Topic report: benthic habitats

HELCOM ACTION project, HELCOM Secretariat

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Summary of main results of the analysis

The results of the SOM analysis suggest that existing measures would not be sufficient in reducing pressures and achieving noticeable improvements in the status of the five benthic habitats in any of the sub-areas of the Baltic Sea.

This result is uncertain because the SOM analysis could only account for changes in 35-60% of pressures which affect the state of benthic habitats. The effect of changes in important pressures, such as e.g. eutrophication effects and food web changes, were not included. Further, the magnitude of the required pressure reductions to achieve a noticeable state improvement is very uncertain.

The probability to achieve GES was not estimated as thresholds were not available.

Main pressures contributing to the disturbance and loss of seabed are:

- effects of eutrophication,
- physical disturbance of marine habitats, and
- physical loss of marine habitats.

Effectiveness of measure types was evaluated to be on a similar level for all measure types.

Main activities contributing to the disturbance and loss of seabed are:

Disturbance to seabed: fish and shellfish harvesting, tourism and leisure activities, and shipping.

Loss of seabed: extraction of minerals, tourism and leisure infrastructure, and transport infrastructure.

Background

Report background

The sufficiency of measures (SOM) analysis assesses improvements in environmental state and pressures that can be achieved with existing measures in the Baltic Sea, and whether these are sufficient to achieve good environmental status (GES). The analysis involves estimating the state of the marine environment in 2030, given measures in existing policies, their implementation status and projected development of human activities over time, which can be compared to the agreed HELCOM threshold for GES, when available.

The main aim of the SOM analysis is to support the update of the HELCOM Baltic Sea Action Plan (BSAP) by identifying potential gaps in achieving environmental objectives with existing measures for the Baltic Sea. In addition, the analysis can indicate both thematically and spatially where new measures are likely needed.

The same overall approach has been applied across all topics included in the SOM analysis to ensure comparability and coherence of the results, while considering topic-specific aspects and making necessary adjustments. The main components of the analysis include assessing the contribution of activities to pressures, the effect of existing measures on pressures, the effect of development of human activities on pressures, and the effect of changes in pressure on environmental state. The SOM approach, model and data collection are described in detail in the methodology report.

The methodology for the SOM analysis is designed to accommodate for the broad array of topics relevant in the HELCOM region and to enable a region-level analysis. It balances between state-of-the-art knowledge, availability of data, and advice taken onboard from various HELCOM meetings and bodies.

The data used in the SOM analysis have been collected using expert elicitation and by reviewing existing literature, model outputs and other data sources. Data availability varies substantially across topics and data components, which is reflected in the presentation of the methods and results in this report.

The SOM analysis presents the first attempt to quantify the effects of existing measures and policies on the environment and achieving policy objectives for various environmental topics in HELCOM and the Baltic Sea area. It is aimed at assessing the overall sufficiency of existing measures at the Baltic Sea level. The results are based mainly on expert elicitation, and thus they should be considered as approximate. Due to the pioneering nature and variable data quality and availability of the SOM analysis, the findings do not provide complete or final answers on the need for new measures, and should be reviewed in relation to the results of other assessments.

This topic report describes the analyses and results for benthic habitats in the SOM analysis, providing detailed topic-specific information. First, it presents background information and describes the data and methods for addressing the topic in the SOM assessment, including relevant assumptions and challenges. Second, it presents and discusses the findings for each result component. Third, it provides discussion on the impacts of alternative assumptions and data, evaluates the quality and confidence of the analysis, and provides implications and future perspectives. The annexes contain detailed information on the data components, topic structure and expert surveys for the analysis, as well as supplementary results.

Similar topic reports will be prepared for all nine topics covered in the SOM analysis. In addition, the results are summarized in the main report and the full methodology is described in the methodology report.

Topic background

Benthic habitats are a key component in supporting Baltic marine biodiversity. They are typically defined based on bathymetric zones (infralittoral, circalittoral and offshore circalittoral) and seabed substrates, but fauna and flora are also taken into account. For the SOM analysis, the HELCOM EN BENTHIC agreed to simplify the habitat classification into five main habitat types: (1) hard substrate vegetation dominated community, (2) soft substrate vegetation dominated community, (3) hard substrate epifauna dominated community, (4) soft substrate infauna dominated community, and (5) coarse substrate infauna dominated community. These types differ from the broad habitat types, as defined in the Commission Decision COM DEC (EU 2017), but they provide a sufficient overview of the state of the main benthic components and reflect the main impacts, which are typically caused by eutrophication, physical disturbance and physical loss. There is a general lack of data and indicators for the major part of benthic habitats in the Baltic Sea. Operational indicators are in place for macroalgae, other macrophytes (in many countries) and soft-bottom macrofauna. The insufficient knowledge of the state is also reflected in this analysis where the gap to good state is not known and the analysis is based on a 'noticeable improvement in state'.

Description of benthic habitats in the SOM assessment

Benthic habitats are considered in two distinct ways in the SOM analysis. The first is as the pressure inputs *Potential loss of seabed* and *Potential disturbance to seabed* (Figure 1). No HELCOM indicator exists for either potential loss or disturbance of the seabed. However, data relevant to the topic has been collected through regular HELCOM reporting processes and is available through the HELCOM Map and Data Service. Additionally, MSFD criteria D6C1[1] and D6C2[2] are relevant to these pressure inputs, respectively. As no GES threshold value exists for either loss or disturbance of the seabed, the SOM analysis assesses the reduction in pressure inputs from present conditions caused by existing measures. The pressures *Physical loss of marine habitats* and *Physical disturbance of marine habitats* are assumed to be directly equivalent to the respective pressure inputs. For benthic habitats this makes the terms pressure input and pressure nearly identical and only the term pressure is used further in this report.

The second aspect of benthic habitats in the SOM analysis are the five state components: *condition of hard substrate vegetation dominated community, condition of soft substrate vegetation dominated community, condition of hard substrate epifauna dominated community, condition of soft substrate infauna dominated community, condition of coarse substrate infauna dominated community* (Figure 1). MSFD criteria D6C3[3] is strongly reflected in the structure of the analysis of these state components. No HELCOM indicator exists for the condition of these habitats, with the exception of the HELCOM indicator "State of the soft-bottom macrofauna community". However, the indicator only includes offshore areas and does not have agreed thresholds in many sub-basins. To achieve a standard approach within and between habitat types, the focus of the SOM analysis is on assessing the pressure reductions required to achieve a "noticeable improvement" in the state component in question. To achieve a standard approach within and between habitat types, the focus of the SOM analysis is on assessing the pressure reductions required to achieve a "noticeable improvement" in the state component in question. This can be compared with the projected pressure reduction from existing measures. This metric was designed with the help of topic experts to encompass the variety of ways benthic habitats might exhibit an improvement in status (e.g. increased biodiversity, increased spatial extent, presence of specific sensitive/threatened species, etc.).

[1]Marine Strategy Framework Directive criteria D6C1 – Primary: Spatial extent and distribution of physical loss (permanent change) of the natural seabed.
[2]Marine Strategy Framework Directive criteria D6C2 – Primary: Spatial extent and distribution of physical disturbance pressures on the seabed.
[3]Marine Strategy Framework Directive criteria D6C3 – Primary: Spatial extent of each habitat type which is adversely affected, through change in its biotic and abiotic structure and its functions (e.g. through changes in species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), by physical disturbance. Member States shall establish threshold values for the adverse effects of physical disturbance, through regional or subregional cooperation.

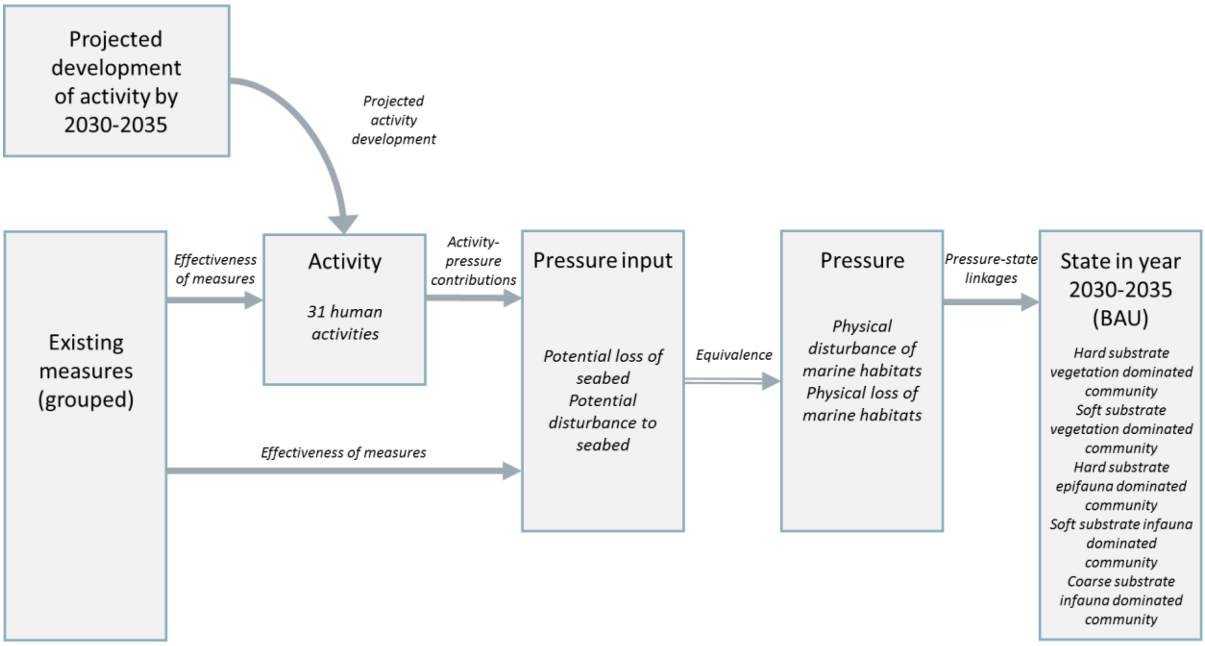

Figure 1. Schematic of the SOM analysis for benthic habitats. The pressure inputs *potential loss of seabed* and *potential disturbance to seabed* are assumed to be equivalent to the pressures *physical disturbance of marine habitats* and *physical loss of marine habitats*.

Supplementary activities

The SOM analysis for benthic habitats was supported by additional analyses of the human activities causing pressures and impacts on benthic habitats. These were carried out in the ACTION project (WP 2) with the objectives to study cost-effective scenarios for bottom trawling fisheries in the Baltic (Bastardie et al. 2020), possibilities for restoration projects in coastal areas (Kraufvelin et al. 2020) and literature reviews of impacts from all kinds of human activities on seabed (Laamanen et al. 2020). The work resulted in a series of proposals of new measures to the updated BSAP (submitted to HELCOM as synopses) and support to estimate costs and effectiveness of measures targeting seabed.

Methods and data

The section below includes an overview of any topic-specific methodologies. A full description of the general approach, methods and data collection for the SOM analysis is available in this document. Note that the detailed results are presented for the most likely development of human activities and using the expert data on effectiveness of measures.

Activity-pressure contributions

For *potential loss and disturbance to the seabed* (benthic habitats), the approach used in HELCOM HOLAS II has been employed, which utilizes the Baltic Sea Pressure Index (BSPI) and Baltic Sea Impact Index (BSII) to integrate data reported to the Secretariat from the Contracting Parties through regular reporting and previous data calls. Detailed explanation of the methodology used to generate these data is available in Annex 1 of the Thematic assessment of cumulative impacts on the Baltic Sea 2011-2016 (HELCOM 2018a). There is close correspondence between the BSPI activity list and the SOM activity list, as both are based in methodologies developed by the HELCOM TAPAS project. However, some activities in the BSPI data have been combined to conform to the SOM activity list. For both potential loss and potential disturbance, the potential impact from each activity in a sub-basin has been divided by the total pressure in the same sub-basin to produce sub-basin specific activity-pressure contributions.

