Baltic Marine Environment Protection Commission

Eutrophication

Thematic assessment 2016–2021

THIRD HELCOM HOLISTIC ASSESSMENT OF THE BALTIC SEA 2016–2021

HOLAS 3

Eutrophication

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What is HELCOM?

Preface

By their nature, many environmental problems transcend political, legal and other anthropogenic boundaries, and thus cannot be adequately solved by individual countries alone. Regional Seas Conventions (RSCs) such as the Convention on the Protection of the Marine Environment of the Baltic Sea Area establish legal frameworks for necessary transboundary cooperation.

The Helsinki Commission (HELCOM) is an intergovernmental body composed of the Baltic Sea coastal states and the EU, and functions as the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. HELCOM functions as a regional platform for cooperation with a broad spatial and sectoral reach, working with biodiversity and protection, shipping, fisheries management, maritime spatial planning (MSP), pressures from land and sea-based activities and regional governance. Furthermore, HELCOM has a wide vertical and horizontal scope, with established structures for transboundary cooperation within and across levels of organization, ranging across technical experts, authorities, managers and national ministries. HELCOM is also an established provider of infrastructure to support both regional and national work, including functioning as the natural regional data hub and tool developer as well as providing concrete support for regional assessments, ensuring that regional coherence and an ecologically valid perspective is maintained.

Benefits of cooperation at the regional level:

- Benefitting from the expertise of others;
- Sharing of knowledge, information and resources;
- Improved effectiveness of measures due to regional coherence and mutually enforcing or synergistic actions;
- Action is taken at the ecologically relevant scale, i.e. the scale at which the environment functions.

HELCOM is...

Environmental policy maker

HELCOM develops common environmental objectives and actions

Environmental focal point

To help decision making in other international fora, HELCOM provides information about

- the state of and trends in the marine environment
- the efficiency of measures to protect it
- common initiatives and joint positions

Body for developing recommendations

HELCOM's own recommendations and those supplementary to measures imposed by other international organisations

Supervisory body

HELCOMS ensures that its environmental standards are fully implemented by all parties throughout the Baltic Sea and its catchment area

Coordinating body

HELCOM ascertains multilateral response in case of major maritime incidents

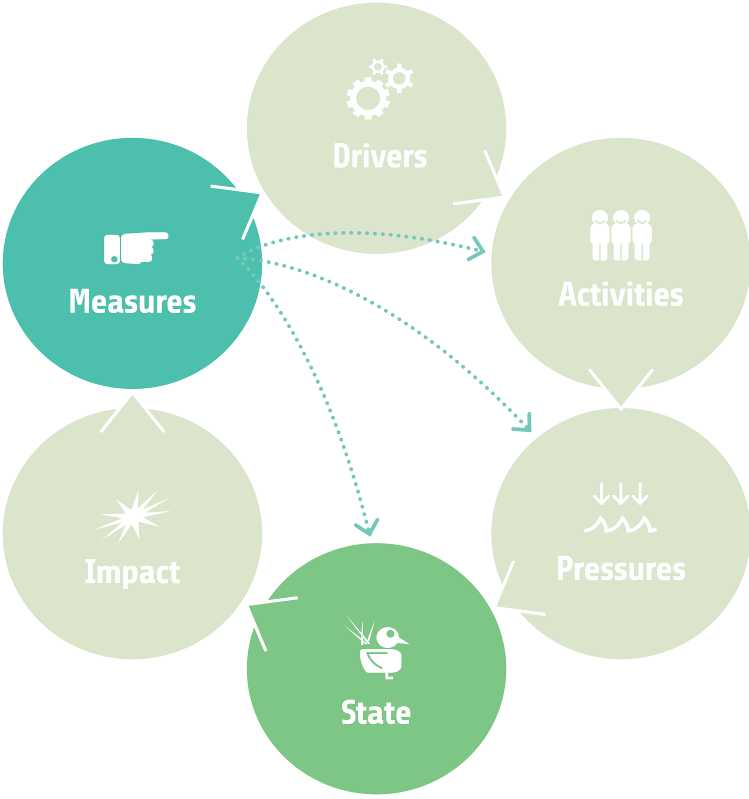


Figure P1. Conceptual overview of the management framework HELCOM works within.

Our activities at sea and on land cause pressures on the marine environment which in turn, to varying degrees, negatively impacts the ecosystem on which we all depend for our survival. These impacts cumulate and cascade through the ecosystem and eventually return to impact our wellbeing and that of society as a whole.

To limit the negative impact of our activities to within what the ecosystem can tolerate, we must understand what effects our actions have and then use that information to manage the activities which are causing negative impact. This is done through establishing well-founded and ecologically relevant targets and objectives to work towards and then taking concrete measures to ensure we reach them. Figure P1 shows the conceptual management framework HELCOM works within, and within which the holistic assessment is made. This is a regional version of the more common Driver-Activites-Pressures-Impacts-Response (DAPSIR) framework, which has been modified to fit the work under HELCOM.

Measures to improve the Baltic Sea environment are undertaken by many actors and at many levels, jointly at the global level, regionally at Baltic Sea level through HELCOM, by countries at national, county and local levels, and by initiatives in the private and public sector. The measures also differ in type, including technical improvements to minimise impact, economic and legislative measures, and measures directed towards raising awareness and incentives for changes in behaviour. In the Baltic Sea, where the transboundary aspects of environmental problems are highly evident, HELCOM plays a central role in coordinating the management objectives and their implementation in line with the Helsinki Convention.

In order to allow the tracking, and to get a comprehensive and accurate overview of progress towards set objectives and targets, as well as to see if our measures are working and sufficient, assessments need to be conducted. In order to better understand the ecosystem and our relationship with it, and to ultimately improve the environmental status of the sea, we need to map activities which affect the marine environment, analyse what effects these activities have and how strong these effects are, and assess what this means for the ecosystem.

When using assessment to track progress of measures and management, and identify possible gaps or barriers, this needs to be done in two ways. On the one hand, we need to assess the level of implementation of the agreed measures, i.e. has the agreed action actually been taken and to what degree. This tells us about possible implementation gaps and can help to identify unforeseen barriers or challenges that need to be addressed. In HELCOM this is achieved through regular reporting and the use of the HELCOM Explorer tool. On the other hand, we need to understand and track the actual effects that the implemented measures have on the marine environment. This helps us understand if the measures which have been put in place are sufficient to limit the negative impact of our activities. Where the measures turn out to not be sufficient, the knowledge we gain from the assessments enables us to identify new or improved measures, which can be more targeted, resource efficient and/or adaptive.

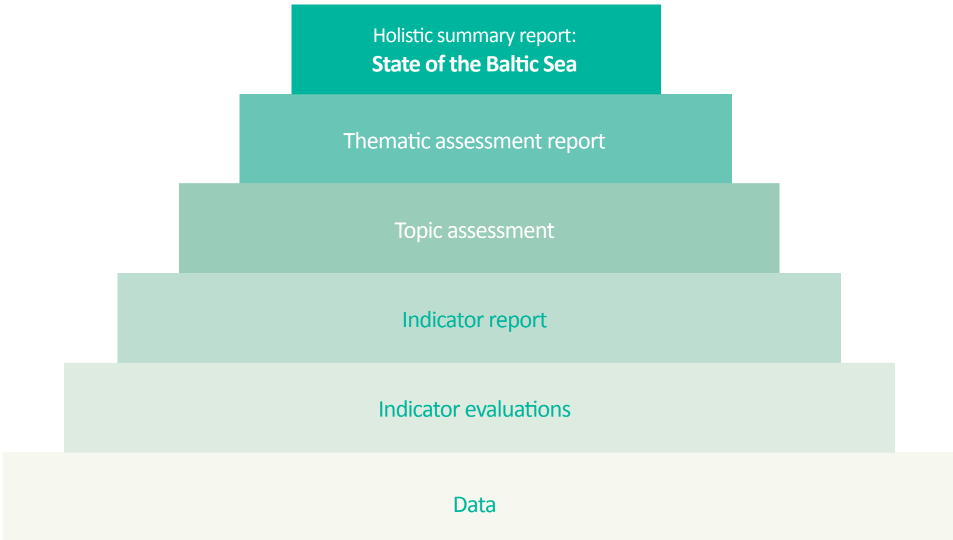


Figure P2. The structure and process of the HELCOM holistic assessment. Within the assessment structure, highly detailed results are progressively aggregated, allowing anyone to explore the results at whatever scale is most relevant to them and culminating in the overall summary report on the State of the Baltic Sea.

Assessments also help us understand what pressures and measures need to be addressed at what level. Our activities cause various types of pressures, the impact of which can vary spatially and temporally. However, because of how dynamic the marine environment is, the majority of pressures in the marine environment have transboundary impacts. For measures and management to be effective it therefore has to be implemented at an appropriate level and this often means that implementation need to be regional, i.e. the scale at which they need to be addressed in order to be effective goes beyond the national borders of one specific country.

HOLAS

The Holistic Assessment of the Status of the Baltic Sea (HOLAS) is a reoccurring, transboundary, cross-sectoral assessment which looks at the effect of our activities and measures on the status of the environment. The assessment is a product of HELCOM. The HOLAS assessment covers, or approaches, the main themes to be considered when taking an ecosystem approach to management and provides regular updates on the environmental situation in the Baltic Sea. Each report captures a ‘moment’ in the dynamic life history of the Baltic Sea. The report highlights a broad range of aspects under the overarching themes of the state of the ecosystem, environmental pressures and human well-being and contributes to a vast sharing and development of knowledge both within and across topics. The focus of the assessment is to show results of relevance at the regional scale and large-scale patterns across and between geographic areas in the Baltic Sea. Each assessment provides a clearer picture of where we are, how things are connected, and what needs to be done.

The holistic assessment also specifically enables tracking progress towards the implementation of the 2021 Baltic Sea Action Plan (HELCOM 2021) goals and objectives and functions as a regional contribution to the reporting under the Marine Strategy Framework Directive (MSFD)(EU 2008). The results of the assessment underpin HELCOM policy and the information from the assessment is incorporated in the ecosystem-based management of the Baltic Sea, as well as guiding measures nationally, regionally and globally.

The HELCOM holistic assessment is a multi-layered product (Figure P2). Within the assessment structure, highly detailed results are progressively aggregated, allowing anyone to explore the results at whatever scale is most relevant to them and culminating in the overall summary report on the State of the Baltic Sea.

Data

The collection, reporting and collation of national monitoring data at the Baltic Sea level forms the basis of the assessment. The data is spatially presented using a defined assessment unit system dividing the Baltic Sea into assessment units representing different levels of detail, in a regionally agreed nested system. The data then feed into regionally agreed evaluation and assessment methods. This allows us to explore trends over time, spatial aspects, as well as results, in order to indicate potential future developments and geographic areas of key importance for the assessed themes.

Indicators

HELCOM core indicators have been developed to assess the status of selected elements of biodiversity and human-induced pressures on the Baltic Sea and thus support measuring the progress towards regionally agreed targets and objectives. The core indicators are selected according to a set of principles including ecological and policy relevance, measurability with monitoring data and linkage to anthropogenic pressures (HELCOM 2020a). The observed status of HELCOM indicators is measured in relation to a regionally agreed threshold value specific to each indicator, and in many cases at the level of individual areas in the Baltic Sea. The majority of the indicators are evaluated using data from regionally coordinated monitoring under the auspice of HELCOM and reported by the Contracting Parties to the Convention. The status of an indicator is expressed as failing or achieving the threshold value. Hence, the results indicate whether status is good or not according to each of the core indicators. HELCOM core indicators make up the most detailed level of results, presented in the dedicated indicator reports (https://indicators.helcom.fi).

Thematic assessments

A basic criterion for HELCOM core indicators is that they are quantitative and that their underlying monitoring data and evaluation approaches are comparable across the Baltic Sea. This is to ensure that they are suited for integrated assessment. Integrated assessments are assessments where the quantitative information from indicator evaluations or other data, as well as qualitative information, is combined by topic, to produce a broader, more holistic overview of the situation for that specific topic and, subsequently, for the theme under which that topic is included. The integrated assessments are made using the BEAT (biodiversity), HEAT (eutrophication) and CHASE (hazardous substances) assessment tools, as well as the Spatial Pressures and Impacts Assessment tool, developed for this purpose by HELCOM. In addition to presenting whether status is good or not, the integrated assessment results also indicate the distance to good status. Distance to good status is shown by the use of five assessment result categories; out of which two represent different levels of good status and three different levels of not good status.

Quantitative integrated results can then be further combined with qualitative assessment results (where quantifiable information is not available) and contextual information to form five thematic assessments, each with their own report (biodiversity, eutrophication, hazardous substances, marine litter, underwater noise and non-indigenous species, spatial distribution of pressures and impacts as well as social and economic analyses). This report represents a thematic assessment and covers the theme eutrophication.

The overall aim of a thematic assessment is to present what the results of the various assessments related to the theme of eutrophication are, how they have been produced as well as their rationale, all within the relevant policy and scientific frameworks. Confidence in the assessments is presented together with the results to ensure transparency and facilitate their use. The thematic assessment reports are an integral part of the overall Status of the Baltic Sea assessment but also function as stand-alone reports. The reports are more technical in nature than the summary report, as they are intended to give details to the assessments, explaining underlying data and indicators to the extent that is needed to ensure that the HOLAS 3 assessment is transparent and repeatable.

Summary report

The main aim, and the added value, of the Summary Report lies in the possibility to link the information from the topical and thematic assessments together and thus highlight the holistic aspects of the assessment for each topic. With this in mind the Summary Report focuses on presenting the results and looking more in depth at why we are seeing these results, i.e., presenting the results of the thematic assessments by topic but linking and combining these topical results with the information and input from the other assessments/sources to provide context and analysis.

Summary

Eutrophication is still among the most influential and long-lasting environmental pressures in the Baltic Sea. Excessive inputs of nitrogen and phosphorus, which are the main triggers of eutrophication, have occurred since around the 1950s, leading to enhanced primary productivity and to indirect effects on other parts of the ecosystem. A key goal of the Baltic Sea Action Plan is to reach a Baltic Sea unaffected by eutrophication (HELCOM 2021). To further this goal, the eutrophication status in the Baltic Sea during the period of 2016-2021 was evaluated. The findings are reported in this eutrophication-focused thematic assessment and also in the ensuing "State of the Baltic Sea" summary report, which offers a holistic assessment of the ecosystem health of the Baltic Sea across all topics of relevance.

Several eutrophication assessments have been carried out within HELCOM since the agreement of the Baltic Sea Action Plan (HELCOM 2009, 2010a, 2014, 2018), and the current assessment represents the inclusion of eutrophication status in the holistic assessment of the Baltic Sea (HOLAS) for the third time. This HELCOM eutrophication assessment was conducted using an improved assessment methodology, extending the spatial coverage of existing indicators, and including new indicators and threshold values for evaluating status. This approach progressively enables the evaluation of progress towards good environmental status. This thematic assessment report also describes the method for the integrated eutrophication assessment using the HELCOM Eutrophication Assessment (HEAT) tool, which has been further improved since HOLAS II. The improvements include an enhanced methodology for confidence assessment, altered grouping of parameters, and a new method to establish class boundaries based on calculating Environmental Quality Ratios (EQR).

Summary of results

The results for the assessment period 2016-2021 demonstrate that eutrophication is still a major problem in the Baltic Sea. At least 93.8 % of the region were assessed to be below good environmental status for eutrophication, including all of the open sea areas and 82.8% of the coastal waters. Nutrient inputs to the Baltic Sea have further decreased, but this has resulted in improvements in eutrophication indicator status and the overall assessment status in only a few areas, while signs of deterioration are also apparent in other areas. Deterioration is mainly driven by nutrient leakage from the sediment so that these legacy nutrients now influence the overall status.

Indicators used in the assessment

Seven eutrophication core indicators were used as the basis of the assessment, covering nutrient levels and direct and indirect effects of eutrophication (Table 1). These were complemented with two pre-core indicators, a biodiversity core indicator, and national indicators for coastal areas in to obtain a more comprehensive assessment for all areas and all relevant aspects. Information on the long-term development over time, as far as data allows, is presented for all open-sea indicator components.

Table 1. Overview of indicators used in the integrated eutrophication assessment in the open sea areas. More detailed information summarising the key findings of these indicators is provided further down in this report. Coastal indicators are listed in Annex 2 Table A2.1.

Criteria group	Indicator	Description	Indicator report
Nutrient levels	Dissolved inorganic nitrogen	Eutrophication core indicator	[link]
	Dissolved inorganic phosphorus	Eutrophication core indicator	[link]
	Total nitrogen	Eutrophication core indicator	[link]
	Total phosphorus	Eutrophication core indicator	[link]
Direct effects	Chlorophyll-a concentration	Eutrophication core indicator reflecting phyto-plankton biomass in the water column	[link]
	Cyanobacterial bloom index	Pre-core indicator reflecting the amount of cyanobacteria (biomass as well as extent and intensity of blooms).	[link]
Indirect effects	Water transparency	Eutrophication core indicator reflecting water transparency as indicated by Secchi depth	[link]
	Oxygen debt	Eutrophication core indicator reflecting the volume specific oxygen concentration below the halocline in relation to saturated concentration, i.e., the debt assumedly caused by eutrophica-tion-related processes	[link]
	Shallow water oxygen	Pre-core indicator illustrating the near-bottom oxygen conditions in shallow water areas. Depending on the area, oxygen conditions were estimated either based on the areal extent of hypoxic (low oxygen) zones, or the minimum acceptable oxygen concentration in near-bottom waters for a given area.	[link]
	State of the soft-bottom macrofauna community	Biodiversity core indicator. Applied above the permanent halocline in the open sea, in areas where it responds only or mainly to eutrophica-tion related pressures, especially when an oxygen indicator is lacking.	[link]

1. Introduction

1.1. Eutrophication in the Baltic Sea

The excess amount of nutrients, reaching the marine environment via rivers and the atmosphere, is the major driving force behind eutrophication. Higher nutrient levels promote the growth of microscopic algae – phytoplankton (expressed as chlorophyll-*a* concentrations) and the accumulation of organic matter in the ecosystem. Increased amounts of organic material reduce water clarity and enhance oxygen consumption in the water column and at the seafloor, through respiration and degradation processes. As a result, oxygen depletion can cause the development or further spread of hypoxic (low oxygen levels) and/or anoxic (absence of oxygen) areas, which can result in suffocation of the benthic fauna. Low oxygen conditions near the sea bottom enhance the release of phosphates from the sediments, which become an additional source of nutrients in the environment. The increase in phosphate concentrations promotes cyanobacterial growth, even when dissolved inorganic nitrogen concentrations are low in the marine environment, because cyanobacteria can obtain nitrogen in a gaseous form (N_2) originating, e.g. from the atmosphere. All these changes have an influence on nutrient cycles, species composition, and subsequently influence food web interactions. For instance, opportunistic species, which benefit from the eutrophic conditions, are favoured directly or indirectly via effects on habitat quality and feeding conditions (Cloern 2001).

The deteriorating development of eutrophication was first recognized as a large-scale pressure on the Baltic Sea in the early 1980s, and in part attributed to human induced nutrient inputs (HELCOM 1987, 2009). Excessive inputs of nitrogen and phosphorus have increased between the 1950s and the late 1980s in the Baltic Sea (Gustafsson et al. 2012), increasing the severity of eutrophication influences on the ecosystem (Larsson et al. 1985, Bonsdorff et al. 1997, Andersen et al. 2017). Although there are several ways for nutrients to reach the Baltic Sea, the highest inputs come from rivers for both nitrogen and phosphorus. Atmospheric inputs of nitrogen account for roughly one third of the total input and stem from combustion processes related to shipping, road transportation, energy production, and agriculture. Atmospheric inputs of phosphorus are minor and constitute a background source that is estimated as an annual fixed rate of 5 kg per km^2. To tackle the human induced effects on the marine environment in regards of eutrophication, actions to reduce nutrient loading by 50% were agreed by the 1988 HELCOM Ministerial Declaration (HELCOM 1988) and reaching a Baltic Sea unaffected by eutrophication was identified as one of the goals of the Baltic Sea Action Plan (BSAP) in 2007 (HELCOM 2007). With the update of the BSAP (HELCOM 2021), the progress of countries in reaching their share of the country-wise allocation of nutrient reduction targets is assessed separately in a follow-up system based on nutrient input ceilings (NIC) for countries per Baltic Sea sub basin.

According to the latest nutrient input assessment (Figure 1), nitrogen and phosphorus loads have decreased in almost all of the subbasins, when comparing the reference period (1997-2003) to 2020 (Inputs of nutrients (nitrogen and phosphorus) to the sub-basins 1995-2020, https://indicators.helcom.fi/). Although some basins have reached the target regarding nutrient inputs, the Baltic Sea as a whole is yet to achieve this at the full regional scale. The total input of nitrogen to the Baltic Sea was 858,905 t in 2020 (12% less compared to the reference period), and the total input of phosphorus 26,389 t (28% less). Most of the decrease in total phosphorus inputs is due to the reduced inputs to the Gulf of Finland, Gulf of Riga and Baltic Proper. The largest relative decreases in the inputs of nitrogen and phosphorus over the past decades has been through direct sources, which currently only account for 3% and 4% of the total loads, respectively (Inputs of nutrients (nitrogen and phosphorus) to the sub-basins 1995-2020, https://indicators.helcom.fi/). Natural sources constitute about one fifth of the diffuse inputs of nitrogen and phosphorus to the Baltic Sea.

Since the 1980s, nutrient inputs to the Baltic Sea have decreased, and in some sub-basins strong reductions have taken place. For example, waterborne nitrogen inputs to the Baltic Sea are currently at the level that they were in the 1960s, and the phosphorus inputs at the level of 1950s (Figure 2).

