Sufficiency of existing measures to achieve good status in the Baltic Sea

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Sufficiency of existing measures to achieve good status in the Baltic Sea

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Summary

Since 1974, HELCOM has agreed on coordinated measures to achieve a good environmental status (GES) of the Baltic Sea marine environment. The HELCOM Baltic Sea Action Plan (BSAP) in 2007 was the first regional action plan to address a broad range of ecosystem components. It is evident that a good status of the Baltic Sea environment will not be achieved by the BSAP target year of 2021. However, numerous existing measures are in place in current policy frameworks, such as the HELCOM BSAP, EU Marine Strategy Framework Directive and Water Framework Directive. Assessing the need for and planning of new measures requires information on what kind of pressure reductions and state improvements can be achieved with existing measures, and whether these are enough to meet GES. This is the aim of the sufficiency of measures (SOM) analysis for existing measures.

This report presents the results of the SOM analysis for existing measures in the Baltic Sea region. The analysis covers nine distinct but interlinked topics: benthic habitats, waterbirds, fish, marine mammals, hazardous substances, input of nutrients, litter, non-indigenous species (NIS), and underwater noise. A full analysis was not completed for marine mammals, waterbirds and some species of fish due to insufficient data.

The outcomes show which activities cause pressures on the Baltic Sea marine environment, how significant these pressures are for marine species and habitats, and how much pressures need to be reduced in order to reach GES. The results indicate how effective the existing measures are in reducing pressures, how much each pressure is reduced in total, and how likely it is to achieve or maintain GES or achieve state improvements with existing measures by 2030. The type of the analysis dependent on the topic (state or pressure-based) and existence of a HELCOM GES threshold value.

According to the results, the existing measures are likely not sufficient to reach GES for most of the analysed species or substances which are currently not in good status. Coastal fish and some commercially exploited fish stocks, which are in GES or close to it in parts of the region, have a higher probability to maintain or reach GES. For pressure-based topics, GES is not projected for NIS. However, more than half of the assessed Baltic sub-areas are expected to reach or maintain nutrient input targets based on existing measures. All or some components in most topics lack environmental goals (GES, nutrient reduction targets, etc.) and these components are assessed as percent change from current conditions. Evaluation of the sufficiency of these projected improvements is not attempted.

However, the results suggest that progress is being made. Existing measures are projected to lead to significant pressure reductions by 2030 if they are fully implemented, despite the generally low probabilities to achieve GES. As the SOM analysis assumes full implementation of the existing measures, nearly all pressures were estimated to show at least minor reductions. The largest reductions could be expected, for instance, for the input of mercury, TBT, PFOS and diclofenac, input of beach litter, and extraction of pelagic fish.

The existing measures target several key human activities in the Baltic Sea region, including offshore, coastal and inland areas, and aim to reduced pressures on marine species and

habitats. Three pressures – eutrophication, extraction of species (incl. prey depletion) and human induced food web imbalance – were indicated to be the predominant drivers of change for the Baltic Sea ecosystem, potentially accounting for 40-100% of the significant pressures for coastal fish, 55-100% for pelagic fish, 20-60% for migratory fish, 35-75% for vegetation and epifauna dominated habitats, 20-65% for infauna dominated habitats, 30-40% for most waterbirds, and approximately 40% for grey seals.

Existing measures with the highest projected impacts are all related to international policies and regulations, such as maritime spatial planning (benthic habitats, birds), the Minamata convention (input of mercury), the Paris agreement (input of mercury), sectoral EU directives (e.g. plastic waste), international fisheries agreements (e.g. EU Common Fisheries Policy and bilateral agreements), IMO regulations (noise), IMO Ballast Water Management Convention (NIS), and HELCOM management plans (fish species). Marine protected areas have traditionally been considered as effective tools for marine conservation, but the SOM analysis showed that because of their limited spatial extent (and potentially limited management), they do not markedly reduce the significant human pressures at the whole Baltic Sea scale.

The main limitations of the analysis are 1) the reliance on expert opinion throughout much of the analysis, 2) the generally low number of contributing experts, particularly for more spatially divided topics such as coastal fish or marine mammals, 3) the lack of fully quantified links within the SOM model, most notably between input of nutrients and the effects of eutrophication, and 4) structural simplifications and assumptions made to allow for the modelling of a broad range of environmental components. These limitations increase the uncertainty of results and may result in underestimations of pressure reductions and state improvements for many topics. Full consideration of these uncertainties and topic specific approaches is recommended before these results are applied. Further reflection on these issues can be found in the topic reports and methodology report (recommended reading: Methodology report – Part 1 Overall approach to estimate the sufficiency of measures, pp. 4-23).

Overall, the results of the SOM analysis suggest that new and/or more stringent measures are needed to achieve GES in the Baltic Sea region in addition to the existing ones. Besides having an adequate set of effective measures in place that target key activities and pressures to the marine environment, it is important that they are fully implemented.

1 Introduction

1.1 SOM approach

Achieving environmental goals requires measures that reduce pressures and improve the state of the environment. Although the assumption is that the implementation of measures leads to pressure reductions, their effects are often uncertain or unknown. Development and implementation of effective measures is crucial for achieving environmental goals via the design of efficient policies and the astute use of resources.

The HELCOM sufficiency of measures (SOM) analysis assesses whether existing measures would be sufficient to achieve a good environmental status (GES) of the Baltic Sea environment. It considers the effects of existing measures and changes in the extent of human activities on pressures and evaluates how changes in pressures affect the state of the marine environment. The aim is to identify gaps in achieving GES and provide information on the need for new measures (Figure 1). The SOM analysis carried out used the State of the Baltic Sea report of 2018 as its starting baseline, utilizing the final data year of that assessment (i.e. 2016) as the start point for the analysis and 2030 as the future target for predicting the gap to GES.

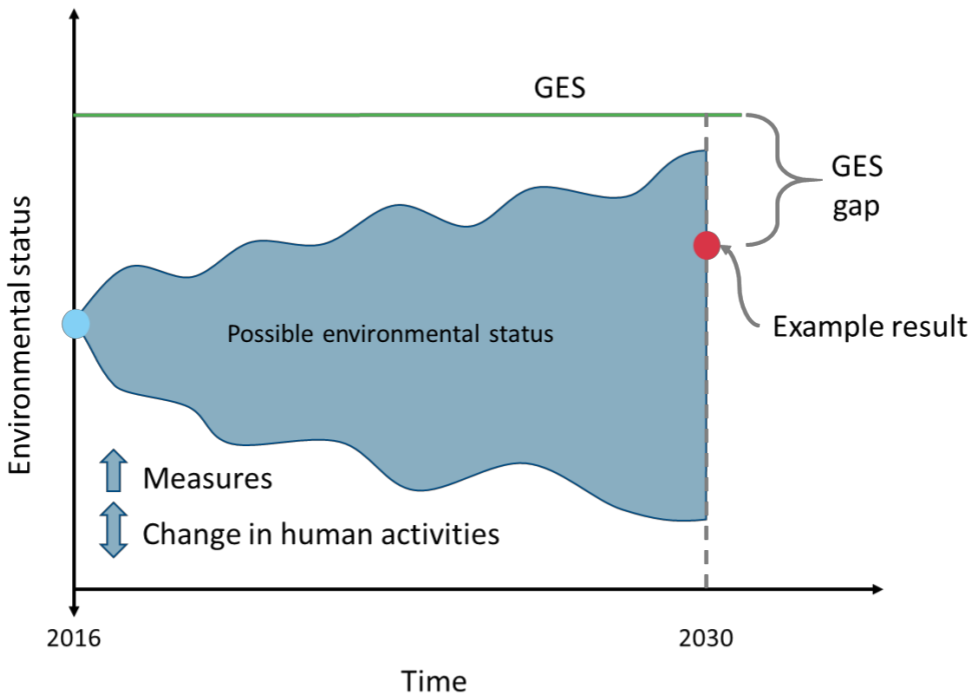

Figure 1. Conceptual illustration of the SOM analysis. The current environmental status, as determined during the Second HELCOM holistic assessment 2011-2016 (light blue circle on left), could develop in a variety of ways by 2030. The example result (red circle on right) indicates that current efforts are likely to be insufficient and a gap to GES would remain by 2030 if only the existing measures are applied.

The analysis assumes that all measures within current policy frameworks will be implemented and their effects on pressures and state will be fully realized by 2030. It considers measures that have been implemented and still affect pressures/state, measures whose implementation is ongoing, and measures that have been planned to be implemented by 2030. The analysis further assumes that there are no time lags between pressure reductions and state improvements. While this certainly is not true, the analysis still provides information on whether new measures are necessary, even if their effects would have long time lags. However, information on time lags between measures and state changes has been evaluated via expert surveys.

The SOM analysis addresses nine environmental topics: benthic habitats, birds, fish, marine mammals, hazardous substances, input of nutrients, non-indigenous species, marine litter, and underwater noise. The methodology for the SOM analysis is designed to accommodate the broad array of topics relevant in the HELCOM region, and to enable a regional-level analysis. It balances between state-of-the-art knowledge, availability of data, and advice taken onboard from various HELCOM meetings and bodies. This is the first time such analysis has been attempted at this scale and across such a diverse array of topics.

The extent and origin of data vary significantly between topics and there are thus considerable uncertainties in the results. The analysis for a few topics relies on existing literature, data and models, while for others it is largely based on data collected through expert surveys. In some cases, there are very few data points (expert responses) for a specific data component. In addition, uncertainties pertaining particularly to the expert-based estimates are often large. Thus, correct interpretation and use of the results of the analysis requires careful consideration of the underlying data and methodology, as well as other contextual information that may be relevant. Information on the origin of data, the number of experts involved, and the confidence and uncertainty evaluations carried out within the assessment are included with each result to provide a transparent balance to the results.

The SOM analysis utilizes generalized measure types as a proxy for the actual existing measures. This simplification allows for effectiveness estimates to be made for a wide range of measures. However, the effectiveness of these measure types includes additional uncertainties due to existing measure design and geographical variation resulting from biotic, abiotic, or societal factors. This uncertainty is expressed in the reported effectiveness estimates. The analysis also relies on quantified links between pressure inputs (e.g. the input of phosphorus) and pressures (e.g. the effects of eutrophication). For several important pressures, that link is not available either due to limited project resources or scientific uncertainty. As a result, the estimates for the sufficiency of measures consider less than 100% of potential pressure reductions (typically 30% – 70%) and the probability of reaching our environmental goals are likely underestimations. This factor is reported with each sufficiency of measures estimate in the topic reports.

The model used in the SOM analysis also contains a broad range of assumptions ranging from the distribution types used when calculating effectiveness estimates to the approach used for combining the effects of multiple existing measures. These assumptions and accompanying methodologies related to the model structure introduce uncertainties that cannot be accounted for in the reported estimates. These assumptions must be considered when assessing the results of the SOM analysis. The model and all applied assumptions are fully discussed in the methodology report.

1.2 Components of the SOM analysis

The SOM analysis involves estimating the sufficiency of measures to achieve state improvements or pressure reductions during the 2016–2030 period, given measures in existing policies, their implementation status and the projected development of human activities by 2030 (Figure 2).

The main components of the analysis are:

1) Listing existing measures and their links to activities and pressures (Steps 1 and 2)
2) Contribution of activities to pressures (Step 3)
3) Effect of existing measures on pressures or pressure inputs (Step 4)
4) Effect of development of human activities on pressures (Step 5)
5) Effect of changes in pressures to environmental state (Step 6).

