HELCOM

Spatial distribution of pressures and impacts

Thematic assessment 2016–2021

Baltic Marine Environment Protection Commission

THIRD HELCOM HOLISTIC ASSESSMENT OF THE BALTIC SEA 2016–2021
HOLAS 3

Spatial distribution of pressures and impacts

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What is HELCOM?

Preface

By their nature, many environmental problems transcend political, legal and other anthropogenic boundaries, and thus cannot be adequately solved by individual countries alone. Regional Seas Conventions (RSCs) such as the Convention on the Protection of the Marine Environment of the Baltic Sea Area establish legal frameworks for necessary transboundary cooperation.

The Helsinki Commission (HELCOM) is an intergovernmental body composed of the Baltic Sea coastal states and the EU, and functions as the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. HELCOM functions as a regional platform for cooperation with a broad spatial and sectoral reach, working with biodiversity and protection, shipping, fisheries management, maritime spatial planning (MSP), pressures from land and sea-based activities and regional governance. Furthermore, HELCOM has a wide vertical and horizontal scope, with established structures for transboundary cooperation within and across levels of organization, ranging across technical experts, authorities, managers and national ministries. HELCOM is also an established provider of infrastructure to support both regional and national work, including functioning as the natural regional data hub and tool developer as well as providing concrete support for regional assessments, ensuring that regional coherence and an ecologically valid perspective is maintained.

Benefits of cooperation at the regional level:

- Benefitting from the expertise of others;
- Sharing of knowledge, information and resources;
- Improved effectiveness of measures due to regional coherence and mutually enforcing or synergistic actions;
- Action is taken at the ecologically relevant scale, i.e. the scale at which the environment functions.

HELCOM is...

Environmental policy maker

HELCOM develops common environmental objectives and actions

Environmental focal point

To help decision making in other international fora, HELCOM provides information about

- the state of and trends in the marine environment
- the efficiency of measures to protect it
- common initiatives and joint positions

Body for developing recommendations

HELCOM's own recommendations and those supplementary to measures imposed by other international organisations

Supervisory body

HELCOMS ensures that its environmental standards are fully implemented by all parties throughout the Baltic Sea and its catchment area

Coordinating body

HELCOM ascertains multilateral response in case of major maritime incidents

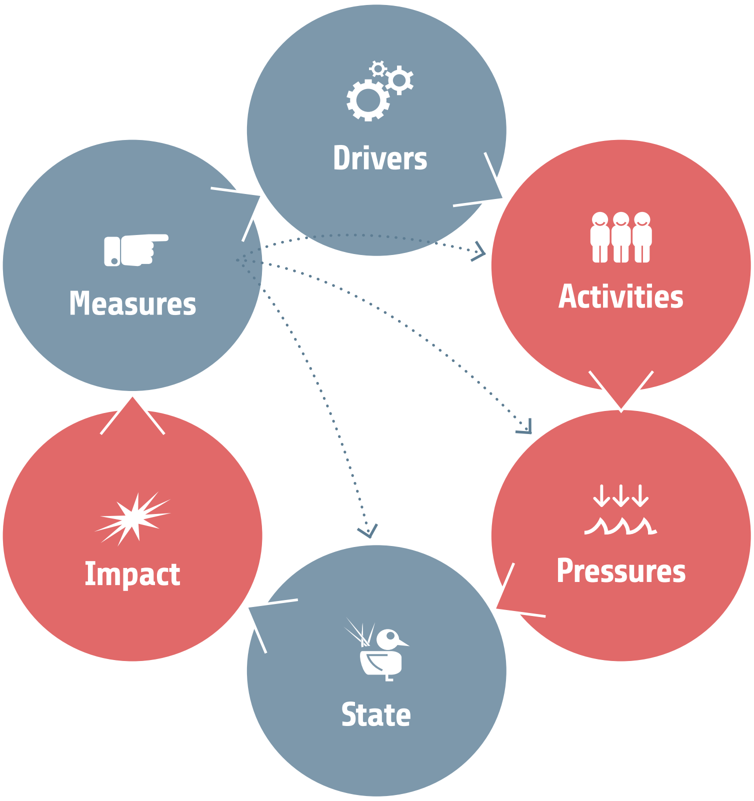


Figure P1. Conceptual overview of the management framework HELCOM works within.

Our activities at sea and on land cause pressures on the marine environment which in turn, to varying degrees, negatively impacts the ecosystem on which we all depend for our survival. These impacts cumulate and cascade through the ecosystem and eventually return to impact our wellbeing and that of society as a whole.

To limit the negative impact of our activities to within what the ecosystem can tolerate, we must understand what effects our actions have and then use that information to manage the activities which are causing negative impact. This is done through establishing well-founded and ecologically relevant targets and objectives to work towards and then taking concrete measures to ensure we reach them. Figure P1 shows the conceptual management framework HELCOM works within, and within which the holistic assessment is made. This is a regional version of the more common Driver-Activites-Pressures-Impacts-Response (DAPSIR) framework, which has been modified to fit the work under HELCOM.

Measures to improve the Baltic Sea environment are undertaken by many actors and at many levels, jointly at the global level, regionally at Baltic Sea level through HELCOM, by countries at national, county and local levels, and by initiatives in the private and public sector. The measures also differ in type, including technical improvements to minimise impact, economic and legislative measures, and measures directed towards raising awareness and incentives for changes in behaviour. In the Baltic Sea, where the transboundary aspects of environmental problems are highly evident, HELCOM plays a central role in coordinating the management objectives and their implementation in line with the Helsinki Convention.

In order to allow the tracking, and to get a comprehensive and accurate overview of progress towards set objectives and targets, as well as to see if our measures are working and sufficient, assessments need to be conducted. In order to better understand the ecosystem and our relationship with it, and to ultimately improve the environmental status of the sea, we need to map activities which affect the marine environment, analyse what effects these activities have and how strong these effects are, and assess what this means for the ecosystem.

When using assessment to track progress of measures and management, and identify possible gaps or barriers, this needs to be done in two ways. On the one hand, we need to assess the level of implementation of the agreed measures, i.e. has the agreed action actually been taken and to what degree. This tells us about possible implementation gaps and can help to identify unforeseen barriers or challenges that need to be addressed. In HELCOM this is achieved through regular reporting and the use of the HELCOM Explorer tool. On the other hand, we need to understand and track the actual effects that the implemented measures have on the marine environment. This helps us understand if the measures which have been put in place are sufficient to limit the negative impact of our activities. Where the measures turn out to not be sufficient, the knowledge we gain from the assessments enables us to identify new or improved measures, which can be more targeted, resource efficient and/or adaptive.

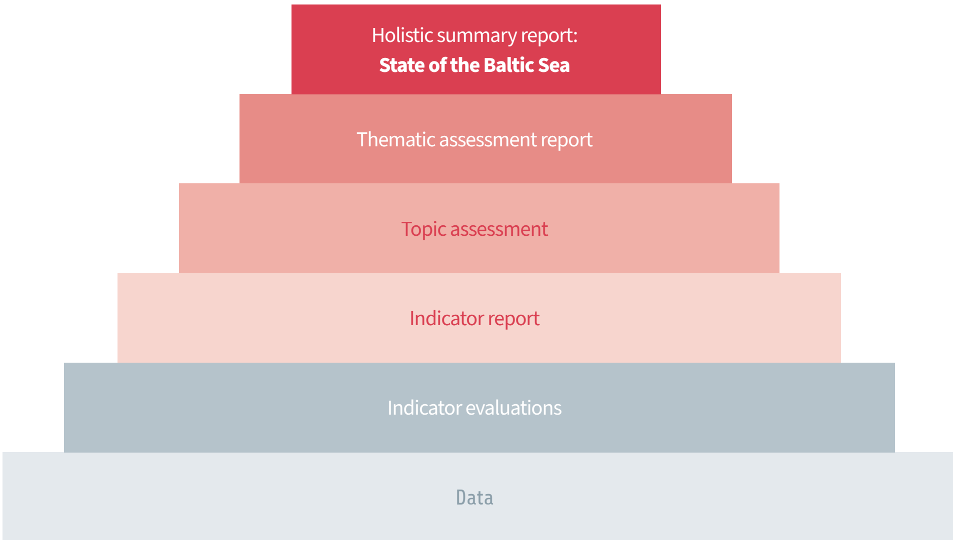


Figure P2. The structure and process of the HELCOM holistic assessment. Within the assessment structure, highly detailed results are progressively aggregated, allowing anyone to explore the results at whatever scale is most relevant to them and culminating in the overall summary report on the State of the Baltic Sea.

Assessments also help us understand what pressures and measures need to be addressed at what level. Our activities cause various types of pressures, the impact of which can vary spatially and temporally. However, because of how dynamic the marine environment is, the majority of pressures in the marine environment have transboundary impacts. For measures and management to be effective it therefore has to be implemented at an appropriate level and this often means that implementation need to be regional, i.e. the scale at which they need to be addressed in order to be effective goes beyond the national borders of one specific country.

HOLAS

The Holistic Assessment of the Status of the Baltic Sea (HOLAS) is a reoccurring, transboundary, cross-sectoral assessment which looks at the effect of our activities and measures on the status of the environment. The assessment is a product of HELCOM. The HOLAS assessment covers, or approaches, the main themes to be considered when taking an ecosystem approach to management and provides regular updates on the environmental situation in the Baltic Sea. Each report captures a 'moment' in the dynamic life history of the Baltic Sea. The report highlights a broad range of aspects under the overarching themes of the state of the ecosystem, environmental pressures and human well-being and contributes to a vast sharing and development of knowledge both within and across topics. The focus of the assessment is to show results of relevance at the regional scale and large-scale patterns across and between geographic areas in the Baltic Sea. Each assessment provides a clearer picture of where we are, how things are connected, and what needs to be done.

The holistic assessment also specifically enables tracking progress towards the implementation of the 2021 Baltic Sea Action Plan (HELCOM 2021) goals and objectives and functions as a regional contribution to the reporting under the Marine Strategy Framework Directive (MSFD) for those HELCOM Contracting Parties that are also EU Member States. The results of the assessment underpin HELCOM policy and the information from the assessment is incorporated in the ecosystem-based management of the Baltic Sea, as well as guiding measures nationally, regionally and globally.

The HELCOM holistic assessment is a multi-layered product (Figure P2). Within the assessment structure, highly detailed results are progressively aggregated, allowing anyone to explore the results at whatever scale is most relevant to them and culminating in the overall summary report on the State of the Baltic Sea.

Data

The collection, reporting and collation of national monitoring data at the Baltic Sea level forms the basis of the assessment. The data is spatially presented using a defined assessment unit system dividing the Baltic Sea into assessment units representing different levels of detail, in a regionally agreed nested system. The data then feed into regionally agreed evaluation and assessment methods. This allows us to explore trends over time, spatial aspects, as well as results, in order to indicate potential future developments and geographic areas of key importance for the assessed themes.

Indicators

HELCOM core indicators have been developed to assess the status of selected elements of biodiversity and human-induced pressures on the Baltic Sea and thus support measuring the progress towards regionally agreed targets and objectives. The core indicators are selected according to a set of principles including ecological and policy relevance, measurability with monitoring data and linkage to anthropogenic pressures (HELCOM 2020a). The observed status of HELCOM indicators is measured in relation to a regionally agreed threshold value specific to each indicator, and in many cases at the level of individual areas in the Baltic Sea. The majority of the indicators are evaluated using data from regionally coordinated monitoring under the auspice of HELCOM and reported by the Contracting Parties to the Convention. The status of an indicator is expressed as failing or achieving the threshold value. Hence, the results indicate whether status is good or not according to each of the core indicators. HELCOM core indicators make up the most detailed level of results, presented in the dedicated indicator reports (https://indicators.helcom.fi).

Thematic assessments

A basic criterion for HELCOM core indicators is that they are quantitative and that their underlying monitoring data and evaluation approaches are comparable across the Baltic Sea. This is to ensure that they are suited for integrated assessment. Integrated assessments are assessments where the quantitative information from indicator evaluations or other data, as well as qualitative information, is combined by topic, to produce a broader, more holistic overview of the situation for that specific topic and, subsequently, for the theme under which that topic is included. The integrated assessments are made using the BEAT (biodiversity), HEAT (eutrophication) and CHASE (hazardous substances) assessment tools, as well as the Spatial Pressures and Impacts Assessment tool, developed for this purpose by HELCOM. In addition to presenting whether status is good or not, the integrated assessment results also indicate the distance to good status. Distance to good status is shown by the use of five assessment result categories; out of which two represent different levels of good status and three different levels of not good status.

Quantitative integrated results can then be further combined with qualitative assessment results (where quantifiable information is not available) and contextual information to form five thematic assessments, each with their own report (Biodiversity, Eutrophication, Hazardous substances, marine litter, underwater noise and non-indigenous species, Spatial distribution of pressures and impacts as well as Social and economic analyses). This report represents a thematic assessment and covers the theme of spatial distribution of pressures and impacts.

The overall aim of a thematic assessment is to present what the results of the various assessments related to the theme of spatial distribution of pressures and impacts are, how they have been produced as well as their rationale, all within the relevant policy and scientific frameworks. Confidence in the assessments is presented together with the results to ensure transparency and facilitate their use. The thematic assessment reports are an integral part of the overall Status of the Baltic Sea assessment but also function as stand-alone reports. The reports are more technical in nature than the summary report, as they are intended to give details to the assessments, explaining underlying data and indicators to the extent that is needed to ensure that the HOLAS 3 assessment is transparent and repeatable.

Summary report

The main aim, and the added value, of the Summary Report lies in the possibility to link the information from the topical and thematic assessments together and thus highlight the holistic aspects of the assessment for each topic. With this in mind the Summary Report focuses on presenting the results and looking more in depth at why we are seeing these results, i.e., presenting the results of the thematic assessments by topic but linking and combining these topical results with the information and input from the other assessments/sources to provide context and analysis.

Summary

The Baltic Sea is influenced by a range of pressures from human activities, occurring at sea as well as in its catchment area. While some activities and pressures may appear to have little importance individually, their summed impact may be considerable when occurring in the same place, particularly in areas with sensitive species or habitats. The HELCOM Spatial distribution of Pressures and Impacts Assessment (SPIA) addresses the cumulative burden on the environment caused by human activitiesin the Baltic Sea region.

This report gives the method description and results from the assessment of spatial pressures and impacts during the years 2016-2021. The SPIA focuses on the spatial dimension and is based on detailed maps on pressures and ecosystem components in the Baltic Sea region. The maps are evaluated together with information on the sensitivity of each ecosystem component regarding each pressure. The main results are presented by two indices: the Baltic Sea Pressure Index gives information on areas where the greatest pressure from human activities likely occurs, and the Baltic Sea Impact Index shows the distribution of potential cumulative impact from these pressures on the environment. However, the applied assessment protocol is flexible so that any combination of pressures and ecosystem components can also be assessed. In addition, results of selected thematic analyses are presented in this report.

Results of the assessment in brief

Potential cumulative impacts from human activities on the environment can be identified in all parts of the Baltic Sea, but there are also some clear spatial differences. Shallow coastal areas are generally subject to the highest levels of impact, due to a high number of ecosystem components, as well as many human activities. Regarding potential cumulative pressures, however, the highest level of pressure is identified in open sea areas.

Eutrophication and hazardous substances are the two most influential pressures for both potential cumulative pressures and impacts, having a wide distribution across the whole Baltic Sea region. Bottom-water habitats not influenced by permanent anoxia and grey seal (Halichoerus grypus) are the ecosystem components most affected by potential cumulative impacts, partly due to the large extent of these ecosystem layers compared to other layers.

A thematic analysis on the potential effect of continuous noise on mobile species shows the relatively highest impact levels in the south, especially around the Arkona Basin. Ships entering and leaving the Baltic Proper go through a rather narrow area in the southwestern Baltic Sea, so that the ship traffic is concentrated within an area where the distribution of mobile species is also high.

A thematic analysis of the potential impact of hazardous substances and eutrophication over all ecosystem components showed that these have widely spread impacts over the Baltic Sea. The combined potential impact from hazardous substances and eutrophication showed a largely similar pattern to that of the total potential cumulative impact expressed as Baltic Sea Impact Index (BSII), reflecting that these pressures are also the main contributors to total impact on the Baltic Sea environment. Both pressures have a wide distribution and are present everywhere in the Baltic, and the relatively highest impact is identified for areas with many co-occurring ecosystem components, such as in the coastal areas.

Regarding physical loss, less than one percent of the whole Baltic Sea was estimated to be impacted by long-term potential loss of seabed. The sub-basins with highest shares of lost seabed were The Sound and Great Belt, estimated at 4.4 % and 0,9 % long term potential loss of seabed, respectively.

The presented results clarify the spatial patterns and relative intensities of potential cumulative pressures and impacts in the Baltic Sea. Hence, they do not provide information on magnitudes of potential pressures or impacts on an absolute scale, but give information on their relative levels when comparing different parts of the region. The assessment is based on currently best available regional data, but spatial gaps may occur in some underlying datasets and this is indicated in the results with separate data availability maps.

What has changed since HOLAS II?

Due to the relative nature of the assessment, it is not possible to compare the magnitudes of pressures or impacts between assessment periods, such as comparing the present results with those of HOLAS II. However, some more restricted comparisons between the two assessment periods could be made, such as comparing the relative spatial distribution of impacts in the region and the pressures identified as potentially most impacting in each assessment. Considering the spatial distribution of impacts, the sub-basins contributing most to the total impact are relatively similar in HOLAS II and HOLAS 3. The highest differences between assessment periods are seen in the northern sub-basins, including the Gulf of Bothnia and the Gulf of Finland, as well as the Kattegat. For the Gulf of Bothnia and Gulf of Finland, the observed differences can be attributed to method development, as relatively higher impacts in the current assessment compared to HOLAS II can be explained by the addition of new layers for habitat-forming species in HOLAS 3.
There are also some differences in the relative contribution of different pressures, when comparing HOLAS II and HOLAS 3, but many of these can be traced to pressure layers which have been developed with a revised methodology in HOLAS 3, particularly ‘hazardous substances’, ‘eutrophication’ and ‘introduction of non-indigenous species’. Further, as the contribution of individual pressures to potential cumulative impacts depends on many other factors in addition to the pressure layer, it is often difficult to identify individual factors driving the identified patterns.

Importance for Baltic Sea management

The increasing use of sea areas leads to complex patterns of interactions between human activities, pressures and ecosystem components at sea. Tools to assess the spatial distribution of pressures and impacts are helpful to evaluate the combined and cumulative impact of human induced pressures on the environment, and to identify potential key areas of concern and enhanced management efforts. Outputs from the SPIA provide valuable information for marine spatial planning and marine management from various perspectives.

- The assessment recognizes and displays the potentially most impacted areas in the region, making it possible to place any local impacts in a regional perspective, and identifying areas which should be given special focus in managementSubstantial amounts of data on human activities, pressures and ecosystem components (species and habitats) are needed to carry out the assessment, and the publication of these data sets provides a unique, region-wide and harmonized data resource to support management
- Substantial amounts of data on human activities, pressures and ecosystem components (species and habitats) are needed to carry out the assessment, and the publication of these data sets provides a unique, region-wide and harmonized data resource to support management
- The cumulative impact assessment is an effective way to describe and visualize potential impacts of human activities on the Baltic Sea environment. This can help raise awareness of these impacts, and can also function as a platform to discuss the underlying causes and potential future solutions
- The interactive tool that supports the written report, makes it possible to further explore the activities and pressures behind identified impacts, as well as the affected ecosystem components, and allows to run the assessment on any given combination of these layers

1. Introduction

The Baltic Sea environment is influenced by pressures from various human activities at sea and in its catchment area. The pressures may affect living organisms directly, with impacts on their occurrence, abundance or physiological status. However, they can also cause indirect impacts via connections among species in the food web, or by affecting habitats on which the species depend. When considered individually, some activities and pressures may appear to have little importance in this respect. However, the summed impact may be considerable when the impacts of different pressures are taken together. This is likely to occur when several pressures occur in the same place in the sea or act on the same sensitive species, for example.

The HELCOM DAPSIM is a conceptual framework seeking to aid the understanding of socio-ecological systems and help address interactions between human activities and the (marine) environment, through a simplified representation of key components. Figure 1 presents the DAPSIM framework applied in HELCOM and indicates what parts of the cycle are relevant for this thematic assessment. The SPIA addresses human activities, pressures as well as impacts, as it by definition addresses the cumulative aspects of how human activities can affect the marine environment.

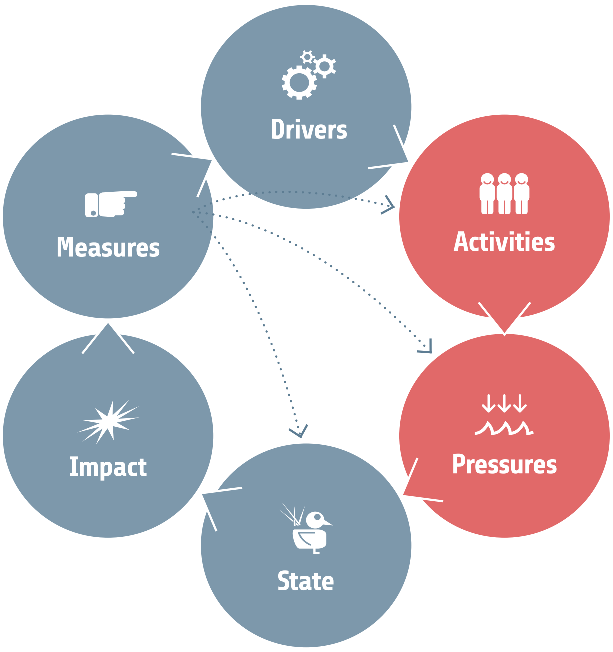


Figure 1. Schematic of the DAPSIM framework indicating in red what sections of the cycle this assessment focuses on.

The SPIA is, hence, different from other thematic assessments, where the topics are addressed in a more sectoral way. The SPIA is looking at the spatial distribution and intensity of different human activities, and using the best available knowledge to quantify their combined pressure and impacts to the environment.

In the Baltic Sea Action Plan, cumulative impacts are mentioned in many actions related to the biodiversity segment (B11, B22, B28, B31), where cumulative impacts on for example red listed habitats should be identified and assessed (HELCOM 2021a). Analyses of cumulative impacts are also important to support the managment of sea-based activities and implementing the ecosystem approach.

The current assessment aims to consider potential impacts from all human activities (Table 1) occurring in the Baltic Sea during 2016-2021. The assessment is based on information on the spatial distribution of the pressures they are likely to be causing, as defined by information from the countries around the Baltic Sea.

Based on their primary way of impact on the environment, pressures from human activities can be broadly categorised into four groups: inputs of substances (including for example nutrients and hazardous substances), inputs of energy (underwater sound, heat), biological pressures (non-indigenous species, disturbance of species and extraction of species, for example), and physical pressures (disturbance to the seabed, loss of seabed, and changes to hydrological conditions; Table 2).

The results are presented in two indices:

— The assessment of cumulative pressures is based on the Baltic Sea Pressure Index, which identifies geographic areas in the Baltic Sea where the cumulative amount of human induced pressures is likely the highest. It can also be used to identify the most widely distributed pressures..
— The Baltic Sea Impact Index estimates the probable cumulative burden on the marine environment, by additionally considering the distribution of species and habitats, as well as sensitivities of ecosystem components to different pressures.

In addition to the two indices, the results are presented by three thematic analyses, where a certain subset of data are used:

— Physical loss of seabed
— Impact of continuous noise to marine mammals
— Eutrophication and hazardous substances

This report presents the method description, data and results for the Spatial Pressure and Impact Assessment. The key results are also presented in the HOLAS 3 summary report.

2. Overview of the spatial distribution of pressures and impacts assessment approach

2.1. Introduction to the assessment methodology

The Spatial distribution of Pressures and Impacts Assessment (SPIA) addresses potential pressures and impacts of human activities on ecosystems in the Baltic Sea. The focus is on the cumulative burden that multiple and simultaneous activities may have on the environment. The methodology builds on the concepts developed by Halpern *et al.* (2008) and was first applied in the initial HELCOM holistic assessment (HELCOM 2010a) and further developed for HOLAS II (HELCOM 2018a,b). Beyond the cumulative aspects, the method enables the spatial presentation and use of either an individual or a subset of spatial data layers, representing activities, pressures and ecosystem components, with the impact adjusted through the use of sensitivity scores.

The method that was applied in the initial holistic assessment is described by HELCOM (2010b) and Korpinen *et al.* (2012), and the method used in HOLAS II is described by HELCOM (2018b). The applied concepts build on for example the work of Andersen *et al.* (2013) and (Stock 2016) for the North Sea. The same methodology has also been used in the Mediterranean and the Black Sea (Micheli *et al.* 2013) and in the Swedish national waters (Hammar *et al.* 2020).

The assessment approach used in HOLAS 3 is based on the same principal methodology as in HOLAS II, including the possibility to estimate the cumulative burden to the environment using an additive model (Figure 2). The key components are georeferenced data sets of human induced pressures (pressure layers), and ecosystem components (ecosystem component layers), as well as sensitivity scores that are used in combining the pressure and ecosystem component layers. The sensitivity scores estimate the potential impact of each assessed pressure on each specific ecosystem component.

2.2. What is different compared to to HOLAS II?

One of the major changes in HOLAS 3 is to recognize the potential of carrying out cumulative impact assessments beyond the focus on overall effects, giving emphasis also to subset assessments so that various combinations of activities, pressures and ecosystem components can be addressed. To clarify this, the assessment in HOLAS 3 is called the Spatial distribution of Pressures and Impacts Assessment (SPIA), where the overall cumulative impact assessment (CIA), including all layers, is one, yet crucial part of this assessment.

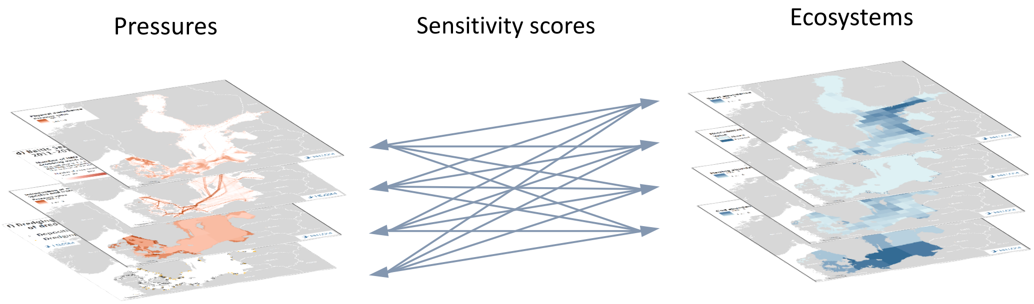
The potential cumulative impact on the environment is calculated with an additive model, including pressure layers, ecosystem components and sensitivity scores. The pressure and ecosystem component layers are created based on HOLAS II, however, 6 new benthic habitat layers are included, as well as all 18 MSFD broad habitat types included in EUSeaMap (compared to 8 layers in HOLAS II). Further, the fish layers created in Pan Baltic Scope replace the ones used in HOLAS II, except for layers on the abundance of cod, herring and sprat. The ecosystem components are described in more detail further down in this report, and all layers are listed in Table 3.

The methodology has been refined for three pressure layers: Eutrophication, Non-indigenous species and Physical Disturbance. A full description of the methodologies can be found in the chapter on spatial datasets, but the main differences are explained below.

Eutrophication is one of the main threats to the biodiversity of the Baltic Sea and the nutrient pressure layers had the biggest contribution to the total impact in HOLAS2 cumulative impact assessment. The concentration of nutrients (total nitrogen and phosphorus) was used to produce the pressure layers in HOLAS II. Based on the feedback from HOLAS II process and the HOLAS 3 preparatory phase, better ways to depict the spatial distribution and the pressure caused by nutrients were needed.

Different options included to use the data and methodologies used in the HELCOM indicator work for eutrophication or finding better ways to interpolate the concentration of nutrients by using the DIVA software, or other sophisticated methods. The interpolation-based method was discarded due to uncertainties in the methodology and because the patterns of concentration are highly variable and the interpolations create deep gradients in the maps, that can be partly considered to be artificial and due to spatial pattern of monitoring stations. Different eutrophication indicator products were compared to find a suitable product to be used in the cumulative impact assessment. The integrated eutrophication status assessment was chosen, because it was considered to best represent the diverse effects of excessive nutrient input, and also had the best spatial coverage. The new methodology is based on the Integrated eutrophication status assessment and utilizes the Eutrophication Quality Ratios available for each monitoring unit on the HELCOM assessment unit level 4. The method offers an agreed and well-documented methodology that is coherent with other eutrophication related work in HOLAS 3, but includes some downsides such as decreased spatial resolution and incorporating also impact indicators in the pressure layer (especially for the coastal areas).

