Thematic assessment of

cumulative impacts

on the Baltic Sea 2011–2016

HELCOM

Baltic Marine Environment Protection Commission

Supplementary report to the HELCOM 'State of the Baltic Sea' report

STATE OF THE BALTIC SEA
- HOLISTIC ASSESSMENT -

Cumulative impacts

Baltic Sea Environment Proceedings 159

Thematic assessment of cumulative impacts on the Baltic Sea 2011-2016. Supplementary report to the HELCOM 'State of the Baltic Sea' report

The production of this report has been carried out through the HELCOM Project for the development of the second holistic assessment of the Baltic Sea (HOLAS II). The methodology was developed through the HELCOM TAPAS project and the assessment was carried out by the HELCOM SPICE project. The work was financially supported through HELCOM and the EU co-financing of the HELCOM coordinated projects TAPAS and SPICE.

SPICE Co-funded by the European Union

TAPAS Co-funded by the European Union

Contributors: Samuli Korpinen[1], Marco Nurmi[1], Juuso Haapaniemi[2], Leena Laamanen[1,2], Henrik Nygård[1], Joni Kaitaranta[2], Henna Rinne[2], Kai Hoppe[3], Emilie Kallenbach[4], Ciaràn Murray[5], Jesper Andersen[6], Ulla-Li Zweifel[2], Lena Bergström[2,7]

Acknowledgements: The spatial data underlying the assessment was based on national data calls supported by national experts and the HELCOM Contracting Parties, and by the achievements of HELCOM expert networks. The sensitivity scores were designed based on the contribution from experts in all nine contracting parties, and from the EU co-financed BalticBOOST project. The assessment method was developed by support of the EU co-financed TAPAS project, and by participants of the workshops HELCOM HOLAS II Pressure index WS 1-2015, HELCOM TAPAS Pressure index WS 1-2016, HELCOM TAPAS Pressure index WS 2-2016, and HELCOM BSPI BSII 1-2018. The assessment was carried out with support from the EU co-financed HELCOM SPICE project, and was guided by the HOLAS II Core team and HELCOM State & Conservation.

For bibliographic purposes, this document should be cited as:
HELCOM (2018): Thematic assessment of cumulative impacts on the Baltic Sea 2011-2016. Baltic Sea Environment Proceedings No. 159. Available at: http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/

Layout: Sara Estlander
Cover photo: Cezary Korkosz

ISSN 0357-2994

1 Finnish Environment Institute (SYKE)
2 Baltic Marine Environment Protection Commission (HELCOM)
3 IOW/BfN Germany
4 NIVA Denmark
5 NIVA Denmark
6 NIVA Denmark
7 Swedish Univeristy of Agricultural Sciences (SLU)

Table of contents

Summary

Cumulative impacts on species and habitats are caused by multiple pressures acting together. The Baltic Sea is influenced by a range of different pressures, as a result of human activities at sea and in its catchment area. If each activity and pressure is considered individually, it may appear to have little importance. However, the summed impact may be considerable when the pressures take place in the same area, in particular when acting on sensitive species or habitats.

This report gives the method description and results for an assessment of cumulative pressures and impacts in the Baltic Sea during the years 2011-2016. The assessment focuses on the spatial dimension. The 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 effects from these pressures.

The key results are also presented in the State of the Baltic Sea report, which summarizes the results from the second HELCOM holistic assessment of the ecosystem health of the Baltic Sea (HELCOM 2018a). This report additionally gives a more detailed description of the underlying assessment method, spatial data sets and sensitivity scores.

View of the Martwa Wisła and Wisła Śmiała rivers, Poland. © magro_kr (CC BY-NC-ND 2.0)

Data included

The analyses are based on spatial data at the Baltic Sea regional scale, to provide a broad regional overview. The assessment was enabled by a huge data collation effort, supported by national data calls, contributions from research projects and the dedicated work of HELCOM experts. In addition to providing the assessment results, this effort has resulted in a significant improvement in the availability of regional spatial data on species, habitats, pressures and human activities in the Baltic Sea. However, the accuracy and completeness of available datasets vary. This should be considered when looking at the assessment results. A summary of quality aspects in the underlying spatial data is provided in this report. More detailed information is found in the metadata fact sheets, which are associated with each of the spatial data sets considered (HELCOM 2018b).

Aerial view of the river Martwa Wisła and Ostrów island, Gdansk, Poland.

Assessment results in brief

The results show that impacts from human activities occur almost everywhere in the Baltic Sea but the highest cumulative pressures are seen by the coast, close to urban areas and in some freshwater outflows. The southwestern Baltic Sea is seen to experience more potential cumulative impact than many of the northern areas. In some areas with poor data coverage the cumulative impacts may currently be underestimated.

- There are great differences in the level of cumulative impacts between different areas of the Baltic Sea.
- The pressures themes attributed to most of the identified impacts were concentrations of nutrients, hazardous substances, and non-indigenous species, followed by the extraction of fish. The results reflect that these are widely distributed pressures in the Baltic Sea, which many species and habitats are sensitive to.
- Other pressures were associated with high sensitivity scores, such as oil slicks and spills, physical loss of seabed, but had relatively low impact at the overall regional scale, as they were not as widely distributed.
- The most widely impacted ecosystem components (species or habitats) in the Baltic Sea were identified as the water-column habitats which cover the entire sea area, marine mammals, and cod.
- Relatively higher impacts are seen in many coastal areas, which reflects that shallow habitats typical for these areas were assessed as sensitive to several pressures, and that more ecosystem components are represented in coastal areas than in the open sea.
- Based on the data available for the assessment and current knowledge, less than 1 % of the Baltic Sea seabed is potentially lost due to human activities while roughly 40 % of the seabed area is potentially disturbed during the assessment period (2011-2016). There is currently no regionally agreed method for assessing how loss and disturbance are causing adverse effects on the marine environment and therefore the allocations made up to now are preliminary.

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.

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). These groups are presented in Figure 1, together with a comprehensive overview of human activities which can be linked to them. Some of the listed human activities are well established in the Baltic Sea and its catchment areas today, whereas others are more limited.

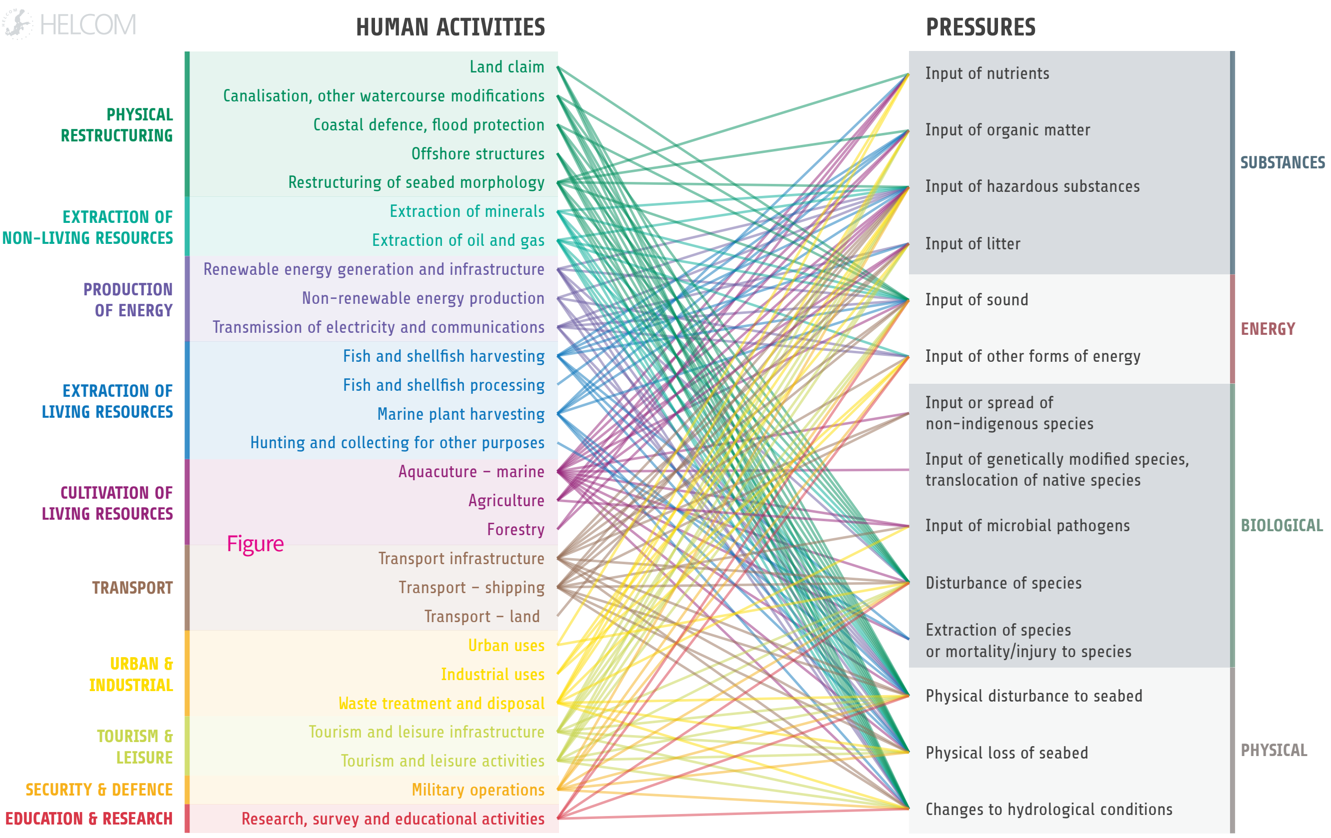

Figure 1. Human activities in the Baltic Sea and their connection to pressure types. The lines show which pressures are potentially connected to a certain human activity, without inferring the pressure intensity nor potential impacts in each case. The figure illustrates the level of complexity involved in the management of environmental pressures.

The current assessment aims to consider impacts from all human activities listed in Figure 1 and occurring in the Baltic Sea during 2011-2016, as defined based on information from the countries around the Baltic Sea. The assessment is based on information on the spatial distribution of the pressures they are likely to be causing. In some cases, however, a pressure that is seen as relevant in relation to human activities has not been possible to include due to lack of data, as specified further in Chapter 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 species to different pressures.

This report presents the method description, data and results for the assessment of cumulative pressures and impacts as carried out within the project to develop a second HELCOM holistic assessment of ecosystem health in the Baltic Sea. The key results are also presented in chapter 6 of summary report ‘State of the Baltic Sea 2011-2016’ (HELCOM 2018a).

Offshore wind farm in the Øresund strait, Denmark.
© OCEANA/Pitu Rovirosa

2. Spatial data sets

The assessments were based on original spatial data sets for 39 human activities occurring in the Baltic Sea, and 6 data sets on pressures estimated by direct measurements at sea. These data were compiled into 18 aggregated pressure layers which were used in the Baltic Sea Pressure Index (BSPI) and the Baltic Sea Impact Index (BSII). In addition, 36 spatial data sets representing different ecosystem components were for assessing cumulative impacts in the Baltic Sea Impact Index.

The layers were collated in order to generally be representative of the years 2011-2016. Data were obtained from the countries through national data calls, by enquiries to the HELCOM expert networks and projects, and from the EUSeaMap project for broad-scale habitats, as explained in more detail in the HELCOM map and data service (HELCOM 2018b) and HELCOM metadatabase (HELCOM 2018c).

All spatial data were collated with the aim to be harmonized and comparable for different geographic areas of the Baltic Sea, and hence 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, and should be considered if examining results in more detail.

Fields on top of a cliff in the Baltic Sea © Pixabay

2.1. Spatial resolution and scaling

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 use in the analyses.

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 used when there was reason to assume that the values representing the lowest measured range were too low to likely impact on species and habitats, based on inputs from the project workshops and the HOLAS II Core Team. 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 2).

2.2. Pressure layers

The list of pressures to include in the assessment (Table 1) 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 watershed (Figure 1). The structure of the list was aligned with the revised Annex III of the Marine Strategy Framework Directive (EC 2017 a, b, see also section 2.6).

The number of data sets representing each pressure was kept low and as similar as possible between pressures, in order to avoid a situation where pressures represented by more data would have stronger influence on the results. Hence, some of the pressure layers used in the assessment are based on an aggregation of several original data sets representing the same pressure. The approaches are described in more detail below and are specified in Annex 1. Spatial data sets representing nutrient concentrations (nitrogen and phosphorus) as well as fishing (catches of cod, sprat and herring) were analyzed both separately and grouped as pressure themes.

The pressure layers to represent 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. The continuous sound layer was based on monitoring at sea combined with modelling. In the other cases, no direct data were available at Baltic-wide scale, and the spatial distributions of the pressures were estimated indirectly. 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 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 (See below and Annex 1).

Table 1. Overview of pressure layers included in the assessment. The list of pressures is structured as in Figure 1, but the names of individual pressures may differ, as the pressure layers used in the assessment were named in order to correspond to the data/approach used for developing them. Pressures representing marine litte', organic matter, genetically modified species and microbial pathogens are listed in Figure 1 but were not included due to poor availability of data with Baltic Sea regional coverage. For more detailed information on the layers, see further below in this chapter, and Annex 1.

Pressure layer	Primary data source/approach for layer development
Input of substances	
Relative distribution of nitrogen concentration	monitoring
Relative distribution of phosphorus concentration	monitoring
Hazardous substances concentrations	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	based on available reporting
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

Relative distribution of nutrient concentration (Nitrogen concentrations and phosphorus)
The layer was based on data on total nitrogen concentrations measured in surface waters (0-10 m), extracted from the oceanographic databases of ICES, the Swedish Meteorological and Hydrological Institute (SMHI), the EEA Eionet database and data from the "Gulf of Finland year 2014" project[1]. The data set included almost 50,000 observations of nutrient concentrations from the years 2011-2016 from more than 1,000 measuring locations at sea, and Baltic-wide layers with full coverage were obtained by interpolation (spline with barriers). To not overestimate values from a certain season, average values for winter (Dec-Feb), spring: (Mar-May), summer (Jun-Aug), and autumn (Sept-Nov) were used to calculate the annual average. The layer was log-transformed and normalized. In this process, all values above the 95th and below the fifth percentile were grouped together, to avoid undue influence of extreme values.

The layer on phosphorus concentrations was developed in the same way as for nitrogen, using data on total phosphorus measured in surface waters (0-10 m), from the same data sources, in all representing the years 2011-2016.

When impacts from concentrations of nitrogen and phosphorus were assessed together as one theme (see Figure 4 in the Results chapter), the sum of both impacts was used; the impact of both nutrient layers to all ecosystem components were summed to assess the impact introduced by concentration of nutrients.

Hazardous substances concentrations
The layer was interpolated based on the data used in the CHASE integrated assessment of hazardous substances, using the assessment component concentration. CHASE contamination ratios were calculated with respect to hazardous substances monitored in water, sediment and biota. The ratios were classified into five classes, values were interpolated to cover the whole Baltic Sea, and normalized to produce the final pressure layer.

Radionuclides
The layer is based on HELCOM MORS Discharge data for 2011-2014. 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 with a linearly decreasing function was used to represent the impact distance from the monitoring stations. The data set was normalized to produce the final pressure layer.

1 http://www.syke.fi/projects/gulfoffinlandyear2014

Oil slicks and spills
The pressure layer is a combination of data sets on illegal oil discharges and polluting ship accidents. The illegal oil discharges data set is based on aerial surveillance data and on polluting ship accidents from HELCOM Contracting parties' reporting on shipping accidents. The data sets were handled separately as explained in more detail in Annex 1. They were then summed and again normalized to produce the final pressure layer.

Pressure layers representing input of energy

Continuous anthropogenic sound
The layer was based on data from the BIAS project representing ambient underwater noise, modelled into a 0.5 km x 0.5 km grid. The layer represents sound pressure levels at one 1/3 octave band of 125 Hz exceeded at least 5% of the time. The data were normalized setting level 0 at 92 db re 1µPa and level 1 at 127 db re 1µP, where the former is set to represent natural levels in the Baltic Sea, and the latter is the maximum of the 5th percentile of the distribution (HELCOM 2018d).

Impulsive anthropogenic sound
The layer is based on the following impulsive sound events: Seismic surveys, explosions, pile driving, and air guns, 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'= 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 2011-2016, 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 cooling water from nuclear power plants and from fossil fuel energy production. The data set on discharge of cooling water from nuclear power plants was obtained by a direct data request to HELCOM Contracting Parties. 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 center. Heat loads from both data sets were summed and normalized to produce the final pressure layer.

Pressure layers representing biological disturbances

Introduction of non-indigenous species

The layer is based on information from the development of the core indicator trends in the arrival of new non-indigenous species (HELCOM 2012). The information represents the number of non-indigenous species in each assessment unit at HELCOM assessment scale 2 in 2011. Hence, the layer indicates the spatial distribution of areas with elevated risk for introduction of non-indigenous species. It does not consider impacts associated with the identity of individual species. Values were normalized to produce the final pressure layer.

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. Individual data sets were handled separately as presented in Annex 1. The layers were summed and normalized to produce the final pressure layer.

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; herring, sprat and cod, during 2011-2016. 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 2011-2013. 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 kilometer 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, F_{MSY}. 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.

Hunting and predator control of seabirds

The layer is a combination of data sets representing game hunting of seabirds and predator control of seabirds. Both data sets were made available by HELCOM Contracting Parties in response to a data request. The number of hunted birds per square kilometer 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 (*Phoca hispida*) and harbour seal (*Phoca vitulina*), and covers the years 2011-2014. The size and scale of the reporting units varies from county to country. Values were averaged over 2011-2014 and the number of hunted seals per square kilometer was calculated. Data sets were normalized so that value 0.5 was set at the quota for hunting in the Baltic Sea. The following quotas for hunting were used: Grey seal: 2000, Ringed seal: 350, Harbour seal 230. The datasets were normalized to produce the final pressure layer.

Pressure layers representing physical disturbances

Physical disturbance to seabed

Physical disturbance is defined as a change to the seabed which can be reverted if the activity causing the disturbance ceases (EC 2017a). The same activities as in the assessment of physical loss, and trawling, were considered as causing physical disturbance (acting via the pressures of siltation, smothering, and abrasion). In addition, shipping was included as potentially causing physical disturbance (Box 1, Figure B.1). However, it should be noted that the identification of "disturbance" and its extent, as applied here, has provisional character, as the available data does not allow for the classification of the effect of exact operations.

To represent the pressure of physical disturbance, impact distances and attenuation gradients for each individual human activities layer were estimated based on literature and expert evaluations, and were implemented by adding corresponding buffers to the human activity data layers (for details, see Annex 1). When merging the individual layers into one aggregated layer on physical disturbance, weighting factors were applied (Table 2). These were included in order to account for the fact that the intensity of the pressure varies between the different human activities. After the weighting, the human activity data layers (adjusted with buffers) were summed together and normalized to produce the final aggregated pressure layer.

Physical loss to seabed

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[2] (Box 1, Figure B.1). 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. Hence, if all of the area of one grid call was covered by the aggregated pressure layer, it was given a pressure value 1.

Altered hydrological conditions

The layer is combination of activities causing changes to hydrological conditions: hydropower dams, watercourse modifications, wind farms and oil platforms. Impact distances and attenuation gradients for individual human activities were estimated based on literature and expert evaluations and implemented accordingly. Data sets were handled separately, summed together and overlapping areas were removed to avoid double counting. The layer was normalized to produce the final pressure layer.

Table 2. Weighting factors applied when producing the aggregated pressure layer physical disturbance based on spatial data sets on human activities. The weighting factors were implemented based on information from literature (HELCOM 2017b).

