North Sea.

The distribution map gives only a broad picture of the distribution of cod. Data sets used for modelling are extensive, but the distribution area of cod is not fully represented as the surveys cover only "smooth" grounds that can be trawled and mainly grounds with depths larger than 20 m. Predictions in coastal areas are highly uncertain. It is also assumed in the model that the survey catchability of cod is independent of body size, area and depth, which is not the case in reality.

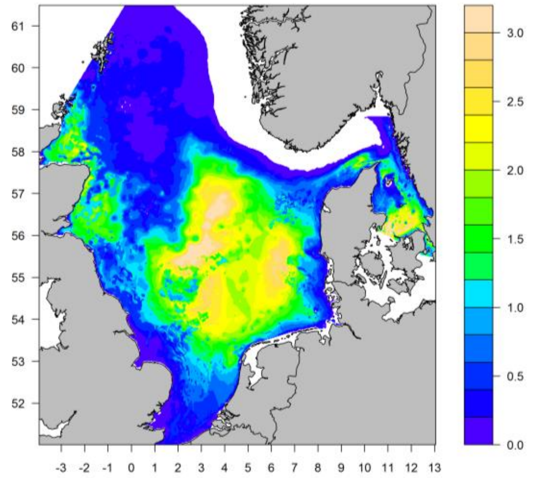
As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degrees (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See "Data sources". Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of Dab (*Limanda limanda*)

Biomass distribution of dab was predicted from observations of catch rates from scientific surveys. For quarters 1 and 3 separately, caught biomass per unit effort local (proxy for densities) were estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average "annual" biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

Dab represents the group of small to medium sized flatfish. The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS, BTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

Dab is one of the most abundant demersal species in the North Sea mainly found on sandy and softer bottom types in the central and southern North Sea. Dab is caught in high numbers in demersal fisheries, but mainly discarded due to its small size and low price.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully covered as the surveys cover only "smooth" grounds which can be trawled and mainly grounds with depth larger than 20 m. Predictions in coastal areas are highly uncertain. It is also assumed in the model that the survey catchability of the species is independent of body size, area and depth, which is not the case in reality.

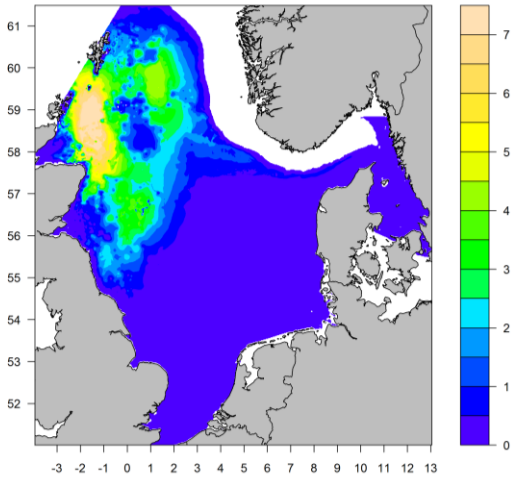
As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See "Data sources". Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of Haddock (*Melanogrammus aeglefinus*)

Biomass distribution of haddock was predicted from observations of catch rates from scientific surveys. For quarters 1 and 3 separately, caught biomass per unit effort local (proxy for densities) were estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average "annual" biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

Haddock represents gadoid fishes on soft bottom habitats. The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

Haddock is a medium body sized gadoid mainly found on soft bottom types in the central and northern North Sea. It is included in this study due to its choice of habitat, high biomass and economic importance.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully covered as the surveys cover only "smooth" grounds which can be trawled and mainly grounds with depth larger than 20 m. Prediction in coastal areas are highly uncertain. It is also assumed in the model that the survey catchability of haddock is independent of body size, area and depth, which is not the case in reality.

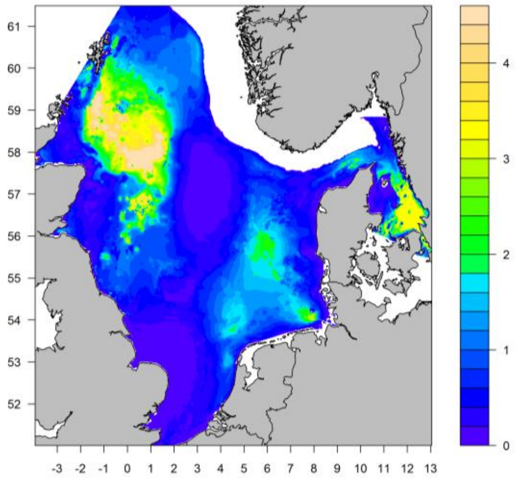
As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

Scale or resolution	Depth map used for prediction: 0.0166x0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See "Data sources". Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of Herring (*Clupea harengus*)

Biomass distribution of herring was predicted from observations of catch rates from scientific surveys. For quarter 1 and 3 separately, caught biomass per unit effort local (proxy for densities) were estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average “annual” biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

Herring represents the group of pelagic medium sized and plankton eating fish. The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

Herring in the Greater North Sea consist of two main stocks, the North Sea herring and the Western Baltic herring. Both stocks can be divided in a number of sub-stocks according to their spawning time and area. Stock distribution is highly related to body size, where juveniles of the North Sea stock are mainly in the eastern area, and adults are more western and northerly distributed.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully covered as the surveys cover only “smooth” grounds which can be trawled and mainly grounds with depth larger than 20 m. Prediction in coastal areas are highly uncertain. It is assumed that the survey catchability of the species is independent of body size, area and depth, which is not the case.

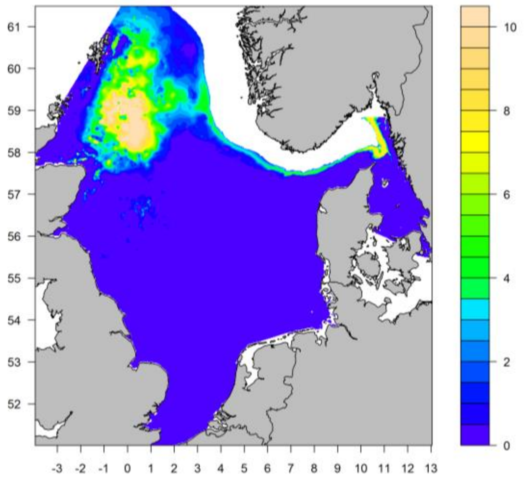
As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See “Data sources”. Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of Norway pout (*Trisopterus esmarkii*)

Biomass distribution of Norway pout was predicted from observations of catch rates from scientific surveys. For quarter 1 and 3 separately, caught biomass per unit effort local (proxy for densities) were estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average "annual" biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

Norway pout is chosen to represent an important forage species in the Northern North Sea. The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

Norway pout is an important commercial and prey species with a more northerly and deeper distribution than sandeel.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully represented as the surveys cover only "smooth" grounds which can be trawled and mainly grounds with depth larger than 20 m. Prediction in coastal areas are highly uncertain. It is also assumed in the model that the survey catchability of the species is independent of body size, area and depth, which is not the case in reality.

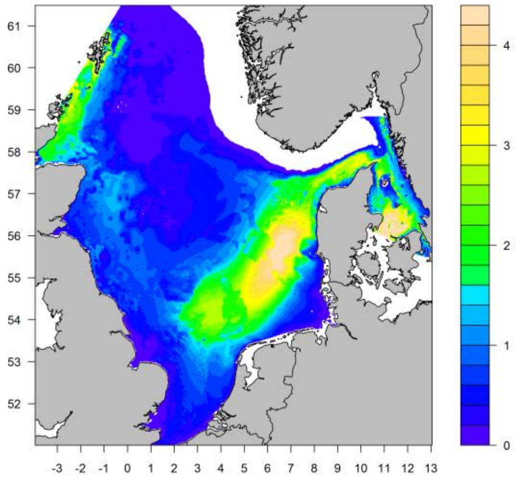
As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See "Data sources". Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of Plaice (*Pleuronectes platessa*)

Biomass distribution of plaice was predicted from observations of catch rates from scientific surveys. For quarter 1 and 3 separately, caught biomass per unit effort local (proxy for densities) was estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average "annual" biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS, BTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

Plaice is a medium to large body sized flatfish with a preference for sandy sediments in the central and southern North Sea. It is a commercially important species with a high biomass. Discards are substantial.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully represented as the surveys cover only "smooth" grounds which can be trawled and mainly grounds with depth larger than 20 m. Prediction in coastal areas are highly uncertain. It is also assumed in the model that the survey catchability of the species is independent of body size, area and depth, which is not the case in reality.

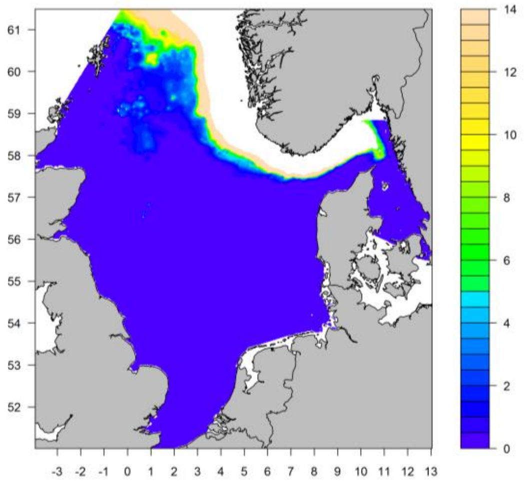
As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See "Data sources". Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of Saithe (*Pollachius virens*)

Biomass distribution of Saithe was predicted from observations of catch rates from scientific surveys. For quarter 1 and 3 separately, caught biomass per unit effort local (proxy for densities) were estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average "annual" biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

Saithe is a large body sized semi-pelagic gadoid that mainly occupies the deeper waters over the shelf edge and beyond. However, juveniles are mainly found in inshore habitats, e.g. the Norwegian fjords. This distribution pattern does not fit to the present survey coverage.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully represented as the surveys cover only "smooth" grounds which can be trawled and mainly grounds with depth larger than 20 m. Prediction in coastal areas are highly uncertain. It is also assumed in the model that the survey catchability of the species is independent of body size, area and depth, which is not the case in reality.

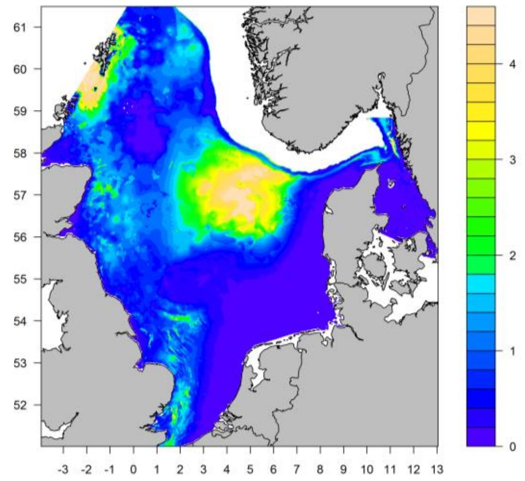
As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See "Data sources". Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of rays and skates

Biomass distribution of the species group “Rays and skates” was predicted from observations of catch rates from scientific surveys. For quarter 1 and 3 separately, caught biomass per unit effort local (proxy for densities) was estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average “annual” biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

The group of rays and skates represents elasmobranchs, sensitive to fishing pressure. The shown biomass distribution is standardized to the mean.



Data sources

- Survey catch rates: ICES coordinated IBTS, BTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

The group of “rays and skates” is defined as all species of rays and skates found in the area. The abundance of “rays and skates” has declined substantially over the last century. Today species with a relative small L-infinity, *Amblyraja radiate* and *Leucoraja naevus,* dominate the group in the central and western North Sea, respectively. *Raja clavata* is the dominant species in south eastern North Sea.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully represented as the surveys cover only “smooth” grounds which can be trawled and mainly grounds with depth larger than 20 m. Prediction in coastal areas are highly uncertain. It is assumed in the model that the survey catchability of the species is independent of body size, area and depth, which is not the case in reality.

As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

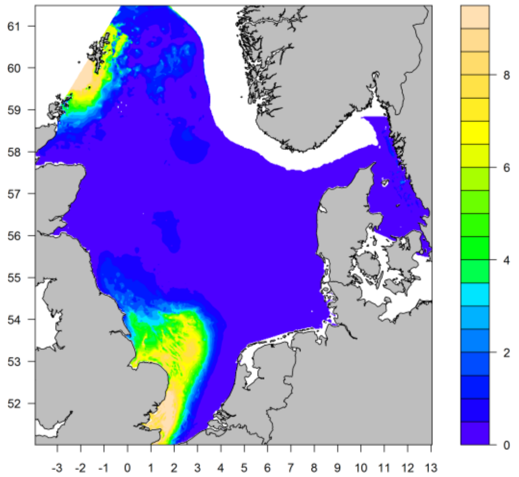
Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See “Data sources”. Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of large rays and skates

Biomass distribution of the species group “large rays and skates” was predicted from observations of catch rates from scientific surveys. For quarters 1 and 3 separately, caught biomass per unit effort local (proxy for densities) were estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average “annual” biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

The group of large rays and skates represents large body sized elasmobranchs, which are sensitive to fishing pressure. The shown biomass distribution is standardized to the mean.

Note: This data set was not used in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS, BTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

The group of “Large rays and skates” is here defined as the species of rays and skates found in the area with the exception of the species *Amblyraja radiate* and *Leucoraja naevus* which have a relatively small l-infinity and seem to be more resistant to the present high fishing pressure. The abundance of the group of “large rays and skates” has declined substantially over the last century. Today *Raja clavata* is the dominant species in the group.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully covered as the surveys cover only “smooth” grounds which can be trawled and mainly grounds with depth larger than 20 m. Prediction in coastal areas are highly uncertain. It is assumed in the model that the survey catchability of the species is independent of body size, area and depth, which is not the case in reality.

As no observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were available, the biomass for these deep areas was simply estimated as described in *Appendix F*.

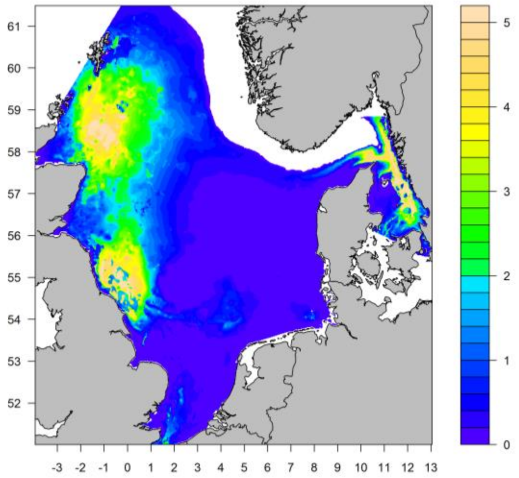
Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See “Data sources”. Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

Biomass distribution of Whiting (*Merlangius merlangus*)

Biomass distribution of whiting was predicted from observations of catch rates from scientific surveys. For quarters 1 and 3 separately, caught biomass per unit effort local (proxy for densities) was estimated from Delta-lognormal GAM models, using catch position, depth, bottom substrate, year and survey as explanatory variables. Predicted biomass distributions by quarter were derived from model parameters and maps of bottom substrate and water depth. An average "annual" biomass distribution was calculated as a simple mean of the standardized quarterly distributions.

Whiting has been chosen to represent the group of small, fish eating demersal roundfish. The shown biomass distribution is standardized to the mean.

Note: This data set was not included in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS, BTS and BITS surveys 1998-2010. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)
- Bathymetric maps: The General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net)
- Bottom substrate: EMODnet - EUSeaMap, predictive seabed habitat map for the North Sea. Data can be downloaded from: http://jncc.defra.gov.uk/page-5040

Spatial extent	North Sea area covered by ICES coordinated surveys

Lineage and data quality

Whiting is a small sized gadoid widely distributed in the greater North Sea. Since the late1970s stock size and commercial landings have declined gradually to a historic minimum. Discard rates of whiting are high. Whiting is a fish predator that feeds heavily on many commercially important species.

The distribution map gives only a broad picture of the species distribution. Data sets used for modelling are extensive, but the distribution area of the species is not fully represented as the surveys cover only "smooth" grounds which can be trawled and mainly grounds with depth larger than 20 m. Predictions in coastal areas are highly uncertain. It is also assumed in the model that the survey catchability of the species is independent of body size, area and depth, which is not the case in reality.

Scale or resolution	Depth map used for prediction: 0.0166 x 0.0166 decimal degree (app. 1.85 km)
Time period covered	1998-2010
Data access	Original data: See "Data sources". Model and predictions: contact DTU Aqua, Denmark.
Additional information sources	None.

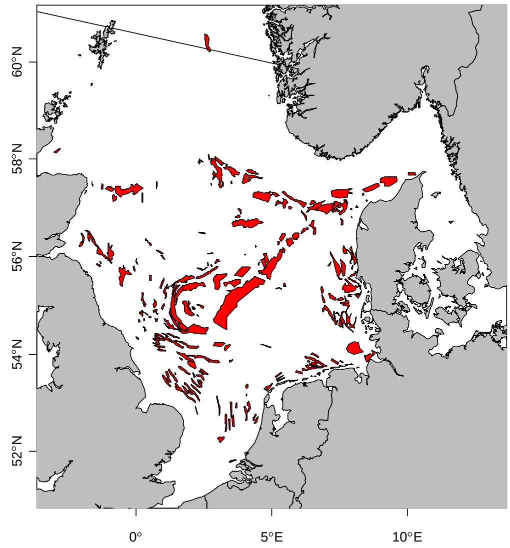
Sandeel (*Ammodytes marinus*) fishing grounds

The sandeel fishing grounds are areas with the right type of habitat (see description below) and high density of sandeel. To map the spatial distribution of foraging habitat of sandeel three types of information were combined:

- Global positioning system (GPS) records from individual ships
- Vessel monitoring system (VMS) data, and
- Maps provided by fishermen

Fishermen from different ports have evaluated the map of the fishing grounds, after which it has been modified according to guidelines they gave. Such evaluation resulted in the inclusion of additional grounds (from more navigation data) and the deletion of non-sandeel grounds.

Note: This data set was not used in the North Sea Impact Index.



