Pan Baltic Scope

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Cumulative Impact Assessment

for Maritime Spatial Planning in the Baltic Sea Region

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Executive Summary

Maritime Spatial Planning is closely linked to environmental management aspects

Cumulative impact assessments make it possible to understand the combined effects on the environment from many human activities taken together. In maritime spatial planning (MSP), evaluation of cumulative impacts represents both a necessity and a way to support long-term sustainability in alignment with the ecosystem-based approach.

The environmental status of the sea is of high concern for planners, due to interactions between humans and the environment. Our sea uses have impacts on the marine ecosystems, but the status of the ecosystems also affect our possibilities to utilise sea resources. It is important to understand how past, current and foreseeable future human activities may affect the marine environment, to help us minimise risks and support long-term sustainability.

What is the problem?

The status of the Baltic Sea is generally not good today. The deteriorated environments reduces biodiversity and the health of species and habitats, working against agreed environmental objectives. It also restricts our prospects for well-being, due to effects on ecosystem productivity and resilience.

Since many human activities, pressures and species are widely dispersed, transboundary analyses of the environment are important. Transboundary coherent cumulative impact assessment makes it possible to compare national results among countries, as well as to see the bigger picture. A prerequisite for achieving this, is that there is shared understanding among users on how to interpret and understand the results **(Chapter 1).**

Most issues relating to MSP and strategic environmental assessment in the Baltic Sea are of transboundary importance

Cumulative impact assessments are conducted in several marine areas globally today, and a variety of assessment methods have been developed. Among Baltic Sea countries, the current implementation of cumulative impact assessment in connection to MSP is also variable. At the scale of the entire Baltic Sea, cumulative impact assessments have been carried out within HELCOM in connection to environmental assessment, producing the Baltic Sea Impact Index (BSII).

An overview of the existing tools and approaches for cumulative impact assessment show that these can meet several current needs within MSP, but also that there is a high demand for further development and improved coherence. The current state of art, however, gives a clear opportunity for connecting development needs and efforts across countries **(Chapter 2).**

Towards improved coherence in how cumulative impacts are assessed

The activity on cumulative impacts in the Pan Baltic Scope project has provided opportunity to share understanding of how, and to what extent, cumulative impacts can be assessed with available tools today, outline key concepts of cumulative impact assessment, as well as develop on the relationships between MSP and environmental management aspects as covered by the MSFD **(Chapters 2-3).**

Our work has helped bring available cumulative assessment tools and approaches to the planners' table, and to identify possible further development options more clearly.

In the context of MSP, cumulative impact assessments are helpful to provide a systemic and holistic evaluation of different planning options. The cumulative impact assessment can depict current conditions where the planning takes place, for evaluating potential environmental impacts of the plan and for comparing different planning scenarios. They can also be used to evaluate the outcome of the plan in relation to set objectives as part of an adaptive management.

Tool development

To facilitate regionally coherent assessments of cumulative impacts, we developed a BSII Cumulative impact Assessment Toolbox (BSII CAT). The toolbox includes tools for calculating the Baltic Sea Impact Index and the Baltic Sea Pressure Index. It also supports the identification of areas with high ecological value or high potential provision of ecosystem services, supporting the green infrastructure concept as developed in Pan Baltic Scope. Last, to support our case studies, the toolbox enables batch impact assessments and impacts assessments targeting ecosystem components important for green infrastructure in a balanced way. The tool uses regional data as default, but it can also be applied using data layers, if these align with the basic requirements of the tool. **(Chapter 4)**

Case studies

We tested the developments in two case studies. Our first case study assessed cumulative impacts on the environment under different scenarios for offshore wind farm development at the scale of the Baltic Sea region. There is a global need to increase renewable energy provision, and offshore wind farms may effectively contribute to national targets with respect to this. However, the additional use of sea space that follows may also have environmental impacts. The results give an overview of how cumulative impacts from offshore wind farms can be quantified in a spatial context, and how the role of different pressures can be compared. Such analyses can potentially also show which species and habitats are the most impacted under different scenarios. However, due to uncertainties in many of the underlying ecosystem components, we chose to not present the scenario results in this level of detail here.

Our second case study focused on impacts on green infrastructure. In MSP, it is often relevant to consider impacts on species and habiatats of concern, hence, maintaining green infrastructure can be an explicit objective of the plan. We focused on habitat aspects and performed an aggregated analysis supported by the BSII-CAT. Importantly, our concept addressed spatial distributions, which is only one component and a full evaluation, it is also important to consider the status of the ecosystem components, which was not included. Also, an assessment of ecosystem function is still missing in the concept at large. The results are useful for screening and conceptual development but should be evaluated critically due to uncertainties in underlying data layers**.** **(Chapter 5)**

Understanding cumulative impacts can support the ecosystem-based approach and promote a sustainable sea use

The cumulative impact assessment can help the planner communicate how the plan may change the presence of environmental pressures, and how it may impact on species and habitats. The assessment results are mainly presented at the overarching level, to indicate priorities for further analyses, but they can also give more specific results for aspects of key concern. Understanding cumulative impacts is important for screening baseline conditions in the initial planning phase, and for supporting planning decisions when comparing different alternatives.

In many cases these aspects are only assessed in a descriptive way today. The results and case studies presented in this report give examples of how quantitative analyses can be carried out. Our examples show that data-driven analyses to address cumulative impacts are possible so that planning can be supported by data and avoid opinion-based decisions.

Following coherent assessment approaches has benefits, as it enhances possibilities to compare results among management policies and among geographical areas. We focused the development parts of our work on the BSII methodology which is currently used in environmental assessments of HELCOM, with the aim to develop on the connections between MSP and environmental management. The BSII is based on a widely used approach which is also followed in the MSP of some countries around the Baltic Sea today.

Another benefit of coherence is that it makes it easier to share future development progress. For example, the BSII CAT developed here is now provided in an openly available code for feedback. The work of Pan Baltic Scope also includes some important assessment improvements compared to previously. However, further developments are still needed for cumulative impacts assessment to be even more reliable and flexible for users' needs in MSP **(Chapter 6)**.

What should be done in the future?

There is a continued need to refine the assessment methods, and to improve the ways in which the tools incorporate information on the relationships between human activities, pressures and impacts on the ecosystem. Data availability and knowledge on underlying ecological and causal relationships are still major knowledge gaps.

The closest hindrance in many geographic areas is a lack of spatial data with appropriate coverage or resolution. Improving data availability is important, since the quality of underlying data has high influence on the quality of the assessment results. The most evident gap identified in our work concerned spatial data on ecosystem components (species, habitats and ecosystem processes).

To take the timely assessment of cumulative impacts forward more broadly, it could also be beneficial to develop approaches that can incorporate qualitative information along with quantitative analyses in a general framework.

At the time when the Pan Baltic Scope project was carried out, there was high variation in MSP implementation and availability of data in different countries. The case studies were applied using currently available data, which were not tuned for the purpose of following-up on national plans regionally. When all countries have finalised their MSP, it would be interesting to repeat some regional case studies using harmonised MSP output data, to follow-up.

Summarising conclusions and recommendations from the Pan Baltic Scope work on cumulative impacts are provided in the end of the report **(Chapter 7)**.

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Abbreviations

Abbreviations	Specification	Comment
MSP	Maritime Spatial Planning	See also Table 1
MSFD	Marine Strategy Framework Directive	See also Table 1
SEA	Strategic Environmental Assessment	See also Table 1
HOLAS II	Second HELCOM holistic assessment of the ecosystem health of the Baltic Sea	See HELCOM 2018a
BSII	Baltic Sea Impact Index	See Chapter 2.1

1. Introduction - Why do we need to worry about cumulative impacts?

Our prospects for using the sea are closely interlinked to the function of marine ecosystems. Human activities impact on the status of the marine environment, but the status also affects our possibilities to utilise sea resources. It is important to understand how past, current and foreseeable future human activities may affect the marine environment, to help us minimise risks and support long-term sustainability.

1.1. What is a cumulative impact assessment?

An important aspect for informed management is to understand how different pressures from human activities may act together on species, habitats, and on their potential for contributing to ecosystem services. Cumulative Impact Assessments provide approaches to evaluate the combined effects on the environment from many human activities taken together. Since many human activities, pressures and species are widely dispersed, transboundary issues are often important.

Moreover, since cumulative impacts can be understood in different ways, it is important to clearly define what is meant by a cumulative impact in each specific assessment (Judd *et al.* 2015). For the purposes of Pan Baltic Scope, we defined cumulative impacts generally as: “Impacts on the environment that result from several human activities and pressures acting together, as caused by past, present or any possible foreseeable actions within the project or work task to solve”.

1.2. The state of the Baltic Sea environment needs to be improved

The status of the Baltic Sea is generally not good today (HELCOM 2018a). The poor environmental conditions have negative effects on biodiversity and the prosperity of species and habitats. It also restricts our prospects for well-being. As one example, the current state of eutrophication was estimated to cause a loss of revenue around 4 billion Euros annually (HELCOM 2018c). In addition, the losses to biodiversity and ecological values of the marine environment are expected to have negative implications on long-term sustainability and the resilience of the ecosystem in relation to future environmental changes.

A wide-scale holistic assessment was recently carried out to provide an overview of the environmental situation in the Baltic Sea during the years 2011-2016 (HELCOM 2018a). The holistic assessment was based on core indicators, which were evaluated in relation to threshold values for good status. In addition, the assessment included integrated thematic assessments on the status of biodiversity, eutrophication and hazardous substances, economic and social analyses, as well as a spatial cumulative impact assessment (HELCOM 2018b-f). The core indicators showed that the main part of the evaluated components did not achieve good status in the seventeen Baltic Sea sub-basins (**Figure 1**).

The wide-spread impacts make it clear that environmental measures are strongly needed to improve the environmental situation. However, the results from the holistic assessment also make it evident that actions to improve the status of the Baltic Sea are expected to significantly benefit our possibilities for well-being in the future.

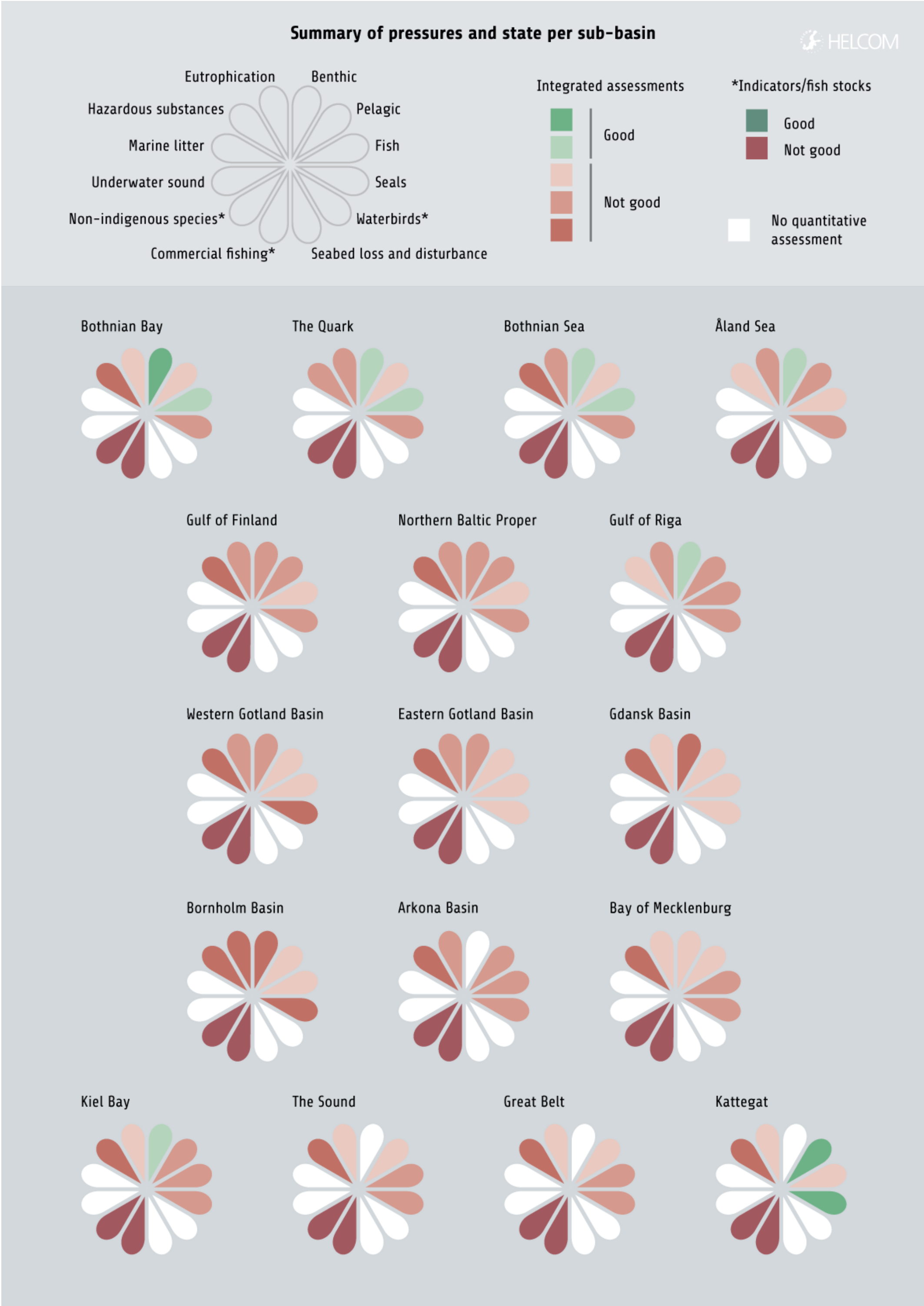


Figure 1. Current assessment status of key elements in different sub-basins of the Baltic Sea. Increasingly red shades indicate poorer status. The figure is from the HELCOM holistic assessment of the ecosystem health of the Baltic Sea covering the years 2011-2016 as a shared assessment for all Baltic Sea countries. Each petal shows the status of a pressure or a biodiversity ecosystem component, as explained in the figure legend. Results for eutrophication, hazardous substances, benthic habitats, pelagic habitats, open sea fish, and seals are integrated based on several indicators. For commercial fishing, the colours correspond to the status of the fish stock in worst status. Non-indigenous species are assessed at the Baltic Sea scale, and the same result is shown for all sub-basins. Birds are not assessed at integrated level. Marine litter, underwater sound, and seabed loss and disturbance are key elements but are not quantitatively assessed at the Baltic Sea scale. Source: HELCOM (2018a).

1.3. Cumulative impact assessment and the ecosystem-based approach

The Ecosystem-Based Approach is advocated as an important strategy for advancing environmental management and promoting sustainable sea use (**Table 1**). Implementing the ecosystem-based approach involves a cross-sectorial, holistic perspective to management with the aim to make connections between social, economic and ecological aspects visible.

Cumulative impact assessment can support the ecosystem-based approach in Maritime Spatial Planning (MSP) by providing a combined perspective on how several human activities together impact on the environment. Since MSP deals with issues that do not fall under a single sector, application of the ecosystem-based approach in MSP covers several aspects which are also of high relevance for strengthening environmental management (**Box 1**).

Box 1. Policy context

In the EU, the Integrated Maritime Policy seeks to strengthen coherence within maritime governance and increase coordination between different policy areas. It focuses on issues that do not fall under a single sector-based policy, e.g. economic growth based on different maritime sectors and marine knowledge. The objective of the policy is to support the sustainable development of seas and oceans, to develop coordinated, coherent and transparent decision-making in relation to relevant sectoral policies whilst achieving good environmental status.

Maritime Spatial Planning is identified as a process to analyse and organise human activities in marine areas to achieve the ecological, economic and social objectives. Its main purpose is stated to promote sustainable development, identify the utilisation of maritime space for different sea uses, and to manage spatial uses and conflicts in marine areas (EC 2014).

The environmental objectives are most comprehensively defined by the Marine Strategy Framework Directive (MSFD). At the overarching level, the objectives are defined by eleven descriptors, which cover aspects that should be fulfilled for good environmental status to be reached (EC 2008, 2017a-b).

For the Baltic Sea, objectives and commitments for the environment are defined by HELCOM countries through the Baltic Sea Action Plan (HELCOM 2007). Recent status assessments show that the measures that have been implemented so far are not sufficient, but it is also evident that the actions that have been implemented have had an effect. For example, there has been a significantly reduced nutrient loading over the past years, several pollution hot spots have been removed, and nature conservation has improved (HELCOM 2018a). Currently, countries around the Baltic Sea are involved in planning for an update of the HELCOM Baltic Sea Action Plan by 2021.

In the context of MSP, a key aim of cumulative impact assessment is to provide a systemic (holistic) evaluation of different planning options. The assessment can, on the one hand, be helpful in order to depict the current conditions in relation to which the planning takes place. Further, it can be used for evaluating potential environmental impacts of the plan, and for comparing different planning scenarios. The cumulative impact assessment can be conducted generally, giving an overarching picture under a cross-sectorial approach, or it can be focus on a narrower aspect. For example, the assessment can aim to evaluate cumulative impacts in relation to a certain sector (intra-sectorial assessment) or to certain species or habitats of concern (**Box 2**).

Box 2. Cumulative Impact Assessment in MSP

Cumulative Impact Assessment can support several steps of the MSP process, as it enables a systematic analysis of how different pressures and human activities may act together on the marine environment.

Background and scoping. Understanding cumulative impacts is important for screening baseline conditions in the initial planning phase. For example, a systematic cumulative impact assessment can help identify areas where the combined impact from many human activities is high, or where human activities impose pressures on sensitive or otherwise important species and habitats.

Planning. Cumulative Impact Assessment can support planning decisions, for example, when comparing different alternatives. Analyses of cumulative impacts can help understand how environmental impacts would occur geographically and how impacts from different human activities and sectors are connected. Hence, cumulative impact assessment is a core aspect of Strategic Environmental Assessments in MSP (XX).

Follow-up. Cumulative Impact Assessments can be used to evaluate the impact of the plan after implementation.

Cumulative impact assessment is also important for developing a shared understanding of key issues and priorities in regional environmental policies (EC 2014, HELCOM 2018a, 2018g). However, to achieve this, there is a need to apply coherent assessment approaches and to develop data and tools that are well suited for its purposes (Baltic SCOPE 2017).

1.4. Aims of the activity

The activity on cumulative impacts within the Pan Baltic Scope project aimed to improve coherence among countries around the Baltic Sea regarding how cumulative impacts are assessed when doing MSP. We have focused on sharing information and experiences, and on working together using currently available data to:

- Increase the capacity and expert knowledge for addressing cumulative impacts
- Support the sharing of tools and data
- Consider how cumulative impact assessments can be used to evaluate the environmental effects of development plans
- Test how cumulative impact assessments can be used to evaluate the effects of human activities on core ecological values, including green infrastructure and ecosystem services
- Identify key outputs from the assessment, and how they should be evaluated.

The practical aspects of our work were carried out around a cumulative impact assessment tool for the Baltic Sea. The tool was further developed as part of this activity and was tested in case-studies as presented at the end of this report.

1.5. Structure of the report

The following chapter of this report contains a summary state of the art on how cumulative impacts are addressed in MSP by the time of the project, together with an identification of key issues for development (Chapter 2). We address some of these development needs in Chapter 3, where we suggest practical steps for how the assessment of pressures from human activities in MSP could be structured and how it could be made coherent with assessments carried out in relation to the Marine Strategy Framework Directive. In

Chapter 4, we introduce the developed cumulative impact assessment tool. Next, we approach some of the identified development needs in case studies, as shown in Chapter 5. In Chapters 6 and 7, we discuss the results from the activity and provide concluding remarks, together with recommendations from the activity on the use of cumulative impacts and suggested next steps.

Table 1. Central terms used in the report and their applied definitions. The list is aligned with the glossary of the European MSP Platform[1], for terms marked *. Other terms are added based on their use in this report and are defined in alignment with the references indicated in the bottom of the table in each case.

Term	Definition
Adaptive management*	A systematic process for continually improving management policies and practices toward achieving articulated goals and objectives by learning from the outcomes of previously employed policies and practices.
Blue growth*	Long-term strategy to support sustainable growth in the marine and maritime sectors as a whole, recognising oceans as drivers for the European economy with great potential for innovation and growth. EC initiative to further harness the potential of European oceans, seas and coasts for jobs, value and sustainability. There are five sectors with high potential for sustainable blue growth, including renewable energy, biotechnology, coastal and maritime tourism, aquaculture and mineral resources.
Cumulative impact assessment[2]	An assessment of impacts on the environment that result from several human activities and pressures acting together, as caused by past, present or any possible foreseeable actions within the work task to solve.
Economic and social analyses	Tools for examining how the (marine) ecosystem affects human welfare, including the contribution from human activities to the economy, the cost-effectiveness of measures and policies to improve the state of the environment, the value of ecosystem services, and environmental benefits of achieving a healthy marine ecosystem, and cost-benefit analysis.
Ecosystem approach/Ecosystem-based approach*	A strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (CBD 2004). According to the joint definition of OSPAR/HELCOM (2003), the ecosystem approach is defined as "the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity". See further the HELCOM/VASAB Guideline for the implementation of the ecosystem-based approach in Maritime Spatial Planning (MSP) in the Baltic Sea area (Baltic SCOPE 2017).
Ecosystem services[3]	Ecosystem characteristics that are actively or passively used to produce human well-being, including provisioning, regulating, cultural and supporting services.
Environmental Impact Assessment*	A process of evaluating the probable environmental impact from a proposed development, taking into account socio-economic, cultural and human health impacts, both beneficial as well as adverse. The EC Environmental Impact Assessment Directive has been in force since 1985. In addition, the Espoo Convention (Convention on Environmental Impact Assessment in a Transboundary Context) obliges contracting parties since 1997 to assess the environmental impact of certain activities at an early stage of planning and it also obliges contracting parties to 'notify and consult each other on all major projects under consideration that are likely to have a significant adverse environmental impact across boundaries.'
Green infrastructure	Defined by the EU Green Infrastructure Strategy as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas (EC 2013). In Pan Baltic Scope, we developed the concept of Green infrastructure as a Baltic Sea spatial network of ecologically valuable areas which are significant for the maintenance of ecosystems' health and resilience, biodiversity conservation and multiple deliveries of ecosystem services essential for human well-being

[1] https://www.msp-platform.eu/msp-eu/glossary
[2] This report
[3] Suggested Pan Baltic SCOPE definition

HELCOM	HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention. The Contracting Parties are Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. HELCOM's vision for the future is a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in good ecological status and supporting a wide range of sustainable economic and social activities.
Integrated Maritime Policy*	European Union coherent approach to maritime issues, with increased coordination between different policy areas, focusing on issues that do not fall under a single sector-based policy, e.g. Blue Growth and marine knowledge (See also Box 1).
Intersectoral	Between several socio-economic sectors
Intrasectoral	Within one socio-economic sector
Marine spatial planning/ Maritime Spatial Planning (MSP)*	Various definitions exist. Defined by UNESCO as 'a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process.' The EC defines MSP as 'a process by which the relevant Member State's authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives' as outlined in the MSP Directive'. (EC 2014; see also Box 1)
Marine Strategy Framework Directive (MSFD)*	The EC Directive that aims to achieve Good Environmental Status of European waters by 2020 and to 'protect the resource base upon which marine-related economic and social activities depend. It enshrines in a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. The MSFD requires each Member State to develop a strategy for its marine waters, to be reviewed every six years (see also Box 1)
Strategic Environmental Assessment (SEA)*	A decision-support process, based on the SEA Directive of the European Union (2001/42/EC), by which environmental considerations are required to be fully integrated into the preparation of plans and programs. Plans and programs are first evaluated if they are likely to have significant environmental effects (screening phase). When a SEA has to be performed, a scoping phase sets the boundaries and assumed effects before the phase of assessment and alternative consideration. The consultation of the report on the environment and possible impacts is a main part of the decision-making process. Finally, a monitoring and evaluation phase is assessing the effects of plans or programs to identify unforeseen adverse effects and undertake appropriate remedial action.
Transboundary MSP*	The engagement of multiple entities (e.g. countries, states, provinces) across one ecosystem in an MSP process. Entities may necessarily share a common border, and it can encompass sub-national entities as well as include considerations for the high seas. Each entity has individual jurisdiction over different ocean spaces, different economic considerations, and drivers for MSP.