Rank	Human activity	Weight
High pressure intensity and/or slow recovery	Coastal defense, Deposit of dredged material, Dredging, Extraction of sand and gravel, Trawling	1
Moderate to high	Pipelines, Shipping	0.8
Moderate	Finfish mariculture, Shellfish mariculture, Wind farms (under construction)	0.6
Low to moderate	Cables (under construction)	0.4
Low	Furcellaria harvesting, Recreational boating and sports, Wind farms (operational)	0.2
No pressure		0

2 Any identification and assessments of losses and disturbances caused by dredging/depositing operations at this stage have a preliminary character.

Box 1.
Human activities potentially attributed to seabed loss and disturbance

Construction and installations

Off-shore 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 pressures exerted during the construction phase have similarities with those during seabed extraction or dredging (see below). Installation of off-shore 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).

Open systems of mariculture affect the seabed habitat through sedimentation of excrements under the fish and shellfish farms, as the accumulated material changes the seabed substrate. However, the extent of the effects in terms of loss and disturbance of the seabed depends on the hydrological conditions and on the properties of the mariculture, and currently limited information exists on the recovery rate when the pressure is removed (but see Kraufvelin *et al*. 2001).

Dredging

Dredging activities are usually divided into capital dredging and maintenance dredging. 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.

Sand and gravel extraction

During sand and gravel extraction sediment is removed from the seabed, for use in construction, coastal protection, beach nourishment and land-fills, for example.

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 which, 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'.

Deposit of dredged material

Deposit of dredged material may cause covering of the seabed, smothering of benthic organisms, and lead to loss of habitat if the sediment characteristics are permanently changed. In addition, increased turbidity during the activity causes increased siltation on the site and in its adjacent areas. In some cases, deposited material may contain elevated concentrations of hazardous substances or nutrients.

The impacts on the species depends mainly on the seabed habitat type, and the type and amount of deposited material. Burial of benthic organisms may cause mortality, but some species have the ability to re-surface (Olenin 1992, Powilleit *et al.* 2009). The probability of survival is higher on unvegetated soft bottoms, whereas vegetation and fauna on hard substrates die when covered by a few centimetres of sediment (Powilleit *et al.* 2009, Essink 1999). The spatial extent of the disturbance is similar to that during dredging (Syväranta and Leinikki 2015, Vatanen *et al.* 2015).

Shipping

Ship traffic can cause disturbance to the seabed in several ways; propeller induced currents may cause abrasion, resuspension and siltation of sediments, ship-bow waves may cause stress to littoral habitats, and dragging of anchors may cause direct physical disturbance to the seabed.

Disturbances to the seabed from shipping mainly occur in shallow areas. The effects are often local, concentrated to shipping lanes, and in the vicinity of harbours. For larger vessels, the effect on turbidity has been observed down to depths of thirty metres (Vatanen *et al*. 2010). Mid-sized ferry traffic has been estimated to increase turbidity by 55 % in small inlets (Eriksson *et al.* 2004). Erosion of the sea-floor can be substantial along heavy shipping lanes, and has been observed to cause up to one metre of sediment loss due to abrasion (Rytkönen *et al.* 2001).

Bottom trawling

Bottom contacting fishing gear causes surface abrasion. During bottom trawling it may also reach deeper down into the sediment, causing subsurface abrasion to the seabed.

The substrate that is swept by bottom trawling is affected by temporary disturbance, and bottom dwelling species are removed from thehabitat or relocated (Dayton *et al*. 1995). The impact is particularly strong on slow growing sessile species which may be eradicated. Since the same areas are typically swept repeatedly, and due to high density of trawling in some areas, the possibility to recover may also be low for more resilient organisms, and a change in species composition may be seen (Kaiser *et al*. 2006, Olsgaard *et al*. 2008).

In addition, the activity may mobilise sediments into the water, which may be transported to other areas and cause smothering of hard substrates, or may release hazardous substances that have been previously buried in the seabed (Jones 1992, Wikström *et al.* 2016).

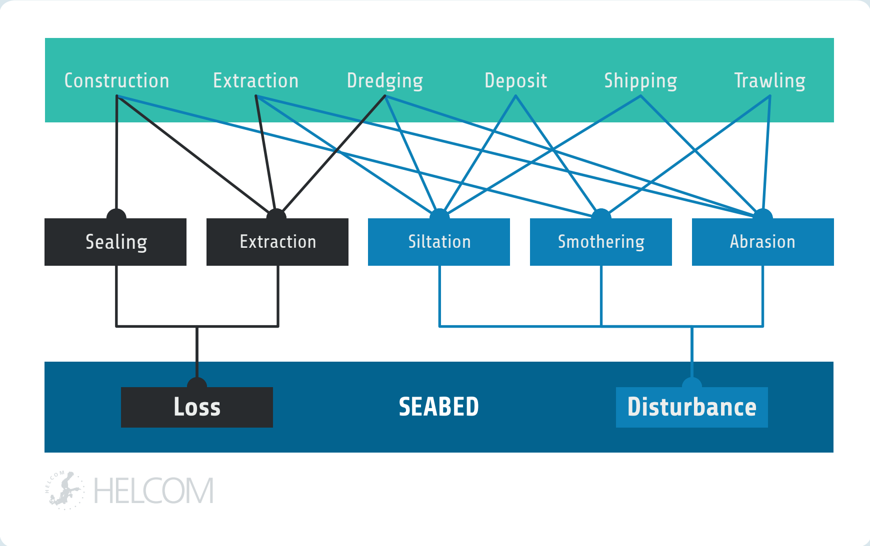

Figure B.1. Generalised overview of human activity types and the physical pressures they may exert on the seabed. The pressures are further grouped into those causing loss and disturbance of the seabed. Black lines link to potential physical loss of seabed habitats, and blue lines link to potential physical disturbance

Table 3. Ecosystem component layers included in the assessment. The layers were based on data collected from various sources, including national data calls and input from HELCOM expert groups For more detailed information on the layers, see further below in this chapter, and the metadata descriptions for each spatial data set (HELCOM 2017b).

ECOSYSTEM COMPONENT
Benthic habitats
Availability of deep water habitat, based on occurrence of H2S
Infralittoral hard bottom
Infralittoral sand
Infralittoral mud
Infralittoral mixed
Circalittoral hard bottom
Circalittoral sand
Circalittoral mud
Circalittoral mixed
Sandbanks which are slightly covered by sea water at all time (1110)
Estuaries (1130)
Mudflats and sandflats not covered by seawater at low tide (1140)
Coastal lagoons (1150)
Large shallow inlets and bays (1160)
Reefs (1170)
Submarine structures made by leaking gas (1180)
Baltic Esker Islands (UW parts, 1610)
Boreal Baltic islets and small islands (UW parts, 1620)
Habitat building species
Furcellaria lumbricalis
Zostera marina
Charophytes
Mytilus edulis
Fucus sp.
Pelagic habitats
Productive surface waters
Mobile species and their key habitats
Cod abundance
Cod spawning area
Herring abundance
Sprat abundance
Recruitment areas of perch
Recruitment areas of pikeperch
Wintering seabirds
Breeding seabird colonies
Grey seal distribution
Harbour seal distribution
Ringed seal distribution
Distribution of harbour porpoise

2.3. Ecosystem component layers

The data sets on ecosystem components, which were additionally used in the Baltic Sea Impact Index, 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 was available and comparable at the Baltic Sea regional scale. The following groups were included 1) benthic habitats based on the EMODnet broad-scale habitats[3] 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 sets were defined to represent the situation during 2011-2016. Hence, 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 (For this, see HELCOM 2018a), but for assessing in which geographical areas these species and habitats are currently under high cumulative pressure from human activities.

3 The broad scale habitats do not completely match the MSFD habitats.

2.4. Connection to the Marine Strategy Framework Directive

The organization of the used pressure layers is in line with the revised Annex III of the Marine Strategy Framework Directive (EC 2017a-b), with some modifications in order to make the list applicable to Baltic Sea conditions. Human activities not occurring in the Baltic Sea were not included. Further, some pressures were sub-divided as they were considered important for the region. Extraction of fish was assessed separately for the three predominating commercial species (in addition to the theme-wise assessment), and hunting of seals and seabirds were assessed separately. Nutrients were addressed by assessing concentrations of of nitrogen and phosphorus at sea both separately and taken together as a theme.

Pressures related to climate change, such as acidification or changes in salinity and temperature, were not included due to a lack of approach for how to handle the monitoring data. Furthermore, data on the inputs of litter, inputs of organic matter, or genetically modified species were not included, due to a lack of spatial information.

The BSPI and BSII were developed to assess the potential extent of current impact from human activities on species and habitats in the Baltic Sea, in the light of the Baltic Sea Action Plan. The current assessment provides a more developed and advanced approach compared to the first version of the BSPI and BSII, as presented in the initial HELCOM holistic assessment (HELCOM 2010a). However, there is a need for continued, further development of the tool and its underlying data layers. A more refined approach should be developed in the future, focussing both on improving the underlying data sets and the analyses. The assessment provides no prejudice to national decisions on how to assess human activities and their impacts in national waters.

3. Method for the assessment of cumulative pressures and impacts

The Baltic Sea Impact Index (BSII) builds on concepts developed by Halpern *et al*. (2008), and was first applied in the initial HELCOM holistic assessment (HELCOM 2010a). The methods that were applied at that time are described in HELCOM (2010b) and Korpinen *et al*. (2012). The concepts were subsequently developed further for parts of the North Sea area in the HARMONY project (Andersen *et al.* 2013), which also developed an assessment software (Stock 2016). The same methodology has also been used in the Mediterranean and the Black Sea (Micheli *et al.* 2013).

Although the method used in the 'State of the Baltic Sea 2011-2016' report (HELCOM 2018a) is similar to that applied in HELCOM (2010a), the assessment approach has been refined further. The main focus of the work has been on improving the data underlying the assessment. Further, the structure by which data layers are included has been changed, in order to provide a more balanced assessment. Hence, results from the assessment in 2010 cannot be directly be compared to the results presented here.

3.1. Assessment tool

The assessment was carried out in an ArcGIS toolbox specifically designed and created for this purpose at the HELCOM Secretariat. The tool uses the same principles as the EcoImpactMapper software, but is run in a spatial framework, and is flexible to further development and modification according to future needs. The developed tool can directly exploit the pressure and ecosystem component layers without conversion and automatically integrates the sensitivity scores for this process.

3.2. Calculation of BSII and BSPI

Both the Baltic Sea Pressure Index and the Baltic Sea Impact Index were carried out at full Baltic Sea regional scale, based on assessment units of 1 square kilometres (grid cells).

The key components of the Baltic Sea Impact Index (BSII) 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 and were defined as presented further below (Chapter 3.5)

The impact index was calculated based on the sum of all impacts in one assessment unit, 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):

Formula A

$$BSII(x,y) = \sum_{i=1}^{n} \sum_{j=1}^{m} PL_i(x,y) * EC_j(x,y) * SS_{i,j}$$

The Baltic Sea Pressure Index was calculated 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.

Formula B

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

3.3. Method implications

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 (e.g. 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 (Figure 3).

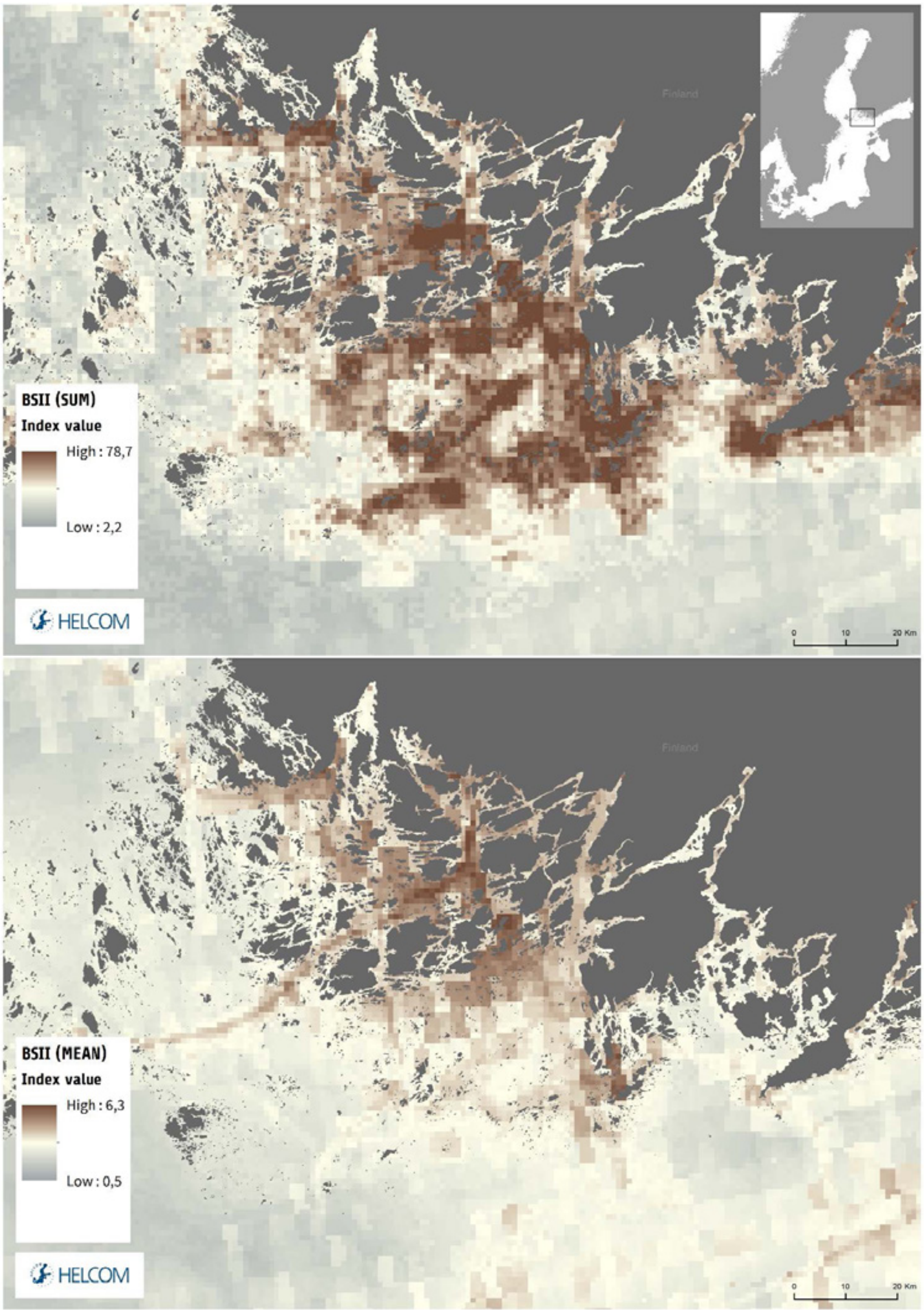

Figure 3. Example of difference in assessment output when the cumulative impact is calculated on the 'sum impact' as in the Baltic Sea Impact Index, (upper) or using the 'mean impact", for comparison (lower figure). The sum approach highlights the distribution of ecosystem components relatively more strongly, whereas the mean approach increases the emphasis on pressures. Hence, the mean approach is less influenced by how many ecosystem component layers are included, although this aspect is also taken into account.

3.4. Sensitivity scores

The sensitivity scores estimate the sensitivity of species and habitats to the different pressures, and are used in the Baltic Sea Impact Index. The sensitivity scores used in this assessment 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. The sensitivity scores finally applied in the assessment are presented in Table 4, for each combination of ecosystem components and pressures. The steps to determine the sensitivity scores are defined below and more background and details are given in Annex 2.

Design of the expert survey

The expert survey was developed in the TAPAS project and was presented in Microsoft Excel, supplemented with guidance on how to respond to the survey (Annex 2).

The survey contained a matrix of all possible combinations of pressures and ecosystem components, in the same format as shown in Table 4. Respondents were asked to provide estimates with respect to combinations of pressures and ecosystem components within their area of expertise.

The first three questions addressed the aspects of tolerance/resistance, recoverability, and sensitivity. Answers to these themes were requested in the categories ‘high’, ‘moderate’ and ‘low/none’, with the possibility to provide additional free text information. The replies were transformed to numeric scores from 0 to 2. ‘Low’ sensitivity, ‘high’ tolerance and ‘high’ recoverability received the score 0, while ‘high’ sensitivity, ‘low’ tolerance and ‘low’ recoverability received the score 2, and replies saying ‘moderate’ received score 1. The aim of the survey was to give sensitivity estimates, where tolerance/resistance and recoverability are two components, and the survey also asked for all of these aspects in order to evaluate the consistency in the replies.

In addition, the survey requested information on the impact distance and impact type for different pressures, as they were defined in the expert survey. The replies were used as information to support the development of aggregated pressure layers. Predefined reply alternatives for the impact distances were provided, but self-defined distances were also permitted. For the impact type, four basic response curves were given as alternatives (for further details, see Annex 1).

Finally, the participating experts were asked to provide a self-evaluation of how certain they were of their judgment. A low score was to be assigned if limited or no empirical documentation was available to support the judgement. In these cases, the judgement was mainly based on inference from other, similar ecosystem components/pressure types or from knowledge on the physiology and ecology of the species. A moderate score was to be assigned if empirical documentation was available, but show contradictory results in different studies, or if the documentation was based on grey literature with limited scope. Finally, a high confidence score was to be given if documentation was available with relatively high agreement among studies.

Inclusion of results from the survey

The results were analyzed and evaluated in relation to the number of replies, the variability among obtained responses, and the self-evaluation provided by the experts. After the evaluation, the sensitivity scores were based on the answers regarding ‘sensitivity’, while the responses to the themes ‘tolerance/resistance’ and ‘recoverability’ were analyzed as aspects to assess the level of consistency in the replies. The average of all replies provided to each ecosystem-pressure combination was used. The results were validated against an external literature review (see Annex 1). The review focused on the pressures physical loss and physical disturbance, but also covered other pressures.

Table 4. Sensitivity scores applied in the Baltic Sea Impact Index. The pressures are named as in Figure 1, and were entered into the assessment represented by spatial data sets as presented in Table 1. Ecosystem components are consistent with Table 3. The sensitivity scores of the broad habitat layers 'Infralittoral mixed' and 'Circalittoral mixed' were produced as means of the layers on mud, sand and hard bottoms. The scores are color-coded so that higher scores are red, intermediate scores white and low scores blue. The pressures and ecosystem components are sorted so that pressures with the highest total scores appear towards the top of the table, and ecosystem components with the highest total scores appear in the left-hand side of the table.

