Sufficiency of existing measures for the input of nutrients into the Baltic Sea

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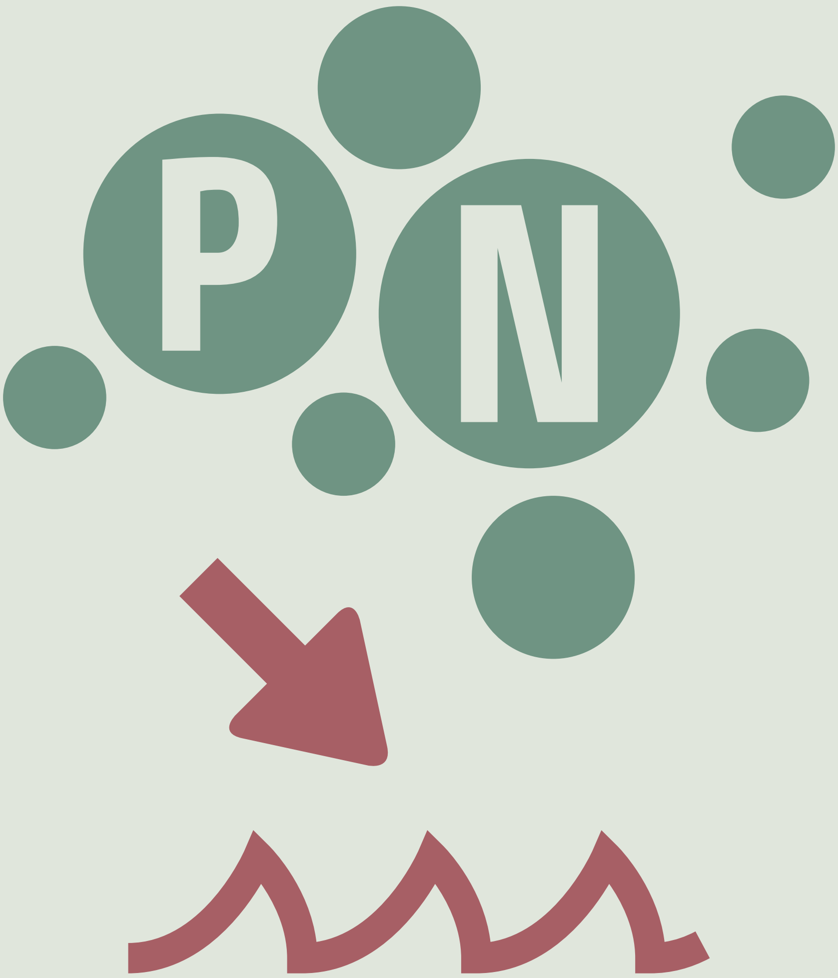
Eutrophication

2021



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ACTION

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Sufficiency of existing measures for the input of nutrients into the Baltic Sea

Table of Contents

Summary of main results

The SOM analysis has assessed the projected reductions in the input of phosphorus and nitrogen to the Baltic Sea and compared them to nutrient reduction targets. Most of the data come from existing databases, assessments and models, but the estimates on nutrient runoff from agriculture are partially based on expert estimates. No estimates for potential reductions from scattered dwellings were included in the analysis.

For the input of phosphorus, existing measures appear sufficient in achieving or maintaining nutrient reduction targets in the Kattegat, Danish Straits and Bothnian Sea. They are not sufficient in the Baltic Proper, Gulf of Riga and Gulf of Finland. In the Bothnian Bay, the projected pressure reductions are of similar magnitude as those required.

For the input of nitrogen, existing measures appear sufficient in achieving or maintaining nutrient reduction targets in the Kattegat, Danish Straits, Bothnian Sea and Bothnian Bay. They are not sufficient in the Baltic Proper and Gulf of Finland. In the Gulf of Riga, the projected pressure reductions are of similar magnitude as those required.

Reductions in the input of nutrients from existing measures range from low to moderate, depending on the sub-area. Reductions are projected in all sub-areas.

State components most affected by the input of nutrients are benthic habitats and certain fish species/species groups.

Main activities contributing to the input of nutrients are: diffuse losses through rivers from agriculture and background, as well as point source inputs from wastewater treatment plants. Transboundary loads from non-Contracting Parties are also important in some basins.

Introduction

Report background

The sufficiency of measures (SOM) analysis assesses improvements in environmental state and reduction of pressures that can be achieved with existing measures in the Baltic Sea region, and whether these are sufficient to achieve good environmental status (GES). The analysis involves estimating the state of the marine environment in 2030, based on a starting point of 2016 (i.e. the latest HELCOM status assessment), and given measures in existing policies, their implementation status, and the projected development of human activities over time. The evaluation can be carried out compared to relevant and agreed HELCOM threshold values for GES, where available.

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

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

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

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

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

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

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

Topic background

Eutrophication is caused by excessive availability of nitrogen and phosphorus for primary producers enhancing the growth of phytoplankton, leading to cyanobacterial blooms, reduced light conditions in the water, oxygen depletion and many other undesirable ecosystem changes.

In 2011-2016, all the open and nearly all of the coastal Baltic Sea sub-basins were assessed to be in a eutrophication status that is below GES (HELCOM 2018). The deteriorated status was demonstrated mostly through nutrient levels and direct effects (chlorophyll-a and Secchi depth). The indicator level was below the threshold for good status for nitrogen in all open sub-basins, for phosphorus in all but Bothnian Bay and for chlorophyll-a and Secchi depth in all but Kattegat. The deep-bottom oxygen indicator was also below the threshold throughout the deep waters of the main Baltic basin.

Nutrient inputs into the Baltic Sea started to increase in 1950s and eutrophication was first recognized as a large-scale pressure of the Baltic Sea in the early 1980s (HELCOM 2018a). In 2018, total input of nutrients (flow normalized riverine loads) to the Baltic Sea amounted to about 875,000 tons of nitrogen and 34,000 tons of phosphorus. Rivers exported the largest proportion of the nutrient inputs, while direct point sources accounted for 4-5% of the total loads (HELCOM 2018b). A major part of the anthropogenic inputs originated from diffuse sources, mainly agriculture, while point sources, dominated by municipal wastewater treatment plants, contribute with 12% and 24% of the riverine nitrogen and phosphorus loads, respectively. Natural sources accounted for one third of the riverine inputs and atmospheric inputs comprised for about 30% of the total nitrogen inputs, originating mainly from combustion processes related to shipping, road transportation, energy production, and agriculture.

As a response to the increased nutrient inputs, actions to reduce loading were agreed on by the 1988 HELCOM Ministerial Declaration and reaching a Baltic Sea unaffected by eutrophication was included as one of the main goals of the Baltic Sea Action Plan adopted in 2007 (BSAP; HELCOM 2007). The BSAP included the HELCOM Nutrient Input Reduction Scheme that set the Maximum allowable inputs (MAI) and Country-Allocated Reduction Targets (CART). According to the revised scheme adopted in the 2013 HELCOM Ministerial Declaration (HELCOM 2013a), reduction requirements were set for nitrogen inputs to the Baltic Proper, Gulf of Finland and Kattegat and for phosphorus inputs to Baltic Proper, Gulf of Finland and Gulf of Riga. A prerequisite for the other sub-basins without reduction requirements was that nutrient loads should not increase compared to the inputs in the reference period (1997−2003). Presently, instead of CARTs, countries aim to achieve the nutrient input ceilings (NICs).

The largest relative decreases in inputs of nitrogen and phosphorus over recent decades have occurred in direct point sources. Also, the atmospheric input of nitrogen has decreased remarkably between 24 and 30% during 1995−2015 for all sub-basins, while changes in waterborne, diffuse nutrient inputs are clearly more variable (HELCOM 2018a). The normalized input of nitrogen was reduced by 12% and phosphorus by 26% between the reference period (1997−2003) and 2018 (HELCOM 2019). The strongest relative changes over the past decades are seen in the Kattegat and the Danish straits for nitrogen input, whereas the most pronounced results for phosphorus input are seen in the Gulf of Finland, where the phosphorus input has been cut with more than half compared to the reference period.