The result is the projected reduction in pressures, which can be compared to the required pressure reductions to achieve/maintain GES or state improvements (Steps 7 and 8). This allows the probability to achieve/maintain GES or achieve state improvements with existing measures to be assessed. The overall approach aims to operationalize a large part of the DPSIR (drivers-pressures-state-impacts-response) framework (e.g. Patrício et al. 2016).

In the SOM analysis, existing measures are those measures in current policy frameworks (e.g. HELCOM BSAP, EU MSFD, EU WFD, EU Biodiversity Strategy 2020) that affect pressures and environmental state within the time frame of the analysis (2016–2030) (Steps 1 and 2). This includes measures that have been implemented, are partially implemented or are planned to be implemented by 2030. Measures which have already been fully implemented and have fully affected pressures and environmental state by 2016 have been excluded, as no further improvement of status is expected during in 2016–2030. Information on existing measures was compiled through a literature review and then supplemented by Contracting Parties, particularly in regard to national measures.

The contribution of activities to pressures indicates the activities that contribute to each pressure and the percent share of their contribution (Step 3). The data are either based on expert elicitation or utilize existing databases and information sources.

Effectiveness of measures was assessed as the percent reduction in the pressure from implementing a measure type (Step 4). Measure types represent more general formulations of individual measures to simplify the analysis. Information on effects of measure types was collected using expert elicitation and literature reviews. Effectiveness of measures types was used as a proxy to assess the effectiveness of existing measures.

In addition to the effect of existing measures, changes in the extent of human activities may affect pressures over time (Step 5). Four alternative scenarios for future changes in human activities were developed based on existing information and projections from the Baltic Sea region and results were estimated for each of the four scenarios to capture uncertainties and variation in the future development of human activities. Change scenarios were made for agriculture, forestry, waste waters, (commercial) fish and shellfish harvesting, aquaculture, renewable energy production, tourism and leisure activities, transport shipping and transport infrastructure. The extent of other activities was assumed to stay unchanged.

Changes in human activities affect both the initial pressures from activities and the impacts that measures have on these pressures, and therefore pressures may increase even if there are existing measures reducing them.

Expert elicitation was used to identify most important pressures for each state component (Step 6). Using these data, and the pressure reductions available from previous steps, an estimate of total pressure reduction was calculated for each state component. Expert elicitation was also used estimate the total pressure reduction required to reach a specific status (GES, noticeable state improvement, 10%/25%/50% improvement). Total pressure reduction is then compared to required pressure reduction to calculate a probability of achieving a specific status.

A detailed description of the SOM approach, methodology, model and data collection is presented in a separate methodology document. Detailed methodology and results for each topic are presented in eleven topic reports.

For many topics the analysis is limited in its scope. For example, with biodiversity selected species, species groups or habitat types are analysed and for hazardous substances, only four substances are analysed in full. Thus, the results cannot be considered as representative of the state for biodiversity or hazardous substances as a whole, but rather on the specific elements included in the analysis and as potentially indicative of related aspects of broader issues.

The scale at which the assessment was made needed to balance between the number of experts available to provide responses and increased variation present at higher spatial scales. The higher the spatial resolution, the fewer experts are available for a given assessment area and the more the results were driven by individual responses. However, while more responses and experts are available for example when considering the whole Baltic Sea scale, larger assessment areas generally encompass more environmental variation and thus the confidence of expert responses may have been reduced when trying to assess areas far from their national territory.

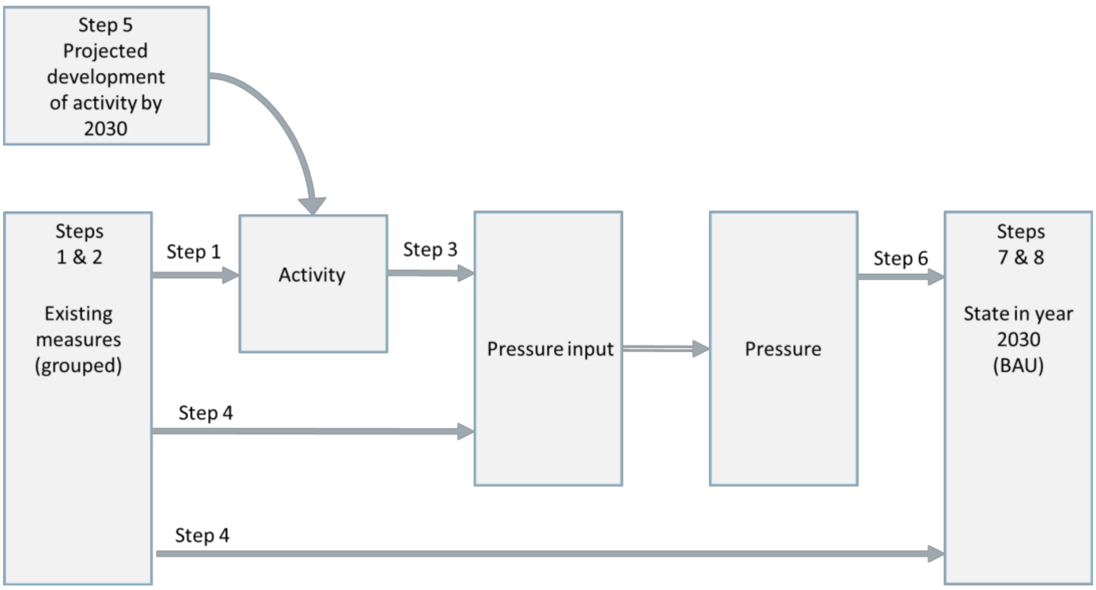

Figure 2. General schematic of the main components of the SOM analysis

1.3 How to use the results

This section provides an overview of the different result types in the SOM analysis, describes the relationship between the various result types, reviews potential applications of the SOM results, and provides an outline of the results and other content available across the reports that make up the sufficiency of measures report series.

Overview of different results types

The SOM analysis includes a large number of results, each containing useful information on the efforts to improve the Baltic Sea environment. Table 1 presents seven motivating questions, each linked to one or more result type and description. These result types appear in the SOM topic reports and may also appear in a summarized form in this main report. The results are grouped into results relevant to the state or pressure parts of the assessment. While all SOM topics cover at least some of the pressure results, not all topics assess state components and therefore do not include state result types. For result types with more than one wording, the application of a specific wording will vary within a topic depending on the presence of a GES threshold value or other environmental target and the recommendation of topic experts.

Table 1. List of result types found in the SOM main report or topic reports; each linked with a description and motivating question. Each topic will include only a portion of these results. For result types with more than one wording, the application of a specific wording will vary within a topic depending on the presence of a GES threshold value or other environmental target and the recommendation of topic experts.

Assessment section	Question	Result type		Description
State	Will we reach our environmental goals?	Probability of achieving or maintaining…	GES	Calculated probability that an established HELCOM GES threshold value is achieved or maintained for the specific state component. Values range from 0% to 100%.
			An environmental target	Calculated probability that an established environmental target is achieved or maintained for the specific state component. Values range from 0% to 100%.
		Probability of achieving…	A 10% state improvement	Calculated probability that a 10% improvement is achieved for the specific state component. This approach is utilized when no established HELCOM GES threshold value or other environmental target exists. Values range from 0% to 100%.
			A 25% state improvement	Calculated probability that a 25% improvement is achieved for the specific state component. This approach is utilized when no established HELCOM GES threshold value or other environmental target exists. Values range from 0% to 100%.
			A 50% state improvement	Calculated probability that a 50% improvement is achieved for the specific state component. This approach is utilized when no established HELCOM GES threshold value or other environmental target exists. Values range from 0% to 100%.
			A noticeable improvement	Calculated probability that a noticeable improvement is achieved for the specific state component. This approach is utilized when no established HELCOM GES threshold value or other environmental target exists and some uncertainty in the topic suggests a more qualitative approach. Values range from 0% to 100%.

State	How much will total pressure be reduced?	Total pressure reduction		Calculated combined reduction in the most significant anthropogenic pressures affecting a specific state component. A 100% reduction would indicate total removal of anthropogenic pressures and negative values indicate increases in anthropogenic pressures.
	How much does total pressure need to be reduced?	Total pressure reduction required to achieve or maintain…	GES	Estimated reduction of the most significant anthropogenic pressures required to achieve or maintain an established HELCOM GES threshold value for the specific state component. Values range from 0% to 100%.
			An environmental target	Estimated pressure reduction required to achieve or maintain an established environmental target for the specific state component. Values range from 0% to 100%.
		Total pressure reduction required to achieve…	A 10% state improvement	Estimated pressure reduction required to achieve a 10% improvement for the specific state component. Values range from 0% to 100%.
			A 25% state improvement	Estimated pressure reduction required to achieve a 25% improvement for the specific state component. Values range from 0% to 100%.
			A 50% state improvement	Estimated pressure reduction required to achieve a 50% improvement for the specific state component. Values range from 0% to 100%.
			A noticeable improvement	Estimated pressure reduction required to achieve a noticeable improvement for the specific state component. Values range from 0% to 100%.
	How long will it take for state components to improve after measures are implemented?	Time lags in realizing state improvements after measures have been implemented		Estimated time lag in years between the full implementation of a measure and its full effect on the environment. Values are only used for discussion and are not used to calculate any other result.
	Which anthropogenic pressures are impacting a specific state component?	Significance of pressures affecting a specific state component		Estimates of the anthropogenic pressures affecting a specific state component. Calculated from semi-quantitative expert responses; summing to 100%.

Pressure	Will we reach our environmental goals?	Comparison between projected pressure reduction and a GES threshold value or other environmental target	Comparison between the projected reductions from existing measures for a specific pressure and a GES threshold value or other environmental target. Only present for topics with a pressure level GES threshold value or other environmental target (i.e. NIS and Input of nutrients).
	What are the pressure reductions from existing measures?	Projected reductions from existing measures for a specific pressure	Calculated reduction of a specific pressure. A 100% reduction would indicate total removal of the specific pressure and a negative value indicates an increase in the specific pressure.
	How effective are measures?	Effectiveness of measure types in reducing a specific pressure	Estimates of the effectiveness of measure types in reducing a specific pressure from a specific human activity. Values range from 0% to 100%.
	Which activities contribute to pressures?	Activity-pressure contributions for a specific pressure	Estimates of the contribution of human activities to a specific pressure. Values range from 0% to 100%.
	What measures are being implemented in the Baltic Sea?	List of existing measures implemented in the Baltic Sea region	List of existing measures in the Baltic Sea region having an effect of the pressures/environment in 2016–2030.
	What are the impacts of existing measures?	Impacts of existing measures in reducing a specific pressure	Calculated impact of existing measures based on the list of existing measures, effectiveness of measures estimates and activity-pressure contributions. Values range from 0% to 100%.

Relationships between results

The quality of and certainty in specific results varies by topic. Because of this, it is important to understand when a result is independent or dependent on previous results. Results that are dependent on previous results will inherit any assumptions and flaws in the underlying result, while those that are independent do not have this characteristic. Consideration of the quality of dependent results should include consideration of all results contributing to the dependent result. Figure 3 shows the relationships between results and their status as dependent or independent.