	Sensitivity scores: mean																				
	Submarine structures made by leaking gas (1180)	Estuaries (1130)	Coastal lagoons (1150)	*Zostera marina*	Ringed seal distribution	Large shallow inlets and bays (1160)	Reefs (1170)	Harbour seal abundance	Mudflats and sandflats not covered by seawater at low tide (1140)	Recruitment areas of pikeperch	Sandbanks which are slightly covered by sea water at all time (1110)	*Furcellaria lumbricalis*	Recruitment areas of perch	Grey seal abundance	Charophytes	Circalittoral hard bottom	Wintering seabirds	Distribution of harbour porpoise	Baltic Esker Islands (UW parts, 1610)	Boreal Baltic islets and small islands (UW parts, 1620)	Breeding seabird colonies
Oil slicks and spills	1.8	1.6	1.7	1.6	1.4	1.6	1.9	1.6	1.8	1.7	1.5	1.5	1.6	1.3	1.5	1.3	2.0	1.6	1.6	1.6	2.0
Physical loss	1.7	1.8	1.9	1.9	0.5	1.8	2.0	0.6	1.9	1.6	1.9	1.9	1.6	0.6	1.9	1.9	0.9	1.2	1.8	1.8	0.9
Physical disturbance	1.2	1.6	1.7	1.9	0.6	1.6	1.6	0.7	1.7	1.1	1.6	1.7	1.3	0.7	1.9	1.3	0.8	1.3	1.5	1.5	0.9
Inputs of nitrogen	1.6	1.4	1.5	1.9	0.5	1.3	1.3	0.3	1.5	0.7	1.5	1.5	1.4	0.3	1.7	1.3	0.2	0.2	1.3	1.2	0.3
Inputs of phosphorus	1.6	1.4	1.5	1.9	0.5	1.3	1.3	0.3	1.5	0.7	1.5	1.5	1.4	0.3	1.7	1.3	0.2	0.2	1.3	1.2	0.3
Changes to hydrological conditions	1.3	1.5	1.6	1.7	0.6	1.3	1.4	0.7	1.8	1.2	1.3	1.7	1.2	0.7	1.4	1.4	0.5	0.4	1.3	1.1	0.4
Extraction of herring	0.8	1.1	1.1	0.9	1.5	1.1	0.9	1.2	0.9	2.0	0.9	0.7	1.6	1.2	0.8	0.8	1.1	1.5	0.8	0.8	1.0
Extraction of cod	0.8	1.1	1.1	0.9	1.5	1.1	0.9	1.2	0.9	2.0	0.9	0.7	1.6	1.2	0.8	0.8	1.1	1.5	0.8	0.8	1.0
Extraction of sprat	0.8	1.1	1.1	0.9	1.5	1.1	0.9	1.2	0.9	2.0	0.9	0.7	1.6	1.2	0.8	0.8	1.1	1.5	0.8	0.8	1.0
Inputs of hazardous substances	0.7	0.8	1.0	0.9	1.4	0.7	1.2	1.5	0.6	0.6	0.9	0.9	0.4	1.4	0.8	1.2	1.4	1.6	0.8	0.8	1.3
Introduction of non-indigenous species	1.4	1.3	1.4	1.1	1.1	1.3	1.2	0.8	0.9	0.9	0.9	1.2	1.0	0.8	1.4	1.2	0.6	0.4	1.3	1.3	0.8
Disturbance of species	1.0	1.0	1.0	1.2	1.2	0.9	0.8	1.3	1.0	1.0	1.1	0.6	1.3	1.0	0.7	0.4	1.3	1.2	0.7	0.7	1.8
Input of heat	1.0	0.9	1.3	1.6	0.6	1.2	1.0	0.3	1.7	0.3	0.9	1.5	0.4	0.3	0.9	1.2	0.4	0.5	1.0	1.0	0.3
Hunting of seabirds	1.5	0.8	0.6	0.8	1.6	0.7	1.1	1.9	0.8	0.5	1.0	0.7	0.0	1.6	0.7	1.0	1.7	0.0	0.5	0.5	1.6
Hunting of seals	1.5	0.8	0.6	0.8	1.6	0.7	1.1	1.9	0.8	0.5	1.0	0.7	0.0	1.6	0.7	1.0	1.7	0.0	0.5	0.5	1.6
Inputs of impulsive sound	1.0	0.9	0.8	0.1	1.6	0.9	0.3	1.6	0.2	1.1	0.2	0.3	0.9	1.6	0.0	0.3	0.9	1.9	0.5	0.5	0.8
Inputs of continuous sounds	1.0	0.8	0.7	0.2	1.5	0.8	0.3	1.5	0.2	0.6	0.2	0.2	0.4	1.4	0.0	0.3	0.8	1.7	0.5	0.5	0.6
Inputs of electromagnetic and seismic waves	1.0	0.8	0.6	0.5	0.4	0.8	0.6	0.6	0.5	0.7	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.3	0.5	0.5	0.3
Introduction of radionuclides	0.5	0.7	0.2	0.6	1.2	0.2	0.6	1.0	0.3	0.5	0.4	0.5	0.4	1.0	0.4	0.5	0.7	1.0	0.1	0.1	0.2

	Sensitivity scores: mean															Scores for layers that were finally not included[b]				
	Cod abundance	Infralittoral hard bottom	*Fucus* sp.	Cod spawning area	Productive surface waters	Circalittoral mixed	Infralittoral mixed	Circalittoral mud	*Mytilus edulis*	Infralittoral mud	Infralittoral sand	Deep water habitat[a]	Circalittoral sand	Herring abundance	Sprat abundance	Harbour seal haulouts	Grey seal haulouts	Recruitment areas of roach	Abundance of pelagic spawning flounder	Migration routes for birds
Oil slicks and spills	0.5	1.7	1.4	1.0	1.4	1.1	1.5	1.1	1.6	1.4	1.4	1.0	0.9	0.9	0.9	1.6	1.4	1.7	1.1	1.9
Physical loss	1.0	1.8	1.8	0.7	0.4	1.8	1.8	1.6	1.8	1.7	1.8	0.9	1.8	0.9	0.5	0.8	0.8	1.7	1.0	0.8
Physical disturbance	0.7	1.3	1.7	0.8	1.0	1.1	1.2	1.0	1.6	1.1	1.2	0.7	1.1	0.7	0.5	0.9	0.9	1.1	0.8	0.5
Inputs of nitrogen	1.5	1.3	1.3	1.7	1.5	1.2	1.3	1.2	0.9	1.3	1.3	1.8	1.2	0.7	0.6	0.3	0.3	0.5	1.3	0.2
Inputs of phosphorus	1.5	1.3	1.3	1.7	1.5	1.2	1.3	1.2	0.9	1.3	1.3	1.8	1.2	0.7	0.6	0.3	0.3	0.5	1.3	0.2
Changes to hydrological conditions	0.4	1.2	1.3	0.9	0.6	1.3	1.1	1.3	1.6	1.1	0.9	1.3	1.1	0.7	0.7	0.6	0.6	1.2	0.9	0.4
Extraction of herring	1.6	0.6	0.5	1.3	1.0	0.6	0.4	0.6	0.4	0.3	0.3	0.7	0.3	1.2	1.2	1.0	1.0	1.6	1.8	0.7
Extraction of cod	1.6	0.6	0.5	1.3	1.0	0.6	0.4	0.6	0.4	0.3	0.3	0.7	0.3	1.2	1.2	1.0	1.0	1.6	1.8	0.7
Extraction of sprat	1.6	0.6	0.5	1.3	1.0	0.6	0.4	0.6	0.4	0.3	0.3	0.7	0.3	1.2	1.2	1.0	1.0	1.6	1.8	0.7
Inputs of hazardous substances	0.8	1.0	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.0	0.9	0.9	0.9	0.4	0.4	1.6	1.6	0.6	0.7	1.2
Introduction of non-indigenous species	0.6	1.1	1.2	0.4	1.0	1.0	1.0	0.9	1.4	0.9	0.9	0.7	1.0	0.6	0.6	0.5	0.5	0.9	0.8	0.3
Disturbance of species	0.9	0.3	0.6	0.6	0.8	0.4	0.3	0.4	0.4	0.4	0.3	0.2	0.3	0.4	0.4	1.6	1.4	0.8	0.9	1.4
Input of heat	0.7	1.3	1.5	0.6	1.0	0.9	1.1	0.9	1.0	1.0	1.0	0.6	0.7	0.6	0.6	0.2	0.2	0.3	0.8	0.6
Hunting of seabirds	0.7	0.7	0.3	0.2	0.5	0.7	0.7	0.5	0.2	0.7	0.7	0.3	0.7	0.2	0.2	2.0	2.0	0.5	0.0	1.8
Hunting of seals	0.7	0.7	0.3	0.2	0.5	0.7	0.7	0.5	0.2	0.7	0.7	0.3	0.7	0.2	0.2	2.0	2.0	0.5	0.0	1.8
Inputs of impulsive sound	0.9	0.2	0.3	1.0	0.6	0.3	0.3	0.3	0.1	0.3	0.3	0.6	0.3	1.1	1.1	1.5	1.5	1.0	0.7	0.8
Inputs of continuous sounds	0.2	0.2	0.3	0.6	0.6	0.3	0.3	0.3	0.2	0.3	0.3	0.5	0.2	0.6	0.6	1.5	1.5	0.6	0.3	0.7
Inputs of electromagnetic and seismic waves	0.5	0.6	0.5	0.5	0.4	0.6	0.6	0.8	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.4	0.6	0.0
Introduction of radionuclides	0.6	0.4	0.5	0.5	0.0	0.4	0.3	0.5	0.5	0.4	0.2	0.0	0.2	0.3	0.3	0.3	0.3	0.5	0.4	0.0

a The ecosystem component was represented by the layer "Availability of deep water habitat, based on occurrence of H2S", defining areas without H2S occurrence as available habitat for benthic fauna.

b Some original data sets were not included in order to avoid impacts from double counting, as similar aspects were also represented in other layers. These were: haulout areas for seals, and roach recruitment habitats. Abundance of pelagic spawning flounder and migration routes for birds were not included due to lack of sufficient spatial data.

Response rate and evaluation of the sensitivity scores

A total of 81 persons from 9 countries responded to the survey (Table 5). Between 1 and 35 replies were provided to the different combinations. The lowest response rate, only one response, was given to the ecosystem component representing submarine structures made by leaking gases. The mean number of replies per pressure and ecosystem component combination was 12.1 with respect to 'tolerance' (standard deviation= 6.1), 11.8 for 'recoverability' (standard deviation = 6.1) and 11.4 for the theme 'sensitivity' (standard deviation = 5.7)

There was some variability in the scores provided by different experts to the same pressure and ecosystem component combination. The standard deviation from the mean for responses to a certain combination was on average 0.55, for 'tolerance' (ranging between 0 and 1), and 0.62 for 'recoverability' as well as 'sensitivity' (ranging between 0 and 1.41).

Based on the self-evaluation, the experts estimated the lowest level of certainty in setting sensitivity scores (on average 1.2) to the pressure radionuclides (referred to as 'Input of radionuclides' in the survey). Other pressures for which the experts indicated low certainty (below 2 on average) were 'Changes in hydrological conditions, 'Inputs of other forms of energy', 'Input of hazardous substances', 'Input of litter', 'Introduction of non-indigenous species and translocations', 'Changes in climatic conditions', and 'Acidification'. The highest confidence in providing sensitivity score was indicated by the experts for 'Inputs of nutrients'[4].

Among the ecosystem components, the lowest confidence was assessed in relation to impacts on 'Baltic esker islands' (1.8) and the highest confidence to deep water habitats (defined by the pressure layer 'Availability of deep water habitat, based on occurrence of H2S' (2.5). In general, the variability in assessed confidence was lower among ecosystem components than among pressures. When looking at the sensitivity scores, the lowest confidence (1.0) was given to the pressure – ecosystem component combination 'Submarine structures made by leaking gas' in relation 'Input of radionuclides', 'Climate change' and 'Acidification'. The highest average confidence score (3.4) was given in relation to the combination 'Roach' and 'Input of nutrients'. The variability in the results from the self-assessment of confidence by the experts was rather small (ranging 0.27-0.71 for ecosystem components and 0.19-0.50 for pressures).

Combinations of pressures and ecosystem components with the lowest points and least confidence regarding the expert self-evaluation are listed in Table 6. The combinations with reduced confidence were checked against the obtained sensitivity scores. For combinations where the average sensitivity score was also low (0-1.0), the influence of these combinations on the assessment outcome is low. In one case, a moderate sensitivity score was observed in combination with reduced confidence (sensitivity of submarine structures to the oil spills).

Table 5. Number of replies per HELCOM Contracting Parties

Country	Number
Denmark	19
Estonia	0
Finland	11
Germany	17
Latvia	2
Lithuania	3
Poland	8
Russia	0
Sweden	21
Total	**81**

Literature review

Sensitivity scores for assessing impacts on benthic habitats and species were also based on a literature review provided by the BalticBOOST project. The literature review assessed the sensitivity of all kinds of benthic habitats to the pressures physical loss, physical disturbance and changes in hydrological conditions. The review suggested that the pressure physical loss is given the highest sensitivity score in all cases. The literature for evaluating sensitivity scores for the pressures physical disturbance and hydrological conditions are presented in Annex 2, which also lists literature to support the evaluation of sensitivity score for benthic habitats in relation to other pressures, as well as other literature referred to.

4 For information on which pressure layers where finally agreed on to represent these pressures, see Table 1.

Table 6. Combinations of pressures and ecosystem components where sensitivity scores in the expert survey had low confidence, according to three criteria: 1) few replies obtained in the survey (less than 8), 2) high variability in responses from different experts (standard deviation above 1.0), or 3) low confidence in the assessment based on the self-evaluation from the experts (mean value below 1.5). The combinations are organized by pressures in alphabetical order. The reason for the combination being listed is explained in the last column. SD = Standard deviation. For information on which pressure layers where finally agreed on to represent these pressures, see Table 1. Pressures and ecosystem components marked * were not included in the Baltic Sea Impact Index.

Pressure	Ecosystem component	Decisive confidence criterion
All	Submarine structures made by leaking gases	Few replies (on average 3.5)
Many	Baltic esker islands	Few replies (on average 3.4)
Many	Baltic boreal islets	Few replies (on average 3.2)
Acidification*	All	Few replies (on average 5.5)
	Bird migration routes*, Grey seal haul-outs, Harbour seal haul-outs, Grey seal abundance, Harbour seal abundance, Estuaries, Recruitment areas of pikeperch, Recruitment areas of roach	High variability (SD 1.0 to 1.4)
	Submarine structures made by leaking gases	Low certainty (on average 1.0)
	Ringed seal distribution	Low certainty (on average 1.4)
Changes in climatic conditions*	Baltic esker islands, Boreal Baltic islets, Submarine structures made by leaking gases	High variability (SD 1.2 to 1.4)
	Mudflats and sandflats, Estuaries	Low certainty (1.3 and 1.0, respectively)
	Grey seal haul-outs and Harbour seal haul-outs	Low certainty (on average 1.4 in both cases)
Changes in hydrological conditions	Submarine structures made by leaking gases	Low certainty (on average 1.3)
Extraction of / injury to mammals	*Furcellaria lumbricalis* and Charophytes	High variability (SD 1.2 in both cases
	Productive surface waters	High variability (SD 1.0)
	All habitats and all habitat-forming species	Few replies (on average 5.6)
Fishing mortality	Circalittoral hard bottom	High variability (SD 1.0)
	Productive surface waters	High variability (SD 1.0)
Input of continuous sound	Baltic esker islands	Low certainty (on average 1.4)
Input of hazardous substances	Submarine structures made by leaking gases	Low certainty (on average 1.3)
	Mudflats and sandflats, Estuaries	Low certainty (on average 1.4 in both cases)
Input of litter	Submarine structures made by leaking gases	Low certainty (on average 1.2)
	Baltic esker islands, Boreal Baltic islets	Low certainty (1.4 and 1.3, respectively)
	Breeding seabird colonies	Low certainty (on average 1.4)
Input of other forms of energy	Baltic esker islands	Low certainty (on average 1.4)
	All habitats and all habitat-forming species	Few replies (on average 6.5)
Inputs of radionuclides	Grey seal abundance and Harbour seal abundance	High variability (SD 1.0 in both cases)
	Many (34 of 40 ecosystem components)	Low certainty (from 1.0 to 1.4)
Introduction of non-indigenous species	Distribution of harbour porpoise, Harbour seal haul-outs, Grey seal haul-outs, Migration routes for birds, Breeding seabirds colonies, Wintering seabirds, and Submarine structures made by leaking gas	Low certainty (on average 1.2 to 1.4)
Mammal mortality	Productive surface waters	High variability (SD 1.0)
Oil spills	Submarine structures made by leaking gases	Low certainty (on average 1.3)

3.5. Confidence in the assessment

A quantitative evaluation of confidence in the BSII and BSPI assessments was not made, and the overall confidence in the assessment should be evaluated qualitatively, by examination of the underlying spatial data sets and sensitivity scores. One current limitation to providing a quantitative assessment is that many data sets only include information on which activities, pressures or ecosystem components are present, while absence of information may be due to either a true absence of the concerned element, or to missing data. In particular, the assessment of potential loss and disturbance can be underestimated in some sub-basins due to lack of data of human activities connected to this pressures. For examining this aspect, the spatial data sets on human activities underlying the assessment should be evaluated qualitatively. An overview of the shares of the defined assessment data sets (see tables 1 and 3) that are ultimately included in different parts of the Baltic Sea region is provided in connection to the result maps (Figures 2, 3 and 6 in Chapter 4).

The relative influence of the sensitivity scores on the results can be inflated if the assessment is based on only a limited number of spatial data sets (Korpinen *et al.* 2012). However, in the present assessment, the overall spatial data availability were sufficiently high in this respect.

The assessment is based on additive effects. However, in reality impacts may also be synergistic (or antagonistic), so that the overall effect of many pressures can be larger (or smaller) than the sum due to interactions in the food web and ecosystem feedbacks. The current version of the BSII does not take such more complex linkages into account.

The BSII is designed to evaluate spatial aspects, identifying areas where human induced pressures are likely to have relatively high or low cumulative impact on the marine environment. Hence, results for particular areas are to be compared to each other only in relative terms, while the assessment does not give information on absolute impact levels.

In addition to these more general aspects of confidence relating to the approach, an assessment of the confidence in the current assessment results is provided in the connection to the results (Chapter 4).

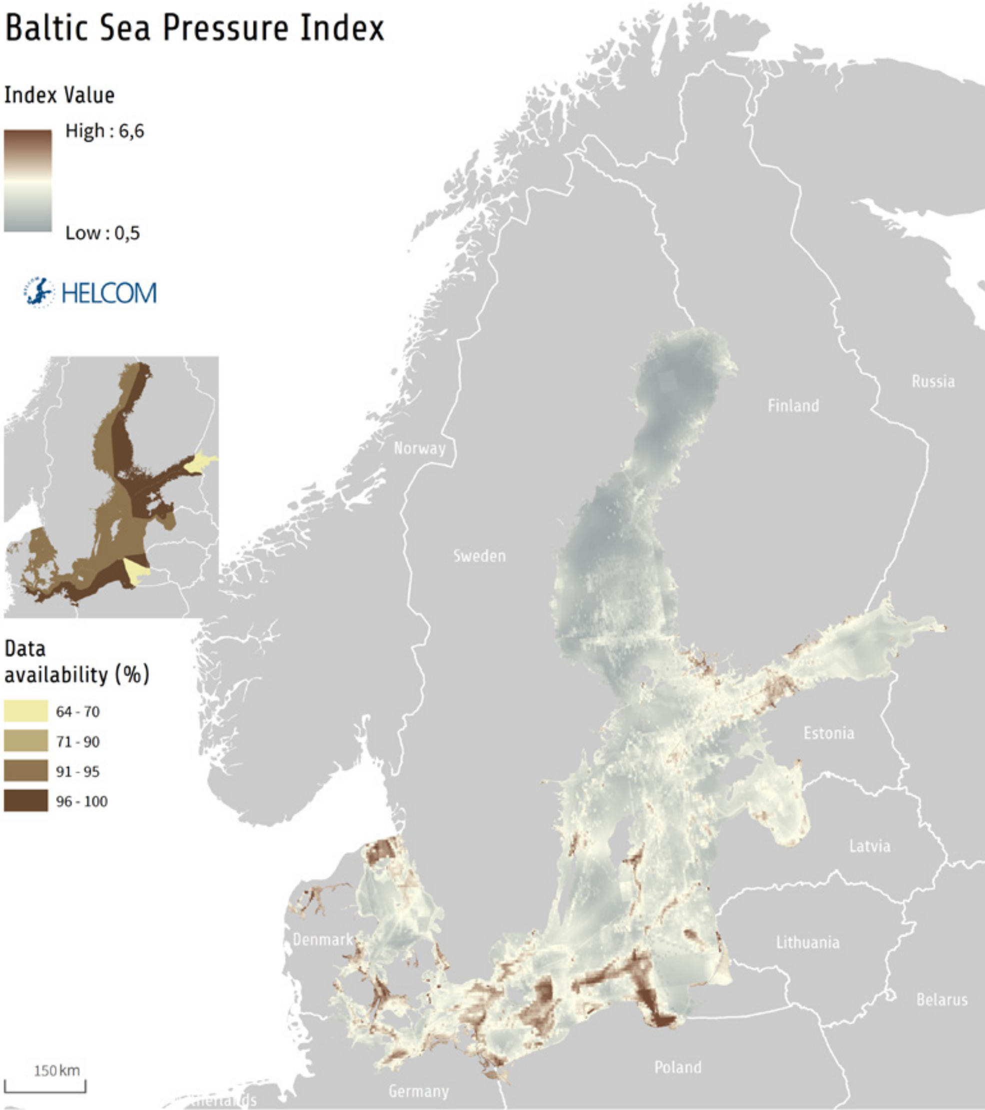

Figure 2. The Baltic Sea Pressure Index shows spatial variation in potential cumulative pressure on the Baltic Sea, by combining data on several pressures together. The index is based on currently best available regional data, but spatial gaps occur in some underlying datasets, as identified in the smaller map.