The MAI has been fulfilled in the Kattegat, Danish Straits, Bothnian Sea and Bothnian Bay, whereas reductions are still required for nitrogen input to the Gulf of Riga, Gulf of Finland and Baltic Proper (HELCOM 2019). Currently, for the whole Baltic Sea, nitrogen is closer to reach the MAI compared to phosphorus. Based on the progress towards the NICs Denmark was the only country, which had achieved the NIC for both nutrients, whereas there are large differences between the other countries in reaching their NICs.

Description of nutrients and eutrophication in the SOM analysis

Nutrients and eutrophication are considered in two distinct ways in the SOM analysis (Figure 1). **The first is as the pressure inputs *input of nitrogen* and *input of phosphorus***, which reflect the structure of the HELCOM indicator "Inputs of nutrients (nitrogen and phosphorus) to the sub-basins" and the nutrient reduction targets as Maximum Allowable Inputs (MAIs) established in the HELCOM Baltic Sea Action Plan and updated by the 2013 Ministerial Declaration. The MAI values have been designed to reach good status with regard to eutrophication and the goals of MSFD criteria D5C1[1]. Separate MAI have been established for each of the 7 PLC sub-areas (Figure 2). In the latest HOLAS assessment period (2011-2016) (HELCOM 2018, 2019), MAI were met in three sub-areas for both nitrogen and phosphorus (Kattegat, Danish Straits, Bothnian Sea).

The **second aspect of nutrients and eutrophication in the SOM model is the pressure *effects of eutrophication***, which includes e.g. oxygen debt and water clarity. This aspect more directly reflects the structure of the MSFD criteria D5C1. In the expert surveys on pressure-state linkages, this pressure could be selected as being significant to any of the various state components included in the SOM analysis, and is thus included in the pressure-state assessment of the analysis. No connection has been estimated between the input of nutrients and the effects of eutrophication in the SOM analysis, i.e. the analysis cannot say how changes in the input of nutrients impact eutrophication effects. However, modelling exercises exist that can provide information of this relationship (e.g. Murray et al. 2019; HELCOM 2013c).

[1] Marine Strategy Framework Directive criteria D5C1 – Primary: Nutrient concentrations are not at levels that indicate adverse eutrophication effects. The threshold values are as follows:
(a) in coastal waters, the values set in accordance with Directive 2000/60/EC;
(b) beyond coastal waters, values consistent with those for coastal waters under Directive 2000/60/EC. Member States shall establish those values through regional or subregional cooperation

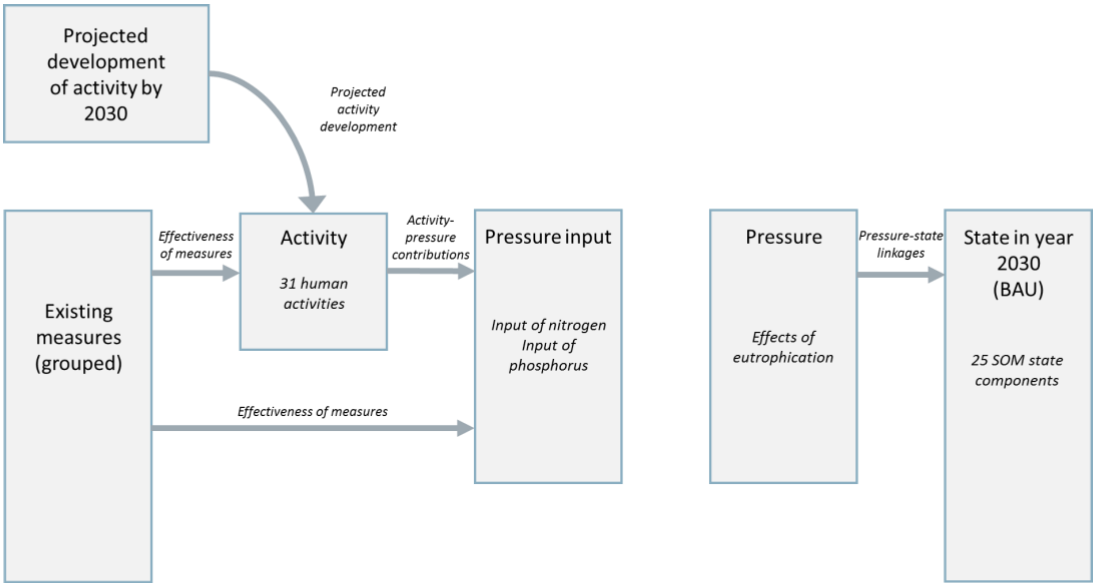

Figure 1. Schematic of the SOM analysis for nutrients and eutrophication. The impacts of the pressure inputs (*input of nitrogen, input of phosphorus*) on the pressure (*effects of eutrophication*) have not been estimated within the SOM analysis.

Supplementary activities

In addition to ACTION WP4 and WP5 supporting the SOM analysis for eutrophication, they also had broader aims. The aim of the WP4 was to contribute to the implementation of the EU MSFD and nutrient reduction targets of the Baltic Sea Action Plan by developing and evaluating approaches to determine the effectiveness of measures to reduce nutrient loads to the Baltic Sea from its catchment and atmosphere. It had three main components: 1) Following up existing measures 2) Compatibility of targets under different marine policies 3) Potential nutrient load reductions through existing measures. For more information, see HELCOM ACTION 2021p, 2021q.

WP5 reviewed the current knowledge and analyse how natural conditions influence the recovery of the Baltic Sea, as well as how the projected future change in climate will affect the measures taken to improve the Baltic Sea (HELCOM ACTION 2021r).

Methods and data

Substantial amount of information for the input of nutrients comes from ACTION work package 4, which provides an overview of the division of activities and pressures related to eutrophication (i.e. nutrient inputs), creating an overview of source apportionment and identifying activity-pressure contributions. This aspect is developed based on the national data reported to the HELCOM Pollution Load Compilation (PLC).

For the effectiveness of measures and projected pressure reductions, information on load reductions due to full implementation of existing measures is required. The information on effectiveness of measures is provided per activity: waste water treatment (reductions achieved by implementing HELCOM Recommendation 28E/5 on municipal waste water treatment), atmospheric nitrogen emissions (based on EMEP data and predictions of the full implementation of the Gothenburg protocol/EU-NEC Directive), and agriculture (expert survey on the nutrient runoff from agriculture guided by the HELCOM Agri group). Inclusion of the estimated reduction from scattered dwellings was not possible due to the development timeline for PLC-7.

Activity-pressure input contributions

For the *input of nitrogen and phosphorus*, source apportionment data collected within the PLC-6 and PLC-7 projects are used. This data follows the load-oriented approach which represent loads to the sea from each given source/sector. The year for data collection was 2017 (PLC-7) for all countries except for Sweden and Denmark where PLC-6 data collected in 2014 was used because appropriate PLC-7 data were not available at the time. The data was downloaded from the PLC-water database via the PLUS interface on January 30, 2020 for the PLC-6 data and on March 31, 2020 for the PLC-7 data. In addition, the direct inputs from coastal industry and municipal wastewater treatment, and marine aquaculture in 2017 were obtained from the PLC-water database on March 25, 2020. Atmospheric nitrogen deposition split into sectors, countries and basins for 2014 was obtained from EMEPs assessment (Bartnicki and Benedictow, 2017). Atmospheric phosphorus deposition has been calculated based on the 5 kg phosphorus per sq. km value used in PLC-7. There is a complete data set for all countries and basins for the direct inputs and atmospheric deposition. All countries have reported some information on the division between the source categories, but detailed attribution to sources/sectors are missing in some countries. Further, some countries only provided aggregated information on diffuse and inland point contributions. Sectoral estimates of these aggregated data have been attempted based on the following methodology.