2. Current application of cumulative impact assessments

Cumulative impact assessments are conducted in several marine regions globally (**Table 2**). A variety of assessment methods have been developed, even though many of the methods have strong similarities.

A central concept for most cumulative impact assessments is that of impact chains, or linkages (Knights *et al.* 2015). The linkage model helps the user outline and communicate in what way human activities can give rise to different types of pressures, and how these may affect different parts of the ecosystem. A simplified example is shown in **Figure 2**.

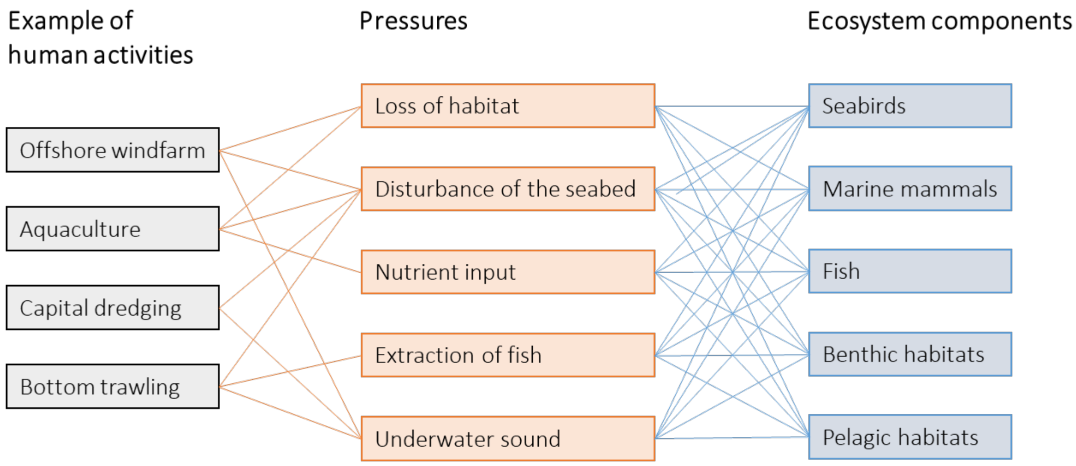


Figure 2. Example of linkages examined in the cumulative impact assessment. The connection between human activities, pressures they give rise to and effects on these on species and habitats are focal aspects. The figure shows only a few possible human activities and linkages as an example. A comprehensive cumulative impact assessment may include tens of activities and pressures and involve multiple interconnected links (see also Table 2).

Hence, the cumulative impact assessment reflects the combined effect of many types of human activities. It may be carried out with a focus on selected species or habitats, or in order to give a combined overview for a specific geographical location.

Evaluating the importance of different connections in the linkage model requires both qualitative and quantitative information about the activities and how they may lead to pressures. In initial screening, an overview of the most likely linkages can be helpful to clarify what components and data should be explored further (For examples, see **Section 3.1**).

From the perspective of impacts on species, the assessment assumes that the impact of a certain pressure is the same regardless of what human activity caused it, and the pressure should be estimated by the same unit in all cases. For example, a seabed area can be considered as equally lost regardless of this is due to the establishment of a wind farm turbine or capital dredging. However, other types of pressures associated with each of these activities may differ.

The second step of the model addresses the level of impact these pressures may have on the ecosystem. The relationships between pressures and different ecosystem components are assessed comprehensively by addressing all possible combinations of co-occurring pressures and ecosystem components. The relative importance of each relationship is based on ecological information on how sensitive different species are towards different pressures. Usually, the assessment focuses on species or habitats (ecosystem structures).

However, a more developed assessment could also address impacts on ecosystem processes (functions), in order to inform better on further potential impacts on the provision of ecosystem services.

A key development step for spatial assessments was made by Halpern *et al*. (2008), who applied a simplified additive model for mapping human impacts on marine ecosystems, based on the central concepts outlined above, and presented a global assessment (See also Halpern *et al.* 2015). This approach identifies areas where pressures from human activities overlap with selected species or habitats and estimate the sensitivity of species to different pressures using so-called sensitivity scores. Cumulative impact assessments building on their work has by now been applied in many sea areas, including the Baltic Sea (**Table 2**), as also explain in more detail in the next section.

Table 2. Examples of published work on cumulative impact assessment

Geographical area	Reference
North Sea	Andersen *et al.* 2013
	SwAM 2018
	SEANSE project[4]
The Mediterranean and Black Sea	Micheli *et al.* 2013
	Menegon *et al*. 2016
Hawaiian islands	Selkoe *et al*. 2009
California current region	Halpern *et al*. 2009
British Columbia	Murray *et al.* 2015
Baltic Sea	HELCOM 2010, Korpinen *et al*. 2012
	HELCOM 2018a-b
	SwAM 2018

2.1. Current application at the Baltic Sea scale: the Baltic Sea Impact Index

2.1.1. Background to the approach

Cumulative impact assessment at the scale of the entire Baltic Sea has been carried out within HELCOM in connection to environmental assessments. The assessments produce the Baltic Sea Impact Index (BSII). The first version of the BSII was published under the initial holistic assessment of the ecosystem health of the Baltic Sea (HELCOM 2010a-b, Korpinen *et al.* 2012). The BSII was subsequently updated as part of the second HELCOM holistic assessment (HOLAS II) and the methodology was also developed further (HELCOM 2018a-b).

Due to the methodological developments, the results from the first and the second assessments are not directly comparable. One main difference is that the second Baltic Sea Impact Index was based on an extended set of spatial data, which was aligned with the assessment structure of the Marine Strategy Framework Directive. The work also gained from method refinements from other projects carried out in the

[4] Parallel to the Pan Baltic Scope project the DG Mare sister project SEANSE analyses cumulative impacts of existing and planned OWF using the CEAF approach under development. The work targets the whole North Sea for 5 species: harbour porpoise, common guillemot, red-throated diver, black-legged kittiwake and lesser black-backed gull, and focuses on spatial and temporal cumulations and transboundary effects (https://www.msp-platform.eu/projects-/strategic-environmental-assessment-north-seas-energy-seanse).

time in between the two assessments, as well as by developments in connection to HOLAS II (HELCOM 2017, Korpinen *et al.* 2017).

With respect to the development of the data sets, a key aspect was to update and improve the spatial information and the sensitivity matrix that was used in the assessment. These are described in more detail below.

With respect to method development, parameters for estimating the spatial extent and intensity of pressures from different human activities were developed, with the aim to provide a more clear-cut distinction between the mapping of human activities on the one hand and pressures on the other hand, a more balanced emphasis with respect to how much different pressures were represented, and an improved transparency in how the results and underlying data availability was presented.

The descriptions below refer to the BSII of HELCOM (2018a-b).

2.1.2. Spatial data included

The Baltic Sea Impact Index (BSII) is based on Baltic-wide spatial data layers on pressures of relevance for the Baltic Sea, as well as of key ecosystem components (species and habitats) occurring in the Baltic Sea. The scope of BSII includes land-sea interactions since the pressures layers also consider pressures emerging from activities on land.

In all, 18 data layers on pressures and 36 ecosystem component layers were included in the assessment carried out by HELCOM (2018 a-b, **Annex 1-2**). Human activities are included by that tens of spatial data layers on human activities form the basis for defining several of the pressure layers (for details, see HELCOM 2018b).

The data included in the BSII of HELCOM (2018a-b) represent the time period 2011-2016. For pressures which vary between years, such as extraction of species and underwater noise, average values for the years 2011-2016 were used. For pressures of the more permanent type, which are accumulating, information from past years was also included. In relation to this, it should be noted that for example the data layers on nutrient pressures (nitrogen and phosphorus) and hazardous substances are based on measurements at sea, and hence include the combined effect at sea from current loading as well as accumulated levels due to historic inputs.

The Baltic-wide data sets and methodologies which are currently available (HELCOM 2018a-b) were based on the best available knowledge at that time; however, they contain some uncertainties that need to be resolved in the future.

2.1.3. Sensitivity matrix

A sensitivity matrix contains scores to describe the relative sensitivity of each ecosystem component to each pressure (**Annex 3**). The sensitivity scores were developed based on a large-scale expert survey and literature review. They are used in the calculations to determine the relative importance of each pressure layer in the assessment result (**Figure 3**, and formula below). For several pressures in the Baltic Sea, there is a continued need to develop knowledge on how they may affect species and habitats.

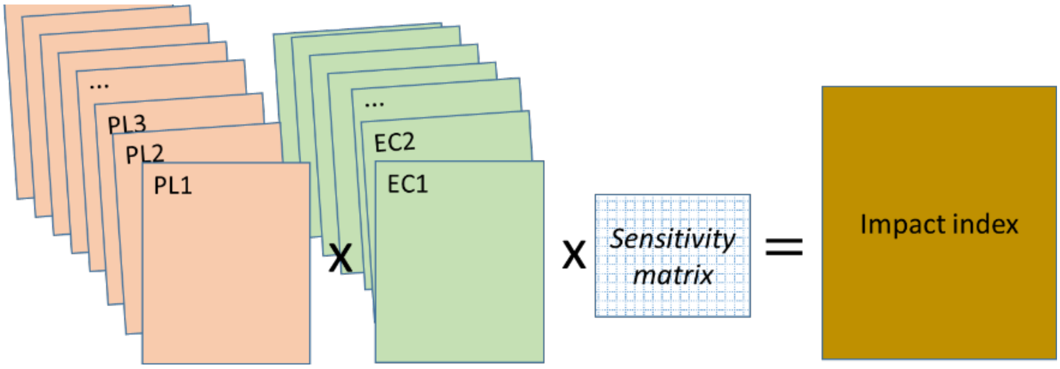


Figure 3. Generalized illustration of the spatial approach to assess cumulative impacts as applied, for example in the Baltic Sea Impact Index. In the version of the Baltic Sea Impact Index presented in HELCOM (2018amb), 18 spatially referenced pressure layers (PL) and 36 ecosystem component layers (EC) were used. A sensitivity matrix was used to quantify the relative sensitivity of each ecosystem component to each pressure.

2.1.4. Calculation

The Baltic Sea Impact Index is calculated in additive manner as the sum of impacts of every pairwise combination of pressures and ecosystem components in one assessment unit, as shown in the formula below (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):

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

Results for all combinations of pressure and ecosystem component layer maps are summed in order to produce the Baltic Sea Impact Index (**Figure 4**).

2.1.5. Outputs from the assessments

The data layers are included in the assessment as GIS raster files with a 1x1 km grid, and the resulting BSII is presented with the same resolution (**Figure 4**). In addition, numerical statistics give the impact scores for all pressures and ecosystem component combinations, and the impact sums for each pressure layer and ecosystem component layer. The default assessment gives the sum of overlapping elements within each grid cell as default. However, other options are also possible, such as mean or maximum.

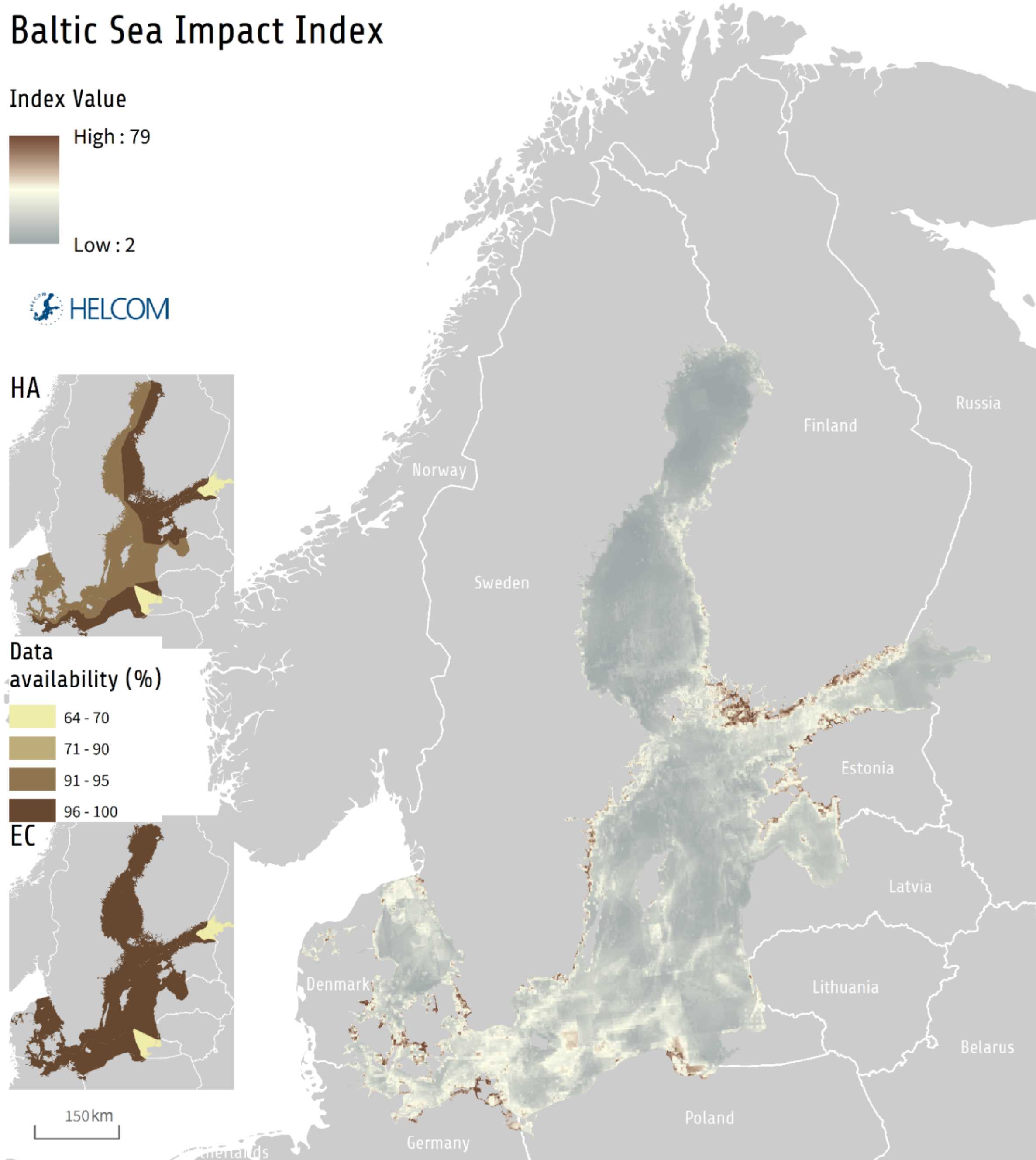


Figure 4. Distribution of cumulative impacts on the Baltic Sea environment according to the second HELCOM holistic assessment of the ecosystem health of the Baltic Sea (larger map). Impacts are estimated by the Baltic Sea Impact Index. The result represents the years 2011-2016. The map identifies areas with relatively higher or lower potential impact on ecosystem components (species and habitats) at the overarching level. The analysis was based on best available regionally comparable data at the time of the assessment (HELCOM 2018a-b). The smaller maps on the side indicate the coverage of the underlying data layers so that lighter colours indicate areas with gaps in some underlying data. Further details on the underlying data can be obtained from the HELCOM Maps and Data Services[5] (EC=Ecosystem components layers, HA=human activities and pressures data sets). Figure source: HELCOM 2018a.

[5] http://maps.helcom.fi/website/mapservice/

2.2. Current uses of cumulative impact assessment in connection to MSP in Baltic Sea countries

The current implementation of cumulative impact assessment in connection to MSP is highly variable among Baltic Sea countries. According to a questionnaire carried out at the initiation of the Pan Baltic Scope project[6], aspects of effects on biodiversity, flora, fauna, water, climate, as well as on the seascape and cultural heritage are widely considered. In some cases, the cumulative impacts assessment also addressed effects on geology, soil, air, human health, or hazardous substances. Both quantitative analyses and qualitative descriptions are in use.

This section summarises the current use of cumulative impact assessment in MSP for different countries around the Baltic Sea. We also provide an evaluation of development needs, focusing on the most relevant next steps.

2.2.1. Estonia

Timeline for MSP

The draft of Estonian MSP was published in April 2019. The draft includes a preliminary planning solution. In this stage, the public can examine the draft plan and offer suggestions. Afterwards, amendments are made to the MSP, and the planning solution and its impact assessment report are prepared (approximately September – November 2019). After this there will be an additional publishing phase where the public can also make their suggestions to the plan and the impact assessment report (approximately November 2019 - January 2020). This is followed by an approval round among bodies and persons that have interests in the planning solution (approximately February 2020-May 2020) with the final plan to be adopted in October 2020.

Approach to cumulative impact assessment

Cumulative impacts are addressed in two ways. First, the draft includes some generic description on the separate and synergistic effects of various human uses on different nature assets without providing any specific spatial analyses. Second, when spatial information on human uses is available the online cumulative impact assessment tool is used to predict the separate and synergistic effects of all these human uses, either those currently present or those planned for future implementation.

The assessment tool (PlanWise4Blue) combines impact coefficients derived from the literature meta-analysis of impacts of different human uses on natural environment and modelled distributions of natural assets (e.g. Liversage *et al.* 2019). In the case that impact evidence is missing, expert knowledge is used to derive the impact coefficients. A range of impact types can be included for analysis, being e.g. dredging, wind farm, fish farming, shipping, underwater cables, commercial fishing, harbours, military activities, wastewater discharge, and mussel and algal cultivation. These were selected due to the relevance of these pressures in the study area. Among nature assets, the underlying environmental GIS layers span from underwater habitats to fish, birds and mammals.

Users with or without science training can use the portal to estimate areas impacted and changes to natural assets (km^2) caused by different impact-types. Impact estimates are often based on best available knowledge from manipulative and correlative experiments and thus form a link between science and management.

Key development needed

The major limitation of the cumulative impact assessment procedure is a lack of rigorous scientific knowledge on the effect of many combinations of pressures on different nature assets and associated

[6] Joint questionnaire of Pan Baltic Scope Activities 1.2.1 & 1.2.2

ecosystem services. In recent years human uses have significantly diversified and intensified in the marine environment whereas most of existing scientific evidence on impacts is published on a few sea uses only. Important developmental needs also relate to future impacts posed by the contemporary climate change. In the coming decades species ranges are expected to be dramatically altered and thereby the current network of marine protection areas needs to be revised.

2.2.2. Finland

Timeline for MSP

The planning responsibility is within eight coastal Regional Councils, which draft a total of three MSPs that cover both territorial waters and EEZ. The MSPs overlap land-sea planning in territorial waters. The regional councils draft regional land use plans that legally guide more detailed municipal local planning that also covers territorial waters. An overview of the current state including the status of the marine environment, the status of Blue Growth sectors and characteristics of the three planning areas have been prepared during 2018. Future scenarios for Blue Growth as well as an impact assessment will occur during 2019. Target setting dialogues in Regional Councils will occur during 2019 and early 2020, and Regional Councils approve the plans by March 2021.

Approach to cumulative impact assessment

The aims of the plans are to 1) manage human pressures to the marine environment and promote an implementation of numerous measures, such as those related to the seafloor, hydrography, noise pollution, the prerequisites for shipping or the realization of actions related to protected areas, and 2) combine different forms of utilisation in marine areas in a sustainable manner that takes ecosystem services into account, and to, in this way, also avoid forms of use that contradict one another.

The Land Use and Building Act states that when a plan is drawn up, the environmental impact of implementing the plan, including socio-economic, social, cultural and other impacts, must be assessed to the necessary extent. Such an assessment must cover the entire area where the plan may be expected to have a material impact. When investigating the impact of a land use plan, as referred to the law, the purpose of the plan, earlier investigations and other factors affecting the need for investigation must be considered.

According to the Land Use and Building Decree, an investigation must provide the data necessary for assessing the significant direct and indirect impact of the plan’s implementation on the following aspects:

1. people’s living conditions and environment;
2. soil and bedrock, water, air, and climate;
3. plants and animals, biodiversity and natural resources;
4. regional and community structure, community, and energy economy, and traffic;
5. townscape, landscape, cultural heritage, and the built environment.

In addition, the impact of a regional plan on the structure of the following aspects must be considered:

- area and community
- the built environment
- nature
- landscape
- arrangement of traffic and technical services
- economy
- health
- social circumstances and culture
- any other significant impacts

Further, a municipality whose territory is affected by the material impact of a local master plan or a local detailed plan, as referred to in section 9 of the Land Use and Building Act, must be involved to an adequate degree in investigating the impact of the plan. A regional council whose administrative area is affected by the material impact of a plan must be similarly involved.

Regarding the assessment method, it is stated that planning should be based on adequate studies and reports. In a cumulative impact assessment process, one should be able to understand negative and positive direct and indirect impacts. Only the significant effects are reported. In the assessment work, a manual matrix (scaled as ++, +, 0, -, --) is used. The decision making and valuation of significant impacts are based on expert knowledge.

Key development needed

The significant impacts of human activities on environment must be considered in MSP. An approach on how to measure/value direct and indirect significant impacts is missing. The method will be agreed during 2020.

2.2.3. Åland

Timeline for MSP

As an autonomous region of Finland, the territory of the Åland Islands is governed by its government and parliament. The territory of the Åland Islands has its legislation, exempt from the constitution, which Åland shares with Finland, and therefore Åland also has its planning mandate when it comes to marine spatial planning and other developmental plans and projects. Based on Åland's Land Use and Building Act[7], municipalities are to designate general as well as detailed land-use plans[8], whereas the Government of Åland is to plan and implement the MSP, which in turn is regulated in the Water Act[9]. There is currently no plan that overlaps with the MSP; however, the WFD and MSFD do overlap with the MSP at sea.

During 2018 and 2019, as a first step for the MSP process, a timeline and communication plan were designated. The MSP process continued to appoint an overview for the current state, including the status of the marine environment, the status of Blue Growth Sectors, and a description of the characteristics of the planning area. Future Scenarios, as well as impact assessments, will be developed during and after the first MSP draft, which is planned to be proposed in late 2019. Two hearing processes will be included in the MSP process before it is to be accepted by the Government of Åland.

Approach to cumulative impact assessment

The aims of the plans are to 1) manage human pressures to the marine environment and promote an implementation of numerous measures, such as those related to the seafloor, hydrography, noise pollution, the prerequisites for shipping or the realization of actions related to protected areas, and 2) combine different forms of utilisation in marine areas in a sustainable manner that takes ecosystem services into account, and to, in this way, also avoid types of use that contradict one another.