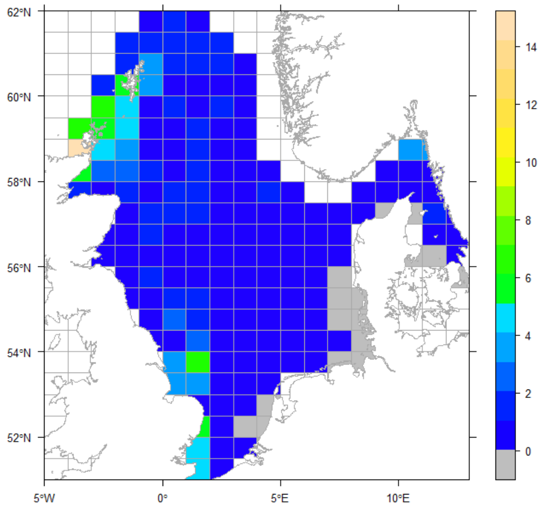
Data sources	
• GPS and logbook information from the fishing industry and VMS data from the sandeel fishing fleet.	
Spatial extent	North Sea
Lineage and data quality	
Sandeel (*Ammodytes marinus*) constitute a large proportion of the fish biomass in the North Sea and are an important prey species for many fish species, seabirds and mammals. High concentrations of sandeel are limited to shallow, turbulent sandy areas, located at depths of 20–70 m where the content of the finest particles of silt and clay is low. Because of the limited availability of such substratum, the distribution of post-settled sandeel is very patchy. The data quality of the distribution map is considered high, because the mapping of the sandeel grounds is based on a considerably large data set and it has been prepared in cooperation with the fishing industry.	
Scale or resolution	Unknown
Time period covered	Most recent years
Data access	See “Additional information sources”.
Additional information sources	Jensen, H., Rindorf, A., Wright, P. & Mosegaard, H. 2011: Inferring the location and scale of mixing between habitat areas of lesser sandeel through information from the fishery. - ICES Journal of Marine Science 68(1): 43-51.

Abundance of sensitive non-assessed fish species

Large (vulnerable) species are species with an asymptotic length of very old fish ($L_{infinity}$) larger than 100 cm, as Dulvy et al. (2003) have shown that extinction risk is related to maximum length. Only euhaline fish species where included. Furthermore, species for which formal assessments are provided by ICES (Atlantic cod, hake and saithe) were excluded from further analyses. The data used to estimate distribution were catch rates in the IBTS for the years 1983 to 2010 (quarter 1). Only the hauls where all species caught were recorded were used.

The figure shows the average survey catch rate of large (vulnerable) species.

Note: This data set was not used in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS surveys 1991-2010, quarter 1. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)

Spatial extent	North Sea

Lineage and data quality

The data used to estimate abundance were catch rates of fish in the IBTS for the years 1983 to 2010 (quarter 1). Only hauls of the duration between 25 and 35 minutes and where all species were recorded were used. Data were corrected for known and obvious errors using an algorithm kindly provided by Niels Daan (pers. comm., Daan 2011).

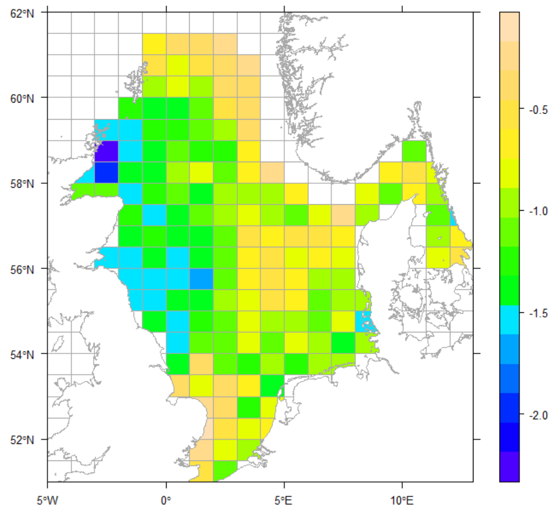
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	1983-2010
Data access	Original data: See “Data sources”. Analysis and results: contact, DTU Aqua, Denmark.
Additional information sources	Dulvy, N.K., Sadovy, Y & Reynolds, J.D. 2003: Extinction vulnerability in marine populations. - Fish and Fisheries 4: 25-64.

Large Fish Indicator (LFI)

The Large Fish Indicator (LFI) describes the proportion (by weight) of the fish community that is larger than 40 cm. Trawl survey time series are used to estimate LFI. The analysis shows that large fish dominate in the Norwegian trench and in the south western part of the North Sea. Additionally it is seen that large fish dominate more in the eastern part of the NS compared to the western part.

On the map, LFI is depicted on a logarithmic scale.

Note: This data set was not used in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS survey 1983-2010, quarter 1. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)

Spatial extent	North Sea

Lineage and data quality

The data used to estimate LFI were catch rates of fish from the IBTS for the years 1983 to 2010 (quarter 1) where the pelagic species have been removed. Only hauls of the duration between 25 and 35 minutes and where all species were recorded and measured in length were used. Only ICES rectangles that provided more than 28 hauls in the period (one haul per year) were used.

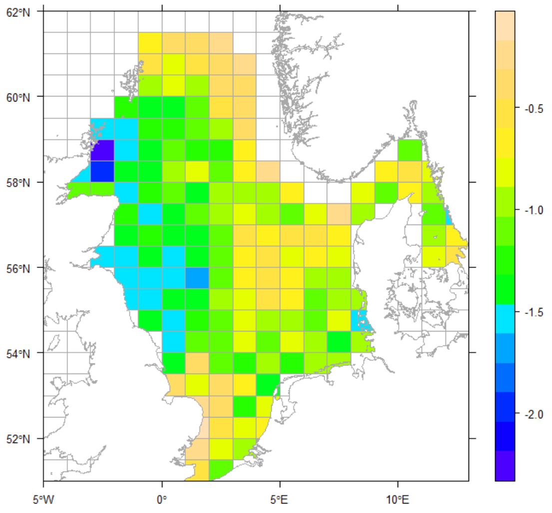
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	1983-2010
Data access	Original data: See “Data sources”. Analysis and results: contact DTU Aqua, Denmark.
Additional information sources	None.

Size spectrum height

The height of the size-spectrum is an indicator of the total community abundance level. Size spectrum slope and height for demersal fish species were calculated from trawl survey time series. The heights of the size-spectra are smallest in the north western part of the NS.

On the map, the size-spectrum height is depicted on a logarithmic scale.

Note: This data set was not used in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS survey 1983-2010, quarter 1. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk).

Spatial extent	North Sea

Lineage and data quality

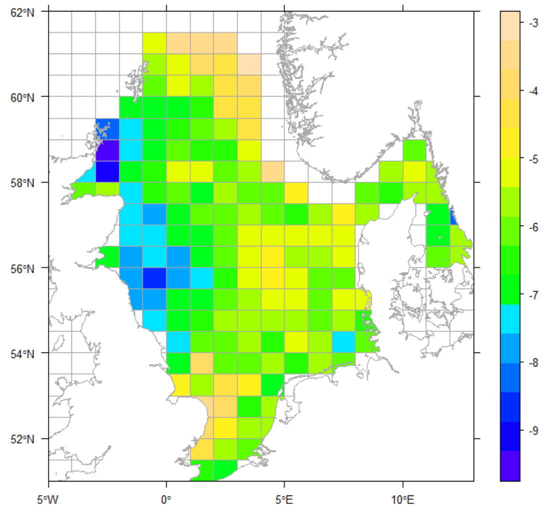
The data used to estimate size-spectrum were catch rates of fish in the IBTS for the years 1983 to 2010 (quarter 1) where the pelagic species have been removed. Only hauls of the duration between 25 and 35 minutes and where all species were recorded and measured in length were used. Only ICES rectangles that provided more than 28 hauls in the period (one haul per year) were used.

Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	1983-2010
Data access	Original data: See “Data sources”. Analysis and results: contact DTU Aqua, Denmark.
Additional information sources	None.

Size spectrum slope

The slope of the size-spectrum indicates the ratio between small and large fish in the community. A steepening slope of the size spectrum indicates an increasing ratio of smaller individuals. Size spectrum slope and height for demersal fish species were calculated from trawl survey time series. The slope is most shallow in the Norwegian trench and in the south western part of the NS (large individuals dominate). Additionally it is seen that the slopes in the eastern part of the NS are shallower than in the western part, meaning that large fish dominate more in the eastern part.

Note: This data set was not used in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS survey 1983-2010, quarter 1. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)

Spatial extent	North Sea

Lineage and data quality

The data used to estimate size-spectrum were catch rates of fish in the IBTS for the years 1983 to 2010 (quarter 1) where the pelagic species have been removed. Only hauls of the duration between 25 and 35 minutes and where all species were recorded and measured in length were used. Only ICES rectangles that provided more than 28 hauls in the period (one haul per year) were used.

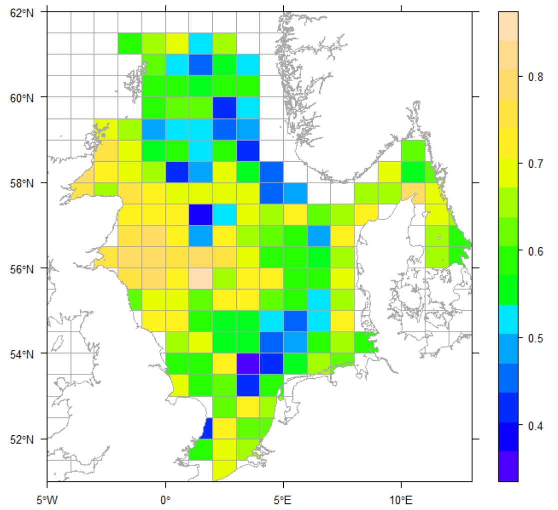
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	1983-2010
Data access	Original data: See “Data sources”. Analysis and results: contact DTU Aqua, Denmark.
Additional information sources	None.

Species evenness

Species evenness is an indicator of how evenly the population abundances are distributed among species, and is defined as 1 minus the Simpson index (Simpson 1949). The indicator is estimated from trawl survey time series. As the number of recorded species increases with sample size the indicator is standardised to 25 hauls. Species evenness is in general quite high and decreases in the northern part of the NS, and in the central part of the southern NS.

The figure shows the species evenness index, standardised to 25 hauls.

Note: This data set was not used in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS survey 1991-2010, quarter 1 and 3. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)

Spatial extent	North Sea

Lineage and data quality

The data used to estimate abundance were catch rates of fish in the IBTS for the years 1991 to 2010 (quarters 1 and 3). Only data from 1991 on onwards is used as the procedures for identifying species on board the research vessels changed in 1991. Only hauls of the duration between 25 and 35 minutes and where all species were recorded were used. Data were corrected for known and obvious errors using an algorithm kindly provided by Niels Daan (pers. comm., Daan 2011). Further, in the few cases where fish were only recorded to family, the fish were allocated to the most frequently encountered species in the family. Only ICES squares that provided more than 40 hauls in the period (~2 hauls per year) were used.

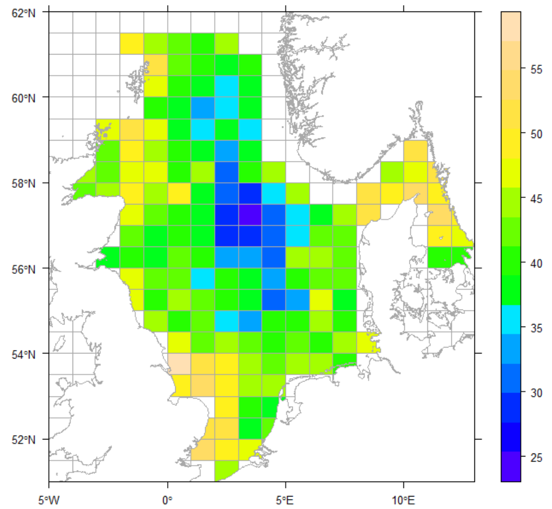
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	1991-2010
Data access	Original data: See “Data sources”. Analysis and results: contact DTU Aqua, Denmark.
Additional information sources	None.

Species richness

Species richness is an indicator of the number of species (species diversity). The indicator is estimated from trawl survey time series. As the number of recorded species increases with sample size the indicator is standardised to 25 hauls. Species richness is highest where different bodies of water meet (Atlantic and English Channel boundary).

The figure shows the number of species recorded, standardised to 25 hauls.

Note: This data set was not used in the North Sea Impact Index.



Data sources

- Survey catch rates: ICES coordinated IBTS survey 1991-2010, quarter 1 and 3. Data can be downloaded from the ICES DATRAS database (http://datras.ices.dk)

Spatial extent	North Sea

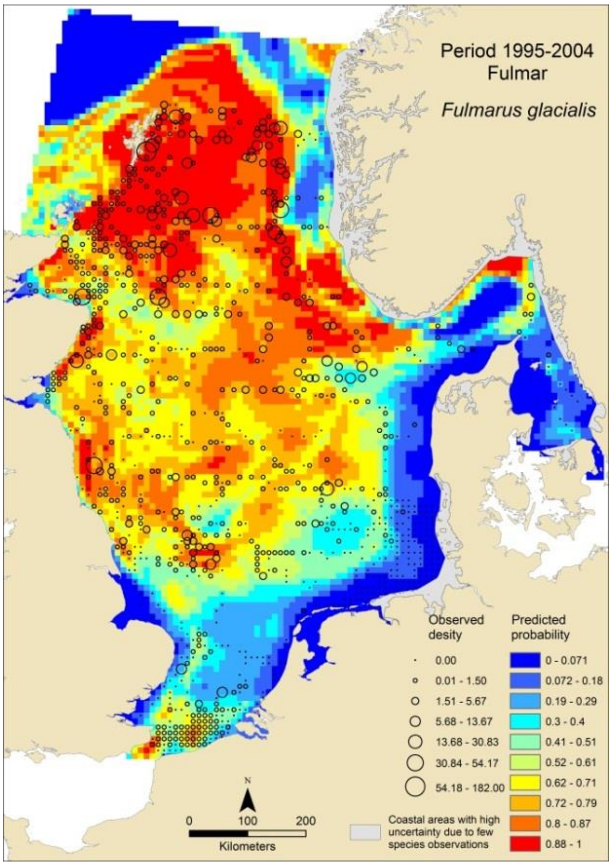
Lineage and data quality

The data used to estimate abundance were catch rates of fish in the IBTS for the years 1991 to 2010 (quarters 1 and 3). Only data from 1991 on onwards is used as the procedures for identifying species on board the research vessels changed in 1991. Only hauls of the duration between 25 and 35 minutes and where all species were recorded were used. Data were corrected for known and obvious errors using an algorithm kindly provided by Niels Daan (pers. comm., Daan 2011). Further, in the few cases where fish were only recorded to family, the fish were allocated to the most frequently encountered species in the family. For the ecosystem component layer only ICES squares that provided more than 40 hauls in the period (~2 hauls per year) were used.

Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	1991-2010
Data access	Original data: See “Data sources”. Analysis and results: contact DTU Aqua, Denmark.
Additional information sources	None.

Fulmar (*Fulmarus glacialis*), probability of presence

Probability of presence of birds modelled using Multivariate Adaptive Regression Splines (MARS) based on observations (presence/absence) and environmental predictors for Fulmar (*Fulmarus glacialis*).



Data sources

- Species data used:

From the European Seabird at Sea (ESAS) database. The processing of the data is described in Fauchald et al. 2011 (Ecology 92: 228-239). The period used was 1995-2004, and the observations are from the months October-March. The abundance of birds was converted to presence/absence.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (MODIS Aqua, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for a winter season October 2003 - March 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities), salinity at surface (mean values for 2003-2004) was considered but was not used as it was highly correlated with temperature.

Spatial extent	North Sea

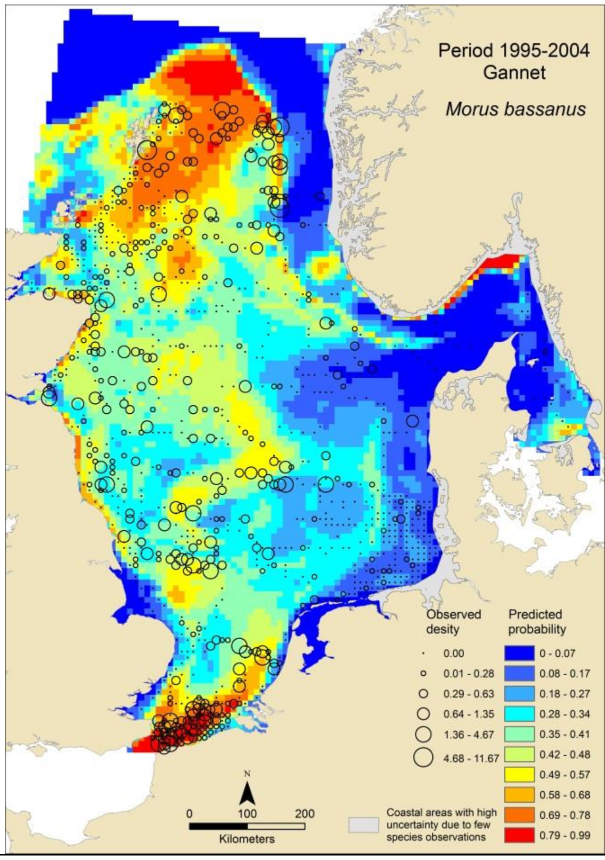
Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13:265-275). The R version 1.7-6 was used. The data used are described above. The model was fitted using a multispecies MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for fulmar was 0.8 and the deviance explained by the model 0.29.

Scale or resolution	10 km
Time period covered	1995-2004
Data access	Original data: See "Data sources". Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

Gannet (*Morus bassanus*), probability of presence

Probability of presence of birds modelled using Multivariate Adaptive Regression Splines (MARS) based on observations (presence/absence) and environmental predictors for Gannet (*Morus bassanus*).



Data sources

- Species data used:

From the European Seabird at Sea (ESAS) database. The processing of the data is described in Fauchald et al. 2011 (Ecology 92: 228-239). The period used was 1995-2004, and the observations are from the months October-March. The abundance of birds was converted to presence/absence.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (Modis, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for a winter season October 2003 - March 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities). Salinity at surface (mean values for 2003-2004) was considered but was not used as it was highly correlated with temperature.