For diffuse sources, the contribution reported as unknown from Estonia was assumed to be to equal shares comprising of scattered dwellings and stormwater/overflows. Latvia only report natural background contributions and the sum of anthropogenic contributions. Based on proportions of what was reported from Lithuania, but expecting somewhat smaller contribution from agriculture, for nitrogen it was assumed that 90% of the contribution comes from agriculture, 5% from atmospheric deposition and 2.5% each from stormwater/overflows and scattered dwellings. For phosphorus, it was assumed that 80% of the contribution comes from agriculture and 10% each from scattered dwellings and stormwater/overflows. Russia reported only agriculture, unknown and natural background. For the Gulf of Finland, the unknown input was quite high, so it was distributed by assuming the same contribution from atmospheric deposition and forestry as the sum from Sweden to Bothnian Sea and Bothnian Bay, having somewhat similar catchment size and reasonably the same catchment characteristics. Following the approximate shares for the other countries, it was further assumed that 2.5% (10% for phosphorus) of the anthropogenic losses could be attributed to scattered dwellings and stormwater/overflows. The remaining unknown losses were added to natural background.

For inland point sources, Latvia, Lithuania and Russia all reported an aggregated sum of the indirect point sources. These were distributed between industry and municipal wastewater treatment (WWTP) according to the average proportions for all the other countries (for total nitrogen 20% industry and 80% WWTP and for total phosphorus 8% industry and 92% WWTP).

Annex 1 presents the methodology and calculations to generate the activity-pressure data.

Effectiveness of measures

In place of pressure reductions calculated from data on activity–pressure contributions, effectiveness of measures, existing measures, the SOM analysis for the input of nutrients has taken advantage of other assessments to generate projected pressure reductions. For nutrients, direct sectoral/vectoral projections from external sources are combined with the activity–pressure contribution data (source apportionment) to create projected pressure reduction estimates. These direct sectoral/vectoral projections estimate pressure reductions based on the assumption that a specific set of measures are fully implemented. Two data sets have been generated in this way: projected reductions in nitrogen and phosphorus from municipal WWTPs and projected reductions in the atmospheric deposition of nitrogen. Thus, only nutrient runoff from agriculture is based on expert elicitation. Description of the methodology for these assessments is included below.

Projected reductions in nutrient runoff from agriculture

The expert survey on reductions from agricultural nutrient runoff follows the general format of the effectiveness of measures survey for the other topics in the SOM analysis, but there were also significant adjustments. The expert survey enabled respondents to provide both model and expert-based estimates of the effectiveness of measures. Model-based estimates were preferred, when available, but as these were not available for all Baltic Sea countries, expert assessments were welcomed.

The survey asked for effectiveness of measures to reduce the nutrient runoff from agriculture separately for phosphorus and nitrogen. First, the survey allowed the respondents to provide assessments of the effects of measures either based on model estimates, expert evaluation, or both. The model-based estimates could be provided as the total reduction in nutrient runoff or by measure (based on HELCOM palette of measures), in tons or percent. The expert-based estimates could be provided as a total reduction in nutrient runoff (tons or percent) or the relative effectiveness of measures, as for other topics in the SOM analysis. Secondly, nationally consolidated responses were preferred. The survey is available in Annex 8.

Pressure reductions can be positive (pressure is reduced), negative (pressure is increased) or zero (no change in pressure), depending on the combined effect of existing measures and changes in the extent of human activities. When the reduction in pressure inputs from existing measures is larger than the increase from changes in human activities, pressure inputs are reduced.

Projected reductions in nitrogen and phosphorus from municipal WWTPs

HELCOM ACTION project Work Package 4 estimated potential reductions in nitrogen and phosphorus to each of the PLC sub-areas from municipal wastewater treatment plants (MWWTPs), assuming the requirements of the HELCOM Recommendation 28E/5 and the EU Urban Wastewater Directive are met (HELCOM ACTION 2021p). These documents place limit values on the concentration of nitrogen and phosphorus in MWWTP discharge or the required nutrient reduction percentage in MWWTP discharge, but do not stipulate the specific technical measures used to reach these targets. As a result, it is not clear what technical measures would be implemented to realize these reductions.

Potential reduction calculations utilized PLC-7 data, which includes both treatment plants discharging wastewaters directly to marine wasters and inland plants. However, as treatment reduction percentages are not part of the PLC database, potential reduction was only evaluated against nutrient concentrations in MWWTP discharge. This may result in an over-estimation of potential reduction. Total phosphorus (PTOT) and total nitrogen (NTOT) loads of individual plants were divided by flows to obtain nutrient concentrations in MWWTP discharge. These concentrations were compared to the nitrogen and phosphorus limit values of the HELCOM recommendation and EU directive. Where the HELCOM and EU limit values differed, the stricter value was used. If the calculated concentration was above the limit value, the difference in mg/l was converted to tons for the estimation of the remaining reduction potential. Additionally, retention of nutrients in inland waters was taken into account to obtain the estimate of the actual reduction potential benefitting the Baltic Sea.

Data of MWWTPs for the year 2017 (PLC-7 data) was collected from the PLC database. Russia has only submitted aggregated data and the limit values were applied to these aggregated units as if they were a single MWWTP. This likely causes an over-estimation of potential reduction, when the limit values for larger plants are applied to what may be a collection of smaller plants. Similarly, Sweden has only submitted aggregated data for inland MWWTPs to the PLC-database, but for the analysis conducted by HELCOM ACTION Work Package 4, Sweden submitted data of individual plants. Population equivalent numbers (PE) were mostly missing in the database, but some countries (Denmark, Finland, Germany, Poland and Sweden) could submit this information, enabling the classification of plants according to the PE numbers. Since the correlation between the wastewater flow and PE is tight (r2 0.81, n = 1741), the flow was used to estimate the missing PE values according to this formula: PE = flow*0.00904+4265.

As there is no estimate of the retention of individual plants in the PLC-database, inland nutrient retention was estimated in other ways: A) For Danish plants 25% NTOT retention and 10% PTOT retention were used (Lars Svendsen, personal communication); B) To estimate the retention for other countries, MWWTP loads per sub-catchments were summed and the sums were compared with source apportionment figures (MWWTP loads reaching the Baltic Sea) derived from the PLC-7 data; and C) Many countries (LT, LV, PL, RU) were lacking MWWTP loads in their source apportionment figures and for those countries published retention estimates were applied (Stålnacke et al. 2015).

Projected reductions in atmospheric deposition of nitrogen

The HELCOM ENIRED II project has modelled the potential reduction of airborne input of nitrogen by 2030 due to implementation of the Gothenburg Protocol/EU-NEC Directive (Gauss et al. 2020). ENIRED II provides data on total nitrogen deposition in 2005 and 2030, and from this a percent reduction can be calculated. However, in order to better conform to the base year used in the SOM analysis (2016), estimated nitrogen deposition for 2014 was calculated using the nutrient source apportionment data developed for the SOM analysis (see section 7). This estimated value for 2014 was then used as the baseline in the SOM analysis and a percent reduction in the atmospheric deposition of nitrogen between 2014 and 2030 was calculated. This results in estimated reductions for each of the seven PLC sub-areas for 1) transboundary deposition and 2) deposition originating from the HELCOM Contracting Parties, Baltic Sea shipping, and North Sea shipping.

Topic specific model structure, assumptions and challenges

Data estimating reductions from scattered dwellings was not available for this assessment and is assumed to remain constant. This is also the case for Russian agricultural emissions. Inclusion of these data would allow for a more comprehensive assessment.

Overview of data

Table 1 shows the origin and spatial resolution for the data components in the SOM analysis for the input of nutrients. Projected reductions in nutrient inputs from agricultural measures is based on a mix of expert data and existing national assessments. Activity-pressure input contributions, projected reductions in nutrient inputs from atmospheric deposition and wastewater treatment measures, and development of human activities are based on existing literature, data and projections.