The EIA and SEA Act[10] states that when a plan with significant environmental effects is drawn up, the environmental impact of implementing the plan, must be assessed to the necessary extent and written in the format of an Environmental report. The Environmental report must cover the entire area where the plan may be expected to have a considerable environmental impact.

[7] Plan- och bygglag (2008:102) för landskapet Åland
[8] "generalplaner" and "detaljplaner", respectively
[9] Vattenlag (1996:61) för landskapet Åland
[10] Landskapslag (2018:31) om miljökonsekvensbedömning och miljöbedömning

The legislation defines in the beginning what an Environmental Impact is, and how it should be considered. An Environmental impact is a direct or indirect, positive or negative, temporary or permanent, cumulative or non-cumulative effect that occurs in the short, medium, or long term for:

1) population and societal wellbeing, including health
2) flora and fauna protected under the Nature Conservation Act[11]
3) soil, bedrock, water, air, and climate
4) assets, cultural heritage, and landscapes
5) the interaction between the factors listed in 1-4

According to the EIA and SEA Act, The Environmental report shall include:

1. a summary of the content, its primary purpose, and its relation to other relevant plans or programs
2. a description, identification, and assessment of reasonable alternatives concerning the purpose and geographical scope of the plan
3. information on:
    a. the probable outcome and development of environmental conditions if the plan is not implemented
    b. environmental conditions in the areas that are likely to be significantly affected
    c. existing environmental issues that are relevant to the plan, in particular, environmental issues that are related to an area with considerable importance to the environment
    d. how to consider relevant environmental quality goals and objectives
4. an identification, description, and assessment of the considerable environmental impacts the implementation of the plan might lead to
5. information on planned measurements to prevent, counter and mitigate substantial environmental effects
6. a summary of the deliberations, the reasons behind the choices of various alternatives, and possible problems in data collection/compiling
7. a description of the proposed methodologies used in the monitoring and evaluation of the environmental impacts the implementation of the plan might lead to
8. a non-technical summary of factors 1-7

The Environmental reports scope and degree of detail must be reasonable concerning:

1) the methodologies used in the assessments and currently available knowledge
2) the content and degree of detail of the plan
3) in which stage of the decision-making process the plan is in
4) that a few questions can be assessed better when other plans or programs impact reports are examined
5) the public interest

Key development needed

The considerable impacts of human activities on the environment must be considered in MSP. An approach on how to measure/value considerable environmental impact is missing.

2.2.4. Latvia

Timeline for MSP

[11] Landskapslagen (1998:82) om naturvård

The MSP has been developed for the entire part of the Baltic Sea under the jurisdiction of the Republic of Latvia up to the outer border of the exclusive economic zone. The legal basis for MSP in Latvia is the Spatial Development Planning Law (in force from 1st December 2011) and Cabinet Regulation No. 740 of 30th October 2012 on the Procedures for the Development, Implementation and Monitoring of the Maritime Spatial Plan. Development of the plan was started in 2014 when a national MSP coordination group was established and initial introductory seminar about national MSP for general public was organised. The first MSP draft was prepared during 2015 and first round of national public consultations and cross-border consultations were held in late 2015 and early 2016. The second version of the Latvian MSP was elaborated, and a second round of public consultation launched on July 2018. The plan was approved in May 2019.

Approach to cumulative impact assessment

The MSP has been developed using the latest scientific research data regarding the status of the marine environment, nature assets and new data sets have been developed (for example, regarding distribution of fish species and fishery activity, sea bottom sediments and benthic habitat distribution and potential of ecosystem service supply etc.) Based on the precautionary principle, the available spatial data sets regarding the distribution of nature assets were used to identify appropriate locations for human activities and avoiding those where they could cause significant damage (MoERPD 2018).

The impact of human activities on various components of the marine ecosystem was assessed using an impact matrix (in which experts had assessed whether the sea use envisaged by the plan would have no, moderate or significant impact on marine ecosystem components, including benthic habitats, spawning, nursery and distribution areas of fish, migration routes and wintering areas birds). The assessment results were used for mapping spatial impact scenarios and optimal sea use solutions. The interaction of commercial activities and the environment were considered at stakeholder and expert meetings, resulting in the formulation of criteria for use of the sea (MoERPD 2018).

Based on the outcomes of discussions with stakeholders, the long-term development vision and the priorities, as well as considering the criteria for defining priorities for using the marine space**,** the MSP defines three categories of marine space use:

1. Priority uses –includes existing and planned uses of the marine space, which are essential for ensuring the spatial interests of the priorities defined in the strategic part.

2. Existing uses and objects, which are connected to the use of the marine space and whose location and management is determined by regulatory enactments.

3. General use, where all sea uses are allowed (incl. fishery, shipping, tourism and leisure, scientific research etc.) which do not contravene the restrictions defined in regulatory enactments and do not cause significant negative impact to the marine environment. In order to initiate new uses of the sea, it is necessary to apply for a license area, obtain a license for exploration, carry out the EIA procedure and obtain a license for the construction works or/and exploitation of resources (MoERPD 2018).

Key development need

Scientifically sound and transparent linkages between activities, pressures, ecosystem components and ecosystem services are missing. This could be considered as a major limitation in implementation of cumulative impact assessment procedure. According to the national MSP strategic and spatial priorities, several tasks and objectives have been defined, including the strategic objective “The marine ecosystem and its ability to regenerate is preserved, ensuring the protection of biological diversity and averting excessive pressure from economic activities” and the related task 2.6 “To develop methodology for evaluation of spatial cumulative impacts from the use of the sea using good environmental status indicators and to ensure application of the methodology within the EIA process”.

2.2.5. Germany

Timeline for MSP

The SEA of the first German MSP from 2009 includes the Cumulative impact assessment on a minor scale due to knowledge gaps and lack of data at that time. This approach has been further developed in the SEAs of the sectoral plans for offshore wind energy (BFO 2013, 2016-2017 and Draft Site Development Plan 2019) and will be extended for the MSP update.

Approach to cumulative impact assessment

In general, the cumulative impact assessment is carried out with an intra-sectoral focus. The sectoral plans focus on offshore wind farms, including their platforms and cabling, and impacts from other existing activities (i.e. fishing, shipping) are mentioned as existing use. The procedures follow a qualitative or descriptive approach. Compulsory mitigating/preventing measures are always considered.

The following table lists the species and their respective stressors with a focus on offshore wind energy:

Species	Stressors
Birds (seabirds and migrating birds)	habitat loss, collision risk, barrier effect
Marine mammals	noise disturbance → temporal habitat loss
Benthos	habitat loss, changes in habitat structure (in discussion: sedimentation, temperature rise due to cabling)
Fish	changes in habitat/new habitat due to wind farm foundations (in general discussion, as temporal impacts mainly: sedimentation/sediment disturbance and noise during pile driving)

The assessment, mainly by principle of exclusion and under consideration of the precautionary principle, is done with the following methods:

- Seabirds: Divers are the main concern in Germany in terms of habitat loss since they are both very prone to disturbance and a highly protected species. There is a special area defined within the EEZ of the North Sea where divers occur in spring. Cumulative effects are not likely to have a significant effect as long as there are no more offshore wind farms being permitted and thus build within this area; qualitative approach.
- Migrating birds: Currently there is not much known about actual collision risk and barrier effects. Knowledge gaps where described in detail and there is no final conclusion on potential cumulative effects yet. A comprehensive study is planned in 2019 for the Baltic Sea EEZ.
- Marine mammals: Similar to divers, there is a specific area where harbour porpoises mainly stay during summer. Also, mitigating measures are taken for every wind farm project all year around. Cumulative effects are not considered to have a significant effect on harbour porpoises, if less than 1 % of the "harbour porpoise area" is influenced by pile driving (using compulsory mitigating measures); qualitative approach.
- Benthos: Very conservative assumptions are taken into account for the area which is permanently "lost" to wind farms/foundations, platforms and cabling in relation to entire area of German EEZ; quantitative approach.
- Fish: Cumulative effects are measured only descriptive, as there is not much known so far.

Parallel to the Pan Baltic Scope project another approach (CEAF) is under development in the DG Mare sister project SEANSE, analysing the cumulative impacts of existing and planned OWF for the whole North Sea for 5 species: harbour porpoise, common guillemot, red-throated diver, black-legged kittiwake and lesser black-backed gull with a focus on spatial and temporal cumulations and transboundary effects.

Key development needed

From the cumulative results, the pressures and ecosystem components concerned should be identifiable and individually quantifiable. Linking the pressures to human activities is another important aspect, especially to strengthen the tools ability for the assessment of alternatives.

In general, the assumptions used in the method need to be further validated. Besides a fundamental improvement of data quality, it would make sense to consider the seasonal distribution of ecosystem components and temporal processes in human activities in more detail. It would be a great advantage if the tool could also be used for a robust assessment of the functional connectivity and interrelation of ecosystem components.

2.2.6. Poland

Timeline for MSP

The Maritime Spatial Plan for the Polish Sea Areas covers the internal sea waters of Gdańsk Bay, territorial sea and the Exclusive Economic Zone and is prepared jointly by the three Maritime Offices (in Szczecin, Słupsk and Gdynia) in the scale of 1:200 00. The works has been started in 2016 with the data and planning proposals gathering round, followed by four national consultation meetings, 8 sectoral meetings, three international and several meetings at the ministerial level. The first version of the Plan (v.0), prepared in 2017, was just a preliminary division of sea-basins (due to priority function) with the conflicts and synergies analyses for every single area. The next version (v.1) was subject of the official public consultations the period May-July 2018, with the open public debate in June. The Plan was not agreed, and several comments and remarks were received by end of August 2018. After analysing the comments, the next (v.2) version was prepared and given to the ministerial arrangements and consultation in January-February 2019. Another round of the arrangements was also unsuccessful due to the national defense and mineral extraction issues. There were additional negotiations held and the final (v.3) version was prepared beginning of August 2019. That version and its SEA would be now a subject to the transnational ESPOO consultations and then, to the national legislative process.

Approach to cumulative impact assessment

The environmental aspects has been taken in Polish MSP in two ways. First, at the very early stage of stocktaking when the description of the ecological components were provided as well as the profound analyses of spatial dependencies and consequences of the human activities to the areas of high ecological values. The first stage of planning also encompassed the detailed conflicts analyses the different human activities were analyzed against each other as well as their influence / impact on ecosystem components. Performing such analysis at the initial stage made it possible to consider the sensitivity and the value of the marine ecosystem from the beginning of planning. The planners gained a great knowledge on where the most important areas are, and what are the main treads and sometimes – how to avoid them. Secondly – the Plan have been accompanied from its first version by a Strategic Environmental Assessment, where the profound analyses of the pressures and impacts have been performed. As the Polish MSP is of general character (deciding about functions not concrete investments) the assessment was quite difficult from the beginning. The functions have been broken down to the activities described in the functions' definitions. The starting point for works on the impact assessment was to determine the expected significant impacts that may result from the implementation of the provisions of the draft plan regarding the so-called functions of "sea basin". The focus was both on the on significant negative and positive impacts. The most important was the identification of *significant impacts,* as their occurrence would be one of the criteria

for the assessment of the plan solutions. Then the analysis of those impacts has been performed based on "sea-basin" cards describing the priority and allowable functions. Finally, the proper assessment was made considering direct, indirect, secondary and cumulative impacts.
The Cumulative impacts have been defined as *the sum of the effects of the implementation of various types of activities and intentions, including those already carried out previously*, considered together. These impacts will therefore result from the simultaneous implementation of activities under several functions. So, there was a simple assumption – more functions assigned to the area, the stronger cumulative impact. The general conclusion was that the largest accumulation of functions (and related activities) occurs in the coastal zone from Świnoujście to Ustka, in the areas foreseen for future development with release approval and in the Gulf of Gdansk area. The scope and scale of the cumulative impacts will depend on the schedule of implementation of individual activities (investments), the applied technological solutions and minimizing the negative impact on the environment. Their more detailed assessment was not possible at this stage of the strategic environmental impact assessment.

Key development needed

The key development need is to elaborate the methodology that could deepen the cumulative impact assessment at the level of the general plan, where no concrete activities (investments) are prescribed nor their timeline. There is also a discussion on the goal of the cumulative impact assessment at this level, as almost every investment must perform its EIA (with cumulative impact assessment as a part) based on environmental research, which are not performed for planning purposes. So, there may be a need to rethink the goal of the cumulative impact assessment.

Other needs are those for more knowledge on marine ecosystems, on their temporal changes, on other change factors so that we could perform better spatial analyses.

2.2.7. Sweden

Timeline for MSP

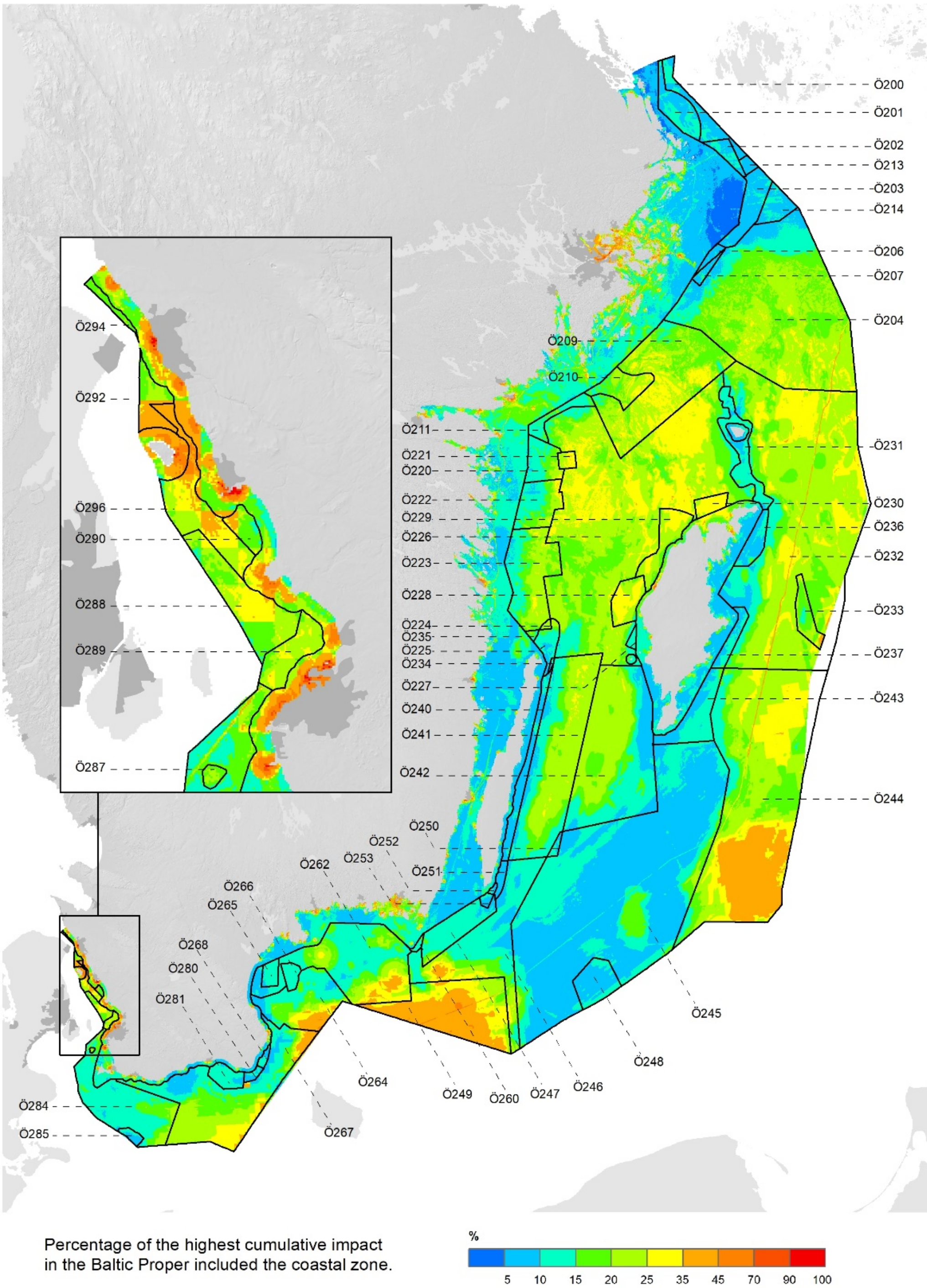
Proposals for Swedish MSP and related environment impact assessments and sustainability appraisals were published for public consultation from March 2018 to mid-August 2018. In addition, there was an Espoo-consultation. Revised versions were published for public review from March to June 2019. These MSP proposals describe existing uses of the sea and visualize them numerically with explanatory maps. All relevant sectors and stakeholders have been invited, and several consultation meetings have been held during this period, in addition being able to submit written comments. There were around 1,400 comments on the 2019 review versions. After finalization, the proposals including impact assessments will be submitted to the Swedish Government (December 2019). The Government will then process the plans at political level and approve them before the EU deadline in March 2021.

Approach to cumulative impact assessment

The Swedish Agency for Marine and Water Management (SwAM) has developed Symphony as a support tool for the MSP process. The tool is based on the method originally published by Halpern *et al.* (2008). Symphony is intended for use as a support tool for people who develop plans as well as those who contribute with knowledge and expert opinions. Symphony analyses how environmental pressures affect different areas of the sea, in a transparent manner. In addition, it can be used to show how different planning options affects the environmental impact in different areas. This future-oriented function is at the core of Symphony.

Symphony consists of four elements: ecosystem components, pressures, a sensitivity matrix, and an analytical platform. The spatial resolution is 250 x 250 metres, and data are adapted to this grid regardless of the actual resolution of the data. Symphony uses 32 ecosystem components, also called nature values, which represent the Swedish sea's ecosystem. These incorporate habitats, populations, species, and groups of species. The maps for each ecosystem component cover the entire Swedish marine area and have a specific value in each pixel. This value is a relative estimate of the value of the geographic position (pixel) for the respective ecosystem component. Because the underlying data differ between the various ecosystem components, data processing also differs and is described in detail in the Metadata annex of the report (SwAM 2018). The 41 pressures used in Symphony are a selection of physical and chemical factors from human activities that can harm the marine environment (the ecosystem components). Certain human activities result several pressures, for example trawling for fish damages the bottom environment by scraping as well as muddying the water with sediment. Similar pressures can also be generated by various human activities, for example underwater noise from shipping and wind power turbines. The pressures included in Symphony are intended to represent all major ways in which humans affect the marine environment. The maps that describe the pressures indicate the pressure intensity in each geographic position (pixel). If the pressure does not occur in the area, the value is 0. If the pressure has the highest recorded intensity for Sweden, the value is 100. In some cases, the max value of 100 is based on established target values. The results are visualised as maps, tables, and graphs (see Figure below). They have been continuously used to evaluate planning alternatives during the MSP process in Sweden, as well as being a core component for the Strategic Environmental Assessment of the Swedish MSP (SwAM 2019).

More detailed information can be found in the report and its annexes and data and metadata can be downloaded from the Symphony website.



The Figure shows example of Symphony application, environmental impact in Swedish part of Baltic Sea, with some of the current planning overlaid.

Key development needed

SwAM is in the process of developing an open source user-friendly application. This will enable a greater transparency for the method and results, as well as allow stakeholders to examine the calculations in detail. This will allow external scientists to evaluate the method and data further and suggest improvements.

Another development goal would be to tie the pressures from human activities to the indicators from the EU Marine Strategy Framework Directive. This will allow a spatial presentation of the indicators, a way for Sweden (and other EU Member States) to report on progress and development in an easily communicated way, and a tool to monitor pressure development. To achieve this, the indicators will have to be translated into pressure layers with a temporal and spatial resolution.

2.3. Summary

The examples given in this chapter show that existing tools and approaches for cumulative impact assessment can meet several needs within MSP, but also that there is a high demand for further development.

We identified the main benefits of using cumulative impact assessments as:

- Get an overview and an understanding of how things are connected to each other
- Provide guidance on how to minimize negative impact
- Show what the plan means for the environment: Assess if the expected change will be positive or negative compared to the current situation

However, a prerequisite for achieving this, is that there is shared understanding among users on how to interpret and understand the results. Approaches for assessing cumulative impacts are still under development.

There is a continued need to refine the methods, and to improve the ways in which the tools incorporate information on the relationships between human activities, pressures and impacts on the ecosystem. Further, data availability and knowledge on underlying ecological and causal relationships are still major knowledge gaps.

A current hindrance in many geographic areas is a lack of spatial data with adequate coverage or resolution for the area that is to be assessed, for all components that are included. In most cases, a transboundary perspective is lacking.

When a quantitative assessment is not possible, cumulative impacts can be addressed in a qualitative way. Such an approach could still apply the same structure as in a quantitative analysis and be supported by quantitative information when this is available by putting different pieces of information together.

Under both qualitative and quantitative approaches, the cumulative impact assessment should help the planner communicate how the plan may affect the distribution of environmental pressures and impact on the environment, on the overarching level and with examples for selected aspects of key concern.

3. Connections between human activities and pressures in MSP and MSFD

To support a comparison of how human activities are assessed in MSP and in the Marine Strategy Framework Directive (MSFD), **Table 1** gives an inventory list of activities of potential relevance for the Baltic Sea and shows how they are classified with respect to these. The table also provides information on what regionally coherent data sets are currently available for each of the listed aspects.

Table 2. List of human activities of potential relevance for the Baltic Sea. Columns 1 and 2: The activities are grouped and named as in the MSFD (EC 2017b). Column 3: "SEA USE" includes a list of sea uses defined in "HELCOM-VASAB Guidelines on transboundary MSP output data structure in the Baltic Sea" and implemented in the MSP Output data section of the BASEMAPS platform (https://basemaps.helcom.fi/). "NL" is shown if the sea use is not currently listed in the guidelines. Column 4: The last column gives information on by which spatial data layer each activity was represented in the State of the Baltic Sea report (HELCOM 2018a), confined to activities which occurred at least somewhere in the Baltic Sea including the Kattegat during 2011-2016. These layers are available at the HELCOM maps and data services. "(-)" is shown if the sea use was not included in State of the Baltic Sea report. The HELCOM data only encompass regionally fully harmonised data layers.