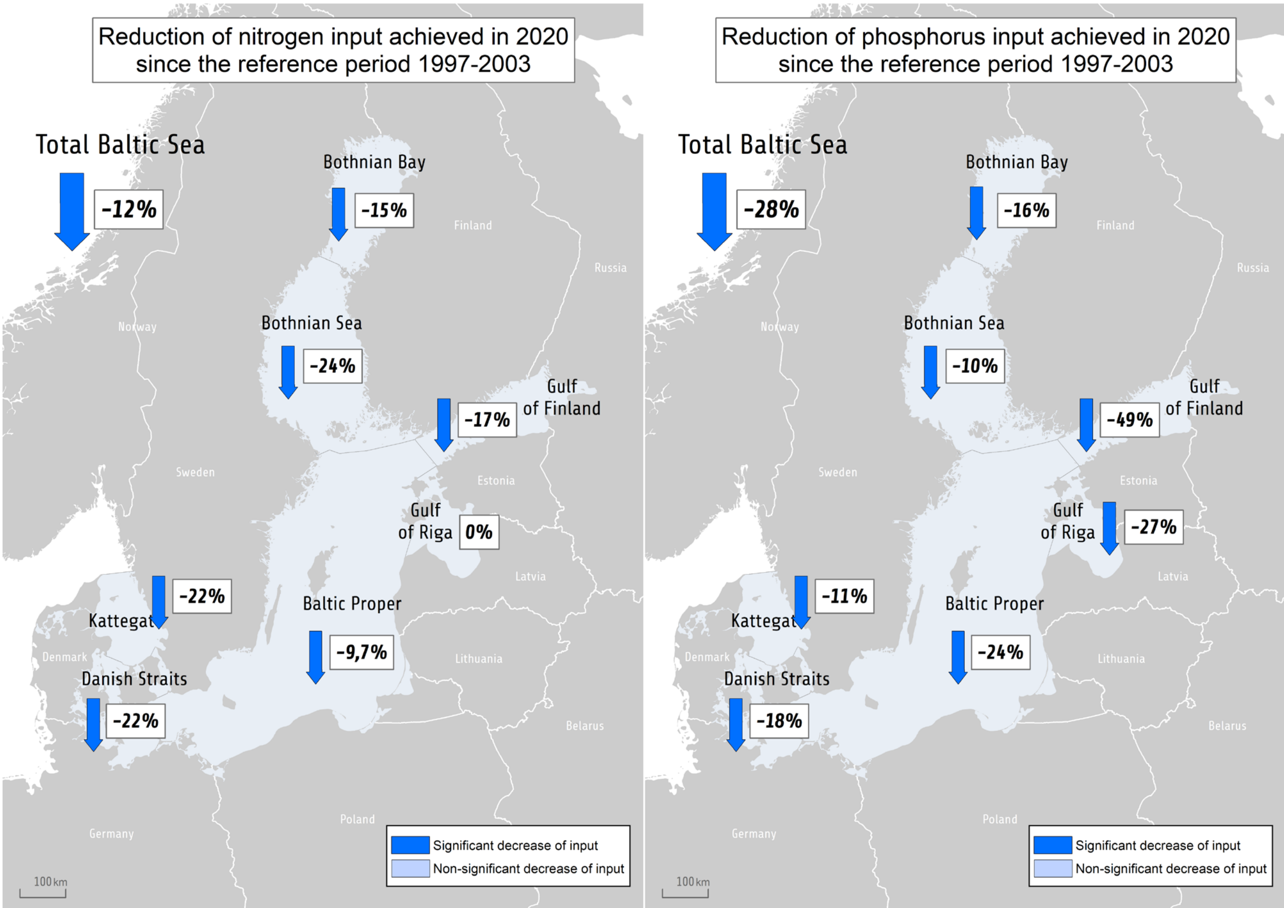


Figure 1. Reductions of total annual inputs of nitrogen (left) and phosphorus (right) achieved in 2020 since the reference period 1997–2003 (in %). The annual inputs in 2020 and in the reference period were calculated using normalized annual data. The arrows indicate decreasing (↓) inputs, while the colours indicate if the change was statistically significant. More information in the Inputs of nutrients indicator report.

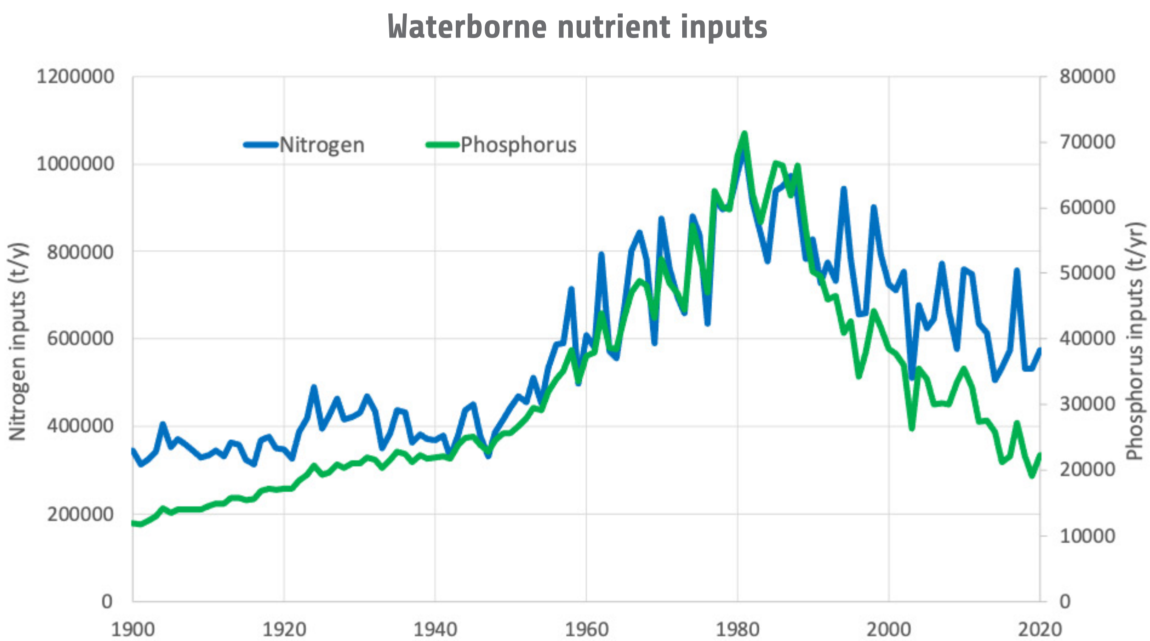


Figure 2. Temporal development of waterborne inputs to the Baltic Sea from 1900 to 2021 with inputs of nitrogen (blue) and phosphorus (green). Sources, Kuliński *et al.*, 2022.

Since the Baltic Sea Action Plan (BSAP), several HELCOM eutrophication assessments have been carried out to quantify the effects of eutrophication in the Baltic Sea (HELCOM 2009, 2010a, 2014, 2018). The current assessment is the third HELCOM holistic assessment for which an assessment of eutrophication has been applied and covers the situation during the assessment period of 2016-2021. This report presents the integrated assessment results for this period, the indicators that were used, and the methodology for the integrated assessment using the HEAT HOLAS 3 tool.

In comparison to the previous State of the Baltic Sea report (HELCOM 2018), the current report shows more detailed assessment outputs with respect to numerical results for assessment units, indicators, and changes over time. In comparison to previous HELCOM eutrophication assessments, the spatial extent of some indicators has been extended, including relevant threshold values, and some new indicators are included, thereby enhancing the coverage of the assessment criteria. For other indicators, threshold values for evaluating status have been refined and more ecologically relevant assessment units have been applied for certain areas, leading to an approach which increasingly enables the evaluation of progress towards improved status.

Combatting eutrophication lays the foundation for a major segment of HELCOM's work towards a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in good environmental status. Through the actions included in the 2021 Baltic Sea Action Plan, the HELCOM Contracting Parties have renewed their firm determination to assure the ecological restoration of the Baltic Sea, ensuring the possibility of self-regeneration of the marine environment and preservation of its ecological balance. They have agreed that each country individually, as well as jointly where needed, takes all appropriate measures to conserve natural habitats and biological diversity and to protect the ecological processes of the Baltic Sea.

The ultimate goal of the Baltic Sea Action Plan (BSAP) with respect to eutrophication is that the Baltic Sea is unaffected by eutrophication. This is described through the mutually supportive and interlinked ecological objectives of attaining:

— Concentrations of nutrients close to natural levels
— Clear waters
— Natural level of algal blooms
— Natural distribution and occurrence of plants and animals
— Natural oxygen levels

To reach this desired state, the following management objective has been identified for eutrophication:

— Minimize inputs of nutrients from human activities

These objectives have been chosen as a representation of the desired state of the environment. A healthy and resilient ecosystem is one that can maintain its species and communities over time, despite external stress, as a consequence of maintain pressures at sustainable levels. This includes populations with age and spatial distributions corresponding to their natural limits, and key ecosystem functions and processes that are naturally upheld, in an interacting network of species and habitats. A prerequisite to securing the vitality and long-term survival of species and populations is ensuring an adequate quality, distribution, and occurrence of natural habitats that can support the communities they host. Each of these key elements strengthen the functionality, health, and resilience of the food webs, ultimately safeguarding the integrity and long-term sustainability of the ecosystem as a whole. To achieve the desired state, it is vital that pressures, particularly those that exert significant stress or are spatially widespread, are managed to prevent detrimental effects.

1.2. Overview of the thematic assessment report

This assessment aims to broadly describe the changes in the Baltic Sea related to eutrophication, reflecting both the physicochemical and biological changes in the environment. The overall assessment comprises results on nutrient levels, and direct and indirect effects of eutrophication. The current assessment covers the period 2016-2021 and is based on data/information collected through harmonised national monitoring programmes from Baltic Sea countries.

This report presents a description of methods, data, and results used for the Eutrophication assessment. The key results will also be presented in the summary report 'State of the Baltic Sea 2016-2021'.

2. Overview of the eutrophication assessment approach

2.1. Introduction to the state of the art of the assessment

The eutrophication assessment was carried out using the HELCOM Eutrophication Assessment Tool (HEAT HOLAS 3). In general, the same process and indicators applied in HOLAS II (Eutrophication 2011-2016) were used, with the exception of and adjustment to the groupings and the shallow-water oxygen indicator being included as a pre-core indicator for the first time in HOLAS 3. The integrated assessment initially combines elements (indicators) by six criteria, in line with the structure of the MSFD methodological standards on good environmental status (EC 2017), and then further aggregates these into three criteria groups: nutrient levels, direct effects, and indirect effects of eutrophication (Figure 3). The indicators within each assigned group are integrated using weighted averaging of the scaled ecological quality ratios (EQRS), which estimate the distance between the assessment value (evaluation result) and the threshold value.

In a stepwise approach, first the assessment value is calculated based on measurements for each indicator. Essential information on reference values, threshold values and acceptable deviations from reference conditions is required to calculate the Ecological Quality Ratio (EQR) in the HEAT tool and to determine EQR class boundaries required for the classification of the results. The EQR

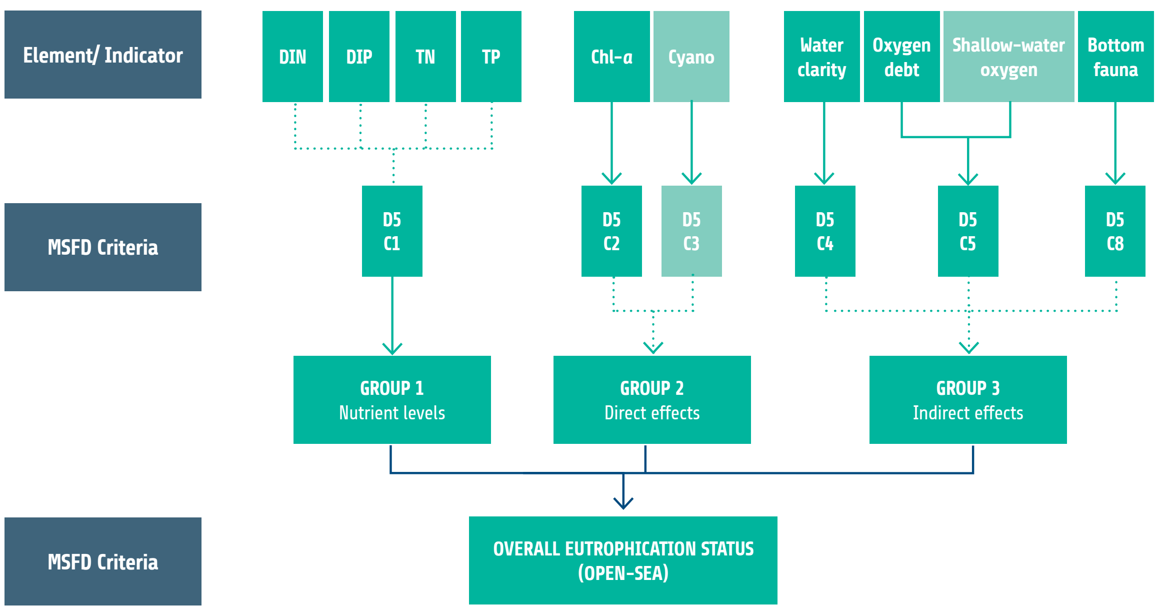


Figure 3. Structure of the eutrophication assessment for open-sea areas. The aggregation of indicators in HEAT HOLAS3 based on criteria, and subsequently on criteria groups, considers the MSFD methodological standards. Pre-core indicators associated with primary criteria are shaded grey, whereas core indicators have no shading. Dashed blue lines indicate a process of weighted averages and solid red line indicates where a One-Out-All-Out process is applied.

value is calculated as the ratio between the reference value and the assessment value of the indicator or vice versa depending on the response to eutrophication (e.g. positive response for nutrient concentrations or negative response for Secchi depth). The different steps in the calculation procedure of HEAT are illustrated in Figure A1.2 of Annex 1. In a subsequent step, the EQR values are scaled to an equidistant five class scale of 0.2 width between 0 and 1 (EQRS), where values above 0.6 indicate good status, to arrive at a common scaling for all indicators. The EQRS classes and result categories are shown in Table 2. The weight of the indicators within the different criteria groups is evenly distributed unless otherwise justified (see indicator weights in Table A1.1 of Annex 1). The overall eutrophication status is determined using one-out-all-out between criteria groups, meaning that the final status is equal to the status of the lowest-assessed criteria group. The HEAT tool generates output tables of the assessment results on indicator, criteria group and integrated level and produces status and confidence maps for the different indicators, criteria groups and the overall integrated eutrophication assessment result.

For the interpretation of the results, a major change from HOLAS II to HOLAS 3 is the transition to applying scaled EQR (EQRS) values instead of Eutrophication ratios (ER) to evaluate the eutrophication status across the different Baltic Sea sub-basins. This new approach is devised to improve the comparability between indicators and criteria groups as well as between coastal and open sea assessment units.

Status class	EQRS
High	>=0.8 to <1.0
Good	>=0.6 to <0.8
Moderate	>=0.4 to <0.6
Poor	>=0.2 to <0.4
Bad	<0.2

Table 2. Result categories of the assessment using the EQRS values and the colour scheme when presenting the results in map.

Since the previous assessment for the period 2011-2016 (HOLAS II), several indicators used in the assessment have been improved in terms of the methodology applied, as well as reviewing the scientific rationale for the threshold values. To improve the spatial evaluation of the eutrophication status across the Baltic Sea, with respect to the differences in natural environmental conditions two new assessment units have also been included in the assessment for HOLAS 3. These are generated as a result of splitting old larger assessment units. In the southwestern Baltic Sea, the assessment unit Bornholm Basin has been split to include a new assessment unit, the Pomeranian Bay, with the remaining part maintained as the Bornholm Basin. In the Gulf of Finland the assessment unit has been split into eastern and western Gulf of Finland. These divisions are only currently applied for the eutrophication assessment due to the high ecological relevance. The assessment also includes a new pre-core indicator to describe oxygen conditions in the shallow areas of the Baltic Sea and the spatial extent of the total nutrient indicators has been increased, now covering the whole Baltic Sea. In addition, a major change in how the assessment is performed is a change in the indicator aggregation, with the indicator Water transparency (Secchi depth) moved from the direct effects to the indirect effects category (Figure 3).

2.2. Overview of data collection and monitoring

Assessing the effects and the measures taken to combat eutrophication requires access to extensive temporal and spatial monitoring data, collected in a comparative way from the entire region, to provide the most accurate overview of progress. HELCOM strives to account for this through regionally agreed monitoring programmes. Environmental monitoring is a well-established function in HELCOM, with countries following commonly agreed procedures and collating data in centralized databases.

Monitoring of physical, chemical and biological variables of the Baltic Sea open areas started already in 1979 and monitoring of inputs of nutrients was initiated in 1998. Today there are 40 agreed HELCOM monitoring programmes covering sources and inputs of human pressures and various variables reflecting the state of the environment. HELCOM monitoring programmes are compiled in the HELCOM Monitoring Manual and are supported by over 40 monitoring guidelines, outlining how monitoring should be implemented. Both the monitoring programmes and the guidelines are periodically reviewed to ensure they remain up to date. The following monitoring programmes are of direct relevance for the eutrophication assessment presented in this report:

- HELCOM monitoring programme Water column physical characteristics
- HELCOM monitoring programme Water column chemical characteristics
- HELCOM monitoring programme Nutrients
- HELCOM monitoring programme Phytoplankton species composition, abundance and biomass
- HELCOM monitoring programme Pigments

The monitoring is implemented by the HELCOM Contracting Parties, i.e. the countries bordering the Baltic Sea. The HELCOM monitoring programmes are the source of data for indicator-based assessments of the state of the marine environment, pressures on the marine environment, as well as the analysis of long-term trends.

Current monitoring and assessment activities are guided by the HELCOM Monitoring and Assessment Strategy adopted in 2013. The HELCOM Monitoring Manual in turn was developed to support the implementation of the HELCOM Monitoring and Assessment Strategy (HELCOM 2013). Principles of the HELCOM Monitoring and Assessment Strategy are as follows:

1. National monitoring programmes use the principles of the Joint Monitoring System to achieve a high degree of coordination, cooperation, sharing and harmonization.
2. The Joint Monitoring System feeds a Data Pool that is the basis for the Assessment System.
3. This system produces assessments of the health of the Baltic Sea that can be used by HELCOM countries as well as the EU, observers, stakeholders, etc.

HELCOM cooperates with several international organizations to deliver and store monitoring data and information, including the Co-operative Programme for the Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe (CLRTAP/EMEP), the International Council for the Exploration of the Sea (ICES) and the European Environmental Agency (EEA).

2.3. Assessment scales

The use of assessment scales (both temporal and spatial) is critical to ensure a harmonised evaluation across all assessed topics (i.e., providing a snapshot of status for a given period) and to facilitate clear spatial comparisons. The latter is critical where ecological or hydrogeographical gradients are present (as is the case in the Baltic Sea) and also when carrying out integrated assessments between closely related indicators under a single topic or theme.

2.3.1 Spatial scale

The integrated eutrophication assessment is conducted for both open sea and coastal assessment units. The open sea assessment is done using agreed HELCOM indicators as described in the report and applied at HELCOM assessment unit level 4b (see HELCOM Monitoring and Assessment Strategy, Annex 4). Assessment units are defined by the HELCOM Contracting Parties, and it can have multiple indicators. Each indicator can have different temporal (months) and spatial (e.g., depth) coverage and reference values within the different assessment units. The coastal areas in six countries were assessed by national indicators used in the Water Framework Directive (EC 2000).

2.3.2 Temporal scale

Each holistic assessment covers a timespan of six years, referred to as the assessment period. The current assessment focuses on the period 2016–2021. In addition, data showing more long-term temporal development have been provided in order to understand long-term trends and evaluate the direction of ongoing changes.

2.4. Overview of indicators included in the thematic assessment

Eutrophication status was evaluated in open-sea areas by assessing core- and pre-core indicators within three criteria groups: nutrient levels, direct effects and indirect effects of eutrophication (Core indicator reports: https://indicators.helcom.fi/).

To assess nutrient levels, core indicators on the concentrations of nitrogen and phosphorous were used. Dissolved inorganic nitrogen and phosphorous are directly utilizable for phytoplankton enhancing primary production and they are measured in the winter season when primary productivity is low. Measurements of total nitrogen and total phosphorous also include nutrients that are bound in humic substances, phytoplankton, or in particles in the water. Total nutrient concentrations define the overall degree of nutrient enrichment of the water. As rising winter temperatures are anticipated to result in year-round phytoplankton production and higher proportions of nutrients being bound in phytoplankton biomass compared to dissolved forms, using estimates of total nutrients enables the evaluation to take climate change into account.

Chlorophyll a concentration was used to assess the direct effects of eutrophication. In addition, the 'Cyanobacterial bloom index' was included as a pre-core indicator to evaluate the magnitude and frequency of cyanobacterial blooms, where applicable.

To assess indirect effects of eutrophication, the core indicators 'Oxygen debt' and Water transparency were used. The first core indicator measures the volume-specific oxygen debt below the halocline. Hence, the indicator estimates how much oxygen is 'missing' from the Baltic Sea deep water. In shallow areas where the oxygen debt indicator is not applicable, the pre-core indicator 'Shallow-water oxygen' is used to estimate the bottom area or water volume with oxygen concentrations below area-specific threshold values or the occurrence of by using near-bottom oxy-

Table 3. Eutrophication indicators applied in the integrated assessment, listed according to criteria group, and criteria presented in EC 2017/848. The last column indicates whether the criterion is primary or secondary. In coastal areas national indicators are used, and each of the coastal indicators listed do not necessarily apply for all coastal assessment units. WFD = Water Framework Directive. TN= total nitrogen, TP= total phosphorous.

Criteria group	Indicator name	Coastal/ open sea	MSFD criteria (primary/ secondary)
Nutrient concentration	Dissolved inorganic nitrogen (DIN)	Open sea & coastal	D5C1 (primary): Nutrient concentrations are not at levels that indicate adverse eutrophication effects.
	Dissolved inorganic phosphorous (DIP)	Open sea & coastal	
	Total nitrogen	Open sea & coastal	
	Total phosphorus	Open sea & coastal	
Direct effects	Chlorophyll-a	Open sea	D5C2 (primary): Chlorophyll-a concentrations are not at levels that indicate adverse effects of nutrient enrichment.
	WFD indicator results on phytoplankton (mostly chlorophyll-a and biovolume)	Coastal	
	Cyanobacterial Bloom Index (CyaBI)*	Open sea	D5C3 (secondary): The number, spatial extent and duration of harmful algal bloom events are not at levels that indicate adverse effects of nutrient enrichment.

Table 3. (Continued). Eutrophication indicators applied in the integrated assessment, listed according to criteria group, and criteria presented in EC 2017/848. The last column indicates whether the criterion is primary or secondary. In coastal areas, national indicators are used, and each of the coastal indicators listed do not necessarily apply for all coastal assessment units. WFD = Water Framework Directive. TN= total nitrogen, TP= total phosphorous.

Criteria group	Indicator name	Coastal/ open sea	MSFD criteria (primary/ secondary)
Indirect effects	Oxygen debt Shallow water oxygen*	Open sea	D5C5 (primary): The concentration of dissolved oxygen is not reduced, due to nutrient enrichment, to levels that indicate adverse effects on benthic habitats (including on associated biota and mobile species) or other eutrophication effects.
	WFD indicators on oxygen concentration or hypoxia	Coastal	
	Water transparency	Open sea & coastal Coastal	D5C4 (secondary): The photic limit (transparency) of the water column is not reduced, due to increases in suspended algae, to a level that indicates adverse effects of nutrient enrichment
	WFD indicators on macrophytes	Coastal	D5C6 (secondary): The abundance of opportunistic macroalgae is not at levels that indicate adverse effects of nutrient enrichment. D5C7 (secondary): The species composition and relative abundance or depth distribution of macrophytes communities achieve values that indicate there is no adverse effect due to nutrient enrichment including via a decrease in water transparency.
	State of the soft-bottom macrofauna community	Open sea	D5C8 (secondary): The species composition and relative abundance of macrofaunal communities, achieve values that indicate that there is no adverse effect due to nutrient and organic enrichment.
	WFD indicators on macrofauna	Coastal	

*The indicator has been included as pre-core indicator.

gen below the set thresholds depending on vertical stratification. The second core indicator measures the Water transparency as indicated by Secchi depth to estimate the light availability required for the growth of benthic plants and phytoplankton as well as the level of organic matter accumulation. In addition, the indicator 'State of the soft-bottom macrofauna community' was used to assess indirect effects of eutrophication in the open sea areas of the Gulf of Bothnia, Gulf of Finland and Gulf of Riga.