In HOLAS II, the layer on non-indigenous species was based on the HELCOM Core indicator Trend in the arrival of new non-indigenous species, more specifically on the number of non-indigenous species in each of the assessment units in 2011. The layer therefore focused on the number of introduced species and did not consid-



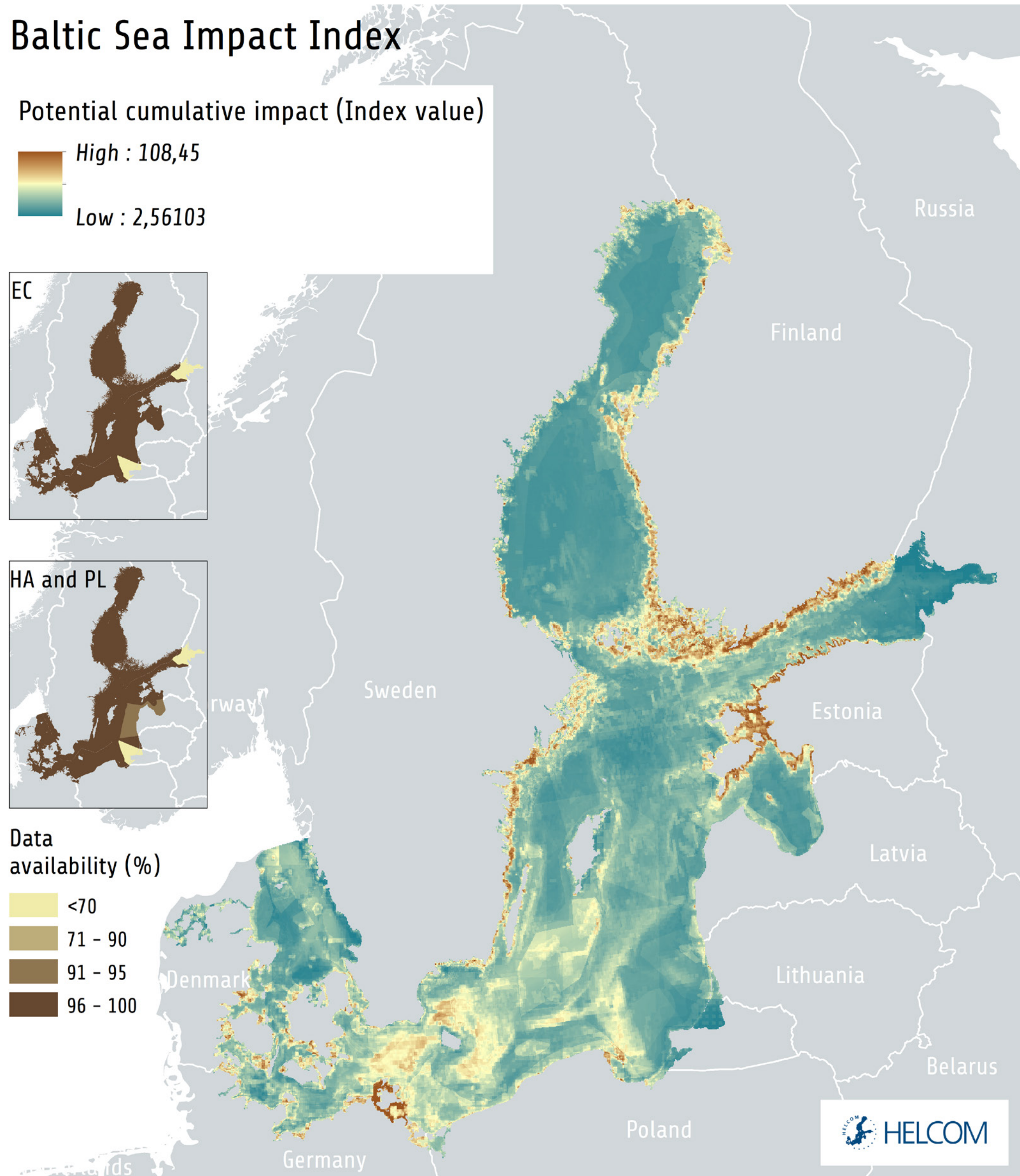


Figure 2. Visual overview of the assessment method.

er their potential effects in the receiving environment. In HOLAS 3, the corresponding layer more directly represents the cumulative negative impacts on marine biodiversity caused by non-indigenous species. The layer is based on the CIMPAL index (Cumulative IMPact of ALien species; Katsanevakis *et al.* 2016), and only considers established non-indigenous species which are either suspected or known to cause adverse effects on the marine environment (Katsanevakis *et al.*, 2016, Teixeira *et al.* 2019). In the pressure layer on non-indigenous species in HOLAS 3, each non-indigenous species is assigned a weight score reflecting its potential impact on ecosystem components. The weight scores are used when integrating spatial layers for individual non-indigenous species (by weighted sum) into a combined pressure layer.

In HOLAS II, the layer physical disturbance was done within the CIA framework, and aggregated from human activities reported by the Contracting Parties. The indicator on Cumulative impact from physical pressures on benthic biotopes (CumI) was accepted to be used in HOLAS 3. The indicator has synergies with the SPIA, and the outputs of the indicator work are used to create the pressure layer on physical disturbance. The biggest differences between these two assessments are in the way the pressures are intersected with ecosystems and the type of sensitivity scores used and therefore the interim data, prior to intersecting the pressures with ecosystems, are used in the SPIA.

Separate sensitivity score questionnaires were carried out for both the initial holistic assessment and HOLAS II, where completely new sensitivity scores were created for the assessment. The development of the indices between these two earlier assessments were substantial, justifying the creation of completely new scores. Also the number of ecosystem components clearly increased and the aggregation of pressures from human activities were introduced, resulting in a need for new sensitivity scores. The method to do the cumulative impact assessment and number of pressures and ecosystem components in HOLAS 3, are rather close to the ones in HOLAS II, therefore only a revision of the scores used in HOLAS II was needed. In the review, sensitivity scores for the new ecosystem components introduced in HOLAS 3 were also gathered. More info on the sensitivity scores can be found in section 2.5.

2.3. Data included in the assessment

The assessments are based on original spatial data sets for 28 human activities occurring in the Baltic Sea, and 6 data sets on pressures estimated by direct measurements at sea. These data were compiled into 17 aggregated pressure layers, which were used in the assessment. In addition, 57 spatial data sets representing different ecosystem components were included in the assessment.

The data layers were collated in order to be representative of the years 2016-2021. Data were obtained from the countries through targeted data calls, by enquiries to the HELCOM expert networks and projects, data request to other organizations, open data sources, and from the EUSeaMap project for broad-scale habitats. These are explained in more detail in the metadata record of each data layer in HELCOM map and data service (HELCOM 2023a) and HELCOM metadata catalogue (HELCOM 2023b).

All spatial data were collated with the aim to be harmonized and comparable across different parts of the Baltic Sea, hence to allow for a broad regional overview of pressures and impacts. The vast data collection has generally improved regional coherence in key data sets and increased the number of spatial data sets available at Baltic Sea regional scale. However, some data gaps and variation in the level of accuracy are still present when comparing different data sets and geographic areas, which should be considered before examining any of the results in more detail. Some particular points for further methodological improvement are given in Box 1. At a general level, more complete availability and storing of data on human activities relevant in Baltic Sea marine environment would increase the accuracy and confidence of the assessment.

The assessments were carried out at the scale of the whole Baltic Sea, applying a spatial resolution of 1 square kilometre. Hence, original data sets of different types were all transformed to grid cells of 1x1km size prior to being included in the analyses.

Box 1

Recognised further data developments which would improve the assessment.

The mapping of human activities leading to physical disturbance and loss would benefit from establishing a regional data collection framework with regular data flows. This would preferably be developed based on the data needs as specified in the data call supporting HOLAS 3. To estimate the area covered by these activities would require that information on their spatial aspects is stored in a systematic and coherent way at the national level, in alignment with the assessment data requirements. Data control and quality assurance would specifically benefit from a regular data collection, so that data are reported frequently, not necessarily every year, but on certain time intervals.

The ecosystem component layers representing habitat-forming species are mainly based on point-wise observations from monitoring programmes and surveys carried out by the Contracting Parties. The distribution maps are developed by aggregating the point-wise data to a 5x5 kilometre grid followed by filtering by relevant depth ranges to identify potentially suitable areas for each species. As the monitoring programmes do not necessarily cover the whole region, a larger grid than the one of 1x1 kilometre that is finally used is applied in order to not underestimate the distributions. Further, observations from within the assessment period are complemented with older data to fill gaps. Adding new data to complement older observations, however, means that the extent of certain species may appear to increase with every assessment, resulting from an increased number of observations, although this may not reflect the reality. More realistic maps would be achieved by combining observations with spatial distribution modelling. Although modelling methods may also change and improve between assessments, this would not lead to a systematic bias towards increasing extent of species in the same way, but rather make the maps more accurate with time. Modelling of the most important habitat-forming species would clearly add value to the SPIA, and would also be beneficial and important for other HELCOM work strands.

Since the original data sets were quantified in various ways, typically using different metrics and ranges of values, all values were normalised prior to the analyses in order to make them comparable with each other on a more similar scale. As a result of the normalisation, all data sets were entered with a minimum value of 0 and a maximum value of 1 in the assessments. The data sets represent continuous, ordinal and binary data, as specified in each of the metadata fact sheets.

Although it would be preferential to scale the pressures in relation to their intensity, it was not possible at this time to obtain information on relevant cut-off values for most pressure layers. Unless otherwise indicated in the data descriptions, the lowest and highest values in each data set represent the actual range of values based on measurements, albeit normalized. Cut-offs were applied when there was reason to assume that the values representing the lowest measured range were too low to likely impact on species and habitats. It should be noted, however, that this fact is accounted for by sensitivity scores applied for estimating impacts, as they estimate sensitivities in relation to ambient conditions of the pressure at sea (Annex 4).

2.4. Spatial data sets

The following section introduces the human activities, pressure and ecosystem component data sets that were used in the SPIA. The data sets are introduced briefly, while more detailed descriptions of the data are presented in Annexes 1 and 2.

Table 1. The 28 human activities data sets that were used in the aggregated pressure layers, as indicated in columns 2–8.

Human activity	Physical loss	Physical Disturbance	Changes to hydrological conditions	Input of heat	Oil slicks and spills	Disturbance of species	Extraction of seabirds
Bathing sites						x	
Bridges and other constructions	x						
Cables	Operational	Under construction					
Coastal defence and flood protection	Operational	Under construction					
Deposit of dredged material		x					
Discharge of warm water from NPP				x			
Dredging	Capital	Maintenance					
Game hunting of seabirds							x
Harbours	x						
Hydropower dams			x				
Illegal oil discharges					x		
Extraction of sand and gravel	x	x					
Finfish mariculture	x	x					
Fishing intensity		x					
Fossil fuel energy production				x			
Furcellaria harvesting		x					
Land claim	x						
Marinas and leisure harbours	x						
Oil platforms	x		x				
Pipelines	x	x					
Polluting ship accidents					x		
Predator control of seabirds							x
Recreational boating and sports		x				x	
Shellfish mariculture	x	x					
Shipping density		x					
Urban land use						x	
Watercourse modification	x		x				
Wind farms	Operational	Under construction, operational	Operational				

2.4.1 Human activities data

Most of the pressure layers were developed directly from monitored or modelled pressure data. However, in some cases no direct data were available at the Baltic-wide scale, and the spatial distributions of these pressures were estimated indirectly based on human activities associated with these. The human activities data that were used to develop pressure layers, and the concerned pressures layers, are listed in Table 1.

As evident from Table 1, many of the concerned pressure layers were based on an aggregation of several original data sets, representing different aspects the same pressure. Further, the same human activities were in some cases identified as relevant for more than one pressure, when applied with different associated extents or attributes. For example, cables under construction were used for the pressure layer 'physical disturbance' while cables reported as operational were used for the layer 'physical loss'. For data on the extraction of sand and gravel, the area used for extraction was considered as 'physical loss', while a buffer of 500 meters around this actual area was considered as 'physical disturbance'.

The sections below provides more detailed information on selected human activities, including by what pathways they are attributed to causing pressure to the environment and example maps.

Construction and installations

Offshore wind farms, harbours, underwater cables and pipelines are examples of constructions that cause a local but permanent loss of habitat. In addition, disturbance to the seabed may occur during the period of construction and installation. The data used for wind farms and pipelines in the assessment, are presented in Figure 3.

The pressures exerted during the construction phase have similarities with those during seabed extraction or dredging. Installation of offshore construction may also encompass drilling, pile driving, or the relocation of substrate for use as scour protection. The area lost by scour protection around the foundation of a wind farm turbine has been estimated to be in the order of tens of metres from the wind turbine (van der Wal and Tamis 2014). The scour protection will give rise to a new man-made habitat.

Pipelines may be placed in a trench and then covered with sediment extracted elsewhere, so that the sediment composition differs from surrounding habitat (Schwarzer *et al.* 2014). On hard substrates, cables are often covered with a protective layer of steel or concrete casings. The loss of habitats by smothering and sealing from cables may occur up to a couple of metres from the cable (OSPAR 2008).

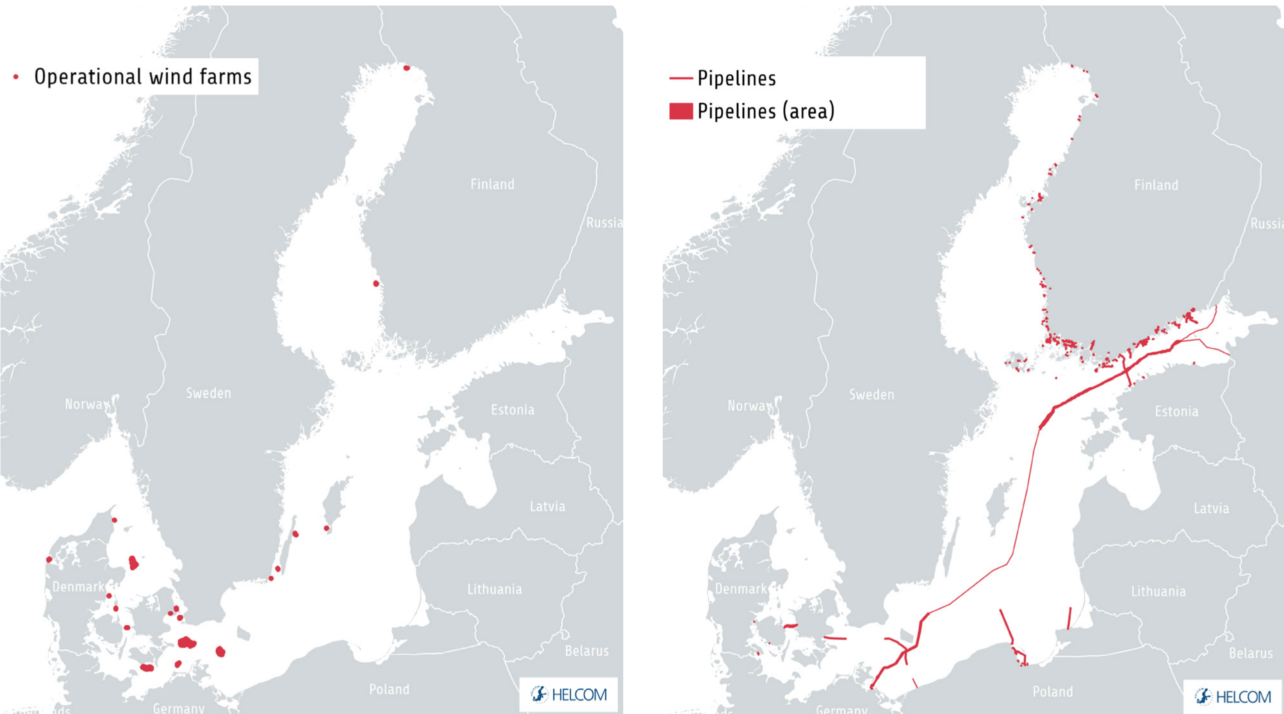


Figure 3. Operational wind farms and pipelines in the Baltic Sea. The symbols are enlarged to make them visible at the displayed scale. The route of the pipelines Nord-stream 1 and 2 are only approximate for Swedish and Russian waters, and these section are included only in this map, but not in the assessment itself.

Extraction of sand and gravel

During sand and gravel extraction sediment is removed from the seabed, for use in construction, coastal protection, beach nourishment and landfills, for example. The data layer representing the activity in HOLAS 3, is presented in Figure 4.

Sand and gravel extraction can be performed using either static dredging or trailer dredging. When static dredging is used, the exerted pressures are of similar type as during dredging, potentially leading to partial or complete physical loss of habitat (depending on the extraction technique and on how much sand or gravel is removed) and altered physical conditions (through changes in the seabed topography, increased turbidity caused by re-suspended fine sediments, smothering or siltation on nearby areas). When performing trailer dredging, the pressure exerted to the seabed is more limited compared to static dredging, although the dredged area is greater. The intensity of the pressure is also dependent on the site. In areas where sediment mobility and dynamics are naturally high, the impacts of sand and gravel extraction are typically lower than in areas with more stable sediment types.

There is high mortality of benthic organisms at the site of sand and gravel extraction, as the species are removed together with their habitat (Boyd *et al.* 2000, 2003, Barrio Frojan *et al.* 2008). Since the extracted material is sieved at sea (to the required grain size) and the unwanted matter is discharged, the extraction may also result in changed grain size of the local sediment on the seabed. Adjacent areas are also affected by the activity albeit less severely (Vatanen *et al.* 2010).

Importantly, there are modern techniques and concepts that, if applied, can help to reduce the extent and intensity of physical disturbance of benthic organisms. Recolonization by sand- and gravel dwelling organisms is for example facilitated if the substrate is not completely removed. Precautionary measures are also recommended in HELCOM Recommendation 19/1 on 'Marine Sediment Extraction in the Baltic Sea Area'.

Dredging

Dredging activities are usually divided into capital dredging and maintenance dredging (Figure 5). Capital dredging is carried out when building new constructions, increasing the depth in existing waterways, or making new waterways, while maintenance dredging is done in order to maintain existing waterways.

Dredging causes different types of pressure on the seabed – removal of substrate alters physical conditions through changes in the seabed topography, increased turbidity caused by re-suspended fine sediments, and smothering and siltation of nearby areas due to settling of suspended load. Physical loss occurs during capital dredging, which usually occurs once at a specific location. It may also be connected to maintenance dredging when performed repeatedly at regular intervals. The physical loss is limited to the dredging site, whilst physical disturbance through sedimentation may have a wider spatial extent.

Disturbance through sedimentation may affect animals and vegetation even farther away from the dredging activity, on the scale of hundreds of metres (LaSalle *et al.* 1990, Boyd *et al.* 2003, Orviku *et al.* 2008). In addition, remobilisation of polluted deposited sediments may contribute to contamination and eutrophication effects.

Figure 4. Extraction of sand, gravel and mud areas in 2016–2021. Spatial information about the Extracting of sand and gravel was reported by Finland, Estonia, Russia and Germany.

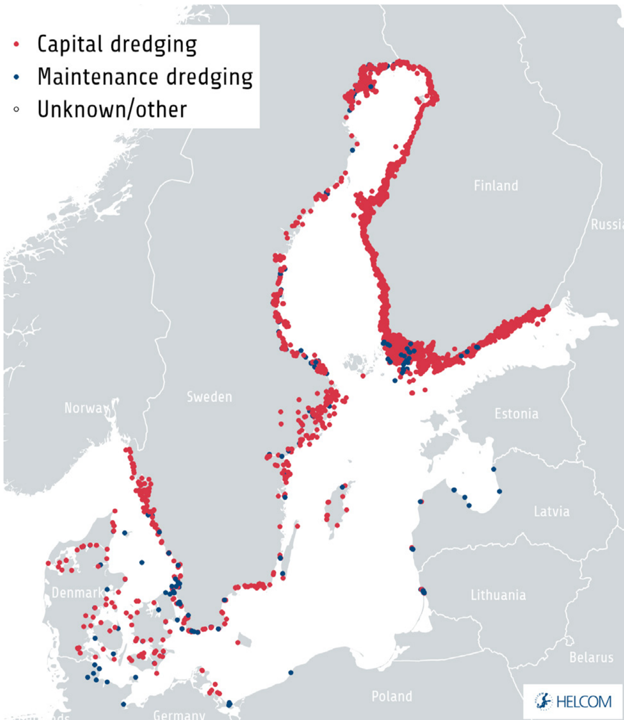


Figure 5. Maintenance, capital and unknown dredging operations in the Baltic Sea in 2016–2021.

2.4.2 Pressure layers

The list of pressures to include in the assessment (Table 2) was identified in order to represent pressures which commonly occur in the Baltic Sea, and are attributed to human activities currently taking place in the Baltic Sea or its catchment area. The structure of the list was aligned with EC (2017 a,b), and the pressures represented either of the following groups:

— Inputs of substances
— Inputs of energy
— Biological disturbances
— Physical disturbances

To avoid a situation where pressures or pressure groups represented by more data would have stronger influence on the results, the number of data layers was kept low and as similar as possible between pressures. To improve accuracy, some of the final pressure layers used in the assessment were rather based on an aggregation of several original data sets. Spatial data set representing fishing (catches of cod, sprat and herring) were analysed both separately and grouped as pressure themes. The approaches are briefly described below, and are specified in Annex 1.

The pressure layers representing inputs of substances were based on monitoring of each relevant parameter. When available, data from monitoring at sea were used, in order to represent the total levels (not only inputs from land or atmosphere), and in order to give a more realistic representation of the spatial distribution. In addition, the continuous sound layer was based on monitoring at sea combined with modelling. In all other cases, no direct data were available at Baltic-wide scale, and the spatial distributions of these pressures were estimated indirectly based on information on human activities. This was in some cases achieved by a parameter representing the effect size of the associated human activity. For example, catches of fish were used to represent the spatial distribution of the pressure “Extraction of fish”, and the number of hunted seals was used to represent the pressure “Seal hunting”. In other cases, the distribution of the pressure was estimated based on the distribution of the underlying human activities, after adjusting for the likely spatial extent and intensity of the pressure to which it was associated.

All pressure layers were defined in order to quantify the relative spatial distribution of the pressure at sea, over a Baltic-wide scale.

Table 2. Pressure layers used in the assessment and their primary data source.

Pressure layer	Primary data source/approach for layer development
Input of substances	
Eutrophication	monitoring
Hazardous substances	monitoring
Radionuclides	monitoring
Oil slicks and spills	monitoring
Input of energy	
Continuous anthropogenic sound	monitoring combined with modelling
Impulsive anthropogenic sound	reports on activities causing impulsive sound
Input of heat	reports from main cooling water outlets
Biological	
Introduction of non-indigenous species	CIMPAL Index (Emodnet biology, EUSeaMap)
Disturbance of species due to human presence	indirect, based on attributed human activities
Fishing of herring (included in theme fish extraction)	reported landings
Fishing of cod (included in theme fish extraction)	reported landings
Fishing of sprat (included in theme fish extraction)	reported landings
Hunting and predator control of seabirds	national reporting
Hunting of seals	national reporting
Physical	
Physical disturbance to seabed	indirect, based on attributed human activities
Physical loss to seabed	indirect, based on attributed human activities
Altered hydrological conditions	indirect, based on attributed human activities

Pressure layers representing input of substances

Eutrophication

The layer depicts the pressure of eutrophication in the Baltic Sea, based on the data from the HOLAS 3 integrated eutrophication assessment. The methodology utilizes the Eutrophication Quality Ratios (EQRS) available for each HELCOM assessment unit on level 4 (Figure 6).

The basic principle of the methodology is to combine the information of the three MSFD criteria groups (C1: Nutrient levels, C2: Direct effect, C3: Indirect effect) and use this value as an indication of pressure for each assessment unit. All criteria groups were included as this is considered to present the complex nature of eutrophication better than using only the nutrient levels. High nutrient levels are not necessarily directly harmful for all species and habitats and including the direct and indirect effects takes better into account the diversity of all ecosystem components included in the assessment.

As the SPIA is carried out using a 1x1km grid while the Integrated eutrophication status is assessed on vector based HELCOM assessment units, the vector data are rasterized. First, the vector data are rasterized to 100x100m resolution, and after that it is aggregated to a 10x10km grid using a mean value. A 10 km grid is used in order to make the gradients between assessment units slightly smoother and finally the values converted to 1x1 km resolution. The scale for the pressure values in the map (0.26-1) represents the scale in the original source data. (Integrated eutrophication assessment).

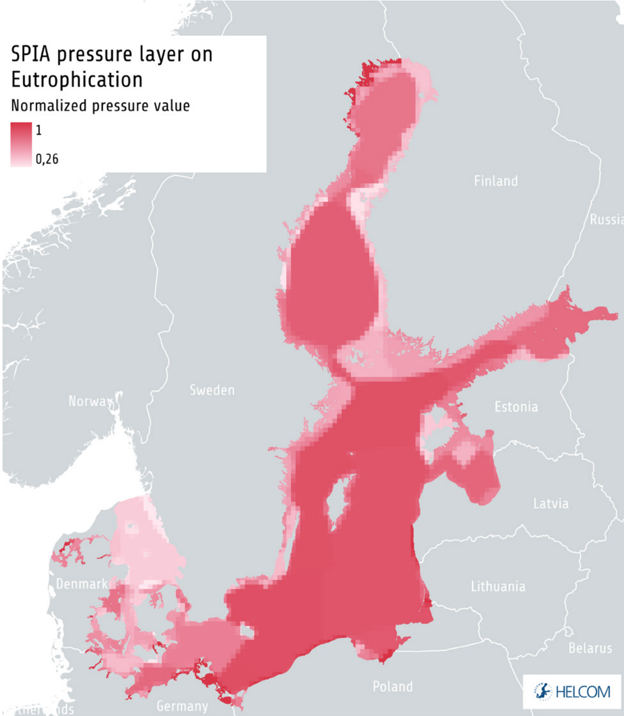


Figure 6. SPIA pressure layer on Eutrophication. The map represent the normalized pressure values, where the intensity of the colour indicates higher pressure.

Hazardous substances

The layer depicts the pressure of hazardous substances in the Baltic Sea, based on the data from the HOLAS 3 integrated hazardous substances assessment. The methodology utilizes the integrated status values available for each HELCOM assessment unit on level 3 (Figure 7).

The results are based on multiple hazardous substances groups integration, done through the CHASE tool. The integrated assessment assess the hazardous substances status in biota, water and sediment, and final result in based on the worst status.

As the SPIA is carried out using a 1x1km grid and the Integrated hazardous substances is assessed on vector-based HELCOM assessment units, the vector data is rasterized. First, the vector data is rasterized to 100x100m resolution, and thereafter it is aggregated to 10x10km grid using a mean value. A 10 km grid is used in order to make the gradients between assessment units slightly smoother and finally values are converted to 1x1 km resolution.

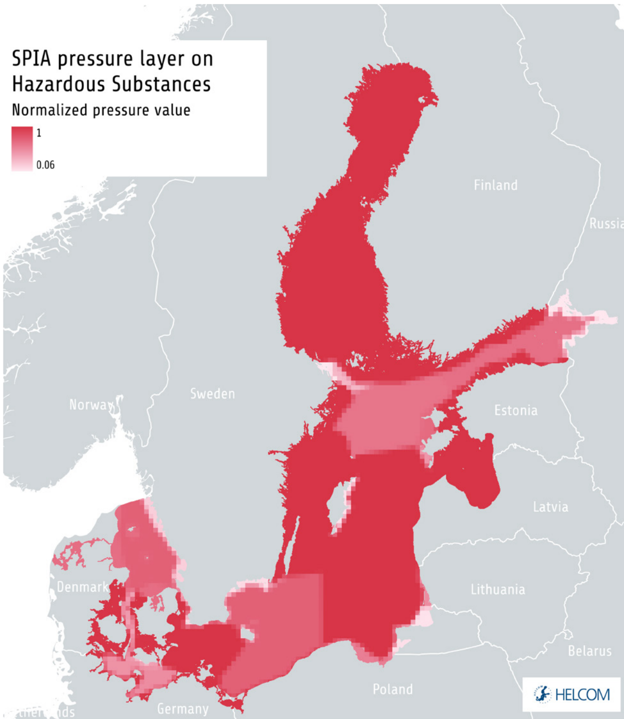


Figure 7. SPIA pressure layer on Hazardous substances. The map represent the normalized pressure values, where the intensity of the colour indicates higher pressure.

Radionuclides

The layer is based on HELCOM MORS Discharge data for 2016-2020. The isotopes taken into account were Cesium-137, Strontium-90, and Cobalt-60. The decay-corrected annual average of the sum of radionuclide discharges (in Becquerels) was calculated for the pressure layer. A 10 km buffer from discharges of radioactive substances with a linearly decreasing function was used to represent the impact distance from the nuclear power plant outlets. The data set was normalized to produce the final pressure layer.