Theme	Activity (MSFD)	SEA USE (MSP)	HELCOM available data layer (2018)
Cultivation of living resources	Aquaculture – marine, including infrastructure	aquaculture-fish	Aquaculture
		aquaculture-mussel	Shellfish mariculture
		aquaculture-plant	Furcellaria harvesting
	Aquaculture — freshwater	NL	(-)
	Agriculture	NL	(-)
	Forestry	NL	(-)
Production of energy	Renewable energy generation (wind, wave and tidal power), including infrastructure	installations-owf	Wind farms (operational and under construction)
		installations-wave	(-)
	Non-renewable energy generation	installations-platform	Fossil fuel energy production
		NL	Nuclear energy production
	Transmission of electricity and communications (cables)	line-electricity	Cables
		line-telecom	
Extraction of living resources	Fish and shellfish harvesting (professional, recreational)	fishing-industrial	Potting/creeling (FPO)
			Gillnet commercial fishery (GNS)
			Demersal long lining activity (LLS)
			Pelagic longlining activity (LLD)
			Bottom trawling activity (OTB, OTT, PTB)
			Surface and mid-water trawling (OTM, PTM)
			Demersal Danish seine (SDN)
			Demersal Scottish seine (SSC)
			Pelagic purse seining (PS)
			Scallop and blue mussel dredging (HMD)
		fishing-recreational	Recreational fishery (RG, [GN, LX])
		fishing-small-boat	Fishery with coastal and stationary gear (FPN, FYK)
	Fish and shellfish processing	NL	(-)
	Marine plant harvesting	NL	Maerl and *Furcellaria* harvesting
	Hunting and collecting for other purposes	NL	Game hunting of seabirds (eider, long-tailed duck, common scoter, velvet scoter)
		NL	Hunting of seals
		NL	Predator control of seabirds (cormorants)
Extraction of non-living resources	Extraction of minerals	extraction-sand	Extraction of sand and gravel
	Extraction of oil and gas, including infrastructure	extraction-oil	Oil platforms
		extraction-co2	(-)
		extraction-gas	(-)
		line-pipeline	Pipelines

	Extraction of salt	NL	(-)
	Extraction of water	NL	(-)
Physical restructuring of rivers, coastline or seabed (water management)	Land claim (permanent changes)	NL	Land claim (urban, industrial, leisure, agriculture)
	Canalisation and other watercourse modifications	NL	Watercourse modification (canalisation, culverting/trenching), Hydropower dams
	Coastal defence and flood protection	NL	Coastal defence (Sea walls, Breakwaters, Groynes, Flood protection etc.)
	Offshore structures (other than for oil/gas/renewables)	other-islands	(-)
	Restructuring of seabed morphology, including dredging and depositing of materials	other-dredging	Dredging sites
		other-dumping	Deposit of dredged material
		coast-deposit	
Tourism and leisure	Tourism and leisure infrastructure	NL	Marinas and leisure harbours
	Tourism and leisure activities	tourism-birdwatching	Recreational boating and sports
		tourism-boating	
		tourism-diving	
		tourism-recreation	
		tourism-seascape	
		tourism-bathing	Bathing sites, beaches
Transport	Transport infrastructure	other-port	Fishing harbours
			Oil terminals, refineries
		transport-infrastructure	Harbours
		other-bridge	Bridges
		other-tunnel	(-)
	Transport – shipping	Transport	Passenger shipping, Shipping (coastal), shipping density
		transport-anchorage	(-)
		transport-deep	IMO ships routeing guide
		transport-flow	IMO ships routeing guide
		transport-recommended	IMO ships routeing guide
	Transport-land	NL	(-)
	Transport- air	NL	(-)
Urban and industrial uses	Urban uses	NL	Urban land use
	Industrial uses	NL	(not used)
	Waste treatment and disposal	NL	Coastal wastewater treatment plants
Security/defence	Military operations	military-training	(-)
		military-radar	(-)
		NL	Waste disposal (munitions)
Education and research	Research, survey and educational activities	research-monitoring	(-)
		other-radar	(-)
(heritage)	(-)	heritage-landscape	(-)
	(-)	heritage-wreck	(-)
(nature)	(-)	nature-biodiversity	(-)
	(-)	nature-infrastructure	(-)
	(-)	nature-scs	(-)
	(-)	nature-spawning	(-)
(other)	(-)	other-multiuse	(-)

Most human activities (sea uses) are associated with several pressures. To support an initial screening, Table 2 gives an overview of which pressures are most likely associated with different human activities. The generalized, initial overview presented in the table should be further elaborated by more specific information when applied, based on project descriptions or published literature of relevance. An example of such application is shown in the case study on offshore wind farms in Chapter 5.

Table 2. Overview of potential relationships between human sea use and pressures in the Baltic Sea. The columns show principal pressures and the rows principal human activities as referred to in the MSFD (listed in Annex III of EC 2017b). For some of the human activities, additional specifications are given in brackets. The cells indicate which pressures can potentially be associated with each of the listed human activities. Cases were a data layer on human activity was directly used when creating the pressure layer in HOLAS II (HELCOM 2018a-b) are marked “X”. Other probable or potential combinations are marked “p”. These pressures were not explicitly linked to human activities data in HOLAS II, as the pressure was rather estimated based on monitoring and measurements at sea, but they may need to be considered when evaluating planning scenarios. Pressures marked (N) were not used in the HOLAS II Baltic Sea Impact Index, as they were considered to have a relatively minor impact, and in the case of marine litter due to lack of data. The list is developed based on the work of HELCOM TAPAS (2017), and HELCOM (2018a-b).

		Physical pressures			Input energy		Input of substances				Biological pressures				
Theme	**Activity**	**Change of seabed**	**Disturbance to seabed**	**Hydrological conditions**	**Sound (cont./impulsive)**	**Oth. energy (heat/EMF (N)**	**Hazardous substances**	Litter (N)	**Nutrients**	Organic matter (N)	**Disturbance of species**	**Extraction/mortality/injury**	Genetic modification (N)	Microbial pathogens (N)	**Non-indigenous species**
Cultivation of living resources	Aquaculture – marine	X	X	p				p	p	p	p	p	p	p	p
Production of energy	Renewable energy (wind farms)	X	X	X	p						p	p			p
	Non-renewable energy (fossil fuel energy production)		p			X	p				p				p
	Transmission (cables)	X	X												p
Extraction of living resources	Fish and shellfish harvesting		X		p			p			p	X			
	Marine plant harvesting		X		p			p			p	p			
	Other hunting and collecting										p	X			
Extraction of non-living resources	Extraction of minerals	X	X		p		p				p				
	Extraction of oil and gas	X	p	X	p		p				p				
Physical restructuring of rivers, coastline or seabed	Land claim	X	p	p											
	Watercourse modification	X	p	X						p	p				
	Coastal defence	X	X	p							p				
	Offshore structures	p	p								p				p
	Restructuring of seabed	p	p	p			p		p	p	p				
Tourism and leisure	Tourism and leisure infrastructure (marinas and leisure harbours)	X	p					p		p	p				
	Tourism and leisure activities (recreational boating)		X				p	p	p		X				
Transport	Transport infrastructure (harbours, oil terminals)	X	X	p	p		p	p			p				p
	Transport – shipping		X		p		p	p	p		p				p
	Transport - land	p	p	p	p		p		p		p				
Urban and industrial uses	Urban uses	p	p	p	p	p	p	p	p	p	X			p	
	Industrial uses (oil and gas refineries)	X	p	p	p	p	p	p	p	p	p	p		p	
	Waste treatment and disposal	p	p			p	p	p	p	p	p			p	

Security/ defence	Military operations		p		p		p	p	p		p	p			
Education and research	Research, survey and educational activities		p		p						p	p			
Heritage															
Nature															
Other - multiuse		p	p	p	p	p	p	p	p	p	p	p	p	p	p

4. Development of the BSII Cumulative impact Assessment Toolbox

To facilitate assessments of cumulative impacts following the outlined approach, we developed a BSII Cumulative impact Assessment Toolbox (BSII CAT) and tested it in the case studies described in **Chapter 5**. The key achievements of developing the toolbox were:

- Transparency in how cumulative impacts are assessed in the BSII by sharing the code and data for calculation
- Possibility to view the underlying ecosystem component and pressures layers
- Possibility to select layers individually and try different combinations, to address specific questions.
- Default sensitivity scores for calculating BSII are provided. It is possible to modify scores to find out their contributions
- An openly available toolbox is provided for further assessment. This can be used with either default data or own data and contains several modules (tools), as described below.

4.1. Tools included in the toolbox

The BSII Cumulative impact Assessment Toolbox includes the following tools:

Baltic Sea Impact Index tool (BSII tool) – calculates the Baltic Sea Impact Index. It uses data layers on ecosystem components and pressures (grid layers), as well as a sensitivity scores matrix as input, and creates a BSII grid layer as output. The tool also creates a BSII statistics matrix, which shows how much each ecosystem component and pressure combination contributes to total impact.

Baltic Sea Pressure Index tool (BSPI tool) – calculates the Baltic Sea Pressure Index. It uses data layers on pressures (grid layers), as well as a sensitivity scores matrix as an input, and creates a BSPI grid layer as output.

Ecological Value tool (EV tool) – supports the identification of areas with high ecological value. It uses data layers on ecosystem components (grid layers) and an ecological value matrix as input. The assessment is performed for each selected ecological value criterion and ecosystem component group, as identified by the matrix. The grid layers are further aggregated to create results for each combination of criterion and group, for all criteria within each group, and as a total ecological value grid layer.

Ecosystem Service tool (ES tool) – supports the identification of areas with high potential provision of ecosystem services. It uses data layers on ecosystem components (grid layers) and an ecosystem services matrix as input. The assessment is performed for each selected ecosystem service and ecosystem component sub-group, as identified by the matrix. Output grid layers are created for: each combination of ecosystem service and ecosystem component sub-group, as an aggregated result for each ecosystem component sub-group, and as a total ecosystem service grid layer.

Baltic Sea Impact Index Batch tool for Ecological Values or Ecosystem Services (BSII Batch tool) – calculates the Baltic Sea Impact Index with respect to areas important for ecological value or for the provision of ecosystem services, referring to the matrix approaches of the EV and ES tools. Upon selection, it addresses either each combination of ecological value criteria and ecosystem component group or each combination of ecosystem service and ecosystem component sub-group, following the same structure as in the EV and ES tools, respectively. As input, the tool uses data layers on ecosystem components and pressures (grid layers), as well as specific sensitivity scores matrices (See below). It creates BSII grid layers for each matrix as output. Optionally, the tool also creates BSII statistics matrices. The sensitivity scores matrices needed for input to this tool can be created with the Sensitivity score matrices for BSII Batch Tool.

Sensitivity score matrices for BSII Batch Tool – creates new sensitivity score matrices by combining existing matrices. Using the BSII sensitivity scores matrix and either the ecological value or ecosystem services coefficients matrices as input, the tool creates one specific sensitivity score matrix for each combination of ecological value criteria and ecosystem component group, or for each combination of ecosystem service and ecosystem component sub-group.

4.2. Availability

The complete BSII Cumulative impact Assessment Toolbox can be run by users who have ArcGIS configuration as stated in the technical manual and required only low to moderate previous experience in ArcGIS. The toolbox is available for download from GitHub. The download package includes a set of default data, which are Baltic Sea regional scale grid layers on ecosystem components and pressures, BSII sensitivity scores following HELCOM (2018b) and coefficient matrices for identifying EV and ES following Ruskule *et al.* (2019). Users can replace the default data with their own data if wanted. The download package also includes a user manual with detailed instructions on how to install and run the toolbox. In order to run the tools, the toolbox should be used together with ArcGIS Pro Desktop software.

A subset of analyses can be run using the online version, which will be available in February 2020[12] The online version will be supported by default data. It will be possible for the user to modify sensitivity scores and select which ecosystem component layers and pressure layers to include in the assessment. The benefit of using the online tool over the downloaded tool is that the user does not need to have any own GIS software installed.

4.3. Technical improvements

The main purpose of the BSII CAT is to provide transparency in how the cumulative impacts are assessed at the regional scale using the Baltic Sea Impact Index and to make the method available for further uses. The default data included in the toolbox cover the whole Baltic Sea. They cover human activities, pressures and ecosystem components as listed in the MSFD (EC 2017a-b), hence providing a connection point between the MSFD and MSP. **Chapter 3** outlines how common sea uses included in MSP related to this listing and potential pressures.

Compared to previously, the toolbox also contains some method developments, which were made in Pan Baltic Scope to allow for higher flexibility in possible assessment setups. For example, nested assessments can be applied to give a more balanced result between ecosystem components groups. This is suitable when ecosystem components are represented by different amounts of input data layers. As a second example, sets of analyses can be included in the same run, supporting the efficient assessment of multiple scenarios.

However, further methodological advancements should still be needed in the future in order to make it fully suitable for use in MSP. The example of connecting human activities to pressures is developed here. Following the linkage chain model (Knights *et al.* 2013) and in line with the needs of environmental assessment, the BSII CAT addresses the relationship between pressures and ecosystem components rather than focusing on impacts from human activities directly. Even though the main purpose in any management is to understand the role of human activities, this approach is based on that a species will respond to the total (cumulative) level of a certain pressure independently on how many or what type of human activities caused this. Hence, in the assessment, the intensity and distribution of a certain pressure

[12] https://maps.helcom.fi/website/bsii

represents the combined pressure from all human activities that give rise to it at the assessed scale. This approach gives a balance as it avoids the risk that pressures which are caused by several human activities are unduly over-estimated. Focusing on the pressures also allows for flexibility, as it is easier to incorporate information on if the pressure associated with a certain human activity varies among geographical areas, for example in relation to depth or wave exposure. It also makes it possible to include spatial differences in historical background levels. Last, it allows for flexibility, if a human activity transitions to more environmentally friendly technology. In this case, one can use information about the activity to redefine its link to the pressure without need to re-asses the sensitivity matrix, which is usually less precise and involves a more complex process.

However, maintaining transparency in how the activity-pressure link is quantified is still highly important, as it should be possible to estimate the relative contribution of different activities, to support identification of management measures. One technical difficulty in focusing the evaluation on the pressure layers is that it involves more analytical steps compared to more simplified approaches. To better support the evaluation of scenarios in MSP and maintain the analytical benefits described above, additional coding to make this step more automated would be beneficial.

5. Case studies

The following case studies were carried out:

A. Expansion of offshore wind energy

Offshore wind energy is spatially limited in the Baltic Sea today, but there is an expressed interest for expansion. Many countries have targets for increasing their capacity for wind energy, to increase the provision of renewable energy and reduce dependence on carbon-based fuels. Offshore wind farms may efficiently support the transformation to renewable energy, but also involve the expanded use of sea space and potential environmental impacts. Our first case study was carried out to assess cumulative impacts on the environment under different scenarios for offshore wind farm development at the Baltic Sea regional level.

B. Cumulative impacts on green infrastructure

The applied green infrastructure concept recognises areas with high ecological value and high contribution to ecosystem services (Liquete *et al.* 2015). Knowledge of areas important for green infrastructure can guide MSP by identifying areas where pressures from human activities should be avoided or minimised to support long term sustainability. A Pan Baltic Scope green infrastructure concept was developed in activity 1.2.4 (Ruskule *et al*. 2019). Our second case study explores how to evaluate cumulative impacts with a focus on ecosystem components important for green infrastructure.

5.1. Case study on offshore wind farms

5.1.1. Background

The capacity for wind energy production is expected to increase in the near future in the Baltic Sea, as the implementation of national strategies for renewable energy. In the EU, binding targets are set to have at least 40% reduction in greenhouse gas emissions by 2030 compared to 1990 levels, and a binding target of at least 27% share of renewable energy consumption in Europe (EC 2018).

Areas of potential or assigned interest for offshore wind energy production are identified in the countries MSP and sectoral plans. Areas which may be suitable for OWF are identified based on criteria, such as wind conditions (which should typically be at least on the level of 6-9 m/s), depth conditions (typically shallower than 40-60 m), and distance from the shore (which is however highly variable depending on turbine size, local conditions and country), and potentially conflicting sea uses.

Comparing different options for the planning of OWF, it is of high importance to consider environmental aspects, to understand what impacts the offshore wind farms may have on species and habitats.

Question asked

The purpose of the case study was to approach the question:

- *How would OWF development in the Baltic Sea scale affect cumulative impacts on the environment on a regional scale?*

5.1.2. Method

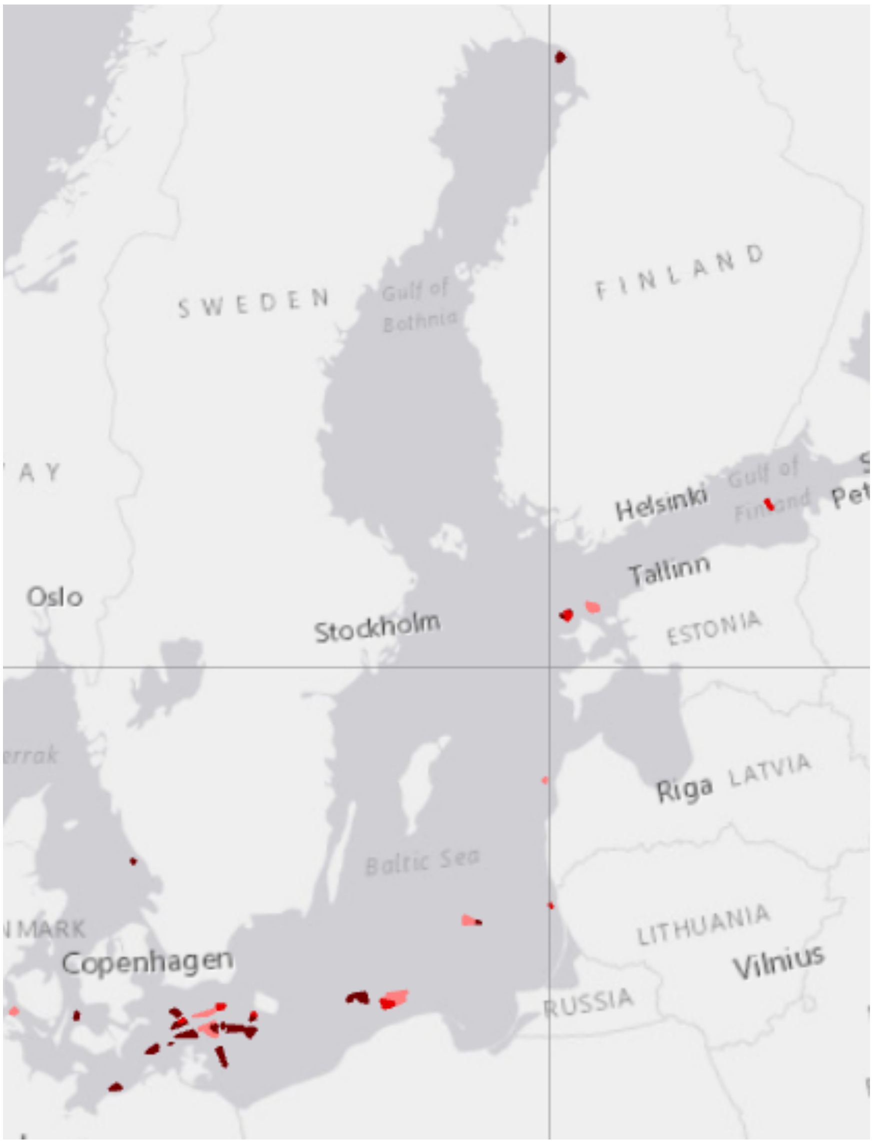
The study was based on two data sets indicating possible localisations for future OWF in the Baltic Sea:

MSP data: Data from national plans on the spatial designations of areas for OWF development were obtained from contacts in the Pan Baltic Scope project. Data from Estonia, Finland, Germany, Latvia, Sweden and Poland were provided. However, it should be recognised that the data from national plans are still in development and may change. For example, in Estonia only the first draft was published at the time of creating the scenarios, and in the end the adopted version may be different. Also, the role of MSP in relation to OWF development varies among different countries. For example, in Finland the plan is typically held at a highly strategic level without area designations in much of the coastline, whereas a binding site-development plan came into force in Germany entailing a legal need of OWF production and an expected full development in relation to the plan in the German EEZ.

For the purposes of the case study, the **MSP scenarios** represented three different levels of fulfilment of OWF development, corresponding to 25% (S1), 50% (S2) and 100% (S3) within each of the assigned areas (**Figure 5**).

Figure 5. Overview of the applied MSP scenarios representing different OWF development levels. Black colour represents areas which were included in all three MSP scenarios (development levels S1, S2, and S3), areas in red were included in S1 and S2, and areas with the lightest colour were only included in S3. The scenarios were applied in order to test the cumulative impact assessment approach for different levels of OWF development, without assumption on how realistic the different scenarios are.

Baltic Sea regional scenarios: An additional source of information was obtained from the BalticLINes project, representing the potential development of OWF at the whole Baltic Sea level (Hüffmeier and Goldberg 2019). The purpose of these scenarios was to increase transnational coherence of shipping routes and energy corridors, circumventing cross-border mismatches. The OWF scenarios describe three levels of development for each of the years 2030 and 2050 (**BalticLINes 2030** and **BalticLINes 2050,** Figure 6). In each of these, level "low" represents a stagnation scenario with low OWF development (7.4 GW in 2030 and 31 GW in 2050), and level "central" represents the most likely scenario based on the underlying analyses (9.1 in 2030 and 58 GW in 2050). Level "high", again, represents the most progressive scenario, highlighting what it would take to reach the 2-degree target stated in the Paris agreement (14 GW in 20130 and 150 GW in 2050; Hüffmeier and Goldberg 2019).



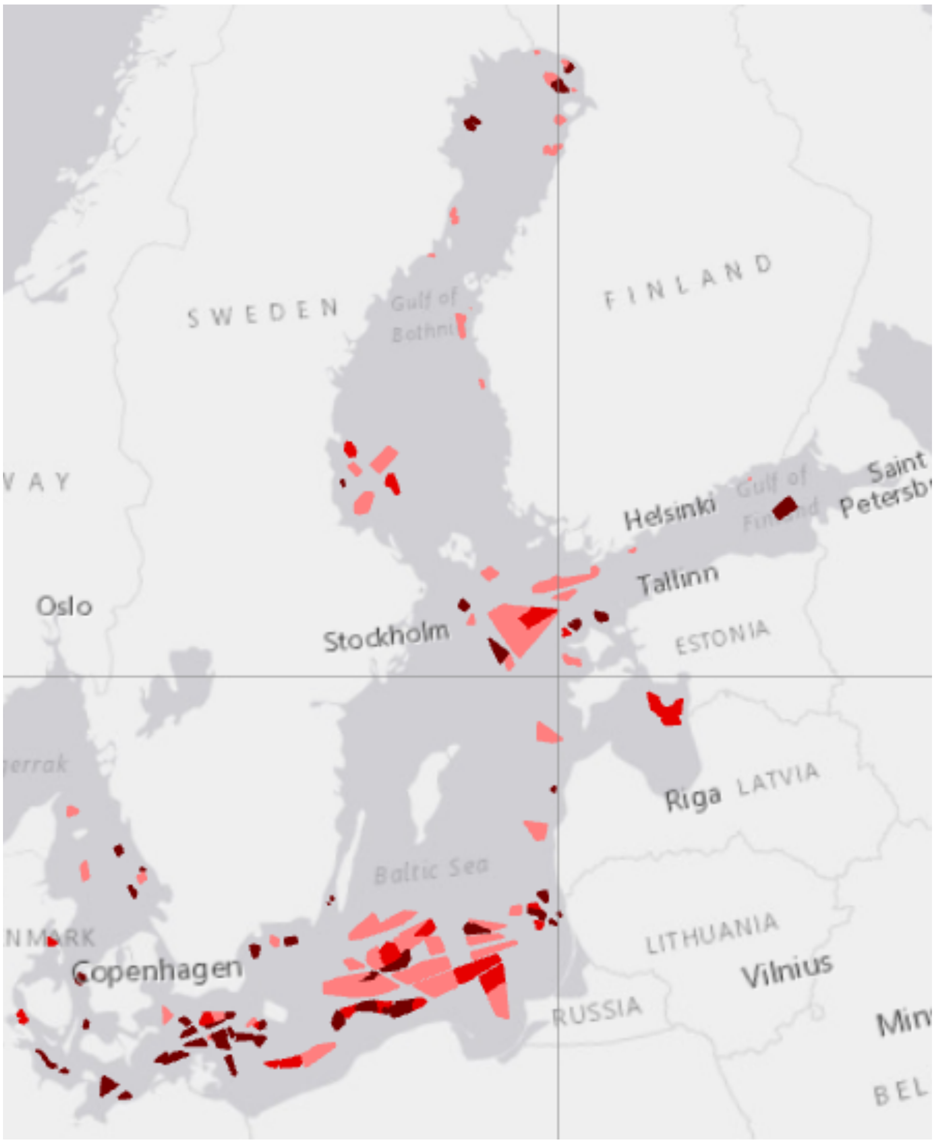


Figure 6. The Baltic LINes data, depicting the BalticLINes 2030 scenarios above and BalticLINes 2050 scenarios below. In each map, black polygons indicate areas that were included in all scenarios ("Low", "Central" and "High"), red polygons were included in the "Low" and "Central" scenarios, and polygons with the lightest colour were only included in the "High" scenarios[13].