The SOM analysis estimates the reduction in the input of nutrients from existing measures, taking into consideration the effects of potential future change in activities. The spatial resolution (level of detail) differs across the data components of the SOM analysis. All areas are based on the 17 HELCOM scale 2 sub-basins and the assessment area ranges from the single Baltic Sea wide area to 17 individual sub-basins. The activity-pressure contributions for the input of nutrients are assessed across 7 sub-areas of the Baltic Sea (Figure 2). The methodology for nutrients differs significantly from the approach for the other topics in the SOM analysis to take advantage of existing data and reduction projections made by ACTION WP6 and other projects. The spatial scale of these projections can be sub-national, national, or the 7 PLC sub-areas of the Baltic Sea. Information on existing measures and their implementation status is at the sub-basin scale. The effect of the development of human activities is assessed for the entire Baltic Sea scale. Table 1 shows the origin and spatial resolution for the data components in the SOM analysis for the input of nutrients.

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

Data component	Origin of data	Spatial resolution
Activity-pressure contributions	HELCOM ACTION	7 sub-areas of the Baltic (Figure 2)
Existing measures	NA	NA
Projected reductions in nutrient inputs	EMEP (HELCOM ENIREDII), HELCOM PLC database (HELCOM ACTION), national estimates of agricultural reduction	7 sub-areas of the Baltic (Figure 2); national or sub-national agricultural estimates
Development of human activities	Literature review, existing data and projections	Whole Baltic Sea
Pressure-state links	Not assessed	Not assessed

NA = not applicable

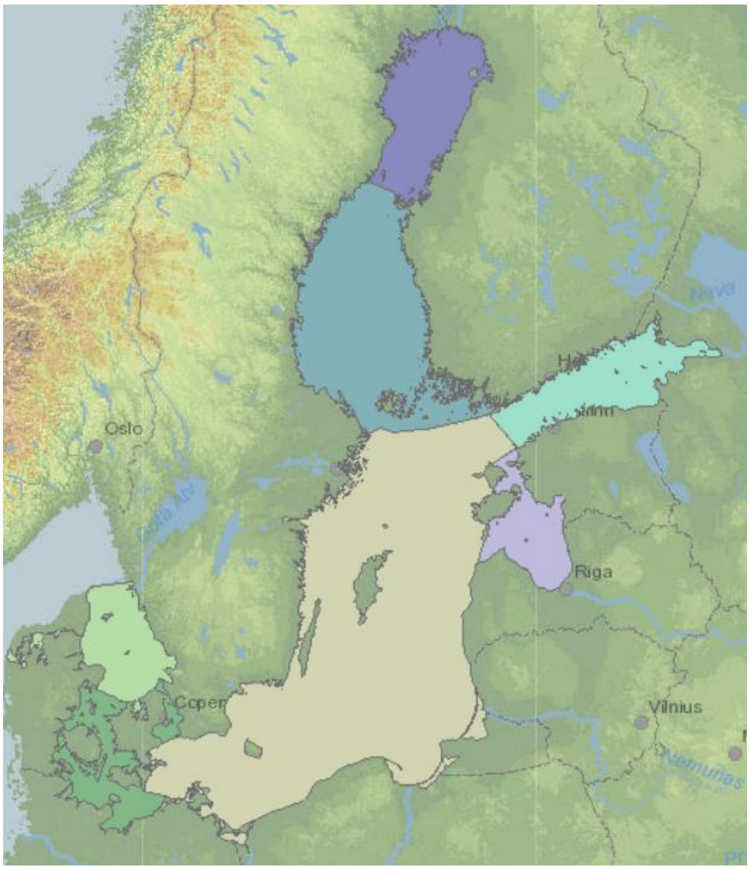

Figure 2. Spatial division of the Baltic Sea used in the SOM analysis of nutrients with 7 sub-areas: Kattegat; Danish Straits (Great Belt, The Sound, Kiel Bay, Bay of Mecklenburg); Baltic Proper (Arkona Basin, Bornholm Basin, Gdansk Basin, Eastern Gotland Basin, Western Gotland Basin, Northern Baltic Proper); Gulf of Riga; Gulf of Finland; Bothnian Sea (Åland Sea, Bothnian Sea, Archipelago Sea); and Bothnian Bay (The Quark, Bothnian Bay).

Development of human activities

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

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

Coverage of activities that contribute to the input of nutrients in the change scenarios is moderate. Agriculture and forestry (diffuse losses through rivers), marine aquaculture and waste waters have development scenarios. These cover 25-60% of the activities contributing to the input of nutrients, depending on the nutrient and the sub-area. Other activities and sources contributing to the inputs are assumed to stay constant until 2030.

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

Results and interpretation

Background

The SOM results are presented in the format of percent shares or probabilities. The main finding of the analysis is the probability to achieve GES or specific state improvements/pressure input reductions, taking into consideration the effects of existing measures and changes in the activities on pressure inputs. The contribution of activities to pressure inputs, the effect of measures on pressure inputs, and the significance of pressures to state components are presented as percent values (e.g. how many percent would the measure reduce the pressure input). Results are presented mainly in tables, which show the most likely (expected) values and standard deviations. Standard deviation is a way of showing the variation in the values. When it is high, values are spread over a wider range, and when it is low, values are closer to the most likely value. More detailed information on how each result has been calculated is presented in a separate document.

In the detailed results, the projected development of human activities is based on the most likely future development until 2030 (for details, see the methodology document), and the impacts of alternative scenarios on human activities are examined in the discussion section.

Format of presentation

The format the results are reported in different ways (not presented, qualitative/semi-quantitative, quantitative) depending on the type of result and the number of participating experts. All results for eutrophication are presented as quantitative estimates, as they are mainly based on estimates from existing data and models. For the other topics in the SOM analysis, which rely largely on data from expert surveys, in most cases 3-5 expert estimates are required to present the results at all, and some result components with 3-4 experts may be presented in a semi-quantitative or qualitative format. Results that do not meet the data standards described here are marked with 'insufficient data' in the SOM reports. These criteria are described in more detail in the other topic reports.

Coverage of pressures in the SOM analysis

In general, the SOM analysis has only been able to account for a portion of all pressures that affect the state components, and the effect of several significant pressures have not been included due to not being able to quantify the link between the pressure inputs, pressures and state components in the analysis. This means that the effect of reductions in these excluded pressures on the state components is not included in the total pressure reductions, and the projected total pressure reductions and probability to achieve GES are underestimated for some of the other topics in the SOM analysis. This underestimation does not apply to the results for the input of nutrients, as the assessments stops at the level of pressure inputs. However, as the SOM analysis has not been able to include a quantitative link between the input of nutrients and effects of eutrophication, this has an impact on the results for other topics and state components in the SOM analysis that are affected by eutrophication. Thus, the pressure total reductions and state improvements for state components affected by eutrophication are likely underestimated, as the effects of reducing the inputs of nutrients are not accounted for.

Are existing measures sufficient for achieving reduction targets?

For eutrophication, it is possible to compare the projected reductions in the input of nutrients from existing measures in the SOM analysis with the HELCOM nutrient reduction targets agreed in the HELCOM Baltic Sea Action Plan and revised in the Ministerial Declaration in 2013 (HELCOM 2013a). This comparison gives some indication on whether existing measures are sufficient in reducing nutrient inputs as required by the reduction targets.

The SOM analysis projects reductions in the input of phosphorus and nitrogen in all sub-areas of the Baltic Sea. The findings of the analysis suggest that existing measures may not be sufficient in reducing the input of nutrients as indicated by the maximum allowable inputs (MAI) in the nutrient reduction scheme. The spatial distribution of the reductions also differs from the scheme. Projected reductions in phosphorus input are smaller than needed in the Baltic Proper, Gulf of Riga and Gulf of Finland, and in nitrogen input in the Baltic Proper and Gulf of Finland. However, the SOM analysis suggests that both phosphorus and nitrogen inputs are reduced with existing measures also in those basins not requiring any further reductions based on MAI.