4.1. Cumulative pressures on the Baltic Sea marine area

Pressures from human activities occur everywhere in the Baltic Sea, but are mainly concentrated near the coast and close to urban areas (Figure 2). The most widely distributed pressures at regional scale are nutrients (including nitrogen and phosphorus), hazardous substances, non-indigenous species, and extraction of fish.

4.2. Cumulative impacts in the Baltic Sea marine area

The assessment of potential cumulative impacts indicates that there are great differences in the level of cumulative impacts between different areas of the Baltic Sea. The southwest Baltic Sea and many coastal areas experience higher potential cumulative impacts than the northern areas and many open sea areas (Figure 3). However in areas

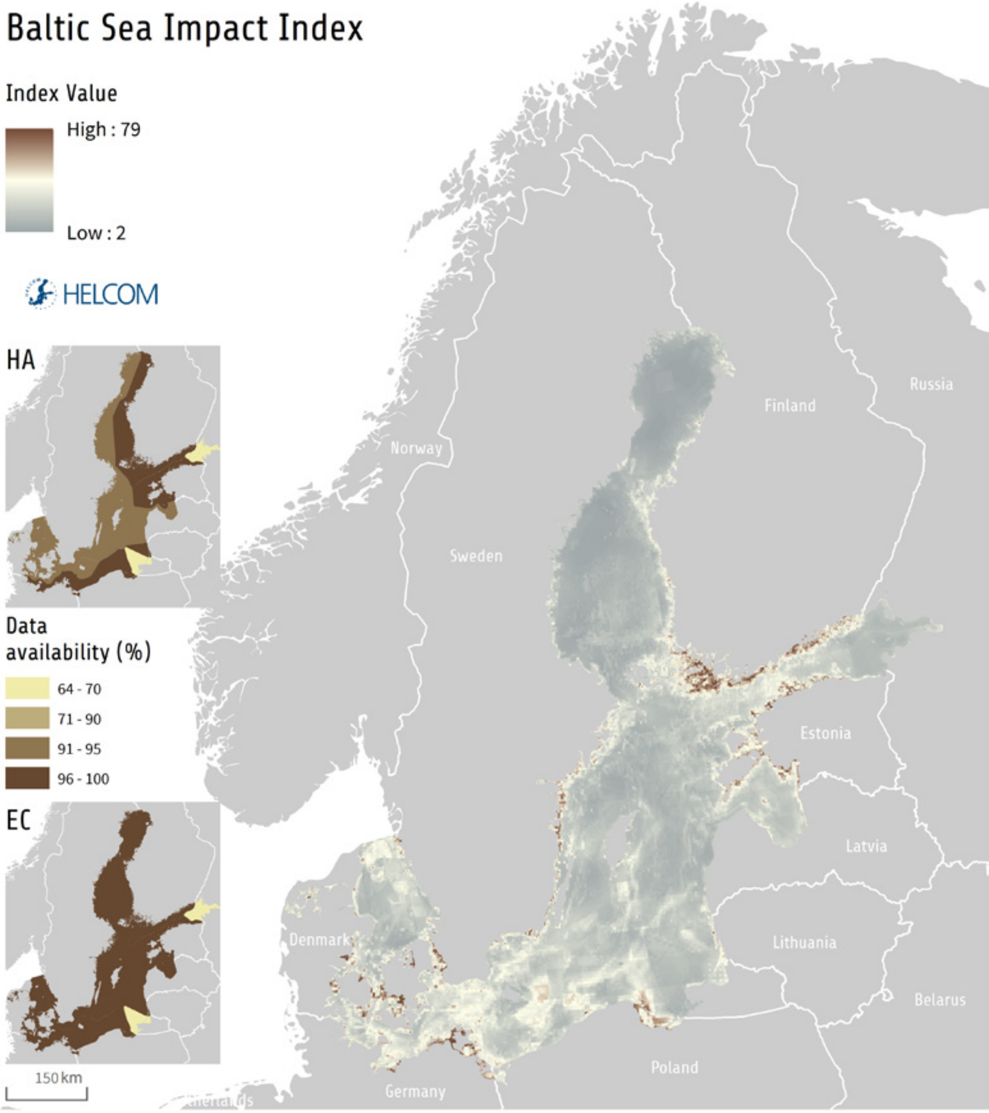

Figure 3. Distribution of cumulative impact from human activities on the Baltic Sea environment, based on the Baltic Sea Impact Index. The index addresses the total added impact from pressures on species and habitats, focusing on spatial variation to identify areas subjected to potentially higher and lower impact. The analysis is based on currently best available regional data, but spatial gaps occur in some underlying datasets, as identified in the smaller map (EC=Ecosystem components layers, HA=human activities and pressures data sets).

with poor data coverage the potential cumulative impacts may be underestimated.

Most of the identified impacts were attributed to nutrient concentrations and hazardous substances, followed by non-indigenous species, and the extraction of fish (Figure 4). Nutrient concentrations included phosphorus and nitrogen concentrations, and the theme representing the extraction of fish included cod, sprat and herring extraction. The results reflect that these are the pressures which are most widely distributed in the Baltic Sea, and to which many species and habitats are sensitive. Other pressures, such as oil slicks and spills, physical loss and physical disturbance, were associated with high sensitivity scores but had lower influence to the overall regional scale as they are not as widely distributed.

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 most widely impacted ecosystem components in the Baltic Sea were the deep water habitats and productive surface waters, the marine mammals (grey seal, harbour porpoise, ringed seal, and harbour seal), as well as cod (Figure 5). Relatively high impacts are seen in many coastal areas, which reflects that shallow habitats typical for these areas were assessed as sensitive to several pressures, and that more ecosystem components are represented in coastal areas than in the open sea.

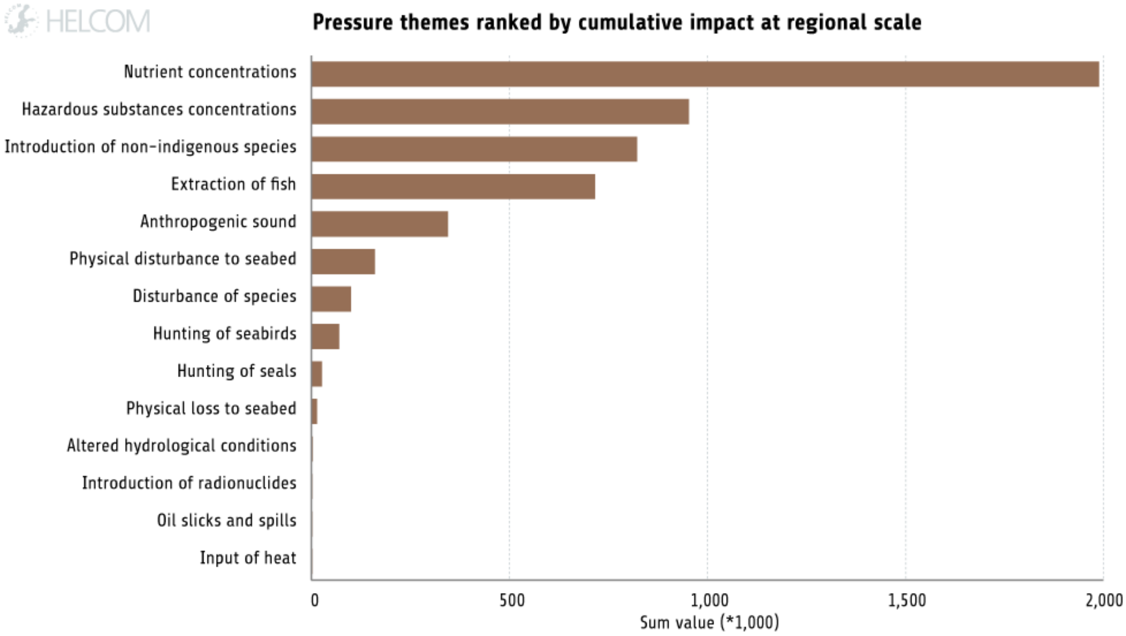

Figure 4. Ranking of pressures themes attributed to cumulative impacts at regional scale in the Baltic Sea Impact Index. The 'sum value' is calculated as the sum of impacts from each pressure on all studied ecosystem components at Baltic Sea scale. For further explanation to the pressures, see HELCOM (2018E).

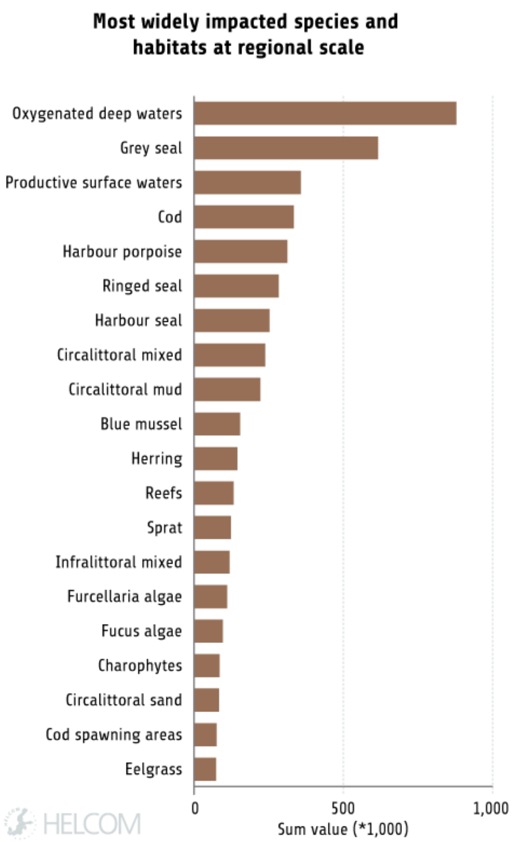

Figure 5. List of most widely impacted ecosystem components (species or habitats), according to the Baltic Sea Impact Index. Note that only results for the twenty most impacted ecosystem components are shown. The 'sum value' is calculated as the sum of impacts from all pressures on each ecosystem component.

4.3. Cumulative impacts on benthic habitats

A separate analysis was carried out for potential cumulative impacts on benthic habitats only, as these are particularly affected by physical pressures. In this case the evaluation was based on pressure layers representing physical loss and physical disturbance to the seabed, combined with information on the distribution of eight broad benthic habitat types and five habitat-forming species, which have been identified as relevant for the HELCOM area[5].

The evaluation suggests that benthic habitats are potentially impacted by loss and disturbance in all sub-basins of the Baltic Sea, but the highest estimates were found for coastal areas and in the southern Baltic Sea (Figure 6). The most impacted sub-basins were identified as the Sound, Bay of Mecklenburg, and the Kiel Bay (Figure 7). As the shallow waters usually host more diverse habitats, the impacts also accumulate more in coastal areas.

The top human activities causing cumulative impacts on benthic habitats, according to this assessment, are bottom trawling, shipping, recreational boating and sediment dispersal caused by various construction and dredging activities and deposit of dredged sediment.

5 Eight broad scale habitats (Circalittoral hard substrate, Circalittoral mixed substrate, Circalittoral mud, Circalittoral sand, Infralittoral hard substrate, Infralittoral mixed substrate, Infralittoral mud and Infralittoral sand) and 5 habitat forming species (*Furcellaria lumbricalis, Zostera marina, Mytilus edulis, Fucus* spp. and Charophytes).

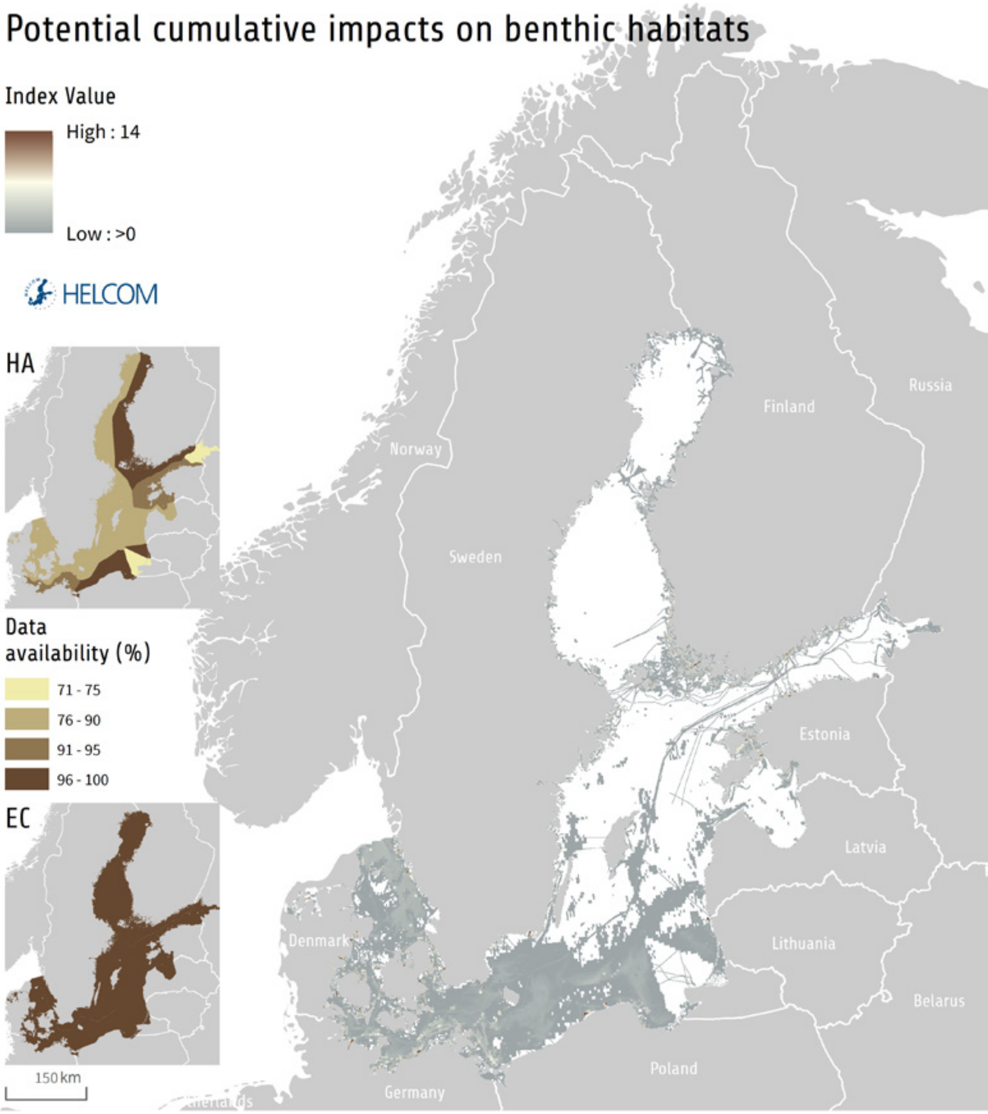

Figure 6. Map of potential cumulative impacts on benthic habitats in the Baltic Sea. The cumulative impacts are calculated based on the method of the Baltic Sea Impact Index as the 'sum of impact', specifically for the two pressures physical loss and physical disturbance. Benthic habitats were represented by eight broad scale habitat types and five habitat forming species (*Furcellaria lumbricalis*, *Zostera marina*, *Mytilus edulis*, *Fucus* spp. and *Charophytes*). White color on the map indicates areas where impact is assessed as zero, due to absence of pressures or ecosystem components, or both. The analysis is based on currently best available regional data, but spatial gaps occur in some underlying datasets, as identified in the smaller map (EC=Ecosystem components layers, HA=human activities and pressures data sets).

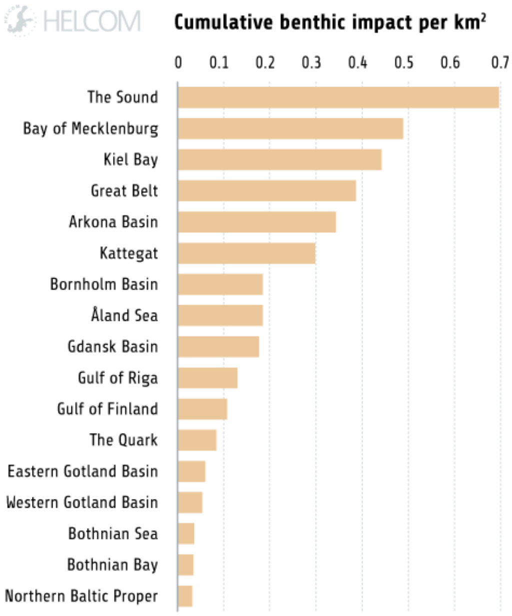

Figure 7. Cumulative impacts on benthic habitats in the Baltic Sea sub-basins. The values are calculated as the 'summed impact' from physical loss and physical disturbance on the studied benthic habitat types and habitat forming species, divided by the area of the sub-basin. The estimates are based on currently best available regional data, but spatial and temporal gaps may occur in underlying datasets.

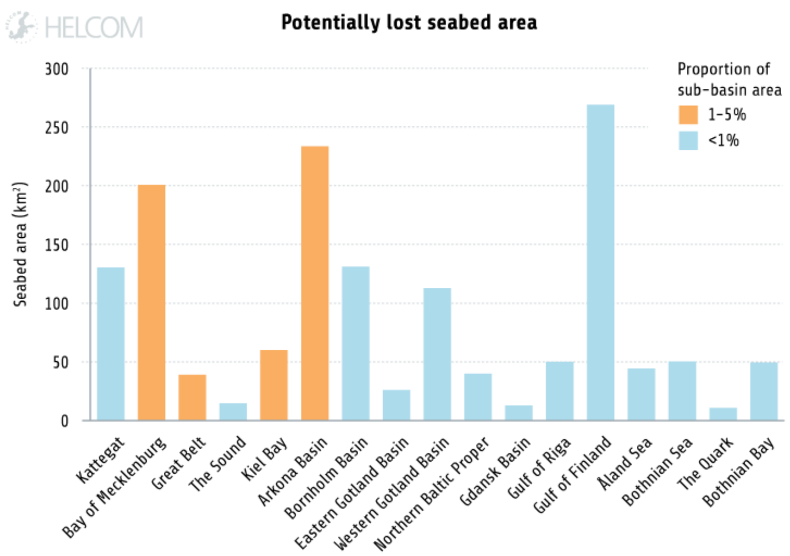

Figure 8. Estimate of seabed area (km²) potentially lost due to human activities per Baltic Sea sub-basin. The estimation is calculated from spatial data of human activities causing physical loss, as listed in the text (see Chapter 2.2).