Effectiveness of measures and pressure-state linkages

Measure types (Annex 3) and structural relationships between the measure types and activities and pressures (Annex 7) were designed by the HELCOM Expert Network on Benthic Habitats and Biotopes (EN BENTHIC 3-2019) in collaboration with HELCOM ACTION WP6. The measure types were informed by the existing measures list (Annex 4), but were also designed to acknowledge the full breadth of potential measures.

For benthic habitats, the effectiveness of measures survey structure comprised 15 unique measure types covering 9 activities. The same measure type may be listed under multiple activities and pressures. Altogether this resulted in 44 assessments of measure type effectiveness across the two pressures, *Potential disturbance to seabed* and *Potential loss of seabed*. The exact list of measure types, and their grouping by activities and pressures is shown in Annex 7. The effectiveness of measures survey itself is included as Annex 8.

Effectiveness of the measure types and links between the pressures and state components were determined using online expert surveys implemented in December 2019 – February 2020 with follow-up surveys conducted in the spring 2020. The expert pool consisted of the HELCOM Expert Network on Benthic Habitats and Biotopes, topics experts from the HELCOM ACTION project and nationally nominated experts. Additionally, the project received survey responses from experts not on the original invitation list; these responses were also included in the analysis. The full description of the methodology and data collection is available as part of the SOM methodology report.

Topic specific model structure, assumptions and challenges

Unlike all other SOM assessments for biodiversity topics (e.g. birds, fish) which used abundance of one or more life stages of the targeted species/population as the evaluating metric, the SOM assessment for benthic habitats attempted to assess the condition of broad habitat types by an undefined metric of "noticeable improvement". This alternative analysis structure resulted from discussions with topic experts on ways to assess broad areas of habitat that lack systematic condition assessments. While abundance can only objectively increase or decrease, habitat condition is much more multifaceted. Improvements might be seen in e.g., prevalence of heavily impacted areas, prevalence of weedy species, quantity of habitat type, or habitat diversity, and further, each of these potential metrics do not necessarily improve simultaneously. The less defined metric of 'noticeable improvement' was implemented to allow for expert opinion to determine the general condition of a habitat type flowing from the complex interactions of more specific metrics. The efficacy of this approach is discussed in the section Lessons learned.

Overview of data

The SOM analysis for benthic habitats evaluates the sufficiency of measures in achieving a noticeable improvement in state, considering the effects of existing measures and future development of human activities.

Table 1 shows the origin and spatial resolution for the data components in the SOM analysis for benthic habitats. Activity-pressure contributions are based on data obtained from the HELCOM Map and Data Service. Information on existing measures comes from literature reviews and Contracting Parties, and development of human activities is based on existing literature, data and projections.

Estimates of the effectiveness of measures were collected both via expert surveys and a literature review for all topics included in the SOM analysis. The aim of the literature review was to compile information from scientific articles and reports providing estimates on the effects of measures in reducing pressures that could be used in the SOM analysis, either by including the estimates in the SOM model or by providing comparison points. The literature review was conducted by topic, with the information collected into structured excel files (see the methodology document, Annex 5 and Annex 6 for more information). For benthic habitats, 71 effectiveness estimates from 25 studies were compiled. Out of these, 24 estimates could be included in the model while rest can inform interpretation of the results. Detailed results are presented using only the expert data, and the implications of using the literature data for the effectiveness of measures are reviewed in the discussion section.

The spatial resolution (level of detail) differs across the data components of the SOM analysis. All assessment areas are based on the 17 HELCOM scale 2 sub-basins and the assessment area ranges from the entire Baltic Sea to individual sub-basins. The activity-pressure contributions for benthic habitats are assessed for each of the 17 sub-basins (Figure 2), while the effectiveness of measure types in reducing pressures and the effect of development of human activities are assessed at the scale of the entire Baltic Sea. The spatial resolution for the pressure-state linkages is four sub-areas of the Baltic Sea (Figure 2). Table 1 shows the origin and spatial resolution for the data components in the SOM analysis for benthic habitats.

Table 1. Data for benthic habitats (more information on data collection is available in the methodology document)

Data component	Origin of data	Spatial resolution
Activity-pressure contributions	HELCOM Map and Data Service	17 sub-basins
Existing measures	Literature review, Contracting Parties	17 sub-basins
Effectiveness of measures	Expert evaluation	Whole Baltic Sea
Development of human activities	Literature review, existing data and projections	Whole Baltic Sea
Pressure-state links	Expert evaluation	4 sub-areas (Figure 2)

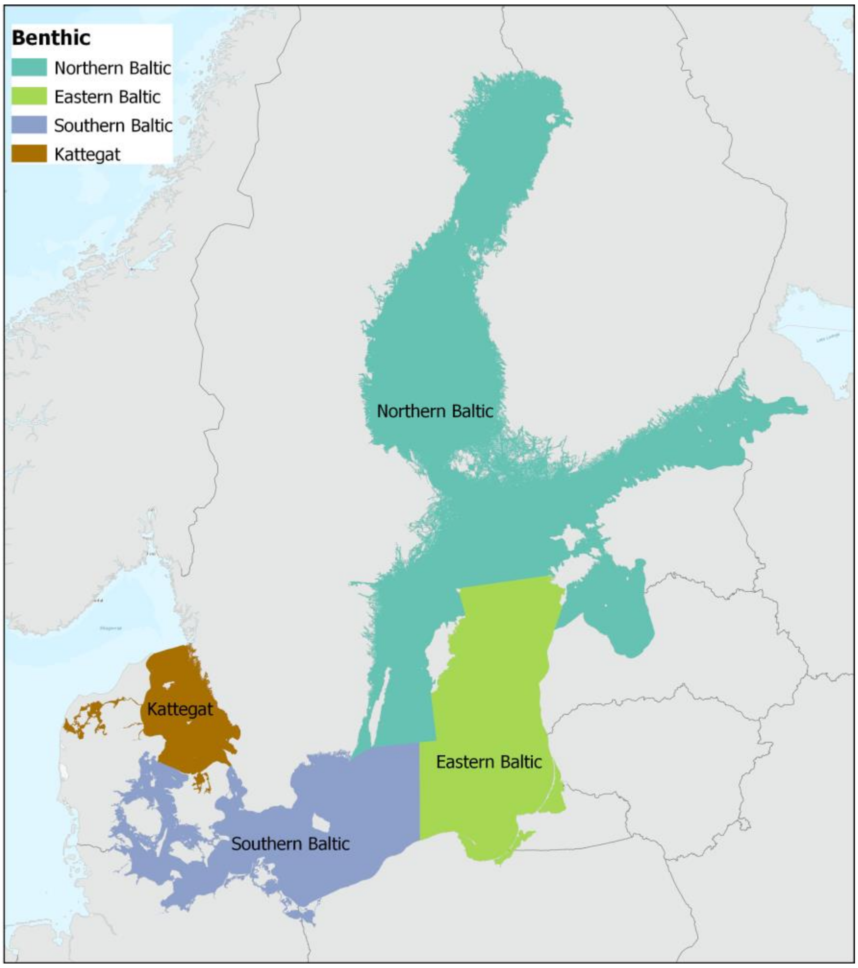

Figure 2. Spatial division of the Baltic Sea used for state assessments for benthic habitats. The four sub-areas are: Kattegat; Southern Baltic (The Sound, Great Belt, Kiel Bay, Bay of Mecklenburg, Arkona Basin, Bornholm Basin); Eastern Baltic (Gdansk Basin, Eastern Gotland Basin); and Northern Baltic (Western Gotland

Basin, Gulf of Riga, Northern Baltic Proper, Gulf of Finland, Åland Sea, Bothnian Sea, The Quark, Bothnian Bay).

Development of human activities

In addition to existing measures, changes in the extent of human activities may affect pressures over time. Four scenarios for future changes in human activities were developed: 1) no change, 2) low change, 3) moderate (most likely) change, and 4) high change. These alternative scenarios aim to capture uncertainties and variation in the future development of human activities. The results of the SOM analysis were estimated for each of the four scenarios to assess how the alternative assumptions on the development of human activities affect the findings. Detailed results are presented for the most likely development scenario, and implications of using the other scenarios on the results are reviewed in the discussion section.

The scenarios specify a percent change in each activity in 2016–2030 based on existing information and projections from the Baltic Sea region. Change scenarios were made only for predominant activities in the Baltic Sea region, including agriculture, forestry, waste waters, (commercial) fish and shellfish harvesting, aquaculture, renewable energy production, tourism and leisure activities, transport shipping and transport infrastructure. Other activities are assumed to stay unchanged. This means that only 9 of the 31 standard SOM activities have change scenarios in the SOM analysis. This results in varying influence of these scenarios on the results across topics, pressures and state components, depending on the significance of the activities to the pressures relevant to the topic.

For benthic habitats, coverage of activities that contribute to pressures in the change scenarios is high for potential physical disturbance to seabed and from moderate to high for loss of seabed. For disturbance to seabed, there is information on the development of the most important activities, including fish and shellfish harvesting, tourism and leisure activities and transport shipping. These cover over 80% of the activities contributing to the disturbance to seabed in 15 of the 17 sub-basins. For loss of seabed, the coverage of activities in the change scenarios is lower as the extraction of minerals, extraction of oil and gas, coastal defence and tourism and leisure infrastructure are assumed to stay constant. The main activity having a development scenario is transport infrastructure, which has a high contribution to the loss of seabed in 8 of the 17 sub-basins.

The current situation with COVID-19 and its possible implications to the development of human activities is not reflected in the scenarios, as there is no information on the long-term effects it may have on the economy or activities. The current situation poses a challenge for choosing the most likely scenarios for the development of human activities, which has been done based on currently available information.

Results and interpretation

Background

The SOM results are presented in the format of percent shares or probabilities. The main finding of the analysis is the probability to achieve GES or specific state improvements. For topics with pressure targets, the main finding are the pressure reductions, which can be compared to pressure reductions to achieve the target. These results are produced by estimating the effects of existing measures and changes in the activities on pressures. The contribution of activities to pressures, the effect of measures on pressures, and the significance of pressures to state components are presented as percent values (e.g. how many percent would the measure reduce the pressure). Results are presented mainly in tables, which show the the most likely (expected) values and standard deviations. Standard deviation is a way of showing the variation in the values. When it is high, values are spread over a wider range, and when it is low, values are closer to the most likely value. Figures and graphs presenting distributions are included in the annexes. They show the same results as the tables but allow either more detailed information or alternative visualisation of the results.

For the data that are based on expert surveys, the confidence rating gives the most common answer to experts' assessment of the confidence in their own survey responses on a low-moderate-high scale. More detailed information on how each result has been calculated is presented in a separate document.

This document presents the detailed results based on the expert-based data (survey responses). Literature data on the effectiveness of measures has been collected and included in an alternative model estimation. The impacts of using the literature data are evaluated in the discussion section. In the detailed results, the projected development of human activities is based on the most likely future development until 2030 (for details, see the methodology document), and the impacts of alternative scenarios on human activities are examined in the discussion section.