The coastal areas in six countries were assessed by national indicators used in the Water Framework Directive (EC 2000) and their respective threshold values, used to evaluate biological quality elements such as phytoplankton (chlorophyll-a), benthic invertebrate fauna and macrophytes (macroalgae and angiosperms), and supporting physical and chemical elements such as concentrations of nitrogen, phosphorus, and water transparency. Different indicators were used by different countries. While some of the applied indicators are calculated similarly as the open sea indicators, differences in methodological approaches and monitoring exist between the open sea and the coastal assessment units and also between coastal assessment units of the different countries.

For core and pre-core indicators used in the open sea assessment units, the threshold values applied are listed in Table 4.

Table 4. Overview of threshold values for core and pre-core indicators in open sea assessment units. 'NA' is shown where the indicator is not applicable.

Assessment unit (open sea)	DIN (µmol L-1)	DIP (µmol L-1)	Chloro-phyll-a (µg L-1)	Secchi depth (m)	TN (µmol L-1)	TP (µmol L-1)	O2 debt (mg L-1)	Shallow water O2	CyaBI	BQI
Kattegat	5.0	0.49	1.50	7.6	17.40	0.64	NA	2, 4 and 6 mg L-1 (1752 km2*)	NA	NA
Great Belt	5.0	0.59	1.70	8.5	21.00	0.95	NA	2, 4 and 6 mg L-1 (348 km2*)	NA	NA
The Sound	3.3	0.42	1.20	8.2	17.30	0.68	NA	2, 4 and 6 mg L-1 (57 km2*)	NA	NA
Kiel Bay	5.5	0.57	2.00	7.4	16.40	0.41	NA	2, 4 and 6 mg L-1 (684 km2*)	NA	NA
Bay of Mecklenburg	4.3	0.49	1.80	7.1	16.70	0.45	NA	2, 4 and 6 mg L-1 (710 km2*)	0.89	NA
Arkona Basin	2.9	0.36	1.80	7.2	19.50	0.48	NA	2, 4 and 6 mg L-1 (1730 km2*)	0.85	NA
Bornholm Basin	1.8	0.28	1.60	7.1	16.05	0.55	6.37	NA	0.83	NA
Pomeranian Bay	5.5	0.40	2.90	7.1	23.80	0.74	NA	near-bottom concentration of 4 mg L-1 for seasonally stratified and 6 mg L-1 for well mixed areas	0.81	NA
Gdansk Basin	4.2	0.36	2.20	6.5	18.80	0.60	8.66	NA	0.77	NA
Eastern Gotland Basin	2.6	0.29	1.90	7.6	16.50	0.45	8.66	NA	0.89	NA
Western Gotland Basin	2.0	0.33	1.20	8.4	15.10	0.45	8.66	NA	0.85	NA
Gulf of Riga	5.2	0.41	2.70	5.0	28.00	0.70	NA	near-bottom concentration of 4 mg L-1 for seasonally stratified and 6 mg L-1 for well mixed areas	0.90	0.5
Northern Baltic Proper	2.9	0.25	1.70	7.1	16.20	0.38	8.66	NA	0.93	NA
Western Gulf of Finland	3.3	0.50	1.90	5.9	18.70	0.54	8.66	NA	0.88	0.5
Eastern Gulf of Finland	4.3	0.68	2.30	5.3	22.30	0.56	NA	volume (14 km3) below threshold (6 mg L-1)	0.91	0.5
Åland Sea	2.7	0.21	1.50	6.9	15.60	0.28	NA	NA	0.91	4
Bothnian Sea	2.8	0.19	1.50	6.8	15.70	0.24	NA	near-bottom concentration of 7.7 mg L-1	0.92	4
The Quark	3.7	0.10	2.00	6.0	17.30	0.24	NA	near-bottom concentration of 8.1 mg L-1	NA	1.5
Bothnian Bay	5.2	0.07	2.00	5.8	16.90	0.18	NA	near-bottom concentration of 8.8 mg L-1	NA	1.5

* Average of areas affected by concentrations below 2, 4 and 6 mg L -1. Areas are summed for each concentration before the average over time is calculated. This means that an area with concentrations below 4 mg L -1 counts double and areas below 2 mg L -1 count trice. In this way, the indicator value is a combination of severity of hypoxia and extent.

2.5. Assessment data flow

The eutrophication status assessment results presented below are based on data from the assessment period 2016-2021 obtained through the eutrophication assessment data flow as visualized in figure 4 (see also Figure A1.2).

The HELCOM data flow model for the eutrophication assessments is based on reporting of monitoring data by the Contracting Parties to the HELCOM COMBINE database, which is hosted by the International Council for Exploration of the Sea (ICES). After receiving the data, ICES performs quality assurance of the data and transfers it to the database.

For each eutrophication assessment period, data from the COMBINE database are extracted and is drawn as such into a separate assessment database, which is also hosted by ICES. Additional data products, such as WFD indicator results or predefined earth observation data products, can also be submitted by the provider directly to the HELCOM assessment database, without going via the COMBINE database.

At this stage, indicator aggregation and assessment results are produced dynamically using algorithms specified for the individual core indicators and the overall eutrophication assessment using the HELCOM HEAT tool.

Visualised data products such as bar charts and result maps, including the underlying data of the assessments, were reviewed and accepted by the Contracting Parties.

At the HELCOM web portal, the results are presented in the HELCOM indicator web page and the HELCOM Map and data service, including visualizations of the data and assessment results in chart type. The spatial data are read from an interface produced with ArcGIS server rest interface.

Access to the eutrophication assessment workspace is restricted to experts named by the Contracting Parties to be responsible for data and assessment product review, in order not to present unaccepted products to the public.

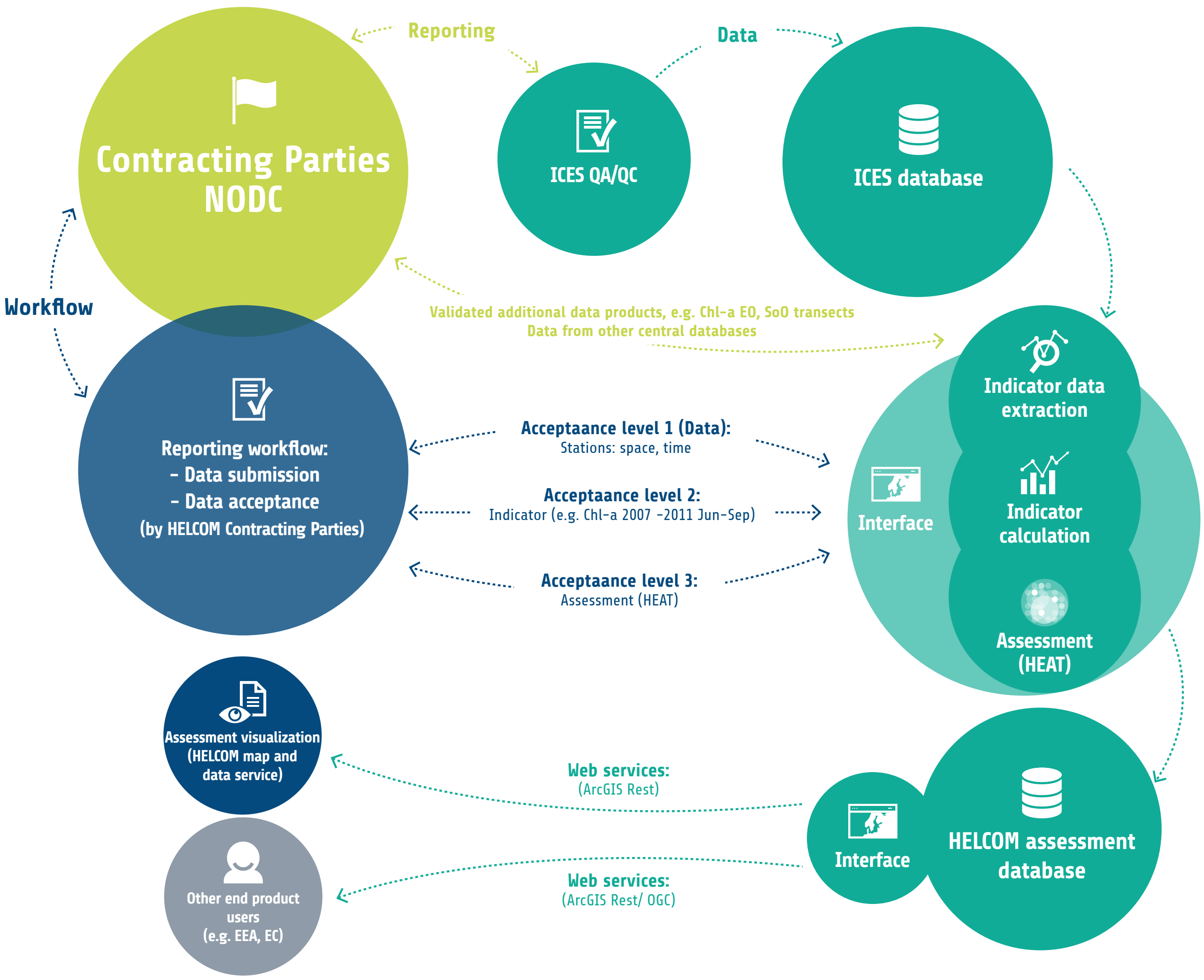


Figure 4. Eutrophication assessment data and information flow. The colour of the items indicates the actor/host: Lime green = Contracting Parties, Blue = HELCOM portal hosted at the HELCOM Secretariat, Turquoise = ICES, Grey = Other end-users, for example European Environment Agency (EEA), European Commission (EC).

3. Results for the integrated eutrophication assessment

Assessment results in short

The Baltic Sea is still impacted by eutrophication, according to the most recent integrated eutrophication status assessment for 2016–2021 (Figure 5). Only 12 of the 252 assessment units included in the HELCOM evaluation, which covered both open (19) and coastal water bodies (233), achieved good status. This is further demonstrated by the fact that 93.8% of the Baltic Sea's surface area, from the Kattegat to the inner bays, is affected by eutrophication.

3.1. Details on the assessment results for eutrophication

Eutrophication is particularly prominent in the open sea areas, where good status was not achieved in any of the basins (Figure 5, Table 5 and 6). Although 43 of the assessed units are regarded as being in bad status, the area covered is only 1.3% of the total Baltic Sea area (these generally being smaller coastal assessment units). Only a few coastal areas were unaffected by eutrophication. In many open-sea areas, good status was not achieved with respect to any of the assessed criteria; nutrient levels, direct or indirect effects of eutrophication (Figure 6). Generally, indicators for nutrient levels were the ones furthest away from good status, and therefore had the highest influence on the overall integrated assessment. Good status of nutrient levels in the open sea assessment units was only achieved for the Great Belt. For the direct effects of eutrophication, good status was only achieved for Kattegat and Kiel Bay. For indirect effects, good status was observed in Kattegat and the northern-most sea units (Bothnian Sea, the Quark, and Bothnian Bay) (Figures 7).

The observed relatively poorer status in nutrient values and direct effects in comparison to indirect effects, may be opposite to expectations of how the ecosystem would respond to reduced loading. Under nutrient reduction, it would be expected that inorganic nutrient levels improve first, followed by direct effects, and that indirect effects would react with a time delay. The observed outcome can be a product of poorly harmonized threshold values for different indicators or may reflect a need to reconsider the way indicators are grouped in the assessment. On the other hand, many of the direct responses can also be expected to respond on a short time scale to changes in nutrient loading. Indicators representing changes in chlorophyll-a, cyanobacteria, and, for example, many annual macroalgae, are likely to respond to changes within the same growing season. In contrast, total nutrient concentrations, water transparency, and oxygen levels will respond with a delay of decades (estuaries) and several decades (open basins). In addition, primary productivity may be limited by nutrient composition rather than nutrient concentration and may also be regulated by additional factors, such as the level of grazing. Due to the overall complexity of the relationships involved in the ecosystem responses, however, an explanation cannot be unanimously identified. Also, considering the level of eutrophication and the resulting anoxic/hypoxic areas, the internal load of nutrients (PO_4) can play an important role in delaying the achievement of expected results. Internal load is caused by phosphate release from sediments under anoxic conditions that can counteract the nutrient

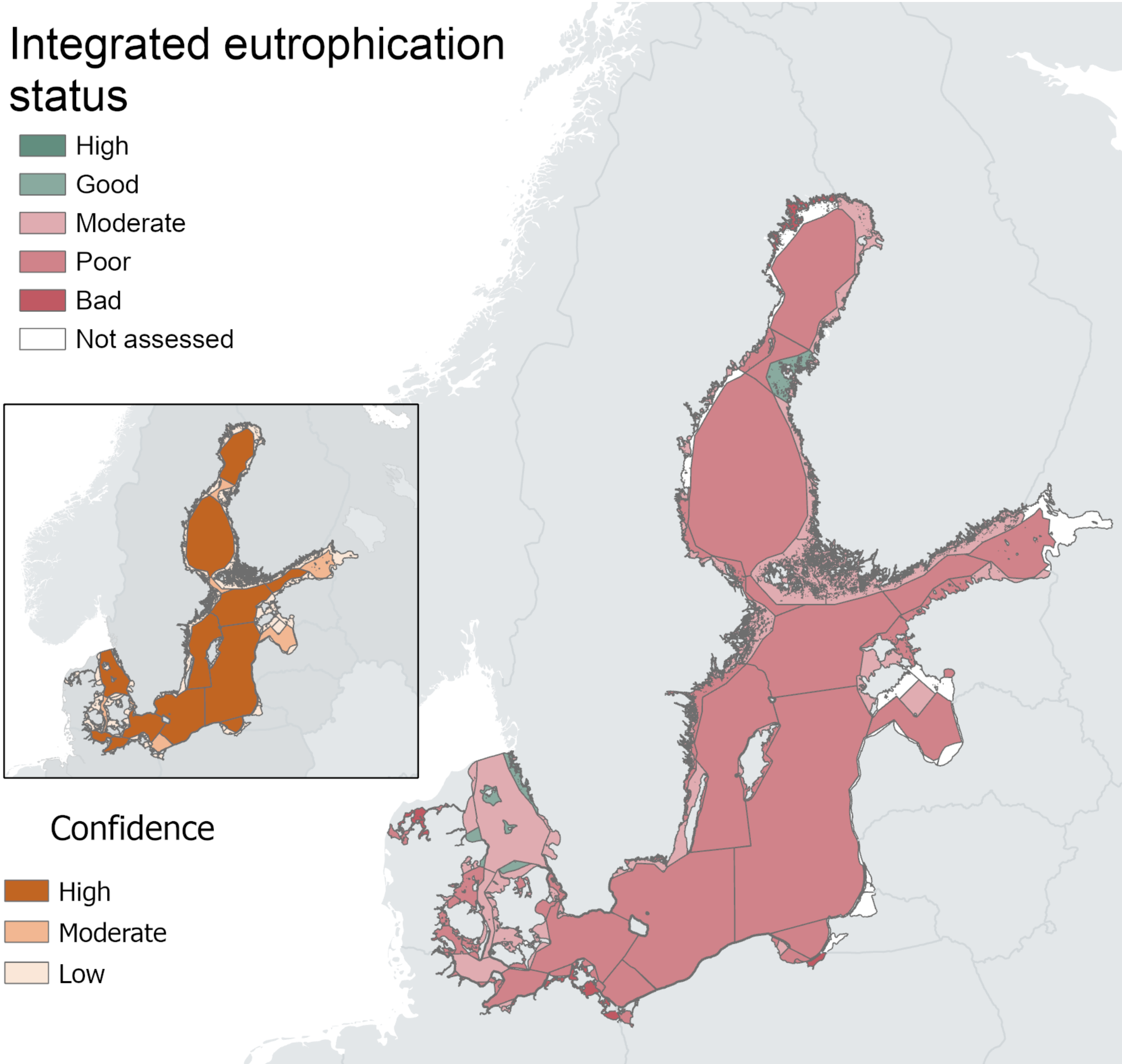
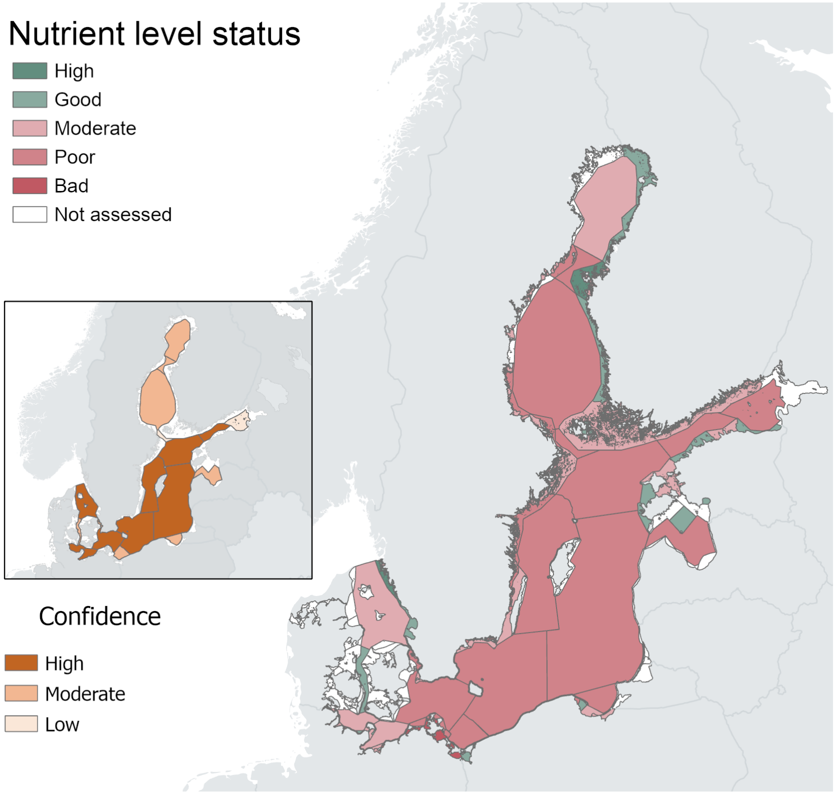


Figure 5. Integrated assessment results for eutrophication in the Baltic 2016–2021: Each assessment unit shows the results for the integrated assessment in colours representing the assessment status. In coastal areas HELCOM utilizes national indicators used in the Water Framework Directive to arrive at an assessment of eutrophication status in six countries. White areas denote that data has not been available for the integrated assessment. The inserted map shows the confidence assessment results, with darker colours indicating higher confidence for the indicators included.



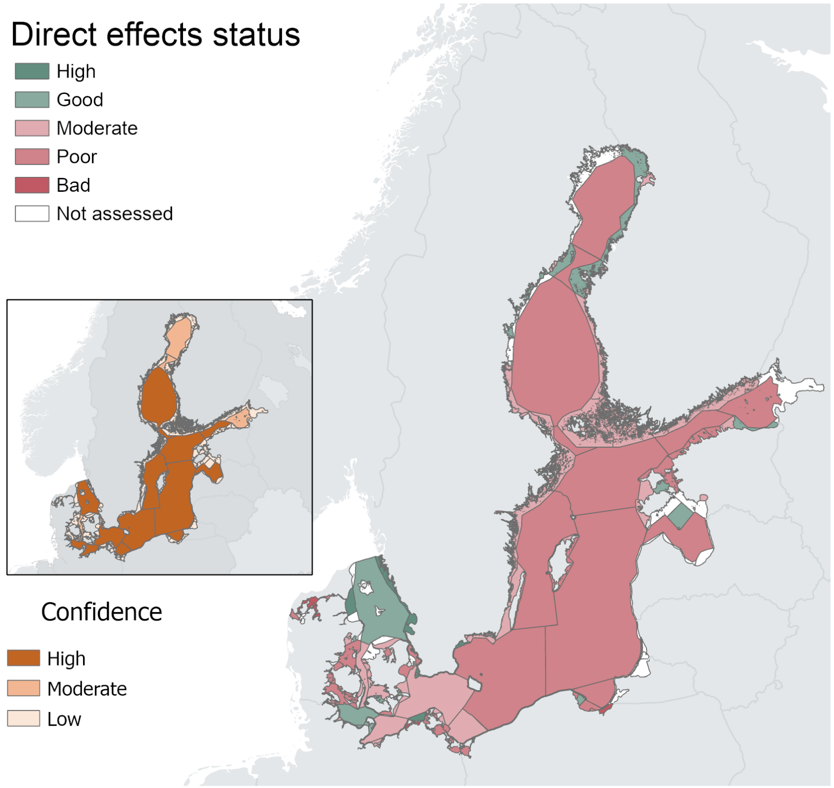


Figure 6. Integrated assessment results for eutrophication by criteria groups 2016–2021 (top: nutrient status, middle: direct effects, bottom: indirect effects). Each assessment unit shows the results for the criteria group in colours representing the assessment status. In coastal areas HELCOM utilizes national indicators used in the Water Framework Directive to arrive at an assessment of eutrophication status in six countries. White areas denote that data has not been available for the integrated assessment. The inserted maps show the confidence assessment results for the respective criteria group, with darker colours indicating higher confidence of the indicators included.

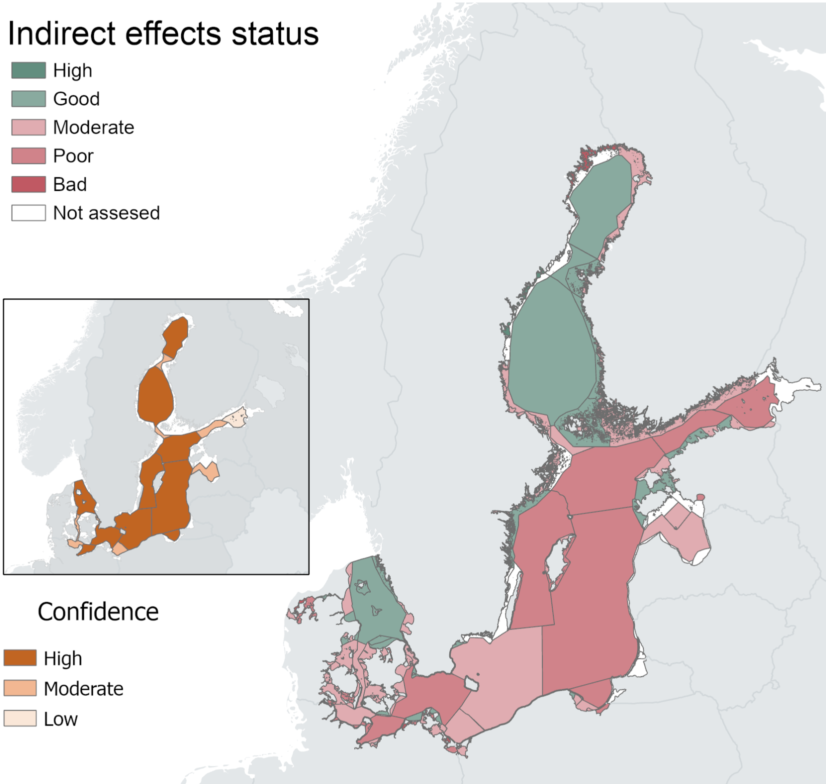


Figure 6. (Continued). Integrated assessment results for eutrophication by criteria groups 2016–2021 (top: nutrient status, middle: direct effects, bottom: indirect effects). Each assessment unit shows the results for the criteria group in colours representing the assessment status. In coastal areas HELCOM utilizes national indicators used in the Water Framework Directive to arrive at an assessment of eutrophication status in six countries. White areas denote that data has not been available for the integrated assessment. The inserted maps show the confidence assessment results for the respective criteria group, with darker colours indicating higher confidence of the indicators included.