Spatial extent	North Sea

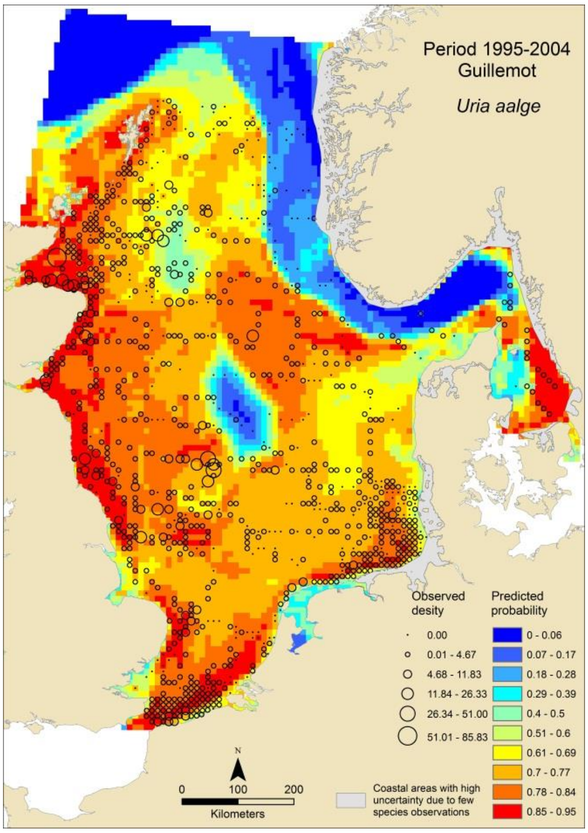
Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13: 265-275). The R version 1.7-6 was used. The data used is described above. The model was fitted using a multi-species MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for gannet was 0.71 and the deviance explained by the model 0.13.

Scale or resolution	10 km
Time period covered	1995-2004
Data access	Original data: See “Data sources”. Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

Guillemot (*Uria aalge*), probability of presence

Probability of presence of birds modeled using Multivariate Adaptive Regression Splines (MARS) based on observations (presence/absence) and environmental predictors for Guillemot (*Uria aalge*).



Data sources

- Species data used:

From the European Seabird at Sea (ESAS) database. The processing of the data is described in Fauchald et al. 2011 (Ecology 92: 228-239). The period used was 1995-2004, and the observations are from the months October-March. The abundance of birds was converted to presence/absence.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (Modis, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for a winter season October 2003 - March 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities). Salinity at surface (mean values for 2003-2004) was considered but was not used as it was highly correlated with temperature.

Spatial extent	North Sea (top 4410000, left 3460000, right 4500000, bottom 3120000)

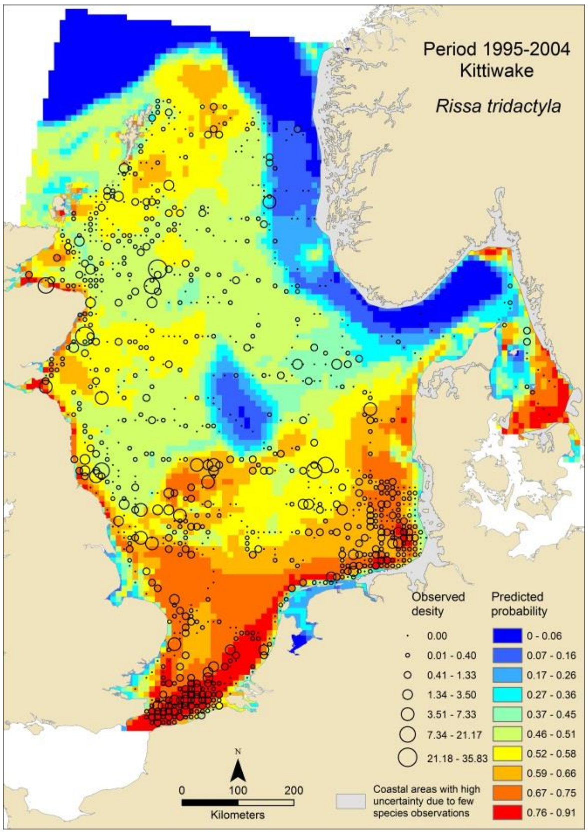
Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13: 265-275). The R version 1.7-6 was used. The data used is described above. The model was fitted using a multi-species MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for guillemot was 0.69 and the deviance explained by the model 0.1.

Scale or resolution	10 km
Time period covered	1995-2004
Data access	Original data: See “Data sources”. Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

Kittiwake (*Rissa tridactyla*), probability of presence

Probability of presence of birds modelled using Multivariate Adaptive Regression Splines (MARS) based on observations (presence/absence) and environmental predictors for Kittiwake (*Rissa tridactyla*).



Data sources

- Species data used:

From the European Seabird at Sea (ESAS) database. The processing of the data is described in Fauchald et al. 2011 (Ecology 92: 228-239). The period used was 1995-2004, and the observations are from the months October-March. The abundance of birds was converted to presence/absence.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (Modis, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for a winter season October 2003 - March 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities). Salinity at surface (mean values for 2003-2004) was considered but was not used as it was highly correlated with temperature.

Spatial extent	North Sea

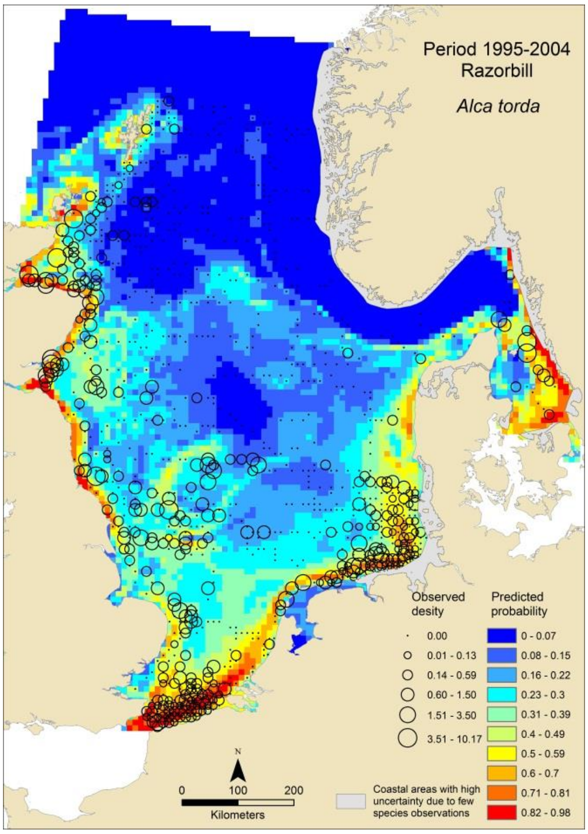
Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13: 265-275). The R version 1.7-6 was used. The data used is described above. The model was fitted using a multispecies MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for kittiwake was 0.65 and the deviance explained by the model 0.07.

Scale or resolution	10 km
Time period covered	1995-2004
Data access	Original data: See “Data sources”. Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

Razorbill (*Alca torda*), probability of presence

Probability of presence of birds modelled using Multivariate Adaptive Regression Splines (MARS) based on observations (presence/absence) and environmental predictors for Razorbill (*Alca torda*).



Data sources

- Species data used:

From the European Seabird at Sea (ESAS) database. The processing of the data is described in Fauchald et al. 2011 (Ecology 92: 228-239). The period used was 1995-2004, and the observations are from the months October-March. The abundance of birds was converted to presence/absence.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (Modis, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for a winter season October 2003 - March 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities). Salinity at surface (mean values for 2003-2004) was considered but was not used as it was highly correlated with temperature.

Spatial extent	North Sea (top 4410000, left 3460000, right 4500000, bottom 3120000)

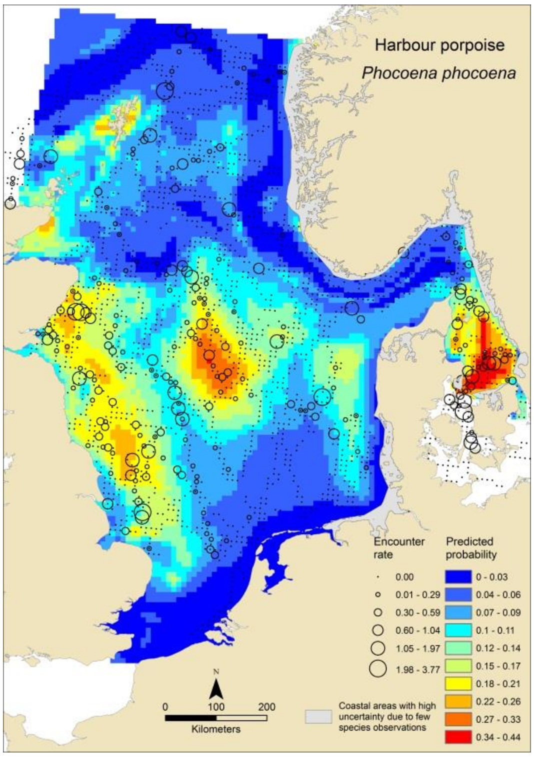
Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13: 265-275). The R version 1.7-6 was used. The data used is described above. The model was fitted using a multi-species MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for razorbill was 0.78 and the deviance explained by the model 0.22.

Scale or resolution	10 km
Time period covered	1995-2004
Data access	Original data: See "Data sources". Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

Harbour porpoise (*Phocoena phocoena*), probability of presence

Probability of presence of Harbour porpoises (*Phocoena phocoena*) modelled using Multivariate additive regression splines (MARS) based on species observations and environmental predictors.



Data sources

- Species data used:

SCANS surveys (Small Cetacean Abundance in the North Sea) 1994 and 2005, both surveys were combined.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (Modis, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for July 2003 and July 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities) and salinity at surface (mean values for 2003-2004).

Spatial extent	North Sea

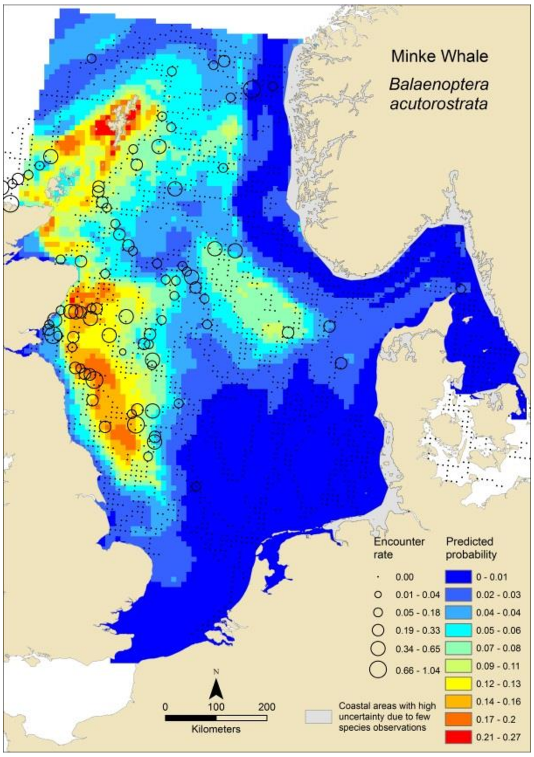
Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13: 265-275). The R version 1.7-6 was used. The data used is described above. The model was fitted using a multispecies MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for harbour porpoises was 0.65, and the deviance explained by the model was 0.07.

Scale or resolution	10 km
Time period covered	1994 and 2005 surveys combined
Data access	Original data: See “Data sources”. Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

Minke whale (*Balaenoptera acutorostrata*), probability of presence

Probability of presence of Minke whales (*Balaenoptera acutorostrata*) modelled using Multivariate additive regression splines (MARS) based on species observations and environmental predictors.



Data sources

- Species data used:

SCANS surveys (Small Cetacean Abundance in the North Sea) 1994 and 2005, both surveys were combined.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (Modis, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for July 2003 and July 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities) and salinity at surface (mean values for 2003-2004).

Spatial extent	North Sea

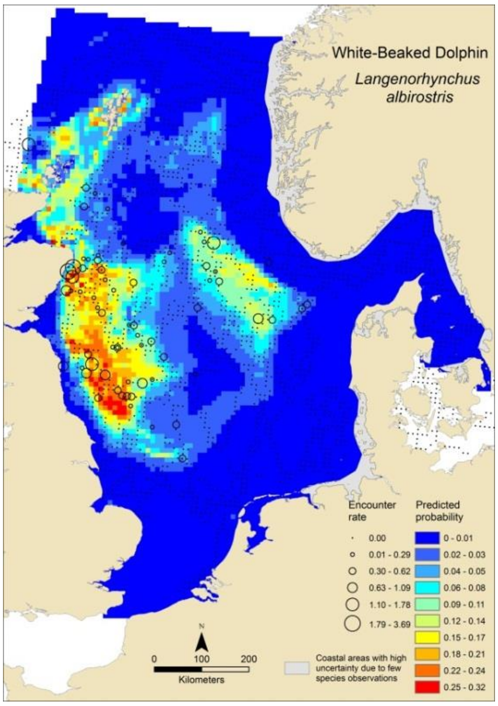
Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13: 265-275). The R version 1.7-6 was used. The data used is described above. The model was fitted using a multispecies MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for minke whales was 0.72, and the deviance explained by the model was 0.12.

Scale or resolution	10 km
Time period covered	1994 and 2005 surveys combined
Data access	Original data: See “Data sources”. Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

White-beaked dolphin (*Lagenorhynchus albirostris*), probability of presence

Probability of presence of White-beaked dolphins (*Lagenorhynchus albirostris*) modelled using Multivariate additive regression splines (MARS) based on species observations and environmental predictors.



Data sources

- Species data used:

SCANS surveys (Small Cetacean Abundance in the North Sea) 1994 and 2005, both surveys were combined.

- Environmental data used:

Depth, slope (calculated based on depth in ArcGIS using the standard slope tool), distance to land, chlorophyll (Modis, mean chlorophyll concentration mg/m^3 during 2003-2010), U velocity at 3 m, V velocity at 3 m, temperature at surface (mean values for July 2003 and July 2004, source: http://www.myocean.eu/), current speed (calculated based on U an V velocities) and salinity at surface (mean values for 2003-2004).

Spatial extent	North Sea

Lineage and data quality

The model was created using the MARS R functions written by Elith & Leathwick (2007, Diversity & Distributions 13: 265-275). The R version 1.7-6 was used. The data used is described above. The model was fitted using a multispecies MARS model with a binomial distribution (see Elith & Leathwick 2007). Species-specific responses and predictions were created based on the model. Evaluation of the predictive performance was made using AUC based on a 10-fold cross validation. The mean AUC value for white beaked dolphins was 0.79, and the deviance explained by the model was 0.23.

Scale or resolution	10 km
Time period covered	1994 and 2005 surveys combined
Data access	Original data: See “Data sources”. Predicted distribution: Contact the HARMONY Team.
Additional information sources	None.

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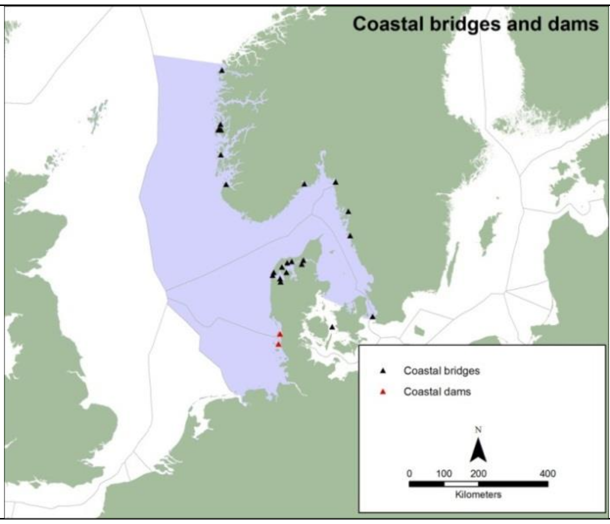
Appendix B - Stressor data layers

List of the human stressors

- Bridges and coastal dams
- Coastal nuclear power plants
- Coastal population density
- Coastal waste water treatment plants
- Disposal sites for dredged material
- Dumped munitions
- Heavy metal inputs from rivers and the atmosphere
- Industrial ports
- Marine aquaculture sites
- Military areas
- Nutrient enrichment
- Offshore oil and gas installations
- Offshore wind turbines
- Oil and gas pipelines
- Oil spills
- Recreational shipping (in deep/shallow waters)
- Riverine discharges of radionuclides
- Riverine discharges of synthetic pollutants
- Sea cables
- Sediment extraction sites
- (Commercial) Shipping intensity
- Fishery effort from the Dregde segment
- Fishery effort from the beam trawl > 80 mm segment
- Fishery effort from the small-meshed beam trawl (Crangon crangon) segment
- Fishery effort from the pelagic segment
- Fishery effort from the TR1 (demersal trawl and seine with meshes ≥ 100 mm) segment
- Fishery effort from the TR2 (trawl with 70-99 mm meshes) segment
- Fishery effort from the "other trawl" segment
- Fishery effort from the pots and traps segment
- Fishery effort from the set net segment

Bridges and coastal dams	
Major bridges and coastal dams in the North Sea, drawn in Google Earth.	

Data sources

- Google Earth

Spatial extent	German, Danish, Swedish, and Norwegian North Sea

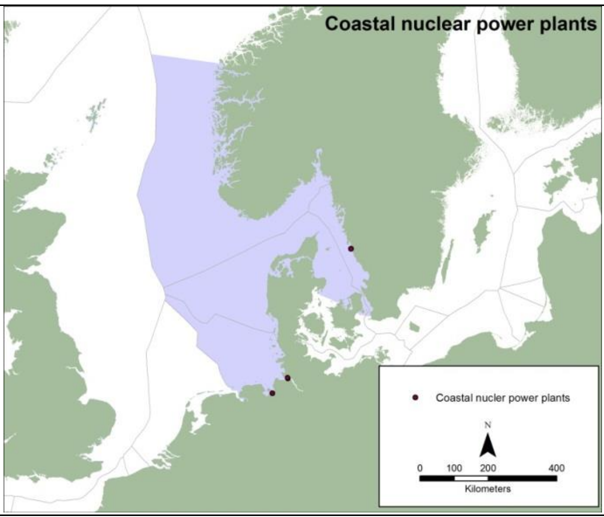
Lineage and data quality

Bridges and coastal dams were identified and drawn in Google Earth. Most environmental effects of coastal bridges and dams are higher for a dam than for a bridge of the same length. For example, a bridge still allows water flow between piers, and the seabed is only sealed below the feet of the piers and potential surrounding protection structures. Thus, for the cumulative impact index, all cells containing a bridge were assigned a value of 0.5. All cells containing a coastal dam were assigned a value of 1.

Scale or resolution	1 km
Time period covered	Recent snapshot (2010)
Data access	Contact the HELCOM Secretariat or the HARMONY team.
Additional information sources	None.

Coastal nuclear power plants

Operational coastal nuclear power plants in the German, Danish and Swedish parts of the North Sea. There are no coastal nuclear power plants in the Norwegian part of the study area.