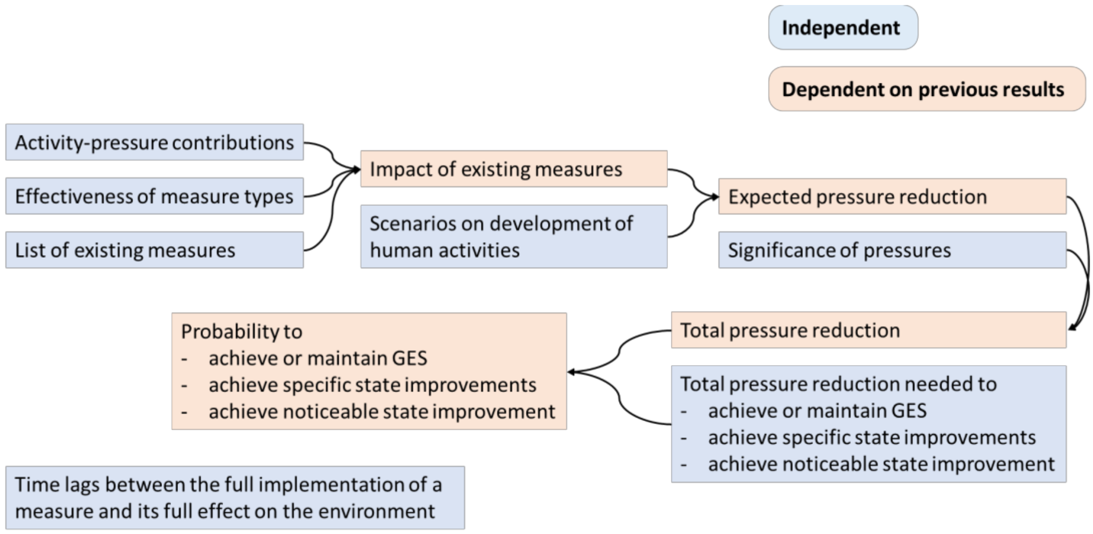

Figure 3. Diagram of the relationships between each SOM result. Results appearing in blue are independent and those appearing in tan are dependent on previous results. Note that results on time lags do not have connections to other results, indicating they are not included in the model calculations.

Potential result applications

The SOM analysis provides multiple data and result layers, and thus there are several ways the results can be used. The main aim has been to support the update of the HELCOM Baltic Sea Action Plan (BSAP) by providing information for evaluating the need for new measures by indicating gaps to GES. It presents the first attempt to quantify the effects of existing measures and policies on the environment. This analysis has been implemented but is far from complete, for example, due to lack of data and missing linkages between pressure inputs, pressures and state components in the analysis. Further, the quality and information content of the results depends on the specific topic addressed, and some results may not be available for certain topics due to a lack of data or inconsistency of available data.

In principle, the results could be used to consider:

- whether GES/state improvements can be achieved with existing measures;
- the most significant pressure(s) affecting a state component(s);
- pressure reductions from existing measures;
- pressures for which new measures might be needed;
- most impactful measure types for each pressure and associated existing measures;

- main activities causing pressures;
- links from existing measures to activities and pressures;
- the impact of changes in the extent of human activities to pressures and achievement of state improvements.

Therefore, the SOM analysis can be seen as a tool contributing to the assessment of the gap to GES and thus the need for new measures or the strengthening of existing ones. In some cases, it can provide supporting information on the effectiveness of measures in reducing pressures and on assessing which activities would be the most important to target with new measures.

The results of the analysis may provide inputs for regionally coordinated implementation of the EU Marine Strategy Framework Directive, for those HELCOM Contracting Parties being members of the EU, by supporting the joint documentation of the Programmes of Measures. Further, the results may have relevant application for next steps in the process to update the BSAP as they may support the Segment Teams of the Drafting Group of the Baltic Sea Action Plan (DG BSAP) when working further on the segment introductions and actions in spring 2021. The results may also provide supporting information for the implementation of the updated BSAP, in terms of giving indications on the prioritization of measures.

In addition to the use of the numerical results of the analysis, the overall approach, assessment framework and model must be further developed and utilized in later analyses of the marine environment. The conceptual approach and model developed here can be used in estimating the effectiveness of new measures, and as a basis for cost-effectiveness analysis (as done in ACTION WP 6.2). The framework can be improved by including additional linkages, topic-specific features and improved data to allow for a more complete, accurate and quantitative analysis of the effectiveness and sufficiency of measures in the future (see section 3.3 Knowledge gaps and development opportunities). The business-as-usual (BAU) state, developed as part of the SOM analysis, can be used in assessing the cost of degradation and economic benefits from achieving good environmental status of the marine environment, as it provides the reference status to which GES can be compared to.

The sufficiency of measures report series

In total, there are 14 different SOM reports, each containing unique information or perspectives. This main report is designed to be less technical and to give a broad and approachable overview of the results, while referencing to the detailed methodology and topic reports in question. The methodology report includes the full methodology used in the SOM analysis, detailed information on the data collection and background data on the development of human activity scenarios. A practical guide to interpreting the SOM results provides example analysis for each result type in the SOM reports using figures and tables taken directly from the topic reports. The 11 topic reports present the full results and interpretation per topic addressed. The topic reports are more technical in nature and may be better understood with a general understanding of the approach and its assumptions (recommended reading: Methodology report – Part 1 Overall approach to estimate the sufficiency of measures, pp. 4-23). Table 2 includes descriptions and links to the full SOM report series.

Table 2. Description of the SOM reports. The topic reports are organized by the type of assessments made in each report. A sufficiency of measures assessment for state components considers projected total pressure reduction against estimated required pressure reduction to reach a quantified goal (GES threshold value or other environmental goal) and presents the probability of achieving that goal. A sufficiency of measures assessment for pressures considers projected pressure reduction against a quantified goal and presents a comparison to that goal. When no goal is available, a change assessment is made. These results are presented as either a probability of achieving various levels of improvement (10%, 25%, 50%, noticeable improvement; state components) or as projected percent change (pressures). For state components, the number of distinct spatial assessments is noted in parentheses (whole Baltic – a single assessment carried out for the whole Baltic Sea; 1 sub-area – a single assessment carried out for an areas less than the whole Baltic Sea; 2+ sub-areas – multiple assessments carried out on various sub-divisions of the Baltic Sea). For pressures, change is tracked over each of the 17 HELCOM scale 2 sub-basins, but the presentation scale is noted in parenthesis (17 sub-areas – presents change for each of the scale 2 sub-basins, 2 to 16 sub-areas – presents the average change within the given number of sub-areas, Baltic Sea average – presents the average change across the Baltic Sea).

Report	Description
Main report	Introduction and summary of the SOM results (this report)
Methodology report	Full methodology of the SOM analysis and background data on development of human activity scenarios
A practical guide to interpreting the SOM results	Provides example analysis for each result type in the SOM reports using figures and tables taken directly from the topic reports

Report	Description			
Topic report	Sufficiency of measures assessment for state components based on a GES threshold value or other environmental target	Change assessment for state components based on improvement from 2016 conditions	Sufficiency of measures assessment for pressures based on a GES threshold value or other environmental target	Change assessment for pressures based on improvement from 2016 conditions
Benthic habitats		- Hard substrate vegetation dominated community (4 sub-areas) - Soft substrate vegetation dominated community (4 sub-areas) - Hard substrate epifauna dominated community (4 sub-areas) - Soft substrate infauna dominated community (4 sub-areas) - Coarse substrate infauna dominated community (4 sub-areas)		- Potential disturbance to seabed (17 sub-areas) - Potential loss of seabed (17 sub-areas)
Coastal fish	- Perch and other coastal piscivores (4 sub-areas) - Cyprinids and other mesopredators (4 sub-areas) - Flounder (3 sub-areas)	- Perch and other coastal piscivores (2 sub-areas) - Cyprinids and other mesopredators (2 sub-areas) - Flounder (1 sub-area)		- Targeted extraction and bycatch of coastal fish (Baltic Sea average)
Commercial fish	- Cod (2 sub-areas) - Herring (3 sub-areas) - Sprat (1 sub-area) - Plaice (1 sub-area)	- Herring (1 sub-area)		- Targeted extraction and bycatch of cod (Baltic Sea average) - Targeted extraction and bycatch of flatfish (Baltic Sea average) - Targeted extraction and bycatch of pelagic fish (Baltic Sea average)

Report	Description			
Topic report	Sufficiency of measures assessment for state components based on a GES threshold value or other environmental target	Change assessment for state components based on improvement from 2016 conditions	Sufficiency of measures assessment for pressures based on a GES threshold value or other environmental target	Change assessment for pressures based on improvement from 2016 conditions
Hazardous substances	- Mercury (whole Baltic) - TBT (whole Baltic) - PFOS (whole Baltic) - Diclofenac (whole Baltic)			- Input of mercury (Baltic Sea average) - Input of TBT (Baltic Sea average) - Input of PFOS (Baltic Sea average) - Input of Diclofenac (Baltic Sea average)
Input of nutrients			- Input of nitrogen (7 sub-areas) - Input of phosphorus (7 sub-areas)	
Marine litter				- Input of the top 15 litter items to the beach (6 sub-areas)
Marine mammals	- Grey seal (whole Baltic) - Ringed seal (2 sub-areas) - Harbour seal (3 sub-areas) - Harbour porpoise (2 sub-areas)			- Bycatch of porpoise (Baltic Sea average) - Bycatch of seal (Baltic Sea average) - Intentional killing of grey seal (Baltic Sea average) - Intentional killing of ringed seal (Baltic Sea average) - Intentional killing of harbour seal (Baltic Sea average) - Disturbance or displacement of grey seal by human presence (Baltic Sea average) - Disturbance or displacement of ringed seal by human presence (2 sub-areas) - Disturbance or displacement of harbour seal by human presence (3 sub-areas) - Disturbance or displacement of harbour porpoise by human presence (2 sub-areas)

Report	Description			
Topic report	Sufficiency of measures assessment for state components based on a GES threshold value or other environmental target	Change assessment for state components based on improvement from 2016 conditions	Sufficiency of measures assessment for pressures based on a GES threshold value or other environmental target	Change assessment for pressures based on improvement from 2016 conditions
Migratory fish	- Salmon (5 sub-areas) - Eel (whole Baltic)	- Sea trout (5 sub-areas)		- Targeted extraction and bycatch of salmon (Baltic Sea average) - Targeted extraction and bycatch of sea trout (Baltic Sea average) - Targeted extraction and bycatch of eel (Baltic Sea average) - Disturbance of salmon: obstructions (dams) (Baltic Sea average) - Disturbance of sea trout: obstructions (dams) (Baltic Sea average) - Disturbance of eel: obstructions (dams) (Baltic Sea average)
Non-indigenous species (NIS)			- Anthropogenic introduction of NIS (whole Baltic)	
Underwater noise				- Input of continuous noise 63/125 Hz (5 sub-areas) - Input of continuous noise 2 kHz (5 sub-areas) - Input of impulsive noise with peak energy below 10 kHz (5 sub-areas)

Report	Description			
Topic report	Sufficiency of measures assessment for state components based on a GES threshold value or other environmental target	Change assessment for state components based on improvement from 2016 conditions	Sufficiency of measures assessment for pressures based on a GES threshold value or other environmental target	Change assessment for pressures based on improvement from 2016 conditions
Waterbirds	- Common eider (whole Baltic) - Great cormorant (whole Baltic) - Sandwich tern (1 sub-area) - Great black-backed gull (whole Baltic)	- Long-tailed duck (1 sub-area) - Red-throated diver (1 sub-area)		- Bycatch of pelagic feeders (Baltic Sea average) - Bycatch of benthic feeders (Baltic Sea average) - Bycatch of surface feeders (Baltic Sea average) - Waterbird disturbance: collisions (Baltic Sea average) - Disturbance or displacement of waterbirds by human presence (by species; Baltic Sea average) - Intentional killing of waterbirds (by species; Baltic Sea average))

2 Results

The SOM analysis has generated a wide variety of results that are fully presented in the respective topic reports, including deeper presentation of the uncertainties and assumptions affecting each result. This section summarizes the main findings of the analysis, while providing new perspectives and insights not found in the topic reports. Most applications of the SOM results will require the additional context presented in the topic reports for accurate use.