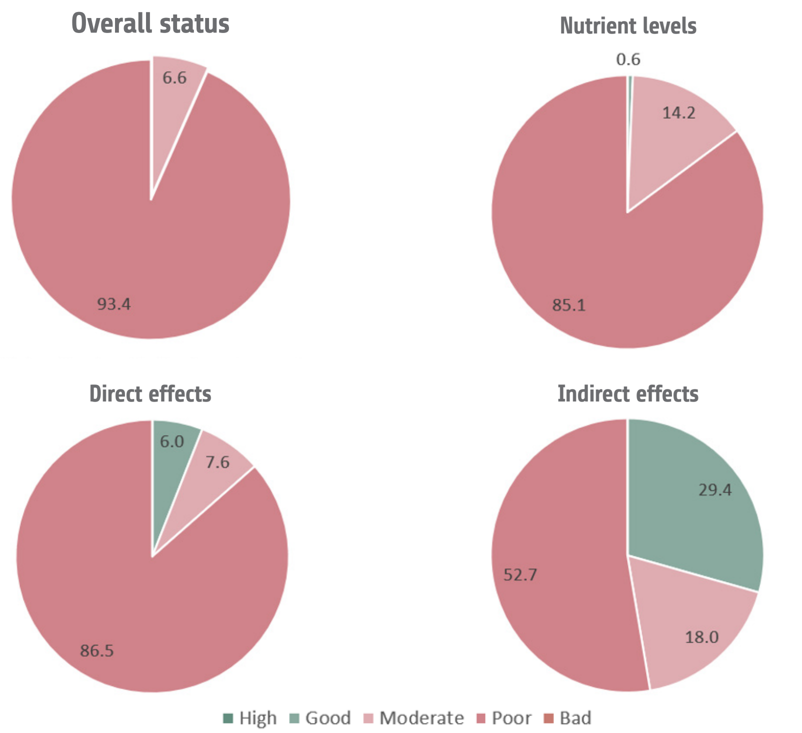


Figure 7. Proportional division (% of total open sea area) of open sea assessments (overall and per criteria group) in the HELCOM region. Basin-wise specifics can be found in Table 6.

Table 5. Eutrophication indicator results in the open sea for the assessment period 2016–2021. Values show the scaled eutrophication quality ratios of the indicator, criteria group, or integrated status, as estimated in HEAT, with the colour coding indicating the status class (see legend below table), which has been assigned using more decimals than represented in the table. Note that due to truncated decimals, the status class may vary for identical value with two decimals. White cells denote that the sub-basin was not assessed (in the open sea) due to the lack of agreed threshold value or a commonly agreed indicator methodology. An 'NA' is shown for cases where the indicator is not applicable. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', TN = 'Total nitrogen', DIP = 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', C1 = 'Criteria group 1 for nutrient levels', Chl a= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index', C2 = 'Criteria 2 for direct effects', Secchi= 'Secchi depth', O2 debt = 'Oxygen debt', Shallow O2* = 'Shallow water oxygen', BQI = 'Benthic quality index', and C3 = 'Criteria 3 for indirect effects'. Indicators marked with '*' have not been adopted in HELCOM yet and are currently tested. For more details, see core indicator reports: HELCOM 2023 x-y

Assessment unit	Indicator results (EQRS)														Integrated status assessment
	Nutrient levels					Direct effects			Indirect effects						
	DIN	TN	DIP	TP	C1	Chl a	Cyano*	C2	Secchi	O_2 debt	Shallow O_2*	BQI*	C3		
	Dec–Feb	All year	Dec–Feb	All year		Jun–Sep	20 Jun –31 Aug		Jun–Sep	All year	All year	May–Jun			
Kattegat	0.58	0.67	0.57	0.48	**0.57**	0.69	NA	**0.69**	0.86	NA	0.59	NA	**0.72**		**0.57**
Great Belt	0.52	0.80	0.59	0.88	**0.70**	0.49	NA	**0.49**	0.48	NA	0.54	NA	**0.51**		**0.49**
The Sound	0.27	0.52	0.34	0.43	**0.39**	0.26	NA	**0.26**	0.51	NA	0.41	NA	**0.46**		**0.26**
Kiel Bay	0.76	0.72	0.51	0.20	**0.55**	0.66	NA	**0.66**	0.59	NA	0.48	NA	**0.53**		**0.53**
Bay of Mecklenburg	0.58	0.56	0.31	0.23	**0.42**	0.56	0.35	**0.46**	0.29	NA	0.30	NA	**0.29**		**0.29**
Arkona Basin	0.40	0.57	0.25	0.24	**0.36**	0.41	0.49	**0.45**	0.38	NA	0.40	NA	**0.39**		**0.36**
Bornholm Basin	0.16	0.34	0.14	0.23	**0.22**	0.30	0.46	**0.38**	0.44	0.37	NA	NA	**0.41**		**0.22**
Pomeranian Bay	0.14	0.27	0.20	0.25	**0.21**	0.49	0.36	**0.42**	0.12	NA	0.72	NA	**0.42**		**0.21**
Gdansk Basin	0.36	0.35	0.18	0.32	**0.30**	0.32	0.38	**0.35**	0.23	0.27	NA	NA	**0.25**		**0.25**
Eastern Gotland Basin	0.31	0.28	0.15	0.20	**0.23**	0.28	0.32	**0.30**	0.25	0.27	NA	NA	**0.26**		**0.23**
Western Gotland Basin	0.21	0.33	0.17	0.21	**0.23**	0.15	0.31	**0.23**	0.17	0.27	NA	NA	**0.22**		**0.22**
Gulf of Riga	0.17	0.52	0.11	0.34	**0.29**	0.32	0.34	**0.33**	0.17	NA	0.70	0.58	**0.48**		**0.29**
Northern Baltic Proper	0.23	0.38	0.11	0.18	**0.23**	0.17	0.28	**0.22**	0.23	0.27	NA	NA	**0.25**		**0.22**
Gulf of Finland Western	0.17	0.42	0.17	0.27	**0.26**	0.17	0.32	**0.24**	0.24	0.27	NA	0.58	**0.36**		**0.24**
Gulf of Finland Eastern	0.18	0.50	0.22	0.32	**0.30**	0.21	0.46	**0.34**	0.23	NA	0.30	0.58	**0.37**		**0.30**
Åland Sea	0.38	0.49	0.14	0.17	**0.29**	0.22	0.28	**0.25**	0.48	NA	NA	0.63	**0.56**		**0.25**
Bothnian Sea	0.40	0.52	0.15	0.17	**0.31**	0.27	0.26	**0.26**	0.47	NA	0.75	0.77	**0.66**		**0.26**
The Quark	0.40	0.59	0.10	0.22	**0.33**	0.30	NA	**0.30**	0.37	NA	0.73	0.72	**0.60**		**0.30**
Bothnian Bay	0.47	0.55	0.41	0.46	**0.47**	0.33	NA	**0.33**	0.50	NA	0.98	0.81	**0.76**		**0.33**

Status class	EQRS
High	>= 0.8 to < 1.0
Good	>= 0.6 to < 0.8
Moderate	>= 0.4 to < 0.6
Poor	>= 0.2 to < 0.4
Bad	< 0.2

Table 6. Eutrophication indicator results in the open sea for the assessment period 2016-2021. Values show the Eutrophication Status of the indicator, criteria group, or integrated status, as estimated in HEAT, with the colour coding indicating the status class (see legend below table). White cells denote that the sub-basin was not assessed (in the open sea) due to the lack of agreed threshold value or a commonly agreed indicator methodology. An 'NA' is shown for cases where the indicator is not applicable. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', TN = 'Total nitrogen', DIP = 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chl a= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index', Secchi= 'Secchi depth', O2 debt = 'Oxygen debt', Shallow O2* = 'Shallow water oxygen', BQI = 'Benthic quality index'. Indicators marked with '*' have not been adopted in HELCOM yet and are currently tested. For more details, see core indicator reports: HELCOM 2023 x-y

Assessment unit	Indicator results (ES)									
	Nutrient levels				Direct effects		Indirect effects			
	DIN (μmol L^{-1})	TN (μmol L^{-1})	DIP (μmol L^{-1})	TP (μmol L^{-1})	Chl a (μg L^{-1})	Cyano*	Secchi (m)	O_2 debt (mg L^{-1})	Shallow O_2*	BQI*
	Dec–Feb	All year	Dec–Feb	All year	Jun– Sep	20 Jun – 31 Aug	Jun–Sep	All year	All year	May–Jun
Kattegat	5.26	16.30	0.52	0.74	1.39	NA	9.05	NA	1972 km^2	NA
Great Belt	5.72	17.36	0.61	0.71	2.01	NA	7.83	NA	484 km^2	NA
The Sound	5.19	19.00	0.60	0.84	1.94	NA	7.70	NA	123 km^2	NA
Kiel Bay	4.73	14.70	0.72	0.78	1.91	NA	7.35	NA	967 km^2	NA
Bay of Mecklenburg	4.60	17.62	1.22	0.89	1.94	0.49	5.59	NA	1762 km^2	NA
Arkona Basin	3.80	20.36	0.60	0.79	2.29	0.61	6.11	NA	3094 km^2	NA
Bornholm Basin	4.16	22.13	0.71	0.96	2.37	0.61	6.33	8.43	NA	NA
Pomeranian Bay	28.31	39.30	0.79	1.20	4.21	0.43	3.20	NA	0.72 (EQRS)	NA
Gdansk Basin	6.64	25.70	0.74	1.01	3.73	0.45	4.80	13.29	NA	NA
Eastern Gotland Basin	4.20	25.28	0.67	0.82	2.99	0.44	5.72	13.29	NA	NA
Western Gotland Basin	3.50	21.24	0.69	0.78	2.89	0.41	5.14	13.29	NA	NA
Gulf of Riga	10.74	30.55	1.37	0.97	3.92	0.51	3.13	NA	0.70 (EQRS)	0.47
Northern Baltic Proper	4.88	21.26	0.78	0.74	3.78	0.43	5.12	13.29	NA	NA
Gulf of Finland Western	6.97	23.31	1.05	0.84	4.20	0.45	4.29	13.29	NA	0.47
Gulf of Finland Eastern	8.57	25.16	1.30	0.82	4.37	0.65	3.83	NA	47.8 km^3	0.47
Åland Sea	3.57	17.73	0.53	0.59	2.74	0.35	6.36	NA	NA	7.27
Bothnian Sea	3.63	17.12	0.44	0.48	2.47	0.36	6.21	NA	0.82 (EQRS)	7.82
The Quark	4.76	17.62	0.35	0.44	3.17	NA	5.00	NA	0.81 (EQRS)	4.85
Bothnian Bay	6.10	17.87	0.09	0.21	3.25	NA	5.18	NA	0.99 (EQRS)	5.43

load reductions as well as increase the uptake of additional nutrients (N2) from the atmosphere, through promoting cyanobacterial growth. In that sense, phosphorus concentrations reflect both the current level of nutrient inputs and indirect eutrophication effects, which can last for several decades.

Confidence in the indicators was high or moderate for most open sea assessment units, with respect to all indicators for which confidence values were available (Table 7). Regarding the different confidence aspects, temporal confidence was predominantly assessed as high or moderate in 85% of the indicator results for open sea assessment units, reflecting comprehensive data sets regarding monitoring frequency and continuity during the respective assessment seasons. Spatial confidence was assessed as high or moderate in 55% of the indicator results for open sea assessment units, which means that a significantly larger proportion of assessment units with low confidence indicates that spatial coverage and distribution of monitoring stations are inadequate in many areas and need to be improved. The accuracy confidence was assessed as high in 93% of the indicator results for open sea assessment units, indicating a probability of at least 90% for correct classification of the assessment result being above or below the area-specific threshold. The final overall integrated confidence rating of the integrated assessment was high for most of the open-sea assessment units, corresponding to 63%, while confidence was moderate in 37% of the open sea assessment units (Table 7). No assessment unit was assessed as low for integrated confidence.

Confidence class	Confidence (%)
High	>= 75
Moderate	>= 50 to < 75
Low	< 50

Table 7. Confidence of the results at indicator, criteria, and the integrated eutrophication status level (shown in the last column) in the open sea sub-basins. The confidence rating is grouped into three confidence classes (see legend below table). Empty white cells denote that the sub-basin was not assessed due to the lack of commonly agreed indicator methodology. An 'NA' in a white cell is shown for cases where the indicator is not applicable and '–' for cases where the confidence was not evaluated. Indicators marked with * have not been adopted in HELCOM yet and are currently tested. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', TN = 'Total nitrogen', DIP = 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', C1 = 'Criteria group 1 for nutrient levels', Chl a= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index', C2 = 'Criteria 2 for direct effects', Secchi= 'Secchi depth', O2 debt = 'Oxygen debt', Shallow O2* = 'Shallow water oxygen', BQI = 'Benthic quality index', and C3 = 'Criteria 3 for indirect effects'. For more details, see core indicator reports: HELCOM 2023c-k.

Assessment unit	Indicator confidence													Integrated confidence assessment
	Nutrient levels					Direct effects			Indirect effects					
	DIN	TN	DIP	TP	C1	Chl a	Cyano*	C2	Secchi	O_2 debt	Shallow O_2*	BQI*	C3	
	Dec–Feb	All year	Dec–Feb	All year		Jun–Sep	20 Jun –31 Aug		Jun–Sep	All year	All year	May–Jun		
Kattegat	100	100	100	100	100	95	NA	95	92	NA	-	NA	92	96
Great Belt	58	67	42	58	56	68	NA	68	71	NA	-	NA	71	65
The Sound	58	67	58	65	62	58	NA	58	60	NA	-	NA	60	60
Kiel Bay	81	79	81	76	79	89	NA	89	65	NA	-	NA	65	78
Bay of Mecklenburg	96	100	96	97	97	92	82	89	94	NA	-	NA	94	93
Arkona Basin	100	100	100	100	100	100	81	93	99	NA	-	NA	99	97
Bornholm Basin	97	89	94	89	92	91	79	87	81	100	NA	NA	94	91
Pomeranian Bay	60	56	51	56	56	81	70	77	65	NA	50	NA	53	62
Gdansk Basin	61	67	61	67	64	82	71	78	68	100	NA	NA	89	77
Eastern Gotland Basin	81	89	81	89	85	82	81	82	67	100	NA	NA	89	85
Western Gotland Basin	72	83	72	83	78	77	79	78	58	100	NA	NA	86	80
Gulf of Riga	42	81	39	81	60	80	82	80	44	NA	75	63	64	68
Northern Baltic Proper	79	89	79	89	84	86	76	83	60	100	NA	NA	86	84
Gulf of Finland Western	72	89	72	89	81	94	83	90	50	100	NA	38	65	79
Gulf of Finland Eastern	40	57	40	57	49	72	81	75	38	NA	50	38	43	55
Åland Sea	36	38	36	38	37	63	100	76	33	NA	NA	88	69	61
Bothnian Sea	79	68	79	68	74	82	83	83	69	NA	-	100	90	82
The Quark	50	53	50	53	51	72	NA	72	37	NA	-	88	71	65
Bothnian Bay	68	68	68	68	68	67	NA	67	69	NA	-	100	94	76

3.1.1 Coastal assessment

In the current eutrophication assessment, the coastal areas were assessed using indicator results provided by the HELCOM Contracting Parties. Russian coastal waters have not been assessed. The indicators and their threshold values where mainly those used under the Water Framework Directive (WFD), but the overall status was assessed using HEAT HOLAS 3 and therefore the overall status assessment might differ from the WFD. Under the WFD, the emphasis is on the biological elements, and information on nutrients, oxygen concentration and Secchi depth is used only as supportive to the assessment. In HEAT HOLAS 3, the coastal indicators are divided into three criteria groups (nutrient levels, direct and indirect effects of eutrophication), similarly to the open sea area assessment, and the overall status results depend on the worst assessed criteria group (one-out-all-out principle). Following the sequence of processes related to eutrophication – excess nutrient inputs, increased production/organic matter, decreasing oxygen levels, negative impacts on bottom fauna etc, it is reasonable to assess the three criteria groups separately and define the overall status based on the worst criteria result. Either individual WFD water bodies have been assessed or water bodies have been aggregated to larger assessment units.

Based on the integrated assessment, 77.2% of the coastal waters were not in good status, 5.6% were in good status and 17.2% were not assessed (Figure 8). In particular, indirect effects achieved good status in many of the coastal areas, including Swedish coastal areas and many Estonian and Finnish coastal areas (see Figure 5). Coastal waters in good status were mainly located in the Bothnian Bay, Quark, Bothnian Sea and Kattegat.

Although most of the Baltic Sea area was assessed as affected by eutrophication and defined as not being in good status, some discrepancies in the overall assessments can be noted. For example, some coastal areas near the Quark and the Kattegat area were assessed to be in good status, whereas the adjacent open sea areas were classified as poor and moderate, respectively (see Figure 5). The differences in nutrient status results between the open sea and coastal areas were visible between the northern-most open sea areas and the Finnish coastal units. Similarly, the Swedish coast next to Kattegat was assessed as good. Approximately half of the assessed coastal units in Estonia reached good status, while the adjacent open sea areas were in poor status. Nutrient status results were also conflicting near the river Oder delta, where the German coastal unit (GER-020) was 'bad' and on the Polish side (POL-002) nutrients were assessed as achieving good status. A discrepancy evident between the Gdansk basin and the Polish coastal unit, POL-005, was due to the 'high' status of dissolved inorganic nutrients in the coastal area.

Compared to nutrients, the assessment results of the direct effects were more balanced or similar (when looking at coastal and open sea units) in some regions (e.g., the Estonian coast, and the Kattegat area), but the differences were larger in other areas (e.g., the good status of Kiel Bay versus surrounding areas with moderate and poor status, and the good status of Swedish coastal areas near the Quark).

Considering the indirect effects of eutrophication, the assessment results mainly in the northern-most basins and the Kattegat area differ from the rest of the Baltic Sea by having reached good status. The good status in the Kattegat is due to the 'high' results of

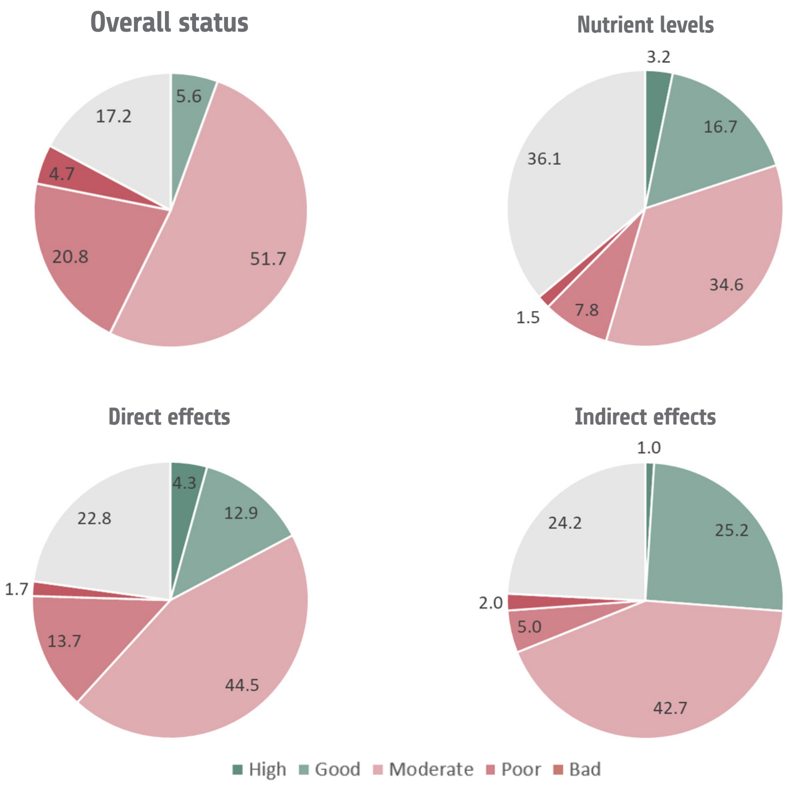


Figure 8. Proportional division (% of total coastal area) of coastal assessments (overall and by criteria group) in the HELCOM region. NA – not assessed. Basin-wise specifics can be found in Annex 2.

Secchi depth. In most of the other open sea basins where the Secchi depth and oxygen indicators were used, the assessment gave similar results, failing to achieve good status. Exceptions were the Pomeranian Bay and the Gulf of Riga, where the shallow water oxygen indicator was assessed as 'good', while Secchi depth was 'bad'. From the Åland Sea to the Bothnian Bay, the bottom fauna indicator showed that good status was achieved. This was also supported by the shallow water oxygen indicator in all northern open sea basins, except the Åland Sea. The Swedish and Finnish coastal areas, adjacent to the Bothnian Sea and the Bothnian Bay, respectively, indicated conflicting below good status results compared to the adjacent open sea areas.

Where coastal waters have been assessed as being in good status while adjacent open sea basins fail to achieve good status this could be due to a lack of alignment of the threshold values used in the assessment, but it could also represent real differences in eutrophication status. For instance, the internal load of phosphates could influence deeper open sea areas more than coastal waters, and thus, the nutrient status of open sea assessment units is worse than the nutrient status of coastal waters.

3.2. Changes over time for eutrophication

To evaluate changes between the previous assessment period and the current one, the assessment results were compared by calculating the percentual change between the two assessment periods. Comparisons were made using recalculated HOLAS II results and applying the approach used in the current HOLAS3 process to avoid methodological changes influencing the outcomes. The HOLAS II period of 2011-2016 was rerun in HEAT to get EQRS values necessary for the comparison (in previous assessments ER values were used). Since in HOLAS II, the Secchi depth indicator was a part of the direct effects of eutrophication, the comparisons between the direct and indirect effects criteria groups, and the integrated assessment results are not valid. Therefore, changes in nutrient levels and separate indicators, used in both assessments, are analysed.