The HELCOM Baltic Sea Action Plan nutrient input reduction scheme defines the targets as maximum allowable inputs (MAI), which indicate the maximum nutrient inputs allowed to each sub-area of the Baltic Sea to achieve GES for eutrophication (HELCOM 2013a, 2013b). Table 2 presents needed reductions based on MAI and exceedance of MAI in 2017, as assessed in the HELCOM core indicator report on the status of nutrient inputs to the Baltic Sea (HELCOM 2019). It also shows the projected reductions in the input of nutrients from existing measures by 2030 based on the SOM analysis. Comparison between needed reductions and projected reductions from existing measures indicates some differences. The SOM analysis projects reductions in nitrogen and phosphorus inputs for all sub-areas of the Baltic Sea. These range on average between 2–14% for phosphorus and 5-19% for nitrogen. Based on nutrient reduction targets, reductions are required only in some sub-areas to achieve GES, with largest reductions allocated to the Baltic Proper and Gulf of Finland for both nitrogen and phosphorus, as well as the Gulf of Riga for phosphorus.

The results of the SOM analysis indicate that projected reductions in phosphorus inputs from existing measures would be larger than those required in the Bothnian Sea, Kattegat and Danish Straits, but smaller than required in the Baltic Proper, Gulf of Riga and Gulf of Finland. In the Bothnian Bay, the projected reductions are of similar magnitude as those needed to meet MAI. For nitrogen, it seems that reductions from existing measures would be larger than required for the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat. The Gulf of Finland and Baltic Proper are projected to have smaller nitrogen reductions than required. The projected reductions are of the same magnitude as those needed in the Gulf of Riga. However, the SOM analysis projects reductions of both phosphorus and nitrogen inputs beyond what is required based on MAI in several basins, including those not requiring further reductions (Kattegat, Danish Straits and Bothnian Sea).

The needed proportional reduction requirements are much higher for phosphorus than those needed for nitrogen: approximately half of the current phosphorus inputs into the Baltic Proper should be reduced, over one third into the Gulf of Finland and nearly one fourth to the Gulf of Riga, respectively (Table 2). However, existing measures are projected to decrease phosphorus inputs to these sub-areas by only 5−14%, thus additional measures are needed. The biggest rivers export a large proportion of nutrient loads into these sub-areas, and recently it was estimated that the proportion of the remaining total nitrogen reduction of the five biggest rivers was 56% of the remaining total nitrogen reduction of the whole Baltic Sea and 88% of the remaining total phosphorus reduction, respectively (HELCOM 2020). Therefore, it is crucial to reduce nutrient inputs of these five rivers: the Vistula, the Oder, the Nemunas (in the Baltic Proper), the Daugava (Gulf of Riga) and the Neva (Gulf of Finland) to reach the MAIs.

There is still potential to reduce nutrient inputs from point sources. Nearly 10% of the remaining reductions would be fulfilled, if all municipal waste waters were treated according to the HELCOM Recommendation 28E/5. However, reaching the MAIs in the Baltic Proper, the Gulf of Finland and the Gulf of Riga would require substantial reductions in agricultural (phosphorus) load. The Gulf of Riga also has substantial transboundary inputs which could be targeted in order to reach targeted levels. According to projections, existing measures targeted to reduce agricultural nutrient loads will not be sufficient and therefore additional measures are needed.

The comparison is a rough approximation for several reasons, most importantly: 1) the SOM analysis does not include all potential sources of nutrient inputs, notably missing any estimate of reductions in inputs from scattered dwellings due to unavailability of data, 2) reductions from agricultural measures in the SOM analysis are partially based on expert elicitation instead of model estimates, and 3) due to varying data sources, the data used to make these nutrient reduction projections come from more than one year (ranging between 2014 and 2020) which may result in underestimating already achieved reductions.

During the last decade, connectivity to wastewater treatment plants has increased and currently it varies from 71% to 93% between the countries. Poland, with the largest population in the Baltic Sea catchment, has the lowest connectivity, and therefore also the highest capacity to reduce nutrient inputs from scattered dwellings. At present, there are no country-wise estimates available of how much nutrient inputs to the Baltic Sea would be reduced in tons, if all scattered dwellings would be connected to wastewater treatment plants.

Table 2. Projected reductions (%) in the input of nutrients from existing measures by 2030 (Source: SOM analysis) and needed reductions based on comparing maximum allowable inputs (MAI) and inputs in 2017 (Source: HELCOM 2019).

Nutrient	**Phosphorus**				**Nitrogen**			
Sub-area	**Maximum allowable input (MAI)**	**Exceedance of MAI**	**Needed reduction (%)**	**Projected reduction with existing measures (%) (minimum-maximum)**	**Maximum allowable input (MAI)**	**Exceedance of MAI**	**Needed reduction (%)**	**Projected reduction with existing measures (%) (minimum-maximum)**
Kattegat	1687	–	–	10 (9–11)	74000	–	–	17 (13–24)
Danish Straits	1601	–	–	6 (5–7)	65998	–	–	19 (11–26)
Baltic Proper	7360	7111	49	14 (10–17)	325000	108102	25	16 (10–22)
Gulf of Riga	2020	610	23	5 (4–5)	88417	5954	6	7 (4–10)
Gulf of Finland	3600	2012	36	11 (11–14)	101800	12662	11	6 (3–8)
Bothnian Sea	2773	–	–	4 (2–13)	79372	–	–	18 (11–23)
Bothnian Bay	2675	47	2	2 (1–7)	57622	639	1	12 (7–15)
Total	21716	9780	31		792209	127357	14	

Colour scale: expected reduction is larger than required by the nutrient reduction scheme, expected reduction is as large as required by the nutrient reduction scheme, expected reduction is smaller than required by the nutrient reduction scheme

Data used: 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)

What are the state components most affected by eutrophication?

The SOM analysis allows for identifying which of the state components reflecting the environmental status for hazardous substances, benthic habitats, birds, fish and mammals are most affected by eutrophication. This assessment is based on results of five expert surveys provide expert views on the significance of various pressures to the state components in the SOM analysis.

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

Table 3 shows the state components most affected by the effects of eutrophication. Eutrophication has the highest effect on benthic habitats, followed by certain fish species/species groups. Achieving GES for eutrophication would likely improve the condition of benthic habitats, at least in the long run.

Table 3. Top five state components most affected by effects of eutrophication. Listing is based on Baltic-wide averages of the significance of pressures to state components presented in each respective topic report. Average number of expert responses for the state component is given in parenthesis (total response count for the state component divided by the number of geographic areas for the state component).

Pressure	**1st most affected state component**	**2nd most affected state component**	**3rd most affected state component**	**4th most affected state component**	**5th most affected state component**
Effects of eutrophication	Hard substrate vegetation dominated community (5.8)	Hard substrate epifauna dominated community (5.3)	Soft substrate infauna dominated community (5.0)	Soft substrate vegetation dominated community (3.8)	

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

Time lags

Information on time lags related to eutrophication and the input of nutrients were not specifically collected in the literature reviews or expert surveys related to eutrophication. However, such information is available from existing literature, e.g. Murray et al. (2019), which suggests time lags in the range of 50 to 100 years between the reduction in the input of nutrients and full impact on the effects of eutrophication.

HELCOM ACTION WP5 has assessed the time lags related to achieving GES for nitrogen by determining the time lag between implemented reductions in nitrogen inputs and the time these changes are measurable in the Baltic Sea (HELCOM ACTION 2021r). The main conclusion from the work is that the time lag depends on how much nitrogen loadings are reduced, but that they are likely decades, and thus it is not realistically possible to reach GES before 2050. For example, a reduction in nitrogen loadings of 30% implemented over the next five years might bring the Baltic Sea in GES status by about 2060-2070. Three causes for the long time lag are identified: the long residence time of the Baltic Sea, the large pool of nutrients that has built up over the decades and that the present nitrogen loading is higher than the natural background. More information can be found in HELCOM ACTION (2021r).