Format of presentation

The format the results are reported in depends on the type of result and the number of participating experts. The formats are: not presented, qualitative/semi-quantitative and quantitative. Further, for all results utilizing other SOM results as input data, reporting is done at the most conservative standard used in the input data. In practice this means that if one input data point is reported as 'insufficient data', all results using that data point will also be reported as 'insufficient data'; similarly for qualitative/semi-quantitative data points. However, note that this standard is only applied in the case of data points actively used to calculate another result. For example, many measure types are hypothetical or otherwise not implemented in the Baltic Sea and therefore do not factor into results on projected pressure reductions from existing measures. Insufficient data for such measure types does not affect reporting other results that rely on data for effectiveness of measure types. Results that do not meet the data standards described here and in greater detail below are marked with 'insufficient data' in the report.

For results concerning required pressure reductions and significance of pressures to state components, results with 2 or fewer respondents are not reported; results with 3 to 4 respondents will be either not reported, or qualitatively/semi-quantitatively reported based on feedback from the SOM topic teams or other HELCOM expert body; results with 5 or more respondents are reported quantitatively. This standard allows flexibility for reporting on assessments that are of spatially limited areas and therefore have fewer experts available to survey, while also being somewhat conservative in reporting fully quantitative results.

For expert-based effectiveness of measures results, measure types with 5 or more respondents are reported quantitatively and those with 4 or fewer respondents are listed as having insufficient data.

For expert-based activity-pressure results, expert responses where primarily sought through the HELCOM expert networks in the form of national responses. Individual expert responses were accepted but were consolidated into average responses by country to conform to the format of other responses. Thus, the maximum number of responses is 9. This maximum is rarely reached due to responses typically only applying to areas adjacent to the specific country. Acknowledging this, activity-pressure relationships are reported if there are expert responses from 3 or more countries or if the number of countries providing expert responses is greater than 1/2 the number of countries bordering any given sub-area (see Table 2 below; responses from experts based in any HELCOM country will be counted toward the reporting threshold, i.e. the reporting assessment is not limited to responses from bordering countries).

For benthic habitats, pressure-state results for coarse substrate infauna dominated community for three geographic areas and soft substrate vegetation dominated community for Kattegat have less than 3 contributing experts and are thus removed. This concerns the results for required pressure reductions, time lags and significance of pressures to state components. Based on the recommendation of topic experts reviewing the SOM analysis for benthic habitats, results based on 3-4 experts are presented in a quantitative format, as they are in line with other results that have a larger number of contributing experts. All effectiveness of measures data are presented, as they are based on the evaluations of 15-19 experts. The criteria do not apply to the activity-pressure contributions data which is based on the approach in HOLAS II instead of expert elicitation.

Table 2. Required number of countries providing expert responses to the activity-pressure survey to meet the minimum data threshold for reporting.

Bordering countries	Required number of countries providing expert responses to meet minimum data threshold	Example areas
1	1	Western Gotland Basin
2	2	Bothnian Sea, Gulf of Riga
3	2	Gulf of Finland
4+	3	Eastern Gotland Basin, Baltic Sea

Coverage of pressures in the SOM analysis

The SOM analysis has only been able to account for a portion of all pressures that affect the state components, and the effect of several significant pressures have not been included due to not being able to quantify the link between the pressures, pressures and state components in the analysis. This means that the effect of reductions in these excluded pressures on the state components is not included in the total pressure reductions, and the projected total pressure reductions and probability to achieve GES are underestimated. The share of pressures covered in the analysis has been calculated based on the significance of pressures to the state component in question. The share varies across topics and state components from low (around 20%) to high (more than 80%).

What are the state improvements from existing measures?

No HELCOM GES thresholds formally exist for the five benthic habitat types addressed in the analysis. Thus, the SOM analysis compares the pressure reduction required to achieve a noticeable improvement in the state of the habitat and the pressure reduction from existing measures.

Overall, the results of the analysis indicate that existing measures would not seem sufficient in achieving a noticeable improvement in the state of the benthic habitats, at least with the measures targeting those pressures that have been linked to the state of the habitats. Reductions in pressures range from low to moderate, and hence probabilities to achieve a noticeable improvement range from very low to moderate, being often very low (Table 3). However, it is worth noting that the SOM analysis has not been able to include the reductions in several important pressures to benthic habitats, and therefore both the pressure reductions and the probability to achieve state improvements are likely underestimations. This is particularly the case for the effects of eutrophication, which is a significant pressure to the state of benthic habitats (Tables 6.1-6.5). Based on the SOM analysis of the input of nutrients, reductions in the input of nitrogen and phosphorus were estimated in all sub-areas of the Baltic Sea with existing measures (see Topic report for input of nutrients). The reductions are possibly moderate (ca. 0-15% for phosphorus and ca. 5-20% for nitrogen) in many sub-areas, which may indicate that in the long run also, effects of eutrophication on benthic habitats may decrease. However, the reductions in the input of nutrients have not been turned into changes in the effects of eutrophication and further in the state of the benthic habitats in the SOM model. Thus, it is certain that pressure reductions and state improvements presented in this report are underestimations.

The previous holistic assessment (HELCOM 2018b) showed that one third of coastal seabed is in good state and almost half of open sea soft-bottom areas are in good state. The assessment is, however, based on only a few indicators. The main pressure affecting the open sea area is hypoxia, caused by eutrophication. In the coastal areas, eutrophication is also a main pressure, but significant impacts are also caused by activities causing physical disturbance or loss of habitats. The latter ones are especially significant in the southern sub-basins where several human activities exert these pressures, e.g. bottom trawling fisheries, shipping, sand extraction, dredging and constructions on seabed. The results of the SOM analysis suggest that the existing measures have moderate effectiveness in reducing the physical pressures. In comparison to the required pressure reductions, the pressure reductions from existing measures seem too low and new measures are likely needed.

The SOM analysis has only been able to account for 35-60% of the pressures linked to the state components (Tables 6.1-6.5, pressures highlighted in white). This percent reflects the share of pressures that 1) have a quantifiable link to the state of benthic habitats and 2) have measures types that affect them in the SOM analysis. It has been calculated based on the significance of pressures to the state of benthic habitats. It is the maximum pressure reduction that could be achieved if the pressures linked to benthic habitats in the SOM analysis were eliminated. The effects of several significant pressures are not included in this total, such as the effects of eutrophication and human-induced food web imbalance (Tables 6.1-6.5, pressures highlighted in grey). Although these pressures are expected to decrease based on the results of the SOM analysis, the analysis is not able to estimate how this would affect the state of benthic habitats.

The calculation of state improvements takes into account all the components of the SOM analysis: the activity-pressure contributions, effectiveness of measure types in reducing pressures, links between existing measures and measure types, projected pressure reductions from existing measures, development of human activities, significance of pressures to state components and pressure reductions required to achieve state improvements. The analysis assumes that all existing measures are fully implemented and that there are no time lags between the input of pressures affecting benthic habitats and their state.

Table 3 shows the expected total pressure reductions from existing measures, the probability of achieving a noticeable improvement in state with such a pressure reduction, and the maximum pressure reduction that could be achieved with the fully quantified pressures in the SOM analysis. Total pressure reductions are calculated based on the reductions in the pressures linked to benthic habitats, significance of different pressures to the state of these habitat types (Tables 6.1-6.5), and spatial weighting to account for the target area of existing measures.

Table 4 presents the average of the most likely total pressure reduction required to reach a noticeable improvement in state for each habitat type and sub-area, based on the expert responses. There is considerable uncertainty among experts about the required pressure reductions to achieve state improvements, as the standard deviations are high compared to the most likely value. This is rather natural as the change was formulated as a noticeable state improvement, which can be interpreted in different ways. The required pressure reductions are 10-60% for hard substrate vegetation dominate communities, 0-65% for soft substrate vegetation dominate communities, 0-75% for hard substrate epifauna dominate communities, 0-70% for soft substrate infauna dominate communities, and 10-45% for coarse substrate infauna dominated communities, based on the 90% confidence intervals. Particularly the lower ends of the required pressure reductions vary substantially across sub-areas. This indicates that the magnitude of the required pressure reductions is very uncertain. Expert's confidence in their own responses to the question on total pressure reduction required to reach a noticeable improvement ranges from low to high, depending on the habitat type and area. Confidence in the estimates for the Northern Baltic is on average low.

Distributions of expert responses on the required pressure reductions to achieve a noticeable improvement are included in Annex 10. The figures indicate that experts have differing opinions about the pressure reductions required and that there is substantial uncertainty about the required pressure reductions (multiple peaks, wide distributions). Thus, these graphs provide further evidence that there is considerable uncertainty in the estimation of the necessary pressure reductions to achieve a noticeable improvement in state for benthic habitats. [to be checked when graphs are in]

Conclusions of the results: The results are very similar for four of the habitat types, but insufficient information was available for coarse substrate infauna. Less than half of the effects of pressures to benthic habitats were included in the analysis, which makes the results highly uncertain (Table 3). The pressures that were included in the model were reduced only slightly(Table 3). The effect of the most important pressures on benthic habitats – eutrophication and food web imbalance – were not assessed within the model. The SOM analysis for eutrophication indicates that nutrient inputs would be reduced by 0-20% in all sub-areas, which is a moderate decrease (see the Topic report for nutrient inputs) but its effect on the benthic habitats cannot be estimated. Despite uncertainties, it is quite clear that the existing measures are not sufficient to achieve a significant improvement in the state benthic habitats (cf. Table 4 for required total pressure reductions).

Table 3. Sufficiency of measures in achieving a noticeable improvement in the state of benthic habitats by habitat type and sub-area. The table presents the expected values and the 10-90 percentile in brackets, which shows the range in which 80% of the observations fall in.

State	**Assessment area**	**Total pressure reduction (%)** [10 percentile – 90 percentile]	**Probability to achieve a noticeable state improvement (%) with expected pressure reduction** [10 percentile – 90 percentile]	**Maximum possible pressure reduction due to model coverage (%)**
Hard substrate vegetation dominated community	Kattegat	6 [4-9]	0 [0-0]	36
	Southern Baltic	9 [6-13]	4 [1-15]	38
	Eastern Baltic	9 [5-13]	2 [0-8]	46
	Northern Baltic	12 [7-18]	7 [1-22]	38
Soft substrate vegetation dominated community	Kattegat	Insufficient data		
	Southern Baltic	10 [7-14]	2 [0-5]	43
	Eastern Baltic	11 [7-15]	3 [0-9]	47
	Northern Baltic	12 [8-17]	3 [1-7]	46
Hard substrate epifauna dominated community	Kattegat	15 [10-20]	16 [1-28]	57
	Southern Baltic	15 [10-21]	11 [3-22]	58
	Eastern Baltic	4 [3-5]	0 [0-0]	28
	Northern Baltic	7 [4-9]	1 [0-2]	33
Soft substrate infauna dominated community	Kattegat	9 [6-13]	2 [0-10]	43
	Southern Baltic	9 [6-13]	2 [0-8]	34
	Eastern Baltic	10 [7-14]	5 [1-20]	38
	Northern Baltic	5 [2-9]	0 [0-0]	32
	Kattegat	Insufficient data		

State	Assessment area	**Total pressure reduction (%)** [10 percentile – 90 percentile]	**Probability to achieve a noticeable state improvement (%) with expected pressure reduction** [10 percentile – 90 percentile]	Maximum possible pressure reduction due to model coverage (%)
Coarse substrate infauna dominated community	Southern Baltic	6 [2-11]	0 [0-1]	39
	Eastern Baltic	Insufficient data		
	Northern Baltic	Insufficient data		

Data used: activity-pressure contributions, effectiveness of measure types, information on existing measures, significance of pressures to state components, required pressure reductions to achieve GES, development of human activities

Table 4. Total pressure reduction required to reach a noticeable improvement in state by habitat type and area. Standard deviation is given in parentheses. Values are calculated directly from expert survey data. Confidence depicts the most common rating of expert's confidence in their own responses to the question on total pressure reduction required to reach a noticeable improvement.