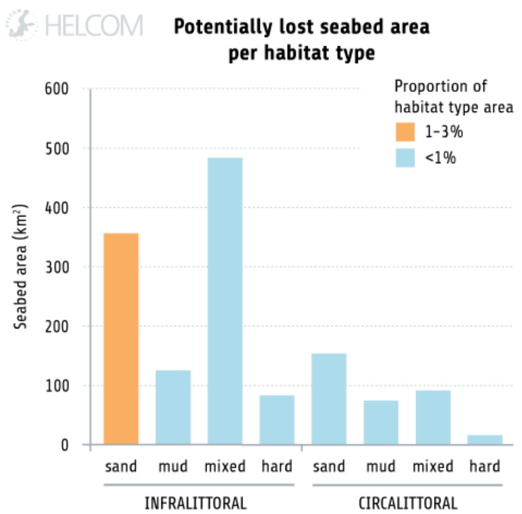

Figure 9. Estimate of area of broad benthic habitat types potentially lost due to human activities. 'Infralittoral' is the permanently submerged part of the seabed that is closest to the surface, typically with benthic habitats dominated by algae. 'Circalittoral' is the zone below the infralittoral, and is in the Baltic Sea typically dominated by benthic animals.

4.4. Physical loss and disturbance[6]

Estimation of physical loss

The level of long term physical loss of seabed in the Baltic Sea was estimated to be less than 1 % on the regional scale (up to the year 2016). The highest estimates of potential loss at the level of sub-basins were found in the more densely populated southern Baltic Sea and ranged between 1 and 5 % in the Sound, the great Belt, the Arkona Basin and the Bay of Mecklenburg. In the majority of the sub-basins, less than 1 % of the seabed area was estimated to be potentially lost (Figure 8).

The human activities mainly connected with seabed loss were sand extraction, dredging and deposit of dredged material, harbours and marinas, and to a lesser extent offshore installations and mariculture. In terms of broad benthic habitat types, the highest proportion of area potentially lost was 'infralittoral sand', but the highest total area potentially lost was estimated for 'infralittoral mixed' substrate' (Figure 9).

6 The identification of which activities lead to loss and/or physical disturbance is still under development and therefore the categorisations made up to now are preliminary.

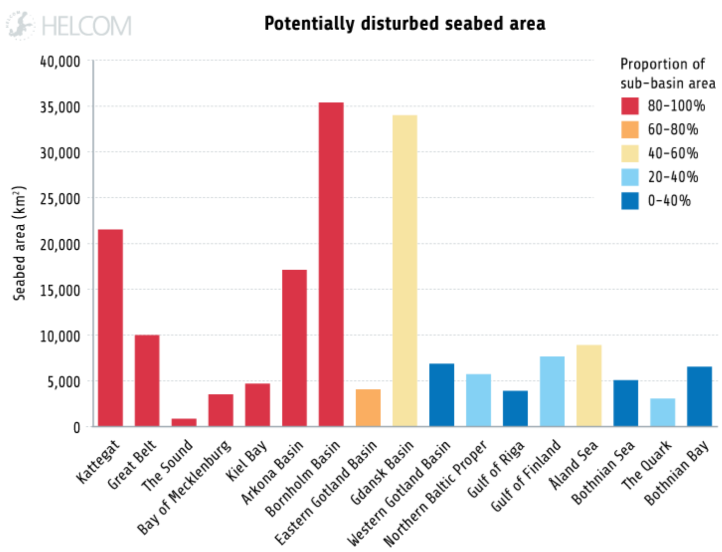

Figure 10. Estimate of seabed area (km²) potentially disturbed in the Baltic Sea sub-basins. The color of the bars indicate the proportion of potentially disturbed seabed area per sub-basin. The area is estimated based on spatial information of the distribution of human activities connected to physical disturbance, as explained further in the text. The estimate is based on any presence of human activity connected to the pressure, and does not consider the level or severity of the disturbance.

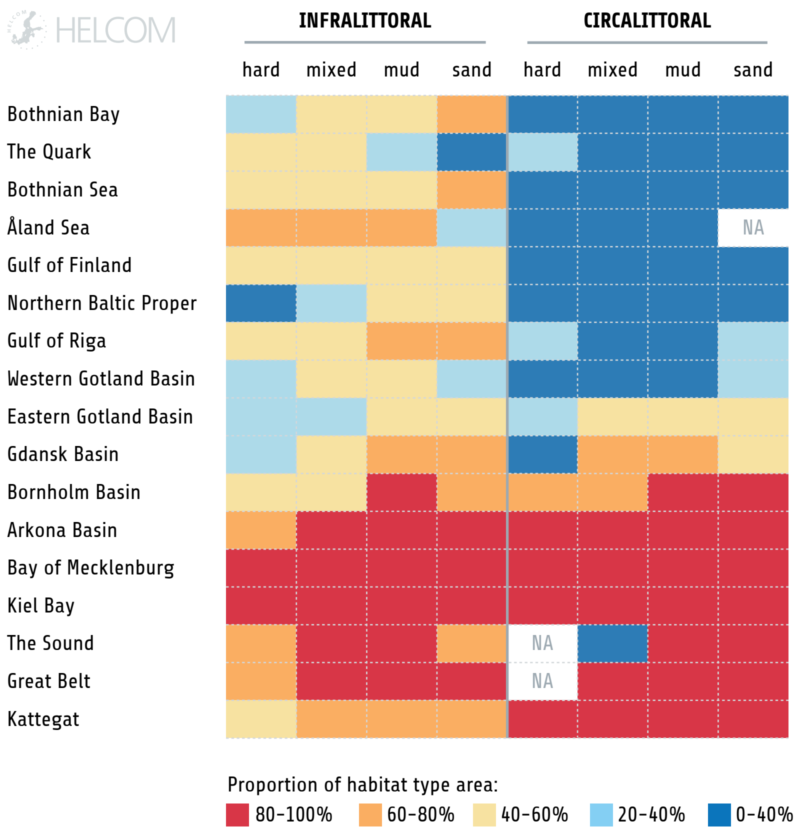

Figure 11. Estimate of the proportion (%, given in ranges) of the different broad benthic habitat types potentially disturbed due to human activities per sub-basin. The estimate is based on the total number of human activities linked to potentially causing this pressure, and does not reflect the actual level of impact. 'NA' denotes that the habitat type is not represented.

Estimated physical disturbance

Around 40 % of the Baltic seabed was estimated to have been potentially disturbed (180 000 km²) during 2011–2016. The spatial extent of potential physical disturbance to the seabed varied between 8 and 95 % per sub-basin (from around 900 to 35,500 km²; Figure 9). However, the estimation does not reflect whether these areas are associated with adverse effects to the benthic habitats, since the intensity of the disturbance is unknown. The intensity or severity of the disturbance is an important aspect which is intended to be covered in future indicator-based assessments.

The activities connected to the widest potential physical disturbance are bottom-trawling, which is common in the southern parts of the Baltic Sea, shipping, and recreational boating. At a local scale, physical disturbance may be caused by dredging and the deposit of dredged material. The largest areas of potentially disturbed seabed were estimated in the Bornholm Basin and the Eastern Gotland Basin, which are also both comparatively large sub-basins (Figures 9-10). The sub-basins with highest proportion of potentially disturbed seabed were found in the southern Baltic Sea, between the Kattegat and the Bornholm Basin (Figure 11).

Importantly, these estimates are based on best available data about the extent of the activities concerned. In some cases, due to limited data, areas licensed for an activity, such as dredging, deposit of dredged material and extraction of sand and gravel, were used in the calculations. This type of information does not necessarily reflect the extent of the exerted pressure, as the activity may be undertaken only in parts of the licensed area. These limitations in data add to the uncertainties of the estimate.

4.5. Confidence in the assessment

The assessments of cumulative pressures and impacts are both directly dependent on the quality of the underlying data layers. The aim has been to include spatial information on Baltic Sea scale, so that the results will be comparable. The results give an estimation of potential pressures and impacts, created with best available data. However, gaps and quality differences may occur in the underlying datasets. 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.

In the results, the completeness of data coverage for different geographical areas is shown on the side of each map. Partial data gaps may particularly be seen for pressure layers on impulsive sound and dredging, and for ecosystem component layers representing habitat-forming species. For these aspects, improved data collection and spatial data refinement would be needed.

In other cases, planned data sets could not be included at all, as it was not possible to achieve data sets with sufficient spatial coverage, namely regarding important habitats for flounder and migration routes for birds. Further, effects of climate change, which could be represented by data sets on changes in acidification, salinity or temperature, were not included for methodological reasons but will be important to include in the future.

Further method development is also needed regarding the data layer representing extraction of fish. The current data layers were based on fish landings, and do not account for whether catches correspond to the agreed reference points for fishing pressure, F_{MSY}. When catches are used directly, the assumption that large catches correspond to high pressure is implicitly made. However, 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. Therefore, catches alone do not provide information on the status of the exploitation relative to the agreed reference point.

The data was collected in order to be representative for the period 2011-2016. However, pressures from some human activities which were included are only present during a limited time period in each place, and may be over-emphasised in the results compared to pressures which are present continuously. This concerns for example pressures associated with construction work. Such activities were not associated with the pressures identified as most impacting at Baltic Sea scale in the current assessment, but may come up if similar assessments are made at smaller spatial scale. In future work, improved methods for representing aspects of temporal duration should be developed.

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. To provide a more comprehensive view, approaches to consider the potential distributions (under low historical and current pressure levels) could be tested, for example regarding cod, for which the current spawning areas are clearly more limited compared to historical records, and sea-grass (*Zostera marina*) which is dramatically reduced in some coastal areas compared to past distributions.

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.

Variation in the level of detail of individual data layers may reduce the confidence in the overall assessment and the possibility to compare geographic areas with each other in more detail. For example, data sets showing species distributions may be given at variable detail for different parts of the region. Furthermore, some activities are represented by licenced areas, such as dredging, disposal of dredged matter and extraction of sand and gravel, but do not necessarily reflect the extent of the exerted pressure, as the activity may be undertaken only in parts of the licensed area.

The applied sensitivity scores are based on an expert survey, and the evidence base for linkages between human activities, pressures and impacts is to be further addressed in the future.

The number of replies for some combinations of pressures and ecosystem components was particularly low in the expert survey. These were in some cases associated with relatively rare ecosystem components at Baltic Sea scale, giving the uncertainty low influence on the final results, or in other cases they represented distant combinations of ecosystem components and pressures (Table 6). However, a further improved documentation of the evidence-base in literature for the sensitivity scores is warranted.

When evaluating the assessment results, it should be remembered that the focus of the BSPI and BSII are to give a broad regional overview, whereas the level of accuracy in detailed results need to be evaluated on a case by case basis.

For more details, the underlying datasets and metadata can be viewed and downloaded from the HELCOM map and data service.

5. References

Andersen, J.H. & A. Stock (Eds) Heinänen, S., M. Mannerla, & M. Vinther (2013): Human uses, pressures and impacts in the eastern North Sea. Aarhus University, DCE – Danish Centre for Environment and Energy. Technical Report from DCE – Danish Centre for Environment and Energy 18. 134 pp.

Andersson, M.H. (2011): Offshore wind farms – ecological effects of noise and habitat alteration on fish. Doctoral Dissertation. Department of Zoology, University of Stockholm.

Andrulewicz, E. D. Napierska & Z. Otremba (2003): The environmental effects of the installation and functioning of the submarine SwePol Link HVDC transmission line: a case study of the Polish Marine Area of the Baltic Sea. Journal of Sea Research 49: 337– 345.

Barrio Frojan, C.R.S., S.E. Boyd, K.M. Cooper, J.D, Eggleton & S. Ware (2008): Long-term benthic responses to sustained disturbance by aggregate extraction in an area off the east coast of the United Kingdom. Estuarine, Coastal and Shelf Science 79: 204-212.

Bergström, L., L. Kautsky, T. Malm, R. Rosenberg, M. Wahlberg, N. Åstrand Capetillo & D. Wilhelmsson (2014): Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environmental Research Letters9:1–12.

Bonsdorff, E. (1980): Macrozoobenthic recolonization of a dredged brackish-water bay in SW Finland. Ophelia, Supplement 1: 145-155.

Bonsdorff, E., E. Leppäkoski & C.S Österman (1986): Patterns in post-impact successions of zoobenthos following physical and chemical disturbance in the northern Baltic Sea. Publications of the Water Research Institute, National Board of Waters, Finland: 68.

Boyd S.E., H.L. Rees & C.A. Richardson (2000): Nematodes as sensitive indicators of change at dredged material disposal sites. Estuarine, Coastal and Shelf Science 51(6):805-819.

Boyd, S.E., D.S. Limpenny, H.L. Rees, K.M. Cooper & S. Campbell (2003): Preliminary observations of the effects of dredging intensity on the re-colonisation of dredged sediments off the southeast coast of England (Area 222). Estuarine, Coastal and Shelf Science 57 (1-2): 209–223.

Dalfsen van, J.A. & K. Essink (2001): Benthic community response to sand dredging and shoreface nourishment in Dutch coastal waters. Senckenbergiana maritima 31: 329-332.

Dayton, P.K., S.F. Thrush, M.T. Agardy & R.J. Hofman (1995): Environmental effects of marine fishing. Aquatic Conservation 5: 205-232.

Degerman, E. & R. Rosenberg (1981): *Miljöeffekter av småbåtshamnar och småbåtar* (in Swedish). SNV, PM 1399. 122 pp.

Eastwood, P. D., Mills, C. M., Aldridge, J. N., Houghton, C. A., and Rogers, S. I. (2007): Human activities in UK offshore waters: an assessment of direct, physical pressure on the seabed. – ICES Journal of Marine Science 64: 453–463.

EC (2017a): Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU

EC (2017b): Commission Directive (EU) 2017/845 of 17 May 2017 amending Directive 2008/56/EC of the European Parliament and of the Council as regards the indicative lists of elements to be taken into account for the preparation of marine strategies.

Erftemeijer, P.L.A. & R.R.L. Lewis III (2006): Environmental impacts of dredging on seagrasses: A review. Marine Pollution Bulletin 52:1553-1512.

Eriksson B.K., A. Sandström, M. Isaeus, H. Schreiber & P. Karås (2004): Effects of boating activities on aquatic vegetation in the Stockholm archipelago, Baltic Sea. Estuarine, Coastal and Shelf Science 61:339–349.

Eriksson B.K. & G. Johansson G (2005): Effects of sedimentation on macroalgae: species specific responses are related to reproductive traits. Oecologia 143:438–44.

Essink, K. (1999): Ecological effects of dumping of dredged sediments; options for management. Journal of Coastal Conservation 5: 69-80.

Gill, A.B. (2005): Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology 42:605–615.

Halpern, B., S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K. S. Casey, C. Ebert, H. E. Fox, R. Fujita, D. Heinemann, H. S. Lenihan, E. M. P. Madin, M. T. Perry, E. R. Selig, M. Spalding, R. Steneck & R. Watson (2008): A Global Map of Human Impact on Marine Ecosystems. Science 319:948-952.

Halpern, B., S, C. V. Kappel, K. A. Selkoe, F. Micheli, C. Ebert, C. Kontgis, C. M. Crain, R. G. Martone, and C. Shearer, S. J. Teck (2009): Mapping cumulative human impacts to California Current marine ecosystems. Conservation letters 2: 138–148.

HELCOM (2010a): Ecosystem Health of the Baltic Sea 2003-2007. HELCOM Initial Holistic Assessment. Baltic Sea Environment Proceedings 122.

HELCOM (2010b): Towards a tool for quantifying anthropogenic pressures and potential impacts on the Baltic Sea marine environment. Baltic Sea Environment Proceedings 125.

HELCOM (2012): Development of a set of core indicators: Interim report of the HELCOM CORESET project. PART B: Descriptions of the indicators. Balt. Sea Environ. Proc. No. 129 B

HELCOM (2017a): Outcome of the 3rd meeting of the Expert Network on dredging / depositing operations at sea. https://portal.helcom.fi/meetings/EN%20DREDS%203-2017-485/MeetingDocuments/Outcome%20of%20the%203rd%20meeting%20of%20the%20Expert%20Network%20on%20dredging.pdf

HELCOM (2017b): Development of HELCOM tools and approaches for the Second Holistic Assessment of the Ecosystem Health of the Baltic Sea. TAPAS final summary report.

HELCOM (2018a): State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Available at: http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials

HELCOM (2018b): HELCOM maps and data service. Available at: http://maps.helcom.fi/

HELCOM (2018c): HELCOM metadata catalogue. Available at: http://metadata.helcom.fi/

HELCOM (2018d). Proposal for a continuous anthropogenic sound layer. Document 4-13 to HOLAS II 9-2018. Available at: https://portal.helcom.fi/meetings/HOLAS%20II%209-2018-524/MeetingDocuments/4-13%20Proposal%20for%20a%20continuous%20anthropogenic%20sound%20layer.pdf

HELCOM (2018e): HELCOM thematic assessment of hazardous substances 2011-2016. Available at: http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials

Ilus, E., J. Ojala & K.-L Sjöblom (1986): Effect of discharges from the Olkiluoto nuclear power station on the receiving waters. Publications of the Water Research Institute, National Board of Waters, Finland: 68.

Jones, J.B. (1992): Environmental impact of trawling on the seabed: a review. New Zealand Journal of Marine and Freshwater Research 26: 59-67.

Kaiser, M.J.,K.R. Clarke, H. Hinz, M.C.V. Austen, P.J. Somerfield & I. Karakassis (2006): Global analysis of response and recovery of benthic biota to fishing. Marine Ecology Progress Series 311: 1-14.

Karppinen, P., A. Haikonen & S. Vatanen (2011): *Helsingin Energian Salmisaaren voimalaitosten jäähdytysvesien leviämiskartoitus* (in Finnish). Kala- ja vesimonisteita: 66

Karppinen, P. & S. Vatanen (2013): *Helsingin Energian Hanasaaren voimalaitoksen ja Katri Valan lämpö- ja jäähdytyslaitoksen jäähdytysvesien leviämiskartoitus* (in Finnish). Kala- ja vesimonisteita: 95

Knights, A., R.S. Koss, & L. Robinson (2013): Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management. Ecological Applications 23: 755-765.

Kogan, I., C.K. Paull, L.A. Kuhnz, E.J. Burton, S. von Thun, H.G. Greene & J.P Barry (2006): ATOC/Pioneer Seamount cable after 8 years on the seafloor: Observations, environmental impact. Continental Shelf Research 26: 771–787

Korpinen, S., L. Meski, J.H. Andersen, J.H. & M. Laamanen (2012): Human pressures and their potential impact on the Baltic Sea ecosystem. Ecological Indicators 15:105-114.

Korpinen, S., U.L. Zweifel, F. Bastardie, D. van Denderen, K. Hopp, P. Jonsson, P. Kauppila, M. Milardi , R. Nielsen, H. Nilsson, K. Norén, H. Nygård, M. Sköld, S. Valanko & M. Zettler (2017): Estimating physical disturbance on seabed. WP 3.1 Deliverable 1 of the BalticBOOST project.