In 2011-2016, all of the open and most of the coastal Baltic Sea sub-basins were assessed to have below-good eutrophication status (HELCOM 2018). According to model simulations made using the Baltic Sea Long-Term Large Scale Eutrophication Model BALTSEM, GES for eutrophication could be met within the next 40 years in the Kattegat, Arkona Basin and Bornholm Basin, if the BSAP nutrient reduction targets are immediately reached (Murray et al. 2019). Under these conditions, GES could also be met within 60 years in the Danish Straits and Gulf of Finland. In the Baltic Proper, Gulf of Riga, Bothnian Sea and Bothnian Bay, GES is not likely to be met during the coming century.

Linking the SOM results of expectations on reaching nutrient load reductions to eutrophication status changes through the BALTSEM simulations provides the following expectations on reaching GES in eutrophication (Table 4).

Table 4. Estimation on whether it is possible to achieve GES for eutrophication if the nutrient load reductions are met (interpreted from Murray et al. 2019 based on scenario $BSAP_0$).

Sub-area	**GES in eutrophication possible by 2035**	**GES in eutrophication possible by 2050**	**GES in eutrophication possible by 2100**
Kattegat	no	no	yes
Danish Straits	no	no	yes
Arkona Basin	yes	yes	yes
Bornholm Basin	no	no	yes
Baltic Proper	no	no	no
Gulf of Riga	no	no	no
Gulf of Finland	no	no	yes
Bothnian Sea	no	no	no
Bothnian Bay	no	no	no

What are the reductions in pressure inputs from existing measures?

This section includes the effects of existing measures in reducing the input of nitrogen and phosphorus in 2016-2030 (Tables 5.1 and 5.2). They are calculated using data on the activity-pressure contributions, pressure reductions from existing measures, and projected development of activities.

The activity-pressure and pressure reductions data are assessed at the level of 7 sub-areas of the Baltic (Figure 2), thus the total pressure reductions are presented for those sub-areas. Reductions in pressure inputs can be positive, negative or zero, depending on the combined effect of existing measures and changes in the extent of human activities. When the reduction in pressure inputs from existing measures is larger than the increase from changes in human activities, pressure inputs are reduced.

Table 5.1 shows the reduction in the total input of phosphorus, as well as the reduction from measures related to municipal wastewater treatment plants (MWWTPs) and agriculture. Table 5.2 shows the reduction in the total input of nitrogen, as well as the reductions originating from MWWTPs, atmospheric deposition and agriculture. The total reduction is the sum of the reductions from all sectors, and it is used in Table 2 in the previous section for comparison with the nutrient reduction targets.

For the total reduction, the percent reductions in the input of nitrogen from existing measures are in general larger than for the input of phosphorus. The only exception is the Gulf of Finland, which has the lowest projected reduction of total nitrogen (6%). By contrast, in five out of seven sub-areas, the average total reduction of nitrogen input is projected to be over 10% and as high as 19%.

The input of nutrients related to MWWTPs is expected to stay the same in the Bothnian Sea and the Bothnian Bay for phosphorus, and in the Kattegat, Danish Straits, Baltic Proper and Gulf of Riga for nitrogen. This means that the measures to reduce the pressure inputs cannot compensate for the pressure increases caused by changes in human activities. Reductions in nitrogen input originating from atmospheric deposition are particularly important in Kattegat, Danish Straits and the Bothnian Sea. The pressure reductions from the agricultural measures range from 1% to 9% for both phosphorus and nitrogen, depending on the sub-area. The estimation of the reductions for MWWTPS does not include uncertainty, because the reported input data does not have any variation.

Projected reductions in sectoral nutrient inputs are either based on meeting the requirements of international policies or national estimates for the reductions in that sector by 2030. Reductions from WWTPs are based on all WWTPs in HELCOM countries meeting the treatment requirements prescribed in HELCOM recommendation 28E/5 and the EU Urban Wastewater Directive. Sectoral reductions from agriculture rely on nationally reported estimates based either on expert opinion or national assessment. Nitrogen reductions from atmospheric deposition cover many sectors and are based on meeting the requirements of the Gothenburg Protocol/EU-NEC Directive. In all cases it is not clear what measures will be implemented to reach these projected reductions, and in some cases such measures are speculative based on the assumption that a non-binding recommendation is fully implemented (HELCOM recommendation 28E/5).

The future development in the extent of human activities to the input of nutrients is relatively well covered, as changes in agriculture, forestry, marine aquaculture and waste waters have development scenarios. However, no change is projected for agriculture, the main contributor to the input of nutrients, and minor changes are projected for forestry and waste waters. Larger changes are projected for marine aquaculture, but its contribution to the total input of nutrients is small. Thus, the impact of changes in the development of human activities on projected reductions in nutrient inputs is limited. Further details on the activity-pressure input contributions can be found in Tables 5.1 and 5.2.

There are no estimates of the effectiveness of measure types for the input of nutrients, as the approach for the SOM analysis differs from the other topics and there are no extensive expert survey data on the effectiveness of various measure types in reducing nutrient inputs.

Table 5.1. Projected reductions (%) in the input of phosphorus from existing measures in 2016-2030. The table depicts the most likely reduction in the input of phosphorus. Minimum and maximum reductions for agricultural measures and total reduction are given in parenthesis. There is no variation in the reported input data for reductions from municipal wastewater treatment plants (MWWTPs). Total input reductions will not necessarily be the sum of reductions due to rounding and the effect of changes in the extent of activities in the most likely development scenario (i.e. marine aquaculture and forestry).

Pressure **Sub-area**	**Total phosphorus input reduction (minimum-maximum %)**	**Phosphorus input reduction originating from MWWTP measures (%)**	**Phosphorus input reduction originating from agricultural measures (minimum-maximum %)**
Kattegat	10 (9-11)	1	9 (9–10)
Danish Straits	6 (5-7)	3	3 (2–4)
Baltic Proper	14 (10-17)	7	7 (3–10)
Gulf of Riga	5 (4-5)	2	3 (2–4)
Gulf of Finland	11 (11-14)	10	1 (0–3)
Bothnian Sea	4 (2-13)	0	5 (3–13)
Bothnian Bay	2 (1-7)	0	2 (1–8)

Colour scale for the projected reductions in percent (based on the most likely value):
<0%,0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Minimum and maximum are calculated based on the survey responses for the effect of existing measures in reducing runoff from agriculture.
Data used: 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 waste water treatment

Table 5.2. Projected reductions (%) in the input of nitrogen from existing measures in 2016-2030. The table depicts the most likely reduction in the input of nitrogen. Minimum and maximum reductions for agricultural measures, reductions from atmospheric deposition and total reduction are given in parenthesis. There is no variation in the reported input data for reductions from municipal wastewater treatment plants (MWWTPs). Total input reductions will not necessarily be the sum of reductions due to rounding and the effect of changes in the extent of activities in the most likely development scenario (i.e. marine aquaculture and forestry).

Pressure Sub-area	Total nitrogen input reduction (minimum-maximum %)	Nitrogen input reduction originating from MWWTP measures (%)	Nitrogen input reduction originating from atmospheric deposition (%)	Nitrogen input reduction originating from agricultural measures (minimum-maximum %)
Kattegat	17 (13-24)	0	12 (10-15)	5 (3-9)
Danish Straits	19 (11-26)	0	12 (8-14)	7 (3-11)
Baltic Proper	16 (10-22)	0	9 (6-10)	7 (3-11)
Gulf of Riga	7 (4-10)	0	2 (1-2)	5 (4-7)
Gulf of Finland	6 (3-8)	3	1 (0-2)	1 (0-2)
Bothnian Sea	18 (11-23)	3	12 (8-16)	2 (0-4)
Bothnian Bay	12 (7-15)	4	6 (4-8)	2 (0-4)

Colour scale for the projected reductions in percent (based on the most likely value):
<0%,0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Data used: 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 waste water treatment, potential reduction of airborne input of nitrogen from ENIRED II

Which activities contribute to pressures?