State	**Hard substrate vegetation dominated community**			
Area	**Kattegat**	**Southern Baltic**	**Eastern Baltic**	**Northern Baltic**
Most likely pressure reduction required (%)	33 (18) ○●●	41 (23) ○●●	38 (19) ○●●	48 (11) ●●●
Confidence	Moderate	Moderate	High - Moderate	Low
Number of experts	4	7	5	5
State	**Soft substrate vegetation dominated community**			
Area	**Kattegat**	**Southern Baltic**	**Eastern Baltic**	**Northern Baltic**
Most likely pressure reduction required (%)	Insufficient data	34 (20) ○●●	30 (21) ●●●	43 (17) ○●●
Confidence	NA	High - Moderate	High	Low
Number of experts	Less than 3	6	3	4
State	**Hard substrate epifauna dominated community**			
Area	**Kattegat**	**Southern Baltic**	**Eastern Baltic**	**Northern Baltic**
Most likely pressure reduction required (%)	33 (18) ○●●	36 (16) ○●●	27 (17) ○●●	42 (19) ○●●
Confidence	High	Low	High	Moderate
Number of experts	4	8	3	3
State	**Soft substrate infauna dominated community**			
Area	**Kattegat**	**Southern Baltic**	**Eastern Baltic**	**Northern Baltic**
Most likely pressure reduction required (%)	32 (24) ○○●	31 (18) ○●●	37 (22) ○●●	54 (14) ●●●
Confidence	High	Moderate – Low	Moderate	Low
Number of experts	3	8	4	5
State	**Coarse substrate infauna dominated community**			
Area	**Kattegat**	**Southern Baltic**	**Eastern Baltic**	**Northern Baltic**

Most likely pressure reduction required (%)	Insufficient data	28 (14) ○●●	Insufficient data	Insufficient data
Confidence	NA	Moderate	NA	NA
Number of experts	Less than 3	4	Less than 3	Less than 3

Colour scale for the percent reduction in pressures required to reach GES in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Categories for the certainty of the reduction required estimate (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●

Data used: expert responses on required pressure reductions to achieve GES

What are the time lags between pressure and state?

Information on time lags between reducing the pressures and state of benthic habitats was collected from experts, who evaluated how long it would take to achieve a noticeable improvement in state assuming sufficient measures were implemented. Table 5 shows the distribution and average of the answers for the habitat types and sub-areas.

The average estimates for the time lag range from 10 to 25 years, depending on the habitat type and area. There is considerable uncertainty in the estimates, as indicated by the standard deviations. However, these expert evaluations indicate that even with sufficient measures, it takes time to achieve state improvements for benthic habitats in the Baltic Sea, and any significant improvements in the state of benthic habitats could be delayed beyond 2030.

Two factors reported contributing to the time lag for all five habitat types were the effects of accumulated nutrients in the sediment which will delay recovery, and generally long recovery times for certain species/communities due to time for re-establishment in an area and life-cycles.

Furthermore, the experts indicated that non-indigenous species (NIS) and hypoxia delay recovery times for most of the habitat types. As established NIS are highly unlikely to be eradicated from the system, their contribution to time lags come from either slowing the recovery of the degraded habitat or if their effects decrease as the ecosystem stabilizes to their co-occurrence (e.g. predation increases). Reduction in hypoxia is tied to eutrophication which has particularly long time lags to recovery. Also, heavy metal accumulation in the sediment was mentioned for at least the soft substrate infauna dominated community. Sediment profile studies have shown how very persistent toxins are buried deeper into the sediment and, in practise, disappear from the ecosystem, but this takes time over a few decades. Other toxins like organotin compounds break down during a couple of decades. There are signs that the pharmaceutical substances are not as persistent.

Table 5. Time lags in achieving a noticeable state improvement with sufficient measures.

Time lag	Hard substrate vegetation dominated community				Soft substrate vegetation dominated community				Hard substrate epifauna dominated community				Soft substrate infauna dominated community				Coarse substrate infauna dominated community			
	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic
0 years (no time lag)	0	0	0	0	Insufficient data (less than 3 experts)	0	0	0	0	0	0	0	0	0	0	0	Insufficient data (less than 3 experts)	0	Insufficient data (less than 3 experts)	Insufficient data (less than 3 experts)
0-5 years	0	1	0	1		0	0	0	0	1	0	0	0	0	0	0		0		
6-10 years	1	2	0	0		3	1	1	1	1	0	0	1	4	1	3		2		
11-25 years	2	4	3	2		3	1	2	2	4	2	2	1	4	1	1		1		
26-50 years	1	1	2	1		1	1	0	1	3	1	1	1	1	2	0		2		
51-100 years	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0		0		
More than 100 years	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0		0		
Excluded	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0		0		
Average	20.0	15.6	25.5	18.8		16.1	20.8	14.2	20.0	21.4	24.2	24.2	20.8	15.3	25.0	10.0		21.5		
Standard deviation	10.9	10.0	9.8	12.4		9.9	12.5	4.7	10.9	12.4	9.4	9.4	12.5	9.2	13.0	4.3		13.6		
Confidence	Moderate-High	Moderate	High	Moderate-High		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate		Moderate		
Number of experts	4	8	5	5		7	3	4	4	9	3	3	3	9	4	5		5		

Data used: expert responses on time lags

What are the pressures contributing to the state components?

These results illustrate the significance of different pressures affecting the state of benthic habitats and enable comparison across habitat types and geographic areas. Experts identified in total 12 distinct pressures significant to the five habitat types (see Tables 6.1-6.5). The most significant pressure across the habitat types was the *effects of eutrophication*, followed by *physical disturbance* and *physical loss of marine habitats*. Other significant pressures were *human induced food web imbalance* (especially to hard substrate vegetation dominated community), *effects of non-indigenous species* (especially to both hard substrate habitats and soft substrate infauna), *heavy metal pollution* (soft substrate infauna) and *changes in hydrologic conditions* (soft substrate vegetation). The expert responses are in line with the scientific studies and the understanding of the ecosystem responses in the Baltic Sea region. A notable result was the greater role of effects of non-indigenous species in the eastern and northern Baltic compared to the southern Baltic and Kattegat. Expert's confidence in their own responses on the significance of pressures to benthic habitats was most often high.

Table 6.1. Significance of pressures (%) affecting *hard substrate vegetation dominated community*.

Area **Pressure**	**Kattegat**	**Southern Baltic**	**Eastern Baltic**	**Northern Baltic**
Extraction of fish (includes prey depletion)	14	11	9	7
Effects of non-indigenous species	4	3	13	14
Physical disturbance of marine habitats	10	20	7	16
Physical loss of marine habitats	12	12	13	9
Effects of eutrophication	38	38	39	41
River, lake, or land habitat loss/degradation		4	11	
Change in hydrologic conditions				5
Human-induced food web imbalance	22	12	9	9
Confidence	High	High	High	High - Moderate
Number of experts	5	9	5	4

Colour scale for the significance of the pressure to the state variable (based on the expected value):
0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Pressures for which we cannot quantify the link between the pressure input, pressure and state in the SOM analysis are highlighted in grey, e.g. we cannot link reductions in nutrient inputs to reductions in the effects of eutrophication and further to the state of benthic habitats.

Data used: expert responses on significance of pressures to state components

Table 6.2. Significance of pressures (%) affecting *soft substrate vegetation dominated community*.

Area Pressure	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic
Extraction of fish (includes prey depletion)	Insufficient data	9		
Species disturbance or displacement by human presence		2		
Effects of non-indigenous species		3	7	5
Physical disturbance of marine habitats		20	11	27
Physical loss of marine habitats		16	22	19
Effects of eutrophication		28	33	41
River, lake, or land habitat loss/degradation		5		
Pharmaceutical pollution				
Change in hydrologic conditions		8	11	8
Human-induced food web imbalance		9	15	
Confidence	NA	Moderate	High	High
Number of experts	Less than 3	7	3	3

Colour scale for the significance of the pressure to the state variable (based on the expected value):
0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Pressures for which we cannot quantify the link between the pressure input, pressure and state in the SOM analysis are highlighted in grey, e.g. we cannot link reductions in nutrient inputs to reductions in the effects of eutrophication and further to the state of benthic habitats.
Data used: expert responses on significance of pressures to state components

Table 6.3. Significance of pressures (%) affecting *hard substrate epifauna dominated community*.

Area Pressure	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic
Extraction of fish (includes prey depletion)	15	7		11
Effects of non-indigenous species		7	17	18
Physical disturbance of marine habitats	19	23	17	21
Physical loss of marine habitats	13	16	26	7
Effects of eutrophication	38	39	26	43
Change in hydrologic conditions		1		
Human-induced food web imbalance	17	6	13	
Confidence	High	Moderate	High	High
Number of experts	5	10	3	3

Colour scale for the significance of the pressure to the state variable (based on the expected value):
0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Colour scale for the significance of the pressure to the state variable (based on the expected value):
0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Pressures for which we cannot quantify the link between the pressure input, pressure and state in the SOM analysis are highlighted in grey, e.g. we cannot link reductions in nutrient inputs to reductions in the effects of eutrophication and further to the state of benthic habitats.
Data used: expert responses on significance of pressures to state components

Table 6.4. Significance of pressures (%) affecting *soft substrate infauna dominated community*.

Area Pressure	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic
Extraction of fish (includes prey depletion)		9		
Species disturbance or displacement by human presence		1		
Effects of non-indigenous species		1		21
Physical disturbance of marine habitats	38	31	34	26
Physical loss of marine habitats		15		8
Effects of eutrophication	29	30	48	37
Heavy metal pollution	10	4	14	5
Pharmaceutical pollution	10			
Change in hydrologic conditions		4		
Human-induced food web imbalance	14	4	3	3
Confidence	High	Moderate	High	High
Number of experts	3	9	4	4

Colour scale for the significance of the pressure to the state variable (based on the expected value):
0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Pressures for which we cannot quantify the link between the pressure input, pressure and state in the SOM analysis are highlighted in grey, e.g. we cannot link reductions in nutrient inputs to reductions in the effects of eutrophication and further to the state of benthic habitats.

Data used: expert responses on significance of pressures to state components

Table 6.5. Significance of pressures (%) affecting *coarse substrate infauna dominated community*.

Area Pressure	Kattegat	Southern Baltic	Eastern Baltic	Northern Baltic
Extraction of fish (includes prey depletion)	Insufficient data	9	Insufficient data	Insufficient data
Effects of non-indigenous species		5		
Physical disturbance of marine habitats		30		
Physical loss of marine habitats		19		
Effects of eutrophication		35		
Heavy metal pollution				
Change in hydrologic conditions		2		
Confidence	NA	High	NA	NA
Number of experts	Less than 3	5	Less than 3	Less than 3

Colour scale for the significance of the pressure to the state variable (based on the expected value):
0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Pressures for which we cannot quantify the link between the pressure input, pressure and state in the SOM analysis are highlighted in grey, e.g. we cannot link reductions in nutrient inputs to reductions in the effects of eutrophication and further to the state of benthic habitats.

Data used: expert responses on significance of pressures to state components

What are the state components most affected by loss and disturbance to the seabed?

The data from the pressure-state expert surveys for hazardous substances, benthic habitats, birds, fish and mammals allow for identifying the state components most affected by physical disturbance and loss of marine habitats. These five expert surveys provide expert views on the significance of various pressures to the state components in the SOM analysis.