Kraufvelin P, B. Sinisalo, E. Leppäkoski, J. Mattila & E. Bonsdorff (2001): Changes in zoobenthic community structure after pollution abatement from fish farms in the Archipelago Sea (N Baltic Sea). Marine Environmental Research 51: 229-24.

Köster, F.W., B. Huwer, H.H. Hinrichsen, V. Neumann, A. Makarchouk, M. Eero, B.V. Dewitz, K. Hüssy, J. Tomkiewicz, P. Margonski, A. Temming, J.P. Hermann, D. Oesterwind, J. Dierking, P. Kotterba & M. Plikshs (2017): Eastern Baltic cod recruitment revisited—dynamics and impacting factors. ICES Journal of Marine Science 74:3-19.

Kotta, J., K. Herkul, I. Kotta, H. Orav-Kotta, & R. Aps (2009): Response of benthic invertebrate communities to the large-scale dredging of Muuga Port. Estonian Journal of Ecology 58: 286–296.

Kuhns, L.A. & M.B. Berg (1999): Benthic invertebrate community responses to round goby (Neogobius melanostomus) and zebra mussel (*Dreissena polymorpha*) invasion in southern Lake Michigan. Journal of Great Lakes Research 25: 910–917.

LaSalle, M.W. (1990): Physical and chemical alterations associated with dredging: an overview. In: Simenstad, C.A. (Ed). Effects of dredging on anadromous pacific coast fishes. Workshop Proceedings, Washington Sea Grant, Seattle, WA, USA. 1–12.

Lederer, A.M., J. Janssen, T. Reed & A. Wolf (2008): Impacts of the introduced round goby (*Apollonia melanostoma*) on dreissenids (*Dreissena polymorpha* and *Dreissena bugensis*) and on macroinvertebrate community between 2003 and 2006 in the littoral zone of Green Bay, Lake Michigan. Journal of Great Lakes Research 34: 690–697.

Leskinen, E., O. Kolehmainen. & I. Isotalo (1986): The response of periphytic organisms to the load of organic and inorganic nutrients from a fish farm. Publications of the Water Research Institute, National Board of Waters, Finland: 68.

Manso, F, R. Radzevicius, N. Blažauskas, A. Ballay & K. Schwarzer K (2010): Nearshore dredging in the Baltic Sea: Condition after cessation of activities and assessment of regeneration. Journal of Coastal Research 51: 187-194

Martin, D., F. Bertasi, M.A. Colangelo, M. de Vries, M. Frost, S. J. Hawkins, E. Macpherson, P.S. Moschella, M. P. Satta, R.C. Thompson & V.U. Ceccherell (2005): Ecological impact of coastal defence structures on sediment and mobile fauna: Evaluating and forecasting consequences of unavoidable modifications of native habitats. Coastal Engineering 52: 10-11.

Micheli, F., B. S. Halpern, S. Walbridge, S. Ciriaco, F. Ferretti, S. Fraschetti, R. Lewison, L. Nykjaer, & A.A. Rosenberg (2013): Cumulative Human Impacts on Mediterranean and Black Sea Marine Ecosystems: Assessing Current Pressures and Opportunities. PLoS ONE 8:e79889

Morton, B. (1996): The subsidiary impacts of dredging (and trawling) on a subtidal benthic Molluscan community in the Southern Waters of Hong Kong. Marine Pollution Bulletin 32: 701-10.

Munsterhjelm, R. (2005): Natural succession and human-induced changes in the soft-bottom macrovegetation of shallow brackish bays on the southern coast of Finland. Doctoral Thesis, University of Helsinki. Walter and Andrée de Nottbeck Foundation Scientific Reports: 26.

Muxika, I., A. Borja & W. Bonne (2005): The suitability of the marine biotic index (AMBI) to new impact sources along European coasts. Ecological indicators 5: 19-31.

Newell, R.C., L.J. Seiderer & D.R. Hitchcock (1998): The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the seabed. Oceanography and Marine Biology: an Annual Review, 36: 127–178.

Nichols, M., R.J. Diaz & L.C Schaffner (1990): Effects of hopper dredging and sediment dispersion, Chesapeake Bay. Environmental Geology and Water Science Journal 15. DOI: 10.1007/BF01704879

Olenin, S. (1992): Changes in a south-eastern Baltic soft-bottom community induced by dredged spoil dumping. In: Bjørrnestad, E., L. Hagerman & K. Jensen (Eds). Proc. 12th Baltic Marine Biologist Symposium. Olsen & Olsen. International Symposium Series, Fredensborg: 119-123.

Orviku, K., H. Tõnisson, R. Aps, J, Kotta, I, Kotta, G. Martin, Ü. Suursaar, R. Tamsalu & V. Zalesny (2008): Environmental impact of port construction: Port of Sillamäe case study (Gulf of Finland, Baltic Sea). In: 2008 IEEE/OES US/EU-Baltic International Symposium: US/EU-Baltic International Symposium 'Ocean observations, ecosystem-based management & forecasting'; Tallinn 27-29 May, 2008. IEEE-Inst Electrical Electronics Engineers Inc. 2008:350-359.

OSPAR (2008): Assessment of the environmental impact of offshore wind-farms. OSPAR Commission, Biodiversity Series 2008:385. ISBN 978-1-906840-07-5.

Pauly, D. V., J. Christensen, R. Dalsgaard, F. Froese & J Torres (1998): Fishing down marine food webs. Science 279:860–863.

Oulasvirta P. & J. Leinikki (2003): *Veneilyn ympäristövaikutukset luonnonsatamissa* (in Finnish). Suomen ympäristö 605. 91 pp.

Phua, C., S. van den Akker, M. Baretta M & J. van Dalfsen (2004): Ecological Effects of Sand Extraction in the North Sea. The North Sea Foundation, 22 pp.

Powilleit, M., G. Graf, J. Kleine, R. Riethmüller, K. Stockmann, M.A. Wetzel & J.H.E. Koop (2009): Experiments on the survival of six brackish macro-invertebrates from the Baltic Sea after dredged spoil coverage and its implications for the field. Journal of Marine Systems 75:441–451.

Roth, E.M., L.A. Verhoef & M.W.L. Dingenouts (2004): Overview of Environmental Impacts of Offshore Wind energy.

Rytkönen, J., T. Kohonen & J. Virtasalo (2001): *Laivaliikenteen aiheuttama eroosio Pohjois-Airistolla* (Erosion caused by ship traffic in the northern archipelago of Airisto – In Finnish). Vesitalous 30: 30-36.

Sandström, A., B.K. Eriksson, P. Karås, M. Isæus & H. Schreiber (2005): Boating and navigation activities influence the recruitment of fish in a Baltic Sea archipelago area. Ambio 34: 125-130.

Schwarzer, K., B. Bohling & C. Heinrich (2014): Submarine hard bottom substrates in the western Baltic Sea – human impact versus natural development. Journal of Coastal Research SI 70: 145 – 150.

Soomere T & J. Kask (2003): A specific impact of waves of fast ferries on sediment transport processes in Tallinn Bay. Proceedings of the Estonian Academy of Sciences: Biology and Ecology 52:319–331

Stock, A. (2016): Open Source Software for Mapping Human Impacts on Marine Ecosystems with an Additive Model. Journal of Open Research Software, 4: e21. DOI: http://dx.doi.org/10.5334/jors.88

Syväranta, J. & P. Vahteri (2013): *Turun sataman kalatalousvaikutusten tarkkailututkimukset 2012* (In Finnish(Alleco Oy raportti 2013:1.

Syväranta, J., J. Leinikki & J. Leppänen (2013): *Tauluksarin– Mustakuvun kasvillisuus- ja sedimenttitutkimukset 2012* (In Finnish). Alleco Oy raportti 2013: 3.

Syväranta, J. & J. Leinikki (2014): *Taulukarin läjitysalueeseen liittyvät silakan kutuselvitykset* (In Finnish). Alleco Oy raportti 2014:1.

Syväranta, J. & J. Leinikki (2015): *Taulukarin kasvillisuus- ja sedimenttitutkimukset 2014* (Investigations of the vegetation and sediments of Taulukari – in Finnish) Alleco Oy raportti 2015:1.

Terlizzi, A, S. Bevilacqua, D. Scuderi, D. Fiorentino, G. Guarnieri, A. Giangrande, M. Licciano, S. Felline & S. Fraschetti (2008): Effects of offshore platforms on soft-bottom macro-benthic assemblages: a case study in a Mediterranean gas field. Marine Pollution Bulletin 56: 1303-1309.

Torn, K., G. Martin, J. Kotta & M. Kupp (2010): Effects of different types of mechanical disturbances on a charophyte dominated macrophyte community. Estuarine, Coastal and Shelf Science 87:27–32.

Vahteri, P. & I. Vuorinen (2001) *Silakan lisääntyminen vaarassa Pohjois-Airistola* (In Finnish). Vesitalous 3: 37-38.

van der Wal, J.T. & J.E. Tamis (2014): Comparing methods to approach cumulative effects in the North-East Atlantic: CUMULEO case study. IMARES - Institute for Marine Resources & Ecosystem Studies C178/13.

Vatanen, S., A. Lindfors & M. Laamanen (2010): *Naantalin alueen vuoden 2009 vesistötöiden vesistö- ja kalatalousseurannan loppuraportti* (Final report from the survey of effects of underwater activities on water and fisheries in Naantali 2009– In Finnish). Kala- ja vesimonisteita 36.

Vatanen S, A. Haikonen & A. Piispanen (2012): *Vuosaaren sataman rakentamisen aikaisen (2003-2008) vesistö- ja kalataloustarkkailun yhteenvetoraportti* (In Finnish). Kala- ja vesimonisteita:57.

Vatanen S, A. Haikonen & J. Kervinen (2014): *Uudenkaupungin väylän ja sataman ruoppaus- ja läjityshankkeen vesistö- ja kalataloustarkkailu – Ennakkotarkkailu sekä rakentamisen aikainen tarkkailu vuonna 2013* (In Finnish). Kala- ja vesimonisteita 137.

Vatanen, S., A. Haikonen & J. Kervinen (2015): *Uudenkaupungin väylän ja sataman ruoppaus- ja läjityshankkeen vesistö- ja kalataloustarkkailu – Rakentamisen aikainen tarkkailu vuonna 2014* (Survey of the effects on water and fisheries of ongoing dredging and dumping activities in the Uusikaupinki waterway and harbour 2014 – In Finnish). Kala- ja vesimonisteita 170.

Wan Hussin, W.M.R., K.M. Cooper, C.R.S. Barrio Frojan, D.C. Defew & D.M. Paterson (2012): Impacts of physical disturbance on the recovery of a macrofaunal community: A comparative analysis using traditional and novel approaches. Ecological Indicators 12: 37-45.

Wilhelmsson, D., T. Malm, R. Thompson, J. Tchou, G. Sarantakos, N. McCormick, S. Luitjens, M. Gullström, J.K. Patterson Edwards, O. Amir, O. & A. Dubi (Eds.) (2010): Greening Blue Energy: Identifying and managing the biodiversity risks and opportunities of offshore renewable energy. Gland, Switzerland: IUCN. ISBN: 978-2-8317-1241. 102pp.

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

The table below gives more details on how the aggregated pressure layers included in the Baltic Sea Impact Index and the Baltic Sea Pressure Index were compiled. The table columns give: **A**: the identity of the aggregated pressure layer (APL); **B:** its temporal nature, indicating whether it represents a cumulative pressure (CUM; values over the assessment period are summed) or a temporary pressure (TEMP; average values over the assessment years are used); **C :** underlying spatial data sets included; **D**: the spatial extent applied; **E:** justification for spatial extent; **F:** data processing applied to arrive at common unit, and final metric; **G**: Whether down-weighting by seabed exposure and water depth was applied, and **H**: method for aggregating spatial data sets to one aggregated pressure layer. *With respect to physical loss and disturbance it should be noted that whether an activity in reality 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 identification of which activities lead to loss and/or physical disturbance is still under development.

A. Pressure layer	B. Nature	C. Underlying spatial datasets	D. Spatial extent[a]	E. Reference	F. Data and data processing	G. Depth / exposure weighting	H. Aggregation method
Physical loss (permanent effects on the seabed)*	Cum.	Land claim	Area of polygon or 50 m buffer for points, 30m buffer for lines	Estimated based on wind turbine erosion protection (van der Wal and Tamis 2014). No direct reference.	Area of polygon, buffered line or point data, equals lost area.	Not relevant	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	As above.	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Coastal defence and flood protection	50 m buffer for lines, area of polygon	as above	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Extraction of sand and gravel	Area of polygon	-	Area of polygon, buffered line or point data, equals lost area.	Exposure affects recovery, but this is not included	
		Dredging (capital)	Area of polygon or a 25/50 m buffer for <5000 m³ / >5000m³ sites	HELCOM 2017a	Area of polygon, buffered line or point data, equals lost area.	Exposure affects recovery, but this is not included	
		Oil platforms	25 m buffer	As above.	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Pipelines	15 m buffer	Between cables and wind farms	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Wind farms (operational)	30 m buffer around each turbine	van der Wal and Tamis 2014	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Cables	1.5 m buffer	Estimate based on side-scan sonar photos (BalticBOOST case study in Mecklenburg Bight)	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Harbors	Polygon with 200 m buffer	Orviku *et al.* 2008; and as for 'Maintenance dredging'	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Marinas and leisure harbour	Point with 200 m buffer	Eriksson *et al.* 2004, Sandström *et al.* 2005	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Bridges	2 m buffer	TAPAS project: based on erosion protection	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Oil terminals, refineries	Point with 200 m buffer	Based on harbour (Orviku *et al.* 2008)	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Finfish mariculture	150 m buffer	Leskinen *et al.* 1986	Area of polygon, buffered line or point data, equals lost area.	Not relevant	
		Shellfish mariculture	Area of polygon, 150 meter buffer for points	-	Area of polygon, buffered line or point data, equals lost area.	Not relevant	

A. Pressure layer	B. Nature	C. Underlying spatial datasets	D. Spatial extent[a]	E. Reference	F. Data and data processing	G. Depth / exposure weighting	H. Aggregation method
Physical disturbance or damage to seabed (temporary or reversible effects)*	Temp.	Shipping density	AIS data calculated directly to 1 km grid cells. No spatial impact outside grid cells.	See Table A.2.2	Average of total shipping density in a 1km x 1 km cell 2011-2014, log-transformed, normalized.	Weighted with depth: 0-10 m= 1 (100%) 10-15 m= 0,5 (50%) 15-20 m= 0,25 (25%) 20-25 m= 0,1 (10%) 25m <= 0 (0%)	Pressure values, including spatial extent and intensity are calculated per specific data sets. The final grid cell intensity is downweighted (by areal %) if the pressure area is smaller than the grid cell. Activities are weighted according to the method described in the document. All the pressure intensities of specific pressure layers are summed per grid cell.
		Recreational boating and sports	Total fuel consumption of recreational boats modelled directly to 1 km grid cells. No spatial impact outside grid cells.	See also Table A.2.2	Total fuel consumption of leisure boats modelled in SHEBA project. Fuel usage range in a 1km x 1 km cell in 2014, log-transformed, normalized.	Weighted with depth: 0-10 m= 1 (100%) 10-15 m= 0,5 (50%) 15-20 m= 0,25 (25%) 20-25 m= 0,1 (10%) 25m <= 0 (0%)	
		Extraction of sand and gravel	500 m buffer with sharp decline (type D decline). Intersected with 1 km^2 grid cells.	HELCOM 2017a	Average amount of extracted material over years, if value missing, 25% percentile of the existing information is given, log-transformed, normalized	Weighted by the exposure map	
		Dredging (maintenance)	500 m buffer with sharp decline (type D decline). Converted first to 100 m^2 and then to 1 km^2 grid cells.	HELCOM 2017a	Average amount of dredged material over years, if value missing 25% percentile of the existing information is given, log-transformed, normalized	Weighted by the exposure map	
		Deposit of dredged material	500 m buffer for points and polygons, sharp decline (type D decline).	HELCOM 2017a	Average amount of deposited material 2011-2014, if value missing 25% percentile of the existing information is given, log-transformed, normalized	Weighted by the exposure map	
		Wind farms (under construction)	1 km buffer with sharp decline after 0.5 km for wind farms under construction.	See Table A.2.1 for type and A.2.2 (re: "wind farms" and "dredging") for extent		Weighted by the exposure map	
		Wind farms (operational)	0.1 km buffer with sharp decline (type D decline).	See Table A.2.1 for type and A.2.2 for extent		Not relevant	
		Cables (under construction)	1 km buffer with sharp decline, after 0.5 km for cables under construction.	See Table A.2.1 for type and A.2.2 for extent	Presence of constructed cables, intensity scaled by their area in the grid cell	Weighted by the exposure map	
		Pipelines (operational)	0.3 km buffer with linear decline (Type B decline).	Based on the operational wind farms (see Table A.2.2)	Presence of operational pipelines, intensity scales by their area in the grid cell		
		Fishing intensity (subsurface swept area ratio average 2011-2016)	0.05 x 0.05 c-square degree grid (reporting unit for VMS data from ICES)	-	Average subsurface swept area ratio 2011-2016, converted to 1x1km raster grid	Not relevant	
		Coastal defence and flood protection (under construction)	500 m buffer with sharp decline (type D decline).	See Tables A.2.1-2 based on wind farms and cables.	Area of coastal defence and flood protection under construction.	Weighted by the exposure map	
		Finfish mariculture	1 km buffer linear decline (Type B decline).	-	Average P load 2011-2015, if values missing 25% percentile was given, log-transformed, normalized	Weighted by the exposure map	
		Shellfish mariculture	Area of polygon, 1 km buffer with linear decline (Type B decline) for points.	-	Average production in 2011-2015, if values missing, 25% percentile was given, log-transformed, normalized	Weighted by the exposure map	
		Furcellaria harvesting	No buffer considered	-	Calculated amount/area of harvested material, normalized	Not relevant	