Oil slicks and spills

The pressure layer is a combination of data sets on oil discharges and polluting ship accidents. The oil discharges data set is based on aerial surveillance data with remote sensing equipment in the Baltic Sea region, the data comprehends the period 2016-2021. The polluting ship accidents data set originates from HELCOM

Contracting Parties' reporting on oil spill volume from shipping accidents for the period 2016-2020. The data sets were handled separately, summed and again normalized to produce the final pressure layer. The detailed information about the applied methodology can be found in Annex 1.

Pressure layers representing input of energy

Input of continuous anthropogenic sound

The layer represents the pressure caused by input of continuous sound (Figure 8). Hence, in contrast to the layer on impulsive sound, it focuses on the more permanent aspect of sound and depicts areas that are under influence of human-induced low frequency continuous noise, mainly from ships. The layer depicts sound exceeding background levels at least 50% of the time, filtering out areas with less frequent traffic, such as smaller fairways on coastal areas and focusing on the most trafficked areas. The underlying data were produced by Quiet Ocean within the HELCOM BLUES project.

The layer is based on the baseline excess level of noise, meaning that the natural background, or baseline, noise, is removed from the data, and only the exceedance caused by commercial shipping is included. Thus, the data directly provides information on the pressure caused by sound. Hence, no threshold values were considered needed for the layer to be included in the SPIA. The layer is based on annual statistics for year 2018 in the whole water column. The layer represents sound pressure levels at one 1/3 octave band of 125 Hz exceeding background levels at least 50% of the time (50 percentile exceedance levels). A more detailed description of the modelling approach is given by Folegot *et al.* (2022).

Input of Impulsive anthropogenic sound

The layer is based on the following impulsive sound events: Seismic surveys, explosions, pile driving, air guns and sonar or acoustic deterrents, as reported to the HELCOM-OSPAR Registry, hosted by ICES, and a national data call. For all event types, numeric intensity values were used to represent the pressure as they are categorized in the registry ('very low'= 0.25, 'low'= 0.5, 'medium'= 0.75, and 'high' and 'very high'= 1). The values were used to represent the pressure intensity. No impact distance was applied due to different types of data sets included. The layer shows areas in the Baltic Sea where impulsive sound events have occurred in 2016-2021, however the pressure was present during a short period of time (days-months-weeks) compared to the other pressures included.

Input of heat

The layer is a combination of two data sets: discharge of warm water from nuclear power plants and from fossil fuel energy production. The data set on discharge of warm water from nuclear power plants was obtained by a direct data request to HELCOM Contracting Parties for the period 2016-2021. The location of fossil fuel energy production facilities was identified, and data extracted from the European Pollutant Release and Transfer Register (E-PRTR). A heat load value of 1 TWh was given to all fossil fuel production sites, based on average value for individual production sites. A buffer of 1 km was used for the extent of pressure, with sharp decline from the centre. Heat loads from both data sets were summed and normalized to produce the final pressure layer.

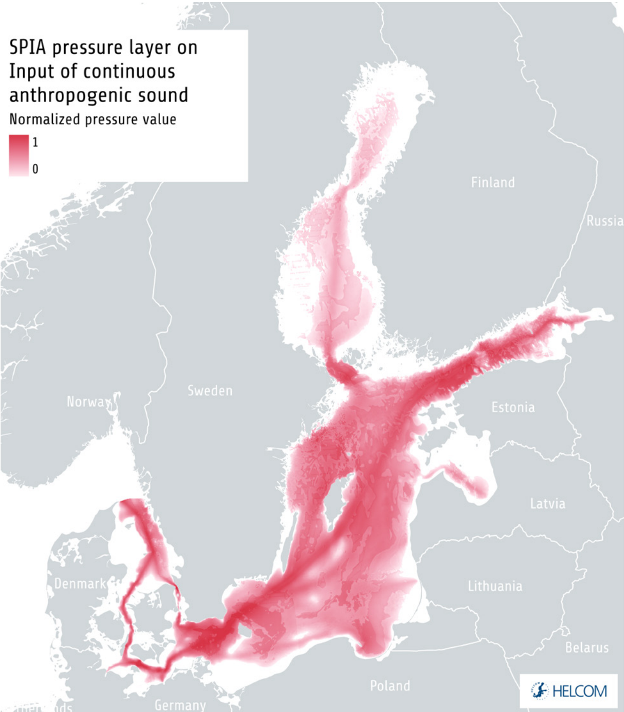


Figure 8. SPIA pressure layer on Input of continuous sound. The map represent the normalized pressure values, where the intensity of the colour indicates higher pressure.

Pressure layers representing biological disturbances

Introduction of non-indigenous species

The layer presents the cumulative negative impacts on marine biodiversity caused by alien species in the Baltic Sea (Figure 9). The layer is based on the Cumulative IMPact of ALien species (CIMPAL) index, developed by Katsanevakis *et al.* (2016). The original methodology was applied for the Baltic Sea similarly as Korpinen *et al.* (2019) applied it for the EU waters in their report Multiple pressures and their combined effects in Europe's seas. The list of species and habitats together with the sensitivity scores are originating from this study.

Previously the pressure layer was based on the HELCOM Core indicator Trend in the arrival of new non-indigenous species, where the introduction of non-indigenous species in HELCOM assessment units was used as the pressure value. The new methodology depicts the pressure in a more realistic way as it focuses only on the established species. Additionally it considers the spatial overlap of the NIS to sensitive habitats using a weighted approach (sensitivity scores). The resulting impact values are used for the pressure layer, as it gives a more realistic assessment of their threat to the marine environment, as compared to using only the observed location of NIS species.

The index follows a conservative additive model for calculating the cumulative negative impacts of invasive alien species (IAS), based on magnitude of impact and the related strength of evidence following an uncertainty averse strategy. Cumulative impacts of IAS were estimated on the basis of the distributions of invasive species and ecosystems, and both the reported magnitude of ecological impacts and the strength of such evidence. 29 invasive species and 12 habitats were used for the layer, detailed information on the species, habitats and sensitivity scores used in the assessment are given in Annex 3.

The information on species and habitats were aggregated to 10x10 km grid, based on their occurrence within each grid cell. Calculation of the index was done with the HELCOM SPIA tool, and the result were converted to the 1x1km SPIA grid.

Disturbance of species due to human presence

The layer is an aggregation of the following human activities data sets: urban land use, recreational boating and sports, and bathing sites. Urban land use data was constructed from CORINE Land Cover (CLC), Version 2020_20u1 for EU countries and from Open Street Map (OSM) open-source data in Russia. Recreational boating and sport data were derived from SHEBA project. Bathing sites data were extracted from EEA data base and complemented with HOLAS II data. Individual data sets were handled separately as presented in Annex 1. The layers were summed and normalized to produce the final pressure layer.

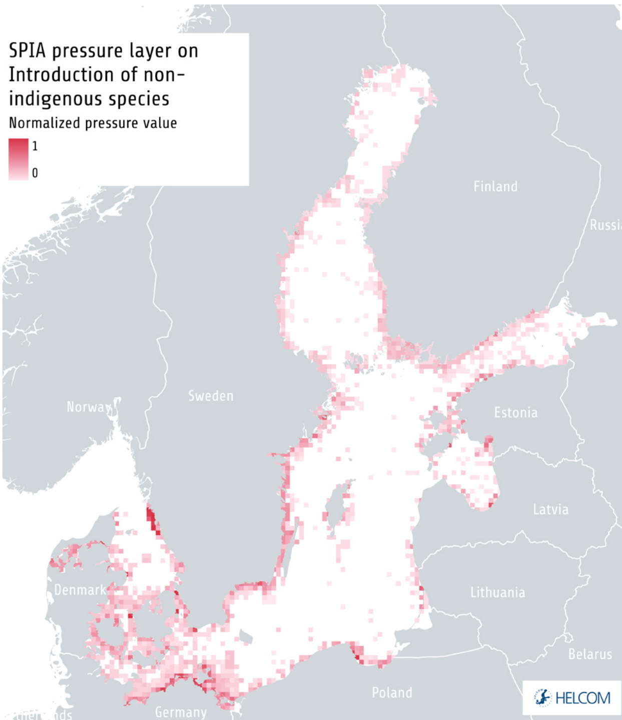


Figure 9. SPIA pressure layer on Introduction of non-indigenous species. The map represent the normalized pressure values, where the intensity of the colour indicates higher pressure

Extraction of fish: Fishing of herring, sprat and cod

Pressures layers representing extraction of fish were based on data on commercial landings of the three main commercial species in the Baltic Sea, namely herring, sprat (Figure 10) and cod, during 2016-2020. The landings data were available at the spatial scale of ICES statistical rectangles and extracted from the EU Joint Research Centre's data collection framework for fisheries data, for Contracting Parties which are part of the European Union. Data for Russia were obtained from ICES annual reports, and were only available at the scale of ICES sub-divisions. The Russian landings data were equally distributed over all ICES rectangles within the concerned sub-divisions. To obtain spatially more detailed information, the landings data were further redistributed within each ICES rectangle based on information on fishing effort (including all gears, c-squares) during 2016-2021. Information on effort was not available for Russia, and average values for the sub-basins were used. In the scaling, the maximum value of tons per square kilometre from the original ICES rectangles was used to scale the maximum pressure. The data set was log-transformed and normalized to produce the final pressure layer.

The data layers representing catches does not account for whether catches correspond to the agreed reference point for fishing pressure, FMSY. The catches are used directly with the implicit assumption that large catches correspond to high pressure. In reality, stocks providing high catches may be large and sustainably exploited, whereas stocks providing low catches may be at a low level but with a high exploitation rate, and catches alone do not provide information on the status of the exploitation relative to the agreed reference point.

When the fishing layers were assessed together as one theme, the pressure layers were summed together. In the Baltic Sea Impact Index, the impact of all three fishing layers to all ecosystem components were summed to assess the impact introduced by fishing. It should be noted that pressures were not aggregated to form one pressure, but individual impacts were summed after the impact calculation.

Hunting and predator control of seabirds

The layer is a combination of data sets representing game hunting of seabirds (2016-2021) and predator control of seabirds (2016-2021). Both data sets were made available by HELCOM Contracting Parties in response to a data request. The number of hunted birds per square kilometre were calculated for both datasets. The datasets were summed and normalized to produce the final pressure layer.

Hunting of seals

The layer is based on data reported by Contracting Parties on the number of hunted seals per reporting unit for grey seal (*Halichoerus grypus*), ringed seal (*Pusa hispida*) and harbour seal (*Phoca vitulina*) and data covers the period 2016-2021. The size and scale of the reporting units varies from county to country. A separate data call was used to gather information on annual hunting quotas, and the values were used to calibrate the pressure value. The received data on the hunting quotas did not always match the spatial unit of the reported hunting values, thus the analysis for some countries was made in the unit of quota values. The data on hunting numbers were complemented with the data collected annually within the framework of the HELCOM Expert Group on marine mammals. The data on hunted seals includes all types of hunting, also regulation of seals.

The data sets were normalized so that value 0.5 was set at the quota for hunting in the units the data were reported. This was done separately for each species and year. Final pressure values is calculated as the average of the normalized hunting values for each species (Figure 11).

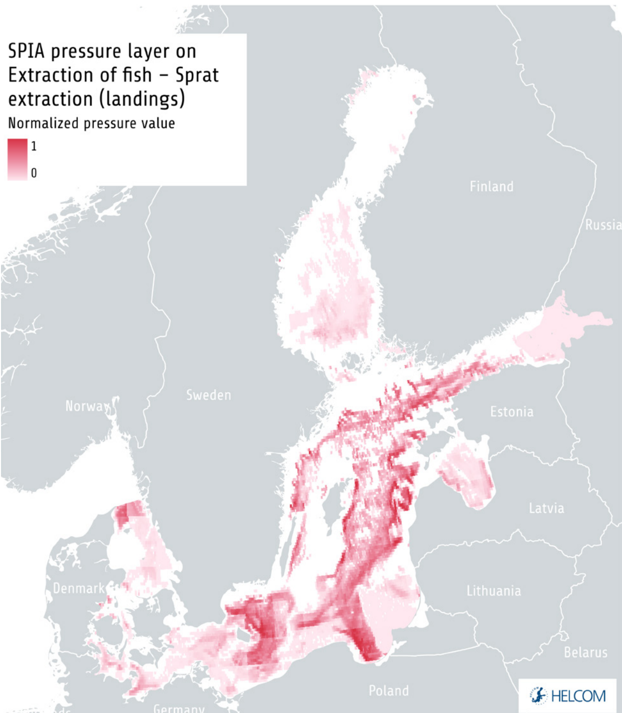


Figure 10. SPIA pressure layer on Extraction of fish pressure layer for sprat. The map represent the normalized pressure values, where the intensity of the colour indicates higher pressure.

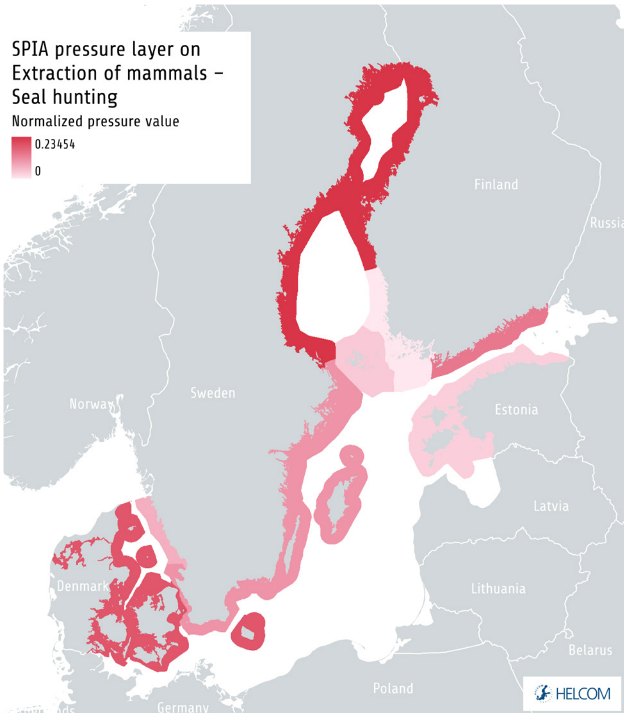


Figure 11. SPIA pressure layer on Hunting of seals pressure layer. The map represent the normalized pressure values, where the intensity of the colour indicates higher pressure.

Pressure layers representing physical disturbances

Physical disturbance to seabed

Physical disturbance is defined as a change to the seabed that can be reverted if the activity causing the disturbance ceases (EC 2017a). The pressure layer is created based on the data from the indicator Cumulative impact from physical pressures on benthic biotopes (CumI), which was accepted for use in HOLAS 3 (HELCOM 2023c). The CumI indicator performs a predictive evaluation of the cumulative (that is, aggregated) potential impact of several anthropogenic physical pressures on the benthic biotopes in the Baltic Sea. The CumI evaluates the spatial extent of disturbance into six different impact levels, from very low to high.

As the SPIA uses different sets of ecosystem components and sensitivity scores than the indicator, CumI data on human activities, prior the inclusion of information on ecosystem components and sensitivity scores, are used in SPIA. Categorical values on the magnitudes of pressure for individual activities are transformed to numerical values, and the pressure layer is the normalized sum of the activities included in CumI (Figure 12).

Physical Loss

Physical loss is defined as a permanent change of seabed substrate or morphology, meaning that there has been change to the seabed which has lasted or is expected to last for a long period (more than twelve years; EC 2017a). The following activities were considered in the assessment as potentially causing loss of seabed: construction at sea and on the shoreline (also including cables and pipelines, marinas and harbours, land claim, and mariculture), extraction of sand and gravel, and dredging. However, it should be noted that the identification of "loss" as applied here has a provisional character, and that the available data does not allow for the classification of the effect of exact operations.

To represent the lost area, the total area covered by the abovementioned human activities was used, based on data represented as polygons. For point and line objects, impact distances for individual layers were estimated based on literature and expert evaluations and implemented accordingly (Annex 1), hence resulting in polygons for these as well. To produce one aggregated pressure layer out from individual human activity data sets, all layers were merged, overlapping areas were removed, and the data were clipped with coastline to remove buffered areas that overlapped with land. The resulting area was considered as potentially lost and no attenuation functions were added. The area lost in square kilometres in each grid cell was used as the pressure value (Figure 13). Hence, if all of the area of one grid cell was covered by the aggregated pressure layer, it was given a pressure value 1.

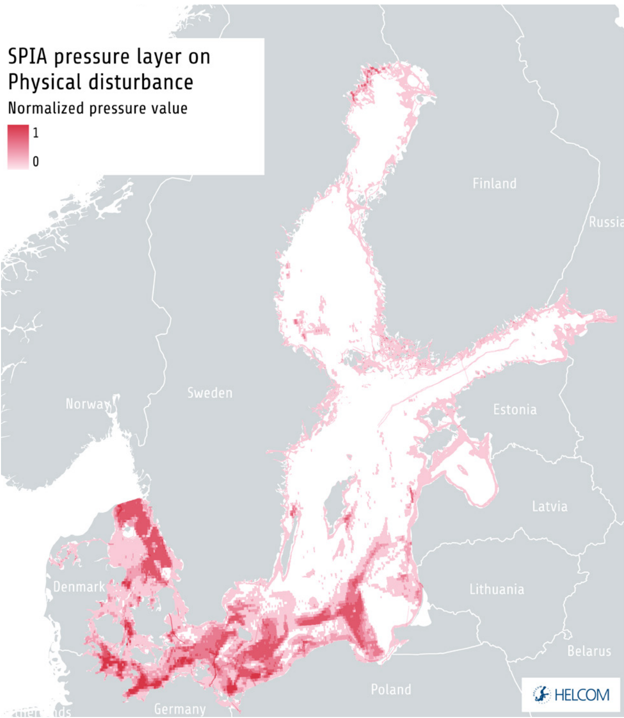


Figure 12. SPIA pressure layer on Physical disturbance. The map represents the normalized pressure values, where the intensity of the colour indicates higher pressure.

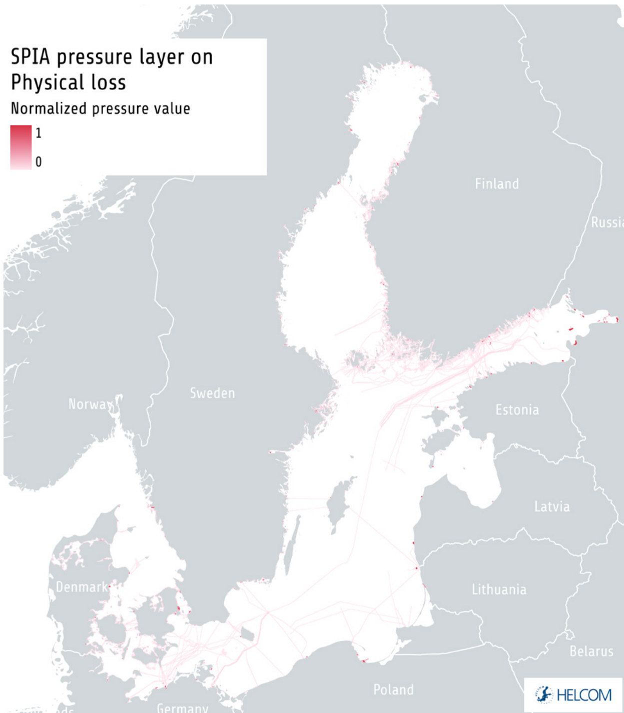


Figure 13. SPIA pressure layer on Physical loss. The map represent the normalized pressure values, where the intensity of the colour indicates higher pressure.

2.4.3 Ecosystem component layers

The data sets on ecosystem components used in the assessment are presented in Table 3. The ecosystem component data sets represent the spatial distribution of habitats and species with high ecological importance in the Baltic Sea, for which data were available and comparable at the Baltic Sea regional scale. The data on ecosystem components represented either of the following larger groups:

1. Benthic habitats based on the EUSeaMap 2021 data and Natura 2000 habitats,
2. Habitat-building species,
3. Pelagic habitats defined as the photic surface layer and the layer beneath,
4. Mobile species (mammals, birds and fish species characteristic species for the Baltic Sea, as well as the habitats they use

Similar to the pressure layers, the ecosystem component data layers were defined to be as up-to-date as possible, based on available data, however focusing on achieving harmonized and comparable data across different parts of the Baltic Sea. As one example, for benthic species data are to large extent reported as point-wise observations, and data from HOLAS II was used to complement data reported for HOLAS 3, to fill in gaps representing potential monitoring gaps during the HOLAS 3 assessment period.

As the ecosystem component layers represent the most recent distribution, they do not include information on where species would occur had there been no historical pressures from human activities. For example, the distribution of cod spawning areas is shown based on information on currently functional spawning areas, which have a clearly more limited distribution than in the past (Köster *et al.* 2017). Hence, the assessment focuses on addressing potential impacts on species and habitats given their current, existing distribution.

The results are not intended to be used for an assessment of their status, but for assessing in which geographical areas these species and habitats are currently under high cumulative pressure from human activities.

Table 3. Ecosystem components used in their assessment and their primary data source.

Ecosystem component layer	Primary data source
Benthic habitats	
Infralittoral coarse sediment	EUSeaMap 2021
Infralittoral mixed sediment	EUSeaMap 2021
Infralittoral mud	EUSeaMap 2021
Infralittoral mud or Infralittoral sand	EUSeaMap 2021
Infralittoral rock and biogenic reef	EUSeaMap 2021
Infralittoral sand	EUSeaMap 2021
Circalittoral coarse sediment	EUSeaMap 2021
Circalittoral mixed sediment	EUSeaMap 2021
Circalittoral mud	EUSeaMap 2021
Circalittoral mud or Circalittoral sand	EUSeaMap 2021
Circalittoral rock and biogenic reef	EUSeaMap 2021
Circalittoral sand	EUSeaMap 2021
Offshore circalittoral coarse sediment	EUSeaMap 2021
Offshore circalittoral mixed sediment	EUSeaMap 2021
Offshore circalittoral mud	EUSeaMap 2021
Offshore circalittoral mud or Offshore circalittoral sand	EUSeaMap 2021
Offshore circalittoral rock and biogenic reef	EUSeaMap 2021
Offshore circalittoral sand	EUSeaMap 2021

Table 3. (Continued). Ecosystem components used in their assessment and their primary data source.

Ecosystem component layer	Primary data source
Sandbanks (1110)	National reporting
Estuaries (1130)	National reporting
Mudflats and sandflats (1140)	National reporting
Coastal lagoons (1150)	National reporting
Large shallow inlets and bays (1160)	National reporting
Reefs (1170)	National reporting
Baltic Esker islands (1610)	National reporting
Submarine structures made by leaking gas (1180)	National reporting
Boreal Baltic islets and small islands (1620)	National reporting
Habitat building species	
Furcellaria lumbricalis distribution	Monitoring/Modelling
Zostera marina distribution	Monitoring/Modelling
Charophyte distribution	Monitoring/Modelling
Mytilus distribution	Monitoring/Modelling
Fucus distribution	Monitoring/Modelling
Potamogeton distribution	Monitoring/Modelling
Myriophyllum distribution	Monitoring/Modelling
Najas marina distribution	Monitoring/Modelling
Fontinalis distribution	Monitoring/Modelling
Callitriche distribution	Monitoring/Modelling
Zanichellia distribution	Monitoring/Modelling
Pelagic habitats	
Productive surface waters (Chl-a)	Satellite observations
Bottom-water habitats not influenced by permanent anoxia	Monitoring/Modelling
Mobile species and their key habitats	
Cod abundance	Survey data
Herring abundance	Survey data
Sprat abundance	Survey data
Potential nursery areas for flounder (PBS)	PanBalticScope project/expert
Potential recruitment areas for perch (PBS)	PanBalticScope project/expert
Potential recruitment areas for pikeperch (PBS)	PanBalticScope project/expert
Potential spawning areas for cod (PBS)	PanBalticScope project/expert
Potential spawning areas for Baltic flounder (PBS)	PanBalticScope project/expert
Potential spawning areas for European flounder (PBS)	PanBalticScope project/expert
Potential spawning areas for herring (PBS)	PanBalticScope project/expert
Potential spawning areas for Sprat (PBS)	PanBalticScope project/expert
Wintering areas for birds	Special protection areas
Breeding areas for birds	Special protection areas
Grey seal distribution	Expert-based
Harbour seal distribution	Expert-based
Ringed seal distribution	Expert-based
Harbour porpoise importance	Expert-based

Benthic habitats

The ecosystem component group “benthic habitats” represent the MSFD Broad habitat types (BHT) and various Natura 2000 habitats. The Broad habitat types originate from the EUSeaMap 2021 data, and cover the whole Baltic Sea region. As they cover the whole region, inclusion of this group of data ensures that there is at least one habitat and sensitivity assigned to all parts of the assessment area (the Baltic Sea region). All 18 Broad habitat types are included in HOLAS 3, as compared to eight that were included in HOLAS II (Example for Infralittoral sand is shown in Figure 14).

The selected Natura 2000 areas are highlighting the areas with most important nature values in the region and enabling the distribution of more precise sensitivity information. The Natura 2000 habitats are selected to cover different types of nature values found in the region, as for example Reefs in Figure 14. The data are based on the reporting by Contracting Parties. Most of the submitted data are based on modelling and limited ground-truthing. Data coverage, accuracy and the methods in obtaining the data vary between countries. Further details about the processing of both datasets are shown in Annex 2.

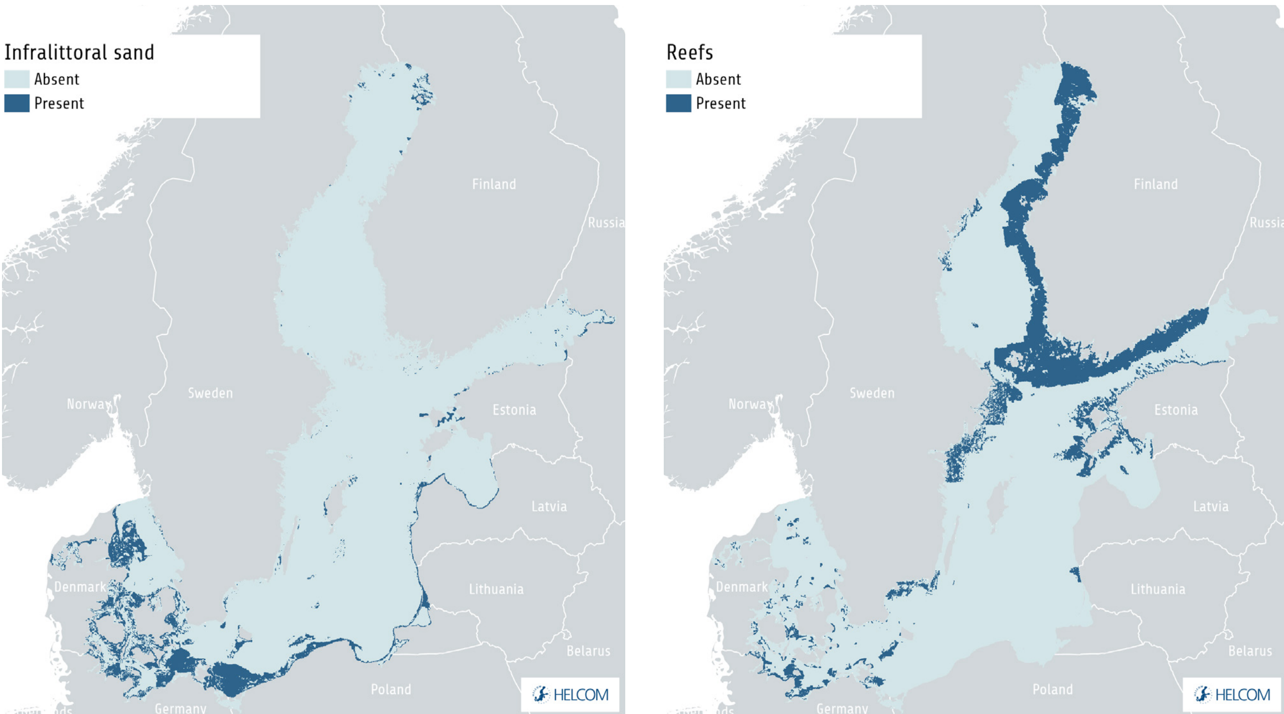


Figure 14. Examples of layers used in the benthic habitats. On the left Infralittoral sand, and on the right Reefs.

Habitat-forming species

The habitat-forming species comprehend the datasets covering benthic species. The areas contained in the different layers of this group highlight the relevant areas of distribution for different species, as observed in Figure 15. The data are based on submission by the Contracting Parties, including mainly observation points, but also modelled distribution for some habitats and regions, and comprises the period of 2011-2021. Data coverage, accuracy, and the methods in obtaining the data vary between countries.