Table 7 shows the state components most affected by the disturbance and loss of marine habitats. State components most affected are the various benthic habitat types, but also TBT concentration and fish species groups are among the most affected state components. The significance of fish shows how the pressures on seabed affect also functional habitats, such as spawning habitats of perch (underwater vegetation) or feeding habitats of cyprinids (underwater vegetation). It has also been shown how the siltation of coastal vegetation has negatively affected herring spawning.

Table 7. Top five state components most affected by physical disturbance and loss of marine habitats. Listing is based on Baltic-wide averages of the significance of pressures to state components presented in each respective topic report. Average number of expert responses for the state component is given in parenthesis (total response count for the state component divided by the number of geographic areas for the state component).

Pressure	1st most affected state component	2nd most affected state component	3rd most affected state component	4th most affected state component	5th most affected state component
Physical disturbance of marine habitats	Soft substrate infauna dominated community (5.0)	TBT concentration (7.0)	Hard substrate epifauna dominated community (5.3)	Soft substrate vegetation dominated community (3.8)	
Physical loss of marine habitats	Soft substrate vegetation dominated community (3.8)	Hard substrate epifauna dominated community (5.3)	Hard substrate vegetation dominated community (5.8)	Perch and other coastal piscivores (4.8)	Cyprinids and other mesopredators (3.7)

Data used: expert responses on significance of pressures to state components for all topics
Less than five most affected state components are presented in cases where there is insufficient data for some state component(s) affected by the pressure, i.e. there are not enough expert responses to the significance of pressures to the state component in the survey (e.g. some mammals species). This corresponds to the criteria for the format of presentation.

What are the pressure reductions from existing measures?

Table 8 shows the pressure reductions in the *potential physical disturbance and loss of seabed* by sub-basin in 2016-2030, taking into consideration the effects of existing measures and the changes in the extent of human activities. They are calculated using data on the activity-pressure contributions, effectiveness of measure types, links between existing measures and measure types, and projected development of human activities. Reductions for other pressures – nutrient inputs, hazardous substances, non-indigenous species – are shown in the respective topic reports.

The activity-pressure data are at the sub-basin level and the effectiveness of measures data at the Baltic Sea scale, and thus the total pressure reductions are presented at the sub-basin level. The projected reductions in pressures account for the joint impacts across the measure types, as well as the spatial area where the pressures can be reduced to avoid overestimating the pressure reductions. Pressure reductions can be positive, negative or zero, depending on the combined effect of existing measures and changes in the extent of human activities. When the reduction in pressures from existing measures is larger than the increase from changes in human activities, pressures are reduced.

The reduction in the *potential physical disturbance and loss of seabed* ranges from very low to high, depending on the sub-basin and pressure. Most often, moderate reductions are projected. In some areas, no changes are expected. Interestingly, pressure reductions are expected to be lower in the Northern Baltic Proper, Gulf of Riga and Gulf of Finland than elsewhere in the Baltic Sea.

Future development in the extent of human activities is expected to influence particularly the physical disturbance to seabed. Tourism and leisure activities, shipping and transport infrastructure are expected to increase by 20-30% by 2030 in the most likely scenario, which increases the pressures from these activities. No change is expected to fish and shellfish harvesting in the most likely scenario, and other main activities affecting the pressures are assumed to stay constant. Thus, the projected pressure reductions are a combination of the effect of increase in human activities and existing measures.

Further details on the effectiveness of different measure types and activity-pressure contributions can be found in Tables 9 and 10.

Table 8. Projected pressure reductions (%) from existing measures on potential physical disturbance and loss of seabed by sub-basin. The table depicts the most likely/expected values of reductions in pressures and gives standard deviations in parenthesis.

Pressure **Basin**	**Potential physical disturbance to seabed**	**Potential physical loss of seabed**
Kattegat	32 (10) ○●●	24 (7) ●●●
Great Belt	13 (13) ○○●	22 (12) ○●●
The Sound	13 (12) ○○●	21 (14) ○○●
Kiel Bay	36 (9) ●●●	36 (9) ●●●
Bay of Mecklenburg	34 (10) ○●●	44 (11) ●●●
Arkona Basin	31 (6) ●●●	43 (8) ●●●
Bornholm Basin	35 (9) ●●●	28 (6) ●●●
Gdansk Basin	14 (11) ○○●	-1 (13) ○○●
Eastern Gotland Basin	28 (7) ●●●	18 (5) ●●●
Western Gotland Basin	33 (21) ○○●	39 (17) ○●●
Gulf of Riga	0 (10) ○○●	11 (10) ○○●
Northern Baltic Proper	9 (6) ○○●	18 (6) ○●●
Gulf of Finland	1 (6) ○○●	13 (7) ○●●
Åland Sea	31 (17) ○●●	12 (6) ○●●

Pressure Basin	Potential physical disturbance to seabed	Potential physical loss of seabed
Bothnian Sea	28 (14) ○●●	31 (10) ○●●
The Quark	27 (14) ○●●	31 (10) ○●●
Bothnian Bay	26 (15) ○●●	31 (11) ○●●

Colour scale for the pressure reductions in percent (based on the expected value):
<0%, 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Categories for the certainty of the pressure reductions (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●
Data used: activity-pressure contributions calculated using data from the HELCOM Baltic Sea Impact Index (BSII), effectiveness of measure types, information on existing measures

How effective are measure types in reducing pressures?

This section presents the percent effectiveness of measure types in reducing potential physical disturbance and loss of seabed from specific activities. The estimates are presented per activity, i.e. they portray the percent reduction in the pressure from the activity in question, and not in the total input across all activities. Information on the reductions over all activities contributing to the pressure is given in the section on the impacts of measure types. Data on the effectiveness of measure types originate from expert surveys on the effectiveness of measures and are at the Baltic Sea scale.

In the following, percent effectiveness is presented per activity, pressure and measure type, and pooled over experts. The effectiveness estimates can be compared across measure types to assess, on average, how effective they are in relation to each other in reducing the pressures from the specific activities, or across activities to assess which measure type could be the most effective for each activity.

Tables 9.1 and 9.2 present the expected effectiveness for each measure type and its standard deviation. Confidence depicts the most common rating of expert's confidence in their own responses to the effectiveness of measure types question. Annex 11 presents the distributions of the effectiveness of measure types for additional information.

Of the measure types targeting *potential physical disturbance to seabed*, only the measure types *full implementation of the EU Maritime Spatial Planning Framework Directive* and *enhance legal protection of habitats and species* can reduce the pressure from all the activities (Table 9.1). The rest of the measure types decrease the pressures from specific activities, e.g. regulations of fishing gears, fishing areas and fishing times, best practices in dredging and sand extraction, as well as speed limits for maritime traffic. Most of the measure types are evaluated to have a similar average effectiveness, and there is considerable uncertainty on the effectiveness, as shown in the standard deviations.

For the potential physical loss of seabed (Table 9.2), the measure types *expand EIA reporting requirements e.g. to cover new activities or include new environmental components*, *full implementation of the EU Maritime Spatial Planning Framework Directive*, and *enhance legal protection of habitats and species* can reduce the pressures from all five activities. As for disturbance, the effectiveness of the measure types is on a similar level to each other, and uncertainty is high also in these estimations.

Overall, the handful of measure types mentioned above were estimated to reduce the two pressures. However, none of them seemed to be more effective than the rest, and variability of the estimates is high. Experts' evaluation of the confidence of the estimates is most often moderate.

Estimates of the effectiveness of measure types are used to assess the effects of existing measures in reducing the disturbance and loss of seabed to the Baltic Sea and to calculate pressure reductions from existing measures by 2030.

Table 9.1 Effectiveness of measure types (%) in reducing the *potential physical disturbance of seabed*. The effectiveness of a measure type is the percent reduction in the pressure resulting from a specific activity. The table depicts the most likely/expected values of effectiveness, and standard deviation is given in parenthesis.

Measure type ID	**Activity** **Measure type**	**Aquaculture – marine**	**Fish and shellfish harvesting**	**Extraction of minerals**	**Restructuring of seabed morphology**	**Tourism and leisure activities**	**Transport – shipping**	**Has corresponding existing measures in the SOM analysis (Yes/No)**
37	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	31 (22) ○○●	Not assessed	28 (23) ○○●	Not assessed	Not assessed	Not assessed	Yes
38	Implement national plan for sand and aggregate extraction	Not assessed	Not assessed	26 (18) ○○●	Not assessed	Not assessed	Not assessed	Yes
39	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (15) ○○●	30 (20) ○○●	23 (15) ○○●	23 (17) ○○●	20 (21) ○○●	20 (20) ○○●	Yes
40	Enhance legal protection of habitats and species	33 (24) ○○●	44 (22) ○●●	37 (22) ○○●	35 (23) ○○●	32 (26) ○○●	26 (18) ○○●	Yes
41	Seasonal restrictions	Not assessed	Not assessed	25 (26) ○○●	22 (19) ○○●	Not assessed	Not assessed	No
42	Alternative extraction technologies	Not assessed	Not assessed	33 (21) ○○●	Not assessed	Not assessed	Not assessed	No
43	Implement industry best practices	33 (22) ○○●	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	No
44	Spatial trawling restrictions	Not assessed	56 (22) ○●●	Not assessed	Not assessed	Not assessed	Not assessed	Yes
45	Seasonal trawling restrictions	Not assessed	33 (23) ○○●	Not assessed	Not assessed	Not assessed	Not assessed	No
46	Technical regulations of fishing gear (e.g. type, modifications, etc.)	Not assessed	46 (20) ○●●	Not assessed	Not assessed	Not assessed	Not assessed	No
47	Technical modifications to ships	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	19 (13) ○○●	No
48	Speed limits	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	23 (12) ○●●	No
49	Limit sediment deposition from e.g. mining to selected "dumping sites"	Not assessed	Not assessed	Not assessed	37 (23) ○○●	Not assessed	Not assessed	Yes

Measure type ID	Activity Measure type	Aquaculture – marine	Fish and shellfish harvesting	Extraction of minerals	Restructuring of seabed morphology	Tourism and leisure activities	Transport – shipping	Has corresponding existing measures in the SOM analysis (Yes/No)
50	Application of best practices	Not assessed	Not assessed	Not assessed	35 (22) ○○●	Not assessed	Not assessed	Yes
51	Expansion of permitting requirements	Not assessed	Not assessed	Not assessed	33 (20) ○●●	Not assessed	Not assessed	Yes
	Confidence	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	
	Number of experts	18-19	17-19	15-19	16-18	17-18	15-17	

Colour scale for the effectiveness of a measure type in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Categories for the certainty of the effectiveness estimate (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●

Data used: expert responses on effectiveness of measure types

Full activity names:

- Aquaculture – marine, including infrastructure
- Fish and shellfish harvesting (all gears; professional, recreational)
- Extraction of minerals (rock, metal ores, gravel, sand, shell)
- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
- Tourism and leisure activities (boating, beach use, water sports, etc.)
- Transport – shipping (incl. anchoring, mooring)

Table 9.2 Effectiveness of measure types (%) in reducing the *potential physical loss of seabed*. The effectiveness of a measure type is the percent reduction in the pressure resulting from a specific activity. The table depicts the most likely/expected values of effectiveness, and standard deviation is given in parenthesis.