Since the previous assessment period, there has been a significant deterioration in most of the eutrophication indicators in all assessment units. The most pronounced changes are observed in the northern basins. The southwestern basins, in turn, show signs of improvement for the integrated assessment results as well as for several indicators. The biggest improvement is seen in dissolved inorganic nitrogen (and total nitrogen) assessment results in the south-western basins (Table 8). The largest deterioration is seen in phosphates (and total phosphorus) estimates from the central Baltic Sea to the eastern and northern basins. A distinct negative change is also visible in cyanobacterial bloom and oxygen debt indicator results in the central basins. The largest improvements are seen in chlorophyll-a and cyanobacterial bloom indicator results in the Pomeranian Bay and the Eastern Gulf of Finland, respectively, although the status remains below good status. In the Kiel Bay, the DIN and TN results shifted from failing to achieve good status in HOLAS II to good status in the current assessment, which improved the nutrient levels assessment to almost good status (EQRS = 0.55). Also, the chlorophyll-a indicator reached good status in Kiel Bay, compared to HOLAS II. In the Great Belt, the total nutrients improved their good status even more, raising the nutrient level assessment EQRS from 0.64 to 0.70.

Table 8. Changes (%) in scaled ecological quality ratios (EQRS) between HOLAS II (2011-2016) and HOLAS3 (2016-2021) for the eutrophication indicators and the integrated assessment of nutrient levels by open sea sub-basins. Only numbers indicating a >= 15% change in the EQRS value are shown. Negative changes in assessment units are written in bolded numbers. Positive numbers indicate an improvement in the status of the ecosystem, whereas negative numbers indicate a deterioration. The background colors indicate the GES/sub-GES status classes of the current assessment (see legend below table). An 'NA' in a white cell is shown for cases where the indicator is not applicable. 'NA in H2' means that the indicator was not applied in the previous, HOLAS II, assessment. Indicators marked with * have not been adopted in HELCOM yet and are currently tested. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', TN = 'Total nitrogen', DIP = 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chl a= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index', Secchi= 'Secchi depth', O2 debt = 'Oxygen debt', and BQI = 'Benthic quality index'. For more details, see core indicator reports: HELCOM 2023-xx.

Assessment unit	DIN	TN	DIP	TP	Nutrient levels	Chl a	Cyano*	Secchi	O_2 debt	BQI*
Kattegat	26↑					-28↓	NA		NA	NA
Great Belt	29↑						NA		NA	NA
The Sound	36↑		23↑			-57↓	NA	-16↓	NA	NA
Kiel Bay	41↑	41↑			22↑	25↑	NA	16↑	NA	NA
Bay of Mecklenburg	96↑	18↑			23↑		-29↓	23↑	NA	NA
Arkona Basin							-30↓	40↑	NA	NA
Bornholm Basin				-18↓			-20↓	-23↓		NA
Pomeranian Bay						119↑	-44↓	20↑	NA	NA
Gdansk Basin	-35↓		-55↓		-25↓	-18↓	-18↓	-48↓	-35↓	NA
Eastern Gotland Basin	-20↓	-19↓	-21↓		-18↓	-16↓	-49↓	-41↓	-35↓	NA
Western Gotland Basin	-23↓						-27↓	-41↓	-35↓	NA
Gulf of Riga			-26↓					-29↓	NA	NA in H2
Northern Baltic Proper			-18↓				-52↓		-35↓	NA
Gulf of Finland Western			-22↓				NA in H2	-18↓	-35↓	NA in H2
Gulf of Finland Eastern			-32↓	18↑		-29↓	72↑	-21↓	NA	NA in H2
Åland Sea			-25↓	-19↓		-17↓	NA in H2	54↑	NA	25↑
Bothnian Sea			-34↓	-17↓			NA in H2	64↑	NA	
The Quark			-33↓	-43↓		-32↓	NA	-21↓	NA	N in H2
Bothnian Bay			-47↓	-17↓	-16↓	-45↓	NA	22↑	NA	

Status class	EQRS
High	>= 0.8 to < 1.0
Good	>= 0.6 to < 0.8
Moderate	>= 0.4 to < 0.6
Poor	>= 0.2 to < 0.4
Bad	< 0.2

Considering long-term trends of nutrient concentrations in the surface layer, there is an overall tendency towards improving conditions in the south-western basins (The Sound, Kiel Bay, Kattegat, Great Belt) and the worsening of conditions in the central (Northern Baltic Proper, Eastern and Western Gotland Basins etc.) and northern basins (The Quark, Bothnian Sea and Bay, Gulf of Finland Western and Eastern basins).

In Kiel Bay, dissolved inorganic nitrogen and total nitrogen concentrations have shown a significant improving trend since the 1990s, and in the majority, values indicating good environmental status have been observed in recent years (Figure 9). Phosphorus values, on the other hand, display high variability and remain mostly above the set thresholds – although a shift in mean concentrations can be observed after the 1980s. Similarly, to nitrogen indicators, an improvement is seen in chlorophyll-a concentrations and water transparency.

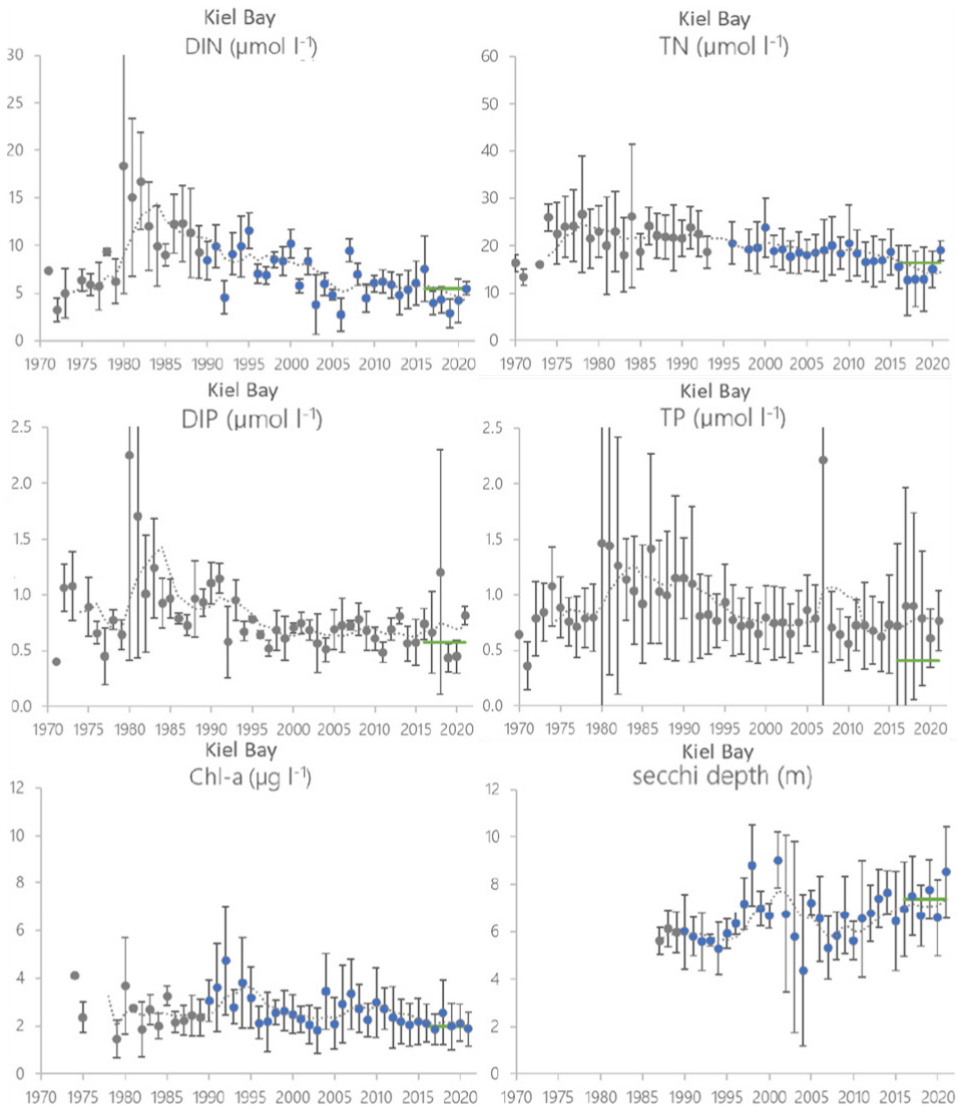


Figure 9. Nutrient, chlorophyll-a, and water transparency indicator long-term values in the Kiel Bay. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold value. Significance of trends was assessed with a Mann-Kendall non-parametric tests for the period from 1990-2021. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange colour. DIN – dissolved inorganic nitrogen; TN- total nitrogen; DIP – phosphates; TP – total phosphorus; Chl-a – chlorophyll-a; Secchi depth – water transparency.

In the central Baltic Sea, increasing concentrations of nutrients in the surface layer have been observed in recent years – the trend is significant for total phosphorus and phosphate concentrations and insignificant for total nitrogen and dissolved inorganic nitrogen concentrations (Figure 10, the northern Baltic Proper is shown as an example). Considering the degraded status of nutrient conditions (i.e., sub-Good Environmental Status), the chlorophyll-a and water transparency show corresponding values, which taken together reflect a significant worsening long-term trend in Secchi depth.

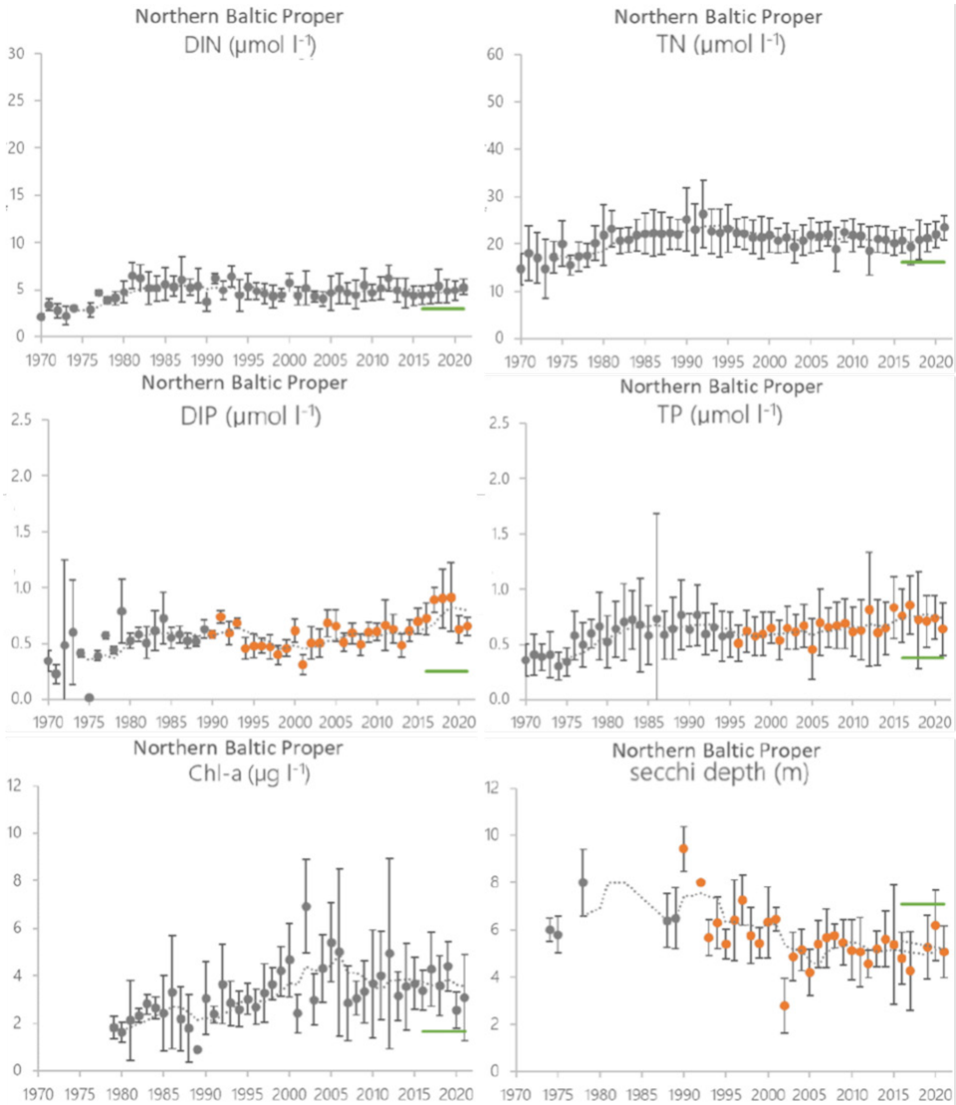


Figure 10. Nutrient, chlorophyll-a, and water transparency indicator long-term values in the Northern Baltic Proper. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold value. Significance of trends was assessed with a Mann-Kendall non-parametric tests for the period from 1990-2021. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange colour. DIN – dissolved inorganic nitrogen; TN- total nitrogen; DIP – phosphates; TP – total phosphorus; Chl-a – chlorophyll-a; Secchi depth – water transparency.

In the northern Baltic Sea, for the Bothnian Sea assessment unit, the nitrogen concentrations have remained quite stable since the 2000s and are slightly above the set threshold (Figure 11). Phosphorus values show significant increasing trends since the 1990s, and phosphate concentrations are clearly elevated in recent years. On the contrary, chlorophyll-a conditions seem to be improving in recent years, with a corresponding significant improvement in water transparency.

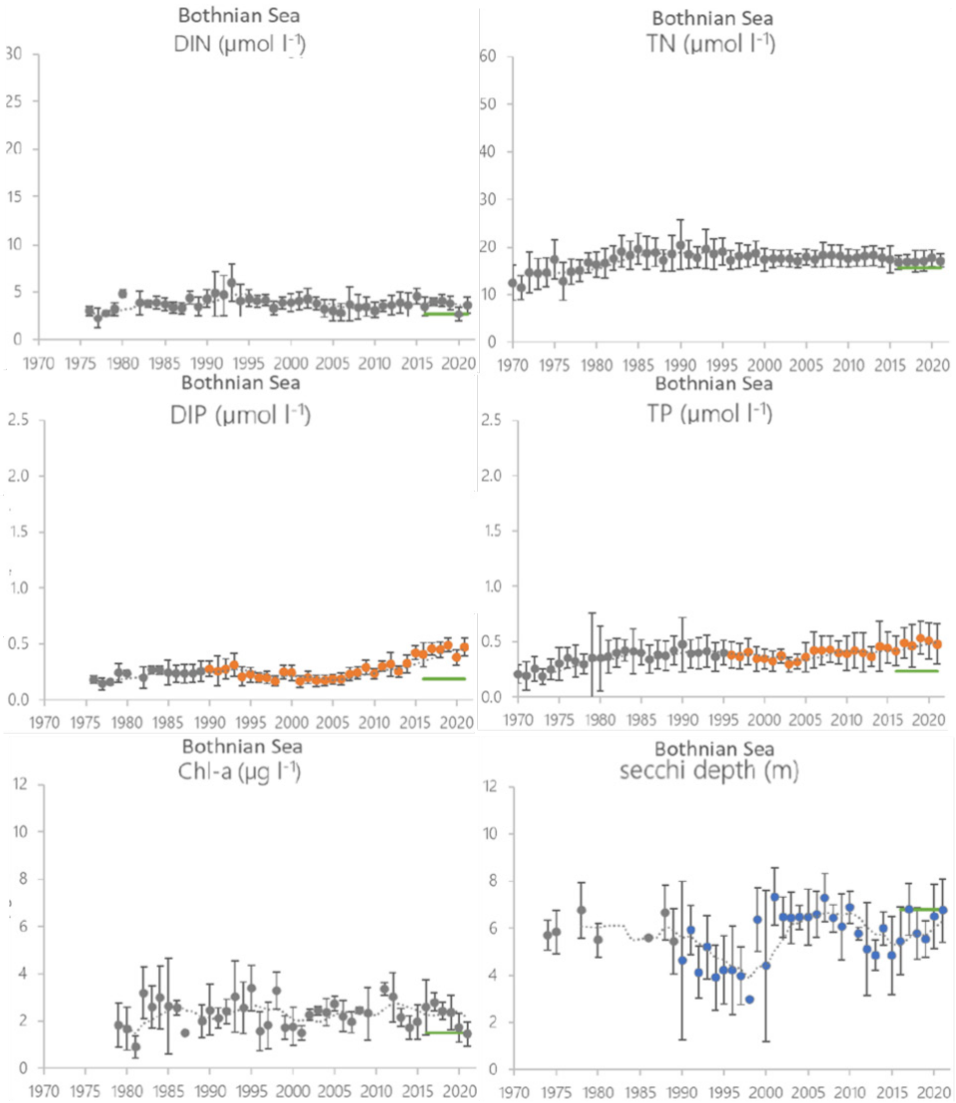


Figure 11. Nutrient, chlorophyll-a, and water transparency indicator long-term values in the Bothnian Sea. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold value. Significance of trends was assessed with a Mann-Kendall non-parametric tests for the period from 1990-2021. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange colour. DIN – dissolved inorganic nitrogen; TN- total nitrogen; DIP – phosphates; TP – total phosphorus; Chl-a – chlorophyll-a; Secchi depth – water transparency.

The cyanobacterial bloom indicator indicates a worsening trend from the 1990s or early 2000s to 2021 (depending on data availability) for most of the assessed areas. For the Bornholm Basin, Eastern Gotland Basin, Gulf of Finland Eastern, and Gdansk Basin, no significant trend was found.

Oxygen debt below the halocline has increased in both assessment areas (Baltic Proper and Bornholm Basin) since the early 1900s. A significant deteriorating trend has been observed in both areas since 1990 (Figure 12). Estimating the trends starting from 1990 and comparing them to the long-term trends, the decadal change rate has quadrupled for the Baltic Proper and doubled for the Bornholm Basin. The Bornholm Basin has experienced larger inter-annual variability because of larger variations in the oxygen concentrations, mainly due to natural water flows or processes. However, inter-annual variability was also high in the Baltic Proper during the last decade, when the five-year moving average revealed a significant increase in oxygen debt.

Although the eutrophication status based on shallow water oxygen conditions has been assessed as both good and not good in different basins, the general decreasing trend in near-bottom oxygen concentrations prevails. In the Gulf of Finland Eastern sub-basin, the near-bottom oxygen concentrations show a declining long-term temporal trend (1906-2021). Oxygen in deep waters has declined over the past decades in the Bothnian Sea (1990-2012), and a similar though more moderate trend has been observed in the Bothnian Bay. In the Gulf of Riga, dissolved oxygen values below 2 ml L^{-1} (2.9 mg L^{-1}) have been observed more often in the past 20 years, and a statistically significant oxygen decrease was found in 2005-2018, based on monitoring data from autumn. The excess load of nutrients is a major factor behind the worsening deep layer oxygen conditions, but partly this trend can be related to the strengthening of the vertical stratification and a long-term increase in water temperature (decrease in oxygen solubility).

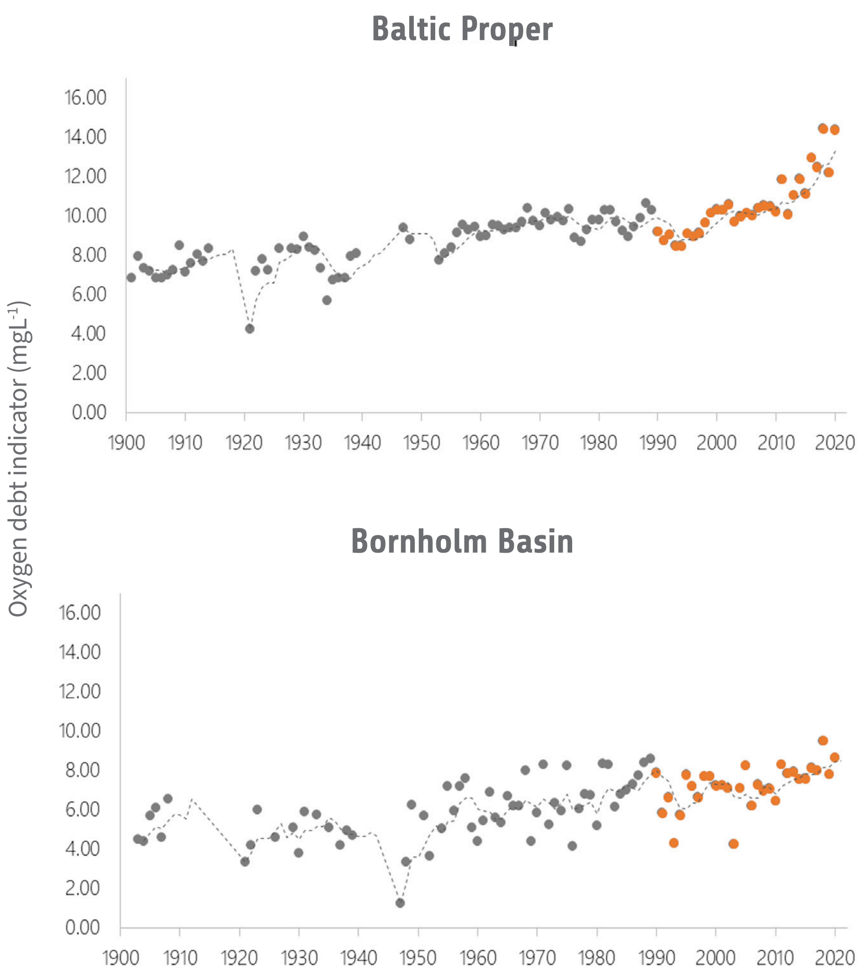


Figure 12. Temporal development in the core indicator 'Oxygen debt' in (top) the Baltic Proper (containing Eastern Gotland Basin, Gdansk Basin, Western Gotland Basin, Northern Baltic Proper and Gulf of Finland Western) and (bottom) Bornholm Basin, showing the volume specific oxygen debt below the halocline based on the data and subbasin division delineation of HELCOM (2017). Note that the oxygen debt indicator value can exceed the solubility of oxygen since it also includes the oxygen required to oxidize reduced compounds like e.g. hydrogen sulphide. The dashed line shows the five-year moving average. The significance of the trend was tested for the period 1990-2020 by the Mann-Kendall nonparametric test. The data within the examined period are coloured orange to visualize the tested significant ($p<0.05$) deteriorating trend (an increasing trend in oxygen debt signifies deteriorating oxygen conditions).

3.3. Relationship of eutrophication to drivers and pressures/biodiversity

3.3.1 Relationship to drivers

DAPSIM (Driver-Activity-Pressure-State-Impact-Measure) is a conceptual management framework utilized in HELCOM for visualizing the relationships between society and the environment (HELCOM, 2020) (Figure 13). Within this framework and for HOLAS 3 purposes drivers were considered to be ''societal and environmental factors that, via their effect on human behaviour or environmental conditions, may influence activities, pressures, or the state of the marine environment''. To make drivers useful in an assessment context, selected driver indicators were developed as explanatory proxies, where suitable information that could be quantified was available. The analysis of these driver indicators can be used as a tool to understand societal trends, inform policy makers of environmental risks and to comprehend the interconnectedness of society and the environment, and identify efficient measures. Concerning eutrophication, two driver indicators were further developed that address two of the most relevant sources of nutrient inputs to the Baltic Sea – agriculture and wastewater.