Benthic habitat-forming species that were included in this assessment as well as in HOLAS II were Furcellaria lumbricalis, Fucus sp., Charophytes, Mytilus spp. and Zostera marina. Except for Charophytes, all species used in HOLAS II, are species with a marine origin that have their main distribution in the southern parts of the Baltic, due to salinity gradient. In order to obtain a better representation of species also in the northern and less saline parts of the Baltic, the following species were added to the current assessment: Potamogeton spp., Myriophyllum spp., Najas marina, Fontinalis spp., Callitriche spp., and Zanichellia spp.. These taxa were included in the national data call for HOLAS 3. Further details about the processing of the dataset are presented in Annex 2.

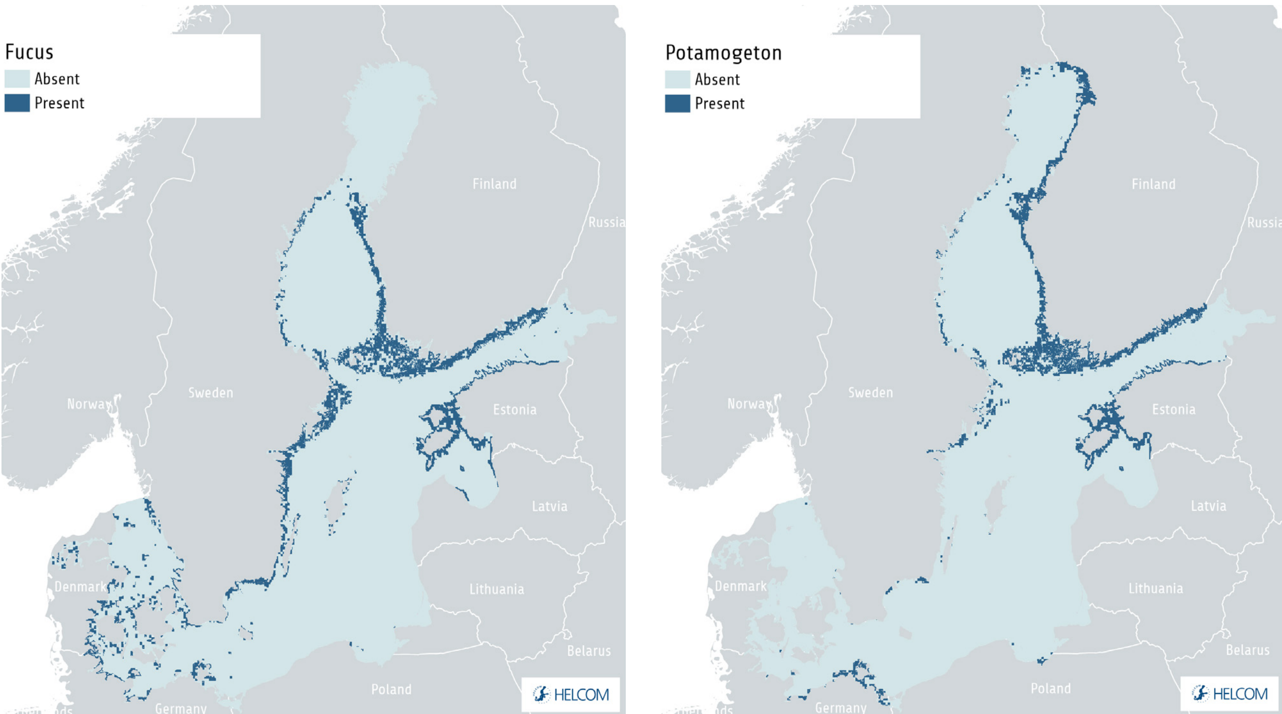


Figure 15. Examples of layers used in the habitat-forming species. On the left, the distribution of Fucus. On the right, the distribution of Potamogeton.

Pelagic habitats layers

Pelagic habitats embody productive surface waters (Chl-A) and bottom-water habitats not influenced by permanent anoxia (H2S)(Figure 16).

Productive surface waters uses Springtime Chl-a concentration as a proxy for productive surface waters. Areas with higher production are given higher importance, as they are considered important areas for the Baltic Sea food web. The dataset was prepared by Finnish Environment Institute.

Bottom-water habitats not influenced by permanent anoxia highlights the suitability of bottom areas for the Baltic Sea biota, with regards to the near bottom areas, based on occurrence of hydrogen sulphide (H2S). The data were provided by the Leibniz Institute for Baltic Sea Research Warnemünde[1] (IOW), and is based on point measurements and modelling. Data were based on five periods per year, for the years 2016-2021. Information on permanent anoxia is available only for open sea areas, and often the anoxia in coastal waters is more temporary in nature.

Further details about the processing of both datasets are presented in Annex 2.

1 Source: https://www.io-warnemuende.de/msr-2016-0100.html

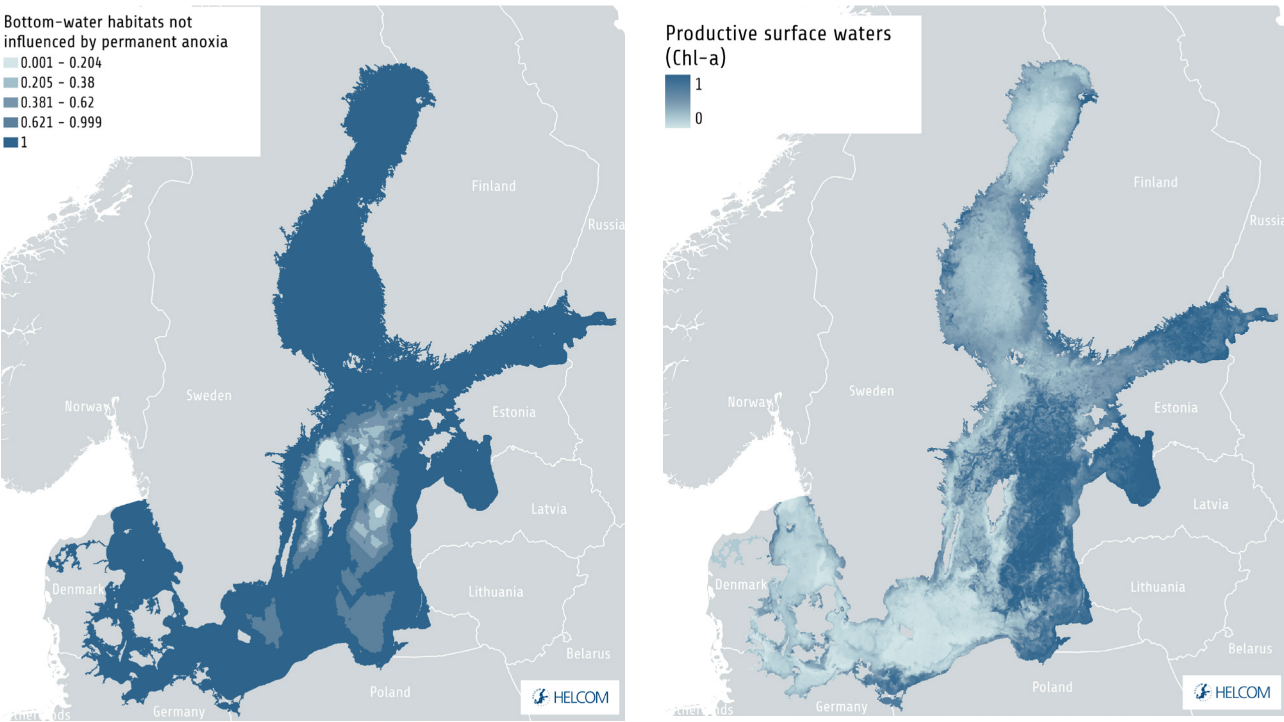


Figure 16. Pelagic habitats layers. On the left, bottom-water habitats not influenced by permanent anoxia. The lower the value the more the habitat is influenced by permanent anoxia, and thus value 1 indicates areas where the bottom-water habitats are not influenced. On the right, productive surface waters.

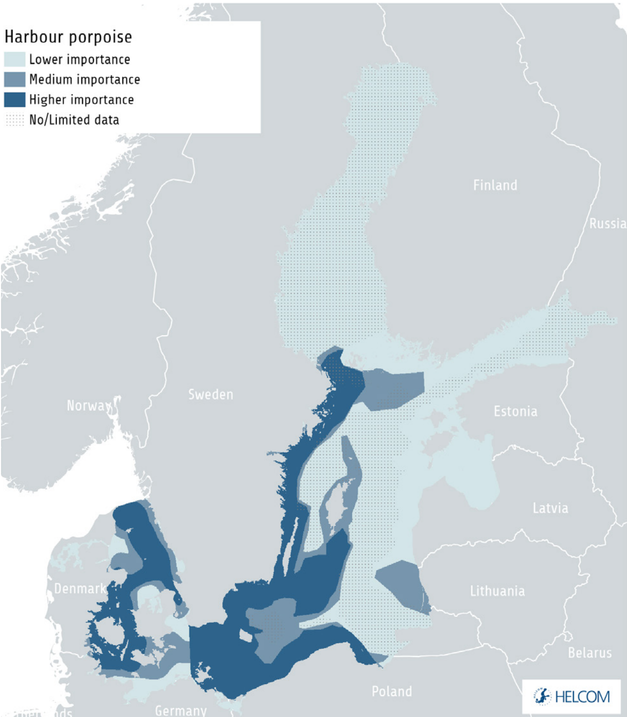
Mobile species layers

Data layers on mobile species included the abundance of cod, herring and sprat, potential nursery, recruitment, or spawning areas for commercially important fish species, as well as wintering and breeding areas for birds, distribution of seals and important areas for harbour porpoise (Examples are shown in Figure 17).

Data on the abundance of cod originated from the Baltic International trawl survey (BITS), whereas data on the abundance of herring and sprat were from the Baltic International acoustic survey (BIAS) data. The areas in this layer highlight the abundance of these relevant commercial species per ICES rectangles surveyed by BITS or BIAS for the period 2016-2020.

Potential nursery areas for flounder, recruitment areas for pike and pikeperch and spawning areas for cod, European flounder, herring and sprat were derived from the EU co-financed Pan Baltic Scope project (HELCOM 2021b). The layers were selected as they represent central ecological functions that need consideration in marine management and maritime spatial planning.

Wintering and breeding areas for birds were extracted from the Natura 2000 Special Protection Areas (SPAs) spatial dataset by EEA that were within the Baltic Sea drainage area.



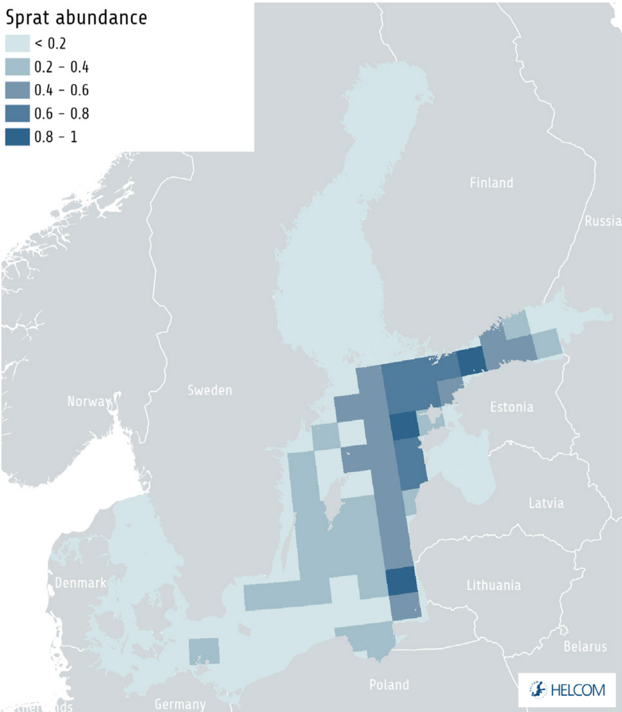


Figure 17. Examples of layers used for the mobile species. The harbour porpoise importance map (top map). The sprat abundance (bottom map).

Seals distribution areas were originally prepared as expert derived distribution categories outlined by abundance and distribution for HOLAS II. The maps were adjusted for HOLAS 3 by the HELCOM Expert Group on Marine Mammals (EG MAMA) seals distribution team, based on improved knowledge on seals distribution in the Baltic Sea. The distribution team is composed of experts representing all Contracting Parties and WWF. The maps were approved by EG MAMA and by the Working Group on the State of the Environment and Nature Conservation (State and Conservation).

Importance areas for harbour porpoise were drafted by the HELCOM Expert Group on Marine Mammals (EG MAMA) harbour porpoise distribution team, which is composed by experts representing Germany, Sweden, Denmark, Poland, and Finland Contracting Parties, and approved by EG MAMA and by the Working Group on the State of the Environment and Nature Conservation (State and Conservation). The map reflects the two separate populations of harbour porpoises in the Baltic region, namely the Belt Sea population primarily occurring at the Kattegat, the Belt Seas and the Western Baltic, and the Baltic Proper population primarily occurring at the Baltic Proper.

Due to differences in conservation status and in the amounts and types of available data, the two populations were handled separately when preparing the maps. For the Belt Sea population, hotspots were identified based on tracking data from tagged porpoises from the period 2007-2021, locations were filtered and a Kernel density raster layer was produced from the analysis producing isopleths, which were merged and compared visually with data from SCANS-III (Lacey *et al.* 2022), the Belt Sea density surface model (period 2002-2016; ITAW/unpublished) and the MiniSCANS-II sightings (Unger *et al.* 2021) by the expert group to ensure that no potentially important areas were missed in the telemetry analysis.

For the Baltic Proper population, the importance map was based on the probability of acoustic detection data from SAMBAH in combination with national expert judgment based on information obtained from the Finnish national passive acoustic monitoring program and passive acoustic research projects in Polish coastal waters. Furthermore, due to the clear difference in abundances of the two populations, the experts decided to use maps representing areas of importance for harbour porpoises rather than distribution maps. In this way, the critically endangered Baltic Proper population will not have less weigh in the assessment due to its low abundance. The data used in the analysis falls under the categories “higher”, “medium”, and “lower” importance, and data gaps are presented as “no/limited data”. Maps for the two populations were merged into one map on areas of importance for harbour porpoise. Further information about the methodology used in the importance areas can be found at https://dce2.au.dk/pub/TR240.pdf.

Further details about the processing of each dataset can be found in Annex 2.

2.5. Sensitivity scores used in the assessment

The sensitivity scores estimate the sensitivity of each ecosystem component to each pressure in the assessment. Hence, the scores channel the impact assessment for each of the pressures to the specific species and habitats that are sensitive to them. The sensitivity score is the same for the whole Baltic Sea, but for some species – pressure composition the sensitivity might differ on different areas, and this requires further attention in the upcoming assessments. The scores used for HOLAS 3 were the same as in HOLAS II, as reviewed by regional experts to ensure the most recent scientific information and understanding was included.

The scores were originally developed for HOLAS II by an expert survey and literature review carried out by the EU co-financed TAPAS and BalticBOOST-projects. In the TAPAS project, the sensitivity scores were obtained from a survey answered by over eighty experts in the Baltic Sea region, representing marine research and management authorities in seven Baltic Sea countries. Before implementation, the sensitivity scores were evaluated in relation to a self-evaluation by the experts regarding how certain they were in their replies. Further, the results were evaluated for compatibility with a literature review, focusing on the physical pressures and benthic habitats, but also including other aspects. More detailed description of the process can be found in the report A protocol for the calculation of the Baltic Sea Impact Index and the Baltic Sea Pressure Index (Korpinen *et al.* 2017). The final sensitivity scores used in the assessment are presented in Annex 4.

3. Results for the spatial distribution of pressures and impacts assessment

Assessment results in short

- Potential cumulative impacts from human activities on the environment can be identified in all parts of the Baltic Sea, but there are also some clear spatial differences. Shallow coastal areas are generally subject to the highest levels of impact, due to a high number of ecosystem components, as well many human activities. Regarding potential cumulative pressures, however, the highest level of pressure is identified in open sea areas.
- Eutrophication and hazardous substances are the two most influential pressures for both potential cumulative pressures and impacts, having a wide distribution across the whole Baltic Sea region. Bottom-water habitats not influenced by permanent anoxia and grey seal (Halichoerus grypus) are the ecosystem components most affected by potential cumulative impacts, partly due to the large extent of these ecosystem layers compared to other layers.
- A thematic analysis on the potential effect of continuous noise on mobile species shows the relatively highest impact levels in the south, especially around the Arkona Basin. The Ships entering and leaving the Baltic Proper go through a rather narrow area in the southwestern Baltic Sea, so that ship traffic is concentrated within an area where the distribution of mobile species is also high.
- A thematic analysis of the potential impact of hazardous substances and eutrophication over all ecosystem components showed that these have widely spread impacts over the Baltic Sea. The combined potential impact from hazardous substances and eutrophication showed a largely similar pattern to that of the total potential cumulative impact expressed as Baltic Sea Impact Index (BSII), reflecting that these pressures are also the main contributors to total impact on the Baltic Sea environment. Both pressures have a wide distribution and are present everywhere in the Baltic, and the relatively highest impact is identified for areas with many co-occurring ecosystem components, such as in the coastal areas.
- Regarding physical loss, less than one percent of the whole Baltic Sea was estimated to be impacted by long-term potential loss of seabed. The sub-basins with highest shares of lost seabed were The Sound and Great Belt, estimated at 4.4 % and 0,9 % long term potential loss of seabed, respectively.
- The presented results clarify the spatial patterns and relative intensities of potential cumulative pressures and impacts in the Baltic Sea. Hence, they do not provide information on magnitudes of pressures or impacts on an absolute scale, but give information on their relative levels when comparing different parts of the region. The assessment is based on currently best available regional data, but spatial gaps may occur in some underlying datasets and this is indicated in the results with separate data availability maps.

3.1. Results

The results section of the assessment is comprised of two indices BSII and BSPI, and three thematic analyses – using a subset of existing data sets. The assessment has a total of 28 human activities, 17 pressure and 57 ecosystem component layers, and each of the individual layers can also be considered as an important part of the results, providing information on the distribution of pressure and ecosystems. The pressure and ecosystem component layers can be accessed and explored in HELCOM map and data service together with the metadata descriptions. The layers are also available in the SPIA tool, where they can be used to run the assessment on any combination of pressures and ecosystems, and the results can be explored by the interactive tool with accompanied result statistics.

3.1.1 Baltic Sea Impact Index

The Baltic Sea Impact index assesses the potential cumulative impact of all pressures over all ecosystem components. The assessment indicates that all parts of the Baltic Sea are under potential cumulative impacts, but that there are great differences in the level of impact between different areas of the Baltic Sea (Figure 18). The potential cumulative impacts are the highest on coastal areas especially in the central and southern Baltic Sea. Open sea areas are in general less affected, but substantial impact can also be found on open sea, especially around Arkona and Bornholm basins, mainly due to commercial fishing practices.

'Hazardous substances' and 'eutrophication' were the pressures contributing most to the total impact, comprising more than three quarters of the total impact (Figure 19). The results reflect that these pressures have the widest distribution and many species and habitats have high sensitive to these pressures. Oth-

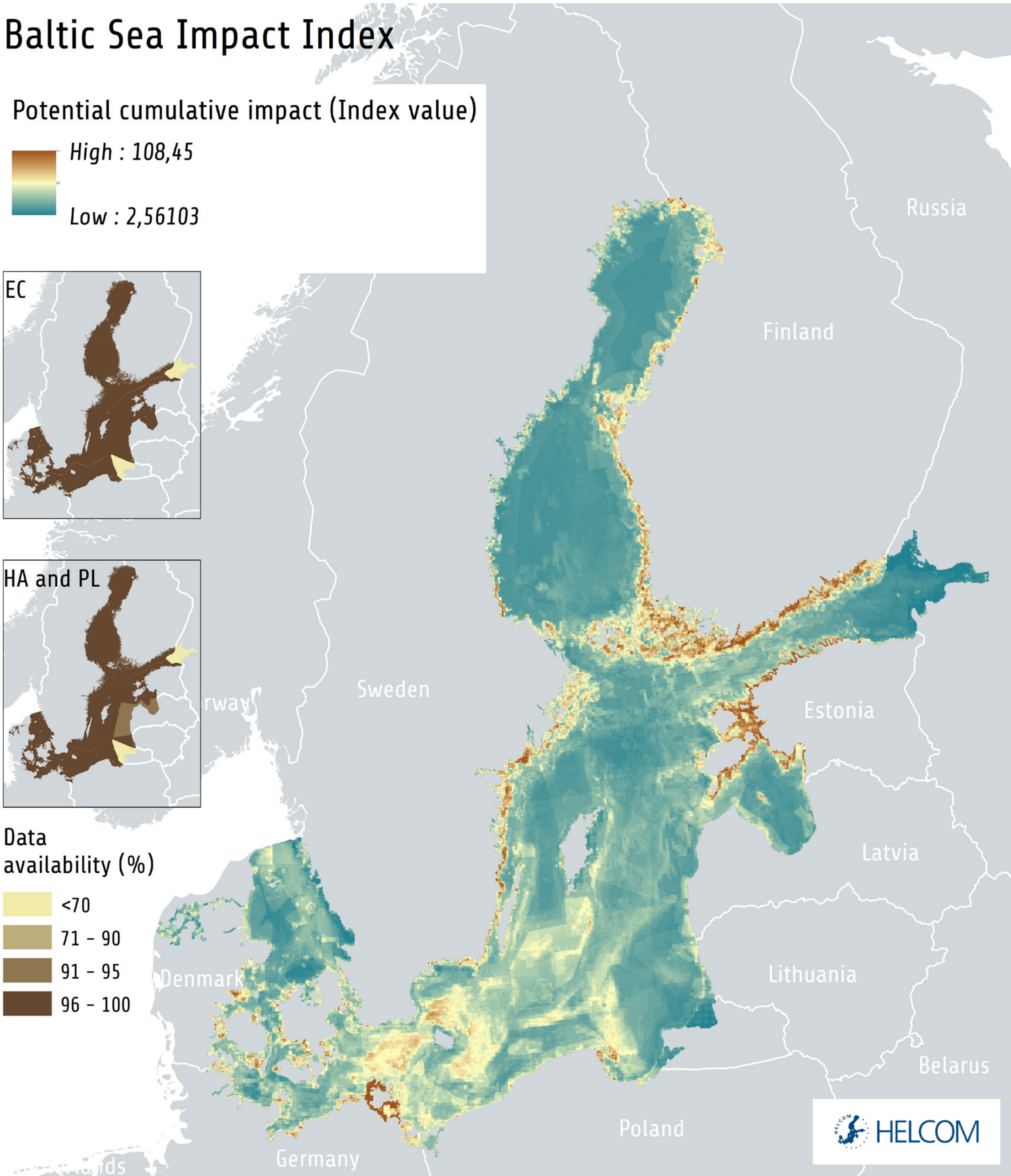


Figure 18. Distribution of potential cumulative impact from human activities on the Baltic Sea environment, based on the Baltic Sea Impact Index. The analysis is based on currently best available regional data, but spatial gaps may occur in some underlying datasets, as described by the data availability maps, showing available data for human activities/pressures (HA and PL) and ecosystem components (EC).

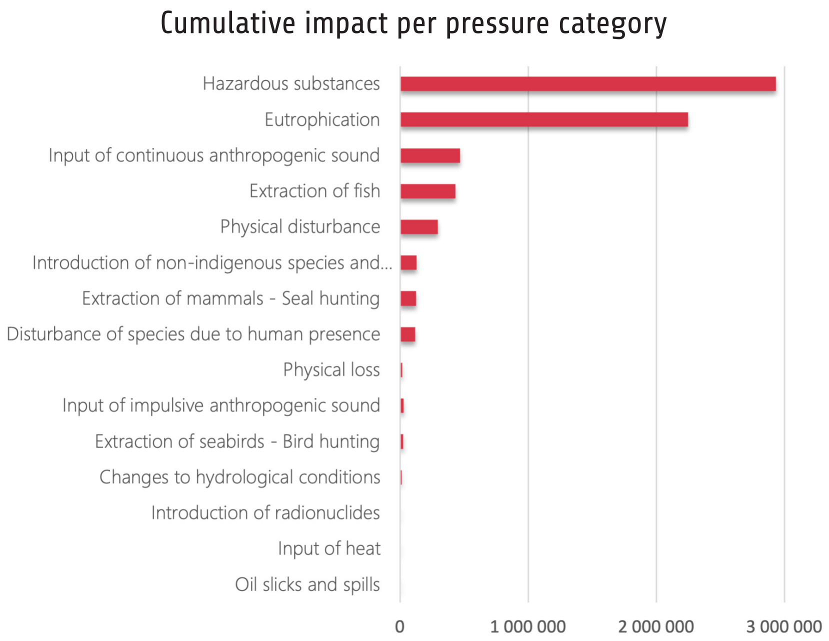


Figure 19. Ranking of pressures themes attributed to potential cumulative impacts in the Baltic Sea Impact Index. The values in the figure represents the sum of the impact index values for the whole assessment area, calculated as described in section 3.4 for all layers in the assessment.

er highly ranking pressures were 'input of continuous anthropogenic sound', 'extraction of fish' and 'physical disturbance'. These pressures also have a wide distribution, but compared to hazardous substances and eutrophication, they are identified as occurring spatially more closely to the human activities causing these pressures. Further, the number of ecosystem components (species and habitats) that are sensitive to these pressures is relatively lower. Other pressures had a more limited distribution and lower contribution to the total impact. However, many species and habitat are also highly sensitive to these pressures, 'physical loss' being one clear example, even though the limited distribution makes their contribution to the total potential cumulative impact low at the scale of the whole Baltic region. However, these pressures might have a significant impact on local scale.

By considering how the spatial distribution of species and habitats overlap spatially with different pressures, the Baltic Sea Impact Index identifies the parts of the biological ecosystem that are potentially most impacted overall. The potentially most impacted ecosystem component is 'bottom-water habitats not influenced by permanent anoxia', followed by 'grey seal distribution' (Figure 20). Together, these two represent about one quarter of the total impact. Bottom-water habitats have relatively low sensitivity to many pressures, but the wide distribution of available bottom-water habitats makes it the potentially most impacted habitat. Grey seal is abundant in most parts of the Baltic Sea. Grey seals are not as widely distributed as deep-water habitats, but impacts are at the same level as it has higher sensitivities to pressures.

As the number of ecosystem components (57) is high compared to the number of pressure layers (17), the patterns of impact given in the results are most influenced by the ecosystem components. Many species and habitats included in the assessment are abundant in shallow areas, accumulating high impact "hot spots" in many coastal regions. These habitats are not among the most widely distributed impacts ecosystems, but are attributed to high local impacts.

The accumulation of impacts in shallow areas can also be seen when looking at the average impact per square kilometre within HELCOM sub-basins (Figure 21). Many of the potentially most impacted sub-basin have large shallow areas compared to open sea areas. This is particularly true for the Åland Sea, The Sound and the Great Belts. There are, however, also sub-basins with broad open sea areas ranking relatively high, driven mainly by the pressure from commercial fishing with bottom-contacting fishing gear. The lowest average impact can be found in basins with vast open sea areas compared to coastal regions, such as the Bothnian Sea and Bothnian Bay.

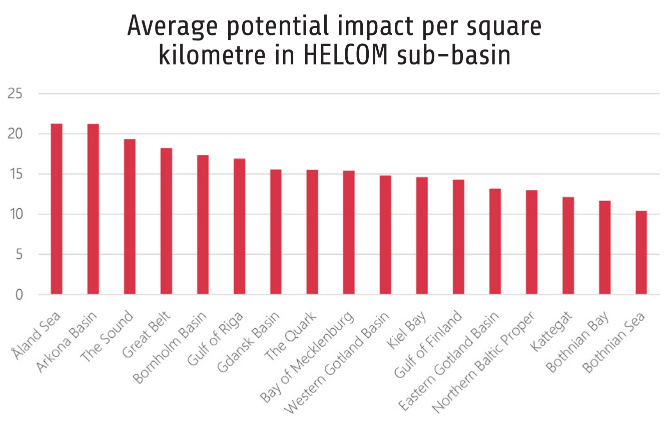


Figure 21. Average potential cumulative impact per square kilometre in HELCOM sub-basin in BSII.