A. Pressure layer	B. Nature	C. Underlying spatial datasets	D. Spatial extent[a]	E. Reference	F. Data and data processing	G. Depth / exposure weighting	H. Aggregation method
Changes to hydrological conditions (e.g. by constructions impeding water movements)	Cum.	Water course modification	1 km buffer	Extent based on wind farms and cables, but expanded to 1 km because hydrological parameters are widely spreading.	Location of water course modifications	Not relevant	Spatial extents and potential attenuation gradients are assigned to the specific pressure layers. They are merged (by affected area, km2) to avoid overlapping areas. Intersected with 1 km grid to calculate % of area affected within a cell.
		Wind farms (operational)	300 m buffer around each turbine with linear decline (Type B decline).		Location of operational turbines as points	Not relevant	
		Oil platforms	500 m buffer around each turbine with linear decline (Type B decline).	See Table A.2.1.	Location of oil platforms as points	Not relevant	
		Hydropower dams	a grid cell in the estuary (no extent added)	-	locations of hydropower dams - those that are operational and produces energy	Not relevant	
Inputs of continuous anthropogenic sounds (into water)	Temp.	Ambient underwater sound	BIAS project ambient underwater sound 2014, data modelled into 0.5 km x 0.5 km grid.	HELCOM 2018d	Ambient underwater sound pressure level at 1/3 octave bands 125 Hz exceeding sound levels 5% of the time in the full water column, normalized.	Not relevant	Data normalized by setting 92 and 127 db re1uPa as pressure thresholds for 0 and 1 respectively
Inputs of impulsive anthropogenic sound (into water)	Temp.	Impulsive sound events 2011-2016	Data converted directly to 1km grid cells	-	Data from HELCOM-OSPAR Database for impulsive sound and national data call (polygons, points, lines) with sound values categorized from very low, low, medium, high and very high. Sum of all events calculated per 1x1 km grid cell. Normalized.	Not relevant	Sum of events based on sound value codes.
Input of heat (e.g. by outfalls from power stations) into water	Temp.	Discharge of warm water from nuclear power plants	1 km buffer with steep decrease around outlet (Type D decline).	See Table A.2.1 for type. Extent based on Ilus *et al.* 1986,	Average input of warm water (Celsius) from the nuclear power plant outlets	Not relevant	Sum of the input of warm water.
		Fossil fuel energy production (only location available)	1 km buffer with steep decrease around outlet (Type D decline).	See Table A.2.1 for type. Extent based on Karppinen *et al.* 2011, Karppinen and Vatanen 2013	Heat load 1 (TWh) was given to all production sites, based on the average heat load of an individual production site in Helsinki in recent years.	Not relevant	
Input of hazardous substances		CHASE Assessment tool concentration component: mean contamination ratio per assessment station.	Interpolated map from the CHASE station data.	-	Mean contamination ratio of the CHASE assessment tool concentration component. Values classified according to classification presented in the thematic assessment for hazardous substances (HELCOM 2018e). Classified values interpolated, generalized and normalized.	Not relevant	Not relevant
Radionuclides	Temp.	10 km buffer with linear decline from discharges of radioactive substances (Type B decline).	Gradual buffer around outlet to 10 km distance (Type B decline).	Based on Ilus *et al.* 1986	Annual averages of CO60, CS137 and SR90 from the period 2011-2015 per nuclear power plant. Aggregation agreed intersessionally between HELCOM Mors Expert group and the Secretariat.	Not relevant	Not relevant

A. Pressure layer	B. Nature	C. Underlying spatial datasets	D. Spatial extent[a]	E. Reference	F. Data and data processing	G. Depth / exposure weighting	H. Aggregation method
Oil slicks and spills	Temp.	Oil slicks and spills from ships and oil platforms	Buffer area depending on reported spill area	See next column.	If oil spill volume was missing (67/560), median of the rest was given. If area of spill was missing (103/560), mean of the existing was given. If the spill was < $1 km^2$, the value of spill volume was given directly to $1 km^2$ grid cell. If the spill area > $1 km^2$, 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.	Not relevant	Sum of layers
		Polluting ship accidents	Point, converted directly to 1 x 1 km grid	See next column.	9/24 accidents with oil spills were missing spilled oil volume, thus a mean of reported volumes was given to accidents with missing oil volume. Spill volume in m^3 was converted to grid	Not relevant	
Relative distribution of nutrient concentrations (phosphorus and nitrogen)		Interpolated nitrogen and phosphorus concentrations in separate layers	Values are aggregated to 5x5km grid and annual seasonal averages calculated.	-	Total nitrogen and total phosphorus concentrations (annual seasonal averages) from 0-10m surface layer for 2011-2016. Lowest and highest 5 percentile of values grouped together to avoid overestimation of extreme values. Generalized, log-transformed and normalized.	Not relevant	Not relevant (separate data layers)
Disturbance of species due to human presence	Temp.	Recreational boating and sports	Total fuel consumption of recreational boats modelled directly to 1 km grid cells.	-	Total fuel consumption of recreational boats presented as presence / absence. Rescaled with depth, log-transformed and normalized.	Rescaled with depth: 0-10m= 100% 10-15 m= 70% 15-20 m= 50% 20-30 m= 20% 30-40 m = 10% 45m < =0%	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.
		Bathing sites, beaches	Point data converted directly to 1 km grid cells	Estimate by TAPAS project of the human disturbance (underwater sound, water sports, visual disturbance)	Location of beaches presented as presence / absence	Not relevant	
		Urban land use	Urban land use data was first converted to 1 km grid cells and expanded with 1 km.	Estimate of the human disturbance (underwater sound, visual disturbance)	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.	Not relevant	
Extraction of, or mortality/injury to fish, (separate layers for Cod, Herring and Sprat)	Temp.	Extraction of fish species by recreational fishery.	Reported per country for eel, cod and salmon (tons).	-	Extraction of fish species by recreational fishing, average of 2011-2016. For cod, recreational landings (tons/km^2) were added to commercial catches.	Not relevant	Tons/km^2 calculated for each species. For cod, recreational fisheries catches were added. Log-transformed and normalized.
		Extraction of target fish species (cod, herring, sprat) in commercial fishery	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) 2011-2013. 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.	Not relevant	

A. Pressure layer	B. Nature	C. Underlying spatial datasets	D. Spatial extent[a]	E. Reference	F. Data and data processing	G. Depth / exposure weighting	H. Aggregation method
Extraction of, or mortality/injury to seabirds (e.g. hunting, predator control)	Temp.	Game hunting of seabirds	Varying reporting units, from counties to HELCOM subdivisions, seaward boundary 3nm from coastline including islands and skerries.	-	Species summed together, average of killed seabirds of years 2011-2015 per reporting unit, numbers of killed birds / km^2 calculated and generalized for the whole reporting unit, normalized	Not relevant	Normalized values summed together
		Predator control of seabirds	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 2011-2015, numbers of killed birds / km^2 calculated and generalized for the whole reporting unit, normalized	Not relevant	
Extraction of, or mortality/injury to mammals		Hunting of seals	Varying reporting units, from counties to HELCOM subdivisions	-	Total number of killed seals (per species) averaged for 2011-2014, numbers of killed seals/ km^2 calculated, and generalized for the whole reporting unit, normalized so that normalized value 0.5 was set to the level of quota for hunting of seal species in the Baltic Sea.	Not relevant	Not relevant (as the species are presented separately in the ecosystem components)
Introduction of non-indigenous species and translocations	Temp.	Spread of non-indigenous species	Reported per coastal areas	-	Number of NIS per HELCOM sub-basins and coastal areas, generalized for the whole reporting unit.	Not relevant	Not relevant

a Applied provisionally for the pruposes of this assessment.

Annex 2. Details on expert survey and literature review to set the sensitivity scores

The sensitivity scores were developed with the EU co-funded TAPAS project and were identified based on a detailed questionnaire to be responded to by Baltic Sea experts through the HELCOM contact points. The replies provide the basis for setting sensitivity scores for use in the Baltic Sea Impact Index as presented in Chapter 3 of this report, and partially supported the development of aggregated pressure layers as described in Chapter 2.

The replies from the expert survey were validated against a literature review conducted with the EU co-funded BalticBOOST project (Korpinen *et al*. 2017; Tables A.2.3-7).

Description of the expert survey

This expert survey was developed in Microsoft Excel together with a guidance document. In addition, the expert survey included guidance text in several steps and also comments for specific points[1].

The survey covered a matrix of 750 potential pressure- and ecosystem-specific combinations (see tables 1, 3 and 4 in this report). In order to estimate as robust pressure- and ecosystem component specific sensitivity scores as possible, the questionnaire addressed the following 6 themes: (1) tolerance/resistance, (2) recoverability, (3) sensitivity, (4) impact distance, (5) impact type and (6) confidence.

For tolerance/resistance, participants in the survey had the following 3 options: High, Medium and Low (lethal). To support the participants, the survey included an explanatory text: "*Tolerance (resistance): How tolerant or resistant is the ecosystem to the human pressure? For example, for a pressure that has devastating effects on the ecosystem component in question, you should set the tolerance to a low value. If you think that a specific human pressure has a relatively minor effect on this ecosystem component, you should set the tolerance to high. Factors to take into account when making your judgment are the typical intensity/level of the pressure when it occurs in the sea and typical biological effects (e.g. the number of trophic levels affected). You should not take into account if there actually is a spatial overlap between the pressure and the ecosystem component, since this will be included in other parts of the assessment.*"

For recoverability, the participants had the following 3 options: High, Medium and Low (> 10 years). To support the participants, the survey included an explanatory text: "*Recoverability: Reflects how long it takes for the ecosystem component to recover once the pressure ceases). The recoverability is estimated on a scale from immediate (high) to >10 years (low). Some human activities cause pressures which cease immediately after stopping the activity (such as underwater sounds from shipping), while some pressures may stay in the environment for a long time (such as contaminants and nutrients from pollution). However, independent of these differences, recovery times of the ecosystem components may differ. For instance, impacts on the species may last longer than the actual time the pressure exists in the sea.*"

For sensitivity, the participants had the following 3 options: High, Medium and Low. To support the participants, the survey included an explanatory text: "*Sensitivity: Although tolerance and recoverability affect sensitivity, other factors may also have an influence, and in some cases the different components of overall sensitivity may not be well known. Sensitivity was asked for as a complement to the above questions to ensure confidence in how the impact scores are calculated. In general, when rating tolerance, recoverability and sensitivity in the survey, you should imagine the human pressures as they typically occur in the study area. For instance, when replying for fish farms, imagine a typical fish farm, neither extremely big nor small. For commercial shipping, you should think of a busy, but not extraordinarily busy, shipping route. Also, assume that the stressor and the ecosystem occur together in the same place. As an example, if you know that an ecosystem component does not naturally occur close to any existing shipping routes, this does not mean that you should give it low vulnerability values. Instead, rate its vulnerability for the (hypothetical) case that the stressor and the ecosystem do occur in the same place, and the stressor is occurring at a typical intensity and frequency.*"

1 Permanent storage address to be added. Currently at: http://www.helcom.fi/Documents/TAPAS_survey.xlsm.

For impact distance, the participants were asked to answer the following question: "How far from the pressure/activity source will potential impacts on the ecosystem diminish to a negligible level, given its vulnerability?" The possible answers to this question were: (1) Local, (2) 1 km, (3) 5 km, (4) 10 km, (5) 20 km and (6) > 50 km.

For impact type, the participant were asked to identify which of the following 'impact distance types' (i.e. form of decay with increasing distance from the pressure source) in Figure A.2.1 could be assumed to be relevant for the pressure in question.

For confidence, participants were asked to self-evaluate the confidence of their judgment, reflecting the information on which their answers are based. For example: (1) a low confidence should be assigned if limited or no empirical documentation (e.g. judgement is based on inference from other, similar ecosystem components/pressure types or from knowledge on the physiology and ecology of the species etc.). (2) A moderate confidence should be assigned if documentation is available, but results of different studies may be contradictory (e.g. including also grey literature with limited scope), and (3) a high confidence should only be given if documentation is available and with relatively high agreement among studies.

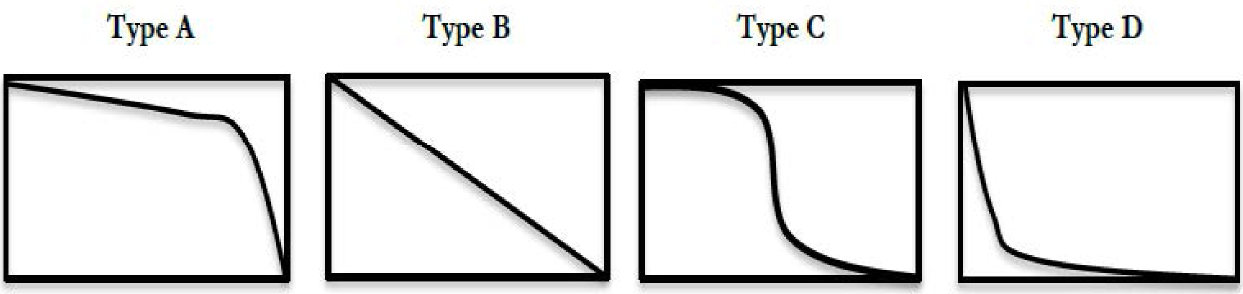

Figure A.2.1. Impact types A, B, C and D. Type A describes a pressure that has a similar impact at most of its distribution range and then rapidly drops, type B describes a pressure that declines monotonously in strength from the source, type C describes a pressure having a somewhat limited decline within a given distance followed by a sharp decline, while type D describes a pressures which mostly has an strong impact in its vicinity.

Sensitivity scores from the expert survey

A summary of the results is shown presented in Table 4 of the main report.

Results for 'Tolerance'

With regard to the theme 1 (tolerance), there was a large variation in the number of replies per combination of pressure and ecosystem component. Between 1 and 35 replies were provided to the different combinations (mean number of replies = 12.1, standard deviation= 6.1). Only one response was given to the ecosystem component 'Submarine structures made by leaking gases' (also with respect to themes 2 and 3 below). There was also some variability in the obtained responses, that is, the scores provided by different experts. The standard deviation around the mean for responses to a certain combination of pressure and ecosystem component was on average 0.55, ranging between 0 and 1. Replies with high variability (a standard deviation above 1.0) can be regarded as less reliable compared to those with lower standard deviation.

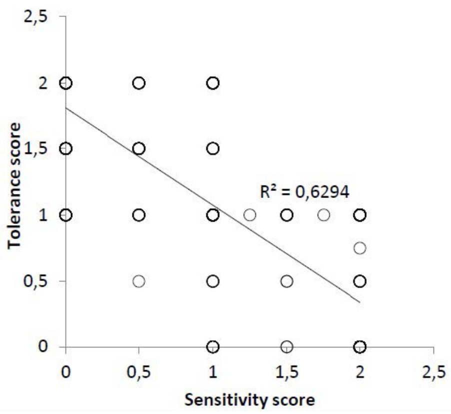

Figure A.2.2. Correlation between the mean scores for 'tolerance' and 'sensitivity' among all responses for combinations of pressures and ecosystem component. The obtained correlation value R^2 was 0.63, which is higher than for the correlations between scores for 'sensitivity' and 'recoverability' (R^2=0.20).

Results for 'Recoverability'

For theme 2 (recoverability), there was also large variation in the number of replies for each combination of pressure and ecosystem component (between 1 and 35 replies, mean number of replies = 11.8, standard deviation = 6.1). The variability in scores among obtained responses was higher than for tolerance. The standard deviation around the mean for responses to a certain combination of pressure and ecosystem component was on average 0.62, ranging between 0 and 1.41.

Results for 'Sensitivity'

For theme 3 (sensitivity) the number of replies for each combination of pressure and ecosystem component ranged between 1 and 35, with a mean value of 11.4 responses per combination (standard deviation = 5.7). The variability in scores among responses, as measured by the standard devaluation from the mean, was on average 0.62, ranging between 0 and 1.41.

Correlation among results

The correlation between the sensitivity scores and the other two themes (tolerance, recoverability) was evaluated as part of the quality assurance. The highest correlation was observed between 'sensitivity' and 'tolerance' (Figure A.2.2). According to the definition of the factor 'sensitivity' in the expert survey, it should include the aspects of both of the other two factors.

Survey results regarding impact types and distances

Table A.2.1 shows the impact distances and impact types per pressure based on the results from the expert survey. The minimum, maximum and mean distances were first calculated based on all obtained responses at the level of each ecosystem component, and the table shows the corresponding values subsequently calculated across all ecosystem components. The standard deviation shows variability in the mean value among the ecosystem components.

Table A.2.2. shows the spatial extent of physical disturbance from different human activities based on literature. The extents were estimated as the distance from the activity at which the pressure intensity can be considered negligible to complement to the expert survey for processing the pressure data layers.

Table A.2.1. Impact distances and impact types per pressure, based on the results from the expert survey. The column 'impact type' shows what impact type was indicated in most cases among the respondents. The value is the average % of the replies indicating that pressure type across all ecosystem components (higher values indicate that the type was identified more frequently as the predominating type, as depicted in Figure A.1.1). For pressures marked *, the aggregated pressure layers were developed based on literature information instead. Pressures marked ** were not used in the final assessment.

Pressure	Min (km)	Max (km)	Mean (km)	Standard deviation (km)	Impact type
1. Physical loss*	0.1	9.4	2.4	2.6	D (58%)
2. Physical disturbance*	0.8	10.6	2.5	2.3	D (34%)
3. Changes to hydrological conditions*	0.5	26.8	7.2	6.3	A (39%)
4. Inputs of continuous anthropogenic sound	5.0	26.4	15.6	5.2	B (31%)
5. Inputs of impulsive anthropogenic sound	2.5	25.7	11.8	5.2	N.A.
6. Inputs of other form of energy (electromagnetic and seismic waves)	0.1	10.2	4.9	3.6	A (48%)
7. Input of heat	0.1	6.5	3.0	1.9	D (33%)
8. Inputs of hazardous substances	0.5	32.9	20.2	7.5	D (39%)
9. Inputs of nutrients	13.7	43.0	25.7	7.4	B (53%)
10. Introduction of radionuclides	10.0	46.4	34.6	6.6	D (40%)
11. Oil slicks and spills	7.1	33.2	16.5	6.1	D (38%)
12. Inputs of litter	6.2	34.1	15.7	6.8	D (60%)
13. Inputs of organic matter	9.3	36.9	20.5	7.4	B (52%)
14. Disturbance of species due to human presence	0.0	14.0	1.9	2.7	C (32%)
15. Extraction of, or mortality/injury to fish	2.0	38.6	11.6	9.2	C (30%)
16. Extraction of, or mortality/injury to mammals and seabirds (e.g. hunting, predator control)	1.0	42.5	19.7	10.5	B (42%)
17. Introduction of non-indigenous species and translocations	14.0	41.0	27.8	6.8	B (47%)
18. Changes in climatic conditions**	22.0	50.0	46.9	7.1	A (28%)
19. Acidification**	32.0	50.0	46.1	5.3	A (40%)

Table A.2.2. Spatial extent of physical disturbance from different human activities. The extents were estimated as the distance from the activity at which the pressure intensity can be considered negligible. Note that the estimates are also affects by hydrographic conditions, and that the estimates given here are usually applicable to exposed or semi-exposed areas. The information is based on results from the BalticBOOST project, and was used as a complement to the expert survey for processing the pressure data layers (Annex 1).

Human activity	Pressure extent (specification to ecosystem component given in brackets)	Literature reference
Capital dredging	4 km (fish), 3 km (benthos), 3 km (vegetation), 3 km (water turbidity)	LaSalle *et al.* 1990, Morton 1996 , Kotta *et al.* 2009, Vatanen *et al.* 2012
Maintenance dredging	4 km (fish), 3 km (benthos), 3 km (vegetation), 3 km (water turbidity)	LaSalle *et al.* 1990, Boyd *et al.* 2003, Orviku *et al.* 2008, Vatanen *et al.* 2010
Sand extraction	5 km (water turbidity), 4 km (fish), 3 km (vegetation), 2 km (benthos)	Nichols *et al.* 1990, Boyd *et al.* 2003, Phua *et al.* 2004, Vatanen *et al.* 2012
Disposal of dredged matter	4 km (fish), 3 km (benthos), 3 km (vegetation), 2 km (water turbidity)	Syväranta *et al.* 2013, Syväranta and Leinikki 2014, Vatanen *et al.* 2014, Syväranta and Leinikki 2015, Vatanen *et al.* 2015
Shipping and ferry traffic	1 km (fish), 1 km (water turbidity, 30 m in depth), 0.5 km (vegetation), 0.3 km abrasion (substrate change)	Rytkönen *et al.* 2001, Vahteri and Vuorinen 2001, Soomere and *Kask* 2003, Eriksson *et al.* 2004, Sandström *et al.* 2005, Vatanen *et al.* 2010, Syväranta and Vahteri 2013
Boating	0.5 km (water turbidity, 4 m in depth),	Degerman and Rosenberg 1981, Oulasvirta and Leinikki 2003, Eriksson *et al.* 2004, Sandström *et al.* 2005
Marinas	0.5 km (fish), 0.5 km (vegetation)	Eriksson *et al.* 2004, Sandström *et al.* 2005; and the references under dredging
Demersal trawling (siltation)	0.1 km	
Demersal trawling (abrasion)	local	
Wind farms, oil rigs (operational)	0.1 km	Eastwood *et al.* 2007
Wind farms, oil rigs (construction)	300 m (wind turbines), 500 m (oil rigs)	Roth 2004, Eastwood *et al.* 2007, Andersson 2011, van der Wal and Tamis 2014; and the references under dredging
Cable placement	0.5-1km	Andrulewicz *et al.* 2003, Kogan 2006; and the references under dredging

Summary of literature review to support the setting of sensitivity scores

Tables A.2.3-4 give the literature to support the setting of sensitivity scores for benthic habitats with respect to the pressures physical disturbance and changes in hydrological condition. Literature to support the assessment of other pressures impacting on benthic habitats is listed in Table A.2.5. The sensitivity of species groups to other pressure types based on the information in the literature review is presented in Table A.2.6.