2.1 Will we reach our environmental goals?

State components

With few exceptions, the SOM analysis suggests that we are not likely to reach our environmental goals at a Baltic Sea scale by 2030, based on the full implementation of existing measures in current policy frameworks. Some species of commercial and coastal fish appear most likely to achieve or maintain GES, but migratory fish and hazardous substances are indicated to remain in poor status. An entire analysis was not completed for marine mammals, waterbirds, and some species of fish due to insufficient data (Tables 3-5). Benthic habitats are not expected to show noticeable improvement by 2030 and no expected improvement is identified for migratory fish (Table 6). In the analyses based on percent improvement in environmental state (Tables 7-9), coastal and commercial fish show the greatest probability of improvement.

It is important to note that the probabilities presented below are potentially underestimations due to missing linkages within the SOM model. The SOM analysis was typically able to track 30%-70% of the pressures most relevant to a given state component. State components particularly susceptible to the effects of eutrophication, non-indigenous species, hydrological change, human induced food-web imbalance, hazardous substances, or river, lake, or land habitat loss/degradation are more likely to be underestimated. This summary suggests topics where further effort might be required and the topic reports should be consulted to provide context on model coverage, confidence, and uncertainty of the results for each state component assessment.

Tables 3-9 summarize the results for the probability to achieve or maintain a specific state condition. Depending on the state component this could be based on reaching or achieving a GES threshold value, noticeable state improvement, or 10%/25%/50% state improvement. For each HELCOM scale 2 sub-basin with an attempted assessment, there is a coloured circle to indicate the probability of achieving or maintaining a specific state condition (0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data). Connected circles indicate basins that were evaluated as a single area. All sub-basins with connected circles will necessarily have the same probability estimate. The order of the sub-basins will change from table to table to allow for the topic specific amalgamation of sub/basins to be correctly indicated – Tables 3-5 appear as separate tables for this reason. The assessment for cod in Arkona Basin in Table 4 has a unique format. Two assessment areas overlap in this sub-basin and the vertical line appearing in that circle indicates a break between assessment units. One unit stretches from The Sound to Arkona Basin and another unit from Arkona Basin to the Bothnian Sea.

Table 3. Probability of achieving or maintaining GES for hazardous substances, marine mammals, and waterbirds.

Colour scale for the probability to achieve or maintain GES (based on the expected value): 0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data. Data used in the calculation of these results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Topic	State component	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Western Gotland Basin	Northern Baltic Proper	Gulf of Riga	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Hazardous substances	Mercury concentration	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
	TBT concentration	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
	PFOS concentration	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
	Diclofenac concentration	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
Marine Mammals	Grey seal	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data
	Ringed seal											insufficient data	insufficient data	insufficient data	insufficient data		insufficient data	insufficient data
	Harbour seal	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data				insufficient data							
Waterbirds	Common eider - Breeding Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data
	Great cormorant - Breeding Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data
	Sandwich tern - Breeding Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data					
	Great black-backed gull - Wintering Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data

Table 4. Probability of achieving or maintaining GES for commercial fish.

Colour scale for the probability to achieve or maintain GES (based on the expected value): 0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data. Data used in the calculation of these results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Topic	State component	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Western Gotland Basin	Gdansk Basin	Eastern Gotland Basin	Northern Baltic Proper	Gulf of Finland	Åland Sea	Gulf of Riga	Bothnian Sea	The Quark	Bothnian Bay
Commercial fish	Cod		grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey		
	Herring	red	red	red	red	red		yellow	yellow	yellow	yellow	yellow	yellow	yellow	grey			
	Sprat		orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange		
	Plaice	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey	grey		

Table 5. Probability of achieving or maintaining GES for coastal fish.

Colour scale for the probability to achieve or maintain GES (based on the expected value): 0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data. Data used in the calculation of these results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Topic	State component	Kiel Bay	Kattegat	The Sound	Great Belt	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Western Gotland Basin	Northern Baltic Proper	Eastern Gotland Basin	Gulf of Riga	Gdansk Basin	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Coastal fish	Perch and other coastal piscivores							red	red	red	grey	grey			red	red	red	red
	Cyprinids and other mesopredators							red	red	red	grey	grey			red	red	red	red
	Flounder		green	green	green	green	green		red	red	grey							
Migratory Fish	Salmon							grey	grey		grey	grey		grey		grey	grey	grey
	Eel	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red	red

Table 6. Probability of achieving a noticeable improvement in state (benthic habitats, marine mammals).
Colour scale for the probability to achieve a noticeable state improvement (based on the expected value): 0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data. Data used in the calculation of these results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Topic	State component	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Western Gotland Basin	Northern Baltic Proper	Gulf of Riga	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Benthic habitats	Hard substrate vegetation dominated community	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
	Soft substrate vegetation dominated community	insufficient data	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
	Hard substrate epifauna dominated community	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
	Soft substrate infauna dominated community	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
	Coarse substrate infauna dominated community	insufficient data	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data
Marine Mammals	Harbour porpoise	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		

Table 7. Probability of achieving a 10% state improvement (commercial fish, coastal fish, migratory fish, waterbirds). Colour scale for the probability to achieve a 10% state improvement (based on the expected value): 0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data. Data used in the calculation of these results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Topic	State component	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Gulf of Riga	Northern Baltic Proper	Western Gotland Bas	Åland Sea	Gulf of Finland	Bothnian Sea	The Quark	Bothnian Bay
Commercial fish	Herring															50%-75%		
Coastal fish	Perch and other coastal piscivores								50%-75%	50%-75%					0%-25%			
	Cyprinids and other mesopredators								50%-75%	50%-75%					insufficient data			
	Flounder								75%-100%	75%-100%								
Migratory Fish	Sea trout	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
Waterbirds	Long-tailed duck – Wintering Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		
	Red throated diver - Wintering Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		

Table 8. Probability of achieving a 25% state improvement (commercial fish, coastal fish, migratory fish, waterbirds). Colour scale for the probability to achieve a 25% state improvement (based on the expected value): 0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data. Data used in the calculation of these results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Topic	State component	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Gulf of Riga	Northern Baltic Proper	Western Gotland Bas	Åland Sea	Gulf of Finland	Bothnian Sea	The Quark	Bothnian Bay
Commercial fish	Herring															0%-25%		
Coastal fish	Perch and other coastal piscivores								0%-25%	0%-25%					insufficient data			
	Cyprinids and other mesopredators								0%-25%	0%-25%					insufficient data			
	Flounder								50%-75%	50%-75%								
Migratory Fish	Sea trout	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
Waterbirds	Long-tailed duck – Wintering Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		
	Red throated diver - Wintering Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		

Table 9. Probability of achieving a 50% state improvement (commercial fish, coastal fish, migratory fish, waterbirds). Colour scale for the probability to achieve a 50% state improvement (based on the expected value): 0%-25%, 25%-50%, 50%-75%, 75%-100%, insufficient data. Data used in the calculation of these results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Topic	State component	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Gulf of Riga	Northern Baltic Proper	Western Gotland Bas	Åland Sea	Gulf of Finland	Bothnian Sea	The Quark	Bothnian Bay
Commercial fish	Herring															0%-25%		
Coastal fish	Perch and other coastal piscivores								0%-25%	0%-25%					insufficient data			
	Cyprinids and other mesopredators								0%-25%	0%-25%					insufficient data			
	Flounder								25%-50%	25%-50%								
Migratory Fish	Sea trout	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%	0%-25%
Waterbirds	Long-tailed duck – Wintering Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		
	Red throated diver - Wintering Season	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		

Pressures

Three pressures have environmental goals under HELCOM: *input of nitrogen, input of phosphorus,* and *anthropogenic introduction of NIS*. However, in the SOM analysis, the likelihood of reaching those goals is not directly assessed. Instead, projected pressure reductions for each pressure are compared to the required pressure reduction to meet the goal. These comparisons are summarized briefly below, but more specific information can be found in the input of nutrients and NIS reports.

The nutrient load reduction targets set for the *input of nitrogen* are already met in the Kattegat, Danish Straits and Bothnian Sea, but additional reductions are projected for these areas. Projected reductions in the Bothnian Bay would be more than sufficient to reach the target, and projected reductions in the Gulf of Riga are approximately equal to the pressure reduction required. More effort is likely needed in the Baltic Proper and Gulf of Finland before the nitrogen targets are met. For the *input of phosphorus*, the targets are already met in the Kattegat, Danish Straits and Bothnian Sea and the SOM analysis projects additional reductions for these areas. The reduction projected in the Bothnian Bay would be approximately equal to the reduction required to meet the reduction target. More effort is likely needed in the Baltic Proper, Gulf of Riga, and Gulf of Finland, where projected reductions appear insufficient to reach the reduction target for phosphorus. However, it is important to note that river borne transboundary inputs of both nitrogen and phosphorus are present in the Baltic Proper and Gulf of Riga, and in particular make up a large component of phosphorus inputs into the Gulf of Riga.

Projected pressure reductions for the anthropogenic introduction of NIS are not likely to be sufficient to meet the ambitious goal of no new introductions in the Baltic Sea in any six-year period. Improvements are expected in the shipping industry as the Ballast Water Management Convention is fully phased in and a potential Regional Baltic Biofouling Management Roadmap would also target this source of introductions. However, as the goal is to reach no new introductions, improvements will need to be made in all major sources of NIS introduction.

Table 10 summarizes the results for the comparison between projected pressure reductions and environmental pressure goals. For each HELCOM scale 2 sub-basin with an attempted assessment, there is a coloured square to indicate the projected status of reaching the respective environmental goal (projected pressure reduction is insufficient to equal or exceed the required reduction; projected pressure reduction is approximately equal to the required reduction; projected pressure reduction exceeds the required reduction; insufficient data). Connected squares indicate basins that were evaluated as a single area. All sub-basins with connected circles will necessarily have the same assessment result.

Table 10. Comparison between projected pressure reductions and environmental pressure goals.

Colour scale for the comparison between projected pressure reductions and environmental pressure goals: projected pressure reduction is insufficient to equal or exceed the required reduction, projected pressure reduction is approximately equal to the required reduction, projected pressure reduction exceeds the required reduction, insufficient data. Data used in the calculation of the nutrient input results: ACTION WP4 based on source apportionment data collected within the PLC-6 and PLC-7 projects, survey responses on reductions in agricultural runoff, ACTION WP4 estimates on reductions in wastewater treatment, potential reduction of airborne input of nitrogen from ENIRED II, HELCOM maximum allowable inputs (MAI). Data used in the calculation of the NIS results: expert estimates of effectiveness of measure types, information on existing measures, expert estimates of significance of pressures to state components, expert estimates of required pressure reductions to achieve GES/state improvements, literature and projections of development of human activities.

Pressure	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Western Gotland Bas	Eastern Gotland Basin	Gdansk Basin	Northern Baltic Proper	Gulf of Riga	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Input of nitrogen																	
Input of phosphorus																	
Anthropogenic introduction of NIS																	

2.2 Top pressures and notable pressure-state relationships in the SOM analysis

One integral part of the SOM analysis is the identification of significant pressures to each of the assessed state components. It could provide useful support for prioritizing what pressures environmental measures should target if these separate assessments could be combined to identify pressures that are the most important across the entire Baltic Sea environment. However, it needs to be remembered that the SOM analysis does not cover all the state components present in the Baltic Sea, nor does it cover all the aspects of environmental health for those it does cover. While this caveat should be kept in mind, it is still useful to consider the pressures most commonly indicated as having significant impacts on state components across the SOM analysis.