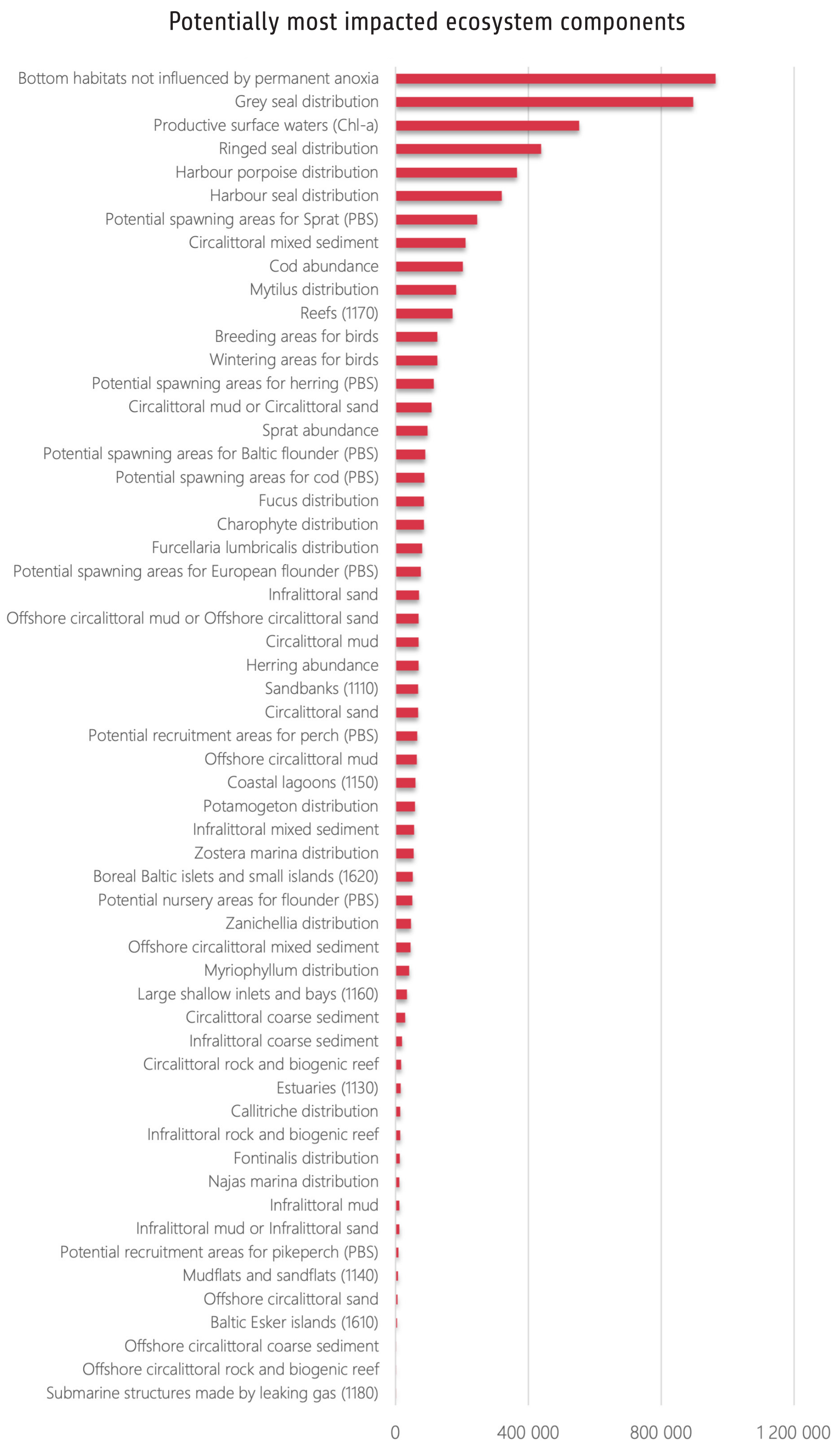


Figure 20. Potentially most widely impacted ecosystem components (species or habitats), according to the Baltic Sea Impact Index. The values in the figure represents the sum of the impact index values for the whole assessment area, calculated as described in section 3.4 for all layers in the assessment.

3.1.2 Baltic Sea Pressure Index

The results of the Baltic Sea Pressure Index present the potential cumulative pressures of all 17 pressure layers in the Baltic Sea, while ecosystem components are not included. Hence, the results provide information about the location of areas with highest potential cumulative pressures, without assessing their specific interactions with species or habitats. However, each pressure is weighted against its average sensitivity score for all ecosystem components, to provide a more realistic result.

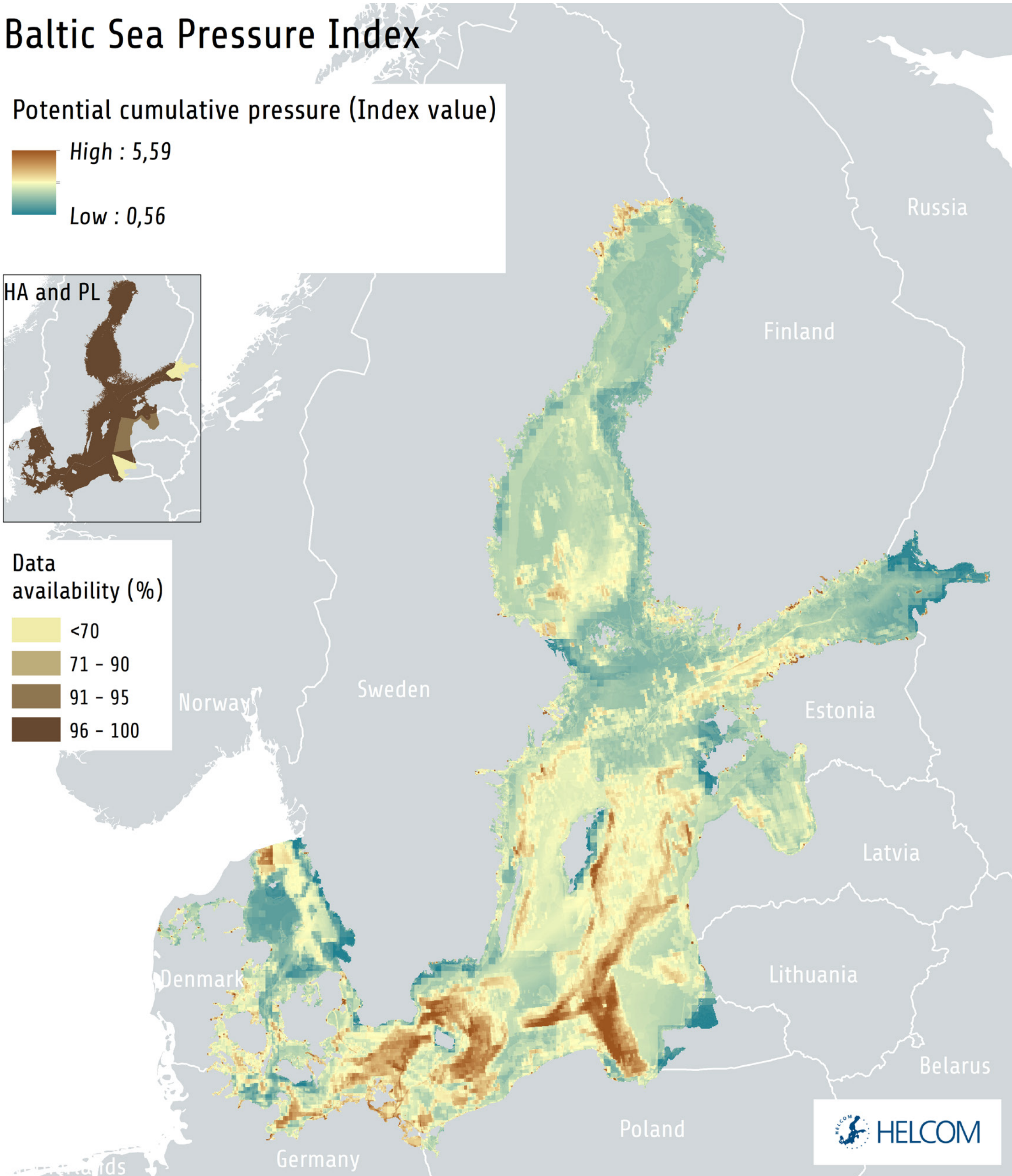


Figure 22. The Baltic Sea Pressure Index shows spatial variation in potential cumulative pressure on the Baltic Sea, by combining data on several pressures together. The index is based on currently best available regional data, but spatial gaps may occur in some underlying data sets, as indicated in the data availability map.

Compared to the BSII, the BSPI gives a different kind of picture, where open sea areas are the most affected (Figure 22). Coastal areas also have high pressure, but to a more limited extent, and mainly in the southern Baltic. When comparing results by the two indices, further, the cumulative distribution of pressures often occur in other areas than identified hot spots for species and habitats, highlighting the importance of addressing the combined impacts. The top pressures for the whole region are hazardous substances and eutrophication (Figure 23).

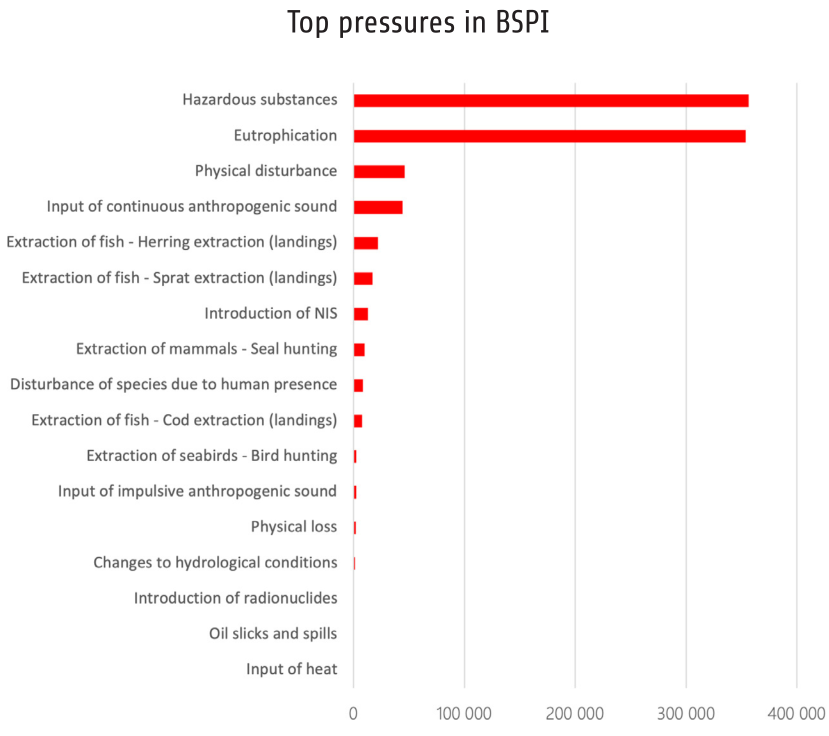


Figure 23. Top pressures in BSPI. The values in the figure represents the unitless BSPI index value, which is the sum of all values of the pressure layer in the Baltic Sea, weighted by the average sensitivity score.

3.1.3 Potential effect of continuous noise to mobile species

The thematic analysis assesses the cumulative potential effect of continuous noise on mobile species and their presence in the HELCOM area. The evaluation is based on the pressure layer on input of continuous noise, combined with information on the distribution of 15 mobile species and their habitats, the full list of ecosystems is presented in Figure 24. The pressure layer represents sound levels at one 1/3 octave band of 125 Hz exceeding the natural background levels at least 50% of the time, meaning

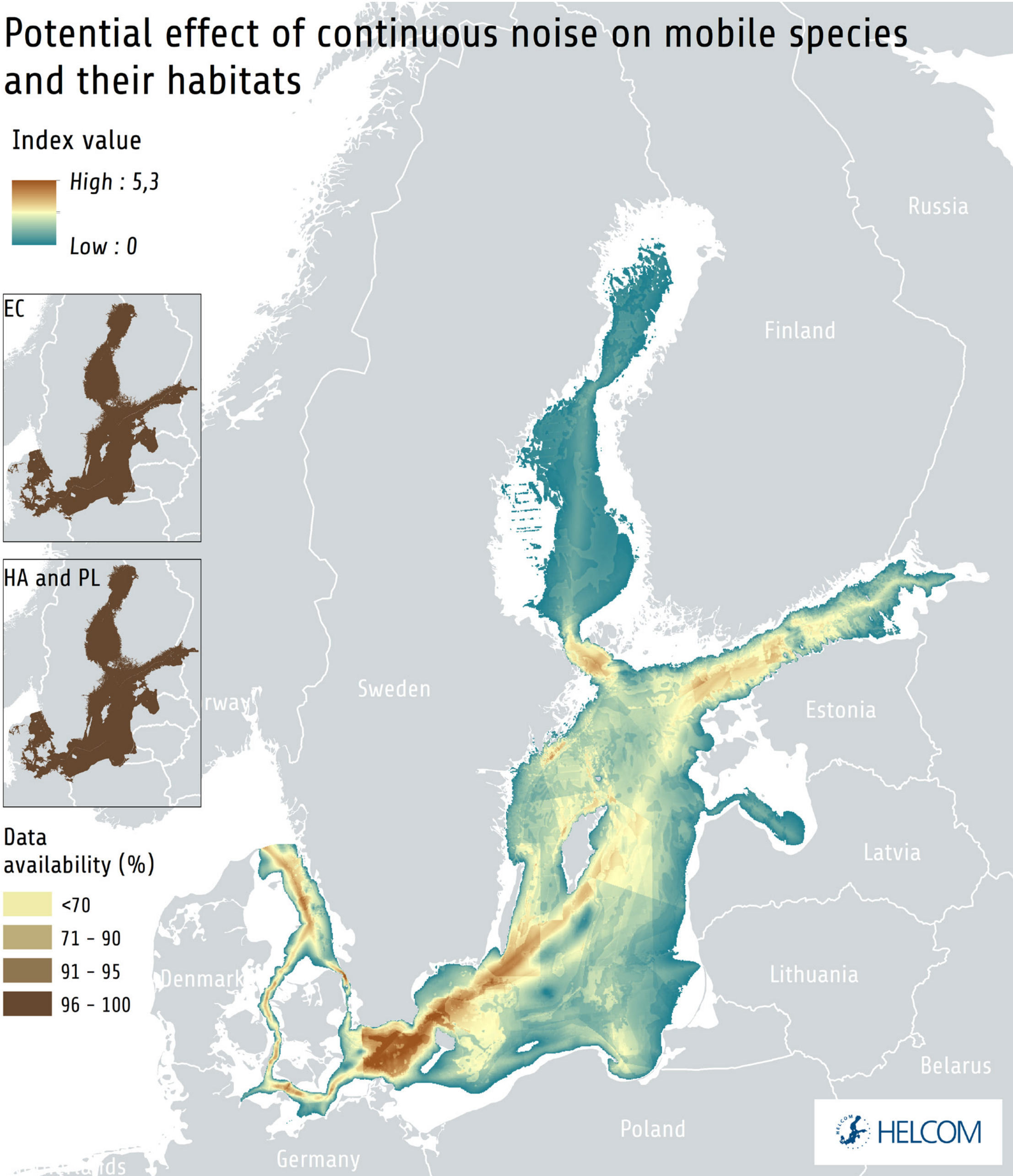


Figure 24. Map on the potential effect of continuous noise on mobile species and their habitats. Data availability for the analysis is good as indicated by the maps. The modelling for continuous noise from commercial vessels covers the whole area. Data sets for mobile species are based on presence of such species in the HELCOM area.

that ambient background levels must be exceeded half of the time for sound to be considered a pressure in a certain area. It is to be noted that further adaptations to this model may be needed since a noise sensitive species is frequency band specific, thus consideration is to be given to the use of other frequencies which are also biologically relevant (e.g., 500 kHz).

According to the analysis, the highest potential effect can be found in the central and southern Baltic Sea (Figure 24). The potential effect is also considerable elsewhere along the main shipping route crossing the Baltic Sea. The potential effect decreases north from Åland islands where shipping is not so prominent, and according to the ecosystem maps, are also less inhabited by assessed mobile species.

Levels of continuous noise from commercial vessels (See section 2.4) are mostly the highest in open sea areas, while only some coastal areas are affected. The pressure layer depicts the sound level at 50 percentile exceedance, which serves to highlight the most intensive shipping routes and decrease the importance of areas with less traffic. The effect of this can be also seen in the potential effect map (Figure 24), which indicates that potential effects from underwater sound are not prominent in the coastal areas, even though many important habitats and mobile species occur here. However, this lacks the noise from recreational vessels which have not been recorded and thus cannot be assessed.

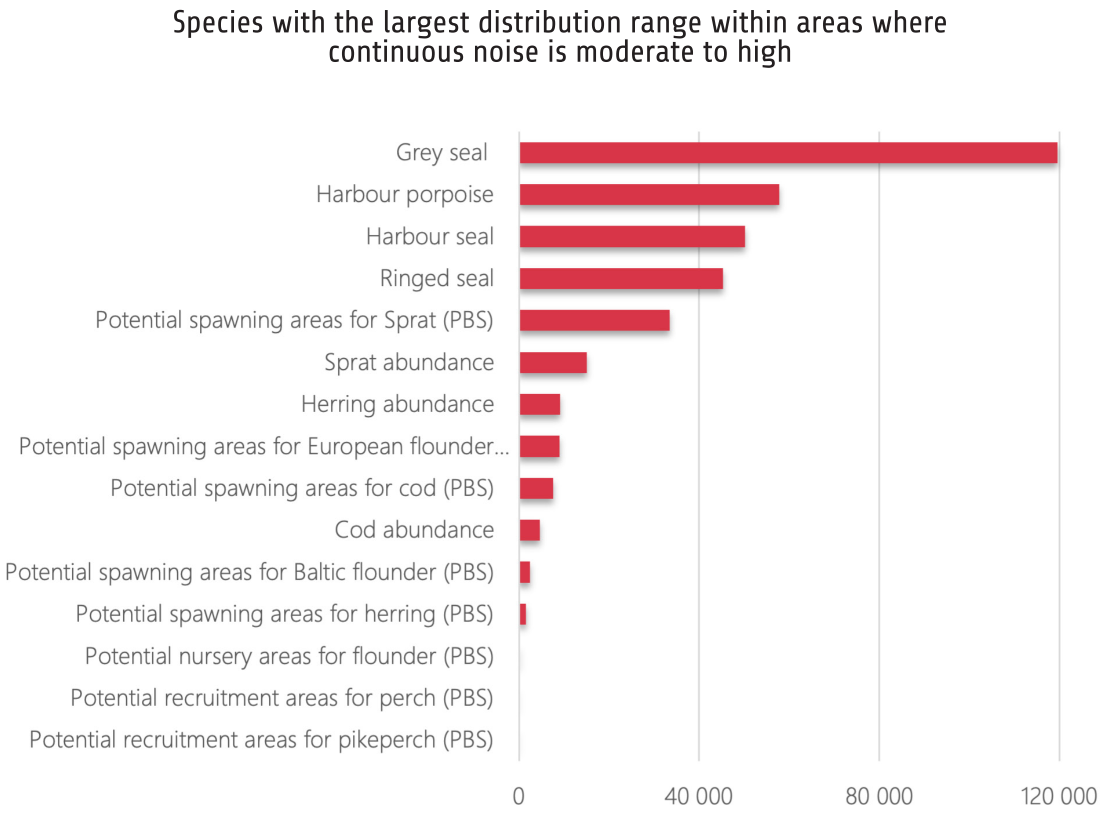


Figure 25. Species with the largest distribution range within areas where continuous noise is moderate to high based on spatio-temporal overlap of vessel noise in the 125 Hz band and species occurrence. The values in the figure represents the sum of the impact index values for the whole assessment area, calculated as described in section 3.4 for the layers included in this analyses.

The most potentially affected species was grey seal, due to its (Figure 25). wide distribution in the Baltic Sea, also occurring in open sea areas where most of the shipping takes place. All other marine mammal species occurring in the Baltic Sea are also on the top of the list, reflecting that these also have a wide distribution, including open sea areas, and high sensitivity to continuous noise (Annex 4). Spawning, nursery and recruitment areas for fish species are ranked lower in the analyses reflecting a relatively more limited distribution, mainly located in coastal waters.

Looking at the different HELCOM sub-basins, the areas with highest average potential effect can be found in the Arkona basin (Figure 26). In this sub-basin, all ships entering or leaving the northern and eastern parts of the Baltic pass through a rather narrow area, compressing the traffic. The Arkona basin is also a hotspot for the occurrence of mobile species, intensifying the impact of this area. All five top-ranked basins are in the southern and central Baltic Sea, along the heavily trafficked main shipping route. The impact was less frequent in more northern basins, where the traffic is mainly concentrated around ports, as well as away from the most intensive shipping routes.

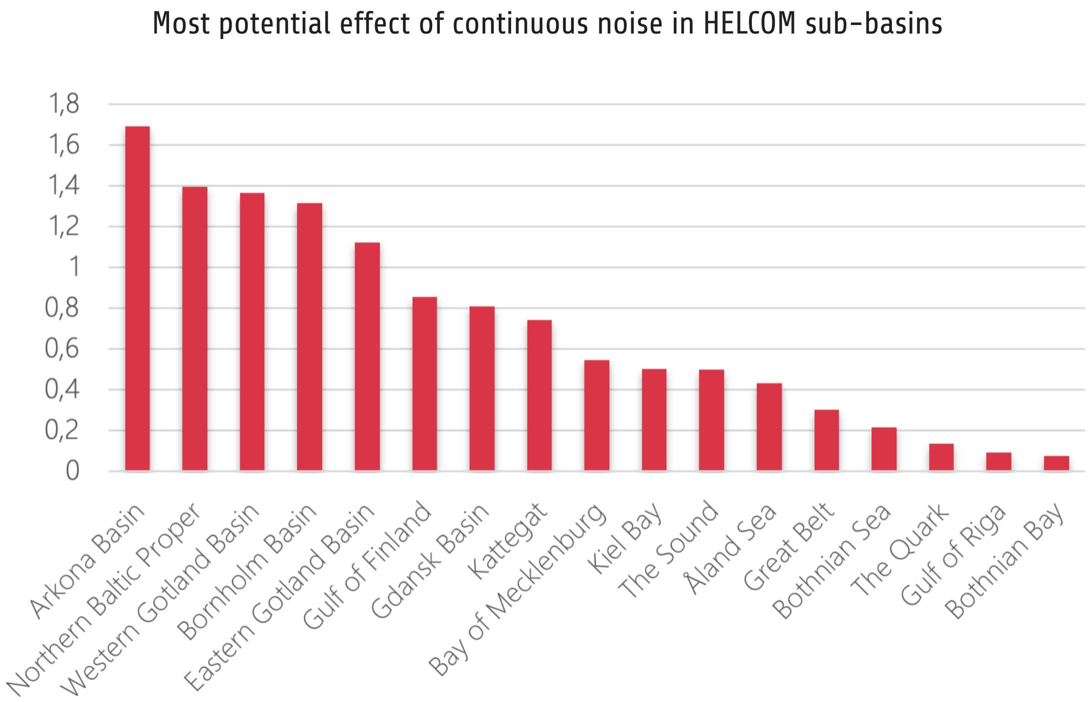


Figure 26. Potentially most effect of continuous noise in HELCOM sub-basins on average.

3.1.4 Potential physical loss of Broad Habitat Types

The level of long-term potential physical loss of seabed in the Baltic Sea was estimated to be less than 1% on the regional scale for the assessment period. The highest estimates of potential loss at the level of sub-basins was above 4% at The Sound (Figure 26). In the majority of the sub-basins, less than 1% of the seabed area was estimated to be potentially lost. Nonetheless, it is important to observe that the area counted in the analysis is directly linked and affected by the data provided for the reporting period.

Figure 27 shows parts of the sub-basins that presented the highest estimates of potential loss. The human activities mainly connected to potential seabed loss for the Baltic Sea were harbours, coastal defence, and marinas and leisure harbours.

Regarding broad habitat types, the highest proportion of area potentially lost was concentrated in infralittoral habitats, as can be observed in Figure 29. It is important to notice that both areas for broad habitat types and human activities for this figure were calculated based on the area of the 1x1 km grid, as this was the area used in SPIA analysis. The habitat types that presented the highest proportion of areas potentially lost in the Baltic Sea were 'infralittoral mixed sediments', 'infralittoral sand' and 'circalittoral mixed', all presenting more than 1%.

Harbours are causing most of the potential loss, according to the analysis when looking at the contribution of individual human activities (Figure 30). The activity is attributed to slightly more than one third of the potential loss. It is followed by coastal defence and marina and leisure harbours.

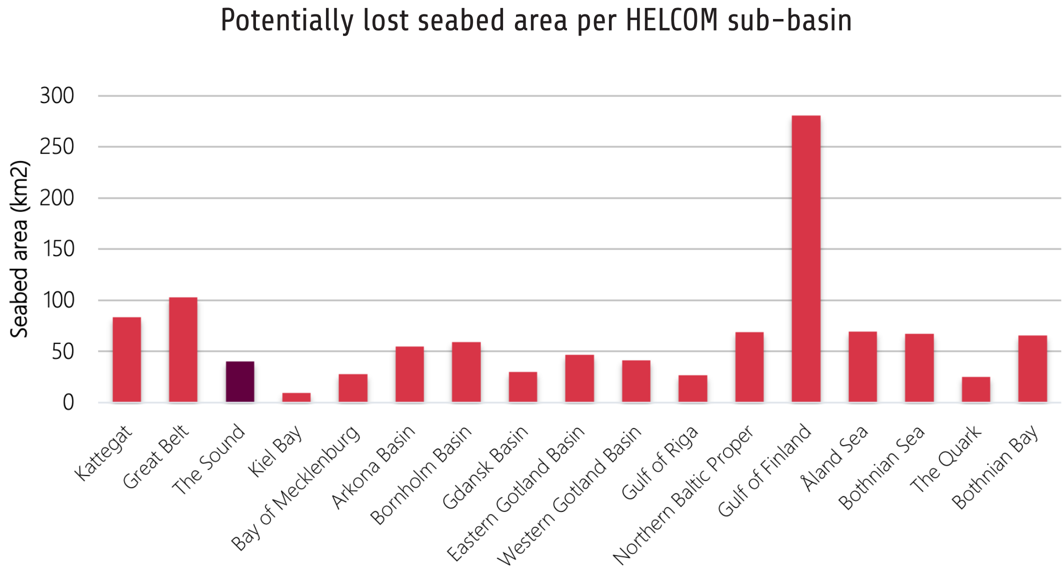


Figure 27. Estimated seabed area potentially lost due to human activities per Baltic Sea sub-basin, given as square kilometres. Values were estimated from spatial data on human activities attributed to causing physical loss. Dark red indicates sub-basins where this represents 1–10% of the total area. For the other sub-basins, the lost seabed area was estimated to cover less than 1% of the total area.

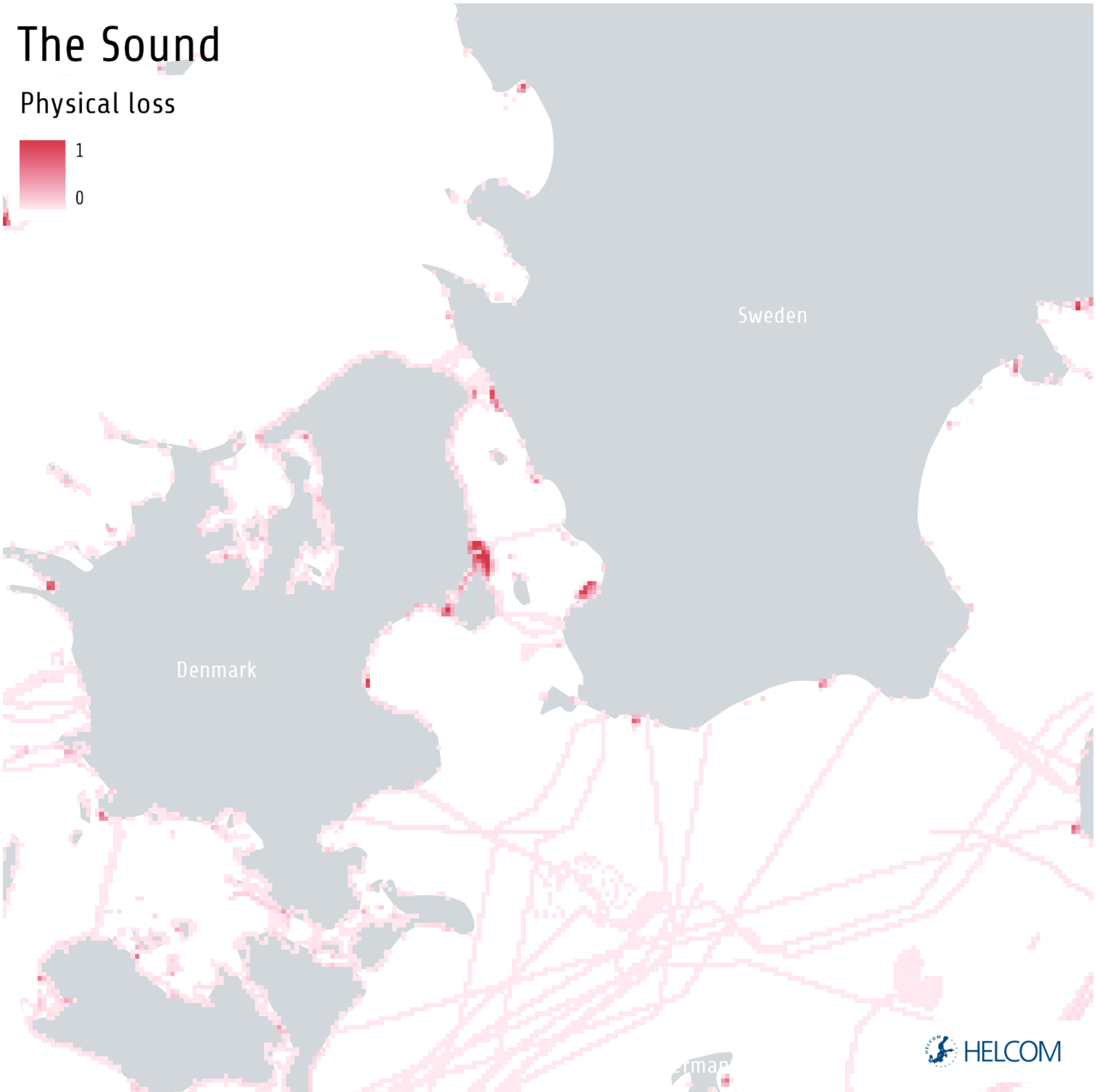


Figure 28. Sub-basins with the highest values for potential physical loss.