For all scenarios, assessment data were created in GIS by adding points, representing turbines, to the initial data sets in which planned OWF areas were identified by polygons. The turbines were assumed to have the same standard distance from each other in all cases (1 240 m in a rectangular pattern). For the MSP S1, S2 and S3 scenarios, each polygon was filled gradually from west to east until the planned fulfilment level of that scenario was reached. Some polygons in the data were so small they would only be filled by a low number of turbines under some of the scenarios. To avoid the creation of unrealistically small OWF, polygons were only included in the scenarios if the total number of turbines would be at least 30 for scenarios 1 and 2, and 10 for scenario 3.

Quantification of pressures

[13] The figure is based on data from the Baltic Lines report (Hüffmeier and Goldberg 2019). However, the areas around Hiiu island and the indicated area between Hiiumaa and Saaremaa in Estonia are today abolished.

Pressures potentially attributed to OWF were identified by initial screening, following **Table 2 (Chapter 3)** and further quantified as presented in **Table 3.** The quantification generally follows the same approach as was used in the baseline layer (Baltic Sea Impact Index, HELCOM 2018a, see **Section 2.1**). When a BSII approach was not available or not applicable to a certain pressure, the pressure was quantified in alignment with the national approach of Sweden (Symphony, see **Section 2.2.7**). For some pressures, evidence of how the layer would be quantified was too weak to be added on the applied Baltic Sea scale, even though these pressures may still be important.

As a result, modified layers were included for three physical pressures: *Physical loss of habitat*, *Physical disturbance to habitat* and *Changes to hydrological conditions*, as well as to three fish extraction layers: *Extraction of herring*, *cod* and *sprat*. In addition, a new pressure layer was introduced to represent *Bird exclusion* from the OWF area.

In the quantification it was recognised that a pressure could either increase (if it is attributed to the presence of the OWF), diminish (if it is attributed to a human activity that can no longer occur in that site or any neighbouring site due to conflicting sea use) or be redistributed (if the conflicting sea use can be carried out somewhere else instead; **Table 3**).

All pressures were characterised in relation to the operational phase of the wind farm. Hence, disturbances relating to construction were not considered.

Assessment

Cumulative impacts were assessed using the BSII Cumulative impact Assessment Toolbox (see **Chapter 4**). The output provides a raster layer on the spatial distribution of total cumulative impact in the Baltic Sea for each assessed scenario, as well as a matrix of impact scores to support more detailed numerical evaluation.

The baseline against which the scenarios were evaluated was that of the most recent HELCOM BSII (HELCOM 2018a-b), which reflects the situation during years 2011-2016 in the Baltic Sea. The total capacity of wind farms at that time was around 1.4 GW, with 531 turbines reported by HELCOM (2018c).

For assessing the scenarios, modified pressure layers were included, as shown in **Table 3**, while all other pressures were kept the same as in the baseline (HELCOM 2018a). The ecosystem component layers and sensitivity scores were also identical to the baseline (2018b, **Annexes 1-3**). The new layer on bird exclusion was given sensitivity score 2, as in SwAM (2019). The analyses were run using raster files with a 1x1 km grid.

The full assessment was run for the MSP scenarios and the *BalticLINes 2050* scenarios. In addition, the BalticLINes 2030 scenario was also included with respect to impacts from the pressures *Physical loss of habitat*, *Changes to hydrological conditions* and *Bird exclusion*.

Table 3. Pressures associated with offshore wind farms in the case study. "Pathway" gives the motivation for pressure modification. "Modification" describes how the layer was modified. The cell size was 1x1 km in all layers.

Pathway	Modification
Physical loss of habitat	
The turbines cover part of the original seabed which cannot be accessed by organisms any more. The diameter of each turbine is small, but an extra area around the turbine is assumed to be covered by scour protection	Added pressure: 30 m impact distance from each turbine, no decline, full weight (1) (HELCOM 2018b) In the scenarios, the new data is added to the baseline layer, ensuring that the resulting value is not higher than 1 in any cell.
Physical disturbance of habitat	
Both increased and decreased pressure levels are considered: **1) Physical disturbance of the seabed may increase close to the turbine foundations due to altered water currents;** **2) Physical disturbance attributed to activities which are not compatible with OWF are expected to be removed, or redistributed to other location**	Added pressure: 100 m impact distance from each turbine, sharp decline. Rescaled as in baseline, including downweighing to values 0-0.2 (HELCOM 2018b) Removed pressures: Any physical disturbance attributed to the human activities dredging, depositing, sand and gravel extraction, coastal defense, or mariculture removed from the OWF polygon. Individual human activity layers were rescaling and weighted in the same way as in the baseline. Redistributed pressures: Any physical disturbance attributed to the human activity trawling was redistributed from the OWF polygon to other parts of the corresponding ICES rectangle. Rescaled following the baseline, hence individual cells in the modified layer can have values above 1 (see also extraction of fish, below). For the final pressure layer, all modified human activity layers were summed and rescaled to values between 0 and 1.
Hydrological conditions	
The physical presence of the turbines alters the water movement in their vicinity	Added pressure: 300 m impact distance, linear decline, weight 1. In the scenarios, the new data is added (sum) to the baseline layer while ensuring that the resulting value is not higher than 1 in any cell
Exclusion of birds [new pressure layer]	
The rotor blades excluded wintering and feeding seabirds from the area	3000 m impact distance, linear decline, weight 1 (SwAM 2019) was applied as a precautionary estimate.
Input of sound: continuous	
Vibrations in the turbines stemming from the rotor blades give rise to underwater sound which is disturbed in the wind farm area	Not applied due to uncertainties in how it would be quantified in relation to other ambient sounds, such as from transportation routes
Non-indigenous species	
The new habitat created by the turbines and potential scour protection forms a novel habitat and may form a stepping stone for non-indigenous species	Not applied due to uncertainties in how it would be quantified in relation to the existing layer which measures the rate of new observations
Extraction of fish	
The fish extraction layers (cod, herring, sprat) in BSII describe the extraction of fish due to large scale trawl fishing, which is in most cases not compatible with OWF.	Redistributed pressure: All fish extraction is redistributed from the OWF polygon to other parts of the corresponding ICES rectangle, confined to cells where fishing activity is already indicated in the baseline layer. The redistribution involves moving a pressure value from one cell in the raster to other cells where fishing may already occur. Hence, resulting rasters in the scenarios can have values above 1.

5.1.3. Results

The total cumulative impact in the scenario with the highest OWF development, the *BalticLINes 2050 High*, is shown in **Figure 7.** According to the results, this most extreme case caused a relative change in total cumulative impact on the Baltic Sea scale of around 0.34 %. This is partly because each pressure has a relatively limited distribution close to each OWF by the assumptions of the analysis (**Table 3)**, but the results also reflect that many widely distributed pressures which contribute to the total cumulative impact in the Baltic Sea are not affected by the OWF, such as eutrophication.

Cumulative impacts from bird exclusion were not included in the total estimate since this is a new layer that was not included in the baseline. Additionally, there remain uncertainties in relation to the assessment of *Bird exclusion* at Baltic Sea scale which are discussed in separate below.

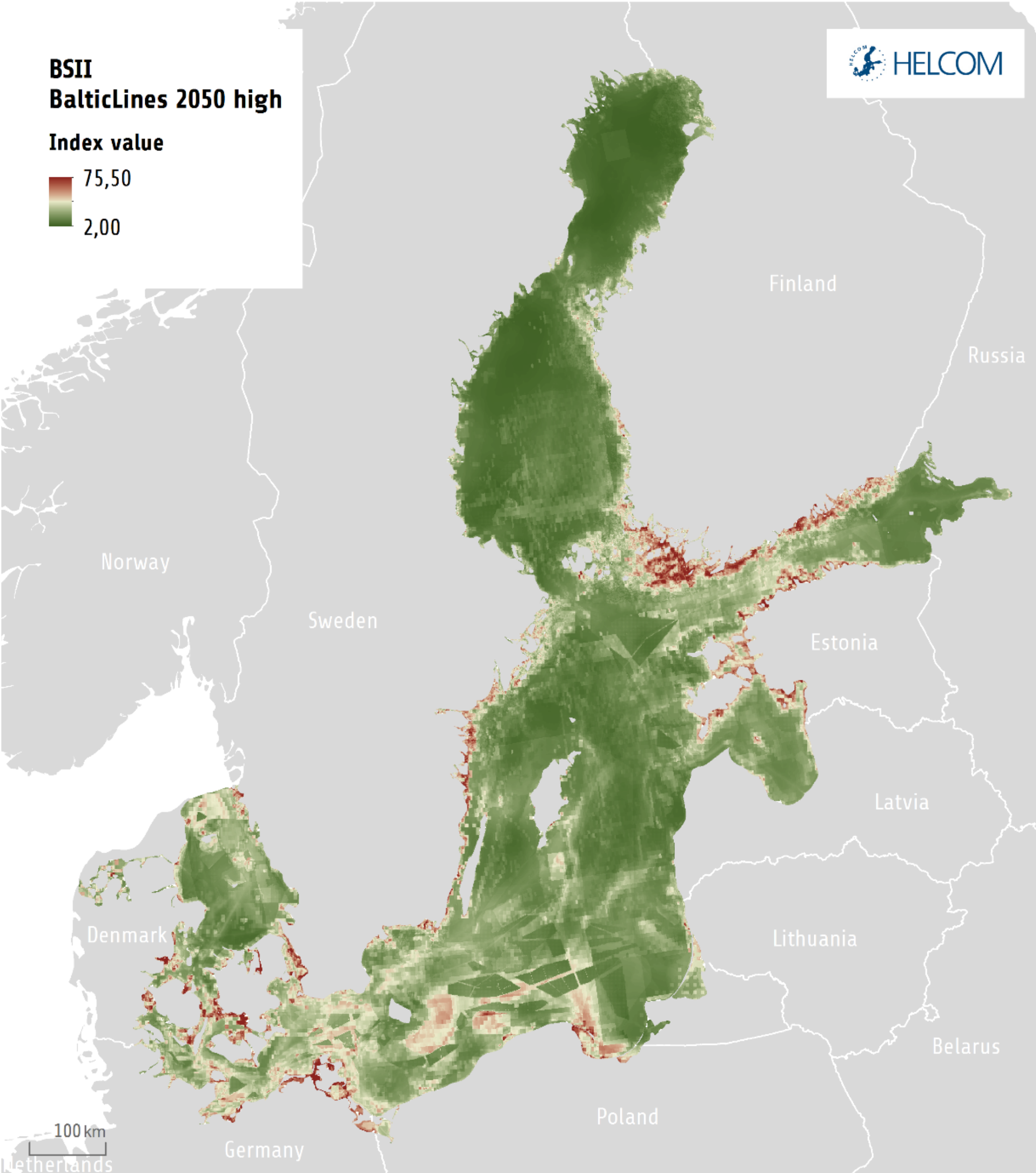


Figure 7a. Total cumulative impact in the BalticSea according to the *BalticLINes 2050 High* scenario. For comparison, **Figure 7b** shows results for the baseline (BSII of 2011-2016: HELCOM 2018a).

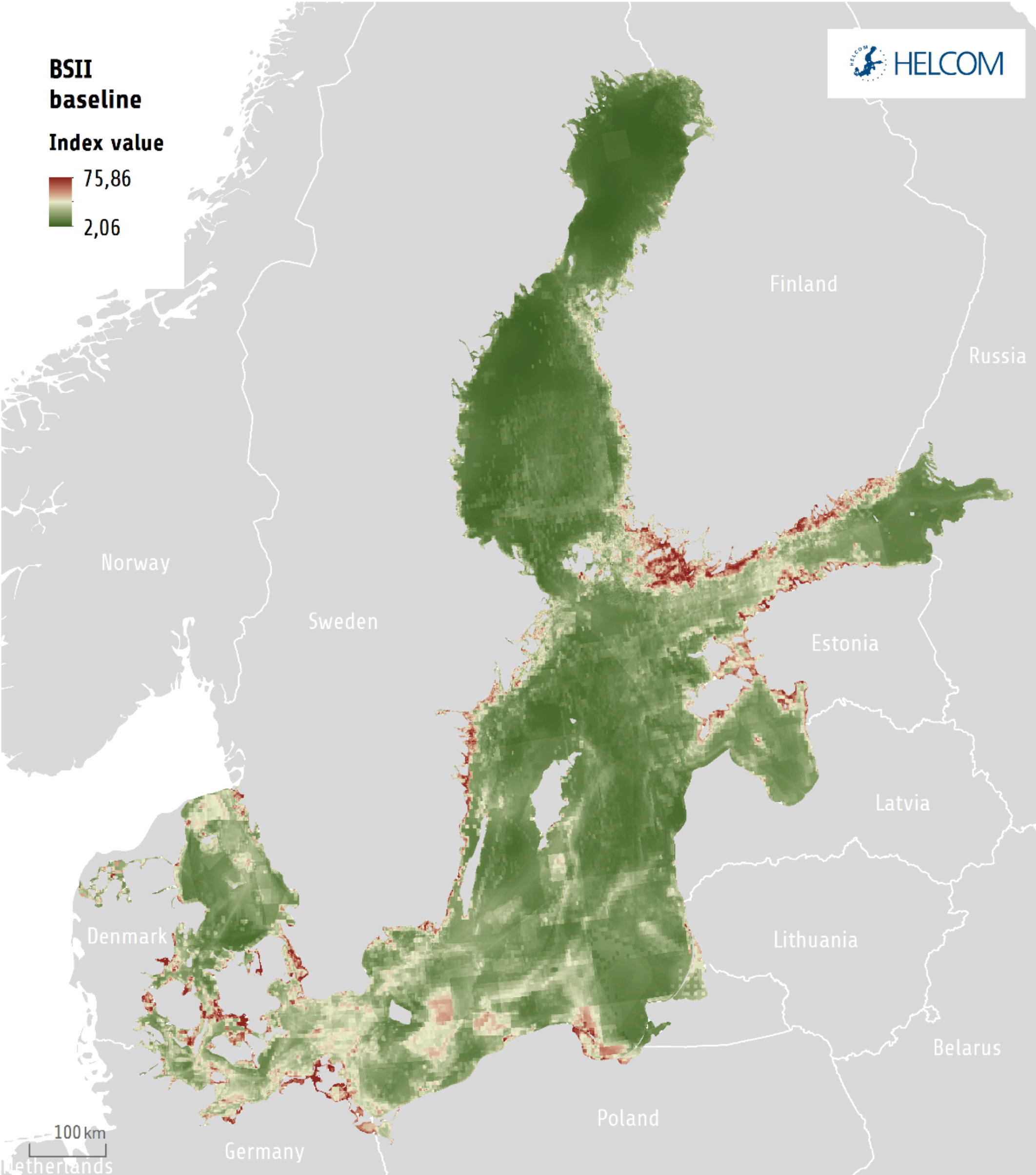
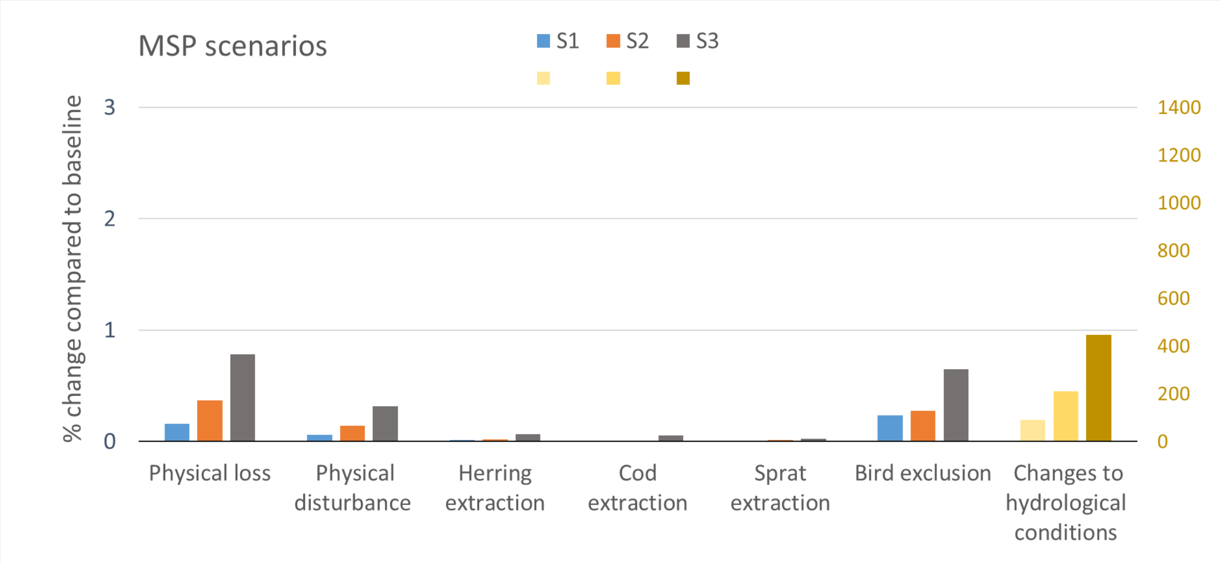


Figure 7b. Cumulative impacts according to the baseline scenario.

Focusing on only those pressures that were modified due to OWF development in our approach, the relative change ranged from 0.2% (increased *Extraction of herring*) to 2.3% (*Physical loss of habitat*; **Figure 8)**, except for *Changes to hydrological conditions* which increased manifold as this pressure is close to non-existing in the Baltic Sea today.



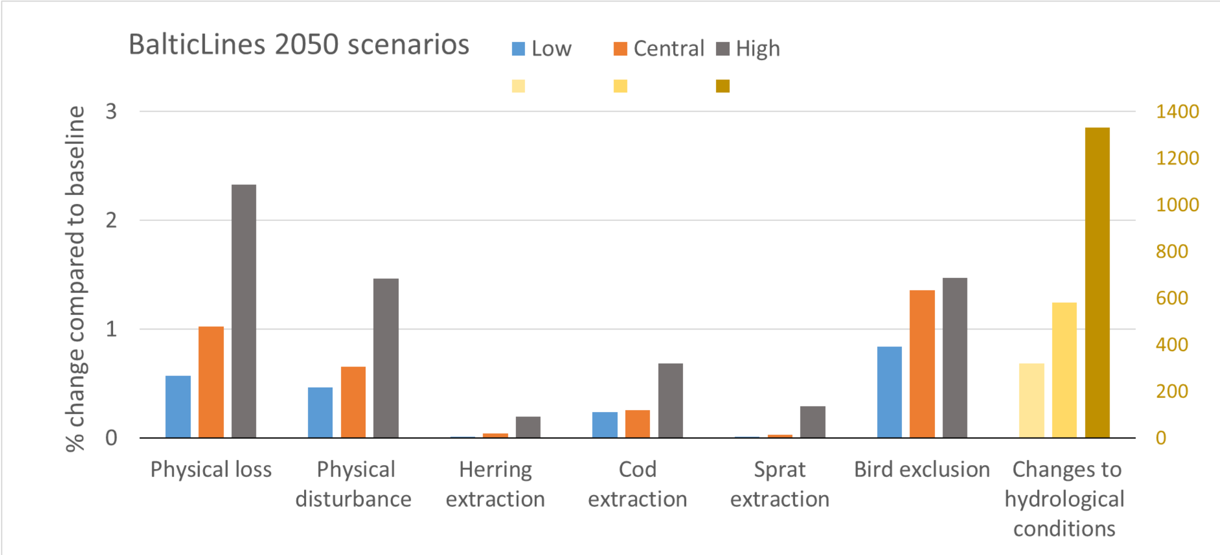


Figure 8. Relative changes in cumulative impacts on species and habitats attributed to individual pressures associated with OWF development, for the applied MSP scenarios (above) and the BalticLINes 2050 scenarios (below). Note that results for *Changes to hydrological conditions* are shown on separate axes. The rates of change are quantified related to corresponding values for the same pressures in the BSII of 2011-2016 (HELCOM 2018a) in all cases but for *Bird exclusion*, which is compared with the BSII pressure *Physical disturbance of species due to human pressure* (Annex 1) since bird exclusion from OWF is not included in the original BSII. See text for a discussion on data uncertainties in the layer on bird exclusion.

The results for the pressure *Physical disturbance of habitats* reflects the combination of changes in several human activities. A certain increase in physical disturbance was assumed in the OWF area due to the presence of the OWF foundations, while some other human activities typically associated with physical disturbance were deemed not compatible with OWF. Hence, any disturbance associated with dredging, depositing, sand or gravel extraction, coastal defence, and mariculture were removed from the OWF area in the modified pressure layer, while physical disturbance arising from trawling was relocated (**Table 3**). Some other human activities in the Baltic Sea are also attributed to causing physical disturbance but were not overlapping with the OWF areas. Certain types of physical disturbance were kept, such as those associated with cables and pipelines, shipping and boating. A close-up view on the pressure layer for the *BalticLINes 2050 High* scenario is shown in **Figure 9**.