Tables 6.1 and 6.2 show the contribution of activities to the input of nutrients. A data-based approach was used to estimate the activity-pressure linkages, which were produced by HELCOM ACTION Work Package 4 and based primarily on PLC-7 data. The activity-pressure contributions were assessed for 7 sub-areas of the Baltic Sea (Figure 2).

The list of activities for the input of nutrients is different than the activities used for the other SOM topics. Here, activities are divided into seven sectors to reflect the different pathways for nutrients that reach the Baltic Sea (see Tables 6.1 and 6.2).

For the input of phosphorus (Table 6.1), 11 different activities were identified to contribute to the pressure. Similar to nitrogen, agricultural runoff contributes the most to the pressure input, although this applies only to 6 of the 7 areas (22-42%). In the Gulf of Riga, transboundary loads from non-Contracting Parties via rivers contribute the most to the pressure (43%). Other activities that have a major contribution to phosphorus input are stormwater/overflows (18%) in the Danish Straits, WWTPs in the Baltic Proper (16%), in the Gulf of Finland (19%) and Danish Straits (21%), and atmospheric deposition on the Bothnian Sea (16%). Most other activities have less than 10% contribution to the input of phosphorus.

For the input of nitrogen (Table 6.2), 15 different activities were identified to contribute to the pressure inputs. Here, agriculture from diffuse losses through rivers (i.e. runoff) contributes the most to the pressure in all 7 areas of the Baltic Sea (16-49%). Most other activities contribute 10% or less, with the exception of WWTPs, atmospheric deposition on the Baltic Sea (from agricultural sources and fossil fuel combustion, i.e. energy production and transportation), and river borne transboundary loads from non-Contracting Parties, which exhibit in some areas higher percentages (11-28%).

Tables 6.1 and 6.2 also include natural background leaching of phosphorus and nitrogen, since it is also included in the MAI. Noteworthy is that water protection measures aimed at reducing nutrient inputs are targeted only to anthropogenic loads. Thus, for example in the Gulf of Finland and the Bothnian Bay, less than half of phosphorus inputs and 41−54% of nitrogen inputs are outside mitigation measures.

According to the results, point sources comprised 4−24% of anthropogenic phosphorus loads and 1−15% of the respective nitrogen loads. Their proportion is substantial (>15%) in the Gulf of Finland (both nutrients), the Danish Straits (phosphorus) and the Baltic Proper (phosphorus). Diffuse sources, agriculture in particular, dominate anthropogenic loads: nutrient inputs from agriculture form 36−51% of the anthropogenic phosphorus loads and 23−54% of the anthropogenic nitrogen loads, respectively.

Part of the nutrient inputs into the Baltic Sea are transboundary, i.e. they originate in a country which is not a HELCOM Contracting Party. Transboundary inputs are especially important in the Gulf Riga, where 43% of phosphorus inputs and 28% of nitrogen inputs originate in Belarus. In addition, 12-16% of nutrient inputs into the Baltic Proper originate in Czech and Ukraine. Therefore, co-operation with regional river basin authorities is vital in order to reduce inputs from these countries.

Table 6.1. Activity-pressure contributions (%) for the input of phosphorus in 2017 (2014 in Denmark and Sweden). The activity-pressure contributions show the percentage share the activity contributes to the pressure (input of nutrients). The table depicts the most likely/expected contribution. The activities are based on seven sectors to reflect the different pathways for nutrients that reach the Baltic Sea and differ from the activity list for other topics. Individual sectors do not necessarily indicate importance but are rather a combination of the available data (Annex 1) and the SOM activity list.

Sector	Diffuse losses through rivers					Background	Municipal and industrial point sources from inland and coastal areas		Inland aquaculture through rivers	Aquaculture emitting directly to Baltic Sea	Atmospheric deposition on Baltic Sea	Transboundary loads from non-CPs via rivers
Input of phosphorus	Agriculture	Forestry	Storm water/overflows	Atmospheric deposition	Scattered dwellings	Background	WWTP	Industry	Freshwater aquaculture	Marine aquaculture	Atmospheric	Transboundary
Kattegat	28	0	6	1	5	40	8	2	1	0	7	0
Danish Straits	31	0	18	1	6	14	21	1	0	2	6	0
Baltic Proper	42	1	3	1	2	10	16	1	1	0	7	16
Gulf of Riga	34	0	4	0	3	9	4	0	0	0	3	43
Gulf of Finland	24	1	3	3	4	41	19	2	0	0	3	0
Bothnian Sea	37	1	1	2	6	26	2	6	1	2	16	0
Bothnian Bay	22	4	1	4	4	54	1	3	0	0	7	0

Colour scale for the activity-pressure contribution in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Data used: produced by ACTION WP4 based on source apportionment data collected within the PLC-6 and PLC-7 projects

Table 6.2. Activity-pressure contributions (%) for the input of nitrogen in 2017 (2014 in Denmark and Sweden). The activity-pressure contributions show the percentage share the activity contributes to the pressure (input of nutrients). The table depicts the most likely/expected contribution. The activities are based on seven sectors to reflect the different pathways for nutrients that reach the Baltic Sea and differ from the activity list for other topics. Individual sectors do not necessarily indicate importance but are rather a combination of the available data (Annex 1) and the SOM activity list.

Sector	Diffuse losses through rivers					Background	Municipal and industrial point sources from inland and coastal areas		Inland aquaculture through rivers	Aquaculture emitting directly to BS Sea	Atmospheric deposition on Baltic Sea					Transboundary loads from non-CPs via rivers
Input of nitrogen	Agriculture	Forestry	Storm water/overflows	Atmospheric deposition	Scattered dwellings	Background	WWTP	Industry	Freshwater aquaculture	Marine aquaculture	Agriculture	Combustion	Transportation	Airborne transboundary	Other	Riverborne transboundary
Kattegat	34	0	1	6	1	22	5	1	0	0	12	2	7	9	1	0
Danish Straits	40	0	2	1	1	8	8	0	0	1	19	3	7	10	1	0
Baltic Proper	41	0	1	1	1	9	6	1	0	0	9	3	7	7	1	12
Gulf of Riga	49	0	1	3	1	9	1	0	0	0	2	1	2	2	0	28
Gulf of Finland	16	1	1	5	1	51	13	2	0	0	2	1	3	2	0	0
Bothnian Sea	16	2	0	4	1	30	8	2	0	1	9	5	11	9	2	0
Bothnian Bay	16	2	0	5	1	51	6	4	0	0	4	2	4	3	1	0

Colour scale for the activity-pressure contribution in percent (based on the expected value): 0-10%, 10-20%, 20-40%, 40-60%, 60-100%
Data used: produced by ACTION WP4 based on source apportionment data collected within the PLC-6 and PLC-7 projects

Background of respondents

Most of the data for nutrients come from existing data sources rather than expert surveys. An expert survey was conducted to assess the effectiveness of agricultural measures to reduce nutrient runoff, and some of these estimates were based on model results instead of expert judgement. Altogether 9 survey responses from 11 individual experts were received for the effectiveness of measures for nutrient runoff survey. One response was a group response with three participating experts. Approximately half of the responses were based on model estimates and half on expert opinion.

The number of experts contributing to the nutrient survey by Contracting Parties is shown in Table 7. Additionally, model estimates were received from Lithuania and Sweden by correspondence, which are marked as asterisks in the table below.

Table 7. Number of experts contributing to the nutrient runoff from agriculture survey

Survey	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
Effectiveness of measures	2	2	2	1	*	1	3	-	*	11

* indicates data submitted by correspondence.

Background information for those experts who responded to the survey shows that the fields of the experts included agriculture, water/soil science, monitoring and Water Framework Directive. All of the experts had at least 5 years of experience in the field (Table 8). Experts represented research institutions, government institutes, state agencies or ministries. Background information for the experts who submitted model-based responses from Lithuania and Sweden is not available and is thus not included in the table below.