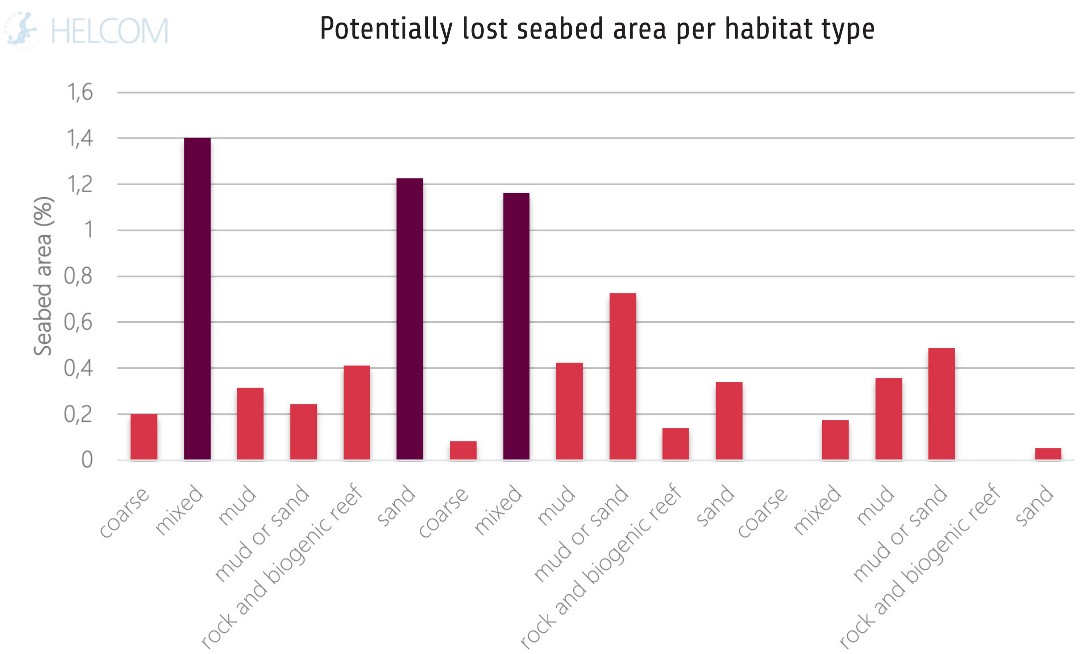


Figure 29. Estimated percentage of broad benthic habitat types potentially lost due to human activities. Dark red indicates habitat types with the highest potential loss percentage.

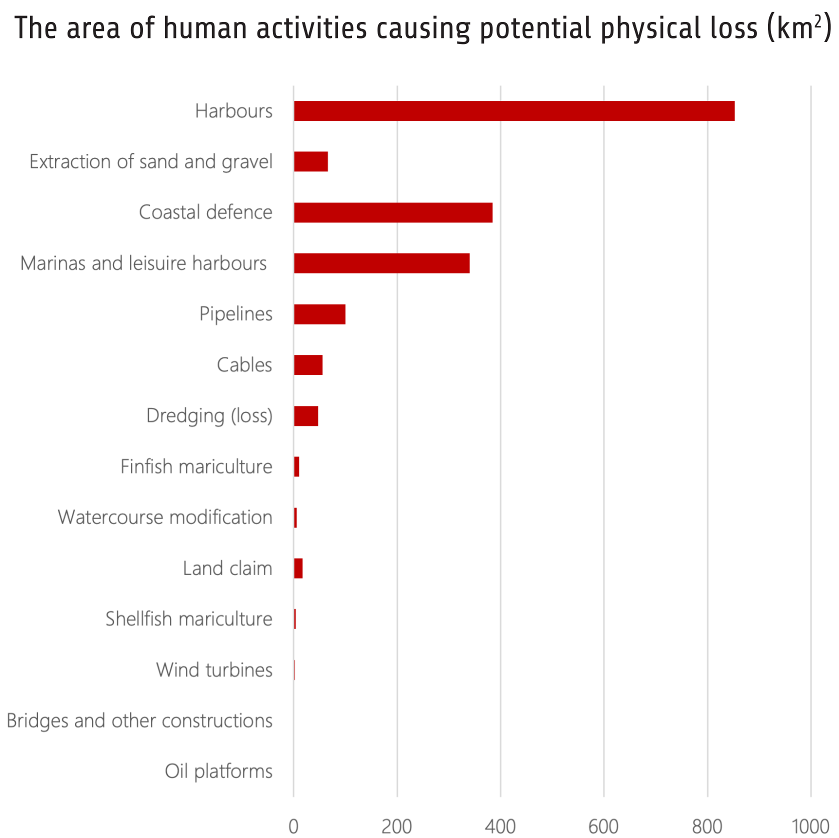


Figure 30. The area of potential physical loss per human activity as square kilometres.

3.1.5 Potential cumulative impacts of eutrophication and hazardous substances

The results show that the potential impact of hazardous substances and eutrophication over all ecosystem components is spread widely over the Baltic Sea (Figure 31). The pattern of the impact is largely following the one of the BSII, as these pressure layers are the main contributors for the total impact. These two pressure layers have a wide distribution and the pressure is present everywhere in the Baltic, thus the pattern of the impact is driven mainly by the hot spots of ecosystem components in the coastal regions.

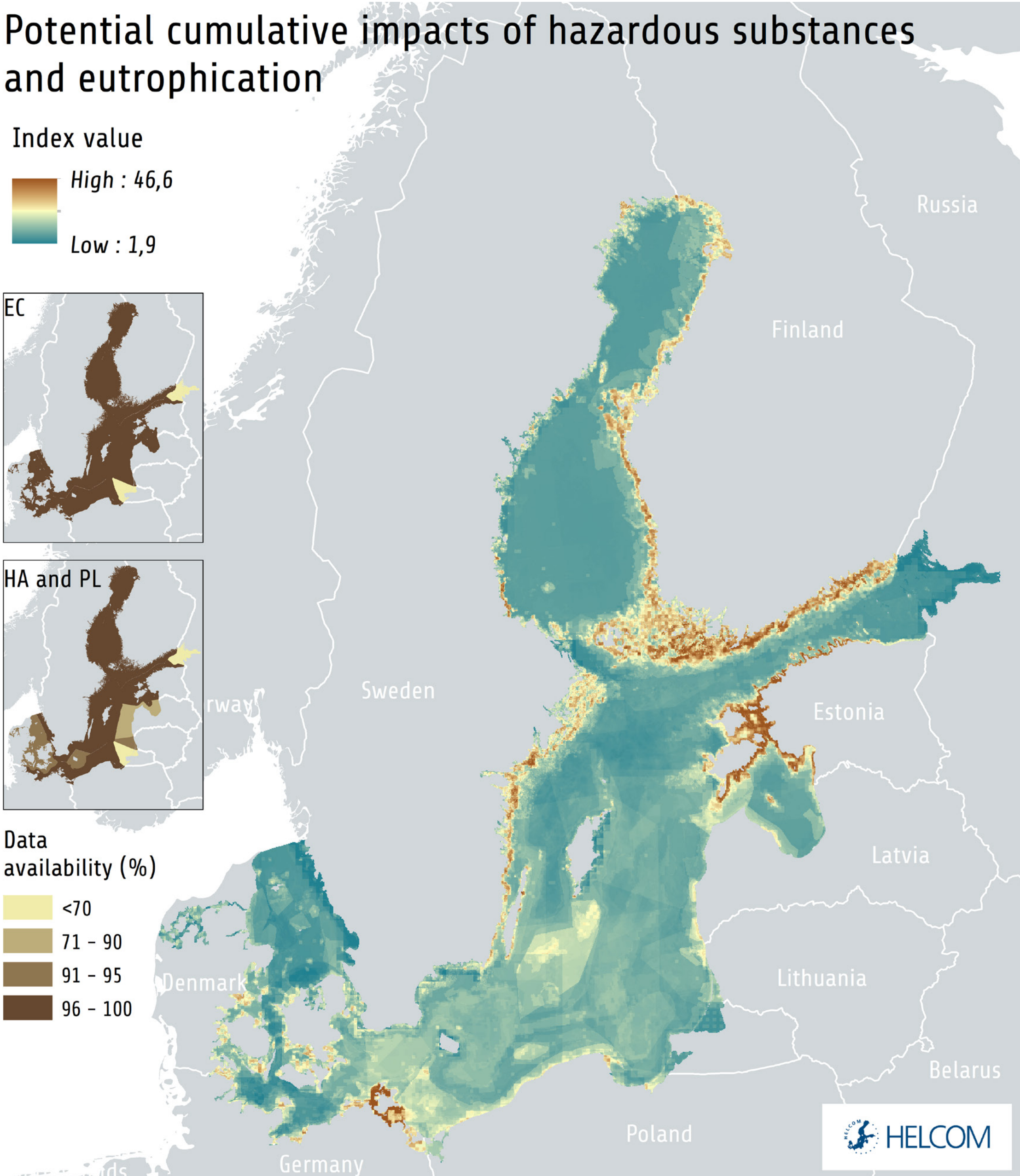


Figure 31. Potential cumulative impacts of eutrophication and hazardous substances over all ecosystem components. Data availability for HA and PL, indicates the availability of underlying indicator groups for the integrated assessments for eutrophication and hazardous substances and the availability of all ecosystem components.

Figure 32 is representing the 20 potentially most impacted ecosystem components in the analysis, and the shares originating from hazardous substances and eutrophication respectively. As in BSII, the two potentially most impacted habitats and species are Bottom-water habitats not influenced by permanent anoxia and grey seals. The main contributors, however, are clearly different for these two components as deep-water habitats are much more sensitive to eutrophication than hazardous substances, and vice versa for grey seals. Same division can be seen for the next two ecosystem components Productive surface waters and ringed seal, for the same reason.

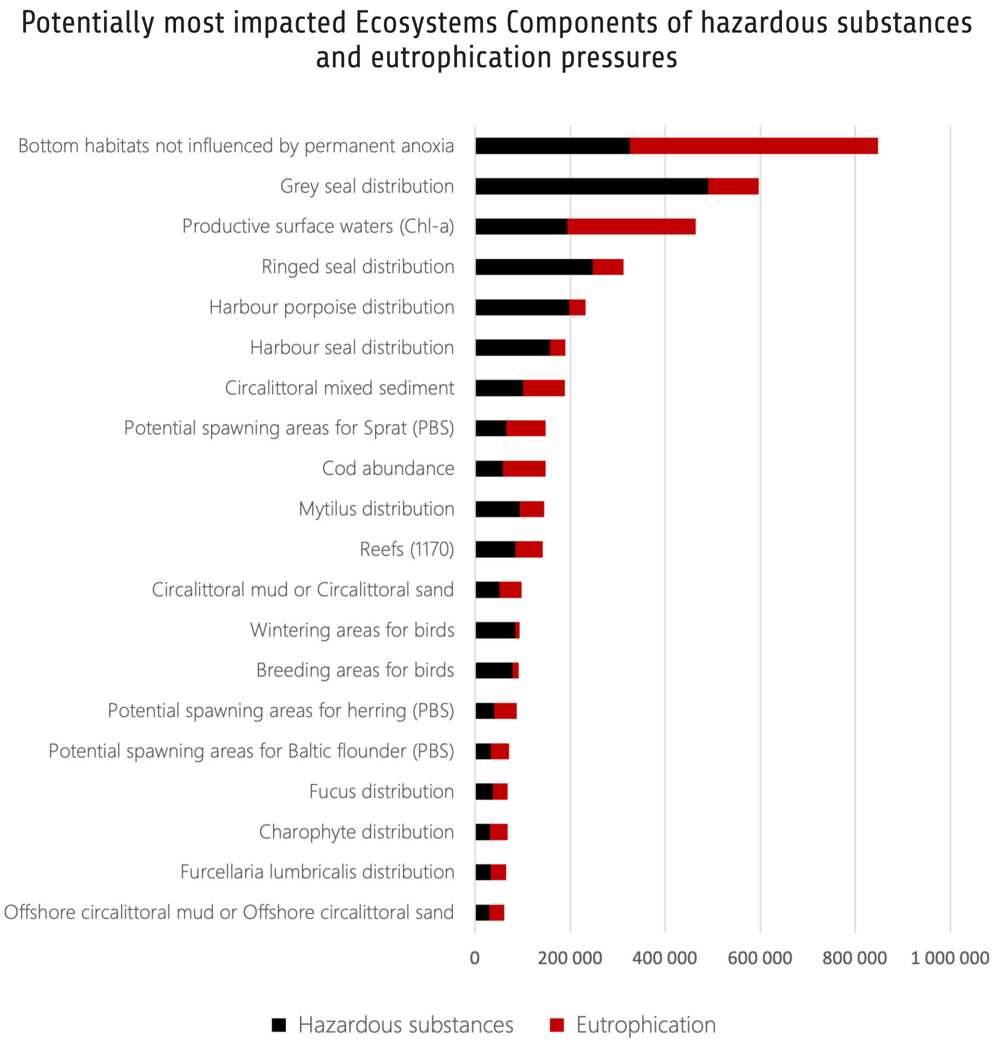


Figure 32. The potentially most impacted ecosystem components for eutrophication and hazardous substances. The results show strong similarities with corresponding results for the BSII where all pressures layers are included. The values in the figure represent the sum of the impact index values for the whole assessment area, calculated as described in section 3.4 for the layers included in this analysis.

3.2. Changes of cumulative impacts over time

The results are providing information on the spatial pattern and the intensity of potential cumulative pressures and impacts in the Baltic Sea. The results of the assessment are provided with unitless indices and do thus not provide information on pressures and impacts on an absolute scale. Rather, it informs on the relative levels of impacts when comparing different areas. Hence, the SPIA is not a status assessment in the same way as the HELCOM indicator-based evaluations are. The SPIA results are best used as a means to describe and communicate relative patterns and relative intensities of pressures and impacts in different parts of the Baltic regions, and can highlight areas that are under relatively highest potential cumulative pressures and impacts. Considering the relative nature of the SPIA, the results are not suited to be directly compared between assessment periods, such as between HOLAS II and HOLAS 3, for example. Further, the methodology and approaches for how to create the underlying spatial data sets have changed for a number of layers, to take up the most recent knowledge and developments. Therefore, in addition to that the results are always relational and meant for consideration within one assessment period, changes between the current and previous assessments can partly be due to methodological changes, or due to the addition of new ecosystem components layers.

However, some type of comparison of the results between assessment is reasonable. One option could be to compare the relative distribution of impacts across sub-basins and the share of potentially most impacting pressures, even though the relative nature of the results should also be kept in mind in these cases. Figure 33 shows the percentages of contribution of HELCOM sub-basins to the total impact in HOLAS II and HOLAS 3. Considering overall differ-

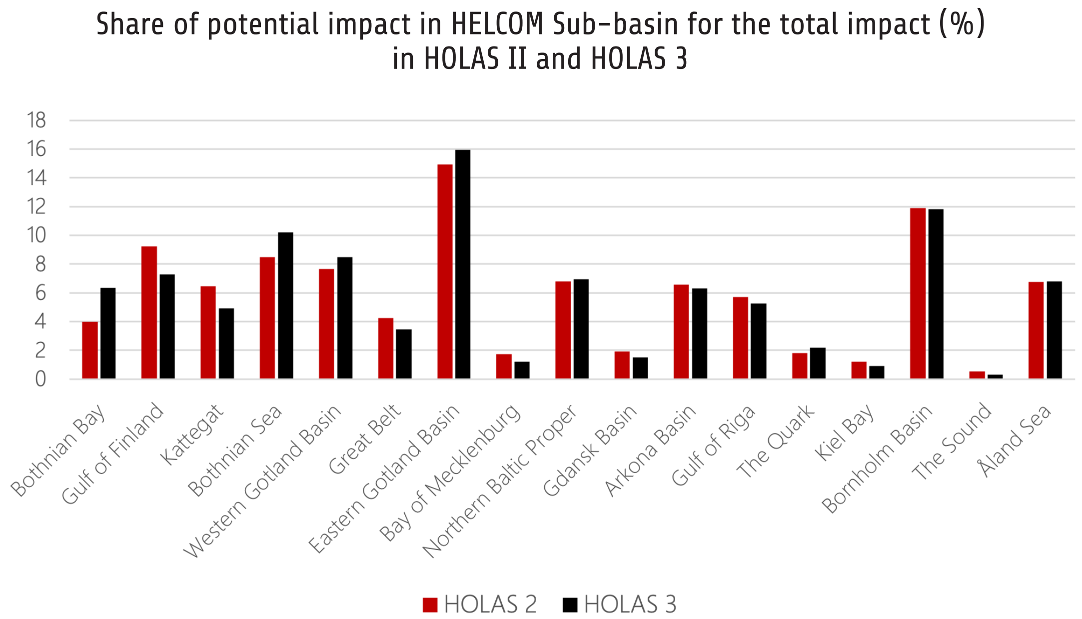


Figure 33. The share of potential impact in HELCOM sub-basins for the total, given as percentages for HOLAS II and HOLAS 3. The sub-basin with highest difference compared to HOLAS II is shown furthest to the left.

ences, the relative contribution of different sub-basins to the total potential impact appears relatively stable situation between the two assessments. The highest differences is seen for the northern sub-basins of Bothnian Bay, Gulf of Finland and Bothnian Sea, as well Kattegat. The added impact to the northern sub-basin can be explained by the addition of new habitat-forming species to HOLAS 3, that thrive in the less saline waters in the north.

Looking at the shares of different pressures to the potential total impact, the comparison shows fluctuation in their contribution between the assessments, especially for those layers for which the methodology has been reviewed between the assessments (Figure 34). This is particularly true for Hazardous substances, Eutrophication and Introduction of NIS. The contribution of individual pressures is dependent on many separate factors, not limited to the pressure itself, and often it is difficult to name individual factors driving that change.

Although the share of contribution from individual pressures has changed considerably for some layers, this is not strongly reflected in the share of contributions for different sub-basins. This outcome can be explained by the relative nature of the assessment – the pressure decreases everywhere and on relative terms the impacts can still have similar distribution patterns.

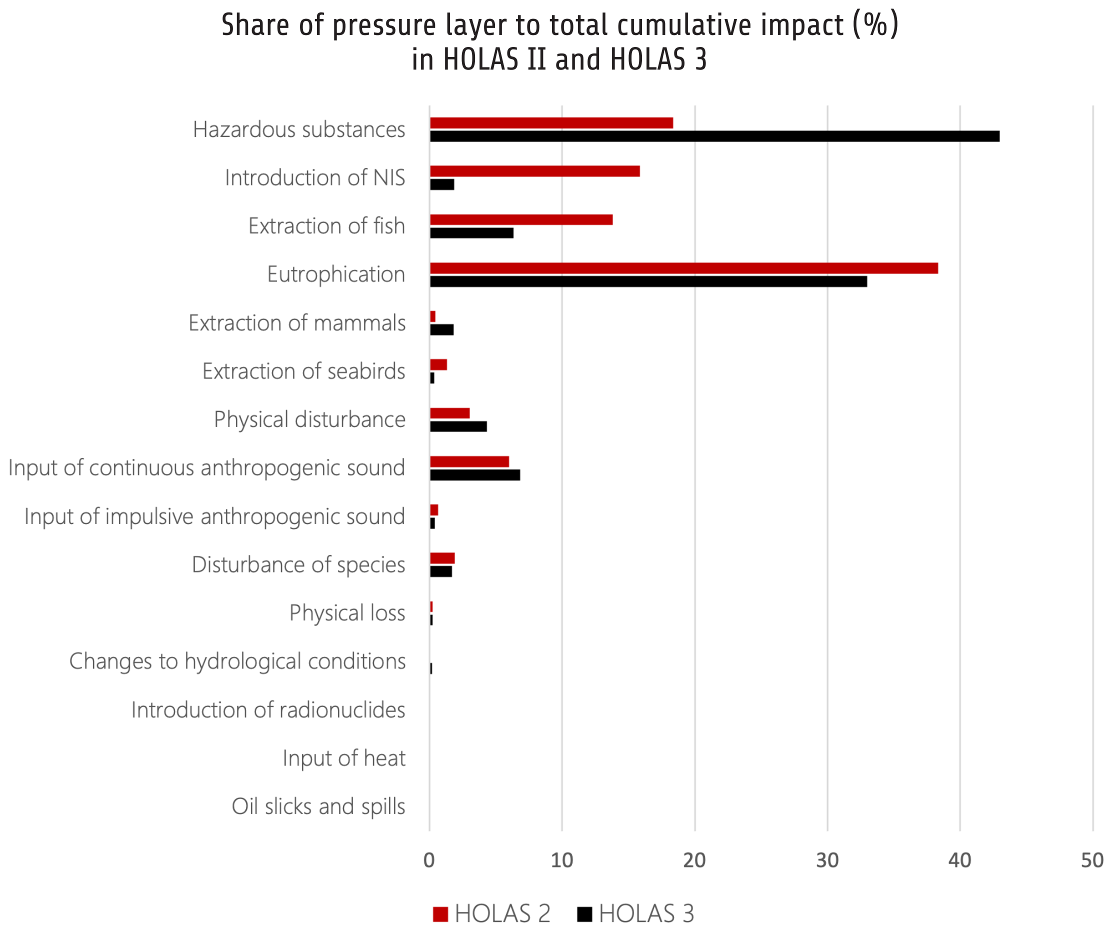


Figure 34. The share of pressure layers contributing to the potential total impact, given as percentages for HOLAS II and HOLAS 3. It should be noted that the methodology for some pressure layers have changed substantially from the previous assessment and the results are not directly comparable. This especially true for hazardous substances, NIS and eutrophication layers.

3.3. How was the assessment carried out

The assessment was carried out using a gridded approach with a resolution of 1 square kilometre. The cumulative burden was calculated as a sum of all impacts in one grid cell, for all ecosystem components, as shown in formula A (where PL=pressure layer, n=the number of pressures, EC=ecosystem components, m=the number of ecosystem components, and SS=the sensitivity of each ecosystem component to each pressure):

(A)

$$BSII(x,y) = \sum_{i=1}^{n} \sum_{j=1}^{m} PLi(x,y) * ECj(x,y) * SSi,j$$

It is also possible to calculate the cumulative pressures without considering the values of ecosystem components, but including the average sensitivity score of all ecosystem component to individual pressure (formula B). This analysis gives the cumulative anthropogenic pressures in each grid cell calibrated with the mean sensitivity score to each pressure.

(B)

$$BSPI(x,y) = \sum_{i=1}^{n} (PLi(x,y) \frac{1}{m} \sum_{j=1}^{m} SSi,j)$$

The assessment does not only provide results for the BSII and the BSPI, but also for a number of thematic analyses where only a subset of datasets are included. These analyses follow the same concept and calculation formula, but applied only for the selected pressure and ecosystem component layers. In these analyses, the same additive model is used and the impacts are calculated as a cumulative sum for the components included.

The applied approach allows for including several ecosystem component layers per grid cell and is suitable when the underlying ecosystem component data sets have relatively high level of detail, as is the case in the current assessment. The Baltic Sea Impact Index was assessed based on the 'sum impact' because, compared to other computation options, the sum approach gives a greater range of high and low impact values and hence distinguishes patterns more clearly.

In cases where there are significant gaps in the underlying ecosystem component data sets, it may be more suitable to use the method of 'average impact' or 'maximum impact'. The 'average impact' has been used in assessments in other sea areas such the California Current (see for example Halpern *et al.* 2009). The 'maximum impact' method might be appropriate to highlight areas of high risk.

One implication of using the 'sum' approach, as applied here, is that the overall assessment outcome depends on the number of ecosystem components and pressures assessed in each grid cell. The highest impacts are often observed in assessment units where several pressures and/or ecosystem components are present. Therefore, a high index score can either be explained by the impact of several pressures, or by the impact of a single pressure on several ecosystem components.

3.3.1 Assessment tool

The assessment was carried out using the SPIA tool designed by the HELCOM Secretariat in the Pan Baltic Scope project and further developed in the HELCOM MetDev project. There are two versions of the SPIA tool, namely the ArcGIS Pro desktop toolbox and a web-based online tool. The desktop toolbox runs the assessment and is also available for download in GitHub. The online tool has functionalities that can be used for various purposes, including presenting and exploring the results.

The HELCOM SPIA online tool is an open-source tool developed by the HELCOM Secretariat and free for everyone to use for running the SPIA analysis with HELCOM datasets as input. The tool includes three sections: information, layers and calculation. The first section introduces the tool, gives background information and provides links for the further reading. In the layers section the user can use the map viewer to explore the pressure and ecosystem layers available for the calculation. In the calculation section, the user can select calculation method (pressure or impact index) and the layers that are to be included. It is possible to run the assessment for the whole Baltic Sea or separately for an individual HELCOM sub-basin. Any combination of pressure and ecosystem layers can be used in the tool, providing a flexible approach to run different kind of analysis. Based on the selection, the tool produces a pre-defined sensitivity score matrix, that the user can use directly or edit the sensitivities in the tool.

Results of the calculation appear on the tools' map viewer where it's possible to explore and download the map together with a statistics matrix of the result. In the interactive map viewer, it is possible to compare the results to any pressure or ecosystem layer used in the calculation.

The map viewer also includes the possibility to explore the contribution of pressure and ecosystem layers to the total impact for each unit of the result raster. In practice this means, that if the user of the tool is interested in a certain hotspot in the map, by clicking the cell the user can see, as a graph and a table, the contribution of each pressure and ecosystem component layer to the total impact, of the particular hot spot. For those pressure layers that are aggregated from various human activities layers, such as physical loss, one can also access the information on the contribution of those activities for the pressure layer, for the particular spot.

3.4. Follow up needs for the SPIA

3.4.1 How is HELCOM working to improve the situation?

The Spatial distribution of Pressures and Impacts Assessment (SPIA) is cross-cutting tool to assess the cumulative burden of all pressures over species and habitats. It addresses themes at the core of HELCOM work, such as eutrophication, hazardous substances, biodiversity and shipping, among others.

HELCOM's strategic programme of measures and actions for achieving good environmental status of the sea, The Baltic Sea Action Plan, is the most comprehensive tool to improve the status of all individual topics (HELCOM 2021a).

HELCOMs work related to Maritime Spatial Planning answers to the growing need of marine space by different human activities, aiming to support regionally coherent regional Maritime Spatial Planning processes.

Further, many HELCOM expert groups work tightly with key topics related to the management of human activities addressed in this assessment, e.g. the HELCOM Expert Group on Dredging/depositing Operations at Sea and the HELCOM Expert Group on Underwater Noise.

3.4.2 What would be needed to do a better assessment next time?

HELCOM has continuously developed tools and methods to carry out cumulative impact assessments, by looking at lessons learned from previous assessments and through dedicated projects such as the EU co-financed Pan Baltic Scope and MetDev. The recently started ReMAP project aims to further develop the SPIA tool with new and improved functionalities.

Additional focus is needed to data development, and especially to data reporting. Many human activities data would benefit from the establishment of a regular data collection framework and data flows. Further, the modelling of species and habitats used in the assessment would greatly increase the accuracy and confidence of the assessment. More focus should also be given to the indirect effects of human activities, such as altering the food web, which have implications that are more complex than the current tool can assess. In order the assessment to be compatible with MSFD definitions, the pressure layers used in the assessment are based on the listing of the MSFD Annex III. However, if the pressures included in the annex are not able to fully cover the complex nature of the impacts, also the pressures included in the assessment should be reviewed in the future, or aim to address this is issue with methodological development.