Measure type ID	Activity Measure type	Coastal defence and flood protection	Extraction of minerals	Restructuring of seabed morphology	Tourism and leisure infrastructure	Transport – shipping infrastructure	Has corresponding existing measures in the SOM analysis (Yes/No)
37	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (24) ○○●	27 (20) ○○●	33 (23) ○○●	29 (24) ○○●	25 (24) ○○●	Yes
38	Implement national plan for sand and aggregate extraction	Not assessed	33 (22) ○○●	Not assessed	Not assessed	Not assessed	Yes
39	Full implementation of the EU Maritime Spatial Planning Framework Directive	22 (19) ○○●	32 (24) ○○●	26 (21) ○○●	24 (24) ○○●	22 (21) ○○●	Yes
40	Enhance legal protection of habitats and species	29 (24) ○○●	40 (19) ○●●	29 (19) ○○●	30 (23) ○○●	32 (25) ○○●	Yes
49	Limit sediment deposition from e.g. mining to selected "dumping sites"	Not assessed	Not assessed	31 (19) ○○●	Not assessed	Not assessed	Yes
	Confidence	Low	Moderate	Moderate	Moderate	Moderate	
	Number of experts	17-18	16-17	15-17	16-18	18-19	

Colour scale for the effectiveness of a measure type in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Categories for the certainty of the effectiveness estimate (based on the relative size of the standard deviation to the expected value): low: ○○●, moderate: ○●●, high: ●●●
Data used: expert responses on effectiveness of measure types
Full activity names:

- Coastal defence and flood protection (seawalls, flood protection)
- Extraction of minerals (rock, metal ores, gravel, sand, shell)
- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
- Tourism and leisure infrastructure (piers, marinas)
- Tourism and leisure activities (boating, beach use, water sports, etc.)
- Transport – shipping infrastructure (harbours, ports, shipbuilding)

Which activities contribute to pressures?

Tables 10.1 and 10.2 show the contribution of activities to *potential physical disturbance and loss of seabed*. Data on activity-pressure contributions for the loss and disturbance to the seabed is based on the approach employed in HELCOM HOLAS II, which utilizes the Baltic Sea Pressure Index (BSPI) and Baltic Sea Impact Index (BSII) to integrate data reported to the Secretariat from the Contracting Parties through regular reporting and previous data calls. The assessment was done at the level of the 17 sub-basins. No variability is present in the underlying data (only point estimates available).

Altogether 16 different activities are identified to contribute to the *potential physical disturbance and loss of seabed*. For *potential physical disturbance to seabed* (Table 10.1), three main activities contributing to the pressure are *fish and shellfish harvesting*, *tourism and leisure activities*, and *transport – shipping*. *Transmission of electricity and communications* has a major role in the Northern Baltic Proper, and *extraction of oil and gas (incl. infrastructure)* in the Northern Baltic Proper and Gulf of Finland (because of the gas pipelines). Although *fish and shellfish harvesting* was highlighted as a major activity, its role is limited to the sub-basins south of Northern Baltic Proper. On the other hand, *tourism and leisure activities* have bigger role in the northern sub-basins. Most other activities contribute on average less than 10% to the disturbance to seabed.

For the *potential physical loss of seabed* (Table 10.2), three most important activities are *extraction of minerals*, *tourism and leisure infrastructure*, and *transport – shipping infrastructure*. Other activities having a major contribution in at least one of the sub-basins are *coastal defence and flood protection* (Kattegat and Great Belt), *transmission of electricity and communications* (Åland Sea), as well as *extraction of oil and gas, including infrastructure* (Eastern Gotland Basin and Northern Baltic Proper). Most other activities contribute on average less than 10% to the loss of seabed.

What are the impacts of measure types?

The impacts of measure types include the effectiveness of measure types and the contribution of activities to pressures. Thus, the impact shows how much a measure type reduces the pressure across all activities contributing to the pressure and gives indications on which kinds of measures could be the most relevant in addressing specific pressures.

For both the potential physical disturbance and loss of seabed, *enhancing legal protection of habitats and species* seems to be the most impactful measure type in almost all sub-basins. Other measure types having a relatively high impact on the disturbance to seabed in most of the sub-basins are *spatial trawling restrictions*, and *full implementation of the EU Maritime Spatial Planning Framework Directive*, *technical regulations of fishing gear* (e.g. type, modifications) and *seasonal trawling restrictions*. For loss of seabed, other measure types with high estimated impacts are *expanding EIA reporting requirements* e.g. to cover new activities or include new environmental components, and *full implementation of the EU Maritime Spatial Planning Framework Directive*.

There is considerable uncertainty in the estimated impacts, stemming from the uncertainty in the effectiveness of measure types. Thus, the ranking of the measure types based on their impacts is rather uncertain, particularly for the loss of seabed. However, the above-mentioned measure types are evaluated to have impacts in the range of 20-50%, while the others influence less than 10%. As there a no large differences in the effectiveness of the measure types, the results on the impacts are mainly driven by the activity-pressure contributions.

Detailed estimates of the impacts of measure types are presented in Annex 12.

[Discussion on existing measures and their impact, which existing measures are driving pressure reductions, which HELCOM measures are important but not yet implemented]

Table 10.1. Activity-pressure contributions (%). The activity-pressure contributions show the percentage share the activity contributes to the pressures (*potential physical disturbance of the seabed*). The table depicts the most likely/expected contribution (%). Standard deviations are not reported, as there is no variability in the underlying data (only point estimates available). Value zero means that the contribution is less than 0.5%.

Potential physical disturbance to seabed	Coastal defence and flood protection	Aquaculture – marine	Renewable energy generation	Transmission of electricity and communications	Fish and shellfish harvesting	Marine plant harvesting	Extraction of minerals	Extraction of oil and gas	Restructuring of seabed morphology	Tourism and leisure activities	Transport – shipping
Kattegat	0	0	0	0	80	0	0	0	0	3	13
Great Belt	0	0	0	0	39	0	3	0	0	15	39
The Sound	0	0	0	0	0	0	1	0	1	16	78
Kiel Bay	0	0	0	0	59	0	0	0	0	3	33
Bay of Mecklenburg	0	0	0	0	54	0	0	0	0	4	38
Arkona Basin	0	0	0	2	63	0	1	0	0	4	26
Bornholm Basin	0	0	0	1	88	0	0	0	0	1	5
Gdansk Basin	0	0	0	0	81	0	0	0	1	7	7
Eastern Gotland Basin	0	0	0	2	85	0	0	2	0	3	4
Western Gotland Basin	0	0	0	0	10	0	0	0	0	55	31
Gulf of Riga	0	0	0	0	0	8	0	0	7	44	37
Northern Baltic Proper	0	0	0	24	0	0	0	15	0	31	27
Gulf of Finland	0	1	0	5	0	0	2	12	4	27	44
Åland Sea	0	3	0	0	0	0	0	2	9	55	28
Bothnian Sea	0	2	0	0	0	0	0	1	9	61	23
The Quark	0	0	0	0	0	0	0	0	4	61	31
Bothnian Bay	0	1	0	0	0	0	0	0	2	67	26

Colour scale for the contribution of the activity to the pressure in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Categories for the certainty of the activity-pressure contribution estimate (based on the relative size of the standard deviation to the expected value):
low: ○○●, moderate: ○●●, high: ●●●
Data used: activity-pressure contributions calculated using data from the HELCOM Baltic Sea Impact Index (BSII)
Full activity names:

- Coastal defence and flood protection (seawalls, flood protection)
- Aquaculture – marine, including infrastructure
- Renewable energy generation (wind, wave and tidal power), including infrastructure
- Transmission of electricity and communications (cables)
- Fish and shellfish harvesting (all gears; professional, recreational)
- Marine plant harvesting
- Extraction of minerals (rock, metal ores, gravel, sand, shell)
- Extraction of oil and gas, including infrastructure (e.g. pipelines)

- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
- Tourism and leisure activities (boating, beach use, water sports, etc.)
- Transport – shipping (incl. anchoring, mooring)

Table 10.2. Activity-pressure contributions (%). The activity-pressure contributions show the percentage share the activity contributes to the pressures (*potential physical loss of the seabed*). The table depicts the most likely/expected contribution (%). Standard deviations are not reported, as there is no variability in the underlying data (only point estimates available). Value zero means that the contribution is less than 0.5%.

Potential physical loss of seabed	Land claim	Canalisation and other watercourse modifications	Coastal defence and flood protection	Transport – land	Aquaculture – marine	Renewable energy generation	Transmission of electricity and communications	Extraction of minerals	Extraction of oil and gas	Restructuring of seabed morphology	Tourism and leisure infrastructure	Transport – shipping infrastructure
Kattegat	0	0	26	0	4	0	0	30	0	3	14	18
Great Belt	0	0	36	0	1	0	0	42	0	0	5	12
The Sound	0	0	9	0	0	0	0	5	0	0	5	76
Kiel Bay	0	0	10	0	0	0	0	47	0	0	6	33
Bay of Mecklenburg	0	0	3	0	0	0	3	66	0	0	1	22
Arkona Basin	0	0	4	0	0	0	1	82	1	0	1	6
Bornholm Basin	0	0	2	0	0	0	2	59	14	0	8	11
Gdansk Basin	0	0	2	0	0	0	0	4	2	0	3	84
Eastern Gotland Basin	0	0	0	0	0	0	3	38	22	0	3	30
Western Gotland Basin	0	0	0	0	0	0	1	0	1	2	50	42
Gulf of Riga	0	0	2	0	0	0	1	1	0	0	33	58
Northern Baltic Proper	0	0	0	0	0	0	7	0	32	0	40	17
Gulf of Finland	0	0	0	0	0	0	3	26	10	0	5	51
Åland Sea	0	0	0	0	16	0	32	0	10	0	22	16
Bothnian Sea	0	0	0	0	6	0	2	0	1	5	34	47
The Quark	0	0	1	0	4	0	4	0	5	0	36	45
Bothnian Bay	0	0	0	0	5	0	0	0	1	1	30	59

Colour scale for the contribution of the activity to the pressure in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%

Categories for the certainty of the activity-pressure contribution estimate (based on the relative size of the standard deviation to the expected value):
low: ○○●, moderate: ○●●, high: ●●●

Data used: activity-pressure contributions calculated using data from the HELCOM Baltic Sea Impact Index (BSII)

Full activity names:

- Land claim
- Canalisation and other watercourse modifications (dams, culverting, trenching, weirs, large-scale water deviation)

- Coastal defence and flood protection (seawalls, flood protection)
- Transport – land (cars and trucks, trains), including infrastructure
- Aquaculture – marine, including infrastructure
- Renewable energy generation (wind, wave and tidal power), including infrastructure
- Transmission of electricity and communications (cables)
- Extraction of minerals (rock, metal ores, gravel, sand, shell)
- Extraction of oil and gas, including infrastructure (e.g. pipelines)
- Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
- Tourism and leisure infrastructure (piers, marinas)

  Transport – shipping infrastructure (harbours, ports, shipbuilding)

Background of respondents

There were two expert surveys for benthic habitats: one on effectiveness of measures and another on pressure-state linkages. For the effectiveness of measures survey, altogether 20 survey responses with 23 contributing experts were received. Three of the answers were group responses with two contributing experts. For the pressure-state survey, 18 responses from 19 experts were received. One of the responses was a group answer with two contributing experts.

The number of experts contributing to the benthic habitats surveys by country is shown in Table 11, with the response count per sub-topic and geographic area presented in Table 12.