The significance of pressures is based on expert assessments of the top pressures affecting each state component in the expert survey on pressure-state linkages. Based on these assessments, the pressures of extraction of fish (includes prey depletion) and effects of eutrophication appear the most often among the top three pressures for each state component in the SOM analysis. The second tier of importance includes the pressures of disturbance or displacement of species by human presence, physical disturbance of the seabed, change in hydrological conditions, and human induced food-web imbalance. Hazardous substances are spread across six pressures in the SOM analysis which reduces their ability to show up in these pressure categories. However, a single merged hazardous substance pressure would also fall in the second tier. A third tier includes the pressures of bycatch of mammals and birds and river, lake, or land habitat loss/degradation.

If this summary is restricted to the single most important pressure, the most often mentioned would be the extraction of fish (includes prey depletion), effects of eutrophication, and the merged hazardous substance pressure discussed above. If it is expanded to the top five pressures, the top tier would be extraction of fish (includes prey depletion), effects of eutrophication, and change in hydrological conditions. Independent of how many top pressures are examined, the top tier of pressures across the SOM analysis includes eutrophication and exploitation of fish which is in good agreement with other HELCOM assessments where the top three pressures have been eutrophication, exploitation of fish stocks and hazardous substances (HELCOM 2010, 2018a).

On the scale of individual state components, SOM assessment results allow for a more quantitative review. According to the survey results, e*utrophication* is the greatest pressure for all the broad benthic habitat types but the second most significant for the deep soft bottom in the southwest Baltic Sea, and coastal fish species. The difference to other pressures is for some habitats even 10-20%. However, the results indicate that eutrophication is only the second or third most significant pressure for offshore fish and not even in top five for waterbirds and grey seal. The planktonic ecosystem was not assessed in this current study, though links with eutrophication and planktonic life forms might be anticipated.

Fishing-related pressures – *extraction of fish* and *fishery bycatch* – were the most significant pressures for cod, herring, sprat, coastal predatory fish, grey seal, and waterbirds (except surface feeding species). These two pressures were the second most significant for migratory fish stocks. The survey also included *human-induced food web imbalance* which is caused by several pressures but most importantly by fishing-related mortality (i.e. fewer top predators) and eutrophication (i.e. more primary production). *Human-induced food web imbalance* was estimated among the top five pressures for benthic habitats, coastal predatory fish and offshore fish and among the top ten for waterbirds and migratory fish.

Together, the pressures reported above are the predominant drivers of change for the Baltic Sea ecosystem, accounting for 40-100% of the significant pressures for coastal fish, 55-100% for offshore fish, 35-75% for vegetation and epifauna dominated habitats, 20-65% for infauna dominated habitats, 30-40% for most waterbirds, 20-60% for migratory fish and approximately 40% for grey seals.

Physical loss and *physical disturbance* of benthic habitats are among the top five pressures for all the broad benthic habitat types and flounder. Particularly for the deep soft and coarse bottoms, physical disturbance is the most significant pressure in the southern Baltic Sea. Physical loss is the second most important for vegetated soft bottom habitats and among the top five for coastal predatory fish. It causes only minor pressure to other state components. Together the two pressures account for 25-50% of significant pressures for vegetated and epifauna dominated habitats, 30-50% for the infauna dominated habitats, 15-45% for coastal fish and approximately 25% for flounder.

Non-indigenous species (NIS) are the second or third most significant pressure for deep hard bottom habitats in the Kattegat, southern and northern Baltic Sea regions, and the third most significant pressure for deep soft bottoms in the northern Baltic Sea. Probably related to these effects, NIS was estimated as the first or second most significant pressure for flounder in the central Baltic Sea.

Disturbance or displacement by human presence was estimated as the most significant pressure for common eider and one of two top pressures for the sandwich tern. It was estimated as the second or third most significant pressure for great cormorant, long-tailed duck, and red-throated diver and among the top five pressure for grey seal.

Obstruction by dams together with *changes in hydrological conditions* (i.e. water flow) is the second most significant pressure for migratory fish stocks in the Baltic Sea. For these species, only *riverine habitat loss or degradation* is more significant (and it is tightly linked with the previous). Together, these riverine/related pressures caused 40-65% of the significant pressures for salmon and seatrout and approximately 30% for eel. *Obstruction or collisions by wind turbines* was estimated among the top three pressures for the red-throated diver and great black-backed gull.

Collectively, the *hazardous substances* pressures were estimated to be the most significant pressure for the grey seal. It was estimated as the third, fourth or fifth most significant pressure for the long-tailed duck, red-throated diver, and great black-backed gull. According to the current estimates, it was not considered a top pressure for benthic habitats or fish stocks.

Intentional killing by hunting or population control was estimated as the most significant pressure for the Great cormorant and great black-backed gull and among the top five for common eider and grey seal. For most of the waterbirds *pressures occurring outside the Baltic Sea* were considered as the second, third or fourth most significant pressure.

Impulsive underwater noise was estimated to be among the top five pressures for grey seal. *Continuous underwater noise* was not indicated as a top pressure for any of the assessed state component, however, this is likely do to the insufficient data gathered on most marine mammal species.

Marine litter, as represented by beach litter, was also not estimated among the most important pressures for any of the state components, but *ghost nets* were estimated be among the top five pressures for flounder and coastal predatory fish in the Baltic Proper.

2.3 Summary of projected pressure reductions

Projected pressure reductions vary considerably across topics, from projected pressure increases in underwater noise (negative reductions) to projected pressure reductions above 60% for beach litter and mercury (Tables 11-12). Projected increases in pressures are driven by expected growth in specific activities outpacing measures designed to manage their impact. Projected reductions occur when management measures exceed the growth of human activities. Keep in mind that not all of these pressures are necessarily causing significant environmental harm. For example, low projected reductions in a well-controlled pressure can be indicative of continued management success rather than of a need for increased management effort. This summary, a portion of the information generated within the SOM approach, identifies pressures whose management may not be expected to improve based on existing measures and effort, however, it is also important that the topic reports are be consulted to provide context on confidence and uncertainty of the results for each pressure assessment.

Tables 11 and 12 summarize the results for the projected pressure reductions. For each HELCOM scale 2 sub-basin with an attempted assessment, there is a circle coloured to indicate the projected pressure reduction (<0%, 0-10%, 10-20%, 20-40%, 40-60%, 60-100%, insufficient data). Connected circles indicate basins that were evaluated as a single area. All sub-basins with connected circles will necessarily have the same pressure reduction estimate. The order of the sub-basins will change from table to table to allow for these spatial relationships to be correctly indicated – Tables 11 and 12 appear as separate tables for this reason.

Table 11. Projected pressure reductions for the majority of topics.

Colour scale for the projected pressure reductions in percent (based on the expected value): <0%, 0-10%, 10-20%, 20-40%, 40-60%, 60-100%, insufficient data. Data used in the calculation of these results: activity-pressure contributions calculated using data from the HELCOM Baltic Sea Impact Index (BSII), effectiveness of measure types, information on existing measures.

Pressure	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Western Gotland Basin	Northern Baltic Proper	Gulf of Riga	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Potential physical disturbance to the seabed	20-40%	10-20%	10-20%	20-40%	20-40%	20-40%	20-40%	20-40%	10-20%	20-40%	0-10%	0-10%	0-10%	20-40%	20-40%	20-40%	20-40%
Potential physical loss of the seabed	20-40%	20-40%	20-40%	20-40%	40-60%	40-60%	20-40%	10-20%	<0%	20-40%	10-20%	10-20%	10-20%	10-20%	20-40%	20-40%	20-40%
Targeted extraction and bycatch of coastal fish	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%
Targeted extraction and bycatch of cod	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		
Targeted extraction and bycatch of flatfish	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data		
Targeted extraction and bycatch of pelagic fish	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%	40-60%
Input of mercury	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%
Input of TBT	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%
Input of PFOS	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%	20-40%
Input of Diclofenac	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%	<0%

Pressure	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Western Gotland Basin	Northern Baltic Proper	Gulf of Riga	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Input of nitrogen																	
Input of phosphorus																	
Input of the top 15 litter items to the beach																	
Bycatch of porpoise																	
Bycatch of seal																	
Intentional killing of grey seal																	
Intentional killing of ringed seal																	
Intentional killing of harbour seal																	
Targeted extraction and bycatch of salmon																	
Targeted extraction and bycatch of sea trout																	
Targeted extraction and bycatch of eel																	
Disturbance of salmon: obstructions (dams)																	

Pressure	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Western Gotland Basin	Northern Baltic Proper	Gulf of Riga	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Disturbance of sea trout: obstructions (dams)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Disturbance of eel: obstructions (dams)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Anthropogenic introduction of NIS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Input of continuous noise 63/125 Hz	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Input of continuous noise 2 kHz	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Input of impulsive noise with peak energy below 10 kHz	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Bycatch of pelagic feeders	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Bycatch of benthic feeders	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Bycatch of surface feeders	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Waterbird disturbance: collisions	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Disturbance or displacement of common eider by human presence	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Disturbance or displacement of great cormorant by human presence	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Pressure	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Western Gotland Basin	Northern Baltic Proper	Gulf of Riga	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Disturbance or displacement of sandwich tern by human presence																	
Disturbance or displacement of long-tailed duck by human presence																	
Disturbance or displacement of red-throated diver by human presence																	
Disturbance or displacement of great black-backed gull by human presence																	
Intentional killing of common eider																	
Intentional killing of great cormorant																	
Intentional killing of sandwich tern																	
Intentional killing of long-tailed duck																	
Intentional killing of red-throated diver																	
Intentional killing of great black-backed gull																	

Table 12. Projected pressure reductions for disturbance or displacement of marine mammals.

Colour scale for the projected pressure reductions in percent (based on the expected value): <0%, 0-10%, 10-20%, 20-40%, 40-60%, 60-100%. Data used in the calculation of these results: activity-pressure contributions calculated using data from the HELCOM Baltic Sea Impact Index (BSII), effectiveness of measure types, information on existing measures.

Pressure	Kattegat	The Sound	Great Belt	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Gulf of Riga	Gulf of Finland	Åland Sea	Northern Baltic Proper	Bornholm Basin	Eastern Gotland Basin	Gdansk Basin	Bothnian Sea	Western Gotland Basin	The Quark	Bothnian Bay
Disturbance or displacement of grey seal by human presence	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)
Disturbance or displacement of ringed seal by human presence							● (grey)	● (grey)	● (grey)	● (grey)						● (grey)	● (grey)
Disturbance or displacement of harbour seal by human presence	● (orange)	● (orange)	● (orange)	● (orange)	● (orange)	● (orange)									● (grey)		
Disturbance or displacement of harbour porpoise by human presence	● (orange)	● (orange)	● (orange)	● (orange)	● (orange)	● (orange)			● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)	● (grey)		

2.4 Activity-pressure contributions

The relationships between pressures and the human activities that cause them can be an important tool for planning environmental management. While it is not always sufficient to simply focus efforts on the activities contributing the most to a specific pressure, results such as these are an important step toward effective management and can be used to guide decision making even when cost data is absent (i.e. may help to identify where measures with potentially strongest results could be targeted or linked to obvious gaps in measures). In this report, four activity-pressure relationships are visualized using Sankey diagrams (Figures 4-7). These relationships have been generated using either expert elicitation (input of continuous noise 63/125 Hz, Figure 5; input of mercury, Figure 6) or published data sources (input of nitrogen, Figure 4; potential physical disturbance of marine habitats, Figure 7). Full results, including confidence and uncertainty for these and other activity-pressure results, can be found in the topic reports.