3.5. Uncertainty and confidence in the assessment

The uncertainty of the assessment is important for the transparency of the analysis and to understand the limitations of a such assessment. Uncertainty can be considered to be comprised of the uncertainty of data and the uncertainty of the methodology, including the assumptions and modelling done to create the data layers.

3.5.1 Uncertainty of the data

The assessments of cumulative pressures and impacts are both directly dependent on the quality of the underlying data layers. The assessment is using the best available data for the region, but gaps might still occur in data sets. In some cases, it has not been possible to achieve data sets with full spatial coverage, but the layers have still been included in order to reflect the currently best available knowledge, rather than omitting this aspect. The completeness of data coverage for different geographical areas is shown on the side of each map.

The data were collected in order to be representative for the period 2016-2021. However, pressures from some human activities which were included are only present during a limited time period in an area and may be over-emphasised in the results compared to pressures which are present continuously. This concerns for example pressures associated with construction work. Another important aspect for further consideration is how to represent the effects of past impacts on species and habitats. The applied approach is limited to estimating impacts on species and habitats within their current distributions, and does not encompass the aspect that an area may be devoid of a certain species due to too high pressure (currently or historically). In these cases, the ecosystem component may be assessed as not subjected to strong impact due to the fact that it currently has a limited distributional range.

The level of accuracy in detailed results needs to be evaluated on a case-by-case basis. While some maps provide information on a relatively detailed spatial scale, other layers are at present not detailed enough to be relevant at a more local scale, for example those showing species distributions. Variability in the level of detail of individual data layers may reduce the confidence in the overall assessment and limit the possibility to compare geographic areas with each other in more detail. For example, data sets on species distributions may be presented at variable detail in different parts of the region. Furthermore, some layers of activities are represented by licenced areas, such as dredging, disposal of dredged matter and extraction of sand and gravel. Hence, they may not necessarily reflect the extent of the exerted pressure, as the activity may be undertaken only in parts of the licensed area.

The quality and confidence of individual data sets are assessed by qualitative means as far as it has been possible, and indicated in the metadata descriptions of the data sets in the HELCOM Metadata Catalogue. The considerations are comprised of the following elements.

— Data source: Are the data coming from one or several sources, and what is the quality of the original data provider(s)?
— Spatial coverage: Are the data covering the whole region, and are there known or suspected gaps in the spatial coverage?
— Temporal coverage: Are the data covering the whole assessment period, if not, can the included year(s) be considered to be representative for the whole period?
— Direct/proxy data: Are the data depicting the phenomenon directly or is it covered by indirect information?

One aspect of confidence is the availability of underlying data sets used in the assessment. Data availability is assessed per Contracting Party, and maps presenting the percentages of available data sets is presented in the result maps. Contracting Parties were asked to fill in whether each data set is relevant for their national waters, indicating the reason why some data are not reported. If data are not relevant for national waters, the data are considered to be reported. Figure 34 represents the overall data availability including all human activities, pressure and ecosystem components used in the assessment.

3.5.2 Uncertainty of the methodology

The assessment is providing information on the spatial pattern and the intensity of the potential cumulative pressures and impacts in the Baltic Sea, based on an additive model. The methodology is largely depended on the input data on pressures and ecosystem, and how these layers are created. All layers are normalized and scaled between 0 and 1, and for most of the layers this is done based on the minimum and maximum values in the original data. Thus, a threshold value that would indicate the tipping point where the activity starts to form pressure to the environment is not used for most of the layers. To reduce the skewness of the raw values, most of the layers are log-transformed. This is done in order to achieve more normally distributed values and reduce the impact of extreme values in the data. Nevertheless, the minimum and maximum values in the original data have a big impact on the pressure pattern of the final layers.

Therefore, it should be kept in mind that the result of the assessment is an unitless index and it is thus not providing any infor-

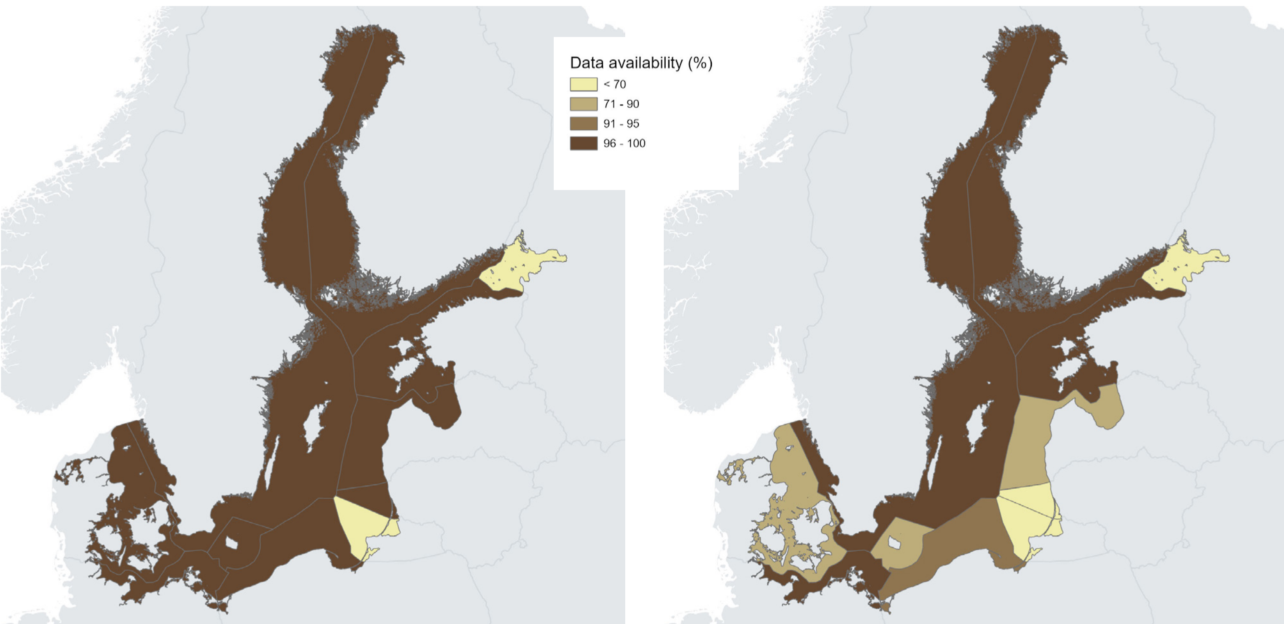


Figure 35. Representation of the data availability for ecosystem components (left) and human activities and pressures (right).

mation on pressures and impacts on an absolute scale, but giving information on relative magnitude between different areas within the assessment period. The results are best considered as a mean of communication of the patterns and intensities of pressures and impacts in different regions and to highlight the areas that are relatively under most severe cumulative pressures and impacts.

3.5.3 Monte Carlo simulation of sensitivity scores

One way to assess the influence of sensitivity scores and the magnitude of effect it has to the cumulative impact, is to use a monte carlo simulation. A Monte Carlo simulation is a model that creates random variables as sensitivity scores for each run and runs the assessment 100 times, providing an output for each run. The result of the simulation provides information on the variance of the results with completely random sensitivity of species and habitats to pressures. Running the cumulative impact index includes millions of individual calculations, and the effect of an individual calculation stage to the results – or the uncertainty – might be difficult to assess without using statistical methods.

Figure 36 presents the distance of maximum and minimum values in the 100 results of the simulation for each cell. The dark-

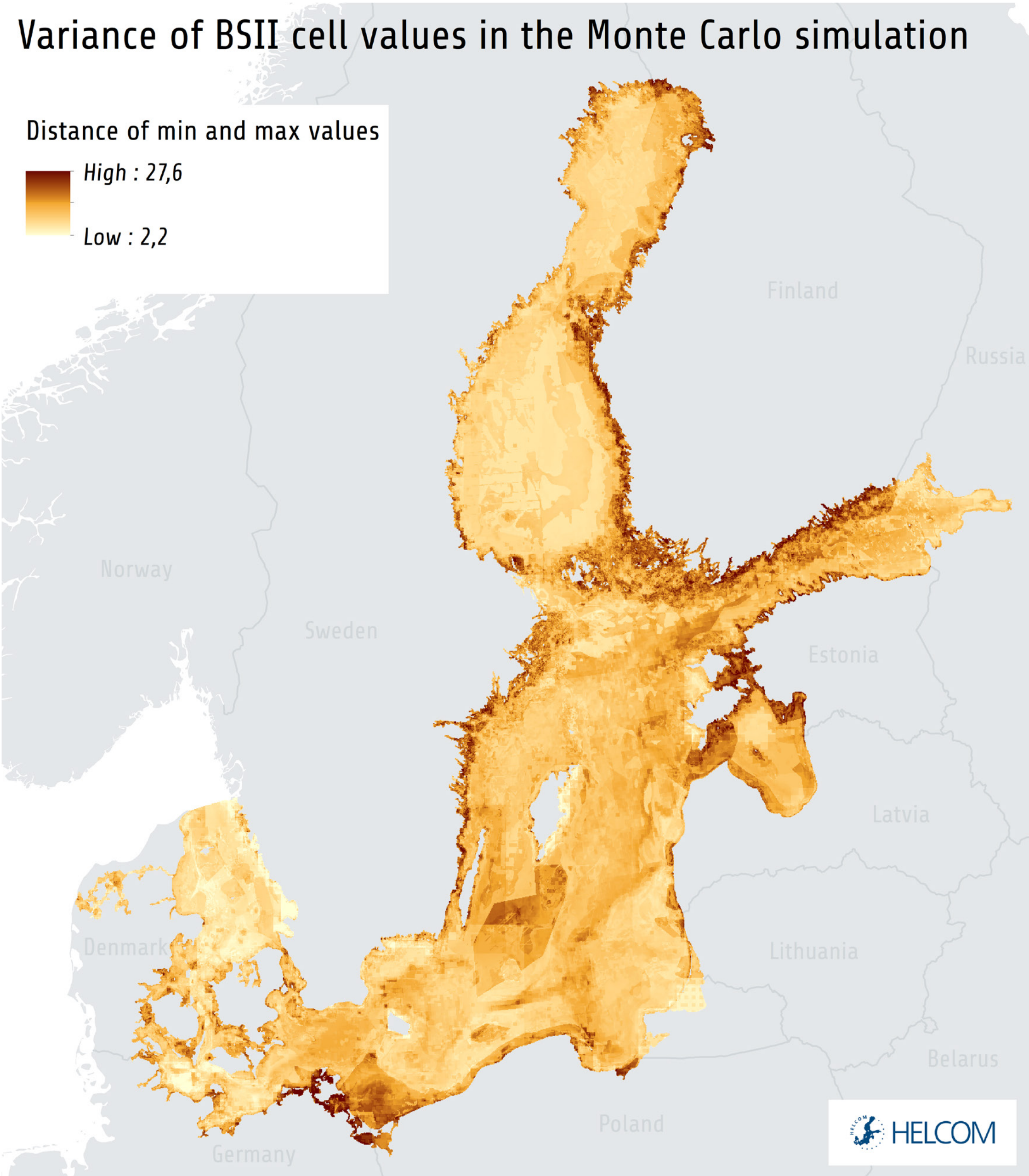


Figure 36. The distance of minimum and maximum values of the BSII results in the Monte Carlo simulation.

er the colour, the longer the distance between maximum and minimum values in the results. Based on the maps and statistical analysis, the sensitivity scores do have an impact on the assessment results, but not equally so across areas, and that for open sea areas the variability is more apparent. This can be considered to be mainly originating from the fact that open sea areas have less ecosystem component layers and a smaller number of pressures, and therefore changes in sensitivity scores in these areas have higher influence on the impact scores in individual pixels, compared to coastal areas where the number of included ecosystem component layers is higher.

The variance in the contribution of five top pressures to the total potential impact was assessed with the Monte Carlo simulation. The results show relatively high variance for the top pressures (Figure 37), where for example hazardous substances varied from 2 to 4 million, while the share in HOLAS 3 BSII results was 3 million.

The set up for the Monte Carlo simulation allowed the sensitivity scores to vary for the full range of 0 to 2. This is providing information of the variance where the uncertainty of the chosen score would be very low, and the actual sensitivity could be anything between those values. It is a challenging task to empirically prove the correct sensitivity score for any combination of ecosystems and pressures, therefore the usage of the full range is justified to follow a precautionary approach. If the confidence of the used sensitivity scores would be considered to be relatively high, a better option would be to let the sensitivity scores vary within a given range in the simulation.

The simulation provides information on the magnitude of effect the scores have to the results for the cumulative impact, and doesn't cover qualitative uncertainties of the scores. The responses of ecosystem to different activities are often complex and comprised of direct and indirect effects that can also be sometimes positive. Presenting the complex interaction with a single value cannot fully address the complexity of the issue, but it is the method most commonly used in cumulative impact assessments.

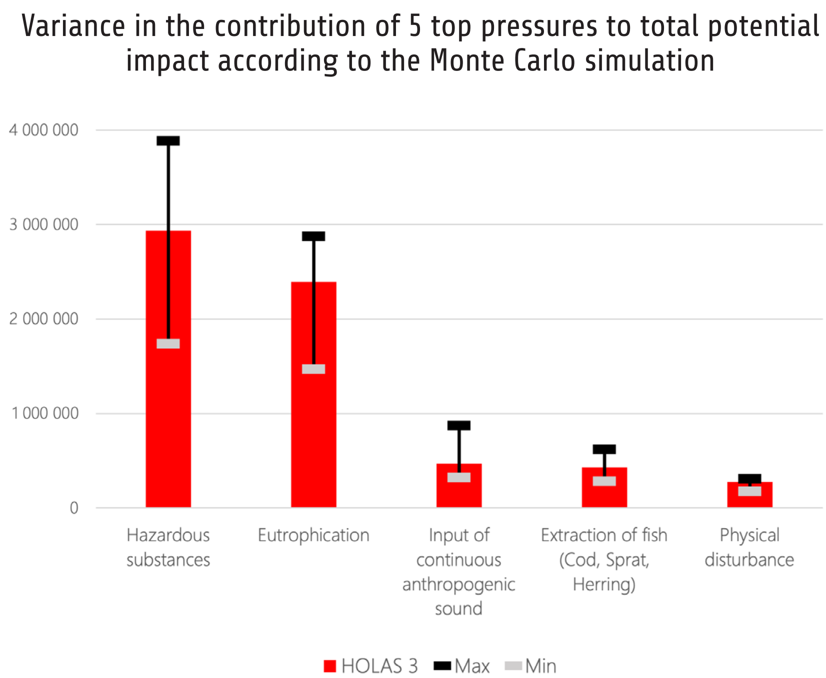


Figure 37. The Variance of top pressures in the Monte Carlo simulation of the BSII.

4. Conclusions

Potential pressures and impacts on the marine environment are widely distributed in the Baltic Sea and no area in the region is without human footprint. The potential pressures and impacts show somewhat varying distribution patterns. The potential cumulative pressures seem to be relatively highest in open sea areas, while the highest potential cumulative impact is seen in coastal areas, likely attributed to higher biodiversity in these shallow areas and closeness to land. However, it should be kept in mind that the assessment doesn't fully take into account the complexity of cascading or indirect effects in the food web, so that pressures appearing in open sea areas are also affecting coastal regions, and vice versa.

The SPIA results validates eutrophication and hazardous substances as being among the highest threats to the Baltic Sea marine environment. As in HOLAS II, eutrophication and hazardous substances were attributed to most of the estimated cumulative impacts, even though the methodologies for developing these layers have changed rather substantially between the assessments. Compared to many other pressures, which may still have locally high impacts, eutrophication and hazardous substances have effectively spread far from their original points of introduction, and have long recovery times even if their inputs would cease.

The assessment applied the same analytical method as in HOLAS II, while the developments in HOLAS 3 have focused on improving the included data layers, with the aim to rely on the most up-to-date scientific knowledge throughout the assessment. It is important to continue work to develop the assessment, and to acknowledge that the SPIA method will provide results that show relative patterns within the assessment period when it is applied in full and without threshold values for all pressures. Hence, the results from the SPIA are most useful for communicating spatial patterns of potential pressures and impacts in the Baltic Sea region, to highlight areas of importance for management focus and further investigations.

As a complement to the full evaluations of potential pressures and impacts, this assessment also aimed to carry out subset analysis. Such thematic analyses can explore potential impacts of individual pressures or groups of pressures more closely, when applicable. For example, the layer on continuous underwater noise is associated with a threshold value, increasing the confidence of individual analysis and possibility to provide relatively more accurate results. In addition, maps on ecosystem components are becoming more accurate, raising the possibilities for thematic subset analyses further.

It is worth emphasizing that the numerous data layers that have been developed and improved for the assessment serve as a crucial part of the results in themselves. All the applied spatial data are available for further use in the SPIA online tool, where the user can analyse cumulative impacts for any chosen combination of pressure and ecosystem component layers, hence expanding beyond the analyses presented in the current report. The online tool also provides useful functionalities to explore the contributions of human activities underlying impacts shown in the currently presented results.

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Annex 1.
Detailed description of the input data for the aggregated pressure layers

The table in this annex (Table A1.1) gives more details on how the aggregated pressure layers included in the Spatial Pressure and Impact Assessment were compiled. Furthermore, the data processing is explained for each underlying spatial dataset in each pressure layer.

It is important to notice that all pressure layers had a specific temporal nature associated in their analysis. A scheme of the temporal nature, indicating whether it represents a cumulative pressure (values over the assessment period summed) or a temporary pressure (average values over the assessment years are used) is observed below (Figure A1.1).

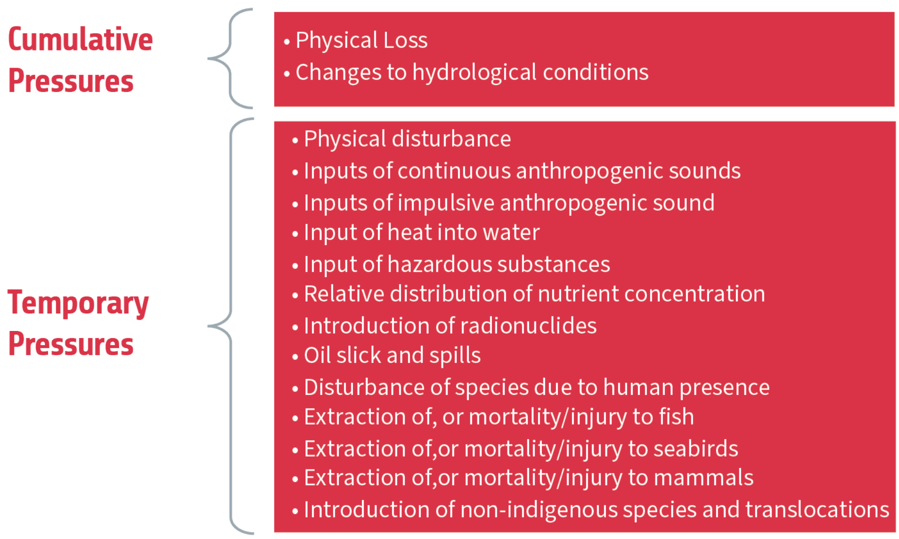

Figure A1.1. Scheme of temporal aspects included in the analysis of the pressure layers.

The pressure caused by human activities in marine environments often spread further than the actual extent of the activity. The spatial extent of the pressure and attenuation gradient from the central areas is different for each activity and pressure in question. The extent and gradients used in this assessment are originating from the expert survey done in TAPAS project (HELCOM 2017b) and literature review done in BalticBOOST (Korpinen *et al.* 2017) projects. The attenuation types are divided into four different scenarios (type A, B, C and D) depicting the different nature of activity pressure relations (Figure A1.2). These types were used in the analysis by creating different sized buffers for each type and this type is indicated for activity-pressure combinations in the table further below.

Another relevant aspect included in the analysis of some pressure layers was the depth / exposure weighting, which characterizes whether down-weighting by seabed exposure and water depth was applied. Layers in which this aspect was relevant were mostly present in the layer Physical Disturbance is described in further detail in the indicator report, together with all references used in the analysis. The layer 'Recreational boating and sports' from the pressure layer 'Disturbance of species due to human presence' was rescaled with depth (0-10m= 100%; 10-15m= 70%; 15-20m= 50%, 20-30m= 20%, 30-40m= 10%, 45m<= 0%). Layers in which the exposure affects recovery but were not included in the analysis were: 'Extraction of sand and gravel' and 'Dredging (capital)', both for the pressure layer 'Physical Loss'.

Finally, with respect to physical loss and disturbance it should be noted that whether an activity leads to loss of or disturbance of the seabed depends on many factors, such as the duration and intensity of the activity, the technique used, and the sensitivity of the area affected.

The columns in the table below give: Column 1: Identity of the aggregated pressure layer (APL); Column 2: Underlying spatial data sets included in the APL; Column 3: Spatial extent applied for the purposes of this assessment (footnotes give justification for the spatial extent); Column 4: The data processing applied to arrive at common unit and final metric; and Column 5: Method for aggregating the spatial data sets to one aggregated pressure layer (footnotes give justification for the spatial extent.

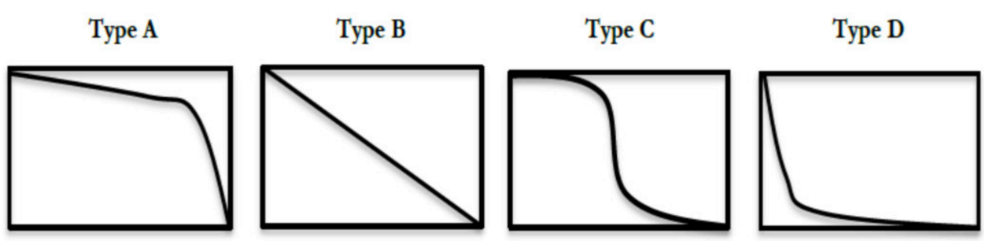

Figure A1.2. Different attenuation gradients used in the assessment. Type A describes a pressure that has a similar impact at most of its distribution range and then rapidly drops, type B describes a pressure that declines monotonously in strength from the source, type C describes a pressure having a somewhat limited decline within a given distance followed by a sharp decline, while type D describes a pressure which mostly has a strong impact in its vicinity.

Table A1.1. Details on how the data for pressure layers included in the Spatial Pressure and Impact Assessment were processed.

Aggregated pressure Layer	Underlying spatial datasets	Spatial extent	Data processing	Aggregation method
Physical loss (permanent effects on the seabed)	Land claim	Area of polygon or 50 m buffer for points, 30m buffer for lines[1].	Area of polygon, buffered line or point data, equals lost area.	Activities are combined and potentially overlapping areas are removed. Dataset is clipped with coastline. Combined layer is intersected with 1 km grid to calculate % of area lost within a cell.
	Watercourse modification	50 m buffer[1].	Area of polygon, buffered line or point data, equals lost area.	
	Coastal defence and flood protection	50 m buffer for lines, area of polygon[1].	Area of polygon, buffered line or point data, equals lost area.	
	Extraction of sand and gravel	Area of polygon.	Area of polygon equals lost area.	
	Dredging (capital)	Area of polygon or a 25/50 m buffer for <5000 m^3 / >5000m^3 sites[2].	Area of polygon, buffered line or point data, equals lost area.	
	Oil platforms	25 m buffer[2].	Buffered point data, equals lost area	
	Pipelines	15 m buffer around cables with operational status[3].	Area of polygon, buffered line or point data, equals lost area.	
	Wind farms	30 m buffer around each turbine with operational status[4].	Buffered point data, equals lost area.	
	Cables	1.5 m buffer around cables with operational status[5].	Buffered point data, equals lost area.	
	Harbours	Polygon with 200 m buffer[6].	Area of polygon, buffered line or point data, equals lost area.	
	Marinas and leisure harbour	Point with 200 m buffer[7].	Buffered point data, equals lost area.	
	Bridges	2 m buffer[8].	Buffered point data, equals lost area.	
	Finfish mariculture	150 m buffer[9].	Buffered point data, equals lost area.	
	Shellfish mariculture	Area of polygon, 150 m buffer for points	Buffered point data, equals lost area.	
Physical disturbance or damage to seabed (temporary or reversible effects)	Detailed information about this pressure layer can be found at the indicator report.			

1 Estimated based on wind turbine erosion protection (van der Wal and Tamis 2014). No direct reference.
2 HELCOM 2017
3 Between cables and wind farms
4 Van der Wal and Tamis 2014
5 Estimate based on side-scan sonar photos (BalticBOOST case study in Mecklenburg Bight)
6 Orviku et al. 2008; and as for 'Maintenance dredging'
7 Eriksson et al. 2004, Sandström et al. 2005
8 TAPAS project: based on erosion protection
9 Leskinen et al. 1986

Table A1.1. (Continued). Details on how the data for pressure layers included in the Spatial Pressure and Impact Assessment were processed.

Aggregated pressure Layer	Underlying spatial datasets	Spatial extent	Data processing	Aggregation method
Changes to hydrological conditions (e.g., by constructions impeding water movements)	Water course modification	1 km buffer[10].	Location of water course modifications used for buffer. Overlaps removed and areas of buffer calculated per each grid cell. The final value was the area of the buffer in each individual cell.	Spatial extents and potential attenuation gradients are assigned to the specific pressure layers. They are merged (by affected area, km^2) to avoid overlapping areas. Intersected with 1 km grid to calculate % of area affected within a cell. Normalized.
	Wind farms	300 m buffer around each turbine classified as operational, with linear decline (Type B decline), composed of 3 rings.	Location of operational turbines as points were buffered and values given over linear decline.	
	Oil platforms	500 m buffer around each turbine with linear decline (Type B decline) composed of 5 rings.	Location of oil platforms as points were buffered and values given over linear decline.	
	Hydropower dams	A grid cell in the estuary.	Locations of hydropower dams were crossed with rivers and the grid cell located in the end of the river was selected as presence (1) – those that are operational and produces energy. Other values in the grid were considered absence.	
Inputs of continuous anthropogenic sounds (into water)	Baseline excess level of noise	Data modelled into 0.4 km x 0.4 km grid.	Baseline excess sound pressure levels at one 1/3 octave band of 125 Hz exceeded at least 50% of the time in the full water column 2018, normalized.	Only baseline excess level included data is directly providing information on the pressure, normalized
Inputs of impulsive anthropogenic sound (into water)	Impulsive sound events (2016-2021)	Data converted directly to 1km grid cells.	Data from HELCOM-OSPAR Database for impulsive sound and national data call (polygons, points) with sound values categorized from very low, low, medium, high, and very high. Sum of all events calculated per 1x1 km grid cell. Normalized.	Sum of events based on sound value codes. Values were normalized.
Input of heat (e.g., by outfalls from power stations) into water	Discharge of warm water from nuclear power plants (2016-2021)	1 km buffer with steep decrease around outlet (Type D decline), composed of 4 rings[11].	Average input of heat load (Twh) of discharge of warm water from the nuclear power plant outlets. No data on heat load was available for the Leningrad nuclear power plant; therefore, the average heat load of discharge of warm water from nuclear power plants was given.	Sum of the input of warm water. Values were normalized.
	Fossil fuel energy production (only location available)	1 km buffer with steep decrease around outlet (Type D decline), composed of 6 rings[12].	Heat load 1 (TWh) was given to all production sites, based on the average heat load of an individual production site in Helsinki.	
Input of hazardous substances	HELCOM integrated hazardous substances assessment	Original data HELCOM AU level3, converted to 1x1km grid.	Contamination values for the integrated assessment were normalized according to following categories (original value/pressure value): 0-0,5/0-0,2; 0,5-1/0,2-0,4; 1-5/0,4-0,6; 5-10/0,6-0,8 and >10/1	Not relevant.
Radionuclides	HELCOM MORS discharge data (2016-2020)	10 km buffer with linear decline composed of 5 rings from discharges of radioactive substances (Type B decline)[12].	Annual averages of CO60, CS137 and SR90 from the period 2016-2020 per nuclear power plant. Gradual buffer around outlet to 10km distance (Type B decline).	Agreed aggregation method applied on HOLAS II used. Annual decay-corrected averages for CS-137, SR-90 and CO-60 were summed, given weight according to the linear decline and normalized.

10 Extent based on wind farms and cables but expanded to 1 km because hydrological parameters are widely spreading.
11 Extent based on Ilus et al. 1986.
12 Extent based on Karppinen et al. 2011, Karppinen and Vatanen 2013.

Table A1.1. (Continued). Details on how the data for pressure layers included in the Spatial Pressure and Impact Assessment were processed.