Agriculture is a vital economic activity and the largest source of nutrient inputs to the Baltic Sea, contributing over 70-90% of nitrogen and 60-80% of phosphorus. It accounts for almost half of the total waterborne inputs to the sea, with a considerable portion originating from fertilizer consumption and manure input. Various drivers determine the size and structure of the agricultural sector in the region (Agricultural nutrient balance HELCOM driver indicator). Globalization, demographics, and changing consumer demand broadly influence agriculture through market forces, while agricultural subsidies and regulations are used to reinforce or weaken those market forces. Much of the nutrient inputs to agriculture occur when inorganic fertilizers or manure are applied to agricultural fields to increase crop growth. Not all the applied nutrients will be retained in the soil or taken up by crops, and this portion can contribute to the nutrient load to the Baltic Sea. Particularly in regions with high animal husbandry density, the distributional challenges for the efficient use of manure resources can lead to nutrient loading. Based on this knowledge, agricultural nutrient balances have been selected as a driver indicator to assess the potential risks of a surplus or deficit of nutrients for agricultural land, and they are a key indicator for the sustainability of agricultural production. Nutrient balances are defined as the difference between nutrient inputs (fertilizer consumption, manure input and other inputs) and nutrient outputs (the uptake of nutrients for crop and pasture production) in agricultural environments.

The nutrient balance in the Baltic Sea region has been relatively stable over the past decade, although several national trends were observed (Agricultural nutrient balance HELCOM driver indicator). All Baltic Sea countries have nitrogen surpluses per hectare, with the highest surplus values were observed in Denmark, driven by high inputs from manure production. Germany and Latvia have shown a decreasing nitrogen surplus trend. Denmark, Germany, and Poland have the highest nitrogen surplus per hectare, parallel to high levels of animal husbandry and crop production. Unlike nitrogen, phosphorus balance shows a more diverse picture with both deficiencies and surpluses. Germany, Estonia, Lithuania, and Sweden have shown phosphorus deficiency, and the highest deficiency values were observed in Estonia. Currently, it is not possible to link the agricultural nutrient balance to specific relevant drivers like consumer demand, globalization or demographics in the Baltic Sea. Further work is required to explore these linkages.

HELCOM will work further to manage agricultural nutrients, and there are several actions in the updated BSAP that could lead to further reducing nutrient surpluses in agriculture. These include balancing fertilization rates site-specifically and promoting precision fertilization practices, discouraging the application of manure and other organic fertilizers in the autumn in fields without green plant cover in winter, and implementing and enforcing the provisions of part 2 of Annex III "Prevention of pollution from agriculture" of the 1992 Helsinki Convention.

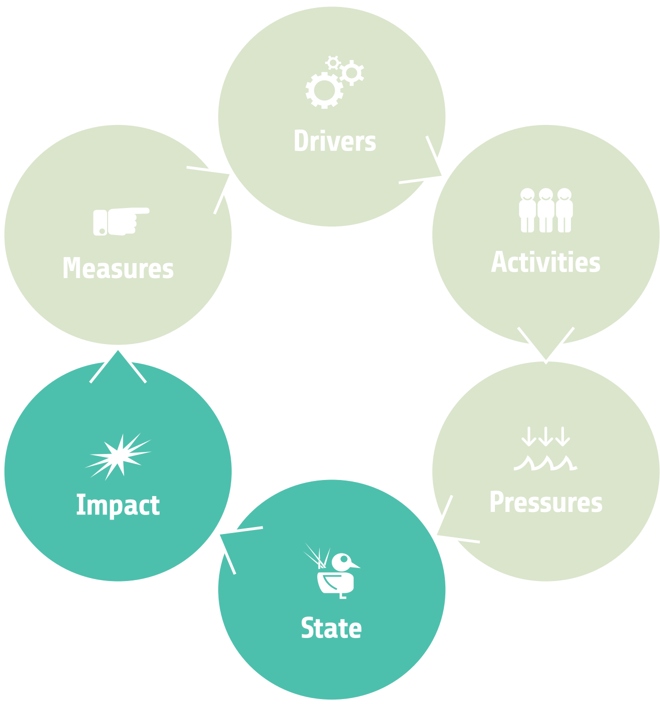


Figure 13. Schematic showing what sections of the DAPSIM cycle this assessment focuses on.

The recent EU agricultural outlook report suggests that agricultural activity and nutrient balance in the Baltic Sea region will remain stable until 2031. Future development under the EU Common Agricultural Policy and the EU Zero Pollution Strategy and Farm to Fork Strategy will have a large influence on how agriculture develops in the HELCOM Contracting Parties that are also EU Member States.

Wastewater treatment has proven to be an impactful method to improve the state of the Baltic Sea, and it is considered one of the most feasible and cost-effective measures (Wastewater treatment HELCOM driver indicator). HELCOM Contracting Parties have made major efforts in this field, and many cities in the region have improved their treatment standards in recent years, now meeting the requirements set by the EU Urban Wastewater Treatment Directive. Furthermore, to protect the sensitive marine environment of the Baltic Sea, HELCOM has recommended even stricter standards (Recommendation 28E/5).

In 2017 HELCOM Contracting Parties reported nitrogen loads of 69 800t and phosphorus loads of 4220 t coming from urban wastewater treatment plants in the Baltic Sea catchment area. In total, around 52 million people were connected to tertiary wastewater treatment plants in the Baltic Sea catchment area in 2020, representing 72% of the total population, and the population connected to tertiary wastewater treatment facilities has been steadily increasing. The HELCOM ACTION project estimated that if all municipal wastewater treatment plants (MWWTPs) would follow the HELCOM recommendation 28E/5, nitrogen loads could be reduced by 20% (13 600 t) and phosphorus loads by 49% (2050 t), with the largest potential for reductions in Poland and Russia and also for nitrogen in Sweden (HELCOM Action project report). These expected reductions constitute 1.6% of the total nitrogen inputs entering the Baltic Sea in 2017 and 7.2% of the total phosphorus inputs (Summary of PLC 7 project).

In the updated BSAP, action E23 aims to strengthen the HELCOM Recommendation 28E/5 on municipal wastewater treatment by 2027, and there is the potential to recommend higher treatment levels expected to result in further reductions of the nutrient load from MWWTPs. Additionally, with the increase of extreme weather events, the reduction of stormwater and combined sewer overflows becomes more important. All of these measures will contribute to reducing the influence of wastewater as a driver of Baltic Sea eutrophication, and they require financial investments and political will.

In the future, additional drivers of Baltic Sea eutrophication, such as energy consumption, could be investigated, and the differentiation between drivers and activities that cause eutrophication needs to be further explored.

The eutrophication pressure is caused by the excess supply of nutrients (nitrogen and phosphorus) to the marine environment. Compilation of data on the nutrient load has been an integral part of the HELCOM assessment system since 1987. It includes annual and periodic reporting of national data and subsequent release of related assessment products. Recently, the Seventh HELCOM Pollution Load Compilation (PLC-7) has delivered detailed data on sources, amounts, and relevant pathways of nutrient inputs into the Baltic Sea.

Nitrogen and phosphorus reach the Baltic Sea via three major pathways. They can be transported by rivers (riverine input), deposited from air (airborne input), and discharged directly to the Baltic Sea from various industrial and municipal wastewater treatment facilities located on the seacoast, as well as from marine fish-farms.

Riverine input was the dominating pathway for nitrogen and phosphorus in 2017, constituting 73% of total nitrogen and 88% of total phosphorus input to the Baltic Sea. The second most important pathway was airborne input, nearly 24% for total nitrogen and more than 7% for total phosphorus.

Total average inputs of both phosphorus and nitrogen for the entire Baltic Sea have reduced over time, but the reduction of nutrient inputs achieved in 2017 since 1995 was not equivalent for different pathways. The highest reduction was achieved for direct point sources. The proportion of direct input was reduced from 5.5 % to 3.1 % for nitrogen and from almost 11 % to almost 5 % for phosphorus. The proportion of airborne input of nitrogen has decreased from about 29% in 1995 to less than 24% in 2017. The proportion of riverine input of both nutrients increased from 1995 to 2017. The growth constituted about 10% for nitrogen and 4% for phosphorus.

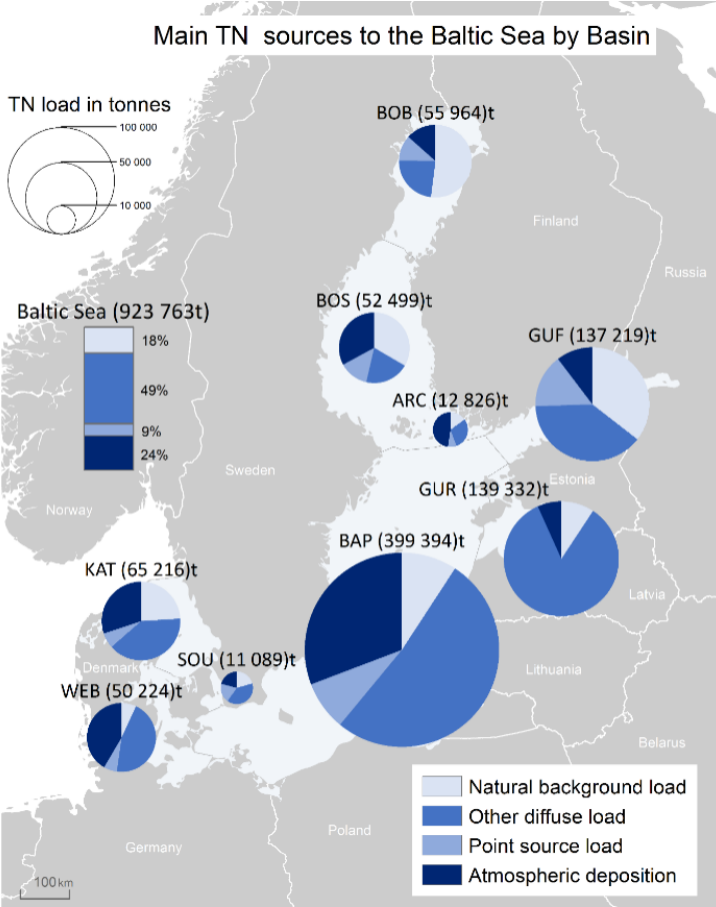
Sources of nitrogen and phosphorus loads on the Baltic Sea can be aggregated in four main groups: natural background load, other diffuse sources (riverine), point sources load (inland and direct), and air deposition. Diffuse loads of both nitrogen (49%) and phosphorus (56%) dominate in the entire Baltic Sea. Deposition from air (24%) and natural background (18%) are other main sources of nitrogen load to the Baltic Sea. For phosphorous loads to the Baltic Sea, natural background (20%) and point sources (17%) are other major contributing sources. Natural background loads of nitrogen and phosphorus constitute nearly a quarter of the riverine load of nutrients to the Baltic Sea in 2017.

Other anthropogenic diffuse sources such as agriculture (the dominating one), managed forestry, wastewater from scattered dwellings, storm waters, etc. made up about two-thirds of the total riverine nitrogen and phosphorus load to the Baltic Sea in 2017. Different land use characteristics (proportions of agricultural lands, managed forests, scattered dwellings etc) result in large variation of loads. Inland point sources constitute 7% of the total nitrogen load and 13% of the total phosphorus load.

3.3.2 Relationship to biodiversity

Eutrophication is one of the main threats to the biodiversity of the Baltic Sea and is caused by excessive inputs of nutrients into the marine environment. Nutrient over-enrichment causes changes in algal species composition and nuisance blooms of algae, increased turbidity, and sedimentation of organic material, eventually leading to oxygen depletion, with severe negative impacts on benthic communities. Eutrophication is associated with changes in species composition within several key trophic groups in the Baltic Sea. Besides pelagic primary producers and benthic fauna, coastal fish and sea birds are also affected in terms of habitat quality, feeding conditions, and food web structure.

While phytoplankton is directly affected by eutrophication pressure, zooplankton and higher trophic groups are more indirectly impacted and may show a delayed or weaker response to eutrophication than phytoplankton. This is further complicated by the fact that the effects of eutrophication cannot be clearly attributed, as there is overlap with other pressures such as climate change, hazardous substances, or non-indigenous species. In particular, the effects of climate change can lead to an intensification of eutrophication effects through increased stratification and further deterioration of near-bottom oxygen conditions, associated with an increase of the internal nutrient loading (HELCOM/Baltic Earth, 2021).



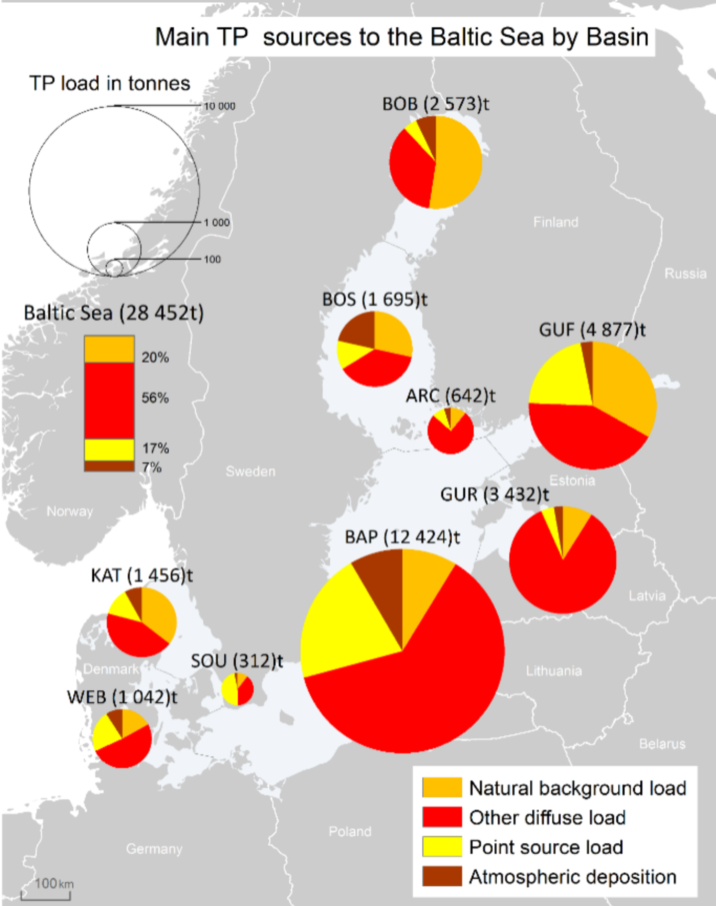


Figure 15. Major sources of A) total nitrogen and B) total phosphorus loads to the Baltic Sea subbasins in 2017 (PLC7).

Phytoplankton blooms are a natural phenomenon in the Baltic Sea ecosystem, with yearly spring blooms dominated by dinoflagellates and diatoms, and blooms in late summer dominated by nitrogen-fixing cyanobacteria. A deviation from the normal seasonal cycle, such as a too high or too low biomass, or the absence of some dominating phytoplankton groups, is indicative of an impairment of environmental status and evaluated with the seasonal succession of dominating phytoplankton groups indicator. Changes in the amount of nutrients or the ratios of nitrogen and phosphorus can lead to alterations in phytoplankton species composition, resulting in more intense and frequent phytoplankton blooms during the summer due eutrophication.

The zooplankton community structure is evaluated with the zooplankton mean size and total stock indicator, and good environmental status is generally achieved when large-bodied zooplankters are abundant. During the period 2016-2021, a negative development towards low mean size values was observed in several sub-basins of the Baltic Sea due to changes in the zooplankton community (increased rotifers and cladocerans), as a probable consequence of eutrophication, but also due to size-selective predation and possible altered environmental conditions with regard to decreased salinity, increased temperature, and deep-water hypoxia. The detected trends indicate that the pelagic food web structure is not optimal for energy transfer and productivity.

In the pelagic habitat assessment, the eutrophication pre-core indicator cyanobacterial bloom index is directly included in the assessment of the biological component (plankton indicators), along with the seasonal succession of dominating phytoplankton groups and zooplankton indicators. Additionally, a eutrophication pressure component consisting of chlorophyll-a and water transparency (Secchi depth) indicators is taken into account for the overall pelagic habitat assessment. None of the open sea or coastal areas assessed had good status from the eutrophication perspective when also taking the eutrophication indicators into account, and there was no clear sign of improvement since HOLAS II.

Benthic habitats are affected by eutrophication, among several other pressures such as fishing, extraction, or shipping. Of special concern is the large area with low oxygen, or no oxygen at all, in deep waters of the central Baltic Sea, which limits the distribution of benthic fauna with implications for overall food web productivity. The eutrophication indicator oxygen debt is directly included in the ‘state component’ of the benthic assessment, together with the soft-bottom macrofauna community indicator. The soft-bottom macrofauna community indicator clearly reacts to hypoxia and anoxia in bottom waters in large areas of the Baltic Sea caused by eutrophication (HELCOM Indicator Report, 2023). Hypoxia has resulted in habitat destruction and the elimination of benthic macrofauna over vast areas, severely disrupting benthic food webs. As conditions deteriorate, species composition changes, leading to smaller-sized and/or tolerant species and resulting in decreasing total biomass and diversity of the soft-bottom macrofauna community as sensitive, large-sized, and long-lived species disappear.

The benthic habitat assessment also considers the eutrophication indicator shallow-water oxygen, reflecting the linkage between oxygen depletion caused or intensified by eutrophication and related deteriorated environmental conditions for the benthic community in shallow areas where the oxygen debt indicator is not applicable.

To reach good environmental status of the Baltic Sea, Contracting Parties have agreed on a nutrient reduction scheme consisting of regional inputs targets. Maximum allowable inputs (MAI) are a part of the HELCOM nutrient reduction scheme, indicating the maximum level of total (water- and airborne) input of nitrogen and phosphorus to the Baltic Sea sub-basins (MAI catchment area meta data) that is allowed to fulfil the targets for a sea unaffected by eutrophication. Nutrient Input Ceilings (NIC) are calculated based on the MAI and define the maximum inputs via water and air to achieve good status with respect to eutrophication for Baltic Sea sub-basins for each country. Regular follow-up of MAI and NICs is undertaken in HELCOM.

3.4. How was the eutrophication assessment carried out?

The integrated assessment of eutrophication was carried out using the HELCOM Eutrophication Assessment Tool (HEAT HOLAS 3 version) which aggregates the indicator results into a quantitative estimate of overall eutrophication status. The HEAT tool was further developed since HOLAS II and the calculation process transferred to an R-script. The assessment procedure is fully available online on GitHub and can be run based on the HEAT master code for both HOLAS II and HOLAS 3. The applied assessment structure using different indicators assigned to the three criteria groups of nutrient levels, direct and indirect effects is presented in Figure 3 of chapter 2, and the more detailed specifications on how the assessment is carried out are presented in Annex 1.

For coastal areas, there was great variation among the indicators used in different parts of the region, which will decrease comparability between the results achieved in different coastal assessment units. A total of 37 coastal indicators were reported and used. Some of the indicators were aggregated in the assessment dataview into quality elements under the notion that they represent similar aspects (e.g., the zoobenthos quality element). However, as these indicators were estimated in different assessment units, this assumption had no effect on the overall HEAT assessment.

The confidence assessment

The confidence assessment is carried out on temporal, spatial, and accuracy aspects and can be complemented by methodological confidence. The confidence of the results in open-sea assessment units is assessed at both indicator and integrated eutrophication status levels. The final confidence rating for each assessment unit may range from high to low and is grouped into three confidence classes: high (75- 100), moderate (50-<75), and low (below 50; Table 7). The calculation of confidence is done in three steps:

1. Indicator confidence

Confidence assessment results per indicator are combined from the following attributes:

- Temporal and spatial confidence on annual basis, averaged over the assessment period
- Accuracy confidence for entire assessment period, averaged with temporal and spatial confidence to indicator confidence
- Partly inclusion of methodological confidence (State of the soft-bottom macrofauna, Shallow-water oxygen indicator in selected assessment units)

To provide an average value, the confidence rating for each assessment is given a value between 0 and 100 based on the defined class boundaries for the different confidence aspects and is grouped into three confidence classes: high (100), moderate (50) and low (0). The confidence on indicator level is averaged from temporal, spatial and accuracy confidence per assessment unit.

2. Criteria-specific confidence
Criteria-specific confidence is assessed as the (weighted) arithmetic mean of the confidences of the indicators within each criterion and follows the corresponding status assessment with respective indicator weights used.

3. Overall confidence
The final confidence rating is the arithmetic mean of the criteria-specific confidences. All criteria are weighed equally, and criteria groups not having any indicators are ignored. Indicators that have not been assigned confidence values are not included in the confidence assessment. The concept of assessing confidence was updated since HOLAS II and implemented in the HEAT tool, so that it is better comparable to what is used in the HELCOM BEAT tool for the integrated assessment of biodiversity. Estimates on spatial representativity and accuracy are now included besides the temporal confidence and partly also methodological confidence of the monitoring data. Further information and details of the calculation as included in the HEAT tool can be found on GitHub (https://github.com/ices-tools-prod/HEAT). Confidence was not assessed for coastal waters.

The results from this confidence assessment methodology are presented in section 3.1 and table 7. For more details on the confidence assessment methodology and integration to the HEAT tool, Annexed table A1.2 gives a broader comprehension of the different types of confidence that are evaluated.

3.5. Follow up and needs for the future with regards to eutrophication

HELCOM has defined five ecological objectives that, when fulfilled, indicate that the Eutrophication Goal of the Baltic Sea Action Plan (BSAP) has been fulfilled. These objectives are:

— Concentrations of nutrients close to natural levels
— Clear waters
— Natural level of algal blooms
— Natural distribution and occurrence of plants and animals
— Natural oxygen levels

In the BSAP, there is an overarching management objective to achieve the ecological objectives: to minimize inputs of nutrients from human activities. Since 2007, HELCOM has set quantitative nutrient input reduction targets. These targets were significantly revised in 2013 and have been adjusted and refined since then. Importantly, these reduction targets have been adopted by the governments of the HELCOM Contracting Parties, and significant work has gone into implementing them.

The 2021 update of the Baltic Sea Action Plan includes four commitments to maintain the ambitious goals of the Contracting Parties. These involve measuring and reporting progress towards the targets, as well as reporting on the measures implemented by Contracting Parties , along with an explanation of how these measures will be sufficient to meet the targets.

Beyond the monitoring and reporting activities, the 2021 BSAP includes measures aimed at specific economic sectors. The most important of these is agriculture, which still remains the foremost anthropogenic source of nutrients in the catchment. While many of these measures should already have been implemented under previous HELCOM commitments, the BSAP 2021 includes additional commitments about structural liming to improve soil granularity and reduce surface losses, as well as measures to reduce losses of ammonium to the atmosphere. As other atmospheric emissions have reduced, particularly with the ongoing electrification of transport and heating sectors, ammonium emissions from agriculture have become the most significant atmospheric nitrogen source to the Baltic Sea. Since ammonium is rarely transported far in the atmosphere, measures taken by the HELCOM Contracting Parties are likely to have a positive effect on the Baltic Sea. The work to develop Best Available Techniques (BAT) and Best Environmental Practices (BEP) for ammonia and greenhouse gas emissions should both reduce eutrophication but also improve air quality and human health, as ammonium is associated with the formation of harmful PM2.5 particles in the atmosphere.