Figures 4-7 present average Baltic wide contributions of activities to pressures, so it is important to note that local, inshore/offshore, or sub-basin conditions may vary from the data presented here. The topic reports may present these relationships at a finer scale. In these figures, the respective pressure is presented on the left with lines connecting the pressure to human activities or sources on the right. The thickness of the line indicates the size of the contribution.

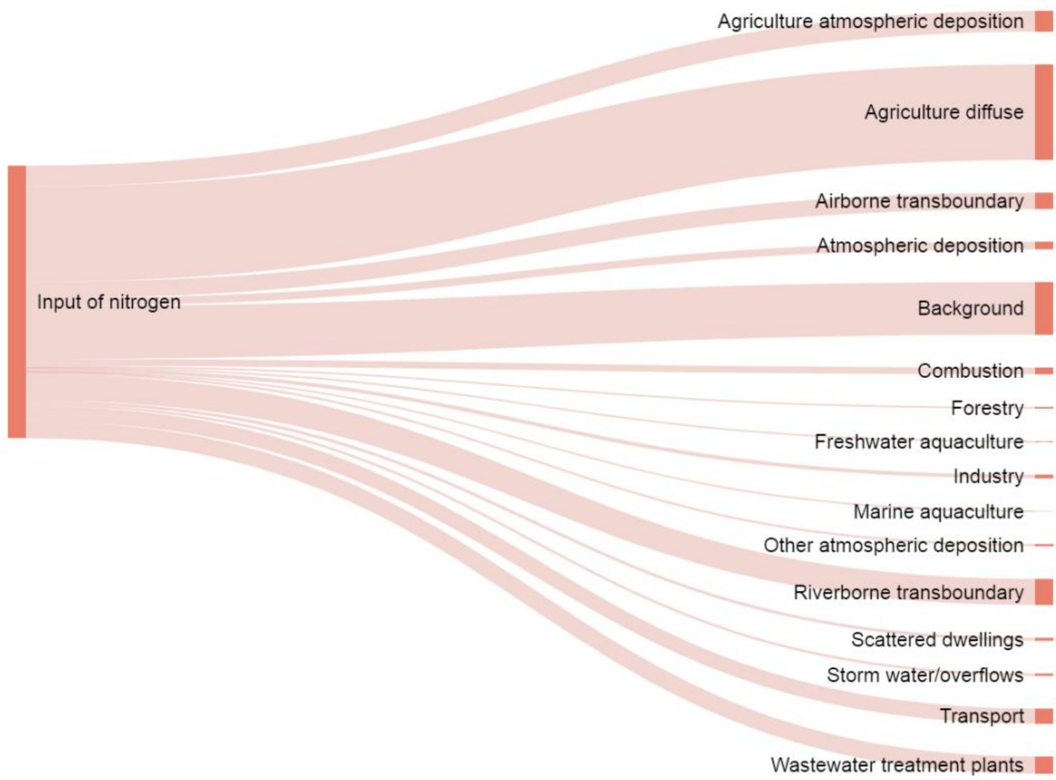

Figure 4. Activities contributing to the input of nitrogen. The sixteen different activities (right side) and their contribution to the pressure for input of nitrogen (left side) are visualized. The larger the contribution of an activity to the pressure, the larger is the connecting line.

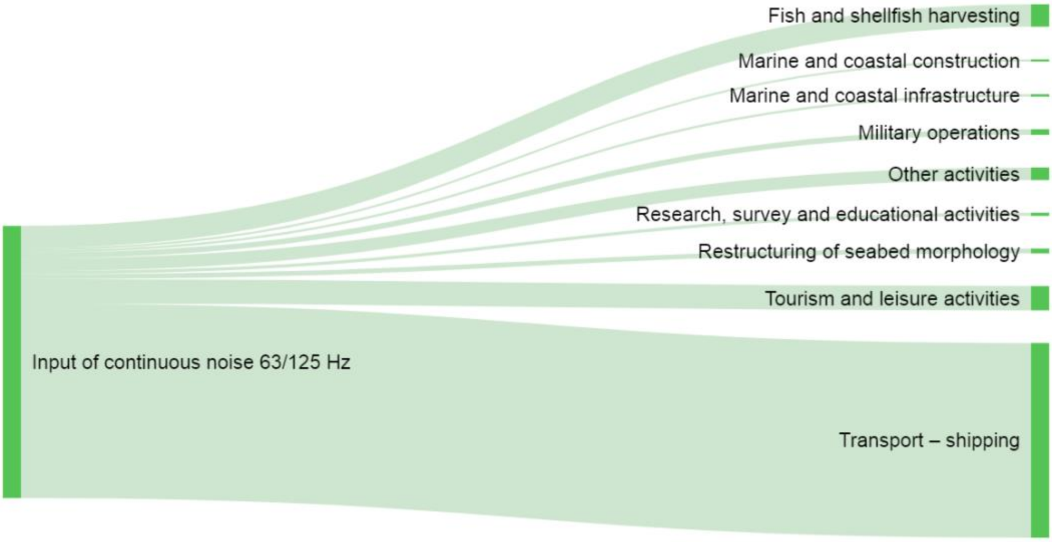

Figure 5. Activities contributing to the input of continuous noise 63/125 Hz. The nine different activities (right side) and their contribution to the pressure for input of nitrogen (left side) are visualized. The larger the contribution of an activity to the pressure, the larger is the connecting line. Tourism and leisure activities includes recreational boating.

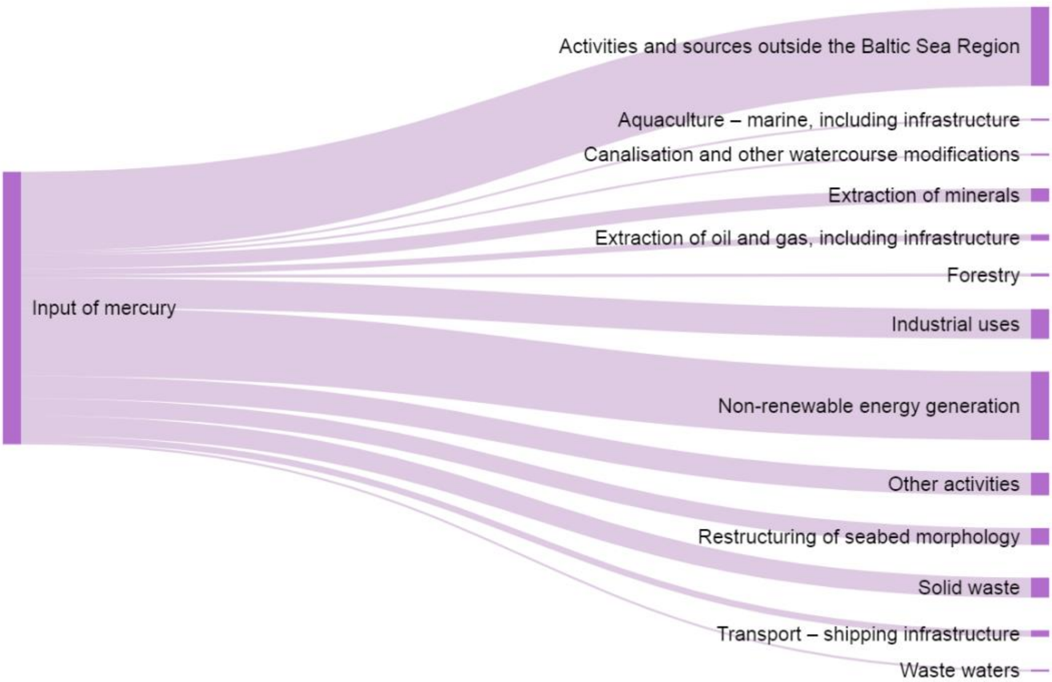

Figure 6. Activities contributing to the input of mercury. The thirteen different activities (right side) and their contribution to the pressure for input of nitrogen (left side) are visualized. The larger the contribution of an activity to the pressure, the larger is the connecting line.

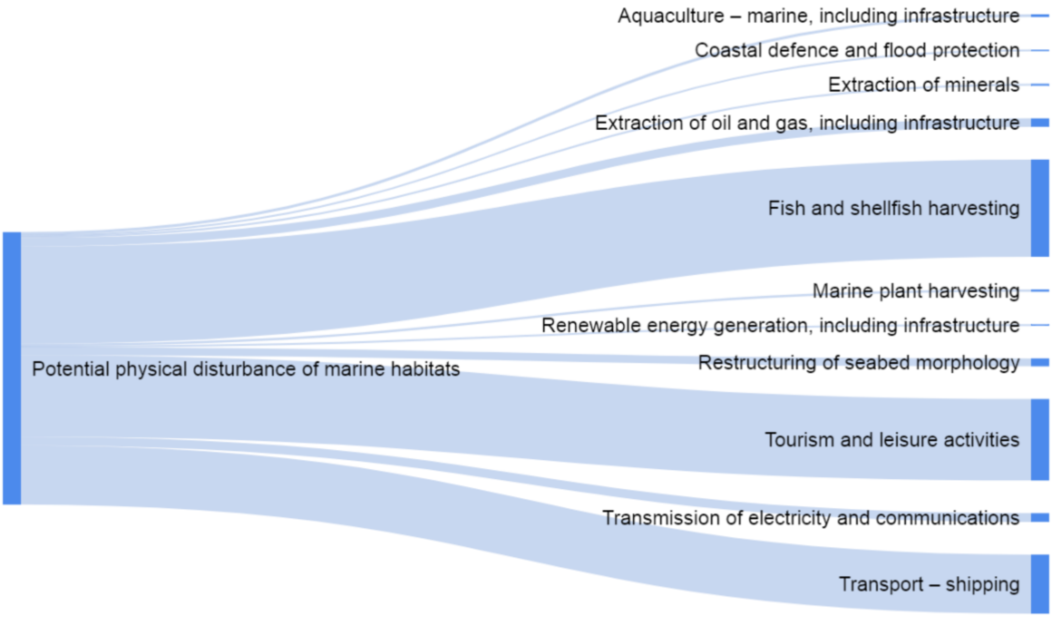

Figure 7. Activities contributing to the potential physical disturbance of marine habitats. The eleven different activities (right side) and their contribution to the pressure for input of nitrogen (left side) are visualized. The larger the contribution of an activity to the pressure, the larger is the connecting line.

2.5 Effectiveness and impacts of measures

Both effectiveness and impact can be used to characterize how measures affect pressures. Effectiveness is a way to quantify the ability of a measure to reduce a pressure from a specific activity and can indicate the most relevant measures for a given activity. Effectiveness estimates are based on expert evaluations of the effects of measure types, which represent more general formulations of individual measures to simplify the analysis. Effectiveness of measure types has been used as a proxy to assess the effectiveness of existing measures. For example, the revision of Denmark's aquaculture manual was not directly assessed. Instead, the general effectiveness of tightened restrictions for aquaculture management are applied to the aquaculture manual revision and any other relevant existing measures. Detailed results on the effectiveness of measure types are available in the topic reports.

Impact of a measure combines information on the effectiveness of a measure and the contribution of activities to pressures to indicate how much a measure reduces the pressure across all activities. Thus, impact gives indications of which kinds of measures could have a large overall influence on the pressure and be the most relevant in addressing specific pressures. This perspective acknowledges that less effective measures targeting a very prevalent activity could be more important than a highly effective measure targeting a minor activity. For the impact of an existing measure at the Baltic Sea scale, both the effectiveness of the measure in the area affected and the spatial area where the measure is applied are relevant. Some measures may have high impact in the affected area but only affect a small area of the Baltic Sea, while some measures may have a relatively low impact in the affected area but affect a large share of the Baltic Sea. Further, it is not reasonable to implement some measures at the Baltic Sea scale (such as marine protected areas) but have these rather target specific areas.