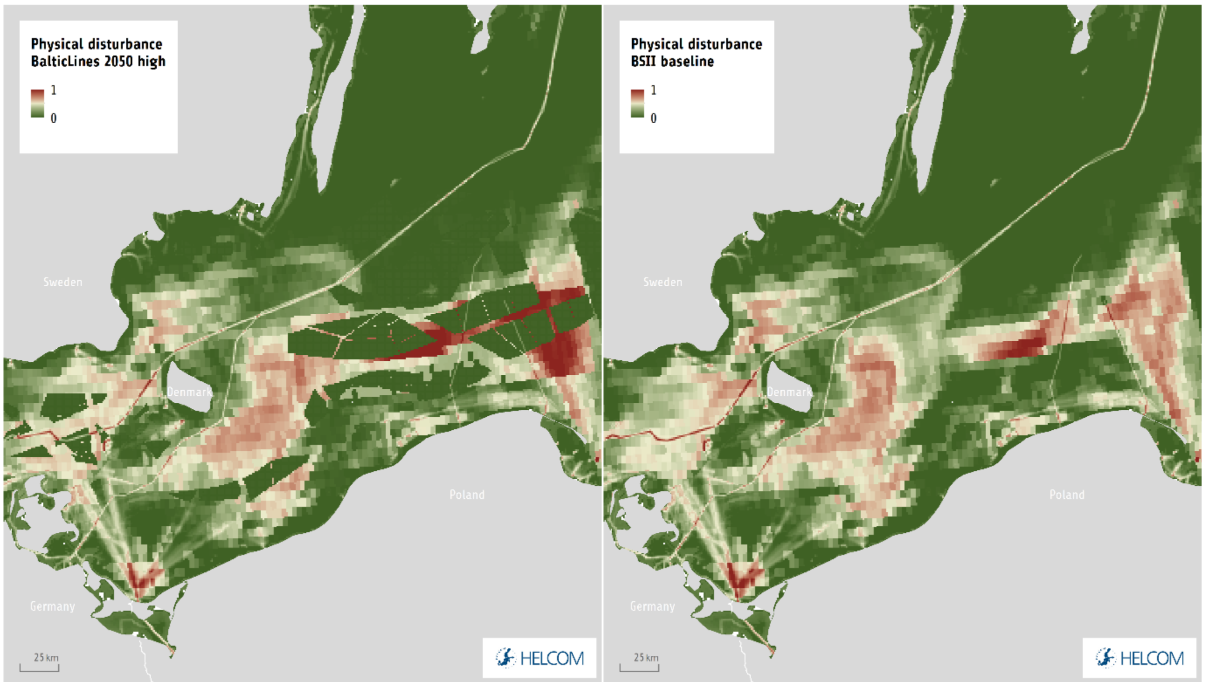


Figure 9. Close up view on the resulting pressure layer for physical disturbance according to the *BalticLINes 2050 High* scenario (left). The corresponding baseline layer is shown for comparison (right).

Pressures representing extraction of fish were expected to be fully redistributed under OWF development. A close-up view on the pressure layer *Extraction of cod* according to the *BalticLINes 2050 High* scenario is shown in **Figure 10**.

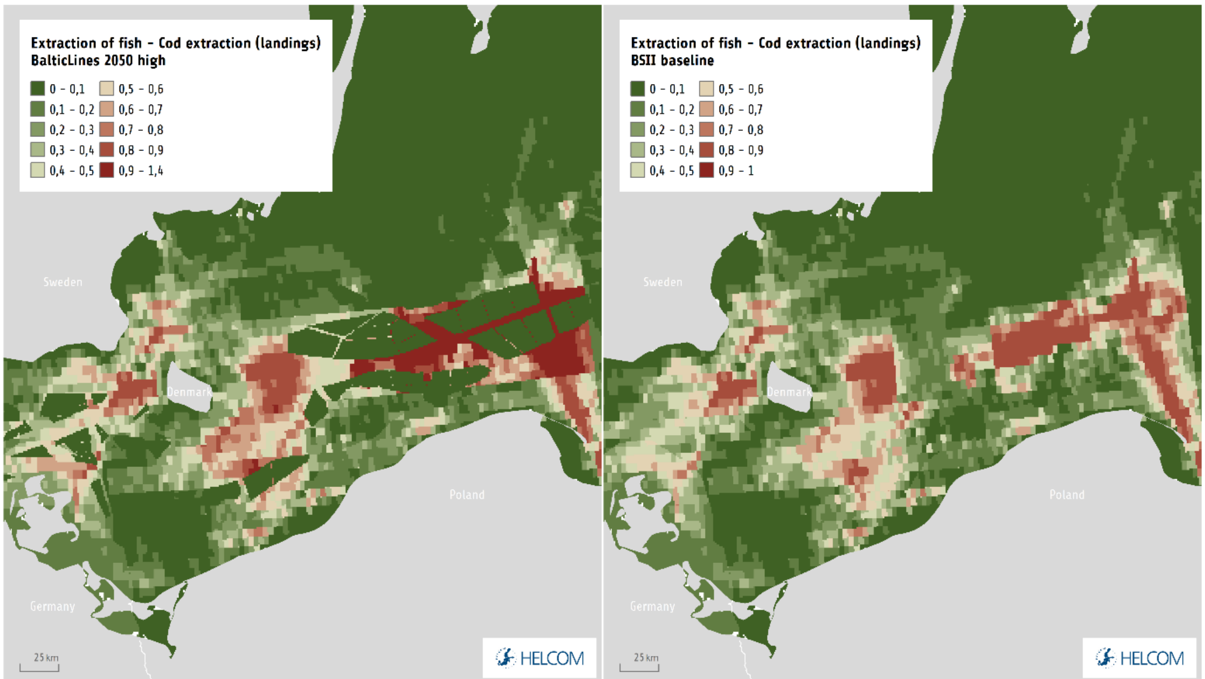


Figure 10. Close up view on the resulting pressure layer for extraction of cod according to the *BalticLINes 2050 High* scenario (left). The corresponding baseline layer is shown for comparison (right).

Changes with respect to all applied scenarios are shown in **Figure 11** for the three pressures *Physical loss of habitat*, *Changes to hydrological conditions* and *Bird exclusion*. The level of impact increased with the increased development of OWF, but with slightly different rates. This reflects that the rate of increase depends both on the location of the OWF, as the impact increases with respect to species and habitats that are present in the OWF area, and on how sensitive these species and habitats are to the pressure, as the impact increases more if they have high sensitivity to the concerned pressure.

However, for the layer *Bird exclusion*, it should be noted that the results do not truly reflect cumulative impacts due to uncertainties in the data on birds. The currently available regional data layers on bird distribution do not encompass important areas for several bird species with well-known distribution in open sea (Skov *et al*. 2011).

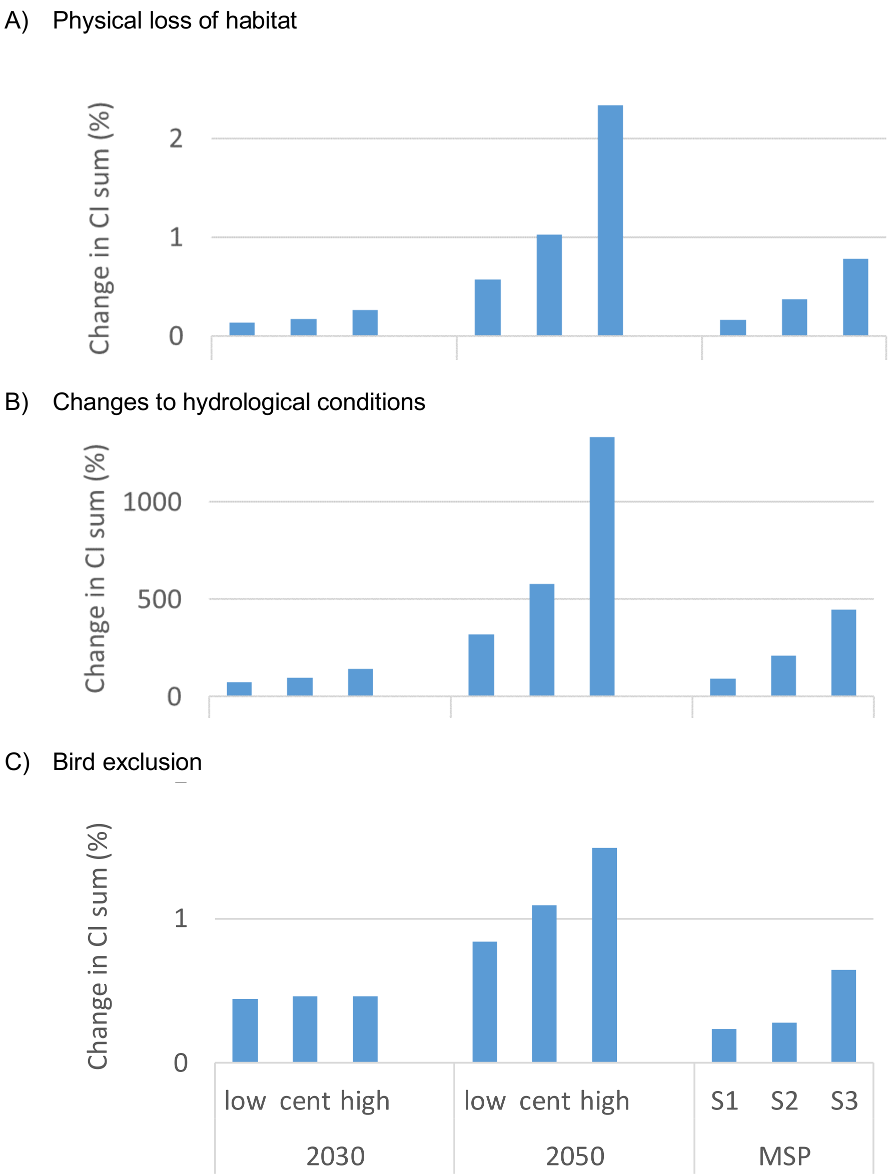


Figure 11. Changes in cumulative impact on species and habitats attributed to selected pressures associated with OWF development, applied to all scenarios: BalticLINes 2030 Low, Central and High, BalticLINes 2015 Low, Central and High and MSP Scenarios S1-S3 **.** Changes are given as % change with respect to a) *Physical loss of habitat*, b) *Changes to hydrological conditions* and c) *Bird exclusion*. For (a) and (b) values are estimated in relation to corresponding values for the same pressures in the BSII of 2011-2016 (HELCOM 2018a). For (c) values are estimated by comparison with the BSII pressure *Physical disturbance of*

species due to human pressure since bird exclusion from OWF is not included in the original BSII. See text for a discussion on data uncertainties in this part of the assesssment. Note that the scales of the vertical axes vary strongly.

5.1.4. Evaluation of the case study on OWF

The case study on offshore wind farm development shows an example of how cumulative impacts on the environment can be evaluated spatially in relation to development scenarios at the Baltic Sea scale. The results give an overview of the relative change in cumulative impact and which pressures are mainly associated with this.

Analyses, as described here, can potentially also show which species and habitats are the most impacted under different scenarios, to understand how impacts can be minimised. However, due to uncertainties in many of the underlying ecosystem components, we chose to not present the scenario results in this level of detail. Some of the data on species and habitats that were included in these analyses are associated with high uncertainty, and the applied resolutions may vary among different layers. If the same models were applied to more specific and detailed data layers, the accuracy of the expected outcomes and the range of conclusions that can be made would be improved.

In addition, the results are dependent on what assumptions are made about pressures associated with the OWF, and at what intensity or distance from the source these occur. However, the same assumptions were used in all scenarios that were compared with each other in this case study.

Given that the uncertainties associated with the method and underlying data sets are minimised and acknowledged, we believe that scenario-based analyses at the regional scale as presented here can provide a valuable way to compare environmental impacts across scenarios and different potential planning solutions. The models will not answer all the questions and will not replace decision-making, but they can serve as valuable tools to support planners when they make decisions.

The development of modified pressure layers attributed to each of the assessed scenarios was relatively time-consuming. Part of the work could be facilitated by incorporating the calculations directly to the assessment tool.

5.2. Case study impacts on green infrastructure

5.2.1. Background

The case study to assess impacts on green infrastructure is related to concepts developed in the Pan Baltic Scope activity on green infrastructure. The concept builds on the approach of Liquete *et al.* (2015) and defines green infrastructure as a combination of aspects relating to ecological value and ecosystem services.

By this concept, areas important for green infrastructure are identified by the presence of species and habitats associated with different ecological value criteria or with contributing to different selected ecosystem services. Ruskule *et al.* (2019) developed matrices to describe these associations in relation to the ecosystem component data layers used in the HELCOM BSII. However, for the ecosystem component fish, maps on essential fish habitats developed in Pan Baltic Scope (HELCOM 2019) were used instead (**Annex 2**). The matrices and the resulting maps on green infrastructure are presented in more detail in Ruskule *et al*. (2019).

For use in MSP, it is additionally relevant to ask how these identified areas may be affected by pressures from human activities, so that maintaining green infrastructure can be included as an explicit objective of the plan.

Question asked

The purpose of the case study was to address the question:

- *In what parts of the Baltic Sea are impacts on green infrastructure particularly high?*

5.2.2. Method

Impacts were assessed with a focus on those ecosystem components that are associated with contribution to the green infrastructure aspects of ecological value or ecosystem services, based on Ruskule *et al.* (2019). We focused on ecosystem components related to habitats. This encompassed ecosystem components within the following groups: benthic habitats (including benthic landscapes, Natura2000 habitats and habitat-forming species), essential fish habitats and bird habitats (**Annex 2**).

Impacts were assessed using a further developed version of the Baltic Sea Impact Index, which was designed within the Pan Baltic Scope project to support the analyses presented here (**Chapter 4**). The assessment applied a hierarchical approach, following the same concept as for the mapping of green infrastructure by Ruskule *et al.* (2019).

The pressures assessed were the same as in the BSII (**Annex 1**), but the pressures impulsive noise and radionuclides were not included. The sensitivity scores used are shown in **Annex 3.**

Assessment of impacts on ecological values

For ecological value aspects, impacts were first assessed separately for each of the six ecological value criteria included in the green infrastructure concept, as well as for each ecosystem component group (benthic habitats, essential fish habitats or bird habitats, **Figure 12**). These results were subsequently aggregated to get an assessment of impacts on ecological values related to each ecosystem component group taken together. Last, these three maps were aggregated to get the overall assessment of impacts on ecological values. By applying such a hierarchical approach, results for each ecosystem component group have equal weight in the results even in cases when the number of underlying maps differs.

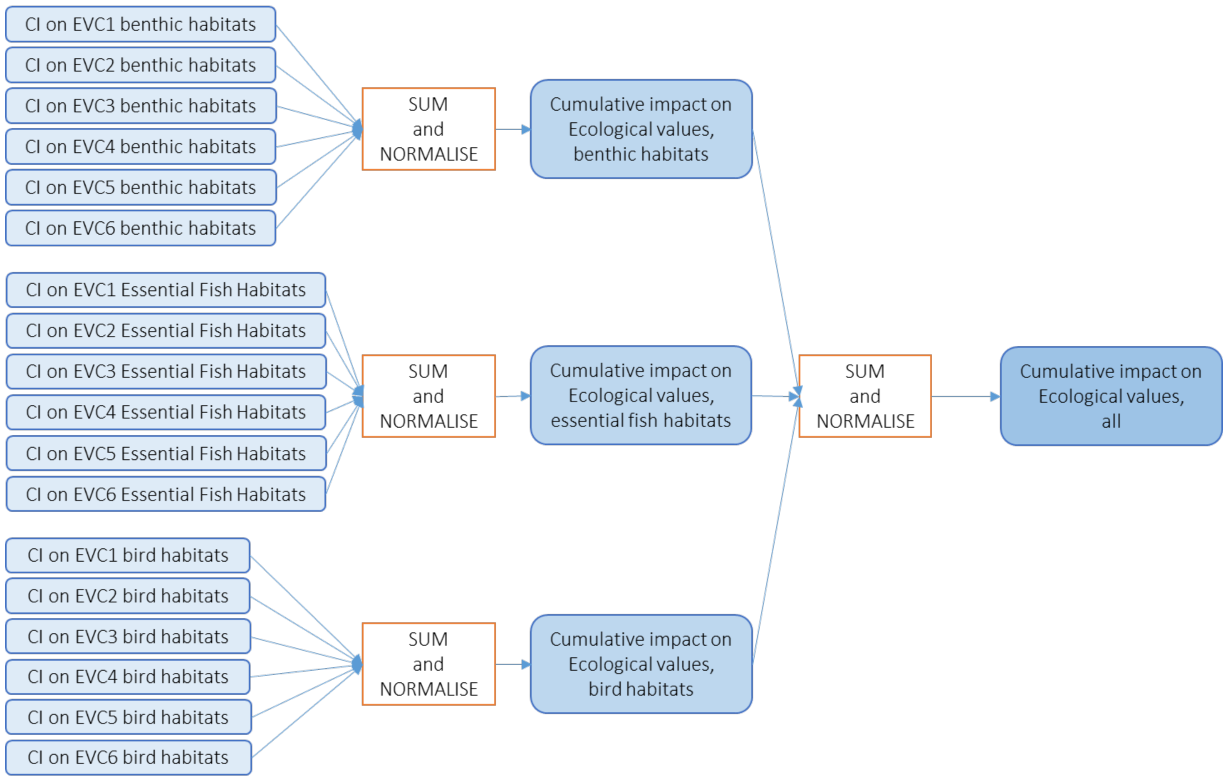


Figure 12. Aggregations applied to the assessment of impacts on ecological value.

Assessment of impacts on ecosystem services

For the assessment of impacts on ecosystem services, impacts were first assessed separately for each of the ten ecosystem services included in the green infrastructure concept, as well as for five ecosystem component sub-groups: benthic landscapes, Natura2000 habitats and habitat-forming species, essential fish habitats and bird habitats.

The subsequently applied aggregation and grouping was different from the one used for ecological values. Essential fish habitats were aggregated together with the other benthic habitats in order to avoid unmotivated double-counting, as they partially represent the same underlying data aspects. The layers were merged using the maximum values in each cell, as a modification to account for data gaps in some of the layers. Last, the result for the benthic ecosystem combined and that for bird habitats were aggregated to get the overall assessment of impacts on ecological services (Figure 13).

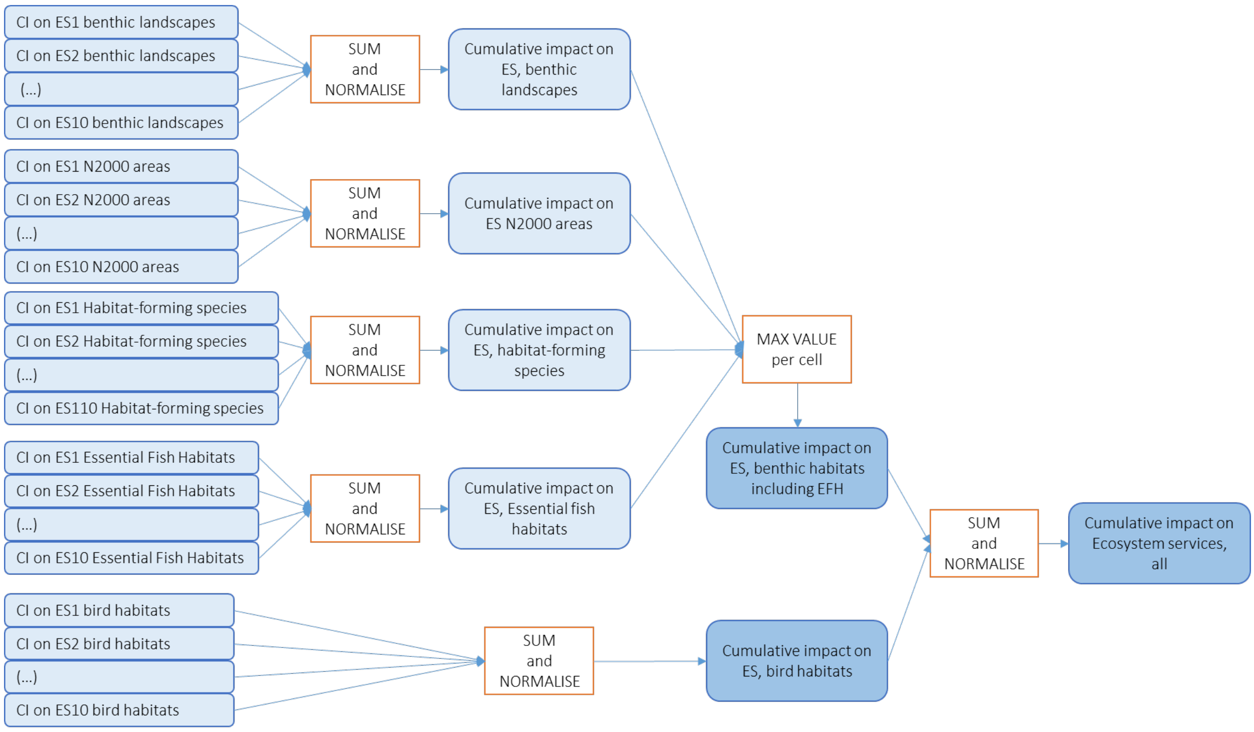


Figure 13. Aggregations applied to the assessment of impacts on ecosystem services.

5.2.3. Results

The maps below show results for the cumulative impact assessment when focusing only on areas identified as being of key importance for green infrastructure, specifically for ecological values (**Figure 14**) and ecosystem services (**Figure 15**). For comparison, each result is shown next to the corresponding map on areas of importance for contributing to ecological values or ecosystem services, respectively.

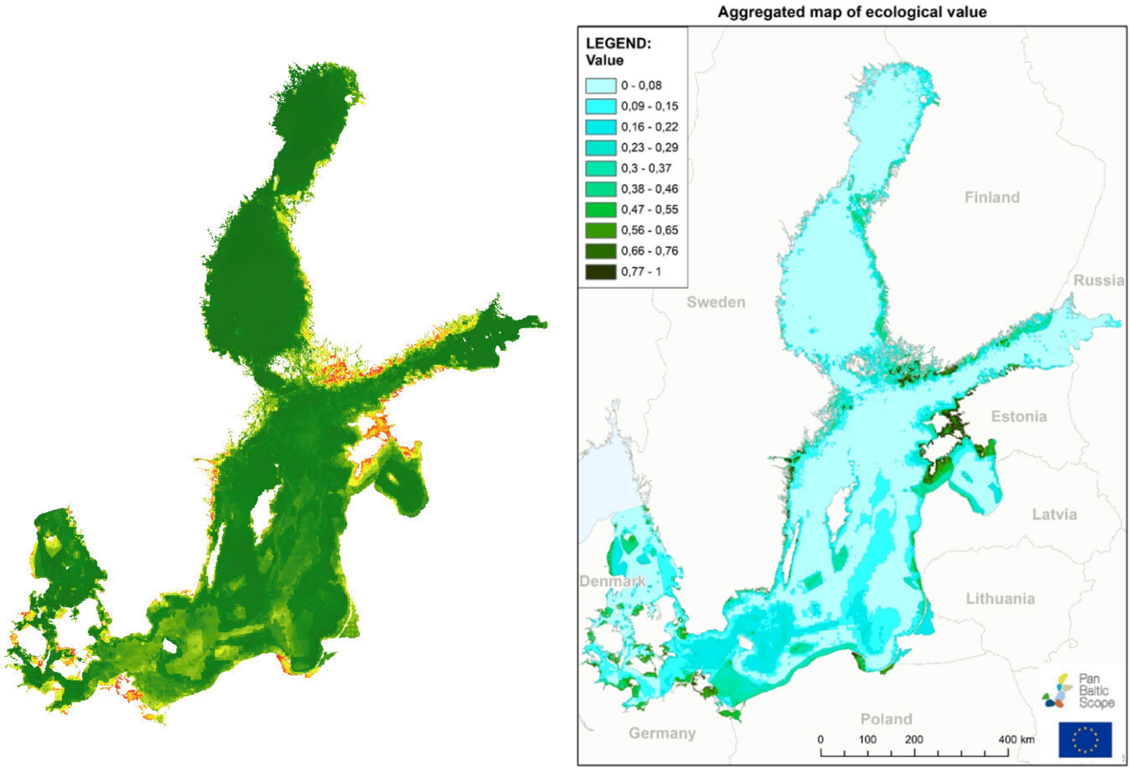


Figure 14. Output map from cumulative impact assessment focusing on areas of particular importance for ecological values. The example case study is applied to the same data as in Ruskule *et al.* (2019). The map to the left indicates where impacts on these areas are potentially the highest, so that increasingly red colour indicates a higher impact. For comparison, the distribution of areas important for ecological values, as in Ruskule *et al.* (2019) is shown to the right. The cumulative impact assessment map shows the same areas, but weighs them by the estimated cumulative impact to pressures.