Data sources

- OSPAR

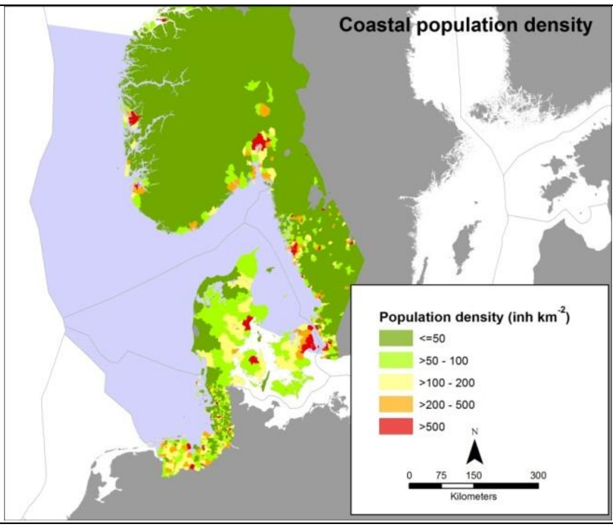
Spatial extent	Danish, Swedish, Norwegian and German North Sea

Lineage and data quality

Coastal nuclear power plants were extracted from a data set on nuclear installations in the OSPAR area. Represented on the mapping grid as presence/absence (i.e. each installation was assigned to the closest cell).

Scale or resolution	Unknown
Time period covered	Recent snapshot (2011)
Data access	Contact the OSPAR Secretariat.
Additional information sources	http://qsr2010.ospar.org/media/assessments/p00456_Liquid_Discharges_data_report_2007.pdf#page=16

Coastal population density

Population density in coastal administrative units, and the number of people living within 25 km from the coastline.	

Data sources

- Germany: Administrative units with numbers of inhabitants for the two states Niedersachsen and Schleswig Holstein, extracted from the ATKIS DLM (data provided by UBA, otherwise subject to payment).
- Denmark: Municipalities with population provided by NST. Also a fine-resolution population grid is available but was not used for this data set as similar data were lacking for the other countries.
- Sweden: Population density in administrative units such as census regions. Data from SCB, provided by Metria.
- Norway: Administrative units (kommuner) provided by KLIF, population numbers manually added from the SSB statistical yearbook 2010 (http://www.ssb.no/aarbok).
- Netherlands (included for the boundary region): Eurostat. NUTS-3 areas from GISCO, manually added population.

Spatial extent	German, Danish, Norwegian, and Swedish North Sea

Lineage and data quality

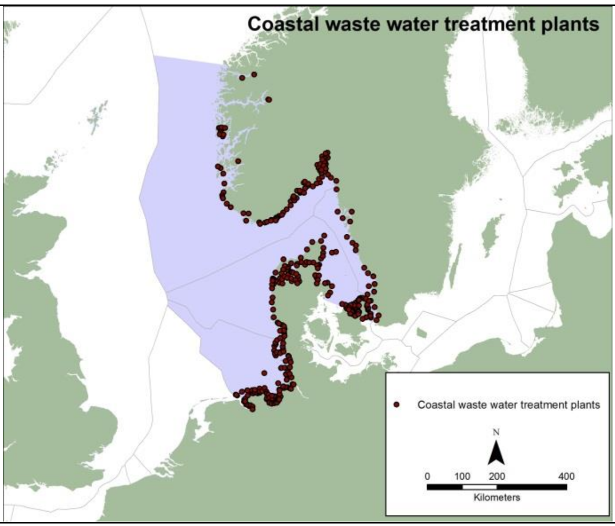
The national data sets containing total population or population densities in different administrative units were merged and unless already contained in the original data, the land area in the unit was calculated and the number of inhabitants/km^2 derived. In addition to the German, Danish, Norwegian and Swedish data, the three Dutch NUTS-3 areas closest to the study area were added in order to receive realistic values at the German-Dutch boundary.

For the impact index, the number of people living within a 25 km radius was calculated for each cell touching the coastline. For all other cells (not touching the coastline), the value was set to zero.

Scale or resolution	1 km (original data: administrative areas varying in size)
Time period covered	Norway: 2010; Germany: unknown (recent snapshot); Sweden: 2000-2009 (mean); Denmark: unknown (recent snapshot)
Data access	Contact the HARMONY team. Original data: See “Data sources”. Permission from owners may be needed.
Additional information sources	None.

Coastal waste water treatment plants

Coastal waste water treatment plants in the German, Danish, Swedish and Norwegian parts of the North Sea.



Data sources

- Denmark: locations provided by NST.
- Germany: extracted from the ATKIS DLM (provided by UBA).
- Sweden: coastal locations provided by SMHI.
- Norway: locations and discharges for different substances provided by KLIF.

Spatial extent	Danish, Swedish, Norwegian and German North Sea

Lineage and data quality

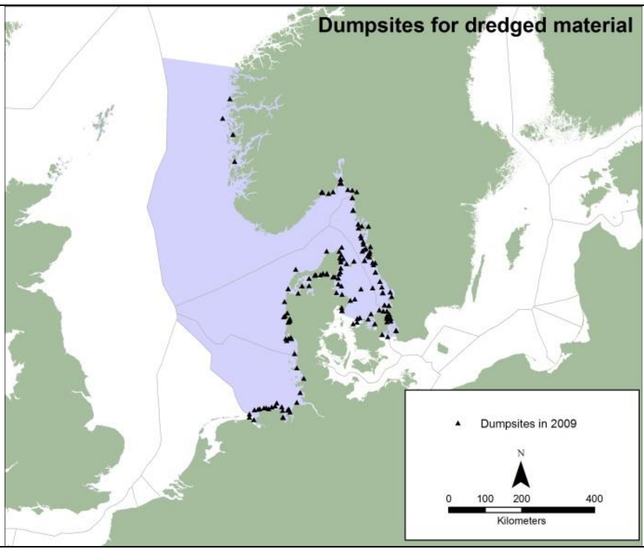
The data set was compiled from national data sources (see above). The German, Danish and Norwegian data sets also contained inland locations. Only locations within 5 km of the sea where included in the compiled data set. The Swedish data contained only urban waste water treatment plants close to the sea. Thus, smaller plants are missing in the Swedish data.

In order to calculate the impact index, each waste water treatment plant was assigned to the closest cell of the mapping grid. The values of cells with an assigned plant were set to 1, and those of all others to 0.

Scale or resolution	Unknown
Time period covered	Denmark: 2009; Norway: 2007-2008; Sweden and Germany: data provided in 2011 but exact period covered is unknown
Data access	Contact the HARMONY team. Original data: See “Data sources”. Permission from owners may be needed. The German data are part of a data product (the ATKIS DLM) which is subject to payment.
Additional information sources	None.

Disposal sites for dredged material

Disposal sites for dredged material in the in the Danish, Swedish, Norwegian and German parts of the North Sea.



Data sources

- Germany: CONTIS database, hosted by BSH: http://www.bsh.de/en/Marine_uses/Industry/CONTIS_maps/index.jsp.
- Denmark: Provided by NST.
- Sweden: Compilation of disposal sites made by the Environmental Protection Agency, based on reports from county administrative boards and supplemented by information from reports and the internet (provided by Metria).
- Norway: Data reported to OSPAR in 2009, available on EIONET: http://cdr.eionet.europa.eu/no/ospar/Dumping.

Spatial extent	Swedish, German, Danish, and Norwegian North Sea

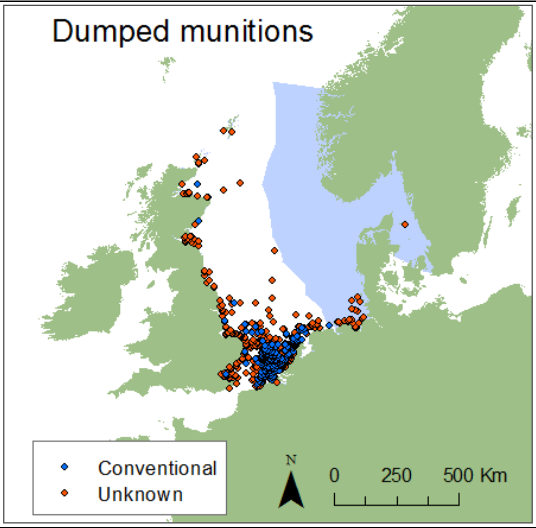
Lineage and data quality

Data were merged from national sources. In general, the data do not cover a longer period, but only a recent year. With the exception of the Swedish data, no information on the disposed volumes was included.

For calculating the impact index, the values of all cells containing at least one sediment dumpsite were set to 1, and the values of all other cells to 0.

Scale or resolution	Unknown
Time period covered	Denmark and Norway: Snapshot (2009); Germany: Snapshot (end 2010); Sweden: Unknown
Data access	Contact the HARMONY team. Original data: See ”Data sources”. Owners’ permissions may be needed.
Additional information sources	None.

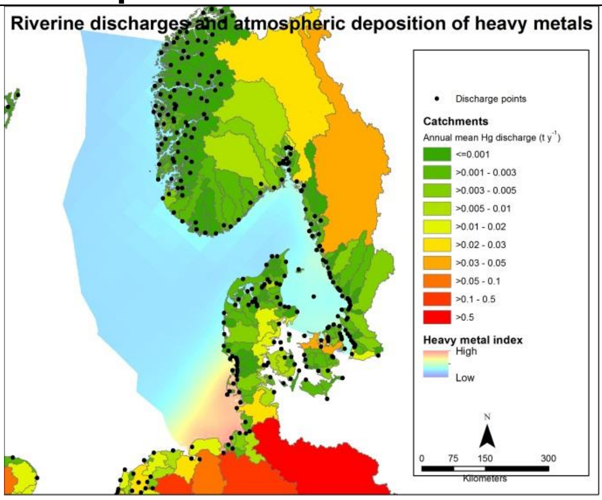
Dumped munitions

Locations of dumped munitions in the North Sea.	

Data sources	
• OSPAR Secretariat.	
Spatial extent	North Sea
Lineage and data quality	
The original data cover the entire OSPAR area. The locations of known dumped munitions were used in HARMONY without further processing, and assigned to the mapping grid as presence/absence.	
Scale or resolution	Unknown
Time period covered	2004-2008
Data access	Contact the OSPAR Secretariat.
Additional information sources	OSPAR QSR 2010: http://qsr2010.ospar.org/en/ch09_09.html

Heavy metals from rivers and the atmosphere

Riverine loads of cadmium (Cd), mercury (Hg) and lead (Pb) were predicted for catchments around the North Sea based on monitoring data, land use and population statistics. Heavy metal loads in the sea were then estimated based on distance from the river mouths and salinity (as an indicator for the extent of freshwater plumes). The resulting data set on riverine discharges was finally combined with EMEP data on atmospheric deposition of the three heavy metals.



Data sources

- Monitored riverine discharges of heavy metals: RID data.
- Catchments: Norway – NVE; Sweden – SMHI; other countries: EEA (http://www.eea.europa.eu/data-and-maps/data/european-river-catchments-1).
- Land cover: CORINE Land Cover 2006, 250m raster, Level 2 classification. Downloaded from EEA: http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-1.
- Population density: In Norway data on community population from SSB, with community boundaries provided by KLIF. Elsewhere: Population density disaggregated with Corine land cover 2000, http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2
- Salinity: Atlantic Margin Model, Access via the MyOcean portal: Product "Atlantic- European North West Shelf - Ocean Biogeochemistry Hindcast", HINDCAST RUN 1, http://www.myocean.eu/web/24-catalogue.php.
- Atmospheric deposition: EMEP, http://www.emep.int/

Spatial extent	North Sea

Lineage and data quality

Because of insufficient coverage of the North Sea region with monitoring data on riverine discharges of heavy metals, riverine discharges were estimated in four steps:

1. A data set of catchments draining into the North Sea was compiled and statistics on land cover (based on CORINE level 2 classification) and population were calculated. The included variables were "urban fabric", "industrial, commercial and transport units", "mine, dump and construction sites", "arable land" and population. Also other variables, such as total agricultural area and area of pastures, were tested but turned out to be strongly correlated to and worse predictors than the variables listed first.
2. Measured discharges of three heavy metals – cadmium, lead, and mercury – were assigned to catchments covered by monitoring data (no monitoring data on other heavy metals were available). For some monitoring data, a clear assignment to a catchment was not possible and they were thus omitted. In total, 23 catchments had monitoring data. All variables were divided by catchment areas to avoid the dominance of catchment size in modelling (e.g. using population density, % of arable land, and discharges per km^2 catchment). Using simple multivariate linear models, discharges per km^2 catchment could be predicted with satisfactory accuracy for all three substances (Cd: function of urban and industrial area, $R^2 = 0.84$; Hg: function of mines/construction sites and population, $R^2 = 0.73$; Pb: function of urban and industrial areas, $R^2 = 0.82$).
3. The linear models were used to predict discharges (per km^2 catchment area) of N, Cd, Hg and Pb for all catchments in the study area.
4. One point was assigned as "discharge location" to each catchment. The spread of the modelled substances in the sea was calculated with an algorithm similar to that proposed by Halpern et al. (Science, 2008). This original algorithm creates "artificial plumes" by assigning a fixed percentage (1%) of the total discharged amount to the cell containing the source. Then, to each of the neighbouring cells, 1% of the remaining amount is assigned. This is repeated until the re-

maining amount falls under a given threshold. This algorithm lets the plumes wrap around e.g. headlands, but does otherwise assume even spread into all directions. Also in our version, the plume initially contains only the cell with the river mouth, and then, all cells neighbouring the plume are step-wise added. However, we did not assign the same proportion of the remaining amounts of the substances in question to all cells. Instead, in each step, the amounts "deposited" in all cells that were newly added to the plume were based on their salinity. Furthermore, we did not allow the plumes to spread into waters with salinity above 34.5 PSU, considered as the limit of the influence of riverine waters.

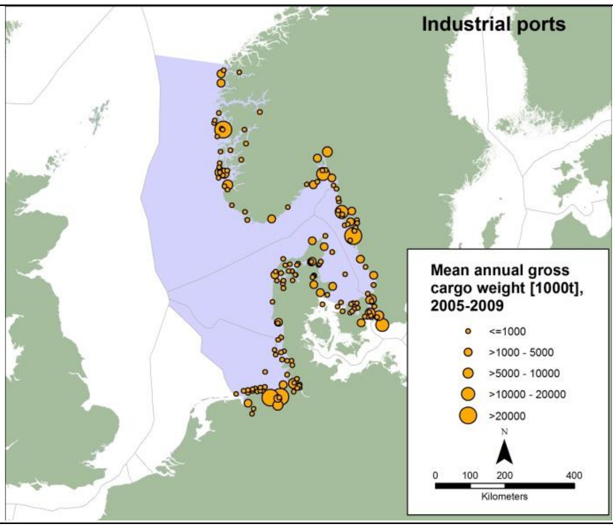
The algorithm described above involves several parameters, such as the percentage of the remaining amounts to distribute, which is retained in each cell. Consequently, the algorithm was first tested by modelling the spread of nitrogen discharges from major rivers, and comparing the resulting patterns to nitrate concentration from the NORWECOM model. The parameters were adjusted so that a good fit with this model's results was reached, and then applied for calculating the "heavy metal plumes".

Finally, modelled atmospheric depositions were added to the amounts of the three heavy metals. The resulting data sets for cadmium, mercury and lead were rescaled to range from 0 to 1 and then averaged in order to produce one heavy metal data set.

Scale or resolution	1 km
Time period covered	2003-2009 averages
Data access	Contact the HARMONY team. Original data: See "Data sources".
Additional information sources	Halpern et al. (2008): http://www.nceas.ucsb.edu/globalmarine/impacts

Industrial ports

Industrial ports with average annual gross cargo weight 2005-2009.



Data sources

- Locations for Germany, Denmark and Sweden: EuroStat GISCO: (http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/introduction)
- Locations for Norway: www.havneportalen.no
- Cargo statistics: EuroStat, ”Maritime transport - Goods (mar_go)”: (http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/data/database)

Spatial extent	German, Danish, Swedish and Norwegian North Sea

Lineage and data quality

Locations of German, Danish and Swedish ports were downloaded from the Eurostat GISCO website. As no data set for Norway was available from Eurostat and no comprehensive national data set existed (Kystverket, personal communication, spring 2011), Norwegian industrial ports were located on an online map provided by a newspaper (see “Data sources”) and checked against Google Earth and the list of harbours in the SBB Havnestatistik (http://www.ssb.no/emner/10/12/60/havn/arkiv/), to make sure that all major ports were covered and their locations correct.

Statistics on annual gross cargo weight were downloaded from Eurostat for 2005-2009. This period was chosen because it was covered for most ports (in some cases, data were available for fewer years in this period). The average of the available years was assigned to the port locations.

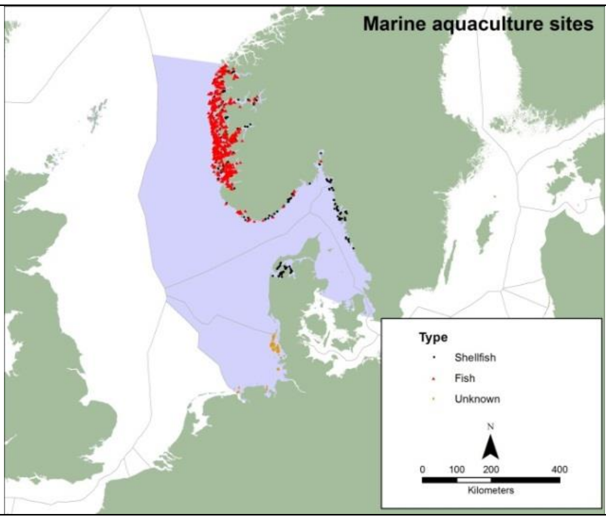
However, the Eurostat cargo statistics cover only major ports, typically 30-40 in each country. To assign values to smaller ports, the annual gross cargo weight for the ports covered by data was compared to the 2005-2009 total gross cargo weight reported for all ports in the respective countries. The difference between the national total and the sum of cargo weight reported for the individual ports in this country was equally distributed to the ports for which no statistics were available.

The total number of ports was assumed to be the number of ports in the GISCO data for Germany, Denmark and Sweden. For Norway, it was assumed to be the number of industrial ports registered on havneportalen.no.

Scale or resolution	1:1,000,000
Time period covered	Recent snapshot (2005-2009)
Data access	Contact the HARMONY team. Original data: see “Data sources”.
Additional information sources	None.

Marine aquaculture sites

Locations of fish farms and shellfish farms in the North Sea.