Table 8. Years of experience in the field for the nutrient survey

	Effectiveness of measures survey	
Years	**Number of experts**	**Share of experts**
0-2 years	0	0 %
3-5 years	0	0 %
5-10 years	3	27 %
10-20 years	3	27 %
over 20 years	5	45 %

Discussion

In the SOM analysis, it is assumed that all agreed and planned measures are implemented by 2030. Thus, reaching the projected reductions in nutrient inputs requires full implementation of measures, such as implementing the nutrient removal requirements of the HELCOM Recommendation 28E/5 on municipal wastewater treatment. Total nitrogen load into the Baltic Sea would decrease by 10500 tonnes and the respective total phosphorus load by 1210 tonnes, if all municipal wastewater treatment plants would follow HELCOM recommendation 28E/5 (HELCOM ACTION 2021p). This would correspond to nearly 10% of the BSAP reduction targets. The current technology would allow for even higher nutrient input reduction, since there are municipal wastewater treatment plants in the Baltic Sea region that already reach even higher nutrient removal rates than the ones in the recommendation. The current HELCOM recommendation requires that 90% of phosphorus and 70-80% of nitrogen is removed from municipal waste waters in large (> 100000 Population equivalents) treatment plants. Since more efficient nutrient removal is technologically easy to implement, stricter removal requirements should be considered.

Impact of alternative scenarios for development of human activities

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

As activities contribute to pressure inputs, their assumed change over time affects the pressure input reductions and probability to achieve GES. The impact depends on to what extent the activities contributing to the specific pressure input are covered in the change scenarios. For nutrients, development scenarios have been made for agriculture and forestry (diffuse losses through rivers), marine aquaculture and waste waters. Thus, the change scenarios cover the activities that contribute to the input of nutrients moderately well.

Overall, the impact of alternative development scenarios is moderate in the case of input of nutrients, and changes in the extent of agriculture are driving the results. The results for the most likely and no change are very close to each other, mainly due to no changes projected for agriculture in either of these scenarios as the most likely development corresponds to no change for agriculture. Assuming a low development scenario for the human activities leads to 3-10% higher reductions in the input of nutrients compared to the most likely development, depending on the sub-area. In the high development scenario, reductions in nutrient inputs are 4-10% lower depending on the sub-area and are negative for some sub-areas, i.e. nutrient input are projected to increase. These results stem mainly from the 10% decrease in agriculture in the low scenario and 10% increase in the high scenario.

Evaluation of quality and confidence

The SOM analysis for the input of nutrients was able to evaluate the sufficiency of existing measures to achieve the nutrient reduction targets. When interpreting the results, the assumptions and generalizations that were made when collecting and using the input data need to be taken into account.

The overall certainty of the assessment could be characterized as high. For the input of nutrients, most of the input data are based on existing models and data, however the reductions in agricultural nutrient runoffs come partly from expert elicitation, and no reductions in inputs from scattered dwellings have been taken into account due to lack of data. There is a continuous need to develop more reliable models to estimate diffuse loads, especially those originating from agriculture. In particular the estimates for the reductions in agricultural inputs exhibit uncertainty, and should be interpreted cautiously.

In addition, there are large uncertainties in load estimates of scattered dwellings and storm water overflows, which are assumed to stay constant in the SOM analysis due to lack of data. Based on the connectivity (e.g. 71% in Poland and 75% in Latvia), scattered dwellings may be an important source of nutrients into the Baltic Sea and detailed studies of the amount of their inputs are urgently needed. Recent Danish estimates of storm waters indicate that they are a more important source of phosphorus in urban areas than previously estimated. In most of the countries reliable estimates of this source are lacking.

One major shortcoming of the analysis was that it could not include the link between the input of nutrients and the effects of eutrophication, which means that there is no assessment on how the changes in the input of nutrients impacts eutrophication. This also affects the results for the other topics in the SOM analysis, such as benthic habitats, because consequences of reductions in nutrient inputs and eutrophication on the probability to achieve state improvements for these topics have not been estimated within the analysis.

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

Lessons learned

The SOM analysis on nutrients benefited from very high data availability from existing literature, models and projections to the extent that almost no expert-based data was used. This is clearly the preferred situation. While other topics in the SOM analysis utilized available literature data, the quantity available to the nutrients analysis required a tailored approach to allow these data to be used. As more data becomes available for a topic, it seems likely that the analysis structure will require more adaptation. There is not a clear transition state between a literature data-based analysis, such as nutrients, and an expert data-based analysis that was conducted for the other SOM topics. This will require a flexible approach as more literature data is developed for inclusion in a future analysis.

The data required to properly link nutrient input to eutrophication exists in e.g. Baltic Sea Long-Term Large Scale Eutrophication Model (BALTSEM) but project resources did not allow for its inclusion. This should be priority number one in any future work on the SOM analysis

Use of results, implications and future perspectives

The aim of the SOM analysis was to comprehensively combine all available information concerning current nutrient inputs into the Baltic Sea, existing nutrient reduction measures, and based on those, project reductions in nutrient inputs by 2030. Even if there were gaps in the coverage of data and countries are developing models for more reliable estimation of diffuse loads, the data presented here demonstrate that the existing measures to reduce nutrient loads, especially those of phosphorus, are not sufficient in achieving targets. This is vital information for decision makers, when planning and targeting new mitigation measures.

Improvements in monitoring and modelling of nutrient inputs originating from diffuse sources are urgently needed in order to get more reliable estimates of loads. An additional challenge is climate change, which will affect nutrient loads in multiple ways and complicates projection of future nutrient inputs.

When using the SOM results on the sufficiency of measures to reach reduction targets, one should bear in mind the uncertainties at all levels of the analysis, as well as the interpretations. These results should thus not be applied as direct guidance or simple rules, but rather to support decision-making, together with other information. In addition, following the precautionary principle, the results should not be used as evidence for reducing the ambition level of actions.

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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

HELCOM ACTION 2021b. Methodology for the sufficiency of measures analysis. Available at: http://www.helcom.fi/SOM/MethodologyReport

HELCOM ACTION 2021c. A practical guide to interpreting the SOM results. Available at: http://www.helcom.fi/SOM/PracticalGuide

HELCOM ACTION 2021d. Sufficiency of existing measures for benthic habitats in the Baltic Sea. Available at: http://www.helcom.fi/SOM/BenthicHabitatsReport

HELCOM ACTION 2021e. Sufficiency of existing measures for coastal fish in the Baltic Sea. Available at: http://www.helcom.fi/SOM/CoastalFishReport

HELCOM ACTION 2021f. Sufficiency of existing measures for commercial fish in the Baltic Sea. Available at: http://www.helcom.fi/SOM/CommercialFishReport

HELCOM ACTION 2021g. Sufficiency of existing measures for hazardous substances in the Baltic Sea. Available at: http://www.helcom.fi/SOM/HazardousSubstancesReport

HELCOM ACTION 2021h. Sufficiency of existing measures for input of nutrients in the Baltic Sea. Available at: http://www.helcom.fi/SOM/NutrientsReport

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

Annexes

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

Annex 1 Activity-pressure data (source apportionment)

Annex 1a is a PDF containing the methodology to generate the activity-pressure data. Annex 1b is an Excel containing the calculations used to generate the activity-pressure data.

Annex 2 Modified activity list (if modified)

Excel containing the modified activity list for input of nutrients.

Annex 3 Measure types list

The SOM analysis for *Nutrients* does not rely on measure types, so no measure type list is available.

Annex 4 Linking existing measures to measure types

The SOM analysis for *Nutrients* does not rely on measure types, so no measure type list is available.

Annex 5 Literature review search terms

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

Annex 6 Literature review summary

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

Annex 7 Topic structure

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

Annex 8 Effectiveness of measures survey

PDF of the Effectiveness of measures survey for *Nutrients*.

Annex 9 Pressure-state survey

The SOM analysis for *Nutrients* does not include a state assessment, so no pressure-state survey is available.