Table 11. Number of experts contributing to the benthic habitats surveys

Survey	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
Effectiveness of measures	7	4	-	4	2	-	-	2	4	23
Pressure-state linkages	7	4	-	4	1	1	-	-	2	19

Table 12. Number of responses to the benthic habitats surveys

<table>
<tr><th>Survey</th><th>Sub-topic</th><th>Geographic area</th><th>Response count</th></tr>
<tr><td>Effectiveness of measures</td><td colspan="2">Whole Baltic</td><td>20</td></tr>
<tr><td rowspan="20">Pressure-state linkages</td><td rowspan="4">hard substrate vegetation dominated community</td><td>Kattegat</td><td>5</td></tr>
<tr><td>Southern Baltic</td><td>9</td></tr>
<tr><td>Eastern Baltic</td><td>5</td></tr>
<tr><td>Northern Baltic</td><td>4</td></tr>
<tr><td rowspan="4">soft substrate vegetation dominated community</td><td>Kattegat</td><td>2</td></tr>
<tr><td>Southern Baltic</td><td>7</td></tr>
<tr><td>Eastern Baltic</td><td>3</td></tr>
<tr><td>Northern Baltic</td><td>3</td></tr>
<tr><td rowspan="4">hard substrate epifauna dominated community</td><td>Kattegat</td><td>5</td></tr>
<tr><td>Southern Baltic</td><td>10</td></tr>
<tr><td>Eastern Baltic</td><td>3</td></tr>
<tr><td>Northern Baltic</td><td>3</td></tr>
<tr><td rowspan="4">soft substrate infauna dominated community</td><td>Kattegat</td><td>3</td></tr>
<tr><td>Southern Baltic</td><td>9</td></tr>
<tr><td>Eastern Baltic</td><td>4</td></tr>
<tr><td>Northern Baltic</td><td>4</td></tr>
<tr><td rowspan="4">coarse substrate infauna dominated community</td><td>Kattegat</td><td>2</td></tr>
<tr><td>Southern Baltic</td><td>5</td></tr>
<tr><td>Eastern Baltic</td><td>2</td></tr>
<tr><td>Northern Baltic</td><td>2</td></tr>
</table>

More detailed information is available on the experts participating in the effectiveness of measures and the pressure state survey. Experts stated the most often marine biology or benthic ecology as their respective field, followed by nature conservation and aquatic sciences.

Most of the participating experts had 10-20 years or over 20 years of experience for both surveys (Table 13). 10-13% of the experts had 5-10 years of experience and 4-5% had 3-5 years of experience. None of the experts had less than 3 years of experience in their field. Experts represented research institutions, state agencies, and ministries.

Table 13. Years of experience in the field for the litter effectiveness of measures survey

	Effectiveness of measures		Pressure-state	
Years	**Number of experts**	**Share of experts**	**Number of experts**	**Share of experts**
0-2 years	0	0 %	0	0 %
3-5 years	1	4 %	1	5 %
5-10 years	3	13 %	2	11 %
10-20 years	11	48 %	8	42 %
over 20 years	8	35 %	8	42 %

Discussion

Impact of alternative scenarios for development of human activities

The detailed results are presented for the most likely development scenario for the extent of human activities in 2016–2030. In addition, three other development scenarios were estimated: no change, low change and high change scenarios. These scenarios cover 9 out of the 31 activities in the SOM analysis. The extent of other activities is assumed to remain constant in all scenarios.

As activities contribute to pressures, their assumed change over time affects the pressure reductions and probability to achieve state improvements. The impact depends on to what extent the activities contributing to the specific pressure are covered in the change scenarios. For benthic habitats, the coverage of activities that contribute to pressures in the change scenarios is high for potential physical disturbance to seabed and from moderate to high for loss of seabed.

Overall, the impact of alternative development scenarios is rather significant for benthic habitats, particularly for disturbance to seabed. Higher pressure reductions are projected if no change is assumed in the extent of activities. These are in the range of 0-20% for disturbance to seabed and 0-15% for loss of seabed, depending on the sub-basin. As expected, pressure reductions would be higher with the low development scenario and lower with the high scenario. With higher pressure reductions, probability to achieve noticeable state improvements increases somewhat, but the impact is minor for all habitat types and areas.

Thus, the projected pressure reductions and also to a minor extent the probability to achieve noticeable state improvements are dependent on the assumption on the development scenario. This applies in particular to disturbance to seabed.

Impact of using literature data on effectiveness of measures

In addition to survey data from experts, literature data on the effectiveness of measures has been compiled. The literature data points have been used in a similar way as the expert survey responses, and when it has been available, it has been used to replace the expert estimates of the effectiveness of the measure type. However, literature estimates are not available for all measure types. Thus, the model including the literature estimates is a combination of literature and expert data on effectiveness of measure types. The origin of other data components is not affected.

For benthic habitats, 15 estimates from 5 studies could be included in the SOM model. The projected pressure reductions from existing measures are not affected by the inclusion of literature data. Thus, the results on sufficiency of measures to achieve noticeable state improvements do not change. However, the available data points are limited to just 3 measure types affecting the activity *Restructuring of seabed morphology* and therefore the lack of change from inclusion of the literature data is not unexpected.

Evaluation of quality and confidence

The SOM analysis for benthic habitats has been unable to assess the sufficiency of existing measures to achieve GES, as no GES thresholds were available. Further, further uncertainty to the assessment has been caused by the use of a qualitative formulation of the state improvement, i.e. noticeable improvement in the state of benthic habitats.

Some results have been left out due to too few data points. This has been the case for results on sufficiency of measures in achieving a noticeable improvement, pressure reduction required to reach a noticeable improvement, pressures contributing to the state components and time lags between pressure and state.

The overall certainty of the assessment for benthic habitats could generally be characterized as low. The number of expert responses is relatively high for the effectiveness of measure types part, and experts from seven coastal countries have contributed to some part of the assessment. However, the results on the effectiveness of measure types show high variability, reflecting either broad estimate ranges from individual experts, varying responses among experts, or both. The pressure-state part of the analysis had fewer expert responses than the effectiveness part, at least for some habitat type – area combinations. This resulted in excluding some results from the report.

As the effects of some important pressures to the state of benthic habitats have not been estimated within the analysis (particularly eutrophication), the pressure reductions and probability to achieve state improvements are likely underestimated. The nutrient inputs have been estimated to decrease due to existing measures (see Topic report for nutrients). However, the SOM model cannot estimate the effect of reductions in the input of nutrients on eutrophication. Additionally, significant time lags exist between nutrient reductions and effects of eutrophication (e.g. Murray et al. 2019), further complicating this relationship. In the long run, the reductions in nutrient inputs will likely affect the condition of benthic habitats.

Quality and precision could potentially be improved with the collection of additional expert responses, but the assessment structure and the definition of the state improvement might also require changes.

For the individual results, average certainty is low for the effectiveness of measures types, and moderate for the projected reductions in pressures, due to the activity-pressure data being point estimates. There is also considerable uncertainty about the required pressure reductions to achieve state improvements. These uncertainties should be kept in mind, in particular when examining the numeric estimates.

The most common confidence level experts reported for their own evaluations is moderate for effectiveness of measures, high for significance of pressures to state components, and from low to high for required pressure reductions.

There were some technical challenges that affected the survey implementation. Firstly, there was a problem in the survey software for the effectiveness of measure types survey that resulted in losing some responses. The original responses became often unusable, as it was not possible to identify which items had been skipped on purpose and which were lost data. This issue was addressed by sending follow-up invitations for experts to review and, when needed, complement their original saved response. Not all experts participated in this follow-up review, and thus their response had to be deleted from the final sample. Secondly, the simultaneous assessment of effectiveness of a measure type and certainty of that effectiveness proved in some cases difficult, as it required placing non-quantitative dots in a coordinate system to generate quantitative estimates. The dots were translated into effectiveness and certainty values between 0 and 100. Some experts would have preferred that the quantitative estimates would have been visible and could have been transparently influenced.

When interpreting the results, the assumptions and generalizations that were made when collecting the input data and defining and using the data on activity-pressure contributions, measure type effectiveness and pressure-state linkages need to be taken into account. The input data are based mainly on expert elicitations rather than existing models and data and reflect substantial uncertainty.

For more information on the SOM methodology, data collection and assumptions, see this document.

Reflection on measure types

Effectiveness of measures estimates were very similar across the measure types. The large majority of measure types for both potential loss and disturbance of the seabed are quite general; often inheriting the imprecise descriptions from existing measures (Annex 4). National variation in standard practices appear higher than for some other topics and when coupled with the already broad wording, this may have resulted in the pattern observed in the effectiveness of measures values. This is evident in the nature conservation measures such as HELCOM recommendations to protect species or habitats. These measures are implemented very differently among the countries and even within countries and it was not possible in the effectiveness estimations to take into account how individual protected areas regulate activities causing the two pressures. Thus, the effectiveness should be seen as the optimal situation where the measures are fully implemented. The SOM assessment has always focused on a regional perspective and, with the exception of impact from the fishing industry, intra-regional variability in measures may be too great to apply the standard SOM approach to loss and disturbance measures. A more targeted approach would be possible in the future, but only if sufficient expertise is available for such an assessment.

Lessons learned

The undefined metric for the state improvement, “noticeable improvement”, is a weakness for the topic. However, no simple specific metric appears to capture a sufficient proportion of the variability present in a component as broad as benthic habitats (even when divided to five habitat types). A potential solution would be to use an indicator for each habitat type (e.g. fucus abundance or extent of hypoxia). However, it is clear that further improvement in this topic requires a diverse expert group with more than surface understanding of the SOM analysis to support a considered redesign.

Use of results, implications and future perspectives

A major gap in the SOM assessment for benthic habitats is the lack of a quantified link between input of nutrients and the effects of eutrophication. Eutrophication is a top pressure on benthic habitats and future assessments must prioritize the full quantification of this pressure. In the case of this assessment, the lack of such a link almost certainly leads to an underestimation of projected improvement.

Our spatial data of sea-based activities is not likely sufficient to cover all the pressures caused by human activities on coastal underwater habitats. In coastal areas, where benthic biodiversity may be much higher than offshore, numerous local activities on the shore exert a high risk for underwater habitats, but this data are rarely included in marine data sets. The shoreline activities such as households, summer houses, recreational areas, beaches, urban areas and transport infrastructure always have impacts on the marine environment While some of these activities are included in the spatial data set used in the activity-pressure contribution result, gaps likely exist due to their widespread but low intensity impacts. Thus, we suggest that the analysis may underestimate pressures in the coastal zones and therefore measures regulating those activities may have a stronger influence on benthic habitats than estimated in this assessment.

This assessment showed that existing measures are likely insufficient to improve the state of benthic habitats. This conclusion is relatively safe even if there are several major assumptions in this analysis and high uncertainty in data. The results indicate that new measures should have a broader scope on the pressures and activities affecting benthic habitats than general measures to promote protected areas. Also, the measures should be spatially broad (to affect wide areas) and simple to implement and follow up (to reduce unclarity of their effectiveness).

Future assessments of the effectiveness of measures in the Baltic Sea should concentrate on:

(1) Inclusion of the pressures having largest adverse effects on benthic habitats in the model to account for changes in these pressures to the state of benthic habitats (e.g. eutrophication);
(2) Enabling a proper sufficiency of measures and gap analysis by using indicators and GES threshold values for each benthic habitat type.

Annexes

Annexes 1–9 contain the expert surveys as well as information on the measure types and the literature review. They are available on the SOM Platform workspace.

Annexes 10–12 contain graphs that provide additional information and perspectives on the results.

Annex 1 Activity-pressure data

The topic uses data from the HELCOM Baltic Sea Impact Index (BSII) to calculate activity-pressure contributions, so no survey template is available.

Annex 2 Modified activity list (if modified)

The topic uses the standard activity list, so no modified activity list is available.

Annex 3 Measure types list

PDF containing the measure types used in the assessment of the effectiveness of measures for *Benthic habitats*. Document includes examples of existing measures that if implemented would be included in the corresponding measure type.

Annex 4 Linking existing measures to measure types

Excel containing the identified existing measures and their relationship to the measure types used in the SOM analysis.

Annex 5 Literature review search terms

Excel containing the search terms used during the literature review on effectiveness of measures for *Benthic habitats*.