The BSAP 2021 also commits Contracting Parties to develop recommendations for manure management specifically for horses, sheep, goats, and fur farms. These sectors have frequently been overlooked in national regulations, as they are often associated with smaller farms or recreational activities. For instance, in Sweden, there were about 360 000 horses in 2016 (Sweden's official statistics 2016), which compares to about 301 000 dairy cows (in 2019, Sweden's official statistics 2019). Horses are concentrated in regions with the highest populations, particularly around major population centres, which are often coastal areas. This reduces the potential for nutrient retention in lakes and streams before inputs reach the sea.

HELCOM Contracting Parties have also committed to implementing EU BAT and BEP for pig and poultry production, as well as developing and applying innovative methods to reduce nutrient surpluses and losses. These methods may cover taxation of nitrogen surpluses and improved water management measures when upgrading agricultural drainage systems.

The wastewater treatment sector is also a significant source of nutrients to the Baltic, although this is somewhat misleading as the sector collects and processes wastewater from us all, rather than being the source itself. The BSAP 2021 identifies ways to improve knowledge transfer between wastewater treatment plants, particularly in smaller settlements. There is a plan to strengthen the present HELCOM recommendation on wastewater treatment and actions to reduce nutrient inputs to treatment plants by reducing phosphorus use in detergents for industrial and institutional use.

To facilitate better manure management, HELCOM has committed to improving the recycling of nutrients to incentivise re-use rather than continued import to the catchment as mineral fertiliser, fodder and food. The recycling strategy involves measures in the agriculture and wastewater sectors to ensure that recycled fertiliser products are safe and clean and can be used in agriculture as effectively as mineral fertilisers, enabling field-level nutrient planning and farm-gate nutrient balances to be achieved.

In addition to joint actions through the EU and IMO, HELCOM Contracting parties continue with national and international research activities to better understand the processes and dynamics governing the Baltic recovery from eutrophication. Sweden has funded researchers to sample bottom sediment from eutrophic bays to the deep offshore basins to better understand the distribution and bioavailability of legacy phosphorus. During the summer of 2022, RV Skagerrak made a series of deepwater sediment incubations, directly measuring the adsorption and re-release of phosphorus under different oxygen conditions. This work will help develop understanding of whether it is possible to affect the internal phosphorus dynamics and speed up the large-scale recovery of the Baltic.

Connected to this work, SMHI have modelled whether it is possible to re-oxygenate the Baltic through large-scale pumping. Preliminary results suggest that a set of 60 – 70 large pumps could oxygenate the Baltic, but there was no sign that any recovery was sustainable without this ventilation even after 20 years of pumping. The study conclusions appear to be that at present, we have no alternative to reducing the nutrient load from land as quickly as possible.

What other regional actions are being taken to address this, outside of HELCOM?

The HELCOM actions are supported by activities in the EU and also within the UNECE. The EU has launched a Zero Pollution Action Plan as part of the EU Green Deal which, together with the coming Integrated Nutrient Management Action Plan, aims to reduce losses of nitrogen and phosphorus by 50% by 2030. This objective will be achieved in part by revisions to EU directives. Of particular interest are proposed revisions to the Urban Wastewater Treatment Directive (UWWTD), the Industrial Emissions Directive and the Marine Strategy Framework Directive.

The initial proposal for a recast UWWTD foresees the achievement of higher standards, particularly for smaller treatment plants, and an improved management of stormwater and combined sewer overflows, which is likely to have a significant positive effect in reducing emissions to water. The revision also implies an increased focus on upstream measures to reduce inputs of hazardous substances to treatment works, and this work will improve the quality of sewage sludge and make it more suitable for nutrient recycling. The European Commission has proposed regional scoreboards to enable citizens to follow up the performance of their respective regions and governments.

The UN Economic Commission for Europe continues to drive improvements in air quality under the Convention for Long-range Transboundary Air Pollution (CLRTAP) and specifically the convention's Gothenburg Protocol, which limits emissions of eutrophying and acidifying substances. The CLRTAP taskforce has published guidance on Integrated Sustainable Nitrogen Management as well as Options for Ammonia Mitigation. Through the implementation of the Gothenburg Protocol, it is expected that atmospheric deposition to the Baltic Sea will be reduced by 15 to 22%, depending on the basin, based also on measures taken by the UNECE States that are not HELCOM Contracting Parties (EMEP MSC-West 2018). The Gothenburg Protocol is currently under review, and the inclusion of the protection of the Baltic Sea ecosystem is promoted as an additional criterion in this process, which might result in stricter emission targets for nitrogen.

The International Maritime Organisation agreed in 2016 to implement a Nitrogen Emission Control Area (NECA) in the Baltic and North Seas, which is expected to reduce inputs by 16 800 tonnes per year. The SCIPPER project suggests that these optimistic assumptions for the effects of the NECA might not hold due to a number of reasons. Firstly, the threat of new ships needing to adhere to the stricter regulations led to a large number of keels being laid speculatively prior to the 2021 deadline so that the completed vessels would remain exempt. Secondly, there was a high rate of non-compliance with the Tier III standards observed, and thirdly, for ships operating at low speed the SCRs (selective catalytic reduction) do not work efficiently, resulting in higher NOx emissions. When ships increasingly operate using ammonia as fuel in the future, an increase in ammonia emissions is expected if no limit values are introduced for these emissions.

What actions/measures would be needed to improve the situation?

Excess input of nutrients remains the main causative factor for the poor eutrophication status of the Baltic Sea. Several other factors are, however, believed to contribute to the problem as well. The Baltic Sea has been a recipient of excessive nutrient inputs for at least 70 years. This has resulted in a degraded ecosystem, which is less able to process today's incoming nutrients. Between 1998 and 2021, there was a substantial increase in the hypoxic and anoxic area of the Baltic seabed (Martin Hansson & Lena Viktorsson, 2021) , which further reduced the ability of the seabed to sequester phosphorus and even released more phosphorus into the water column. As a result, the Baltic Sea is impacted both by new inputs of phosphorus from land, as well as the accumulated historical inputs.

As the 'internal' or accumulated phosphorus load is significantly larger than the annual inputs from land, it takes a considerable time for the input reductions to improve large-scale eutrophication. Estimates suggest a time lag of the order of 70 – 100 years before "natural" nutrient and oxygen conditions are achieved. A result of the high phosphorus levels due to the internal loading is that many coastal areas that were previously phosphorus-limited are now nitrogen-limited, and so measures to reduce nitrogen inputs should lead to local improvements in eutrophication symptoms – particularly concerning the magnitude of the spring bloom and growth of opportunistic seaweeds, if not the summer cyanobacteria blooms (Gustafsson et al. 2013).

Increasing temperatures due to climate change exacerbate the eutrophication problems (HELCOM climate change fact sheet 2021). Higher summer temperatures strengthen stratification and reduce the vertical transport of oxygen, while higher temperatures generally cause increased bacterial oxygen consumption, and hence result in lower oxygen levels in bottom waters. Thus, increased temperatures interact with high nutrient concentrations to sustain large-scale anoxia in the Baltic Sea. Higher temperatures are also expected to favour growth of nitrogen-fixing cyanobacteria. There is a significant risk that climate change will prevent the Baltic Sea from reaching good eutrophication status even if the agreed nutrient reduction targets are achieved. However, studies of the response of the Baltic Sea to different nutrient load scenarios in a likely future climate indicate that the nutrient load reductions of the Baltic Sea Action Plan are necessary to achieve environmental improvements under coming climate conditions (Saraiva et al, 2019)

Fisheries scientists have identified the impact that predatory fish have on the entire Baltic ecosystem, including effects of the loss of predatory fish, such as cod offshore and pike and perch in coastal waters. Theory suggests that there is a trophic cascade from predatory fish via mesopredatory fish and zooplankton to algae. Fewer top predatory fish may increase the number of mesopredatory fish such as sprat and stickleback, which has a negative effect on zooplankton and other grazers. This may limit the natural ability of the pelagic ecosystem to keep algal blooms under control. Theory is supported by model studies, in-situ experiments, monitoring data and lake management examples, but successful large-scale marine management examples are lacking.

The combination of eutrophication, climate change, and fisheries management that is not strong enough has led to a massive decline in the size and abundance of Baltic Sea cod. A similar decline has occurred in coastal predatory fish, probably exacerbated by habitat loss through coastal development. This has released sprat and stickleback populations from predatory pressure. It is unclear if the zooplankton and coastal amphipod populations have declined as a result, but this thematic report identifies problems with chlorophyll concentrations and algal blooms that could be expected from the collapse of the higher trophic levels as well as from eutrophication. Data on the extent of opportunistic filamentous algal blooms in coastal waters is unfortunately lacking at a HELCOM scale.

We lack knowledge on the ideal population and size structure of fish communities that are necessary to eliminate algal blooms and their resulting impacts. However, improvements in fisheries management, as well as protection of the seabed to allow recolonisation by filter feeders, should have a beneficial impact on the eutrophication status.

Even if the agreed nutrient reduction targets are achieved, the natural conditions of the Baltic Sea do not favour a fast recovery. The strong influence of the catchments, the poor water exchange, and the long residence time are all factors that contribute to an ecosystem that will be slow to change for the better. It may take decades or even centuries to achieve a healthy Baltic Sea where all five ecological objectives have been fulfilled. While this may initially be considered somewhat discouraging to management efforts, this should instead rather be taken as a reason to act strong and fast, first and foremost with regards to the overall management objective to minimize inputs of nutrients from human activities.

What would be needed in order to do a better assessment next time?

Monitoring and assessment of eutrophication is still largely dependent on in-situ observations from research vessels, although satellite data and ferry box data are increasingly used. In-situ sampling is expensive, which results in assessments often having a poor temporal and spatial confidence. New technologies, such as gliders instrumented with oxygen, light, sulphide and chlorophyll/turbidity/phycocyanin sensors, together with miniature autoanalysers (so-called “lab-on-a-chip” systems) would permit a massive improvement in data availability with a corresponding decrease in cost-per-sample. This would improve both spatial and temporal assessment confidence in the physical chemical data. These systems could permit the proper resolution of coastal – offshore gradients, which could explain the – seemingly illogical – result that offshore waters in some basins are more eutrophic than their coastal waterbodies. In addition, eutrophication assessments need to become increasingly supplemented by modelling efforts, for instance to determine the area and spatial extent of oxygen deficiency.

It is 10 years since HELCOM’s last comprehensive review of reference conditions and assessment thresholds (TARGREV BSEP133, HELCOM 2013). It is not definite that these reflect good environmental status for eutrophication in today’s climate. Models that contributed to the development of assessment thresholds have been steadily improved over the past decade, reflecting improvements in understanding of the biogeochemistry of the Baltic Sea and the linkages between indicators. A holistic review of eutrophication indicators and assessment thresholds, and the nutrient inputs required to achieve them, would be timely.

The knowledge gaps concerning trophic interactions and resulting algal responses are concerning. We require a better quantitative understanding of how fish populations control eutrophication symptoms and what phyto- and zooplankton abundance, biomass and species composition represent good status. Similarly, in coastal bays, what grazer populations are necessary to keep macroalgal blooms under control? What is the impact of organic carbon loads from land, the resulting “brownification” of water and coastal darkening? We also require a better understanding of the linkages between eutrophication effects and the conditions of pelagic habitats and in particular an understanding of how nutrient ratios influence the composition and succession of plankton and thereby the status of the pelagic indicators. Filling these knowledge gaps will enable further indicator development, which in turn will improve confidence in the overall assessment and point us towards appropriate measures to create, restore and maintain a post-eutrophication ecosystem.

4. Conclusions of the thematic assessment on eutrophication

The assessment results of HOLAS 3 demonstrate that eutrophication remains a major problem in the Baltic Sea, affecting different levels of the food web and contributing to ecosystem degradation. Nutrient inputs and associated elevated nutrient concentrations enhance phytoplankton growth, reducing light availability in the water, which negatively affects macroalgae, macrophytes and zoobenthos, and can lead to oxygen depletion at the bottom. While there are signs of improvements in some areas, particularly in the south-western sub-basins and partially in the northern areas, an alarming further deterioration is observed in central parts of the Baltic Sea. While there is good correspondence of reduced nitrogen inputs and decreasing nitrogen concentrations with decreasing chlorophyll-a concentrations in the south-western areas, phosphorus concentrations are increasing in some central and northern areas despite decreased phosphorus loads. This highlights the process of internal loads due to the release of phosphates from oxygen-depleted sediments, which needs further careful and thorough analysis for a better understanding and to find suitable solutions. It must also be reiterated that while the nitrogen and phosphorus load to the sea has decreased, it still significantly exceeds (MAI) both for the whole sea and for several sub-basins.

Since HOLAS II, the eutrophication assessment procedure has been further developed, and numerous improvements were achieved. These include refining assessment areas by sub-dividing regions with considerable spatial gradients (for example the Gulf of Finland), adjusting and agreeing previously missing threshold values, developing indicators, and including additional data types. A new generation of the HEAT tool (HEAT HOLAS 3) has been developed to address many of the needs identified after the HOLAS II assessment. This relates to the further development of the confidence rating, scaling of the different indicators for better comparability, reviewing indicator placement withing categories and their weighting, and a more transparent assessment process by transforming the HEAT calculation into an R-script publicly available on GitHub. Further improvements regarding monitoring, the use of additional techniques and data types as well as revised thresholds for the complete set of indicators are needed to substantiate status and confidence assessments in the future. In addition, there is a need for a better linkage of eutrophication pressures to biodiversity assessments, aiming to achieve a common understanding of what constitutes a good environmental status. This will help to harmonise the thresholds of the different indicators used in the assessments at the holistic level.

The eutrophication assessment results, indicating a failing good status in all open sea assessment areas, clearly demonstrate that negative impacts on organisms and human well-being will continue. Even if the agreed nutrient reduction targets are achieved, the natural conditions of the Baltic Sea do not favour a fast recovery, and it may take decades or even centuries to achieve a healthy Baltic Sea. This should encourage us even more to act efficiently and strongly in line with the management objective of the BSAP to minimize nutrient inputs from human activities. This becomes even more relevant when considering the increasing effects of climate change and their interaction with such processes.

The Baltic Sea ecosystem, already stressed for decades, is not resilient against further impacts and the additional pressure of climate change. Therefore, efforts should focus on reducing pressures, implementing appropriate measures, and strengthening resilience to create and maintain a post-eutrophication ecosystem that represents a sustainable and healthy Baltic Sea.

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Annex 1.
Manual for the assessment

The integrated assessment initially combines elements (indicators) by six criteria, in line with the structure of the MSFD methodological standards on good environmental status (EC 2017), and then further aggregates these into three criteria groups: nutrient levels, direct effects and indirect effects of eutrophication (Figure A1.1). The indicators within each assigned group are integrated using weighted averaging of the scaled ecological quality ratios which estimate how much different the assessment value is from the threshold value. The weight is evenly distributed unless otherwise justified. Indicator weights applied in HOLAS3 are presented in Table A1.1 below. No averaging is needed for criteria that consist of only one indicator (element). The overall eutrophication status is determined using one-out-all-out between criteria groups.

For each indicator the assessment value is calculated based on the available observation data. Indicator-specific reference values can be calculated based on the threshold value and the acceptable deviation or alternatively be directly reported for use in the HEAT tool. The acceptable deviation between the reference value and the threshold (good/moderate boundary) determines the widths of the class boundaries (for the remaining classes high/good, moderate/poor and poor/bad) in the calculation process. The ecological quality ratio (EQR) is calculated as the ratio of the reference and the assessment value for indicators responding positively to eutrophication (such as nutrients and chlorophyll) or vice versa for indicators responding negatively to eutrophication (such as Water transparency or bottom fauna). For improved comparability, the EQR values are transformed to scaled ecolog-

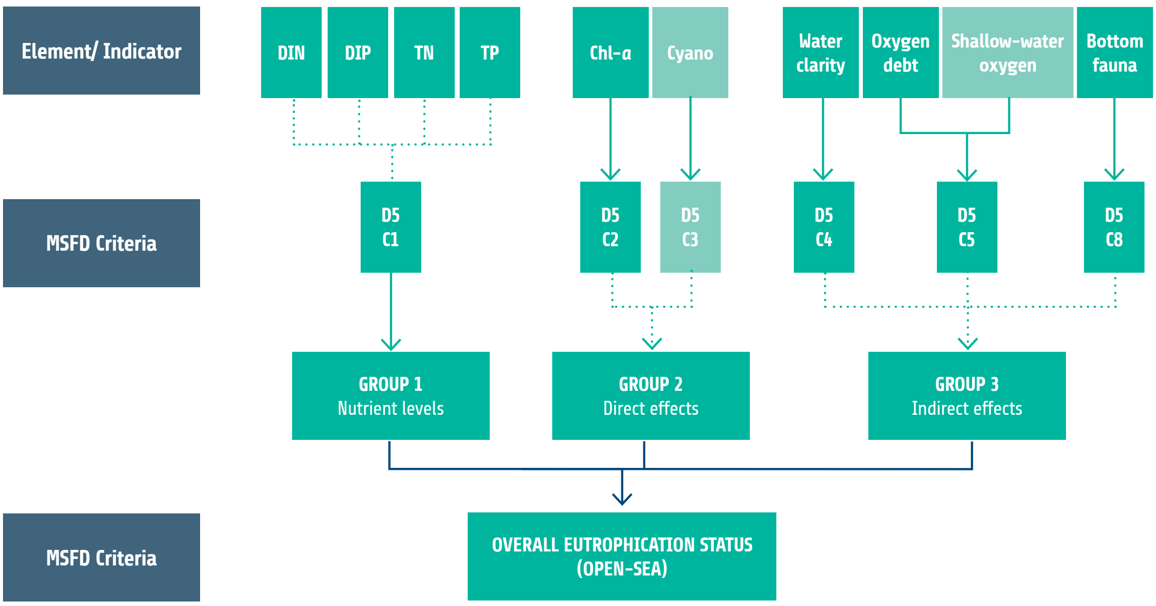

Figure A1.1. Structure of the eutrophication assessment for open-sea areas. The aggregation of indicators in the HEAT HOLAS3 tool based on criteria, and subsequently on criteria groups, considers the MSFD methodological standards. Pre-core indicators associated with primary criteria are shaded grey, whereas core indicators have no shading. Dashed blue lines indicate a process of weighted averages and solid red line indicates where a One-Out-All-Out process is adopted.

ical quality ratios (EQRS) into five equidistant 0.2 bands between 0 and 1. The step-wise procedure as calculated in the HEAT tool is illustrated in Figure A1.2. Details and specific calculation formulas can be found in the HEAT master code available on GitHub.

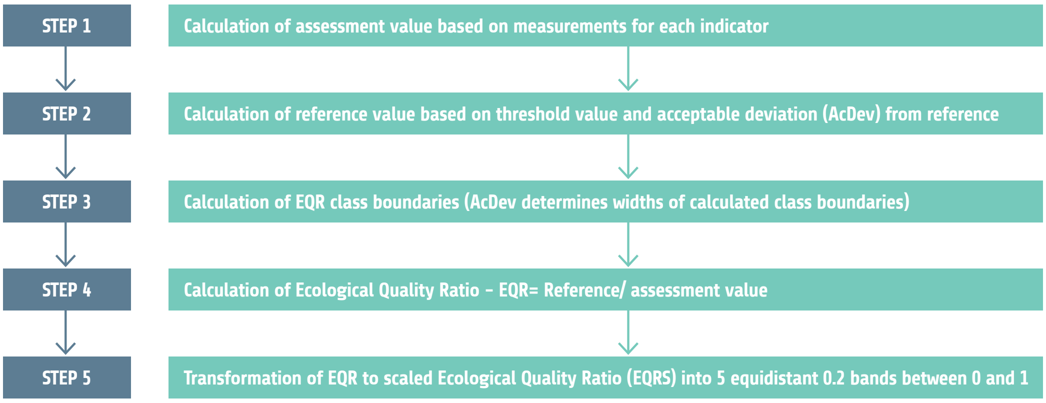

Figure A1.2. Stepwise approach in the HEAT tool to calculate EQR and EQRS values.

Indicator weighting

The HEAT integration is carried out using evenly distributed weights, unless otherwise justified. No averaging is needed for criteria that consist of only one indicator. In the last step, the overall eutrophication status is determined using one-out-all-out between criteria groups, so that the value of the group representing the worst status is used to represent the integrated eutrophication status.

Table A1.1 Indicator weights applied for the open sea assessment units. Indicators marked with '*' have not been adopted as core indicators in HELCOM yet and are currently tested. An 'NA' is shown for cases where the indicator is not applicable.

Assessment units	Nutrient levels				Direct effects		Indirect effects			
	DIN	TN	DIP	TP	Chl a	Cyano*	Secchi	O2 debt	Shallow O2*	BQI
Kattegat	25	25	25	25	100	NA	34	NA	66	NA
Great Belt	25	25	25	25	100	NA	34	NA	66	NA
The Sound	25	25	25	25	100	NA	34	NA	66	NA
Kiel Bay	25	25	25	25	100	NA	34	NA	66	NA
Bay of Mecklenburg	25	25	25	25	66	34	34	NA	66	NA
Arkona Basin	25	25	25	25	66	34	34	NA	66	NA
Bornholm Basin	25	25	25	25	66	34	34	66	NA	NA
Pomeranian Bay	25	25	25	25	66	34	20	NA	80	NA
Gdansk Basin	20	20	30	30	66	34	34	66	NA	NA
Eastern Gotland Basin	25	25	25	25	66	34	34	66	NA	NA
Western Gotland Basin	25	25	25	25	66	34	34	66	NA	NA
Gulf of Riga	17	17	33	33	75	25	20	NA	40	40
Northern Baltic Proper	25	25	25	25	66	34	34	66	NA	NA
Gulf of Finland Western	25	25	25	25	66	34	20	40	NA	40
Gulf of Finland Eastern	25	25	25	25	66	34	20	NA	40	40
Åland Sea	25	25	25	25	66	34	34	NA	NA	66
Bothnian Sea	25	25	25	25	75	25	20	NA	40	40
The Quark	25	25	25	25	100	NA	20	NA	40	40
Bothnian Bay	17	17	33	33	100	NA	10	NA	45	45

Confidence assessment methodology of the HEAT tool

The confidence assessment is based on temporal, spatial and accuracy aspects that are calculated in the HEAT tool based on the available data for the different indicators. It is also possible to report confidence estimates calculated outside of HEAT for selected indicators, so that they can be included in the integrated confidence assessment result. The confidence of the results in open sea assessment units is assessed at both indicator level, criteria group and integrated eutrophication level. The final confidence rating for each assessment unit may range between 100 and 0 and is grouped into three confidence classes: high (100–75), moderate (<75–50) and low (below 50).