Data sources

Data have been compiled from the following national sources:

- Germany: BSH (CONTIS database)
- Denmark: provided by NST
- Sweden: National Board of Fisheries (provided by Metria)
- Norway: Fiskeridirektoratet (Havbruksdatabasen)

Spatial extent	Swedish, German, Danish, and Norwegian North Sea

Lineage and data quality

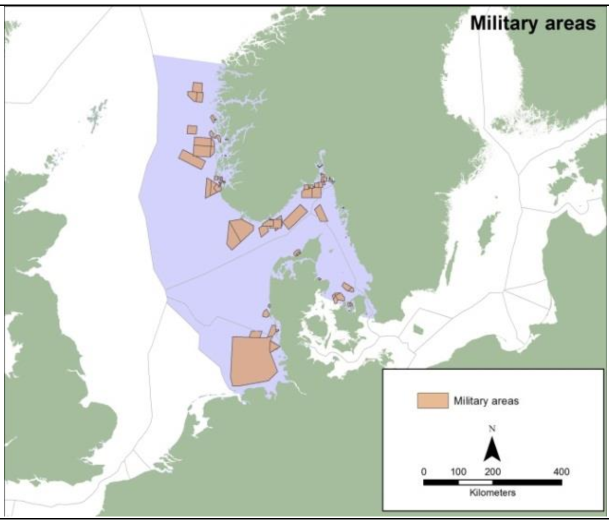
The original data contained descriptive information (e.g. on farmed species) at different levels of detail. No information on the size of the aquaculture sites or the intensity of activities (e.g. annual production) was available. Thus, the compiled data set on marine aquaculture in the North Sea contains only locations.

Fish farms and shellfish farms were distinguished in the original data with the exception of German waters. There, only site locations (all in the Wadden Sea) without any additional information were available. As mostly blue mussels and oysters are grown in the German Wadden Sea, these sites were classified as shellfish farms. The Norwegian data set also included in-land sites which were removed by erasing all sites more than 1 km landwards from a reference shoreline (GSHHS full resolu-tion).

For the North Sea Impact Index, values were assigned to the mapping grid as follows (on the example of shellfish farms, but done similarly for fish farms): Cells containing at least one shellfish farm have a value of 1 (presence), and all other cells have a value of 0. An alternative would have been to count the number of shellfish farms in each cell, but as it was impossible to ac-count for the size of the sites, a simple presence-absence approach was considered more robust.

Scale or resolution	Unknown
Time period covered	Snapshot (2010-2011)
Data access	Germany: http://www.bsh.de/en/Marine_uses/Industry/CONTIS_maps/index.jsp Norway: http://kart.kystverket.no/default.aspx?gui=1&lang=2) Sweden and Denmark: Contact the institutions listed in the “Data sources” section. Owners’ permissions may be needed for the national data. Compiled data set: Please refer to the HARMONY website.
Additional information sources	None.

Military areas

Military areas in the Danish, Swedish, Norwegian and German parts of the North Sea.	

Data sources

- Germany: Drawn manually based on the BSH CONTIS WMS
- (http://gdisrv.bsh.de/arcgis/services/CONTIS/Administration/MapServer/WMSServer)
- Norway: Data collected and provided by KLIF (permissions required for data access)
- Denmark: Drawn manually on top of nautical charts and provided by NST
- Sweden: National Land Survey (provided by Metria)

Spatial extent	Swedish, German, Danish, Norwegian North Sea

Lineage and data quality

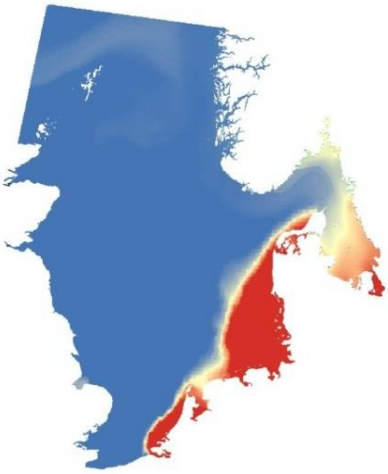
The German military areas are included in the BSH CONTIS database, and the data are owned by the Bundeswehr (Armed Forces). As both institutions refused to share the data set, German military areas were drawn manually based on the BSH CONTIS WMS (URL under “Data sources”).

Otherwise, this data set is a simple compilation of data from national sources, and military areas are represented on the mapping grid as presence/absence.

Note that because no information on the frequency of use was available, some very large military areas could be very dominant in the pressure and impact indices. To counter this effect, they were included in the North Sea Impact Index with a weight of 0.5.

Scale or resolution	Unknown
Time period covered	Snapshot (2011)
Data access	Contact the HARMONY team. Original data: see “Data sources”. Owners’ permissions may be needed.
Additional information sources	None.

Nutrient enrichment

Concentrations of nitrate at 5 m depth, modelled based on field measurements and salinity in the Kattegat, and extracted from the NORWECOM model for the rest of the North Sea.	

Data sources

- NORWECOM nitrate concentrations: Access via the MyOcean portal: Product “Atlantic- European North West Shelf - Ocean Biogeochemistry Hindcast”, HINDCAST RUN 2, http://www.myocean.eu/web/24-catalogue.php; direct data access via OpenDAB: http://thredds.met.no/thredds/dodsC/sea/dataset-na4-norwecom-nws-myocean-ts.html.
- Nitrate concentrations in the Kattegat: HELCOM COMBINE, download via the HELCOM Map and Data Service (http://maps.helcom.fi/website/mapservice/index.html).
- Salinity: Atlantic Margin Model, Access via the MyOcean portal: Product “Atlantic- European North West Shelf - Ocean Biogeochemistry Hindcast”, HINDCAST RUN 1, http://www.myocean.eu/web/24-catalogue.php

Spatial extent	North Sea

Lineage and data quality

Average nitrate concentrations at 5m depth were extracted from the NORWECOM model for 2003-2004. The model is described in detail elsewhere. While repeatedly used and validated in peer-reviewed publications in the North Sea and Skagerrak, the modelled nitrate concentrations are unrealistically low in the Kattegat, as the Baltic outflow seems not to be considered at all.

Consequently, nitrate concentrations in the Kattegat were predicted separately. Annual average nitrate concentrations at 8 monitoring stations in the Kattegat (which had all twelve months covered by at least one measurement from 2003 or later) were combined with average 2003-2004 salinity from the Atlantic Margin Model. A linear regression function (R^2 = 0.46) was then used to predict nitrate concentrations based exclusively on salinity.

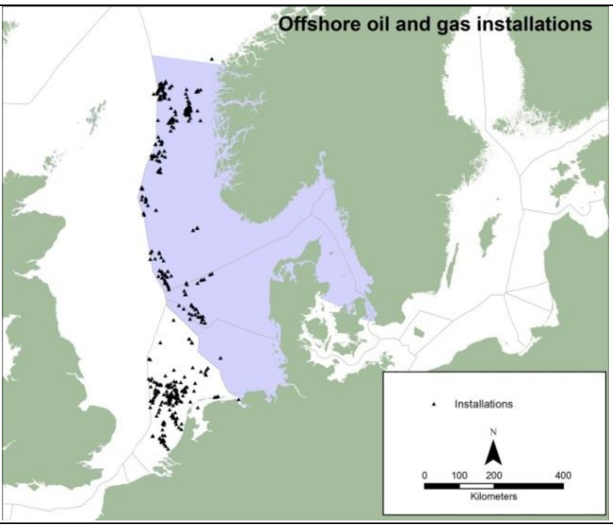
The data from the NORWECOM model and the predicted nitrate concentrations in the Kattegat were merged following the 32 PSU isohaline, close to the boundary of the Swedish and the Norwegian EEZ in the northern Kattegat.

Note that although the data used do not distinguish anthropogenic and natural nutrient loads, we found a strong link between monitored nutrient discharges from river catchments in the study area and the proportion of agricultural land as well as population densities the catchments (R^2 = 0.79). Consequently, it is acceptable to assume that nutrient levels in the study area are dominated by human activity.

Scale or resolution	1/9 deg lat x 1/6 deg lon; ~12 km, but interpolated to 1 km
Time period covered	2003-2004 average
Data access	Contact the HARMONY team. Original data: See “Data sources”.
Additional information sources	Detailed documentation of the NORWECOM and Atlantic Margin Model in the MyOcean Data Catalogue: http://www.myocean.eu/web/24-catalogue.php.

Offshore oil and gas installations

Oil and gas installations in the German, Danish, Norwegian and Dutch parts of the North Sea.



Data sources

- Norway: NPD (http://www.npd.no/engelsk/cwi/pbl/en/factmap/download/shapes_welcome.htm).
- Denmark: NST.
- Germany: Covered by Danish and Norwegian data. Alternative source: CONTIS database (http://www.bsh.de/en/Marine_uses/Industry/CONTIS_maps/index.jsp).
- Sweden: No oil and gas installations in the North Sea.
- Netherlands: Data from 2007 provided by the OSPAR secretariat.
- UK (not included here): https://www.og.decc.gov.uk/information/maps_offshore.htm.

Spatial extent	Danish, Swedish, Norwegian, German and Dutch North Sea

Lineage and data quality

Data on offshore oil and gas installations have been compiled from the sources listed above. The Norwegian data contain both surface and subsurface installations. Both have been included in this data set.

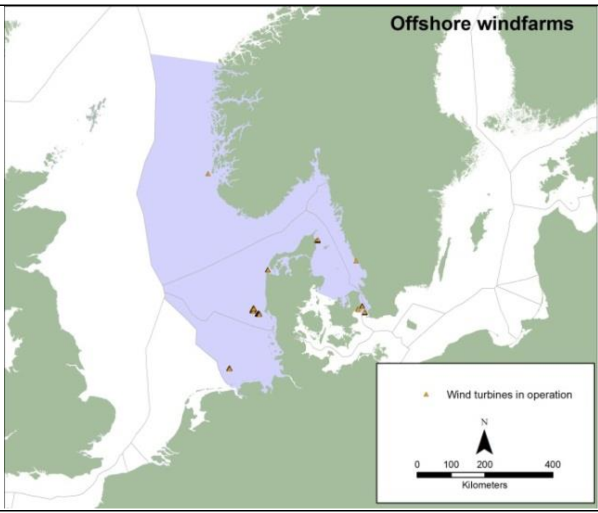
Note that the original Norwegian data also contained onshore facilities such as landings and refineries. These have been identified and removed from the compiled data set manually. Furthermore, it should be noted that the Norwegian data contain some installations which are not in use any more (also outside Norwegian waters).

For calculating the impact index, the values of all cells containing at least one installation were set to 1, and the values of all other cells to 0.

Scale or resolution	Unknown
Time period covered	Norway and Denmark: 2011 snapshot, but including some installations which are out of use; Netherlands: 2007 snapshot
Data access	Compiled data set: contact the HARMONY team. Original (national) data: see “Data sources”.
Additional information sources	None.

Offshore wind turbines

Operational offshore wind turbines in the Norwegian, Swedish, Danish and German parts of the North Sea (note that in Norway, there is only one experimental floating wind turbine).



Data sources

- Germany: BSH (CONTIS database); http://www.bsh.de/en/Marine_uses/Industry/CONTIS_maps/index.jsp.
- Sweden: Metria (compiled from country administrative boards).
- Denmark: NST Original source: ENS; http://www.ens.dk/DA-DK/INFO/TALOGKORT/STATISTIK_OG_NOEGLETAL/OVERSIGT_OVER_ENERGISEKTOREN/STAMDATAREGISTER_VINDMOELLER/Sider/forside.aspx.
- Norway: NVE.

Spatial extent	Swedish, German, Danish and Norwegian North Sea

Lineage and data quality

Locations of operational wind turbines and accompanying information were provided by national sources. For the only existing wind farm in the German North Sea, only the wind farm area was provided. Its twelve turbines were drawn by hand, so that they evenly covered this area.

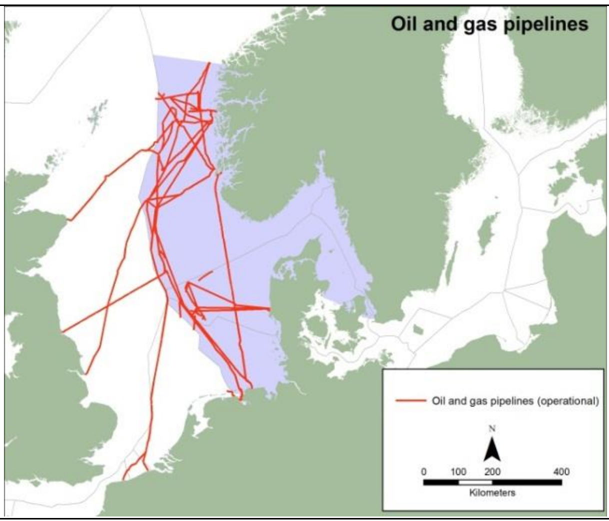
The data include a wind turbine in Lövstaviken (Sweden) that is placed on a small "pier" stretching out from the land, and thus may not be considered "offshore" in all contexts.

Note that more wind farms are planned in parts of the study area.

Scale or resolution	Unknown
Time period covered	Snapshot (2011)
Data access	Contact the HARMONY team. Original (national) data: see "Data sources".
Additional information sources	Interactive map with offshore wind farms at http://www.4coffshore.com/offshorewind/; data also available as shapefile against payment.

Oil and gas pipelines

Major oil and gas pipelines in the North Sea. The data shown on the right are possibly incomplete outside German, Norwegian and Danish waters. There are no oil and gas pipelines in the Swedish part of the North Sea.



Data sources

- Germany: BSH, CONTIS database (http://www.bsh.de/en/Marine_uses/Industry/CONTIS_maps/index.jsp).
- Norway: NPD, data can be downloaded from http://factpages.npd.no/factpages/Default.aspx?culture=en.
- Denmark: Data provided by NST.

Spatial extent	North Sea Data are probably incomplete outside German, Norwegian, Danish and Swedish waters

Lineage and data quality

The original data sets have been collected from national authorities and simply merged. The German data also included planned and approved but not yet constructed pipelines, which were removed.

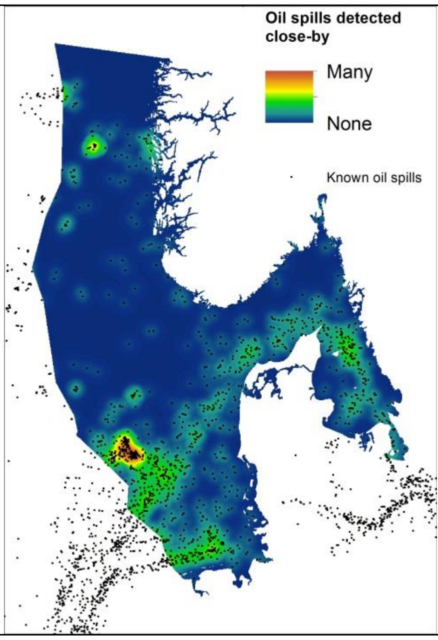
For calculating the impact index, the values of all cells intersected by a pipeline were set to 1, and the values of all other cells to zero.

Data are probably incomplete outside German, Norwegian, Danish and Swedish waters.

Scale or resolution	Unknown
Time period covered	Recent snapshot (2010 to 2011)
Data access	Contact the HARMONY Team. Original data: See “Data sources”. For data sets which cannot be downloaded, permission from owners may be needed.
Additional information sources	None.

Oil spills

Oil spills in the North Sea, detected by monitoring under the Bonn Agreement and by HELCOM. Based on the detected spill locations, an "oil spill risk index" was calculated.



Data sources

- Bonn Agreement data, 2003-2009, OSPAR Secretariat (North Sea excluding most of the Kattegat).
- Kattegat: HELCOM Map and Data Service.

Spatial extent	North Sea

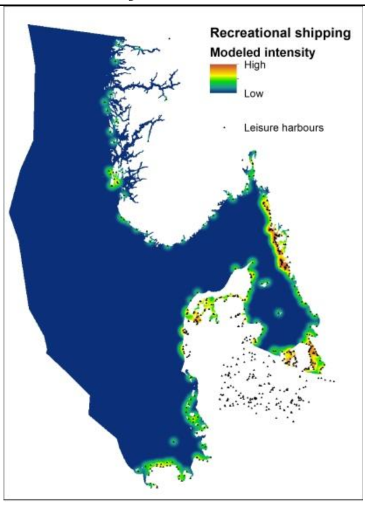
Lineage and data quality

Oil spills in the North Sea are regularly surveyed under the Bonn Agreement based on aerial and satellite observations. However, the data did not cover most of the Kattegat. This gap was filled using a data set on oil spills provided by HELCOM. The comparability of data in the Kattegat with the rest of the North Sea may be affected by differences in monitoring efforts. The Bonn Agreement data did not contain information on the size of the detected spills, although for some spills, they are reported in annual surveillance reports.

Not all oil spills and discharges can be detected. Spills affect an area rather than one point, and they persist over some time and move before and after detection. But given that the surveillance data cover 7 years, it is more likely that damage from oil pollution has occurred in a location where many spills have been detected close-by, than in a location where fewer spills have been detected close-by. Based on this assumption, the detected locations of oil spills were used to calculate an "oil spill index". The value of the index in any location has been calculated as a distance-weighted number of oil spills within a 25 km radius. Weights were linearly diminishing from 1 to 0 over 25 km. As an example, an oil spill being detected directly at a given location would add 1 to this location's index value, and another spill detected 12.5 km away would add 0.5. Detections more than 25 km away do not influence the index.

Scale or resolution	1 km
Time period covered	2003-2009
Data access	Contact the HARMONY Team. Original data: Contact the OSPAR Secretariat for Bonn Agreement data. HELCOM data: http://www.helcom.fi/GIS/en_GB/HelcomGIS/.
Additional information sources	Bonn Agreement: http://www.bonnagreement.org/.

Recreational shipping (in deep/shallow waters)

The intensity of recreational shipping was estimated based on the number of and distance to leisure harbours in each location's surroundings. To account for potential impacts on the sea bottom (such as re-suspension of sediment), the data set was split up into two layers: Recreational shipping in deep waters and in shallow waters.	

Data sources

- Germany: Harbours and landing piers from the ATKIS DLM (provided by UBA) for the states Schleswig-Holstein and Niedersachsen.
- Denmark: Leisure harbours extracted from Top10DK (provided by NST).
- Sweden: Leisure harbours provided by Metria (layer produced in collaboration with the Swedish Maritime Administration).
- Norway: www.havneportalen.no.