Annex 6 Literature review summary

Excel document containing the effectiveness of measures data retrieved from the literature review.

Annex 7 Topic structure

Excel containing the relationships between measure types, activities, pressures, state components, and sub-basins. Also contains information on GES thresholds.

Annex 8 Effectiveness of measures survey

PDF of the Effectiveness of measures survey for *Benthic habitats*.

Annex 9 Pressure-state survey

PDF of the Pressure-state survey for *Benthic habitats*.

Annex 10 Supplementary results for required pressure reductions

This annex presents the probability density functions of required pressure reductions to achieve GES based on responses to the expert survey questions. The graph shows the probability distribution of the pooled expert responses on how much pressures should be reduced to achieve GES. Pressure reduction is presented on the x-axis (0-100%) and probability on the y-axis. The probability density function presents the probability of the pressure reduction falling within a particular range of values. This probability is given by the integral of the probability density over that range—that is, it is given by the area under the density function but above the horizontal axis and between the lowest and greatest values of the range.

The graphs have multiple peaks and the distributions are wide, which indicate that expert have varying views on the pressure reductions required to achieve noticeable improvement. [checked when graphs are in]

[updated graphs to be included later]

[include in all figures and graphs the number of experts contributing to the result, include standard deviations or confidence intervals in the graphs, where appropriate]

Annex 11 Supplementary results for effectiveness of measures

[updated graphs to be included later]

[include in all figures and graphs the number of experts contributing to the result, include standard deviations or confidence intervals in the graphs, where appropriate]

Annex 12 Impacts of measure types

Table A1. Impacts of measure types (%) in reducing the potential physical loss or disturbance of the seabed. The impact shows how much the measure type reduces the pressure across all activities contributing to the pressure.

Pressure for benthic habitats *(geographic area)*	Measure type	Mean (Standard deviation)
Potential physical disturbance to seabed *(Kattegat)*	Spatial trawling restrictions	44 (17)
	Enhance legal protection of habitats and species	40 (18)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	37 (16)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	28 (16)
	Seasonal trawling restrictions	27 (18)
	Speed limits	3 (2)
	Technical modifications to ships	3 (2)
Potential physical disturbance to seabed *(Great Belt)*	Enhance legal protection of habitats and species	34 (12)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	24 (11)
	Spatial trawling restrictions	22 (9)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	18 (8)
	Seasonal trawling restrictions	13 (9)
	Speed limits	9 (5)
	Technical modifications to ships	8 (5)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	1 (1)
	Alternative extraction technologies	1 (1)
	Seasonal restrictions	1 (1)
	Implement national plan for sand and aggregate extraction	1 (1)
Potential physical disturbance to seabed *(The Sound)*	Enhance legal protection of habitats and species	27 (15)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (16)
	Speed limits	18 (9)
	Technical modifications to ships	15 (10)
	Seasonal restrictions	1 (0)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	1 (0)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	1 (0)
	Application of best practices	1 (0)
Potential physical disturbance to seabed *(Kiel Bay)*	Enhance legal protection of habitats and species	37 (15)
	Spatial trawling restrictions	33 (13)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	27 (12)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	26 (13)
	Seasonal trawling restrictions	20 (13)
	Speed limits	8 (4)
	Technical modifications to ships	6 (4)
Potential physical disturbance to seabed *(Bay of Mecklenburg)*	Enhance legal protection of habitats and species	36 (14)
	Spatial trawling restrictions	30 (12)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	25 (13)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	25 (11)

Pressure for benthic habitats *(geographic area)*	Measure type	Mean (Standard deviation)
	Seasonal trawling restrictions	18 (12)
	Speed limits	9 (5)
	Technical modifications to ships	7 (5)
Potential physical disturbance to seabed *(Arkona Basin)*	Enhance legal protection of habitats and species	37 (15)
	Spatial trawling restrictions	35 (14)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	29 (12)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	26 (13)
	Seasonal trawling restrictions	21 (14)
	Speed limits	6 (3)
	Technical modifications to ships	5 (3)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	1 (0)
Potential physical disturbance to seabed *(Bornholm Basin)*	Spatial trawling restrictions	49 (19)
	Enhance legal protection of habitats and species	42 (20)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	41 (17)
	Seasonal trawling restrictions	30 (20)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	28 (18)
	Speed limits	1 (1)
	Technical modifications to ships	1 (1)
Potential physical disturbance to seabed *(Gdansk Basin)*	Spatial trawling restrictions	45 (18)
	Enhance legal protection of habitats and species	41 (18)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	37 (16)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	28 (16)
	Seasonal trawling restrictions	27 (18)
	Speed limits	2 (1)
	Technical modifications to ships	1 (1)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	1 (0)
	Application of best practices	1 (0)
Potential physical disturbance to seabed *(Eastern Gotland Basin)*	Spatial trawling restrictions	47 (19)
	Enhance legal protection of habitats and species	40 (19)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	39 (17)
	Seasonal trawling restrictions	28 (19)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	27 (17)
	Speed limits	1 (1)
	Technical modifications to ships	1 (1)
Potential physical disturbance to seabed *(Western Gotland Basin)*	Enhance legal protection of habitats and species	31 (15)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	21 (13)
	Speed limits	7 (4)
	Technical modifications to ships	6 (4)
	Spatial trawling restrictions	6 (2)
	Technical regulations of fishing gear (e.g. type, modifications, etc.)	5 (2)
	Seasonal trawling restrictions	3 (2)
Potential physical disturbance to seabed	Enhance legal protection of habitats and species	27 (13)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	18 (12)

Pressure for benthic habitats ***(geographic area)***	**Measure type**	**Mean (Standard deviation)**
(Gulf of Riga)	Speed limits	8 (4)
	Technical modifications to ships	7 (5)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	3 (2)
	Application of best practices	2 (2)
	Expansion of permitting requirements	2 (1)
	Seasonal restrictions	2 (1)
Potential physical disturbance to seabed *(Northern Baltic Proper)*	Enhance legal protection of habitats and species	18 (9)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	12 (8)
	Speed limits	6 (3)
	Technical modifications to ships	5 (3)
Potential physical disturbance to seabed *(Gulf of Finland)*	Enhance legal protection of habitats and species	23 (11)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	16 (11)
	Speed limits	10 (5)
	Technical modifications to ships	9 (6)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	2 (1)
	Seasonal restrictions	2 (1)
	Application of best practices	2 (1)
	Expansion of permitting requirements	1 (1)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	1 (1)
	Alternative extraction technologies	1 (1)
	Implement national plan for sand and aggregate extraction	1 (0)
Potential physical disturbance to seabed *(Åland Sea)*	Enhance legal protection of habitats and species	29 (15)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (13)
	Speed limits	6 (3)
	Technical modifications to ships	5 (4)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	3 (2)
	Application of best practices	3 (2)
	Expansion of permitting requirements	3 (2)
	Seasonal restrictions	2 (2)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	1 (1)
	Implement industry best practices	1 (1)
Potential physical disturbance to seabed *(Bothnian Sea)*	Enhance legal protection of habitats and species	30 (16)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (14)
	Speed limits	5 (3)
	Technical modifications to ships	5 (3)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	3 (2)
	Application of best practices	3 (2)
	Expansion of permitting requirements	3 (2)
	Seasonal restrictions	2 (2)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	1 (1)
	Implement industry best practices	1 (1)

Pressure for benthic habitats ***(geographic area)***	**Measure type**	**Mean (Standard deviation)**
Potential physical disturbance to seabed *(The Quark)*	Enhance legal protection of habitats and species	30 (17)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (14)
	Speed limits	7 (4)
	Technical modifications to ships	6 (4)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	2 (1)
	Application of best practices	2 (1)
	Expansion of permitting requirements	1 (1)
	Seasonal restrictions	1 (1)
Potential physical disturbance to seabed *(Bothnian Bay)*	Enhance legal protection of habitats and species	30 (18)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (15)
	Speed limits	6 (3)
	Technical modifications to ships	5 (3)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	1 (1)
	Application of best practices	1 (1)
	Expansion of permitting requirements	1 (0)
	Seasonal restrictions	1 (0)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	1 (0)
Potential physical loss of seabed *(Kattegat)*	Enhance legal protection of habitats and species	31 (10)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (11)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	24 (10)
	Implement national plan for sand and aggregate extraction	10 (7)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	1 (1)
Potential physical loss of seabed *(Great Belt)*	Enhance legal protection of habitats and species	33 (12)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	25 (12)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (13)
	Implement national plan for sand and aggregate extraction	14 (9)
Potential physical loss of seabed *(The Sound)*	Enhance legal protection of habitats and species	31 (19)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (19)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	22 (16)
	Implement national plan for sand and aggregate extraction	2 (1)
Potential physical loss of seabed *(Kiel Bay)*	Enhance legal protection of habitats and species	34 (13)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	26 (13)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (13)
	Implement national plan for sand and aggregate extraction	16 (10)
Potential physical loss of seabed *(Bay of Mecklenburg)*	Enhance legal protection of habitats and species	35 (14)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	27 (16)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (14)
	Implement national plan for sand and aggregate extraction	22 (15)
	Enhance legal protection of habitats and species	37 (16)

Pressure for benthic habitats ***(geographic area)***	**Measure type**	**Mean (Standard deviation)**
Potential physical loss of seabed *(Arkona Basin)*	Full implementation of the EU Maritime Spatial Planning Framework Directive	29 (20)
	Implement national plan for sand and aggregate extraction	27 (18)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (17)
Potential physical loss of seabed *(Bornholm Basin)*	Enhance legal protection of habitats and species	31 (12)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	24 (14)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	22 (12)
	Implement national plan for sand and aggregate extraction	20 (13)
Potential physical loss of seabed *(Gdansk Basin)*	Enhance legal protection of habitats and species	31 (21)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	24 (20)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	21 (17)
	Implement national plan for sand and aggregate extraction	1 (1)
Potential physical loss of seabed *(Eastern Gotland Basin)*	Enhance legal protection of habitats and species	26 (10)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (11)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	19 (10)
	Implement national plan for sand and aggregate extraction	13 (8)
Potential physical loss of seabed *(Western Gotland Basin)*	Enhance legal protection of habitats and species	29 (15)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	26 (15)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	22 (15)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	1 (0)
Potential physical loss of seabed *(Gulf of Riga)*	Enhance legal protection of habitats and species	30 (16)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	25 (16)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	22 (15)
Potential physical loss of seabed *(Northern Baltic Proper)*	Enhance legal protection of habitats and species	18 (10)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	16 (10)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	14 (11)
Potential physical loss of seabed *(Gulf Finland)*	Enhance legal protection of habitats and species	29 (14)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	22 (13)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	21 (12)
	Implement national plan for sand and aggregate extraction	9 (6)
Potential physical loss of seabed *(Åland Sea)*	Enhance legal protection of habitats and species	12 (6)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	11 (6)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	9 (6)
Potential physical loss of seabed *(Bothnian Sea)*	Enhance legal protection of habitats and species	27 (14)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	24 (14)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (13)
	Limit sediment deposition from e.g. mining to selected "dumping sites"	2 (1)
	Enhance legal protection of habitats and species	26 (14)

Pressure for benthic habitats ***(geographic area)***	**Measure type**	**Mean (Standard deviation)**
Potential physical loss of seabed *(The Quark)*	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	23 (14)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	20 (13)
Potential physical loss of seabed *(Bothnian Bay)*	Enhance legal protection of habitats and species	29 (16)
	Expand EIA reporting requirements e.g. to cover new activities or include new environmental components	24 (16)
	Full implementation of the EU Maritime Spatial Planning Framework Directive	21 (14)

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