In the SOM analysis, existing measures are those measures in current policy frameworks (e.g. BSAP, EU MSFD, EU WFD, EU Biodiversity Strategy 2020) that can reduce pressures or improve environmental state during the assessed period 2016–2030. Overall, around 100 existing measures were included in the SOM analysis.

According to the results, the most impactful measures may reduce a pressure as much as 10–35% at the Baltic Sea scale. The measures with the highest impacts are often Baltic Sea wide international policies and regulations, such as maritime spatial planning (benthic habitats, birds), Minamata convention (input of mercury), Paris agreement (input of mercury), IMO regulations (noise), IMO Ballast Water Management Convention (NIS), and HELCOM management plans (fish species). There are many measures that are highly impactful in the area affected but cover a small share of the Baltic Sea, and thus their impact at the Baltic Sea scale is limited. This applies to many national measures and spatially limited measures, such as protected areas, MPAs and Natura 2000 sites. Detailed results on the impacts of existing measures are available in the topic reports.

3 Conclusions and discussion

3.1 Brief summary of approach and results

The sufficiency of measures analysis has assessed the pressure reductions that could be achieved with existing measures in the Baltic Sea during 2016–2030 and evaluated whether these would be sufficient to achieve or maintain GES. Overall, the results indicate that existing measures would not be sufficient to achieve GES or significant state improvements for many of the topics analysed. Further, it has indicated main activities contributing to pressures, main pressures affecting state components, required pressure reductions to achieve state improvements and impacts of existing measures. The analysis has also revealed several uncertainties and knowledge gaps that have affected the certainty and reliability of this evaluation.

In addition to the results, other major outputs include information on what are the limitations of the analysis, what could be achieved and what not, and how to take the work forward in the future. These issues are discussed in the following sections.

3.2 Evaluation of the process and results, lessons learned

The SOM analysis represents a significant effort in advancing the assessment of the sufficiency and effects of measures in reducing pressures and improving environmental state. Due to its broad coverage, contributions from the project team, HELCOM Secretariat, SOM topic teams, several HELCOM expert groups and networks and individual topic experts have been vital for its success. In particular, interdisciplinary expertise and the active engagement of topic experts have been paramount.

The aim has been to develop approaches and methods for assessing the effects of existing measures and thereby support the identification of and need for new measures in the Baltic Sea. The developed approach aims to apply a structured, harmonized, and transparent methodology across numerous relevant state components and pressures in the Baltic Sea region. Data and results have been provided to enable a region-level assessment of several environmental topics: benthic habitats, birds, fish, hazardous substances, input of nutrients, marine mammals, marine litter, non-indigenous species and underwater noise. The approach is flexible in the sense that it can incorporate different types of information (literature and expert-based) and the analysis can be improved in the future when more data become available to parameterize each component in an increasingly quantitative way.

The work builds on previous national, HELCOM and European analyses (HELCOM 2018b, Kontogianni et al. 2015, Oinonen et al. 2016), but the developed approach covers more areas than previous assessments, both in terms of the diversity of topics addressed and spatially (i.e. Baltic Sea scale) and thus represents pioneering work in European marine areas and potentially globally. Additionally, the inclusion of measure-activity-pressure-state chains and joint impacts of measures are important developments in an analysis of this type and scope. The general approaches are applicable in other contexts and can be used as building base for assessments of sufficiency of measures in other marine regions, as well as a baseline for future development withing the Baltic Sea region.

As the first attempt to quantify the effects and sufficiency of existing measures at the Baltic Sea scale, there is considerable room for improvement. It is only in retrospect that these critical lessons can be identified. However, the analysis has demonstrated that this kind of an approach and analyses are possible and produce meaningful results that can offer support for management decisions.

Main lessons learned are related to the following issues:

1. **Active engagement of topic experts.** Those topics which had established SOM topic teams or otherwise organized and active support from topic experts were clearly more likely to succeed in achieving the aims of the analysis. Topic teams provided direct topic-specific expertise, helped develop topic structures, improved the expert surveys and were active in responding to them. They also acted as communicators and interpreters of the approach and results to other experts not as familiar with the analysis. In the reporting phase, topic experts provided useful evaluation, contextualization and interpretation of the results. Analyses were more difficult for topics without designated topic teams, as there was less direct support for the topic and expert survey design, and less integration of topic knowledge through draft comments and interpretation of the results. Fewer respondents to the surveys, potentially due to poorer survey design and communication was also often encountered.
   It is important to note that the topic teams were more than a group of topic experts available for consultation. Their benefit stemmed from their long-term exposure to the analysis which created enough familiarity to allow for some level of integration and ultimately an ability to independently question aspects of topic design and results. In a project with the breadth and complexity of the SOM analysis, this support is irreplaceable.

2. **Scope versus level of detail in the analysis.** There was a clear trade-off between the scope and level of detail in the analysis. Covering all major pressures and state components and implementing a Baltic Sea level analysis reduced the ability to address every topic-specific adjustments and analyses (independent of any differences in data underlying the topic specific assessments). Retrospectively, the scope and level of detail in the analysis were too broad for the resources allocated for the work. With the given resources, it would have been more sensible to simplify the approach (less detailed measure types, pressures and state components) or have a more limited focus (fewer topics). Starting from a few topics and aiming for as comprehensive an analysis as possible and later extending to other topics could have been an option. However, analysing all topics in one go had some benefits. The broader scope allowed the identification of connections and impacts among components of different topics, even if these could not be fully quantified with the available information. Additionally, each topic raised unique issues that challenged the general methodology. Some of these issues were fully resolved but others would need to be integrated from the beginning of a future SOM analysis. In attempting an analysis on such a broad range of topics more of these fundamental issues were identified, which will ultimately speed the development of the overall approach in the future. Furthermore, omitting any of the topics of input of nutrients, coastal fish, hazardous substances, or marine litter would have resulted in serious loss of insight into the general methodology due to their significance across multiple topics

and the lessons learned from the assessment of commercial fish, migratory fish, underwater noise, marine litter, and hazardous substances will lead to substantial revision of topic selection and design. The overly ambitious project scope and the complex, multidisciplinary and overarching nature of the work would also have benefitted from stronger review at certain stages, and this will be an important factor to build into future development processes. Thus, the final analysis was a compromise between feasibility, scope and level of detail, and represents the maximum that could be achieved with the time and resources. Despite these identified issues, the process afforded more understanding of both the general methodology and topic specific implementations, laid a clearer path for future analyses, and has offered support and contextual information for the update of the BSAP.

3. **Complexity versus feasibility of the analysis.** The analysis, data, and model structure were kept relatively simple to make the analysis feasible for such a broad range of topics. This was carried out to account for significant differences in data availability, to cover as broad a range of relevant topics in the region as possible, and to have comparable results across topics. However, for some topics a more complex approach was taken if the data were available or if the data type required an alternative approach to provide a reasonable result. For some topics this approach was a success, for example the topic of eutrophication for which there is a substantial amount of quantitative data available, but for others it also provided more challenges. The best example of this is marine litter, where an item-based approach was chosen based on input from the SOM topic team, and the analysis distinguished between top 15 litter items to the beach. However, it is unclear whether the benefits of this approach outweighed the costs. Litter did not readily fit into the general model framework, and significant changes had to be made to use the model for litter. Further, due to differences in the approach and data, some of the methodological features developed for the other topics do not fully apply in the case of litter (such as joint impacts) and those developed specifically for litter are not well tested and difficult to accurately present (e.g. sub-pressures integrated into a single beach litter pressure, unique structure to the effectiveness of measures survey). As a result, litter is a topic that is difficult to communicate, contains methodological uncertainties not found in other topics, and required a disproportionate amount of resources. Through multiple iterations of the SOM analysis, individual topics may eventually reach this level of complexity, but for the near future this level is not broadly feasible.

4. **Using expert surveys/responses.** Use of expert elicitation enabled the coverage of the broad range of pressures and state components in the analysis. Expert surveys were a major source of information for many topics, as existing literature or model-based data were only available for the input of nutrients and activity-pressure contributions for some topics. However, several experts expressed difficulties in responding to the questions in the surveys, and there was often considerable uncertainty in the expert estimates. Analyses less reliant on expert estimates would be preferable, if data allow. However, for the foreseeable future it is reasonable to assume that some data used by the SOM analysis will remain expert-based, and therefore reflection on the process used for this analysis is crucial. It was a priority that the project use HELCOM resources and expertise when they were available, and

due to the broad coverage of environmental topics covered by HELCOM, no survey responses were sought from outside the HELCOM structure (though additional topic experts, i.e. those not already in established HELCOM groups, were in cases nominated by Contracting Parties, extending the expert pool somewhat). The expert surveys were complex and rather extensive for some topics and distributing them through established HELCOM structures helped ensure expert participation. However, in certain cases the analysis suffers from a low number of responses particularly for assessments covering smaller spatial areas.

5. **Results from the analysis.** One of the great strengths but also weaknesses of the SOM analysis has been the sheer volume of results produced. Since the analysis was based on measure-activity-pressure-state chains, possible results covered all of these stages and linkages between them. The project had difficulties identifying which results should be emphasized as the most important or useful outcomes. Furthermore, early discussions with potential end users did not provide clear insights on this issue, though it is likely that this will be in issue that is far more developed at future iterations of SOM analyses. As more results were circulated for review, particularly to higher HELCOM bodies, the project gained a better understanding for the significance of individual results. However, not all of these results were readily extracted from the current model. Future iterations of the SOM analysis could focus on producing results such as projected activity-pressure relationships to identify activities where further reduction could be possible or presenting clearer impact chains linking existing measures to their broader environmental impact.

6. **Dependence on HELCOM indicators.** The SOM analysis embraced existing HELCOM indicators as a valuable tool for guiding the structure of individual topics and providing the necessary baseline data to conduct the analysis. However, any weaknesses in the indicators were amplified in the SOM analysis due to the integrated nature of the model and the difficulty of effectively expressing nuance across the long impact chains present in the analysis. The continued process of indicator development and revision is greatly beneficial to any future SOM analysis, particularly when topic experts less familiar with the indicator are asked to base their evaluations for the SOM analysis on the information given in the indicator report. At times, topic experts expressed disagreement with the status as described in the indicator. This was often due to unique and distinctive factors, such as variation in local conditions, changes in status between now and the most recent indicator update, or the focus of the analysis on a single component of environmental status (often abundance). However, some of these concerns related to indicator construction, such as a uniform abundance threshold being applied to all seal populations or questionable baseline data for common eider which corresponds to a time before the successful conservation of its predator the white-tailed eagle. The SOM approach performs best with established GES threshold values outlined by current and responsive indicator assessments. Any work to progress to further develop or maintain the quality of HELCOM's indicator catalogue (e.g. new indicators, threshold values) would be highly valuable for future SOM assessments.

7. **Measure types.** One of the main challenges of the SOM analysis was assessing the effectiveness of existing measures implemented within nine different legislative environments. Based on early discussions it became clear that topic experts could not operate on the scale of individual existing measures without support beyond the capacity of the project. One solution would have been to gather very specific groups of national experts to respond to each topic on a national basis, in essence develop a common methodology and conduct nine different effectiveness of measures assessments. The effort, coordination, and national buy-in inherent in such a proposal ruled out this option. Another solution could have been to facilitate the conceptualization of measures for the experts, so that they would have been able to operate on the scale of individual measures or groups of individual measures. However due to the timing of data collection for existing measures from Contracting Parties for whom this was not a feasible solution. The solution implemented in the SOM analysis was the creation of the measure types; lifting the existing measures up to a level of generality where they could be discussed at a regional level. One of the benefits of using measure types was that they can be utilized to assess the effectiveness of measures other than those included in the analysis, such as the effectiveness of proposed new measures for the updated BSAP (as applied separately in the cost effectiveness of new measures study). There were disadvantages to this approach, such as increased uncertainty in the estimates and difficulty in considering recent but fully implemented measures, but this approach was considered the most feasible at the time. The SOM analysis was reliant on clear, descriptive measure types that strike a balance between general applicability and sufficient specificity to allow for a useful estimate of effectiveness. As long as measure types are utilized in the SOM approach, this issue will likely be in constant adjustment as circumstances change and new measures are implemented.