Aggregated pressure Layer	Underlying spatial datasets	Spatial extent	Data processing	Aggregation method
Oil slicks and spills	Illegal oil discharges (2016-2021)	Value of spills (VOLUME) under OR EQUAL 1km^2 was directly given to grid cell. If the spill area > 1km^2, a buffer with the area was added (circular buffer based on estimated radius) and the estimated volume of the spill was divided by the spill area to get the estimated amount of oil / km^2. This value was given to the entire spill area.	If oil spill volume was missing, mean of values was given. If area of spill was missing (103/560), mean of values was given. If the spill was < or = 1km^2, the value of spill volume was given directly to 1km^2 grid cell. If the spill area was > 1km^2, the estimated volume of the spill was divided by the spill area to get the estimated amount of oil / km^2. This value was given to the entire spill area. Layer was log transformed and normalized.	Layers were separately normalised. After that, layers were summed and again normalised to produce the final pressure value between 0 and 1.
	Polluting ship accidents (2016-2020)	Point, spill volume (m^3) converted directly to 1 x 1 km grid.	A mean of reported volumes was given to accidents with missing oil volume. Spill volume in m^3 was given directly to 1km^2 grid cell. Layer was log transformed and normalized.	
Eutrophication	HELCOM integrated eutrophication assessment	Original data HELCOM AU level4, converted to 1x1km grid.	Reverse EQRS value used as pressure value. Data gaps were filled with H2 values. They were normalized according to (ER/pressure values): 0-0,5/0-0,2; 0,5-1/0,2-0,4; 1-1,5/0,4-0,6; 1,5-2/0,6-0,8 and >2/1, for Danish WFD Moderate/0,5; Poor/0,7 and Bad/1.	Not relevant
Disturbance of species due to human presence	Recreational boating and sports	Total fuel consumption of recreational boats modelled directly to 1 km grid cells[13].	Total fuel consumption of recreational boats presented as presence / absence. Rescaled with depth, log-transformed and normalized.	Specific pressure layers first modified by spatial extents and depth influence. Each of them is considered as of equal importance (same weight). Calculate the sum of the pressure in a cell. Normalized.
	Bathing sites, beaches	Point data converted directly to 1 km grid cells.	Location of beaches presented as presence (1) / absence (0).	
	Urban land use	Urban land use data was first converted to 1 km grid cells and expanded with 1 km[14].	Urban land use data was first converted to 1 km grid cells and expanded with 1 km. Thus, coastal urban areas extended also to the sea. These areas were given value 1 and other sea areas, value 0.	
Extraction of, or mortality/injury to fish, (separate layers for Cod, Herring, and Sprat)	Extraction of target fish species (cod, herring, sprat) in commercial fishery (2016-2020)	Reported per ICES Rectangles, Russian data extracted from ICES annual reports, reported per ICES sub-divisions. Values are redistributed with fishing effort data c-squares (all gears) 2016-2021. Effort values missing from Russia and sub-basin average values given.	Extraction of fish species (landings) per ICES c-squares, average of 2011-2016. Landings calculated per km^2.	Tons/km^2 calculated for each species. For cod, recreational fisheries catches were added. Log-transformed and normalized.

13 SHEBA project.
14 Estimate of the human disturbance (underwater sound, visual disturbance).

Table A1.1. (Continued). Details on how the data for pressure layers included in the Spatial Pressure and Impact Assessment were processed.

Aggregated pressure Layer	Underlying spatial datasets	Spatial extent	Data processing	Aggregation method
Extraction of, or mortality/ injury to seabirds (e.g. hunting, predator control)	Game hunting of seabirds (2016-2021)	Varying reporting units, from counties to HELCOM subdivisions, seaward boundary 3nm from coastline including islands and skerries.	Species summed together per year, and average of killed seabirds of years 2016-2021 per reporting unit calculated. Numbers of killed birds / km^2 calculated for the marine area and generalized for the whole reporting unit. The data was converted to 1km x 1km grid. Log transformed.	The two datasets were first separately log transformed and then summed, to get the total value for each grid cell. Normalized.
	Predator control of seabirds (2016-2021)	Varying reporting units, from counties to HELCOM subdivisions. Seaward boundary 3nm from coastline including islands and skerries.	Total number of killed cormorants per year averaged for 2016-2021. Numbers of killed birds / km^2 calculated for the marine area and generalized for the whole reporting unit. Data was converted to 1km X1km grid and overlapping reported areas were summed. Log transformed.	
Hunting of seals	Hunting of Grey, ringed and harbour seals (2016-2021)	Varying reporting units, from counties to HELCOM subdivisions	The number of hunted seals (2016-2021) per unit was normalized with 0,5 set as the quota for hunting, per species and per year. The values were averaged for each species and those values were averaged for the unit to form the final pressure value	Average of the species
Introduction of non-indigenous species	Occurrence of established NIS species and key habitats	10x10 km grid	CIMPAL method was applied to create the pressure layer. The information on species and habitats were aggregated to 10x10 km grid, and a cumulative impact analysis were run for these layers combined with sensitivity values. Final values were normalized and transferred to 1x1km grid.	Not relevant.

Annex 2. Detailed description of the input data for the ecosystem components layers

Figure A2.1. Details on how the data for the ecosystem component layers included in the Spatial Pressure and Impact Assessment were processed.

Ecosystem component	Underlying layer or group of layers	Data processing
Benthic habitats	Broad habitat types - BHT	Data represent the presence / absence distribution of Broad Habitat types (BHT) in the Baltic Sea. The dataset includes an ecosystem component raster layer for all 18 habitat types listed under MSFD BHT in the original EUSeaMap dataset, excluding the habitat "NA" where the classification was not applicable. The habitats are formed by combining the biological zone (infralittoral / circalittoral / Offshore circalittoral) and substrate information (coarse, mixed, mud, sand, mud or sand, rock and biogenic reef), forming altogether 18 layers. Original vector data was transformed to 1x1km grid raster, one data set for each BHT.
	EU Habitat Directive marine habitat types - Natura 2000	The map is a result of a compilation from the data submitted by HELCOM contracting parties to the data call for HOLAS 3. Original vector data was transformed to 1x1km grid raster.
Habitats building species	Benthic species	Data represent the presence / absence distribution of Benthic species in the Baltic Sea in 1x1km grid. All datasets are first aggregated to 5x5km grid and areas below 10m are excluded. For the 5 new species in HOLAS 3 (Potamogeton, Myriophyllum, Najas marina, Fontinalis, Callitriche, Zanichellia) only data reported for HOLAS 3 and data in the biodiversity database was used. For Mytilus no filtering with depth was made.
Pelagic habitats	Productive surface waters (Chl-a)	Productive surface waters are presented as satellite-based earth observation data on springtime (March-May) chl-a surface accumulations during the assessment period 2016-2021. Dataset was prepared by Finnish Environment Institute.
	Bottom-water habitats not influenced by permanent anoxia	The data used to produce the layer was received from Leibniz-Institut für Ostseeforschung Warnemünde (IOW). Areas (polygons) with hydrogen sulfide (H2S) based on point measurements and modelling were used. Five time periods / year, for years 2016-2021 (altogether 30 layers). The polygons were converted to raster layers in a way, that for each time period (6 years, 5 time periods each year), areas with H2S got a value 0, other areas got the value 1. All layers were summed, (representing 6 years, 5 time periods each year, maximum value 30) and data was normalised. Anoxia information is only available for open sea areas. Ecosystem component layers depict the abundance of species or habitats, and the most abundant areas get the highest value (max 1). For this layer, the anoxia information is used for ruling out, or lowering the abundance value, for areas where the bottom is not in a healthy condition, and other areas gets the value 1 (in SPIA the layer value cannot be "null" or "not assessed"). In other words the healthiness state is not assessed by any other means outside the anoxic areas, and for this layer, these areas are considered be healthy. The "reverse" methodology to produce this layer is therefore indicated in the component layer name, to avoid any misinterpretation.

Figure A2.1. (Continued). Details on how the data for the ecosystem component layers included in the Spatial Pressure and Impact Assessment were processed.

Ecosystem component	Underlying layer or group of layers	Data processing
Mobile species	Abundance of cod, herring and sprat	For ICES rectangles surveyed by BITS/BIAS, values shown are the mean CPUE per ICES subdivision based on BITS/BIAS data, average for 2016-2020. For ICES rectangles not surveyed by BITS/BIAS, values are calculated as: MAX-value x Weighting factor. Cod => 30cm was included. The weighting factor is specific to each ICES rectangle, calculated as the ratio between the commercial landings in that rectangle and the commercial landings in the ICES rectangle with highest landings in the Baltic Sea (based on averages for 2016-2020). MAX-value = CPUE according to BITS in the ICES rectangle with highest landings. Landing values per km^2 was used in the calculation and the value in the highest complete ICES rectangle was selected, due to the per km^2 getting exceptionally high in some small ICES rectangle.
	Potential nursery, recruitment and spawning areas for fish	The data is originated from the work within the Pan Baltic Scope project and from a joint regional Expert Workshop on essential fish habitats. Methodology and detailed information are presented in: https://helcom.fi/wp-content/uploads/2021/09/Essential-fish-habitats-in-the-Baltic-Sea.pdf
	Wintering and breeding areas for birds	Data represent the presence / absence of areas for birds. Natura 2000 Special Protection Areas (SPAs) classified as type A and C in the EEA dataset selected. Original vector data was converted to 1x1km grid raster.
	Seals distribution	The ecosystem component maps on mammals' distribution were drafted by EG MAMA seals distribution team.
	Harbour porpoise importance areas	The ecosystem component maps on mammals' distribution were drafted by EG MAMA harbour porpoise distribution team. Methodology applied can be found in: https://dce2.au.dk/pub/TR240.pdf

Annex 3.
Data and sensitivity values used to carry out the calculation of the CIMPAL index used for the pressure layer on introduction of non-indigenous species

Figure A3.1. Habitats and data sources for the layers used in the CIMPAL index for the Baltic Sea.

Code	Habitat	Source
HAB_01	Estuaries-lagoons (infralittoral-subtidal)	derived from Copernicus Water & Wetness 2015
HAB_02	Estuaries-lagoons (littoral-intertidal)	derived from Copernicus Water & Wetness 2015
HAB_03	Estuaries-lagoons (wetlands-saltmarshes)	derived from Copernicus Water & Wetness 2015
HAB_05	Seagrass-seaweed beds	HOLAS 3 Zostera distribution
HAB_07	Soft intertidal	derived from Copernicus Water & Wetness 2015
HAB_08	Rocky intertidal	derived from Copernicus Water & Wetness 2015
HAB_09	Shallow sediment	EUSEAMAP 2021
HAB_10	Circalittoral sediment	EUSEAMAP 2021
HAB_12	Shallow rock (<60)	EUSEAMAP 2021
HAB_13	Circalittoral rock (60-200)	EUSEAMAP 2021
HAB_15	Pelagic (<200)	derived from EMODNET Bathymetry portal
HAB_16	Mesopelagic (200-1000)	derived from EMODNET Bathymetry portal

Table A3.2. Species used in CIMPAL index for the Baltic Sea. Source of all data is Emodnet biology, complemented with data used for the HELCOM indicator Trends in arrival of new non-indigenous species (AquaNIS).

Code	Species
NIS_01	*Acartia tonsa*
NIS_02	*Austrominius modestus*
NIS_03	*Bonnemaisonia hamifera*
NIS_04	*Callinectes sapidus*
NIS_05	*Caulerpa taxifolia*
NIS_06	*Cercopagis (Cercopagis) pengoi*
NIS_07	*Codium fragile subsp. fragile*
NIS_08	*Crepidula fornicata*
NIS_09	*Ensis directus*
NIS_10	*Eriocheir sinensis*
NIS_11	*Fibrocapsa japonica*
NIS_12	*Ficopomatus enigmaticus*
NIS_13	*Gammarus tigrinus*
NIS_14	*Gracilaria vermiculophylla*
NIS_15	*Hemigrapsus sanguineus*
NIS_16	*Homarus americanus*
NIS_17	*Karenia mikimotoi*
NIS_18	*Magallana gigas*
NIS_19	*Marenzelleria spp. (M neglecta_M viridis_M arctia)*
NIS_22	*Mnemiopsis leidyi*
NIS_23	*Mya arenaria*
NIS_24	*Neogobius melanostomus*
NIS_25	*Petricolaria pholadiformis*
NIS_26	*Potamopyrgus antipodarum*
NIS_27	*Pseudochattonella verruculosa*
NIS_28	*Rhithropanopeus harrisii*
NIS_29	*Sargassum muticum*
NIS_30	*Styela clava*
NIS_31	*Telmatogeton japonicus*

Table A3.3. Sensitivity scores of habitats to non-indigenous species. The range of the sensitivity scores is from 0 to 8, the higher the score the higher the sensitivity of the habitat to the pressure caused by the non-indigenous species. The scores are originating from the background material for the report "Multiple pressures and their combined effects in Europe's seas" (Korpinen et al. 2017) , where similar analysis was done.

	HAB_01	HAB_02	HAB_03	HAB_05	HAB_07	HAB_08	HAB_09	HAB_10	HAB_12	HAB_13	HAB_15	HAB_16
NIS_01	0	0	0	0	0	0	0	0	0	0	0	0
NIS_02	0	0	0	0	0	1	0	0	1	0	0	0
NIS_03	0	0	0	0	0	0	0	0	8	0	0	0
NIS_04	1	1	1	0	1	0	1	0	0	0	0	0
NIS_05	0	0	0	0	0	0	8	0	8	0	0	0
NIS_06	1	0	0	0	0	0	0	0	0	0	1	0
NIS_07	0	0	0	0	0	2	0	0	2	0	0	0
NIS_08	0	0	0	0	0	0	4	0	2	0	4	0
NIS_09	0	0	0	0	1	0	1	0	0	0	0	0
NIS_10	2	2	2	0	2	0	0	0	0	0	0	0
NIS_11	0	0	0	0	0	0	0	0	0	0	4	0
NIS_12	1	1	0	0	0	2	0	0	2	0	0	0
NIS_13	4	4	4	4	4	0	4	0	1	0	0	0
NIS_14	0	0	0	0	8	8	8	0	8	0	0	0
NIS_15	2	2	2	0	0	2	2	0	2	0	0	0
NIS_16	0	0	0	0	0	0	0	0	0	0	0	0
NIS_17	0	0	0	0	0	0	0	0	0	0	2	0
NIS_18	0	0	0	0	8	8	8	0	8	0	8	0
NIS_19	4	4	0	0	4	0	4	1	0	0	0	0
NIS_22	2	0	0	0	0	0	0	0	0	0	4	0
NIS_23	4	4	0	0	4	0	4	4	0	0	0	0
NIS_24	4	0	0	0	0	0	4	0	4	0	0	0
NIS_25	0	0	0	0	0	0	0	0	0	0	0	0
NIS_26	0	0	0	0	0	0	0	0	0	0	0	0
NIS_27	0	0	0	0	0	0	0	0	0	0	1	0
NIS_28	2	2	0	0	2	2	2	0	2	0	0	0
NIS_29	0	0	0	0	0	1	0	0	8	0	0	0
NIS_30	0	0	0	0	0	1	0	0	1	0	0	0
NIS_31	0	0	0	0	0	0	0	0	0	0	0	0

Annex 4. Sensitivity scores used in the assessment

Table A4.1. Sensitivity score used in HOLAS 3. The range of the scores is from 0 to 2, the higher the score, the higher the sensitivity of the ecosystem components to the pressure. Further information is given in chapter 2.5.

	PL_01	PL_02	PL_03	PL_04	PL_05	PL_06	PL_07	PL_08	PL_09	PL_10	PL_11	PL_12	PL_13	PL_14	PL_15	PL_16	PL_17
EC_01	0	1	0.8	0.6	0.2	1	1	1.8	0	1.4	0.4	1	0.8	1	0	0	1
EC_02	1.5	0.9	1.3	0.5	0.2	0.6	0.9	1.9	0	0.6	0.2	0.4	0.4	0.4	0	0	0.7
EC_03	1.9	1.3	1.2	0.2	0.2	1.3	1	1.3	0.4	1.7	0.3	0.6	0.6	0.3	0.4	0.4	1.1
EC_04	1.9	1.2	1.1	0.3	0.3	1.1	1	1.3	0.3	1.5	0.3	0.4	0.4	0.2	0.4	0.4	1
EC_05	1.9	1.1	1.1	0.3	0.3	1	1	1.3	0.4	1.4	0.4	0.3	0.3	0.2	0.4	0.4	0.9
EC_06	1.9	1.2	1	0.3	0.3	1	1	1.3	0.3	1.4	0.4	0.3	0.3	0.2	0.4	0.4	0.9
EC_07	1.9	1.3	1.2	0.2	0.2	1.3	1	1.3	0.4	1.7	0.3	0.6	0.6	0.3	0.4	0.4	1.1
EC_08	1.9	1.2	0.9	0.3	0.3	1	0.9	1.3	0.2	1.4	0.3	0.3	0.3	0.2	0.4	0.4	0.9
EC_09	2	1.3	1.4	0.3	0.3	1.2	1.2	1.3	0.5	1.3	0.4	0.8	0.8	0.4	0.5	0.5	1.2
EC_10	1.9	1.1	1.3	0.3	0.3	0.9	1	1.2	0.4	1.1	0.4	0.6	0.6	0.3	0.4	0.4	1
EC_11	1.8	1	1.3	0.3	0.3	0.9	1	1.2	0.5	1.1	0.4	0.6	0.6	0.3	0.4	0.3	0.9
EC_12	1.9	1.2	1.2	0.2	0.3	0.8	1	1.2	0.4	1	0.4	0.5	0.5	0.3	0.4	0.4	1
EC_13	2	1.3	1.4	0.2	0.2	1.2	1.2	1.3	0.5	1.3	0.4	0.8	0.8	0.3	0.5	0.5	1.2
EC_14	1.9	1.1	1.1	0.2	0.3	0.7	0.9	1.2	0.2	0.9	0.3	0.3	0.3	0.2	0.4	0.4	1
EC_15	2	1.3	1.4	0.2	0.3	1.2	1.2	1.3	0.5	1.3	0.4	0.8	0.8	0.4	0.5	0.5	1.2
EC_16	1.9	1.1	1.3	0.3	0.3	0.9	1	1.2	0.4	1.1	0.4	0.6	0.6	0.3	0.4	0.4	1
EC_17	1.8	1.3	1.3	0.2	0.2	0.9	1	1.2	0.5	1.1	0.4	0.6	0.6	0.3	0.4	0.3	0.9
EC_18	1.7	1.2	1.2	0.2	0.3	0.8	1	1.2	0.4	1	0.4	0.5	0.5	0.3	0.4	0.4	1
EC_19	2	1.3	1.4	0.3	0.3	1.2	1.2	1.3	0.5	1.3	0.4	0.8	0.8	0.3	0.5	0.5	1.2
EC_20	1.9	1.1	1.1	0.2	0.2	0.7	0.9	1.2	0.2	0.9	0.3	0.3	0.3	0.2	0.4	0.4	1
EC_21	2	1.7	1.7	0.2	0.2	1.5	0.9	1.5	0.5	1.5	0.4	0.5	0.7	0.3	0.4	0.4	1.2
EC_22	2	1.9	1.7	0.2	0.1	1.6	0.9	1.9	0.6	1.6	0.6	0.5	0.9	0.4	0.5	0.4	1.1
EC_23	2	1.9	1.4	0.1	0	0.9	0.8	1.7	0.4	1.5	0.4	0.5	0.8	0.3	0.4	0.4	1.4
EC_24	1.9	1.6	1.6	0.2	0.1	1	1.1	0.9	0.5	1.6	0.3	0.5	0.4	0.2	0.2	0.3	1.4
EC_25	1.9	1.7	1.3	0.2	0.2	1.5	0.9	1.3	0.5	1.4	0.4	0.5	0.5	0.2	0.3	0.3	1.2
EC_26	2	1.1	1.3	0.2	0.2	0.9	0.9	1.5	0.4	1.5	0.8	0.7	0.8	0.4	0.7	0.7	0.9
EC_27	1.9	1.6	1.5	0.8	0.9	1.2	0.8	1.4	0.7	1.6	0.7	0.8	0.9	0.4	0.6	0.4	1.3

Table A4.1.(Continued). Sensitivity score used in HOLAS 3. The range of the scores is from 0 to 2, the higher the score, the higher the sensitivity of the ecosystem components to the pressure. Further information is given in chapter 2.5.

	PL_01	PL_02	PL_03	PL_04	PL_05	PL_06	PL_07	PL_08	PL_09	PL_10	PL_11	PL_12	PL_13	PL_14	PL_15	PL_16	PL_17
EC_28	2	1.7	1.8	0.2	0.2	1.7	0.8	1.5	0.3	1.8	0.7	0.1	0.1	0.1	0.6	0.4	0.9
EC_29	2	1.7	1.6	0.9	0.8	1.3	1	1.5	0.2	1.7	0.7	0.8	0.7	0.4	0.5	0.3	1.4
EC_30	1.9	1.6	1.3	0.9	0.9	1.2	0.7	1.3	0.2	1.6	0.7	0.8	0.9	0.4	0.6	0.4	1.3
EC_31	2	1.6	1.5	0.7	0.7	1	1.2	1.3	0.6	1.9	0.9	0.7	0.8	0.4	0.7	0.7	1.2
EC_32	1.9	1.5	1.3	0.5	0.5	1	0.8	1.3	0.1	1.6	0.6	0.7	0.8	0.3	0.5	0.3	1.3
EC_33	1.9	1.4	1.3	0.8	1	1	0.7	1.3	0.5	1.8	0.7	0.7	0.9	0.3	0.8	0.6	1.4
EC_34	1.9	1.5	1.1	0.5	0.5	1	0.8	1.2	0.1	1.6	0.6	0.7	0.8	0.3	0.5	0.4	1.3
EC_35	1	0.7	0.4	0.2	0.9	0.7	0.8	1.5	0.6	0.5	0.9	1.6	1.6	1.6	0.7	0.7	0.6
EC_36	0.9	0.7	0.7	0.6	1.1	0.6	0.4	0.7	0.3	0.9	0.4	1.2	1.2	1.2	0.2	0.2	0.6
EC_37	0.5	0.5	0.7	0.6	1.1	0.6	0.4	0.6	0.3	0.9	0.4	1.2	1.2	1.2	0.2	0.2	0.6
EC_38	1.7	1.3	1.3	0.6	1.1	1	0.9	1.1	0.3	1.5	0.6	1.1	1.2	0.8	0.1	0.1	1.3
EC_39	1.8	1.2	1.1	0.6	1	0.5	0.5	1.2	0.3	1.8	0.9	0.9	0.1	0.7	0.1	0.1	1
EC_40	1.8	1.1	1.1	0.6	1.1	0.3	0.6	0.4	0.3	1.9	0.7	0.9	0.2	0.8	0.2	0.2	0.9
EC_41	1.4	0.9	1.1	0.6	1	0.8	0.7	1.7	0.3	1.3	0.6	1.1	1.7	1.1	0.1	0.1	0.4
EC_42	1.7	1.2	1.3	0.6	1.1	1	0.7	1.1	0.3	1.6	0.7	1	1.1	0.8	0.1	0.1	1.2
EC_43	1.7	1.2	1.3	0.6	1.1	1	0.7	1.1	0.3	1.4	0.7	1	1.1	0.8	0.1	0.1	1.2
EC_44	1.6	1.2	1.1	0.6	1.1	1	0.6	1.1	0.3	1.5	0.6	1.4	0.4	1.1	0.1	0.1	1.2
EC_45	1	0.8	1.1	0.6	1.1	0.9	0.6	0.9	0.3	1.4	0.5	1.3	0.7	1.4	0.1	0.1	0.5
EC_46	1.3	1	0.5	0.8	1.1	0.3	1.4	0.2	1.1	2	1.3	1.1	0.8	1.1	1.9	0.3	0.6
EC_47	1.3	1	0.4	0.8	1.1	0.2	1.3	0.3	0.8	2	1.8	1	0.8	1	1.8	0.1	0.8
EC_48	0.6	0.9	0.9	1.4	1.6	0.3	1.4	0.4	1	1.4	1.3	1.2	1.2	1.2	0.2	2	0.8
EC_49	0.6	0.9	0.9	1.5	1.6	0.3	1.5	0.4	1	1.6	1.4	1.2	1.2	1.2	0.2	2	0.8
EC_50	0.7	0.8	0.8	1.5	1.6	1.1	1.4	0.5	1.1	1.5	1.4	1.5	0.8	1.5	0.2	2	1.1
EC_51	1.2	1.2	0.7	1.7	1.9	0.5	1.8	0.4	1	1.6	1.4	1.5	1.5	1.5	0.2	0.1	0.4
EC_52	2	1.7	1.1	0.1	0.1	1.5	0.7	1.4	0.4	1.5	0.2	0.4	0.3	0.4	0	0	0.4
EC_53	1.9	1.6	1	0.1	0.1	1.5	0.7	1.4	0.4	1.5	0.2	0.4	0.3	0.4	0	0	0.4
EC_54	2	1.7	1.4	0.1	0.1	1.5	0.7	1.5	0.4	1.6	0.2	0.4	0.3	0.4	0	0	0.4
EC_55	2	1.6	1.1	0.1	0.1	1.5	0.7	1.5	0.4	1.6	0.2	0.4	0.3	0.4	0	0	0.4
EC_56	2	1.6	1.1	0.1	0.1	1.3	0.7	1.4	0.4	1.6	0.2	0.4	0.3	0.4	0	0	0.4
EC_57	2	1.7	1.4	0.1	0.1	1.5	0.7	1.5	0.4	1.6	0.2	0.4	0.3	0.4	0	0	0.4

Table A4.2. Codes used in the sensitivity score matrix.

	Ecosystem Components		Pressure Layers
EC_01	Productive surface waters (Chl-a)	PL_01	Physical loss
EC_02	Deep water habitats not influenced by permanent anoxia	PL_02	Physical disturbance
EC_03	Infralittoral coarse sediment	PL_03	Changes to hydrological conditions
EC_04	Infralittoral mixed sediment	PL_04	Input of continuous anthropogenic sound
EC_05	Infralittoral mud	PL_05	Input of impulsive anthropogenic sound
EC_06	Infralittoral mud or Infralittoral sand	PL_06	Input of heat
EC_07	Infralittoral rock and biogenic reef	PL_07	Hazardous substances
EC_08	Infralittoral sand	PL_08	Eutrophication
EC_09	Circalittoral coarse sediment	PL_09	Introduction of radionuclides
EC_10	Circalittoral mixed sediment	PL_10	Oil slicks and spills
EC_11	Circalittoral mud	PL_11	Disturbance of species due to human presence
EC_12	Circalittoral mud or Circalittoral sand	PL_12	Extraction of fish - Herring extraction (landings)
EC_13	Circalittoral rock and biogenic reef	PL_13	Extraction of fish - Cod extraction (landings)
EC_14	Circalittoral sand	PL_14	Extraction of fish - Sprat extraction (landings)
EC_15	Offshore circalittoral coarse sediment	PL_15	Extraction of seabirds - Bird hunting
EC_16	Offshore circalittoral mixed sediment	PL_16	Extraction of mammals - Seal hunting
EC_17	Offshore circalittoral mud	PL_17	Introduction of non-indigenous species and translocations
EC_18	Offshore circalittoral mud or Offshore circalittoral sand		
EC_19	Offshore circalittoral rock and biogenic reef		
EC_20	Offshore circalittoral sand		
EC_21	Furcellaria lumbricalis distribution		
EC_22	Zostera marina distribution		
EC_23	Charophyte distribution		
EC_24	Mytilus distribution		
EC_25	Fucus distribution		
EC_26	Sandbanks (1110)		
EC_27	Estuaries (1130)		
EC_28	Mudflats and sandflats (1140)		
EC_29	Coastal lagoons (1150)		
EC_30	Large shallow inlets and bays (1160)		
EC_31	Reefs (1170)		
EC_32	Baltic Esker islands (1610)		
EC_33	Submarine structures made by leaking gas (1180)		
EC_34	Boreal Baltic islets and small islands (1620)		
EC_35	Cod abundance		
EC_36	Herring abundance		
EC_37	Sprat abundance		
EC_38	Potential nursery areas for flounder (PBS)		
EC_39	Potential recruitment areas for perch (PBS)		
EC_40	Potential recruitment areas for pikeperch (PBS)		
EC_41	Potential spawning areas for cod (PBS)		
EC_42	Potential spawning areas for Baltic flounder (PBS)		
EC_43	Potential spawning areas for European flounder (PBS)		
EC_44	Potential spawning areas for herring (PBS)		

Table A4.2. (Continued). Codes used in the sensitivity score matrix.

	Ecosystem Components	Pressure Layers
EC_45	Potential spawning areas for Sprat (PBS)	
EC_46	Wintering areas for birds	
EC_47	Breeding areas for birds	
EC_48	Grey seal distribution	
EC_49	Harbour seal distribution	
EC_50	Ringed seal distribution	
EC_51	Harbour porpoise distribution	
EC_52	Potamogeton distribution	
EC_53	Myriophyllum distribution	
EC_54	Najas marina distribution	
EC_55	Fontinalis distribution	
EC_56	Callitriche distribution	
EC_57	Zanichellia distribution	