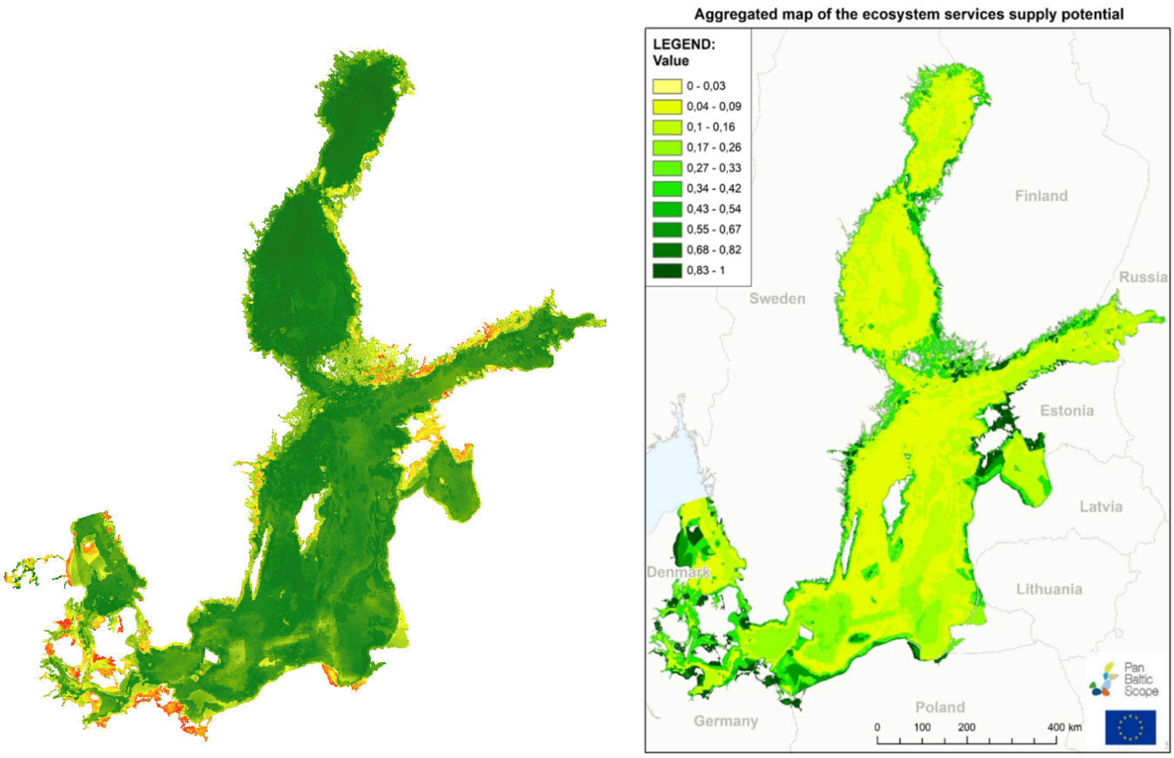


Figure 15. Output map from cumulative impact assessment focusing on areas important for the provision of ecosystem services. The example is applied to the same data as in Ruskule *et al.* (2019). The map to the left indicates where impacts on these areas are potentially the highest, so that increasingly red colour indicates a higher impact. For comparison, the distribution of areas important for ecosystem services provision, as in Ruskule *et al.* (2019) is shown to the right. The cumulative impact assessment map shows the same areas, but weighs them by the estimated cumulative impact to pressures.

5.2.4. Evaluation of the case study impacts on green infrastructure

A cumulative impact assessment focusing on species and habitats of specific concern can help identify areas where management of pressures is particularly warranted. This case study on impacts on green infrastructure reflects a way to assess where pressures from human activities may lead to particularly high impacts on natural values and the provision of ecosystem services.

The assessment also shows a way to deal with complementary data sources and differences in the number of ecosystem components among groups. In an unweighted BSII, ecosystem component groups represented by many ecosystem component layers will be assessed as having higher impact than groups represented by few layers, due to the additive approach. The hierarchical approach adjusts for this imbalance, as it gives equal weight to selected groups. In the current case study, six ecological value criteria were included (**Figure 14**) and ten ecosystem services (**Figure 15**). For ecological values, all ecosystem component layers were given equal weight in the grouping (**Figure 11**). For ecosystem services, the ecosystem component layers representing benthic habitats were aggregated using the maximum approach (**Figure 12**). This was applied in order to make best use of data layers which may be particularly redundant, avoiding double-counting of these. Ideally, redundant layers should not be used, but this was motivated here as there was reason to expect data gaps in some of the included layers and the layers were seen to complement each other in order to give the best available overall picture. Hence, the chosen approach was applied to consider the most sensitive aspect in relation to benthic habitats, given current data availability.

Importantly, the green infrastructure concept addressed here focuses on spatial distributions, which is only one component. For a full evaluation, it is also important to consider the status of the ecosystem components, which is not included here.

Further, with respect to ecosystem services, the current results reflect the potential for ecosystem services provision based on ecosystem structure, but an assessment of ecosystem function is still missing in the concept at large. As one example, the ecosytem service “filtration of nutrients” cannot be assessed directly based on existing maps, but the results are based on information on the presence of filter feeders, as a proxy for the capacity to deliver this ecosystem services.

In addition to supporting planning to avoid impacts, as explained above, the impact assessment in relation to ecosystem services can potentially also have the other perspective and be applied to indicate the importance of certain services. It could be useful for planners to identify areas where maintenance of green infrastructure is of high priority to minimise or buffer impacts of existing pressures. For example the need for services such as filtration of nutirents or erosion control are expected to be higher where pressures such as eutrophication or risks of coastal erosion, which they modulate, are higher.

The results of the case study are useful for screening but should be evaluated critically due to uncertainties in underlying data layers.

6. Discussion

Addressing cumulative impacts in MSP represents both a necessity and an added value. To achieve sustainable planning, there is a need to look at the bigger picture when it comes to an understanding of how different human activities interact with each other and with the environment. In addition, cumulative impacts are helpful for linking different sides of management with each other, such as identifying commonalities between MSP and environmental assessment.

The project has provided an opportunity to share understanding of how, and to what extent, cumulative impacts can be assessed with available tools today. We also approached some of the identified development priorities in the practical parts of our work. These steps are outlined in previous chapters of this report, and shortly summarised below. Further below, we also discuss some remaining identified development needs in more detail.

6.1. Advancements of the project

The main aim of the work on cumulative impacts in Pan Baltic Scope was to improve coherence among countries in how cumulative impacts are assessed in connection to MSP. Our work has helped identify the current state of the art in the Baltic Sea region, bring available cumulative assessment tools and approaches to the planners' table, and to identify possible further development options more clearly.

Cumulative impacts are, in many cases assessed only in a descriptive way today. The results and case studies presented in this report give examples of how quantitative analyses can be carried out. These examples show that data-driven analyses to address cumulative impacts are possible so that planning can be supported by data and avoid opinion-based decisions.

Our analyses were focused on cumulative impacts at the Baltic Sea regional scale to provide a regional overview and support the evaluation of transboundary aspects. Our applied assessment structure followed the methodology of the BSII, which is currently used in environmental assessments of HELCOM. This method is based on a widely used approach that is also followed in the MSP of some countries around the Baltic Sea today, as well as in other sea regions. Although some local adjustments are usually needed in any given setting, such general coherence enhances possibilities to compare assessment results among geographical areas, as well as to share development progress.

To facilitate the sharing of data and methods, we developed a toolbox for assessing cumulative impacts. The analyses supported by the toolbox are fully spatially referenced, addressing the position and relative distribution of human activities, pressures and ecosystem components, which directly supports MSP and the application of the ecosystem-based approach. Although the tool uses regional data as default, it also enables applying other data layers, if these align with the basic requirements of the tool. This is expected to facilitate the use of similar approaches among all countries if preferred.

Our developed Cumulative impact Assessment Toolbox also provides technical improvements compared to what has been previously available. For example, the applied approach enables a balanced assessment of different pressures and ecosystem components using different aggregation options and batch analyses. Further developments are, however, needed to make it even more reliable and flexible for users' needs in MSP.

6.2. Further development points in data and methods

The work has provided a better understanding of what one needs to consider when assessing cumulative impacts, and of what analyses are possible using the applied tools and methodology. In this sense, the work is also helpful to identify development needs and a way forward for further development.

Comparisons among countries show that more specific data and knowledge needs vary nationally. However, a generally identified bottleneck for spatially referenced cumulative impact assessment is a scarcity of suitable spatial data layers. This is important, as the quality of the underlying data has high influence on the quality of the assessment results.

To forward the timely assessment of cumulative impacts more broadly, it would also be beneficial to develop ways to incorporate qualitative information along with quantitative assessment in the general cumulative assessment framework. This may also be beneficial when the cumulative impact assessment is connected to assessment of economic and societal impacts.

Having noted this, the following identified development points focus on ways to forward knowledge with respect to data and assessment methods.

6.2.1. Spatial ecosystem data

The most evident gap identified in our work is missing spatial data on ecosystem components (species, habitats and ecosystem processes) at the resolution needed to support MSP.

When developing the case studies and assessment tools, we chose to base the work on already available data sets rather than allocating time to data development aspects. However, as also emphasised in other places of this report, this entails that the presented results would be significantly improved and more practically relevant if the underlying data sets were available in higher resolution and detail. A more complete availability of regionally coherent data would also support national needs. This data gap also affects the identification of green infrastructure, following the concept described by Ruskule *et al*. (2019) and applied in the case study of impacts on green infrastructure (**Chapter 5**).

At the Baltic Sea scale, a large effort was recently made to support the Baltic Sea Impact index with spatial data (HELCOM 2018a-b, **Chapter 2**). In parts, the set of available data has also been improved since then via other branches of the Pan Baltic Scope project (HELCOM 2019). However, considerable spatial and temporal gaps remain in individual data sets and improving available data sets on ecosystem components is expected to improve the quality of assessment significantly. This gap concerns benthic habitats, but also specifically key habitats for highly mobile species such as sea birds, marine mammals and fish (the latter as far as not covered by HELCOM, 2019).

Preferentially, knowledge about the processes that are behind the ecosystem services should also be included in this development. Including ecosystem services is a promising way to deepen our understanding of cumulative impacts on the environment, but these analyses are still in the beginning stage. More understanding of the connection between ecosystem structure, functions and services needs to be developed.

6.2.2. Sensitivity scores

The sensitivity scores that were used (**Annex 3**) provide rough estimates of how sensitive species are towards different pressures. The scores relating to the pressures physical loss and physical disturbance were developed based on a literature review (Korpinen *et al.* 2017), while the others are based on expert judgement based on results from a Baltic-wide survey (HELCOM 2018a). In coming studies, it would be important to verify the sensitivity scores further against scientific evidence, following the principle of best available knowledge. In the Cumulative impact Assessment Toolbox, it is possible to modify the sensitivity scores in the underlying matrix, to evaluate the relative contribution of these in the overall results.

6.2.3. Spatial data resulting from MSP

Another challenge to the current work was to connect the case studies to ongoing MSP processes. At the time when the work was carried out, there was high variation in MSP implementation and availability of data in different countries (**Chapter 2**). The case studies were applied using currently available data, which were not tuned for the purpose of following-up on national plans regionally. For examples, in the case study on offshore wind farms, the data for Estonian waters is not correct in the BalticLINes scenarios. When all countries have finalised their MSP, it would be interesting to repeat some regional case studies using harmonised MSP output data, to follow-up.

6.3. How to deal with data and knowledge gaps

Most cumulative impact assessment methods are designed so that it is still possible to work with available data if they meet the basic requirements of the tool. This also applies to the BSII Cumulative impact Assessment Toolbox.

From this also follows that the quality of the data that is used can vary between cases, for example, with respect to spatial resolution, main data sources, or the time scale they represent. In these cases, it is up to the user to identify if the available data are suited for the intended purpose and what analytical questions it can address.

Most tools are, also designed so that it possible to gradually include improved information when this becomes available.

We recommend that the spatial data included in the BSII Cumulative impact Assessment Toolbox and the utilised assumptions on sensitivity scores and green infrastructure matrices (ecological value and ecosystem services) are regularly reviewed by regional experts to ensure that any improved information is taken on board and included when available. Some examples of questions that should be continuously addressed and updated are provided in **Box 3**.

Also, it is important to clearly communicate existing uncertainties when presenting the results. Quantification of uncertainty should preferably be implemented in the tool. This will hopefully be enabled in the BSII-CAT in the future. However, uncertainty should also be carefully communicated in words to ensure adequate interpretation of the results, preferably supported by uncertainty maps.

Box 3. Examples of questions to address when updating and improving regional spatial data.

1. How can the time period represented be further harmonised between data sets?
2. For accumulating pressures, how can pressure additions during the assessment period be shown separately from historic inputs?
3. How can the data type, resolution, and quality be further harmonised spatially (across different parts of the Baltic Sea) within each data set?

4. How could pressure layers be rescaled to adequately represent the intensity of pressure at the level where it influences the concerned ecosystem components? Can cut-off values be established for when a pressure should be included in the assessment?

5. How can ways display uncertainties be improved?

6. How are ecosystem components affected by synergistic effects and other types of interactions among pressures?

6.4. Next steps to advance cumulative impact assessments in MSP

Cumulative impact assessment can support decision-making in MSP by identifying areas where it is particularly important to avoid or minimise pressures, to safeguard biodiversity and the provision of ecosystem services. In this sense, the cumulative impact assessment can facilitate the evaluation of different planning options, but it can also spur innovation and initiatives to how impacts can be minimised.

When developing the plan, negative impacts can be avoided, for example by restricting activities in certain areas, by regulating allowed pressure levels, or by protecting key habitats. Potentially, restoration or compensation measures can also be included, with the aim to directly improve the status of the species or habitats. By support from cumulative impact assessment and other available tools, MSP can make a significant difference and contribute to reaching environmental objectives.

However, it is important to recognise that our possibilities for sea use are also dependent on the environmental status. Many pressures that are currently of high importance in the marine environment are only marginally influenced by MSP but still affect the provision of ecosystem services at sea. Including the interactions between land and sea is of high importance to fill the complete picture. Most conspicuously, agriculture, forestry and urban usages contribute to current levels of nutrients and hazardous substances at sea and to the overall impact (HELCOM 2018a).

When it comes to the further advancement of assessment approaches, continued collaboration among countries is highly recommended to ensure mutual learning and efficient development. This development should aim to further advance the regional BSII-CAT, for improved utility to support environmental assessment as well as MSP at the Baltic Sea regional scale. It should equally aim at advancing national CEA tools, as this will further support coherence in data and method development among countries.

Some key development points are identified below.

6.4.1. Applications at different spatial scales

MSP carries a need for assessments at different scales. The assessments at the Baltic Sea scale may give a broad regional overview, for countries to fill further with national and spatially resolved information.

The Baltic-wide assessments are helpful to understand the overall picture, make it easier for countries to compare assessment results, and evaluate transboundary aspects. The large-scale cumulative impact assessment of the Baltic Sea impact index (HELCOM 2018) and targeted cased studies such as those carried out as initial tests in this report (**Chapter 5**), can support scoping in MSP and make it possible to relate the plan to key environmental aspects. A typical aim at this scale is to look at general patterns and identify key issues for further consideration. The regional-scale assessments can serve as an information source to support transboundary cooperation, as the data is covering the whole Baltic Sea.

Nationally, legislation requires planners to consider and understand cumulative impacts. Cumulative impact assessment can support MSP in general by providing an overarching view. More specifically, the assessment can also identify areas that require special attention or more elaborated assessment. In the evaluation of planning alternatives, the risk of cumulative impacts can be assessed in relation to societal effects to identify planning priorities and help determine if the plan should be adjusted to avoid impacts. For example, negative impacts can be avoided or minimised by avoiding or restricting activities, by regulating allowed pressure levels from different activities, or by preventing sensitive species or habitats from being exposed to a certain pressure. An approach like the Baltic Sea Impact Index is today followed for example in Sweden. In some other countries it remains to see how the Baltic-wide approach described here fits national needs. For example, currently in Finland there is yet no agreed approach, and Germany has so far only a qualitative assessment.

When going down further in spatial scale, one practical limitation in cumulative impact assessment is often the increasing need for spatial resolution. The assessment resolution used in the regional assessment at Baltic Sea level, 1x1km, is often too coarse for addressing questions of national importance in MSP. This challenge is not so much related to the basic approach, as many cumulative impact assessment tools, including the BSII Cumulative impact Assessment Toolbox, can be run at various resolution provided that all included data sets have identical resolutions. However, refining the spatial resolution is expected to increase the data demands further, hence also increasing the risk of unjustifiable data gaps and enhancing the need for complementary qualitative approaches. Further, care should be taken when translating results between assessments carried out at different spatial delineation, as the relative importance of different pressures will vary depending on in what area the assessment is applied.

In some cases, more detailed information is only needed after the planning stage, during project-specific environmental impact assessments. However, all activities do not require licensing, which emphasises the importance of addressing cumulative impacts already during planning. For example, shipping does not require licencing, even though environmental impact assessment is required in the changing of routes. Also, fishing is carried out under separate regulation.

6.4.2. Including positive effects of human activities

Currently, most cumulative impact assessments are focused on negative effects on the environment. In some cases, however, activities may be expected rather reduce or redistribute certain pressures.

One example applied in the case study on offshore wind farms (**Chapter 5)** is that offshore wind farms were expected to redistribute fishing intensity and physical disturbance as offshore wind farms are typically not possible to combine with trawling, and to exclude a set of other activities connected to physical disturbance. These assumptions would need to be evaluated further. There are also other examples were pressures might rather be redistributed or lowered. For example, blue mussel and algal farming may even contribute to removing legacy nutrients, thereby reducing the intensity of eutrophication symptoms and contributing to reduced cumulative impact.

6.4.3. Climate change

We strongly recognise that projections to understand future scenarios need to consider climate change.

Importantly, climate changes may affect the assessment in several ways. Changes in temperature, salinity, storminess, and acidity are foreseen and are expected to affect the ecosystem by direct effects on the organisms, but they may also affect the distribution of species as well as the sensitivity of species to other pressures.

Under the limitations of the current project, it was not possible to redefine the spatial data layers on species distribution in relation to future climate change. However, this should be considered in the future, also building on currently ongoing developments nationally[14].

[14] See for example the ClimeMarine project to support climate change predictions for MSP. https://www.smhi.se/en/research/research-departments/oceanography/climemarine-effects-of-climate-change-into-marine-spatial-planning-1.150668

7. Conclusions and recommended way forward

7.1. Conclusions

- Maritime Spatial Planning is closely interlinked to environmental management aspects - We are dependent on the status of the ecosystem and its provision of ecosystem services to carry out activities at sea, and our activities can impact the status of the sea. Hence, evaluating cumulative impacts is central for implementing the ecosystem-based approach.
- Most issues relating to MSP and strategic environmental assessment in the Baltic Sea are of transboundary importance. A shared Baltic view on cumulative impact assessment approaches in MSP has been developed in the Pan Baltic Scope project, by national contributions and the development of an openly available Cumulative impact Assessment Toolbox and regional data.
- Work to assess cumulative impacts has made good progress in the past years. Countries are increasingly considering cumulative impacts in their planning. However, many data gaps and knowledge gaps in underlying ecosystem processes remain, and still, it is a challenge on how to implement the cumulative impact assessment practically.
- As many types of analyses are possible, it is of high importance to define clear questions at the beginning of the analyses, for the results to be useful in practice. It is also important to create an understanding among the involved parties on how the results can be used. For example, in addition to presenting the results, the limitations relating to underlying assumptions, methodology and data must be clearly formulated.

7.2. Recommendations

- Countries should integrate cumulative impact assessments in key steps of their planning process to support and implement an EBA.
- Environmental managers and planners should work together to strengthen the connection between MSP and environmental objectives, including the MSFD.
- Data availability and knowledge on the interactions between human activities and the ecosystem need to be continuously and systematically improved to further support spatially referenced cumulative impact assessment. Suggested ways to achieve this include
    - A regular process among countries to obtain more fine-scaled spatial data on ecosystem components and nature values at the regional scale, to enable incremental improvement of shared data
    - Dedicated activities to support knowledge sharing and developing a more holistic understanding of linkages between pressures and nature assets, for example considering synergistic effects and ecosystem feedbacks
- It would be beneficial to make room for the combined use of qualitative and quantitative approaches in the further development, to meet the reality for implementation in different national and local settings and support linkages to economic and social analyses.
- It is important to co-develop cumulative impact assessments approaches for environmental management and MSP, to support integrated management and the ecosystem-based approach
- Countries should ensure that their assessment approaches are coherent within the Baltic Sea, especially considering the advantage of a transboundary perspective to enhance cooperation and mutual understanding. Such co-development is effectively enabled under a regional umbrella, such as HELCOM, the key aim being to join forces and share development progress to support a scientifically sound and efficient management.