Table A.2.3. Sensitivity of benthic habitats to physical disturbance pressure based on the literature review. The sensitivities are estimated based on activities causing impacts and the recovery time.

Benthic habitat	Reported impacts	Recovery	Sensitivity category	References
Broad-scale seabed habitats				
Infralittoral hard bottom	Strong siltation impacts.	>4 years, depends on shore exposure	High	Essink 1999, Vahteri and Vuorinen 2001, Oulasvirta and Leinikki 2003, Kotta *et al.* 2009
Infralittoral sand	Intermediate-high siltation impacts on eelgrass	>2-6 years	High	Oulasvirta and Leinikki 2003, Erftemeijer and Lewis 2006
Infralittoral mud	Vegetation and fish spawning highly impacted. Impacts not as high as on hard bottoms.	4-6 years	High	Oulasvirta and Leinikki 2003, Eriksson *et al.* 2004, Sandström *et al.* 2005, Munsterhjelm 2005, Torn *et al.* 2010, Vatanen *et al.* 2012
Circalittoral hard bottom	Sedimentation higher due to less wave energy and limits settlement of sessile fauna.		High	Essink 1999
Circalittoral sand	Macrofauna effects after modification are strong and recovery is long.	0.5-4 years	High	Newell *et al.* 1998, Boyd *et al.* 2000, Dalfsen and Essink 2001, Boyd *et al.* 2003, Barrio Frojan *et al.* 2008, Frenzel *et al.* 2009, Manso *et al.* 2010, Vatanen *et al.* 2012, Wan Hussin *et al.* 2012
Circalittoral mud	Intermediate siltation impacts. Altered size distribution (juveniles die). Mortality takes place but recovery is rather fast.	typically 2.5-6 years	Moderate	Essink 1999, Orviku *et al.* 2008, Powilleit *et al.* 2009, Vatanen *et al.* 2012
Habitat forming species				
Furcellaria lumbricalis	Sedimentation effects are high.		High sensitivity	Eriksson and Johansson 2005
Zostera marina	Sedimentation effects are high.	4-6 years	High sensitivity	Oulasvirta and Leinikki 2003, Erftemeijer and Lewis 2006, Munkes *et al.* 2015
Charophytes	Sedimentation and altered wave energy impact highly.		High sensitivity	Eriksson *et al.* 2004, Munsterhjelm 2005, Sandström *et al.* 2005, Torn *et al.* 2010
Mytilus edulis	Sedimentation effects are high.		High sensitivity	Kotta *et al.* 2009
Fucus spp.	No colonization and 80% loss of coverage at impact zone.	>4 years	High sensitivity	Bonsdorff 1980, Bonsdorff *et al.* 1986, Eriksson and Johansson 2005, Vatanen *et al.* 2012, Syväranta *et al.* 2013, Syväranta and Leinikki 2015

Table A.2.4. Sensitivity of benthic habitats to changes in hydrographical conditions, based on the literature review. The sensitivities are estimated based on activities causing impacts.

Benthic habitat	Reported impacts	Sensitivity category	References
Broad-scale seabed habitats			
Infralittoral hard bottom	Accumulation of finer sediments to landward side of coastal structures -> high biological impact on sessile species.	High	Martin *et al.* 2005
Infralittoral sand	Accumulation of finer sediments to landward side of coastal structures -> biological change. Abrasion around an installation changes seabed morphology and substrate.	Moderate	Martin *et al.* 2005, Eastwood *et al.* 2007
Infralittoral mud	Accumulation of finer sediments to landward side of coastal structures -> biological change. Abrasion around an installation changes seabed morphology and substrate.	Moderate	Martin *et al.* 2005, Eastwood *et al.* 2007
Circalittoral hard bottom	No information		
Circalittoral sand	Abrasion around an installation changes seabed morphology and substrate (smaller at greater depths)	Low	Eastwood *et al.* 2007
Circalittoral mud	Abrasion around an installation changes seabed morphology and substrate (smaller at greater depths).	Low	Eastwood *et al.* 2007
Habitat forming species			
Furcellaria lumbricalis	No information		
Zostera marina	No information		
Charophytes	No information		
Mytilus edulis	No information		
Fucus sp.	No information		

Table A.2.5. Sensitivity of benthic habitats to other pressure types based on the literature review.

	Infralittoral hard bottom	Infralittoral sand	Infralittoral mud	Circalittoral hard bottom	Circalittoral sand	Circalittoral mud
Input of organic matter	High (1,9)	High (1,9)	High (1,8,9)	High (1,9)	High (1,9)	High (1,8,9)
Input of hazardous substances	High(2)	High(2,10)	High(2,5,10)	High(2)	High(2,10)	High(2,10)
Input of nutrients	Intermediate(3)	Intermediate(3)	High(3,4)	Intermediate(3)	Intermediate(3)	Intermediate(3)
Input of heat	Intermediate(6)	Intermediate(6)	Intermediate(6)	Intermediate(6)	Intermediate(6)	Intermediate(6)
Inputs of radioactive substances	Low (7)					
Input of impulsive sound	Intermediate (12)	Intermediate (12)	Intermediate (12)	Intermediate (12)	Intermediate (12)	Intermediate (12)
Input of continuous sound	Low (12)	Low (12)	Low (12)	Low (12)	Low (12)	Low (12)
Input of electromagnetism	Low (11,12)	Low (11,12)	Low (11,12)	Low (11,12)	Low (11,12)	Low (11,12)

(1) Recovery time of zoobenthos is 5–10 years (Bonsdorff *et al.* 1986).
(2) Recovery time of zoobenthos is 8- >10 years (Bonsdorff *et al.* 1986).
(3) Recovery time of zoobenthos is ca 5 years (Bonsdorff *et al.* 1986)
(4) Macroalgal mats and anoxia cause mass mortality (Ellis *et al.* 2000)
(5) 30–40% zoobenthos density reduction (Ellis *et al.* 2000)
(6) Increased water temperature by 2–4 C degrees (nuclear) or 1 C degree (coal plant) in the summer until 1–1.5 km distance (Ilus *et al.* 1986, Karppinen and Vatanen 2013); 5–9 C degree increase at 200 m distance outside a coal plant (Karppinen *et al.* 2011).
(7) Increased radioactivity at 10 km distance (Ilus *et al.* 1986)
(8) No recovery of zoobenthic community after 8 years of cessation of a fish farm in a sheltered bay (Kraufvelin *et al.* 2001)
(9) 10-fold periphyton biomass at 500 m distance from a fish farm (Leskinen *et al.* 1986)
(10) Near oil platforms sensitive species are progressively substituted by indifferent, tolerant and second- and first-order opportunistic species (Muxika *et al.* 2005, Terlizzi *et al.* 2008).
(11) Electromagnetic effects may take place, they are stronger for cables with electrodes and weaker for bipolar cables (Andrulewicz *et al.* 2003)
(12) Review of impacts of wind farms under construction and in operation (Bergström *et al.* 2014)

Table A.2.6. Sensitivity of species groups to other pressure types based on the information in the literature review.

	Seals	Porpoise	Fish	Seabirds
Input of impulsive sound	High [3]	High [3]	High [1,2]	
Input of continuous sound	Low [3]	Intermediate [3]	Low [1,2,3]	
Input of electromagnetism	Low [3,4,6]	Low [3,4,6]	Low [3,4,6]	
Disturbance of species: collision				Intermediate [5]

(1, 2) Andersson (2011)
(3) Bergström *et al.* 2014
(4) Andrulewicz *et al.* 2003
(5) Gill 2005
(6) Wilhelmsson *et al.* (2010)

Comparison of expert survey results and literature review

Physical loss

The literature review suggested that all the sensitivity scores for the pressure physical loss be set to 'High' for benthic habitats. The expert survey gave that the mean score for benthic habitats is 1.83 of the maximum 2.0, and that the experts considered benthic habitats to be highly sensitive to physical loss. For the two pelagic habitats, the expert survey gave the scores 0.4 and 0.9 and for mammals, seabirds and pelagic fish the mean score is 0.86 (range 0.5-1.2). No literature evidence suggested otherwise. Spawning areas of coastal fish (roach, pike and pikeperch, spawning among benthic vegetation) received scores 1.3-1.4 in the expert survey which is lower than findings in the literature that benthic vegetation is sensitive to physical loss. The expert survey was followed after increasing the scores by 20%.

Physical disturbance on seabed

The pressure physical disturbance on seabed was estimated by the literature review as highly impacting and the sensitivity scores were 'high' in almost all cases, but the range of habitats considered in the literature study was not as wide as in the expert survey. In the expert survey, the resulting scores were quite variable for different types of habitats: the average score 1.17 (range 1.0-1.3) for all broad-scale habitats, 1.76 (range 1.6-1.9) for all habitat-forming species and 1.56 (range 1.2-1.7) for all the Natura 2000 habitats (the mean is 1.6 (range 1.5-1.7) if 'submarine structures made by leaking gases' is omitted). The maximum score is 2.0. The results shows that the benthic habitats are highly sensitive to this pressure. The observed variability indicated that the experts considered that the more biological elements are included in the habitat classification, the more sensitive is the habitat. For example, the habitat-forming species were considered more sensitive than the broad-scale habitats or Natura 2000 habitats. The sensitivity of pelagic habitats (surface and deep) to physical disturbance was scored as 1.0 and 0.7, respectively, indicating moderate sensitivity. The results of the literature review were similar, showing that the recovery after siltation and consequent turbidity is fast and therefore the sensitivity should be considered as 'moderate' (i.e. score 1.0). The sensitivity of mammals, fish and seabirds in the expert survey ranged between 0.5 and 1.3 (mean 0.81), likely indicating that the highly mobile species are only indirectly affected by seabed disturbance. The literature review results was in line with the expert survey, and the results from the expert survey were used.

Changes in hydrological conditions

Changes in hydrological conditions were not estimated to be as serious as the other two physical pressures according to the expert survey. The broad-scale habitats had sensitivity scores ranging between 0.9 and 1.4 (mean 1.17), indicating moderate impacts, which is partly in line with the literature review, where deeper habitats were estimated as 'low sensitivity' and infralittoral habitats as 'moderate'. Pelagic habitats in surface and deep had sensitivity scores 0.6 and 1.3, Natura 2000 habitats ranged between 1.1 and 1.8 (mean 1.4), habitat-forming species between 1.3-1.7 (mean 1.54) and the mobile species between 0.4 and 1.2 (mean 0.72). The expert survey results were used.

Input of continuous sound

Sensitivity to input of continuous sound was estimated by the expert survey as highest to the marine mammals (mean 1.52), especially harbor porpoise

(1.7). Fish and seabird sensitivities ranged between 0.2-0.8 (mean 0.52) and all habitats between 0-1.0 (mean 0.39). This is in line with the literature-based estimates, which suggested low sensitivity to all habitats, fish and seals. The moderate sensitivity of harbor porpoise was likely an underestimation in the literature review. The expert survey results were used.

Input of impulsive sound

The input of impulsive sound was rated rather similarly, as marine mammal sensitivity scores ranged between 1.5-1.9 (mean 1.62, harbor porpoise getting 1.9), fish and seabirds getting the scores 0.7-1.1 (mean 0.92) and all habitats between 0 and 1.0 (mean 0.41). These results are in contrast with the literature, where moderate-high sensitivity was suggested for all the ecosystem components. As the available literature was not referring to empirical results but to assumptions, the expert survey results were used.

Electromagnetism

Sensitivity of all ecosystem components to electromagnetism scored between 0 and 1.0 (mean 0.54). This is in line with the literature review which estimated low sensitivity to all ecosystem components. The expert survey results were used.

Input of heat

The expert survey resulted in variable sensitivity to input of heat. Pelagic and benthic broad-scale habitats scored between 0.6 and 1.3 (mean 0.96), habitat-forming species scored between 0.9-1.6 (mean 1.3), Natura 2000 habitats between 0.9 and 1.7 (mean 1.11), fish between 0.3-0.8 (mean 0.56), seabirds between 0.3-0.6 (mean 0.4) and marine mammals between 0.2 and 0.6 (mean 0.36). Literature-based scores were obtained only for broad-scale habitats which all scored as 'moderate'. The expert survey results were used.

Input of hazardous substances

Sensitivities against input of hazardous substances depended on the ecosystem component. Pelagic and benthic broad-scale habitats ranged between 0.9-1.2 (mean 0.99), habitat-forming species ranged between 0.8-1.1 (mean 0.92), Natura 2000 habitats had sensitivities between 0.6 and 1.2 (mean 0.83), seabirds and marine mammals ranged between 1.2 and 1.6 (mean 1.44) and fish between 0.4 and 0.9 (mean 0.62). Literature-based estimates could be obtained only for sediment contamination which was considered as highly impacting for zoobenthos. The results seemed to be in contrast with the expert results which considered benthic habitats to be moderately sensitive. The difference may be due to high variability in substances and pollution levels; highly contaminated sediments may cause acute mortality whereas accumulative effects are more of a problem for long-lived predators. There was also some uncertainty among experts about the effects on habitats (and associated species). The expert survey results were used as no targeted deeper review was made for contamination.

Input of nutrients (nitrogen and phosphorous)

Sensitivity to input of nutrients is probably best known in the Baltic Sea. Pelagic surface and deep habitats scored 1.5 and 1.8, respectively, and the benthic broad-scale habitats scored between 1.2-1.3. Of the habitat-forming species, blue mussels scored only 0.9 whereas the plants scored between 1.3 and 1.9. Natura 2000 habitats scored between 1.2 and 1.6 (mean 1.4) and seabirds and mammals between 0.2 and 0.5. Among the fish, the deep-water and vegetation spawners scored high (1.3-1.7) whereas other fish were estimated to have rather low sensitivity (0.5-0.7). According to the scarce literature information, benthic broad-scale habitats were mostly scored as 'moderately sensitive', which is in line with the expert survey. The expert survey results were used.

Input of radionuclides

Input of radionuclides was not considered as highly impacting in the survey, as the expert scores ranged among all the ecosystem components only between 0 and 1.2 (mean 0.44). In the literature review there was only one reference, which indicated moderate sensitivity for broad-scale habitats. The expert survey results were used.

Oil slicks and spills

Sensitivity of broad-scale habitats to oil slicks and spills was estimated to range between 0.9 and 1.7 (mean 1.28) and the highest sensitivity was estimated for infralittoral hard bottoms. Habitat-forming species scored between 1.4 and 1.6 , Natura 2000 habitats between 1.5-1.9, fish between 0.5 and 1.7 (higher values for vegetation spawners), seabirds between 1.9-2.0 and marine mammals between 1.3 and 1.6. The scores showed a rather clear pattern for higher sensitivity in hard bottoms, reefs and vegetation and very high and obvious sensitivity of seabirds. No literature information was available through the review and the expert survey results were used.

Input of litter

The expert survey showed low sensitivity of most of the ecosystem components. Exceptions were seabirds and marine mammals, which scored between 0.9-1.2, while other ecosystem components scored between 0.1 and 0.8 (mean 0.42). No literature information was available through the review and the expert survey results were used.

Input of organic matter

Sensitivity to input of organic matter was relatively clear 'moderate' to the broad-scale habitats, Natura 2000 habitats, fish spawning habitats and habitat-forming species (0.8-1.4, mean 1.11). Marine mammals, seabirds and fish scored only 0.5 in average (0.3-1.1). According to the literature survey, organic enrichment has higher impacts and longer recovery times in case of benthic habitats than what is estimated by the expert survey. This pressure layer was not included in the Baltic Sea Impact Index.

Disturbance to species

Marine mammals and seabirds were estimated to be sensitive to human disturbance (1.0-1.8, mean 1.36). Fish had clearly lower scores (0.4-1.3, mean 0.81) and the habitats were estimated between 0.2-1.2 (mean 0.67). No literature information was available through the review and the expert survey results were used.

Extraction and injury to fish

Sensitivity of fish to fish extraction was estimated to score 1.57 in average (1.2-2.0). Marine mammals and seabirds scored to this pressure – being indirectly impacted by decreased prey – between 0.7 and 1.5 (mean 1.13). Habitats scored between 0.3 and 1.1 (mean 0.74). No literature information was available through the review and the expert survey results were used.

Hunting of seals and seabirds

Hunting of seals and seabirds (including predator control) was estimated to score 1.9 in average (range 1.6-2.0) for seals and 1.65 in average for seabirds (1.6-1.7). Sensitivity of fish to this pressure was obviously low (0-0.7, mean 0.29). Habitats scored between 0.2 and 1.5 (mean 0.7). No literature information was available through the review. As this pressure describes hunting, bycatch of harbor porpoise was not included in this pressure but in the layers representing the extraction of fish.

Introduction of non-indigenous species and translocations of native species

Sensitivity of ecosystem components to introduction of non-indigenous species (NIS) and translocations of native species was generally scored in the survey as 'moderate' (range 0.3-1.4, mean 0.88). Pelagic and benthic habitats as well as Natura 2000 habitats were estimated as more sensitive (mean 1.04, range 0.7-1.4) than the mobile species (range 0.4-1.1, mean 0.69). This is rather obvious as most of the NIS are small and are found to affect invertebrate communities rather than larger species. However, it seems that the experts did not consider the terrestrial NIS (American mink and raccoon dog) which have heavy impacts on seabird populations. Terrestrial NIS are not part of the impact assessment and therefore it was not necessary to change the seabird sensitivity score, but this should be kept in mind in descriptive assessments of NIS. No literature information was available through the review. As literature has shown that the common invasive non-indigenous species, such as round goby and mud crab have strong impacts to habitats formed by blue mussels and vegetation (Kuhns and Berg 1999, Lederer *et al*. 2008), the sensitivity scores of benthic habitat-forming species (ranging from 0.7 to 0.9) in the experts survey were increased by 50% (to ranging from 1.0 to 1.4).

Changes in climatic conditions

Sensitivity of the Baltic Sea habitats and species to changes in climatic conditions was estimated in the expert survey as 'moderate' (range 0.5-1.7, mean 1.01). The highest sensitivity (1.7) was estimated for ringed seal distribution and deep water conditions, which are both well-known phenomenon in the region. The lowest sensitivity (0.3-0.5) was estimated for freshwater fish species living in the coastal waters, where salinity is expected to decrease.

Acidification

The other climate-related pressure acidification, had higher variability in the responses (0.3-2.0, mean 1.02). The highest sensitivity was generally given to habitats where there are sessile species (e.g. submarine structures made by leaking gases, infralittoral hard bottoms, esker islands, boreal Baltic islets), but this pattern was not consistent. No literature information was available through the review. This pressure layer was not included in the Baltic Sea Impact Index.