Spatial extent	German, Danish, Norwegian and Swedish North Sea

Lineage and data quality

Locations of leisure harbours were provided for the Swedish and the Danish part of the study area by the national institutions. However, the Swedish data were more detailed than the other countries', for example distinguishing marinas from adjacent roll-on-roll-off-terminals. To make the four countries' data more comparable, only locations marked as marinas were extracted from the Swedish data set.

German leisure harbours were identified by extracting the locations of harbours and landing piers from a national topographic database. Google Earth and photographs on the Internet were used to check if the respective locations were at least partially aimed at recreational activities (e.g. ferry harbours were removed).

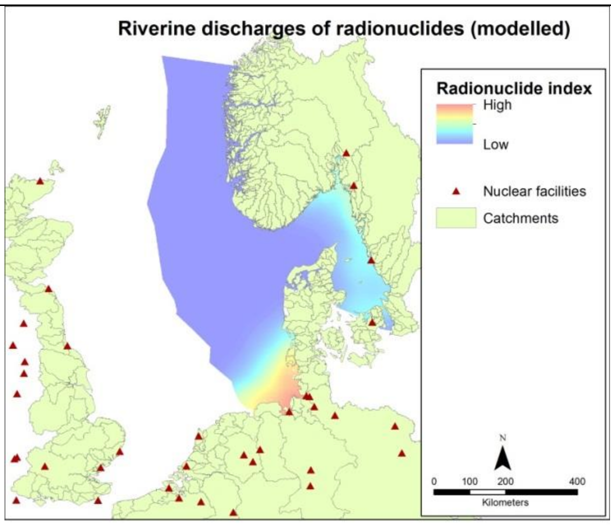
For Norway, no official data were available and leisure harbours were located on an online map provided by a newspaper (see "Data sources").

The locations of leisure harbours were used to estimate the intensity of recreational shipping as follows: All leisure harbours within 20 km distance were assigned values based on the normalized inverse squared distance to the point in question. For example, a leisure harbour right at the point in question would have a value of 1. A leisure harbour 20 km or further away would have a value of 0. Between these extremes, values diminish proportional to the square of the distance. The method corresponds to inverse square-distance weighted interpolation, but differs in that a sum rather than an average is calculated. The maximum distance of 20 km was chosen based on the assumption that most recreational boating trips in the study area's coastal waters are short-term trips, and that potential pressures are dominated by motor boats, but is otherwise arbitrary. Thus, a different maximum distance might be more appropriate for some purposes.

The depth to which impacts on the sea bottom occur depends on a variety of factors, e.g. for physical impacts the wavelength of the produced waves. Here, a depth of 10 m was chosen as a threshold.

Scale or resolution	1 km (original data: about 1:10,000 to 1:25,000)
Time period covered	Recent snapshot
Data access	Processed data set: contact the HARMONY team. Original data: see "Data sources". Permission from owners may be required.
Additional information sources	None.

Riverine discharges of radionuclides

The number of nuclear facilities within the North Sea's river basins was used as a proxy for the riverine discharges of radionuclides from these basins.	

Data sources

- Nuclear facilities: OSPAR Secretariat.
- Catchments: Norway – NVE; Sweden – SMHI; other countries: EEA (http://www.eea.europa.eu/data-and-maps/data/european-river-catchments-1).
- Salinity: Atlantic Margin Model, Access via the MyOcean portal: Product "Atlantic- European North West Shelf - Ocean Biogeochemistry Hindcast", HINDCAST RUN 1, http://www.myocean.eu/web/24-catalogue.php.

Spatial extent	German, Danish, Swedish, and Norwegian North Sea

Lineage and data quality

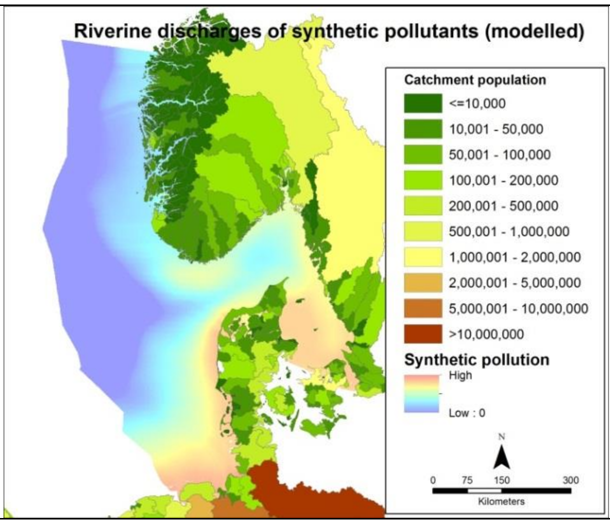
In the absence of recent monitoring data, riverine discharges of radionuclides had to be estimated as a function of the number of nuclear facilities in the river catchments.

The number of nuclear installations in each catchment was assigned to the cell containing the river mouth, assuming that the discharged radionuclides would be linearly proportional to the number of installations in the catchment. The spread of these potential riverine loads was then modelled using the same salinity-based algorithm as described for the heavy metals.

Scale or resolution	1 km
Time period covered	Recent snapshot (2011)
Data access	Contact the HARMONY team. Original data: See "Data sources".
Additional information sources	http://qsr2010.ospar.org/media/assessments/p00456_Liquid_Discharges_data_report_2007.pdf#page=16.

Riverine discharges of synthetic pollutants

Population density in the North Sea's river basins was used as a proxy for the riverine discharges of synthetic pollutants from these basins, and the spread of these discharges in the sea modelled based on salinity.



Data sources

- Population density: In Norway data on community population from SSB. Elsewhere: Population density disaggregated with Corine Land Cover 2000, http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2.
- Catchments: Norway – NVE; Sweden – SMHI; other countries: EEA (http://www.eea.europa.eu/data-and-maps/data/european-river-catchments-1).
- Salinity: Atlantic Margin Model, Access via the MyOcean portal: Product “Atlantic- European North West Shelf - Ocean Biogeochemistry Hindcast”, HINDCAST RUN 1, http://www.myocean.eu/web/24-catalogue.php.

Spatial extent	German, Danish, Swedish, and Norwegian North Sea

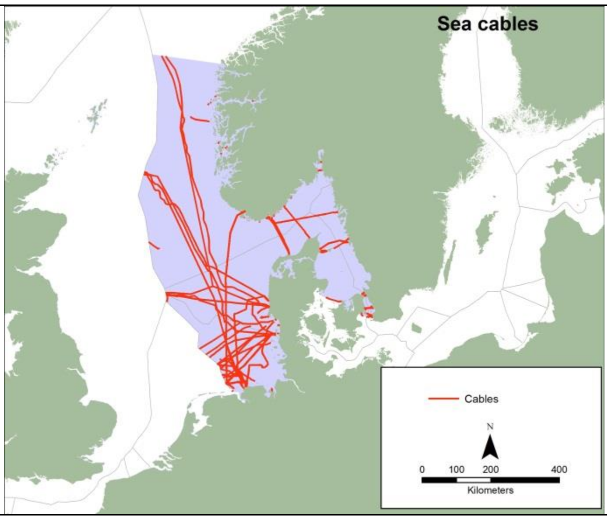
Lineage and data quality

In the absence of recent monitoring data, riverine loads of synthetic pollutants had to be estimated as a function of the number of people living in the river catchments. All data were processed as described for the heavy metals, and a linear relationship between the population of the river basins and the amounts of synthetic compounds released from these basins into the sea was assumed.

Scale or resolution	1 km
Time period covered	Recent snapshot
Data access	Contact the HARMONY team. Original data: See “Data sources”.
Additional information sources	None.

Sea cables

Cables in the German, Danish, Swedish and Norwegian parts of the North Sea.



Data sources

- Norway: NVE (only power cables), data received upon request; checked against online sea charts available from Kystverket, resulting in the addition of one additional cable (http://kart.kystverket.no/default.aspx?gui=1&lang=2).
- Denmark: provided by NST.
- Germany: BSH, CONTIS database (http://www.bsh.de/en/Marine_uses/Industry/CONTIS_maps/index.jsp)
- OSPAR: data set from the QSR 2010; used to add some cables missing from the national data, such as telecommunication cables in Norway.

Spatial extent	Danish, Swedish, Norwegian and German North Sea

Lineage and data quality

Underwater cables data were compiled from national sources, merged, and compared against two other data sets:

- A shapefile with cables compiled by OSPAR. The exact locations of cables existing in both data sets differed by distances up to several kilometres in a few cases. In such situations, the locations given in the national data sets were assumed to be more reliable. Cables shown in the OSPAR data, but missing from the national data sets, have been searched for in Kystverket's (Norway) online nautical charts and (if a name was given in the OSPAR data set) generally on the internet. If either of the searches verified the existence of the cable in question, it was added to the final compiled data set.
- Norwegian nautical charts from Kystverket, on which one additional cable was identified and added manually.

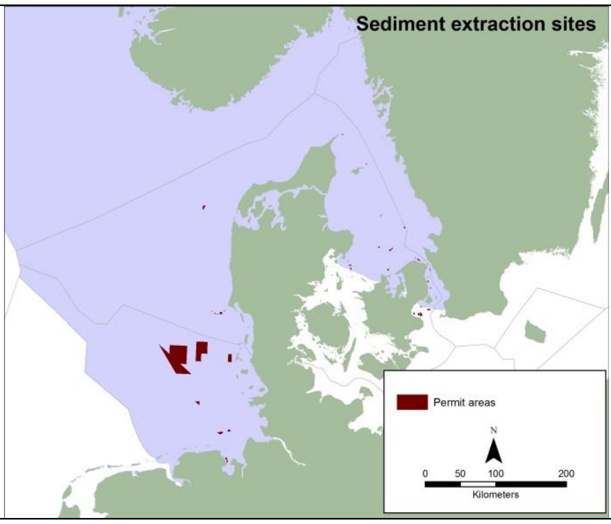
The data were finally clipped to the Norwegian, Swedish, Danish and German EEZ. Given the discrepancies between the different data sets, it must expected that some cables are missing from the data, especially old cables which have been out of use for long time. Furthermore, some cable locations may not be exact.

Planned cables have not been considered. The BorWin 1 cable marked as "under construction" in the original German data was completed in 2009 and is operational, and was thus normally included in this data set.

For the impact index calculation, the values of all cells intersected by a cable were set to 1, and the values of all other cells to 0.

Scale or resolution	Unknown
Time period covered	Norway: 2011; Sweden: 2011; Denmark: 2011; Germany: 2009 or earlier, OSPAR data are older
Data access	Compiled data set: contact the HARMONY team. Original data: See "Data sources". Please request permission from owners.
Additional information sources	None.

Sediment extraction sites

Sediment extraction sites in the German and Danish parts of the North Sea. There is no dredging for sediments in the Norwegian and Swedish North Sea.	

Data sources

- Germany: Landesamt für Bergbau, Energie und Geologie (LBEG) Niedersachsen, Referat L 1.4 – Markscheidewesen.
- Denmark: NST. Data can be downloaded from http://www.naturstyrelsen.dk/Vandet/Havet/Raastoffer/Raastoffer_paa_havet/Kort_og_data/.

Spatial extent	German, Danish, Swedish, and Norwegian North Sea

Lineage and data quality

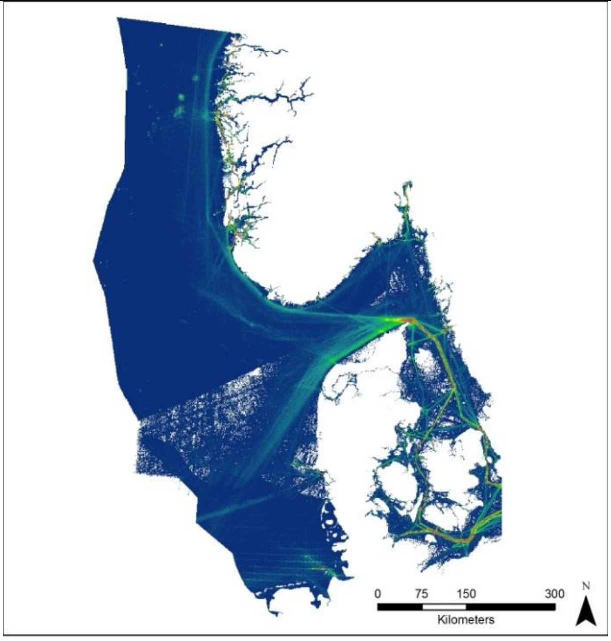
The data have been collected from the German and Danish authorities and simply merged. There are no sediment extraction sites in the Swedish part of the North Sea (SEPA, personal communication). Also in Norway, there are no nationally managed permits for sediment extraction from the seafloor. However, minor local activities may occur irregularly (NGU, personal communication).

For calculating the impact index, the values of all cells intersecting an area, where sand or gravel extraction is permitted, was set to 1, and the values of all other cells to 0, because no information on the intensity of activities was available. However, to avoid an over-dominance of the sometimes large areas in the North Sea Impact Index, they were included with a weight of 0.5.

Scale or resolution	Unknown
Time period covered	Recent snapshot (2011)
Data access	Contact the HARMONY team. Original data: See "Data sources". Owners' permission may be required for other uses.
Additional information sources	http://www.naturstyrelsen.dk/Vandet/Havet/Raastoffer/Raastoffer_paa_havet - exploitation of marine resources in Denmark.

(Commercial) Shipping intensity

Shipping intensity (annual average) in the Danish, Swedish, Norwegian and German parts of the North Sea.



Data sources

- Denmark: Shipping intensity raster provided by NST.
- Norway: AIS points provided by Kystverket.
- Sweden: Classified shipping intensity raster provided by Metria (not used because fully covered by the Danish data).
- Germany: No shipping data received. Thus, global data set described in Halpern et al. (2008) was used.

Spatial extent	Norwegian, Danish, Swedish and German North Sea

Lineage and data quality

First, the national data sets were prepared:

- Denmark: Shipping density was provided as a ready-made raster. It was resampled to 1 km spatial resolution and LAEA-ETRS1989 projection (corresponding to the EEA's 1 km reference grid). These data covered the Swedish and also parts of the German and Norwegian North Sea.
- Sweden: The Swedish part of the North Sea was fully covered by the Danish data set and thus, no Swedish data were used.
- Germany: No national data were received. Thus, a global data set (see "Data sources") was resampled exactly like the Danish data.
- Norway: Data were provided as AIS points for one year. However, most points were not having a timestamp or another indication of their order, and it was thus impossible to convert the points to ship tracks. Instead, the number of recorded points in each cell of the EEA's 1 km reference grid was counted. In spite of this coarse approach, major shipping routes could be identified, but in areas with few ships, using points instead of tracks resulted in a "salt and pepper" effect.

Because the Danish data stretched into Norwegian and German waters, they were used to rescale these other data sets. For this purpose, an area well covered by both data sets was extracted, zeros in either data set were removed and a linear regression equation passing through the origin was calculated. By this equation, the Norwegian data were rescaled to match the Danish data. The German data were rescaled in a similar way, but they fitted the Danish values much worse, probably because of the coarser and less accurate global data set from which they were extracted.

Finally, all three data sets were mosaicked using a smooth blending function. The Danish part of the study area is covered by the Danish data set, the German part by the global data set, and the Norwegian part by a blend of the Danish and the Norwegian data set up to a few kilometres from the boundary, and the Norwegian data alone further away.

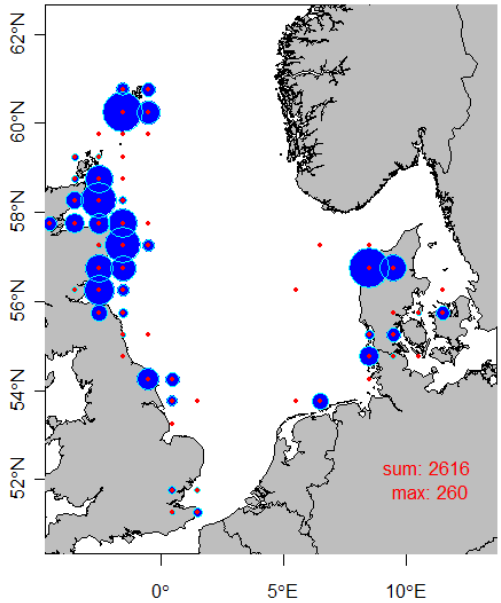
To account for potential impacts on the sea bottom, the final shipping data set was split up into two layers (shipping in shallow waters, shipping in deep waters), using 10m water depth as a threshold.	
Scale or resolution	1 km
Time period covered	2008 (Norway), 2009 (Denmark, Sweden), October 2004 – October 2005 (global/German data)
Data access	Contact the HARMONY team. Original data: See “Data sources”. Owners’ permissions are needed for Norwegian and Danish data. Halpern et al. (2008): http://www.nceas.ucsb.edu/globalmarine/impacts.
Additional information sources	Global data set used for German waters: http://www.sciencemag.org/content/suppl/2008/02/12/319.5865.948.DC1.fullService.

Fishery effort from the Dregde segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on “hours fished” by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The dredge segment fish mainly for scallops and blue mussels.

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessels seems to be missing, such that the coastal fishing effort becomes underestimated. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported “hours fished” by ICES rectangle. No kW-days data were available for the < 10 m vessel group for which there exist efforts from most countries. To estimate kW-days for that group, it is assumed that one “hour fished” for vessel < 10 m is 75% of the pressure for a 10-15 m vessel.

Norwegian data were not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

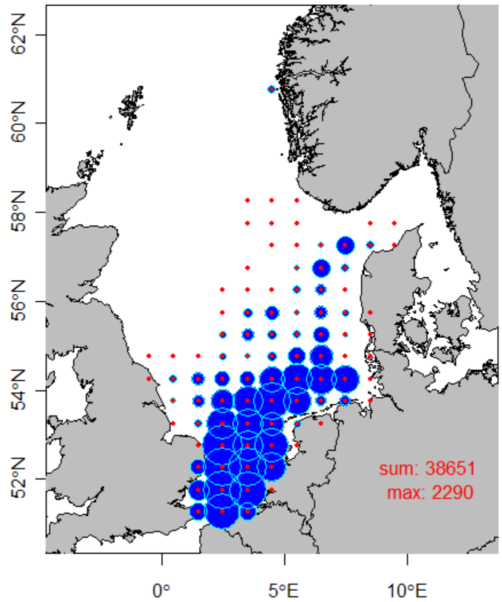
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See “Data sources”. Estimation of spatial kW-days effort: contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the beam trawl > 80 mm segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on "hours fished" by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The BT > 80 segment includes beam trawl with meshes ≥ 80 mm fishing mainly for sole and plaice.