8. References

Andersen, JH & 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

Baltic Scope (2017) Recommendations on maritime spatial planning across borders. http://www.-balticscope¬.eu¬/content/uploads/2015/07/BalticScope_OverallRecomendations_EN_WWW.pdf

CBD Secretariat (2004) CBD Guidelines for the Ecosystem Approach, Montreal. https://www.cbd.int¬/doc/publications/ea-text-en.pdf

EC (2008) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for Community action in the field of marine environmental policy (Marine Strategy Framework Directive). OJ L 164

EC (2013) Green Infrastructure (GI) — Enhancing Europe's Natural Capital. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions /COM/2013/0249

EC (2014) Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. OJ L 257

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

EC (2018) Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. L 328/82

Ehler C & F Douvere (2009) Marine Spatial Planning: a step-by-step approach toward ecosystem-based management. Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICAM Dossier No. 6. Paris: UNESCO

Halpern, B, SS Walbridge, KA Selkoe, CV Kappel, F Micheli, C D'Agrosa, JF Bruno, KS Casey, C Ebert, HE Fox, R Fujita, D Heinemann, HS Lenihan, EMP Madin, MT Perry, ER Selig, M Spalding, R Steneck & R Watson (2008) A Global Map of Human Impact on Marine Ecosystems. Science 319:948-952

Halpern, B, SCV Kappel, KA Selkoe, F Micheli, C Ebert, C Kontgis, CM Crain, RG Martone, C Shearer, and SJ Teck (2009) Mapping cumulative human impacts to California Current marine ecosystems. Conservation Letters 2: 138–148

Halpern, B. S M Frazier, J Potapenko, KS Casey, K Koenig, C Longo J Stewart Lowndes, R Cotton Rockwood, ER Selig, KA Selkoe & S Walbridge (2015) Spatial and temporal changes in cumulative human impacts on the world's ocean. Nature Communications 6. DOI: http://dx.doi. org/10.1038/ncomms8615

HELCOM (2007) Baltic Sea Action Plan. Adopted at HELCOM Ministerial Meeting in Krakow, Poland on 15 November 2007

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 (2018a) State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155

HELCOM (2018b) HELCOM Thematic assessment of cumulative impacts on the Baltic Sea 2011-2016. Available at: http://stateofthebalticsea.helcom.fi/about-helcom-and-the-assessment/downloads-and-data/

HELCOM (2018c) Economic and social analyses in the Baltic Sea region – HELCOM Thematic assessment 2011-2016. Available at: http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/

HELCOM (2019) Proposal for new maps on essential fish habitats in the Baltic Sea. Document 3N-13 to Working Group on the State of the Environment and Nature Conservation, Hamina, Finland, 6-10 May 2019. https://portal.helcom.fi/meetings/STATE%20-%20CONSERVATION%2010-2019-602/¬Meeting¬Documents¬/3N-13%20Proposal%20for%¬20new%20maps%20on%-20essential%20¬fish%20habitats¬%20in¬%20the%20Baltic%20Sea.pdf

Hüffmeier, J & M Goldberg (2019) 2030 and 2050 Baltic Sea Energy Scenarios. Report from the EU Interreg project for the Baltic Sea Region: BalticLINes. Date 22 March 2019. https://vasab.org/wp-content/uploads/2019/05/Baltic-LINes-2030-and-2050-Baltic-Sea-Energy-Scenarios.pdf

Judd, AD, T Backhaus & F Goodsir (2015) An effective set of principles for practical implementation of marine cumulative effects assessment. Environmental Science and Policy 54: 254-262

Knights, A, RS 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

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

Korpinen, S, UL 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

Liversage, K, J Kotta, R Aps, M Fetissov, K Nurkse, H Orav-Kotta, M Rätsep, T Forsström, A Fowler, M Lehtiniemi, M Normant-Saremba, R Puntila-Dodd, T Arula, K Hubel & H Ojaveer (2019) Knowledge to decision in dynamic seas: Methods to incorporate non-indigenous species into cumulative impact assessments for Maritime Spatial Planning. Science of the Total Environment 658: 1452-1464

Liquete, C, S Kleeschulte, G Dige, J Maes, B Grizzetti, B Olah *et al.* (2015). Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study. Environmental Science and Policy, 54, 268–280

Menegon, S, D Depellegrin, G Farella, E Gissi, M, Ghezzo, A Sarretta, C Veniera & A Barbarantia (2018) A modelling framework for MSP-oriented cumulative effect assessment. Ecological Indicators 91: 171–181

MoERPD (2018) Ministry of Environmental Protection and Regional Development, Latvia. Maritime Spatial Plan 2030. http://www.varam.gov.lv/eng/darbibas_veidi/maritime_spatial_planning/?doc=26326

Micheli, F, BS Halpern, S Walbridge, S Ciriaco, F Ferretti, S Fraschetti, R Lewison, L Nykjaer & AA Rosenberg (2013) Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: assessing current pressures and opportunities. PLoS ONE 8:e79889

Murray, CC, S Agbayani, HM Alidina & NC Ban (2015) Advancing marine cumulative effects mapping: An update in Canada's Pacific waters. Marine Policy 58: 71–77, DOI: https://doi.org/10.1016/j.marpol.2015.04.003

Ruskule, A, L Bergström, J Schmidtbauer Crona, J Kotta, P Arndt, S Strāķe, I Urtāne (2019) Green Infrastructure concept for MSP and its application within Pan Baltic Scope project. Report from Pan Baltic Scope.

Selkoe, K, BS Halpern, C Ebert, E Franklin, E Selig, K Casey, J Bruno & R Toonen (2009) A map of human impacts to a "pristine" coral reef ecosystem, the Papahanaumokuakea Marine National Monument. Coral Reefs 28(3): 635–650, DOI: https://doi.org/10.1007/s00338-009-0490-z

Skov, H. S Heinänen, R Žydelis, J Bellebaum, S Bzoma, M Dagys, J Durinck, S Garthe, G Grishanov, M Hario, JJ Kieckbusch, J Kube, A Kuresoo, K Larsson, L Luigujoe, W Meissner, HW Nehls, L Nilsson, I Krag Petersen, M Mikkola Roos, S Pihl, N Sonntag, A Stock, A Stipniece, J Wahl (2013) Waterbird Populations and Pressures in the Baltic Sea. Tema Nord 2011:550

SwAM (2018) (Swedish Agency for Marine and Water Management, Havs- och Vattenmyndigheten) Symphony - Integrerat planeringsstöd för statlig havsplanering utifrån en ekosystemansats. Havs- och vattenmyndighetens rapport 2018:1, ISBN 978-91-87967-88-7

SwAM (2019) (Swedish Agency for Marine and Water Management, Havs- och Vattenmyndigheten) Miljökonsekvensbeskrivning av förslag till havsplaner för Sverige – Bottniska viken, Östersjön och Västerhavet https://www.havochvatten.se/-download/18.67e0eb431695d8639337200b¬/1553505447709¬/mkb-havsplaner-granskning.pdf

Annex 1. Regional data on pressures

Table A.1. Pressure layers available at the Baltic Sea scale and used in the Baltic Sea Impact Index as presented in HELCOM (2018a, b). Physical pressures are given as cumulative values until the year 2016, and other pressure categories are annual averages for 2011-2016. All data sets are normalised to vary between 0 and 1 when used in the cumulative impact assessment. This is applied so that 0=minimum observed value and 1=maximum observed value, unless otherwise indicated. The last column gives a short data description, and more information is available at the Helcom Maps and Data services[15] More detailed data descriptions are also presented in HELCOM (2018b).

Pressure	HELCOM Available data layer	Data description summary
Physical		
Change of seabed substrate or morphology (~ physical loss)	Physical loss of seabed	Based on the presence of selected human activities[16]. For point and line objects, impact distances were implemented based on literature and expert evaluation. Values represent the area lost within each 1x1 km grid cell.
Disturbance or damage to seabed	Physical disturbance to seabed	Based on the presence of selected human activities. Impact distances and attenuation gradients implemented based on literature and expert evaluation. Values represent the weighted sum of all human activities occurring in a grid cell[17].
Changes to hydrological conditions	Changes to hydrological conditions	Based on the presence of selected human activities[18]. Impact distances and attenuation gradients implemented based on literature and expert evaluations
Input of energy		
Input of sound	Input of continuous anthropogenic sound	Based on BIAS data on ambient underwater noise, modelled to Baltic Sea scale. Values represent sound pressure levels at one 1/3 octave band of 125 Hz exceeded at least 5% of the time, normalized by setting level 0 at 92 db re 1µPa (representing natural levels) and level 1 at 127 db re 1µP (maximum of the 5th percentile of the distribution).
	Impulsive anthropogenic sound[19]	Based on events of: seismic surveys, explosions, pile driving, and air guns reported by HELCOM Contracting Parties to Impulsive noise registry hosted by ICES. Values are given in four classes of pressure intensity: very low, low, medium and high.
Input of other forms of energy	Input of heat	Combined based on reported data on the discharge of cooling water from nuclear power plants and estimates for fossil fuel energy production.
Input of substances		
Input of hazardous substances (synthetic substances, non-synthetic substances, radionuclides)	Hazardous substances concentrations	Based on data used in the CHASE integrated assessment of hazardous substances, using the assessment component concentration. Contamination ratios were calculated for hazardous substances monitored in water, sediment and biota, classified into five classes, and interpolated to cover the whole Baltic Sea.
	Introduction of radionuclides[20]	Based on HELCOM MORS Discharge database for 2011-2014, for isotopes Cesium-137, Strontium-90, and Cobalt-60. Values represent the decay-corrected annual average of the sum of radionuclide discharges (in Becquerels). A 10 km buffer with linear decrease was applied to represent the impact distance from the outlets

[15] http://maps.helcom.fi/website/mapservice/

[16] Construction at sea and on the shoreline (including cables and pipelines, marinas and harbours, land claim, and mariculture), extraction of sand and gravel, and dredging. Overlapping areas were removed to avoid double counting.

[17] Several activities were included. To account for the fact that the intensity of pressure varies, weighting factors were applied when merging these into one aggregated layer: High pressure intensity and/or slow recovery (weight 1): Coastal defence, Deposit of dredged material, Dredging, Extraction of sand and gravel, Trawling; Moderate to high (0.8): Pipelines, Shipping; Moderate (0.6): Finfish mariculture, Shellfish mariculture, Wind farms under construction; Low to moderate (0.4): Cables under construction; Low (0.2): Furcellaria harvesting, Recreational boating and sports, Operational wind farms.

[18] Hydropower dams, watercourse modifications, wind farms and oil platforms. Overlapping areas were removed to avoid double counting.

[19] Not included in case study 2

[20] Not included in case study 2

	Oil slicks and spills	Based on a combination of data on illegal oil discharges (aerial surveillance) and polluting ship accidents (as reported by HELCOM countries), which were first handled separately (HELCOM 2018b), and then summed together.
Input of litter (solid waste matter, including micro-size litter)	-	-
Input of nutrients	Relative distribution of nitrogen concentration	Based on data on total nitrogen concentrations in surface waters (0-10 m) from more than 1,000 positions, interpolated to cover the Baltic Sea scale. The data represent annual means (µmol / l, log transformed), based on average values for winter, spring, summer, and autumn. Data were normalized after first grouping all values above the 95th and below the fifth percentile to avoid undue influence of extreme values.
	Relative distribution of phosphorus concentration	Produced in the same way as for relative distribution of phosphorus concentration.
Input of organic matter	-	-
Biological		
Disturbance of species	Disturbance of species due to human presence	Based on data on the human activities: urban land use, recreational boating and sports, and bathing sites. Buffers were added separately to each layer as presented in (HELCOM 2018b), and the layers were summed before normalization. Data represents the cumulative and normalized pressure value for the selected activities.
Extraction of, or mortality/injury to, species, including target and non-targeted catches (by commercial and recreational fishing)	Fishing of herring	Based on commercial landings of herring at the spatial scale of ICES statistical rectangles (for Russia by ICES sub-divisions). The landings data were further redistributed within each ICES rectangle based on information on fishing effort (including all gears; c-squares; for Russia, average values for the sub basins were used). Values represent tons per square km (log-transformed). For the scaling, maximum pressures was identified as the maximum value from the landings data
	Fishing of cod	Produced in the same way as for fishing of herring
	Fishing of sprat	Produced in the same way as for fishing of herring
	Hunting and predator control of seabirds	Based on data sets on the number of hunted birds per unit area for game hunting and predator control of seabirds, which were summed together.
	Hunting of seals	Based on data on hunted seals per reporting unit for grey seal, ringed seal and harbour seal. Values represent the number of hunted seals per square km. Data sets were normalized so that value 0.5 was set at the quota for hunting in the Baltic Sea: Grey seal: 2000; Ringed seal: 350, Harbour seal 230. The data sets were summed and then normalized to produce the final pressure layer
Input of genetically modified species and translocation of indigenous species	-	-
Input of microbial pathogens	-	-
Input or spread of non-indigenous species	Introduction of non-indigenous species	Values represent the number of non-indigenous species in 2011 for each HELCOM assessment unit scale 2. Hence, the layer indicates the spatial distribution of areas with elevated risk for introduction and does not consider impacts associated with the identity of individual species.

Annex 2. Regional data on ecosystem components

Two tables.

Table A.1.2 Ecosystem components included in the Baltic Sea Impact Index as presented in HELCOM (2018a-b) and included in the current report. The data was obtained by the work of HELCOM expert groups, dedicated projects, and dedicated data requests to countries within the HOLAS II project (HELCOM 2018a). More details about the layers, including information on coverage and quality, is available at the HELCOM Maps and data services.[21]

Ecosystem component	
Benthic habitats	
Availability of deep water habitat, based on occurrence of H_2S	**Habitat building species**
Infralittoral hard substrate	*Furcellaria lumbricalis*
Infralittoral sand	*Zostera marina*
Infralittoral mud	Charophytes
Infralittoral mixed substrate	*Mytilus edulis*
Circalittoral hard substrate	*Fucus* sp.
Circalittoral sand	
Circalittoral mud	**Mobile species and their key habitats**
Circalittoral mixed substrate	Cod abundance
Sandbanks which are slightly covered by sea water at all time (1110)	Cod spawning area
Estuaries (1130)	Herring abundance
Mudflats and sandflats not covered by seawater at low tide (1140)	Sprat abundance
Coastal lagoons (1150)	Recruitment areas of perch
Large shallow inlets and bays (1160)	Recruitment areas of pikeperch
Reefs (1170)	Wintering areas of seabirds
Submarine structures made by leaking gas (1180)	Breeding areas of seabirds
Baltic Esker Islands (UW parts, 1610)	Grey seal distribution
Boreal Baltic islets and small islands (UW parts, 1620)	Harbour seal distribution
Pelagic habitats	Ringed seal distribution
Productive surface waters	Distribution of harbour porpoise

Table A.1.2 Data layers on essential fish habitats developed within Pan Baltic Scope activity on green infrastructure (HELCOM 2019).

[21] http://maps.helcom.fi/website/mapservice/

Species	**Type of essential fish habitat**	**Mapping approach**	**Comment**
Cod (*Gadus morhua*)	Spawning area	Environmental envelope	Updated compared to HELCOM 2018b
Sprat (*Sprattus sprattus*)	Spawning area’	Environmental envelope	New map
Herring (*Clupea harengus membras*)	Recruitment area	Habitat requirements	New map
European flounder (*Platichthys flesus*)	Spawning area	Species distribution modelling combined with environmental envelope	New map
Baltic flounder (*Platichthys solemdali*)	Spawning area	Species distribution modelling combined with environmental envelope	New map
Flounders (*Platichtys* spp.)	Recruitment area	Species distribution modelling	New map
Perch (*Perca fluviatilis*)	Recruitment area	Species distribution modelling and mapping	Updated compared to HELCOM 2018b
Pikeperch (*Sander lucioperca*)	Recruitment area	Species distribution modelling and mapping	Updated compared to HELCOM 2018b

Annex 3. Sensitivity scores

Table A.3.1: Sensitivity scores for ecosystem components used in case studies 1 and 2. Unless indicated "new", the scores are the same as applied in the Baltic Sea Impact Index of HELCOM (2018a). Each cell shows the sensitivity score for the identified combination of pressures (shown in the columns) and ecosystem component (species or habitat, shown in the row). The values range from 0 to 2 as explained in more detail in (HELCOM 2018b). An asterisk (*) identifies layers that were only included in case study 1, and ** identifies layers that were only included in case study 2. The other layers were included in both case studies.

	Physical loss	Physical disturbance	Changes to hydrological conditions	Continuous sounds	Impulsive sound*	Input of heat	Hazardous substances	Nitrogen	Phosphorus	Radionuclides*	Oil slicks and spills	Disturbance of species	Extraction of herring	Extraction of cod	Extraction of sprat	Hunting of seabirds	Hunting of seals	Non-indigenous species
Productive surface waters*	0.4	1	0.6	0.6	0.6	1	1	1.5	1.5	0	1.4	0.8	1	1	1	0.5	0.5	1
Oxygenated deep waters	0.9	0.7	1.3	0.5	0.6	0.6	0.9	1.8	1.8	0	1	0.2	0.7	0.7	0.7	0.3	0.3	0.7
Infralittoral hard bottom	1.8	1.3	1.2	0.2	0.2	1.3	1	1.3	1.3	0.4	1.7	0.3	0.6	0.6	0.6	0.7	0.7	1.1
Infralittoral sand	1.8	1.2	0.9	0.3	0.3	1	0.9	1.3	1.3	0.2	1.4	0.3	0.3	0.3	0.3	0.7	0.7	0.9
Infralittoral mud	1.7	1.1	1.1	0.3	0.3	1	1	1.3	1.3	0.4	1.4	0.4	0.3	0.3	0.3	0.7	0.7	0.9
Infralittoral mixed	1.8	1.2	1.1	0.3	0.3	1.1	1	1.3	1.3	0.3	1.5	0.3	0.4	0.4	0.4	0.7	0.7	1
Circalittoral hard bottom	1.9	1.3	1.4	0.3	0.3	1.2	1.2	1.3	1.3	0.5	1.3	0.4	0.8	0.8	0.8	1	1	1.2
Circalittoral sand	1.8	1.1	1.1	0.2	0.3	0.7	0.9	1.2	1.2	0.2	0.9	0.3	0.3	0.3	0.3	0.7	0.7	1
Circalittoral mud	1.6	1	1.3	0.3	0.3	0.9	1	1.2	1.2	0.5	1.1	0.4	0.6	0.6	0.6	0.5	0.5	0.9
Circalittoral mixed	1.8	1.1	1.3	0.3	0.3	0.9	1	1.2	1.2	0.4	1.1	0.4	0.6	0.6	0.6	0.7	0.7	1
Furcellaria lumbricalis	1.9	1.7	1.7	0.2	0.3	1.5	0.9	1.5	1.5	0.5	1.5	0.6	0.7	0.7	0.7	0.7	0.7	1.2
Zostera marina	1.9	1.9	1.7	0.2	0.1	1.6	0.9	1.9	1.9	0.6	1.6	1.2	0.9	0.9	0.9	0.8	0.8	1.1
Charophytes	1.9	1.9	1.4	0	0	0.9	0.8	1.7	1.7	0.4	1.5	0.7	0.8	0.8	0.8	0.7	0.7	1.4
Mytilus edulis	1.8	1.6	1.6	0.2	0.1	1	1.1	0.9	0.9	0.5	1.6	0.4	0.4	0.4	0.4	0.2	0.2	1.4
Fucus sp	1.8	1.7	1.3	0.3	0.3	1.5	0.9	1.3	1.3	0.5	1.4	0.6	0.5	0.5	0.5	0.3	0.3	1.2
Sandbanks (1110)	1.9	1.6	1.3	0.2	0.2	0.9	0.9	1.5	1.5	0.4	1.5	1.1	0.9	0.9	0.9	1	1	0.9

Estuaries (1130)	1.8	1.6	1.5	0.8	0.9	0.9	0.8	1.4	1.4	0.7	1.6	1	1.1	1.1	1.1	0.8	0.8	1.3
Mudflats and sandflats (1140)	1.9	1.7	1.8	0.2	0.2	1.7	0.6	1.5	1.5	0.3	1.8	1	0.9	0.9	0.9	0.8	0.8	0.9
Coastal lagoons (1150)	1.9	1.7	1.6	0.7	0.8	1.3	1	1.5	1.5	0.2	1.7	1	1.1	1.1	1.1	0.6	0.6	1.4
Large shallow inlets and bays (1160)	1.8	1.6	1.3	0.8	0.9	1.2	0.7	1.3	1.3	0.2	1.6	0.9	1.1	1.1	1.1	0.7	0.7	1.3
Reefs (1170)	2	1.6	1.4	0.3	0.3	1	1.2	1.3	1.3	0.6	1.9	0.8	0.9	0.9	0.9	1.1	1.1	1.2
Baltic Esker Islands (UW parts 1610)	1.8	1.5	1.3	0.5	0.5	1	0.8	1.3	1.3	0.1	1.6	0.7	0.8	0.8	0.8	0.5	0.5	1.3
Submarine structures… (1180)	1.7	1.2	1.3	1	1	1	0.7	1.6	1.6	0.5	1.8	1	0.8	0.8	0.8	1.5	1.5	1.4
Boreal Baltic islets… (UW parts 1620)	1.8	1.5	1.1	0.5	0.5	1	0.8	1.2	1.2	0.1	1.6	0.7	0.8	0.8	0.8	0.5	0.5	1.3
Cod abundance*	1	0.7	0.4	0.2	0.9	0.7	0.8	1.5	1.5	0.6	0.5	0.9	1.6	1.6	1.6	0.7	0.7	0.6
Cod spawning area*	0.7	0.8	0.9	0.6	1	0.6	0.9	1.7	1.7	0.5	1	0.6	1.3	1.3	1.3	0.2	0.2	0.4
Herring abundance*	0.9	0.7	0.7	0.6	1.1	0.6	0.4	0.7	0.7	0.3	0.9	0.4	1.2	1.2	1.2	0.2	0.2	0.6
Sprat abundance *	0.5	0.5	0.7	0.6	1.1	0.6	0.4	0.6	0.6	0.3	0.9	0.4	1.2	1.2	1.2	0.2	0.2	0.6
Recruitment areas perch*	1.6	1.3	1.2	0.4	0.9	0.4	0.4	1.4	1.4	0.4	1.6	1.3	1.6	1.6	1.6	0	0	1
Recruitment areas pikeperch*	1.6	1.1	1.2	0.6	1.1	0.3	0.6	0.7	0.7	0.5	1.7	1	2	2	2	0.5	0.5	0.9
Wintering seabirds	0.9	0.8	0.5	0.8	0.9	0.4	1.4	0.2	0.2	0.7	2	1.3	1.1	1.1	1.1	1.7	1.7	0.6
Breeding seabird colonies	0.9	0.9	0.4	0.6	0.8	0.3	1.3	0.3	0.3	0.2	2	1.8	1	1	1	1.6	1.6	0.8
Migration routes birds	0.8	0.5	0.4	0.7	0.8	0.6	1.2	0.2	0.2	0	1.9	1.4	0.7	0.7	0.7	1.8	1.8	0.3
Grey seal abundance	0.6	0.7	0.7	1.4	1.6	0.3	1.4	0.3	0.3	1	1.3	1	1.2	1.2	1.2	1.6	1.6	0.8
Harbour seal abundance	0.6	0.7	0.7	1.5	1.6	0.3	1.5	0.3	0.3	1	1.6	1.3	1.2	1.2	1.2	1.9	1.9	0.8
Ringed seal distribution	0.5	0.6	0.6	1.5	1.6	0.6	1.4	0.5	0.5	1.2	1.4	1.2	1.5	1.5	1.5	1.6	1.6	1.1
Spawning cod (updated map) **	0.7	0.8	0.9	0.6	1	0.6	0.9	1.7	1.7	0.5	1	0.6	1.3	1.3	1.3	0.2	0.2	0.4
Spawning herring (new)**	1.6	1.1	1.2	0.6	1	0.6	0.9	1.4	1.4	0.5	1.7	0.6	1.3	1.3	1.3	0	0	0.4
Spawning areas sprat (new)**	0.7	0.8	0.9	0.6	1	0.6	0.9	0.7	0.7	0.5	1	0.6	1.3	1.3	1.3	0	0	0.4
Spawning European. flounder (new)**	0.7	0.8	0.9	0.3	0.9	0.6	0.9	1.7	1.7	0.5	1	0.6	1.3	1.3	1.3	0	0	1

Spawning Baltic flounder (new)**	1.6	1.1	1.2	0.3	0.9	0.6	0.9	1.7	1.7	0.5	1.7	0.6	1.3	1.3	1.3	0	0	1
Recruitment flounders (new)**	1.6	1.1	1.2	0.3	0.9	0.6	0.9	1.7	1.7	0.5	1.7	0.6	1.3	1.3	1.3	0	0	1
Recruitment perch (updated)**	1.6	1.3	1.2	0.4	0.9	0.4	0.4	1.4	1.4	0.4	1.6	1.3	1.6	1.6	1.6	0	0	1
Recruitment pikeperch (updated)**	1.6	1.1	1.2	0.6	1.1	0.3	0.6	0.7	0.7	0.5	1.7	1	2	2	2	0.5	0.5	0.9