8. **Modelling options and features.** The initial objective was to develop a relatively simple, transparent and uniform probabilistic model framework for assessing the impacts and sufficiency of measures on the environmental state of the Baltic Sea through activity-pressure-state chains. The idea was that this framework could then be developed to better account for topic specific deviances, more detailed representations of different components, and other features. However, since the model framework was developed as a part of a policy-oriented project, involving strong stakeholder interaction, there was a desire to adopt a more detailed and bottom-up development strategy from the beginning of the project. The modelling framework could have benefitted from thorough piloting and testing of the approach, first using more general and uniform data, which would have also facilitated the use of SOM approach and model for cost effectiveness analysis and possible future analyses. The probabilistic modelling approach used is in principle based on Bayes theorem where the probability of subsequent events is affected by the information on the outcome of preceding events. Better testing and piloting could have enabled faster and further development of this approach for other input data (e.g. literature, models, meta-analysis) and for other probabilistic analysis types (e.g. fuzzy, qualitative or discrete analyses). In hindsight, streamlined and systematic development process would have also required more coordination and communication across all project participants, and more discussion on common goals and challenges related to different phases and tasks of the project.

9. **Spatial units and their limitations.** The model used a flexible spatial approach where the analysis units, comprising the 17 HELCOM scale 2 sub-basins (or topic specific aggregations of those), varied across four data layers (existing measures, activity-pressure, effectiveness of measure types, and state). Activity-pressure contributions and state assessment data (required pressure reduction and significance of pressures) varied widely across topics, whereas the effectiveness of measure types were all assessed at the Baltic Sea scale and existing measures were evaluated for each sub-basin. The use of using non-uniform spatial scales enabled the assessments to be tailored to topic requirements (data availability, natural conditions, expert knowledge) and allowed for the flexible presentation of results at different spatial scales. However, at the same time not all of the spatial scales applied will be policy relevant, nor is there yet a common understanding how these results should be aggregated and compiled. This is especially the case when extracting "trace back" results, e.g. which activities should be further targeted to improve state taking into account the existing measures and, for example, proposed new measures for the updated BSAP.
   There also remains the issue that the HELCOM scale 2 sub-basins may be too coarse for some topics. For example, the analysis on coastal fish needed to aggregate HELCOM scale 3 sub-basins to the scale 2 level in order to complete the analysis. It is not yet clear how this aggregation affects the applicability of topic results or if the chosen aggregation method (one-out-all-out) is the most appropriate for policy applications. This SOM analysis has focused on a regional perspective and it is possible that all environmental topics may not be suited to this type of analysis.

10. **Use of SOM approach and data for other analyses such as cost effectiveness analysis.** The SOM approach was further applied in the ACTION project to analyse the effects of new measures proposed for the updated BSAP. New measures were added to the analysis to assess the sufficiency of new and existing measures to reach GES. In retrospect the needs for analysing the effects and sufficiency of new measures could have been better taken into account when planning and implementing the SOM analysis. Some of the data/topic structures and modelling features developed for the SOM analysis were a bit ad hoc and/or complex, and thus complicated the application of the approach for new measures and ruled out a complete optimization of methods. Also, when collecting the effectiveness data for existing measures, more emphasis could have been given to the data collection for new measures. However, given the timetable of the project and timing of proposals for new measures, this was not feasible.

3.3 Knowledge gaps and development opportunities

Several knowledge gaps and development opportunities were revealed during the process. In principle, the analysis was feasible for all topics, but some results were not presented due to too few data points, which were deemed insufficient for presenting quantitative or even qualitative results. This applied to results reliant on expert estimates, and affected in particular the biodiversity topics: mammals, birds, benthic habitats and fish.

1. **Reducing reliance on expert elicitation.** Reducing the reliance on expert-based estimates is an important development area in the future. Literature and model estimates are missing for all topics and data components. Even for the input of nutrients, the topic best covered with existing data, more reliable estimates of the effect of agricultural measures and measures targeted to scattered dwellings would be needed.

   Activity-pressure contributions were data-based for benthic habitats, non-indigenous species and input of nutrients, and expert-based for the other topics. Effectiveness of measures estimates were mainly based on expert estimates, although they were complemented with literature data. However, these literature data could only partially be utilized in the analysis. Significance of pressures and effect of pressure changes on state components were entirely based on expert elicitation. Thus, literature and model-based estimates of all of these components would be useful for the future analysis of sufficiency of measures.

2. **Improved use of literature data.** One easy way to reduce the reliance on expert elicitation would be through improved use of available literature data. Literature data were collected on the effectiveness of measures in reducing pressures for all topics. But, to a large extent, these data could not be utilized in the analysis, as their inclusion would have required more work on the analysis of collected data (e.g. transforming data into reduction with percentages, topic specific knowledge on the applicability of specific studies to the Baltic Sea) and model development. There are clear changes to the topic structures which could be made to allow for better inclusion of literature estimates in the future. Additionally, the probabilistic modelling approach used for the SOM analysis is in principle based on Bayes theorem where the probability of subsequent events is affected by the information on the outcome of preceding events. Even if the pooled distributions used in the analysis are ostensibly continuous, in reality each of these probability distributions is a histogram with a limited amount of values, each assigned a probability. Thus, the model can be developed also for more discrete approaches on events and their probabilities. This increases the flexibility to use data of different formats and structures in the analysis, such as data from expert surveys, individual studies, models and meta-analyses. For the current analysis the model was piloted on more or less uniform data on different topics to develop a prototype and to identify possible pitfalls and development opportunities.

3. **Improved linkages between pressure inputs, pressures and state components.** Estimates on the linkages between pressure inputs (such as the input of nutrients and introduction of non-indigenous species), pressures (such as effects of eutrophication and non-indigenous species) and state components (such as benthic habitats and fish) are important to enable an integrated analysis and consideration of how various pressures affect state components. Some important linkages were missing from the SOM analysis, in particular the link between input of nutrients and effects of eutrophication. Including this information would be a major improvement, as eutrophication affects many of the state components in the analysis.

   The development opportunities for these missing linkages vary considerably. The data required to quantify link between input of nutrients and effects of eutrophication is readily available and only requires additional resources to implement. However, other links may remain unestablished for the foreseeable future due to scientific uncertainties (e.g. introduction of NIS and their effect on the environment) or complex dynamics between pressures (e.g. human induced food web imbalance). These factors rely on developments at both the research and HELCOM indicator level to provide strong support for future SOM work.

4. **Improved expert surveys.** It appears that experts were more comfortable in evaluating certain elements of the surveys, including the activity-pressure contributions and effectiveness of measures. There seemed to be more problems with the pressure-state linkages, and on occasions it appeared that experts considered their responses guesses rather than reliable expert judgements that would be based on existing knowledge. Problems were encountered particularly when experts were asked about pressure reductions required to maintain GES for state components which currently meet GES threshold values. Although this information was given in the survey, expert responses often gave indications that high pressure reductions would be required to maintain GES, which seems counterintuitive. There are a few potential explanations for this. The question formulation may have been unclear, which lead to inconsistencies in the responses. Another possibility is that experts' opinion of GES and/or the status of the indicator could have differed from the latest HELCOM assessment, or that the experts based their response on some other knowledge not taken into account in the assessment. In any case, the expert surveys should emphasize that the current status meets the GES threshold value when that is the case, and that the experts should use this information as the basis of their assessment. The question formulation could also be improved.

5. **Collecting more data.** Only few expert responses could be gathered for some of the topics/survey elements/state components, and sometimes results had to be excluded due to too few expert evaluations. Collecting additional data could enable the inclusion of these results and would improve the (geographical) representativeness of the results for these topics.

6. **Explore data collection alternatives.** Broader review of the data collection process for expert opinion should be considered as part of any future SOM analysis. While the survey approach used in the SOM analysis could continue to be used and improved, other options are available. One such option would be a facilitated workshop setting, were experts could discuss issues and agree on model input data. However, such an approach would require significant preparatory work to ensure buy-in and preparedness among participants. Versions of this approach were piloted in the SOM project and were not successful. However, the preparatory work for these workshops were clearly insufficient.

   Another alternative to consider should be targeting an expert pool beyond the HELCOM community. Expert identification would be a challenge and it is likely that the surveys would need to be significantly streamlined and made more flexible so that experts in a specific issue (e.g. waterbird bycatch) could quickly reach the relevant material and would not be discouraged by the overall scope of the survey. However, there would be clear benefits to data quality if successfully implemented.

7. **Continued focus on topic specific design.** The analysis aimed at a uniform and integrated approach across topics, so that the different elements can be modelled in the same framework and interact with each other. This meant rather strict requirements on the uniformity of data across topics and allowed for less topic-specific adjustment than was requested. Litter was the expectation to this and proved a valuable test of our ability to create a fully tailored topic. This effort too significant resources but did manage to meet many of the challenges presented by the topic. Moving forward other topics should be considered for topic-specific redesigns. However, resources will remain a limiting factor in any such effort.

8. **Estimating the economic benefits of measures**. The work focused dominantly on assessing the sufficiency of existing measures, with further complementary analyses of the costs and effectiveness of proposed new measures for the updated BSAP (for details, see the cost-effectiveness report). An important component missing from the analysis are the economic benefits of measures, i.e. the monetary value of achieving GES overall or specifically for the various pressures and state components. Assessment of the changes in human well-being would provide additional support for evaluating the impacts and efficiency of policies by revealing how citizen around the Baltic Sea would benefit from achieving GES. This would mean improved analysis of the impact of the measures on human well-being.

9. **Improved support for choosing actions.** Providing improved support for decisions on which activities and pressures should be addressed in the future is an important development area for future analyses. This requires information on:

   - which pressures are the most significant and require the largest reductions to achieve GES/state improvements across state components,
   - are significant pressures reduced with existing measures in the right areas, and
   - which activities these pressure reductions target and are they those that contribute the most to pressures.

   In principle, all of this information is produced in the SOM analysis, and to some extent it is included in this main report, the topic reports and the report on cost-effectiveness of new measures. However, not all of these results are easily extracted from the model because they require further development of data and result aggregation/compilation methods and levels (both thematically and spatially). Unfortunately providing these results has not been feasible with the resources available for the work. More focus on management applicable results should be a priority for future analyses.

10. **Continued model development.** The possible opportunities for further development of the mathematical/theoretical and technical implementation of the analysis are related to many of the development opportunities listed above. These include for example improved use of literature data, inclusion of improved linkages, implementing topic specific features, optimal policy design, and improved support for choosing actions. Systematic development of the model as well as the whole analysis requires strong dialogue and systematic data flow between different phases of the whole analysis (data collection, model development and dissemination) to understand the limitations and opportunities related to each of these phases and to ensure the best outcome.

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SOM report series

HELCOM ACTION 2021a. Sufficiency of existing measures to achieve good status in the Baltic Sea. Available at: http://www.helcom.fi/SOM/MainSOMReport

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Model code is available at: https://github.com/LiisaSaikkonen/ACTION_SOM