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG were used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however, data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessel seems to be missing, such that the coastal fishing effort becomes an underestimate. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported "hours fished" by ICES rectangle. No kW-days data are available for the < 10 m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it is assumed that one "hour fished" for vessel < 10 m is 75% of the pressure for a 10-15 m vessel.

Norwegian data are not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

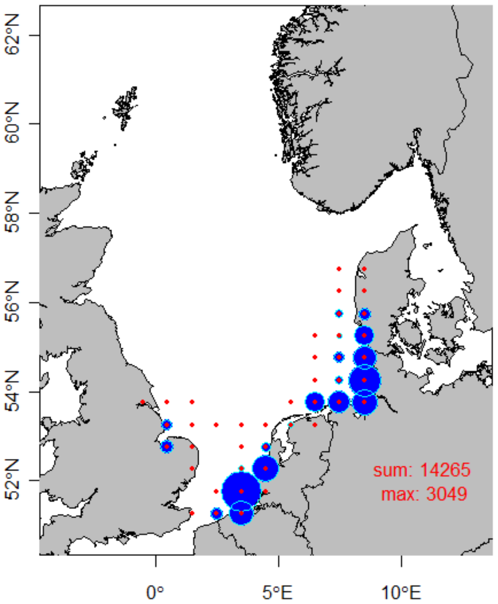
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See "Data sources". Estimation of spatial kW-days effort: Contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the small-meshed beam trawl (*Crangon crangon*) segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on “hours fished” by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The BT-Crangon segment includes small meshed beam trawl fishing for brown shrimps (*Crangon crangon*).

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however, data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessels seems to be missing, such that the coastal fishing effort becomes underestimated. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported “hours fished” by ICES rectangle. No kW-days data were available for the < 10m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it was assumed that one “hour fished” for vessel < 10 m is 75% of the pressure for a 10-15 m vessel. Norwegian data were not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

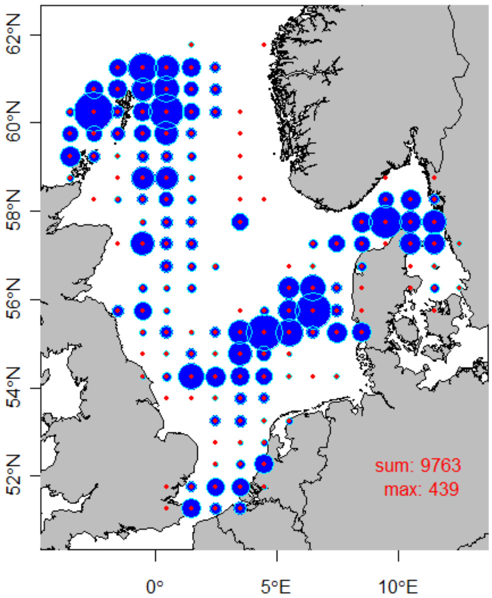
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See “Data sources”. Estimation of spatial kW-days effort: Contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the pelagic segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on “hours fished” by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The pelagic segment includes pelagic trawl and purse seine fishing mainly for herring and mackerel.

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessel seems to be missing, such that the coastal fishing effort becomes an underestimate. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported “hours fished” by ICES rectangle. No kW-days data were available for the < 10m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it is assumed that one “hour fished” for vessel < 10 m is 75% of the pressure for a 10-15 m vessel. Norwegian data were not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

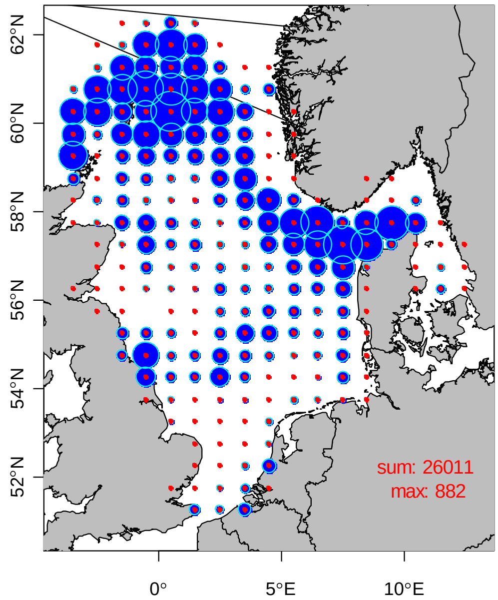
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See “Data sources”. Estimation of spatial kW-days effort: Contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the TR1 (demersal trawl and seine with meshes ≥ 100 mm) segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on “hours fished” by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The TR1 segment includes demersal trawl and seine with meshes ≥ 100 mm fishing mainly for roundfish.

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessel seems to be missing, such that the coastal fishing effort becomes an underestimate. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported “hours fished” by ICES rectangle. No kW-days data were available for the < 10m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it was assumed that one “hour fished” for vessel < 10 m is 75% of the pressure for a 10-15 m vessel. Norwegian data were not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

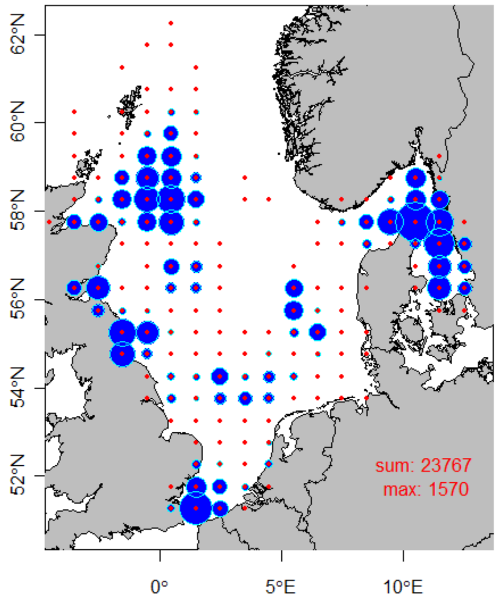
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See “Data sources”. Estimation of spatial kW-days effort: contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the TR2 (trawl with 70-99 mm meshes) segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on "hours fished" by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The TR2 segment includes trawl with 70-99 mm meshes in the cod end, fishing mainly for Nephrops.

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessel seems to be missing, such that the coastal fishing effort becomes an underestimate. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported "hours fished" by ICES rectangle. No kW-days data were available for the < 10 m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it was assumed that one "hour fished" for vessel < 10 m is 75% of the pressure for a 10-15 m vessel. Norwegian data were not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

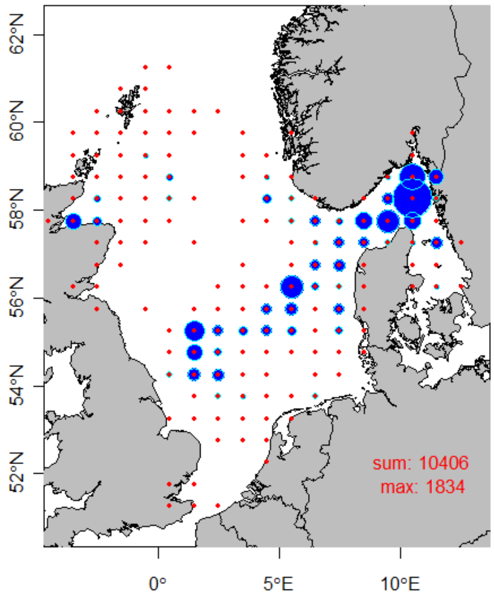
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See "Data sources". Estimation of spatial kW-days effort: Contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the "other trawl" segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on "hours fished" by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The "Other trawl" segment includes small meshes trawl fishing mainly for industrial species and *Pandalus*.

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however, data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessel seems to be missing, such that the coastal fishing effort becomes an underestimate. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported "hours fished" by ICES rectangle. No kW-days data were available for the < 10 m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it was assumed that one "hour fished" for vessel < 10 m is 75% of the pressure for a 10-15 m vessel. Norwegian data were not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

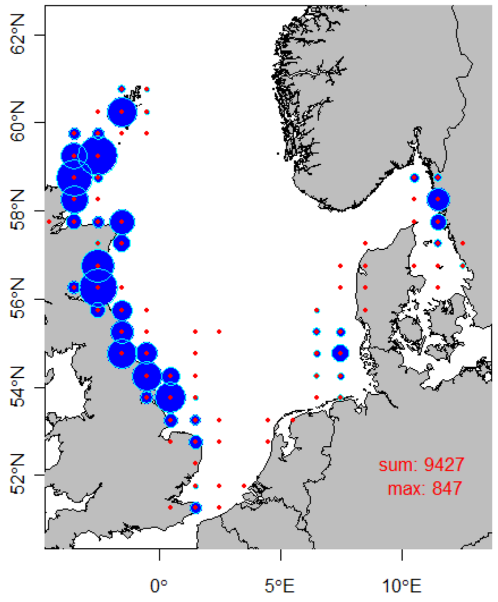
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See "Data sources". Estimation of spatial kW-days effort: Contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the pots and traps segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on "hours fished" by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data are not available.

The pots and trap fishery are mainly coastal and small scale fisheries targeting crustacean (e.g. lobster, Nephrops, brow crabs and spider crabs), molluscs (e.g. whelks and cuttlefish) and fish (e.g. eels).

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and must be considered as high quality data. The quality of the total effort by segment and area are high; however, data with higher spatial resolution (ICES rectangles) are not required for management purposes and the quality might be much lower. In some cases effort from small vessel seems to be missing, such that the coastal fishing effort becomes an underestimate. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported "hours fished" by ICES rectangle. No kW-days data are available for the < 10 m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it is assumed that one "hour fished" for vessel < 10 m is 75% of the pressure for a 10-15 m vessel. Norwegian data are not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

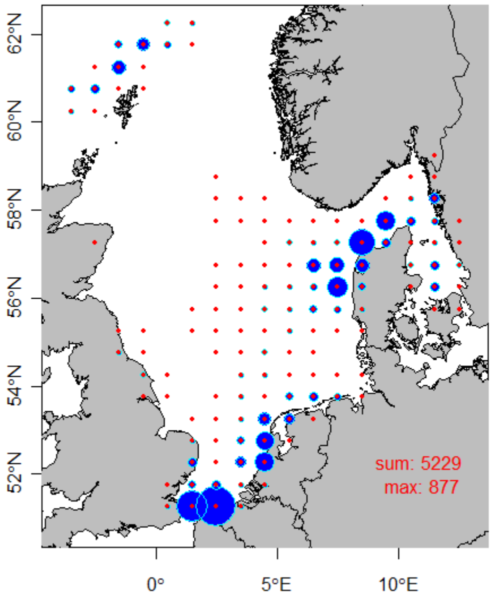
Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See "Data sources". Estimation of spatial kW-days effort: Contact DTU Aqua, Denmark.
Additional information sources	None.

Fishery effort from the set net segment

Effort data (kW-days) by fleet segment and ICES rectangle were estimated from total national effort (kW-days) by management area and information on “hours fished” by ICES rectangles. Basic effort data have initially been collated for management purposes by the STECF-SGMOS Effort Management Working Group. Norwegian effort data were not available.

The set net segment includes all types and mesh sizes of set nets fishing for sole (southern NS and Kattegat), cod and plaice (central NS) and monkfish (north eastern NS).

On the figure, the area of the dots is proportional to effort. The total effort (Mega Watt Days) and the maximum effort per ICES rectangle are shown. A red dot indicates that effort has been recorded for the given ICES rectangle.



Data sources

- Anon. 2011, (DRAFT) Report of the SGMOS-10-05 Working Group on Fishing Effort Regimes, Regarding Annexes IIA, IIB and IIC of TAC & Quota Regulations, Celtic Sea and Bay of Biscay. 27 September – 1 October 2010, Edinburgh Scotland. 355 pp. Effort data are available from: https://stecf.jrc.ec.europa.eu.

Spatial extent	Greater North Sea

Lineage and data quality

The quality of the total effort is high, but the spatial distribution of effort should be considered as preliminary. Effort data collated by the STECF SGMOS WG are used for fisheries regulation within the European Union and can be considered as high quality data. The quality of the total effort by segment and area are high; however, data with higher spatial resolution (ICES rectangles) are not used for these management purposes and the quality might be much lower. In some cases effort from small vessel seems to be missing, such that the coastal fishing effort becomes an underestimate. Spatial distributed effort is derived from reported kW-days by country, area and gear segment, and reported “hours fished” by ICES rectangle. No kW-days data were available for the < 10 m vessel group for which there exist spatial efforts from most countries. To estimate kW-days for that group, it was assumed that one “hour fished” for vessel < 10 m is 75% of the pressure for a 10-15 m vessel. Norwegian data were not available through the EU WG. Spatial effort information could not be obtained from other sources.

For calculating the impact index, fishing efforts were divided by the sea area of the respective ICES rectangles (kW days per km^2), ignoring that some parts of the sea are not fished (e.g. too shallow). Note that the coarse resolution of the fisheries data somewhat limit the accuracy of predicted impacts from fisheries.

Scale or resolution	ICES rectangles 1.0 degree longitude x 0.5 degree latitude
Time period covered	2009
Data access	Original data: See “Data sources”. Estimation of spatial kW-days effort: Contact Morten Vinther, DTU Aqua, Denmark.
Additional information sources	None.

Appendix C - Online survey: By ecosystem component

To which components of the North Sea Ecosystem do your responses apply? Please fill in the survey for all ecosystem components for which your expertise allows you to make judgements. You can only submit responses for one ecosystem component at a time. For example, you might want to fill in the survey for all three marine mammal species listed below. In this case, start with filling in the survey for the first species (e.g. harbour porpoise) and submit your response. Then, change the ecosystem component to the next species (e.g. minke whale). Your replies for harbour porpoises will still be set. Adjust the replies as needed for minke whales, then submit the survey again.

If you need a break in taking the survey, you can submit your replies and later reload them using the "load last replies" button below. You can also use this function to update your earlier replies. You can make a safety copy of your replies by submitting your replies (using the button at the bottom of the site) at any time while replying to the survey.

For which ecosystem component are you filling the survey in?

[*followed by a list of the ecosystem components, of which one could be chosen*]

If you have already submitted the questionnaire for the ecosystem component you chose, you can reload your last replies using the button below. You can use this function to resume filling in the survey after a break, to reload your replies for updating or to use them as a foundation for filling in the survey for another ecosystem component.

Load replies for this ecosystem component

How many years of work or research experience do you have in relation to this ecosystem component?

Sensitivity to human activities

The purpose of this part of the online survey is to find out which human activities have the greatest potential negative impacts where they coincide with the ecosystem component in question. Please read the instructions carefully.

Below, you will find a list of several human activities or infrastructure, such as commercial shipping and marine construction works. Please go through the activities one by one and rate their potential impacts in the six-step approach described below.

STEP 1. For each activity, you can choose up to two ***pressures*** (e.g. noise, introduction of microbial pathogens) by which it affects the ecosystem component. If you think that the activity causes more than two pressures affecting the ecosystem component, please choose the two pressures to which you find that the ecosystem component is the most vulnerable. For example, if you are filling out the survey for minke whales, you may choose that the activity ″commercial shipping″ affects the whales mostly by two pressures: ″physical collisions″ and ″noise″. If you think that these are the two most important pressures by which commercial shipping in the North Sea affects minke whales, this is what you should choose. Of course, if you think that the activity affects the ecosystem component mostly by causing only one pressure, leave the second pressure blank. Similarly, if you think that the impacts of the activity on the ecosystem component are negligible, just skip the activity without filling in any fields other than your confidence in this judgement.

Most of the pressures you can choose from are defined in the Marine Strategy Framework Directive, we have however added some additional pressures such as physical collisions. See here [*link to table with pressure descriptions as in Table 1*] for a description of the pressures. Furthermore, some human activities are clearly related to a certain pressure in the Marine Strategy Framework Directive, and some pressures are caused by global changes rather than particular activities. In these cases, we have pre-chosen a pressure, and would be glad if you could fill in the fields for this pre-chosen activity-pressure combination. For example, the activity "oil spills" (of course, spilling oil is not an activity in a strict sense) has the pre-chosen pressure "Introduction of hazardous substances: non-synthetic substances and compounds".

STEP 2. Once you chose a pressure, you should judge how far from the location of the activity the pressure will occur. We call this the ***Pressure distance***. In the minke whale example, in order for a collision to occur, the whale and the ship have to be in the same location, and thus the pressure distance should be ″*local*″. In contrast, noise can travel large distances in water, and consequently, you should set the *pressure distance* for noise to the greatest distance at which you think that the noise from passing ships will still have a diminished but significant impact on the whales.

STEP 3. In this step, you are asked to rate the the ***Impact extent***. Does the pressure cause harm on the level of individuals, or are there effects on the population or even community level? Consider, for example, the impact of fisheries on a given fish species. The activity ″Fisheries: Pelagic trawl and seiners″ would cause the pressure ″Biological disturbance: Extraction of living resources″. Clearly, *individuals* are affected; but at a typical intensity of effort in the North Sea, does the extraction of individuals lead to effects on the *population* level, such as a significant decline in numbers, or changes in age and size structure? And do these lead to further effects at the *community* level, such as a change in species composition?

STEP 4. In this step, you will rate the ***Impact level***. It describes the degree to which the ecosystem component is affected by the pressure and ranges from ″*minor disturbance*″ to ″*devastating/lethal*″. This aspect is a measure of both the intensity of the pressure, caused by the activity at its typical intensity and frequency, and the sensitivity of the ecosystem component. For instance, harbour porpoises are sensitive to noise. If you think that marine construction works cause much noise, you may judge that this is a major disturbance. Also recreational shipping causes the pressure ″noise″. However, you may think that it typically doesn't cause enough noise to be a ″*major disturbance*″, and thus rate its impact level as ″*medium disturbance*″ or ″*minor disturbance*″. The impact level should be defined in close vicinity of the pressure source, not as an average over the pressure distance.

STEP 5. In this step you are asked to estimate the ***Recovery time***, that means the time it typically takes for the ecosystem component to recover after it has been affected by the activity/pressure. For example, how long does it take for a certain benthic habitat affected by physical damage from bottom trawling to return to its natural state? Please relate the recovery time to the impact level. For example, a fish does not recover from being caught; however, if you have rated the impact extent of a certain fishery as ″population″ or ″community″, think of the time it takes the population or community to return to their natural state once the pressure ceases. For permanent pressures - e.g. sealing of the seabed due to the fundaments of wind turbines - please choose the longest recovery time.

STEP 6. Last but not least, please indicate your ***Confidence*** in your judgement. The confidence score should reflect the basis on which you base your answer, which is both your personal level of expertise and the amount and quality of the information on which you base your answer. Please check this document [*link to the document in Appendix E*] for more examples.

In general, when filling in the survey, you should imagine the human activities as they typically occur in the eastern North Sea. For instance, when filling in the survey for fish farms, imagine a typical fish farm, neither extremely big nor small. For commercial shipping, you should think of a busy, but not extraordinarily busy, shipping route. Also, assume that the activity and the ecosystem component occur together in the same place. As an example, if you know that an ecosystem component does not naturally occur close to any existing offshore wind farms, this does not mean that you should give it low sensitivity values. Instead, rate its sensitivity for the (hypothetical) case that the activity and the ecosystem component DO occur in the same place, and the activity is at a typical intensity and frequency.

Please consider each human activity, even if you're not sure of its potential impacts. By default, all activities are set not to cause any pressures or impacts on the ecosystem component. If you agree, just set the confidence. You can also indicate that you don't know if the activity can have an impact on the ecosystem component. In this case, you don't need to fill in any of the fields for this activity. However, if you have an opinion on if the human activity causes a pressure on the ecosystem component for which you're filling in the survey, but you're not sure, it's better to give your best estimate with the confidence set to low, rather than just keeping the default "no impact" setting or using the "don't know" option.

[*followed by the list of ecosystem components as in the example in Figure 8*.]

As a final summary, which three pressures do you think pose the greatest threat to the ecosystem component for which you are filling in the survey? The order doesn't matter.

no pressure

no pressure

no pressure

And which three pressures do you think pose the greatest threat to the North Sea ecosystem in general (NOT any particular ecosystem component)? The order doesn't matter. If you already filled in these fields earlier, you may leave them blank.

no pressure

no pressure

no pressure

Comments
[Text box for comments]

Submit replies
[Submit button]

Thank you very much for taking the time to fill in our survey! Please click the "Submit replies" button below to send your replies to us.

Appendix D - Online survey: By human activity

Please fill in the survey for all human activities for which your expertise allows you to make judgements, also if the activity has only negligible impacts on the marine environment in your opinion (this is something we would like to know!).

You can only submit responses for one activity at a time. For example, if you're a fisheries expert, you might want to fill in the survey for all types of fisheries listed below. In this case, start with filling in the survey for the first fishery type (e.g. "Fishery for scallops and blue mussels using dredge") and submit your response. Then, change the activity to the next fishery type (e.g. "Pots and traps"). Your replies for the dredge fisheries will still be set. Adjust the replies as needed for pots and traps, then submit the survey again.

If you need a break in taking the survey, you can submit your replies and later reload them using the "Load last replies" button below. You can also use this function to update your earlier replies.

For which human activity are you filling in the survey? Human activities marked with * require the choice of a specific pressure. See the continued instructions below for more information.

[*Followed by a list of human activities, of which one could be chosen. It was also possible to define an "own" human activity if the respondents thought that we were missing something important.*]

If you have already submitted the questionnaire for the activity you chose above, you can reload your last replies using the button below. You can use this function to resume filling in the survey after a break, to reload your replies for updating or to use them as a foundation for filling in the survey for another activity.

Load replies for this human activity

How many years of work or research experience do you have in relation to this human activity?

Impacts on the ecosystem components

The purpose of this part of the online survey is to find out which components of the North Sea ecosystem (broad-scale coastal ecosystems, benthic habitats and their communities, plankton communities and selected species of fish, birds and marine mammals) could be negatively impacted by the human activity for which you are filling in the survey. Please read the instructions carefully.

Below, you will find a list of the ecosystem components. Please go through the ecosystem components one by one and rate the potential impacts of the human activity you chose above, following the six-step approach described below.

STEP 1. For each ecosystem component, you can choose up to two ***pressures*** (e.g. noise, introduction of microbial pathogens) by which the human activity affects it. If you think that the activity causes more than two pressures affecting the ecosystem component, please choose the two pressures to which you find that the ecosystem component is the most vulnerable. For example, if you are filling out the survey for ″commercial shipping″, you may choose that it mostly affects the ecosystem component ″minke whales″ by two pressures: ″physical collisions″ and ″noise″. If you think that these are the two most important pressures by which commercial shipping in the North Sea affects minke whales, this is what you should choose. Of course, if you think that the activity affects the ecosystem component mostly by causing only one pressure, leave the second pressure blank. Similarly, if you think that the impacts of the activity on the ecosystem component are negligible, just skip the ecosystem component without filling in any fields other than your confidence in this judgement.

Most of the pressures you can choose from are defined in the Marine Strategy Framework Directive, we have however added some additional pressures such as physical collisions. See here [link to document describing the pressures, as in Table 1] for a description of the pressures. Furthermore, some human activities are clearly related to a certain pressure in the Marine Strategy Framework Directive. Such human activities are marked with a * in the list above. If you fill in the survey for one of these activities, please choose the following pressures for each ecosystem component on which the activity can have an impact. For example, the activity ″oil spills″ (of course, spilling oil is not an activity in a strict sense) must always have the assigned pressure ″Introduction of hazardous substances: non-synthetic substances and compounds″.

Activity	**Pressure**
Oil spills	Introduction of hazardous substances: Non-synthetic
Increased sedimentation from land (e.g. because of deforestation)	Physical damage: Siltation changes
Decreased sedimentation from land (e.g. because of river dams)	Physical damage: Siltation changes
Acidification	Others: Changes in pH
Ocean warming	Hydrological interference: Thermal changes
Increased UV radiation	Others: Electromagnetic disturbance
Riverine inputs of organic matter	Nutrient and organic matter enrichment: Organic matter

Activity	Pressure
Riverine inputs, direct discharges and atmospheric deposition of nutrients	Nutrient & organic matter enrichment: Nutrients
Riverine inputs, direct discharges and atmospheric deposition of heavy metals	Introduction of hazardous substances: Non-synthetic
Riverine inputs, direct discharges and atmospheric deposition of radio-nuclides	Introduction of hazardous substances: Radio-nuclides
Riverine inputs, direct discharges and atmospheric deposition of PCBs	Introduction of hazardous substances: Synthetic
Riverine inputs, direct discharges and atmospheric deposition of PAHs	Introduction of hazardous substances: Synthetic
Riverine inputs, direct discharges and atmospheric deposition of other synthetic compounds	Introduction of hazardous substances: Synthetic

STEP 2. Once you chose a pressure, you should judge how far from the location of the activity the pressure will occur. We call this the ***Pressure distance.*** In the minke whale example, in order for a collision to occur, the whale and the ship have to be in the same location, and thus the pressure distance should be ″**local**″. In contrast, noise can travel large distances in water, and consequently, you should set the **pressure distance** for noise to the greatest distance at which you think that the noise from passing ships will still have a diminished but significant impact on the whales.

STEP 3. In this step, you are asked to rate the ***Impact extent***. Does the pressure cause harm on the level of individuals, or are there effects on the population or even community level? Consider, for example, the impact of fisheries on a given fish species. The activity ″Fisheries: Pelagic trawl and seiners″ would cause the pressure ″Biological disturbance: Extraction of living resources″. Clearly, **individuals** are affected; but at a typical intensity of effort in the North Sea, does the extraction of individuals lead to effects on the **population** level, such as a significant decline in numbers, or changes in age and size structure? And do these lead to further effects at the **community** level, such as a change in species composition?

STEP 4. In this step, you will rate the ***Impact level***. It describes the degree to which the ecosystem component is affected by the pressure and ranges from ″**minor disturbance**″ to ″**devastating/lethal**″. This aspect is a measure of both the intensity of the pressure, caused by the activity at its typical intensity and frequency, and the sensitivity of the ecosystem component. For instance, harbour porpoises are sensitive to noise. If you think that marine construction works cause much noise, you may judge that this is a major disturbance. Also recreational shipping causes the pressure ″noise″. However, you may think that it typically doesn't cause enough noise to be a ″**major**

disturbance", and thus rate its impact level as "**medium disturbance**" or "**minor disturbance**". The impact level should be defined in close vicinity of the pressure source, not as an average over the pressure distance.

STEP 5. In this step you are asked to estimate the ***Recovery time*,** that means the time it typically takes for the ecosystem component to recover after it has been affected by the activity/pressure. For example, how long does it take for a certain benthic habitat affected by physical damage from bottom trawling to return to its natural state? Please relate the recovery time to the impact level. For example, a fish does not recover from being caught; however, if you have rated the impact extent of a certain fishery as "population" or "community", think of the time it takes the population or community to return to their natural state once the pressure ceases. For permanent pressures - e.g. sealing of the seabed due to the fundaments of wind turbines - please choose the longest recovery time.

STEP 6. Last but not least, please indicate your ***Confidence*** in your judgement. The confidence score should reflect the basis on which you base your answer, that is both your personal level of expertise and the amount and quality of the information on which you base your answer.

Please check this document [*link to descriptions in Appendix E]* for more examples.

<u>In general, when filling in the survey, you should imagine the human activities as they typically occur in the North Sea. For instance, when filling in the survey for fish farms, imagine a typical fish farm, neither extremely big nor small. For commercial shipping, you should think of a busy, but not extraordinarily busy, shipping route. Also, assume that the activity and the ecosystem component occur together in the same place. As an example, if you know that an ecosystem component does not naturally occur close to any existing offshore wind farms, this does not mean that you should give it low sensitivity values. Instead, rate its sensitivity for the (hypothetical) case that the activity and the ecosystem component DO occur in the same place, and the activity is at a typical intensity and frequency.</u>

<u>Please consider each ecosystem component</u>, even if you're not sure about potential impacts from the activity for which you are filling in the survey. By default, all ecosystem components are set to not being affected by the activity. If you agree, just set the confidence. You can also indicate that you don't know if the activity can have an impact on the ecosystem component. In this case, you don't need to fill in any of the fields for this ecosystem component. However, if you think that the activity causes a pressure on the ecosystem component in question, but you're not sure, it's better to give your best estimate with the confidence set to low, rather than keeping the default "no impact" setting or using the "don't know" option.

[*followed by the list of ecosystem components as in the example in Figure 8.*]

As a final summary, which three pressures do you think pose the greatest threat <u>to the North Sea ecosystem in general (NOT any particular ecosystem</u>

component)? The order doesn't matter. If you already filled in these fields earlier, you may leave them blank.

no pressure

no pressure

no pressure

Comments
[Text box for comments]

Submit replies
[Submit button]

Thank you very much for taking the time to fill in our survey! Please click the "Submit replies" button below to send your replies to us.

Appendix E - Online survey: Additional explanations for sensitivity criteria

Field	Meaning for broad-scale habitats, communities, coastal ecosystems	Meaning for species
Pressure distance	How far from the location of the activity will the pressure diminish to a negligible level, given the sensitivity of the community, habitat or the coastal ecosystem as a whole? For instance, a wind turbine may affect benthic habitats and their communities by the pressure "sealing", which is local (only the area under the wind turbine's foundation is sealed). In contrast, pollutants released by an activity can be transported and may affect benthic communities far away from the site of the activity causing the pollution, and thus the pressure distance should be rather large.	How far from the location of the activity will the pressure diminish to a negligible level, given the sensitivity of the species? For instance, a wind turbine may affect a given bird species by the pressure "physical collisions", which is local (if the bird is just 20m away from the wind turbine, they still don't collide). In contrast, oil spills travel and may affect birds far away from where the spills originally occurred, and thus the pressure distance should be rather large.
Impact extent	Does the pressure cause harm on the level of individuals, or are there effects on the population or even community level? Consider, for example, the impact of bottom trawling on a given benthic habitat and its community. Clearly, **individuals** of different benthic species are killed or damaged. But does bottom trawling lead to lasting changes at the level of one or more benthic *populations*? And does it even have an effect on the whole benthic *community*, e.g. because the effects on populations disrupt the trophic network or the habitat is physically strongly altered (e.g. complete destruction of structurally important macroflora)?	Does the pressure cause harm on the level of individuals, or are there effects on the population or even community level? Consider, for example, the impact of fisheries on a given fish species. The activity "Fisheries: Pelagic trawl and seiners" would cause the pressure "Biological disturbance: Extraction of living resources". Clearly, **individuals** are affected; but at a typical intensity of effort in the North Sea, does the extraction of individuals lead to effects on the **population** level, such as a significant decline in numbers, or changes in age and size structure? And do these lead to further effects at the **community** level, such as a significant change in species composition?
Impact level	How strongly are the community and its habitat, or the coastal ecosystem, affected? This aspect is a measure of both the intensity of the pressure, caused by the activity at its typical intensity and frequency, and the sensitivity of the ecosystem component. A *minor disturbance* means that the habitat and its biological community are negatively affected, but no major changes are caused. An example for a *minor disturbance* could be temporary thermal changes due to cooling water emissions, which might mean thermal stress for some species. In contrast, a *medium disturbance* would mean that the thermal stress more strongly affects important species or physical properties, and may also lead to a greater	How strongly is the species affected? This aspect is a measure of both the intensity of the pressure, caused by the activity at its typical intensity and frequency, and the sensitivity of the ecosystem component. For instance, harbour porpoises are sensitive to noise. If you think that marine construction works cause much noise, you may judge that this is a *major disturbance*. Also recreational shipping causes the pressure "noise". However, you may think that it typically doesn't cause enough noise to be a "**major disturbance**", and thus rate its impact level as "**medium disturbance**" or "**minor disturbance**". The impact level should be defined in close vicinity of the pressure source, not as an

Field	Meaning for broad-scale habitats, communities, coastal ecosystems	Meaning for species
	vulnerability to other stressors such as invasions by non-native species. A *major disturbance* would mean that the community and habitat are strongly affected, resulting in considerable and not easily reversible changes compared to its natural state. Ultimately, the impact level should be set to *devastating/lethal* if the habitat and its community is completely destroyed by the activity at its typical intensity (e.g. a benthic habitat under the foundation of a wind turbine). The impact level should be defined in close vicinity of the pressure source, not as an average over the pressure distance.	average over the pressure distance.
Recovery time	How long does it typically take for the community, its habitat or the coastal ecosystem to recover after it has been affected by the activity/pressure, assuming that the pressure stops? For instance, how long does it take a given benthic habitat and its community to return to a natural state after a bottom trawl? For permanent pressures - e.g. sealing of the seabed due to the fundaments of wind turbines - please choose the longest recovery time.	How long does it typically take for individuals, the population or community to recover after it has been affected by the activity/pressure, assuming that the pressure stops? If you rate the recovery time for species, please relate it to the impact level. For example, a fish does not recover from being caught; however, if you have rated the impact extent of a certain fishery as ”population” or ”community”, think of the time it takes the population or community to return to their natural state once the pressure ceases. For permanent pressures - e.g. sealing of the seabed due to the fundaments of wind turbines - please choose the longest recovery time.

Appendix F - Gap-filling for fish distribution layers

The main sources for mapping the distribution and density of fish species were the ICES coordinated IBTS, BTS and BITS survey. These surveys cover areas with water depth in the range 5-225 m. Most coastal areas, for example fjords, were not covered. Likewise, observations from the deeper parts of the North Sea and Skagerrak, e.g. the Norwegian trench, were missing.

The densities of fish populations were estimated from spatial GAM models of survey CPUE with location and water depth as the main explanatory variables. Based on bathymetric maps, the densities in the full area could then be calculated (see the data sheets for fish biomass). Predictions outside the observed depth and spatial range are very uncertain, and give in most cases unrealistic results. As an alternative, the densities in the area outside the survey coverage were estimated from the densities in the surrounding areas and the biology of the species. These estimates are only made for the offshore and deeper part of the North Sea and Skagerrak lacking data. Within this area, only one estimate was used without out considering the depth variation within the area.

1. **Cod**: According to the prediction, cod biomass is highest (density index is 3-5 times the average density) at the slope (100-200m) of the Norwegian trench. Cod occurs down to depth of 500-600 m. The density in the deep part is estimated to 1.

2. **Haddock**: The biomass of haddock is highest in the north western part of the North Sea. Along the Norwegian trench, the biomass index is less than 0.5. Haddock occurs in general at 10-200 m depth. The density in the deep part is estimated to 0.1.

3. **Saithe**: The biomass index of saithe is highest (> 10) along the slopes of the trench at depth of around 200 m. The distribution of the catches (ICES WGNSSK, 2011) follows closely the predicted distribution, and only limited catches are taken in the deeper part of the trench. The biomass index for the trench area is guesstimated to 5.

4. **Norway pout**: The biomass index is highest in the north western part of the North Sea. Along the trench the biomass index is estimated in the range 2-10. Norway pout lives mainly at depths of 40-300 m. The biomass index for the trench is estimated as 3.

5. **Plaice**: The species is mainly found in the eastern part of the central North Sea. The species is in general found at depths of 20-50 m but occurs down to 200 m. The density index in the trench area is set to 0.05.

6. **Dab**: The biomass index of dab is highest in the central North Sea. The species is mainly found in shallow waters. The biomass index in the trench area is set to 0.

7. **Herring**: The biomass distribution of the pelagic herring is highly seasonal. The mean annual biomass index shows the highest concentrations (index 3-4) in the north western part of the North Sea and in the southern Kattegat. Catch distribution (ICES HAWG, 2011) follows largely the estimated index. Catches in the trench area are in general low except for the eastern part of the Skagerrak area. The biomass index in the trench area is set to 1.

8. **Rays and skates**: The distribution of the biomass index reflects the contributions from the different species of rays and skates. *Raja clavata* is most common in the south eastern part of the North Sea while smaller species like *Amblyraja radiate* and *Leucoraja naevus* dominates the relative high index in the central and western North Sea. Catches of mainly *Dipturus linteus* are still taken from the trench area. The index in the trench area is set to 1.

HUMAN USES, PRESSURES AND IMPACTS IN THE EASTERN NORTH SEA

This study reports a first attempt to map human activities, pressures and potential cumulative impacts in the eastern parts of the North Sea, including Skagerrak, Kattegat and the northern parts of the Sound. The mapping is based on existing data on human activities in Denmark, Germany, Norway and Sweden. In addition, we have collated map on ecosystem components, e.g. broad-scale benthic habitats, fish, birds and marine mammal. In order to link human activities and ecosystem component, an online survey was carried out involving exports form the countries involved in the study. The estimated potential impacts were highest in the German Bight, the Sound and in the coastal water of the Kattegat, whilst the lowest impacts were estimated for the western and northern parts of the study area. The results can be used for the initial assessment sensu the EU Marine Strategy Framework Directive.

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