The indicator confidence for eutrophication indicators is calculated from the following parameters:

- General temporal confidence (GTC) related to the annual number of observations in indicator-specific assessment seasons
- Specific temporal confidence (STC) based on temporal coverage in the different assessment seasons (winter, growing season, whole year), class boundaries are defined by the number of missing months where no data are available
- Specific spatial confidence (SSC) based on percentage of sampled grid cells in relation to total number of grid cells in the area (sampled area/total area)
- Accuracy confidence (ACC) based on the variable confidence level in relation to the threshold for estimates of correct classification (see https://github.com/ices-tools-prod/HEAT for full definitions and abbreviations used).

The aspect of temporal coverage of monitoring data considers the confidence of the indicator in terms of its year-to-year variation and the continuity of observations during the indicator-specific assessment seasons (winter, growing season, whole year). The general temporal confidence is assessed based on the number of annual observations during the assessment period, whereas for the specific temporal confidence the number of missing months in the respective assessment seasons of the different indicators determines the classification. The different natural variability of e.g. winter nutrients and chlorophyll in the growing season, as well as the slightly different length of the assessment season, is reflected in the different requirements for the confidence classes.

The aspect of spatial representability in the confidence assessment is considered by a specific spatial confidence aspect and based on a gridded approach with a predefined grid cell size of 10K, 30K or 60K. The distribution of observations within the area is considered by counting the number of sampled and not sampled grid cells in the area and calculating the percentage of sampled grid cells in relation to the total number of grid cells in the respective area. Similar to temporal confidence, the class boundaries for specific spatial confidence reflect the different natural variability of winter nutrients and chlorophyll through different requirements for the percentage of sampled grid cells.

The accuracy of the indicator result indicates how certain the assessment is in relation to the variability of the data. The accuracy aspect of the confidence assessment is considered by calculating variable confidence level per assessment indicator to estimate the probability or certainty of the classification of being below or above the area-specific thresholds (depending on the response of the indicator to eutrophication) and thus the classification as failing or achieving GES. In contrast to temporal and spatial confidence, the accuracy is assessed over the entire assessment period and not on annual basis, because it is a matter of estimating the probability of correct classification for the overall result.

The variable confidence level is calculated in the assessment procedure of HEAT based on the observed value (ES), the target value/threshold (ET) and the standard error of the respective assessment indicator per assessment area on the basis of the normal distribution function. The calculated confidence level is directly used as the probability of correct classification for good or not good status. The class boundaries for the accuracy confidence are taken directly from the BEAT assessment to ensure a harmonised approach as far as possible and are listed in below. In case of missing information on standard deviation, number of observations and standard error, no calculation of variable confidence levels and thus no quantitative accuracy estimates will be possible. Alternatively, a qualitative estimate based on expert judgement for the respective indicator and area can be used. The different confidence aspects and their respective class definitions are listed in Table A1.2.

All confidence aspects were assessed for nutrient indicators (DIN, TN, DIP and TP), chlorophyll-a, cyanobacterial bloom index and Water transparency. For the indicators describing oxygen conditions, Oxygen debt and shallow water oxygen, confidence estimates are partly available based on different methods for confidence estimates and the values have been included in the overall confidence assessment for those assessment units where these indicators were applied, and confidence estimates were available. Confidence estimates of the zoobenthos indicator ('State of the soft-bottom macrofauna community') were also included in the integrated confidence assessment in selected sub-basins and derived following a similar, but slightly different confidence methodology corresponding to the assessment procedure in the BEAT tool (see the soft-bottom macrofauna indicator report).

Table A1.2. Confidence aspects considered in the integrated confidence assessment using HEAT and class definitions for 'high', 'moderate' and 'low' confidence.

Confidence aspect	High	Moderate	Low
Temporal confidence (frequency and continuity of monitoring during indicator-specific assessment seasons)	Indicator-specific number of annual observations (>15 for dissolved nutrients, >17 for cyanobacterial bloom index, >20 for total nutrients, chlorophyll, Water transparency), Data available in all months of the indicator-specific assessment season	Indicator-specific number of annual observations (between 5-15 for dissolved nutrients, between 6-17 for cyanobacterial bloom index, between 7-20 for total nutrients, chlorophyll, Water transparency), Data not available in one month of the indicator-specific assessment season	Indicator-specific number of annual observations (<5 for dissolved nutrients, <6 for cyanobacterial bloom index, <7 for total nutrients, chlorophyll, Water transparency), Data not available in two or more months of the indicator-specific assessment season
Spatial confidence (data coverage and distribution of monitoring stations in the assessment unit)	Indicator-specific percentage of area with data in an assessment unit based on area-specific grid cell size (> 80% for chlorophyll, >70% for all other indicators)	Indicator-specific percentage of area with data in an assessment unit based on area-specific grid cell size (between 60-80% for chlorophyll, between 50-70% for all other indicators)	Indicator-specific percentage of area with data in an assessment unit based on area-specific grid cell size (<60% for chlorophyll, <50% for all other indicators)
Accuracy confidence (probability of correct classification in relation to the threshold value)	Assessment result is considered correct with >90 % probability	Assessment result is considered correct with a probability between 70% and 90%	Assessment result is considered correct with less than 70% probability

Annex 2. Supplementary supporting information

Table A2.1. Integrated assessment results for coastal assessment units using national indicators. Integrated assessment results for national coastal and open sea assessment units by coastal WFD water type/water body. The table includes information on the assessment unit (CODE, defined in the HELCOM Monitoring and Assessment Strategy Annex 4) and Ecological Quality Ratio Scaled (EQRS). EQRS shows the HOLAS3 2016-2021 periods concentration in relation to the reference value of the Assessment Unit, decreasing along with increasing eutrophication. An 'NA' is shown for cases where the indicator is not applicable. Class estimates the ecological status based on the EQRS value, which has been assigned using more decimals than represented in the table. Note that due to truncated decimals, the status class may vary for identical value with two decimals.

Assessment Unit	Sub basin	EQRS Nutrients	Class	EQRS Direct	Class	EQRS In-direct	Class	Integrated EQRS	Class
DEN-001	Kattegat	NA	NA	0.41	Moderate	0.39	Poor	0.39	Poor
DEN-002	Kattegat	NA	NA	0.56	Moderate	0.50	Moderate	0.50	Moderate
DEN-006	The Sound	NA	NA	NA	NA	0.58	Moderate	0.58	Moderate
DEN-016	Great Belt	NA	NA	0.64	Good	0.52	Moderate	0.52	Moderate
DEN-017	Great Belt	NA	NA	0.95	High	0.48	Moderate	0.48	Moderate
DEN-018	Great Belt	NA	NA	1.09	High	0.61	Good	0.61	Good
DEN-024	Kattegat	NA	NA	0.39	Poor	0.42	Moderate	0.39	Poor
DEN-025	Great Belt	NA	NA	0.35	Poor	0.54	Moderate	0.35	Poor
DEN-028	Great Belt	NA	NA	NA	NA	0.58	Moderate	0.58	Moderate
DEN-029	Great Belt	NA	NA	0.44	Moderate	0.49	Moderate	0.44	Moderate
DEN-034	Great Belt	NA	NA	0.68	Good	0.51	Moderate	0.51	Moderate
DEN-035	Great Belt	NA	NA	0.68	Good	0.59	Moderate	0.59	Moderate
DEN-036	Great Belt	NA	NA	0.71	Good	0.71	Good	0.71	Good
DEN-037	Great Belt	NA	NA	0.77	Good	0.44	Moderate	0.44	Moderate
DEN-044	Arkona Basin	NA	NA	0.41	Moderate	0.53	Moderate	0.41	Moderate
DEN-046	Arkona Basin	NA	NA	0.43	Moderate	0.59	Moderate	0.43	Moderate
DEN-047	Arkona Basin	NA	NA	0.41	Moderate	0.64	Good	0.41	Moderate
DEN-048	Arkona Basin	NA	NA	0.75	Good	0.56	Moderate	0.56	Moderate
DEN-049	Arkona Basin	NA	NA	0.29	Poor	0.40	Poor	0.29	Poor
DEN-056	Bornholm Basin	NA	NA	NA	NA	0.72	Good	0.72	Good
DEN-059	Great Belt	NA	NA	0.29	Poor	0.37	Poor	0.29	Poor

Table A2.1. (Continued). Integrated assessment results for coastal assessment units using national indicators. Integrated assessment results for national coastal and open sea assessment units by coastal WFD water type/water body. The table includes information on the assessment unit (CODE, defined in the HELCOM Monitoring and Assessment Strategy Annex 4) and Ecological Quality Ratio Scaled (EQRS). EQRS shows the HOLAS3 2016-2021 periods concentration in relation to the reference value of the Assessment Unit, decreasing along with increasing eutrophication. An 'NA' is shown for cases where the indicator is not applicable. Class estimates the ecological status based on the EQRS value, which has been assigned using more decimals than represented in the table. Note that due to truncated decimals, the status class may vary for identical value with two decimals.

Assessment Unit	Sub basin	EQRS Nutrients	Class	EQRS Direct	Class	EQRS In-direct	Class	Integrated EQRS	Class
DEN-062	Great Belt	NA	NA	0.44	Moderate	0.45	Moderate	0.44	Moderate
DEN-068	Great Belt	NA	NA	1.13	High	0.54	Moderate	0.54	Moderate
DEN-072	Great Belt	NA	NA	0.60	Moderate	0.53	Moderate	0.53	Moderate
DEN-074	Great Belt	NA	NA	0.22	Poor	0.15	Bad	0.15	Bad
DEN-080	Great Belt	NA	NA	0.40	Moderate	0.59	Moderate	0.40	Moderate
DEN-082	Great Belt	NA	NA	0.20	Poor	0.09	Bad	0.09	Bad
DEN-083	Great Belt	NA	NA	0.22	Poor	0.26	Poor	0.22	Poor
DEN-084	Great Belt	NA	NA	0.35	Poor	0.67	Good	0.35	Poor
DEN-085	Great Belt	NA	NA	0.38	Poor	0.45	Moderate	0.38	Poor
DEN-086	Great Belt	NA	NA	0.38	Poor	0.50	Moderate	0.38	Poor
DEN-087	Great Belt	NA	NA	0.24	Poor	0.50	Moderate	0.24	Poor
DEN-089	Great Belt	NA	NA	0.35	Poor	0.54	Moderate	0.35	Poor
DEN-090	Great Belt	NA	NA	0.44	Moderate	0.48	Moderate	0.44	Moderate
DEN-092	Great Belt	NA	NA	0.45	Moderate	0.54	Moderate	0.45	Moderate
DEN-093	Great Belt	NA	NA	0.70	Good	0.38	Poor	0.38	Poor
DEN-096	Great Belt	NA	NA	NA	NA	0.55	Moderate	0.55	Moderate
DEN-101	Great Belt	NA	NA	0.23	Poor	0.38	Poor	0.23	Poor
DEN-102	Great Belt	NA	NA	0.18	Bad	0.43	Moderate	0.18	Bad
DEN-103	Great Belt	NA	NA	0.26	Poor	0.41	Moderate	0.26	Poor
DEN-105	Great Belt	NA	NA	0.37	Poor	0.33	Poor	0.33	Poor
DEN-106	Great Belt	NA	NA	0.13	Bad	NA	NA	0.13	Bad
DEN-108	Great Belt	NA	NA	0.28	Poor	0.26	Poor	0.26	Poor
DEN-109	Great Belt	NA	NA	0.38	Poor	0.34	Poor	0.34	Poor
DEN-110	Great Belt	NA	NA	0.38	Poor	0.47	Moderate	0.38	Poor
DEN-113	Great Belt	NA	NA	0.19	Bad	0.42	Moderate	0.19	Bad
DEN-114	Great Belt	NA	NA	0.38	Poor	0.32	Poor	0.32	Poor
DEN-122	Great Belt	NA	NA	NA	NA	0.48	Moderate	0.48	Moderate
DEN-123	Great Belt	NA	NA	0.47	Moderate	0.46	Moderate	0.46	Moderate
DEN-124	Great Belt	NA	NA	0.23	Poor	0.40	Moderate	0.23	Poor
DEN-125	Great Belt	NA	NA	0.17	Bad	0.42	Moderate	0.17	Bad
DEN-128	Great Belt	NA	NA	0.23	Poor	0.44	Moderate	0.23	Poor
DEN-136	Kattegat	NA	NA	0.50	Moderate	0.48	Moderate	0.48	Moderate
DEN-137	Kattegat	NA	NA	0.73	Good	0.39	Poor	0.39	Poor
DEN-138	Kattegat	NA	NA	NA	NA	0.60	Good	0.60	Good
DEN-139	Kattegat	NA	NA	NA	NA	0.63	Good	0.63	Good
DEN-140	Kattegat	NA	NA	NA	NA	0.65	Good	0.65	Good
DEN-141	Great Belt	NA	NA	0.75	Good	0.55	Moderate	0.55	Moderate
DEN-142	Great Belt	NA	NA	0.72	Good	0.52	Moderate	0.52	Moderate
DEN-144	Great Belt	NA	NA	0.42	Moderate	0.27	Poor	0.27	Poor

Table A2.1. (Continued). Integrated assessment results for coastal assessment units using national indicators. Integrated assessment results for national coastal and open sea assessment units by coastal WFD water type/water body. The table includes information on the assessment unit (CODE, defined in the HELCOM Monitoring and Assessment Strategy Annex 4) and Ecological Quality Ratio Scaled (EQRS). EQRS shows the HOLAS3 2016-2021 periods concentration in relation to the reference value of the Assessment Unit, decreasing along with increasing eutrophication. An 'NA' is shown for cases where the indicator is not applicable. Class estimates the ecological status based on the EQRS value, which has been assigned using more decimals than represented in the table. Note that due to truncated decimals, the status class may vary for identical value with two decimals.

Assessment Unit	Sub basin	EQRS Nutrients	Class	EQRS Direct	Class	EQRS In-direct	Class	Integrated EQRS	Class
DEN-145	Great Belt	NA	NA	0.48	Moderate	0.56	Moderate	0.48	Moderate
DEN-146	Great Belt	NA	NA	0.54	Moderate	0.30	Poor	0.30	Poor
DEN-147	Great Belt	NA	NA	0.48	Moderate	0.68	Good	0.48	Moderate
DEN-154	Kattegat	NA	NA	NA	NA	0.63	Good	0.63	Good
DEN-157	Kattegat	NA	NA	0.10	Bad	0.35	Poor	0.10	Bad
DEN-158	Kattegat	NA	NA	0.11	Bad	0.20	Poor	0.11	Bad
DEN-159	Kattegat	NA	NA	0.06	Bad	0.36	Poor	0.06	Bad
DEN-160	Kattegat	NA	NA	0.33	Poor	0.44	Moderate	0.33	Poor
DEN-165	Kattegat	NA	NA	0.40	Moderate	0.49	Moderate	0.40	Moderate
DEN-200	Kattegat	NA	NA	0.53	Moderate	0.67	Good	0.53	Moderate
DEN-201	Arkona Basin	NA	NA	0.31	Poor	0.56	Moderate	0.31	Poor
DEN-204	Great Belt	NA	NA	0.49	Moderate	0.56	Moderate	0.49	Moderate
DEN-205	Kattegat	NA	NA	NA	NA	0.74	Good	0.74	Good
DEN-206	Great Belt	NA	NA	0.44	Moderate	0.45	Moderate	0.44	Moderate
DEN-207	Great Belt	NA	NA	0.89	High	0.62	Good	0.62	Good
DEN-209	Great Belt and Bay of Mecklenburg	NA	NA	0.28	Poor	0.65	Good	0.28	Poor
DEN-212	Great Belt	NA	NA	0.36	Poor	0.55	Moderate	0.36	Poor
DEN-214	Great Belt	NA	NA	0.28	Poor	0.37	Poor	0.28	Poor
DEN-216	Great Belt	NA	NA	0.28	Poor	0.45	Moderate	0.28	Poor
DEN-217	Great Belt	NA	NA	0.32	Poor	0.46	Moderate	0.32	Poor
DEN-219	Great Belt	NA	NA	0.40	Poor	0.58	Moderate	0.40	Poor
DEN-222	Kattegat	NA	NA	1.07	High	0.56	Moderate	0.56	Moderate
DEN-224	Great Belt	NA	NA	0.34	Poor	0.57	Moderate	0.34	Poor
DEN-225	Kattegat	NA	NA	NA	NA	0.57	Moderate	0.57	Moderate
DEN-231	Great Belt	NA	NA	NA	NA	0.43	Moderate	0.43	Moderate
DEN-232	Kattegat	NA	NA	0.30	Poor	0.47	Moderate	0.30	Poor
DEN-233	Kattegat	NA	NA	NA	NA	0.37	Poor	0.37	Poor
DEN-234	Kattegat	NA	NA	0.19	Bad	0.39	Poor	0.19	Bad
DEN-235	Kattegat	NA	NA	0.26	Poor	0.60	Good	0.26	Poor
DEN-236	Kattegat	NA	NA	0.13	Bad	0.15	Bad	0.13	Bad
DEN-238	Kattegat	NA	NA	0.11	Bad	0.19	Bad	0.11	Bad
EST-001	Gulf of Finland	0.75	Good	0.61	Good	0.54	Moderate	0.54	Moderate
EST-002	Gulf of Finland	0.59	Moderate	0.50	Moderate	0.65	Good	0.50	Moderate
EST-003	Gulf of Finland	0.56	Moderate	0.36	Poor	0.57	Moderate	0.36	Poor
EST-005	Gulf of Finland	0.68	Good	0.33	Poor	0.62	Good	0.33	Poor
EST-006	Gulf of Finland	0.67	Good	0.31	Poor	0.62	Good	0.31	Poor
EST-007	Gulf of Riga	0.50	Moderate	0.37	Poor	0.59	Moderate	0.37	Poor
EST-008	Gulf of Riga	0.34	Poor	0.22	Poor	0.47	Moderate	0.22	Poor

Table A2.1. (Continued). Integrated assessment results for coastal assessment units using national indicators. Integrated assessment results for national coastal and open sea assessment units by coastal WFD water type/water body. The table includes information on the assessment unit (CODE, defined in the HELCOM Monitoring and Assessment Strategy Annex 4) and Ecological Quality Ratio Scaled (EQRS). EQRS shows the HOLAS3 2016-2021 periods concentration in relation to the reference value of the Assessment Unit, decreasing along with increasing eutrophication. An 'NA' is shown for cases where the indicator is not applicable. Class estimates the ecological status based on the EQRS value, which has been assigned using more decimals than represented in the table. Note that due to truncated decimals, the status class may vary for identical value with two decimals.

Assessment Unit	Sub basin	EQRS Nutrients	Class	EQRS Direct	Class	EQRS In-direct	Class	Integrated EQRS	Class
EST-009	Gulf of Riga	0.48	Moderate	0.27	Poor	0.43	Moderate	0.27	Poor
EST-010	Northern Baltic Proper	0.60	Good	0.57	Moderate	0.64	Good	0.57	Moderate
EST-011	Eastern Gotland Basin	0.63	Good	0.60	Moderate	0.66	Good	0.60	Moderate
EST-013	Gulf of Riga	0.66	Good	0.50	Moderate	0.35	Poor	0.35	Poor
EST-014	Gulf of Riga	0.56	Moderate	0.75	Good	0.64	Good	0.56	Moderate
EST-016	Gulf of Riga	0.47	Moderate	0.38	Poor	0.71	Good	0.38	Poor
EST-019	Gulf of Riga	0.66	Good	0.64	Good	0.50	Moderate	0.50	Moderate
FIN-001	Åland Sea	0.45	Moderate	0.40	Moderate	0.40	Moderate	0.40	Moderate
FIN-002	Åland Sea	0.53	Moderate	0.45	Moderate	0.52	Moderate	0.45	Moderate
FIN-003	Gulf of Finland	0.42	Moderate	0.45	Moderate	0.49	Moderate	0.42	Moderate
FIN-004	Gulf of Finland	0.47	Moderate	0.42	Moderate	0.52	Moderate	0.42	Moderate
FIN-005	Åland Sea	0.54	Moderate	0.52	Moderate	0.46	Moderate	0.46	Moderate
FIN-006	The Quark	0.54	Moderate	0.55	Moderate	0.57	Moderate	0.54	Moderate
FIN-007	The Quark	0.80	High	0.63	Good	0.68	Good	0.63	Good
FIN-008	Bothnian Sea	0.64	Good	0.53	Moderate	0.53	Moderate	0.53	Moderate
FIN-009	Bothnian Sea	0.63	Good	0.58	Moderate	0.64	Good	0.58	Moderate
FIN-010	Bothnian Bay	0.67	Good	0.54	Moderate	0.52	Moderate	0.52	Moderate
FIN-011	Bothnian Bay	0.79	Good	0.66	Good	0.55	Moderate	0.55	Moderate
FIN-012	Åland Sea	0.61	Good	0.47	Moderate	0.47	Moderate	0.47	Moderate
FIN-013	Åland Sea	0.61	Good	0.52	Moderate	0.58	Moderate	0.52	Moderate
FIN-014	Åland Sea	0.58	Moderate	0.50	Moderate	0.66	Good	0.50	Moderate
GER-001	Bay of Mecklenburg	0.23	Poor	0.57	Moderate	0.34	Poor	0.23	Poor
GER-002	Bay of Mecklenburg	0.43	Moderate	0.57	Moderate	0.53	Moderate	0.43	Moderate
GER-003	Bay of Mecklenburg	0.15	Bad	0.52	Moderate	0.37	Poor	0.15	Bad
GER-004	Bay of Mecklenburg	0.48	Moderate	0.50	Moderate	0.53	Moderate	0.48	Moderate
GER-005	Bay of Mecklenburg	0.09	Bad	0.52	Moderate	0.38	Poor	0.09	Bad
GER-006	Bay of Mecklenburg	0.34	Poor	0.43	Moderate	0.56	Moderate	0.34	Poor
GER-007	Arkona Basin	0.10	Bad	0.18	Bad	0.10	Bad	0.10	Bad
GER-008	Arkona Basin	0.13	Bad	0.26	Poor	0.27	Poor	0.13	Bad
GER-009	Arkona Basin	0.09	Bad	0.18	Bad	0.29	Poor	0.09	Bad
GER-010	Arkona Basin	0.38	Poor	0.87	High	0.62	Good	0.38	Poor
GER-011	Arkona Basin	0.14	Bad	0.38	Poor	0.53	Moderate	0.14	Bad
GER-012	Arkona Basin	0.14	Bad	0.37	Poor	0.32	Poor	0.14	Bad
GER-013	Arkona Basin	0.15	Bad	0.38	Poor	0.51	Moderate	0.15	Bad
GER-014	Arkona Basin	0.06	Bad	0.18	Bad	0.27	Poor	0.06	Bad
GER-015	Arkona Basin	0.35	Poor	0.51	Moderate	0.62	Good	0.35	Poor
GER-016	Pomeranian Bay	0.13	Bad	0.27	Poor	0.21	Poor	0.13	Bad
GER-017	Pomeranian Bay Basin	0.12	Bad	0.24	Poor	0.13	Bad	0.12	Bad
GER-018	Arkona Basin	0.21	Poor	0.35	Poor	0.54	Moderate	0.21	Poor

Table A2.1. (Continued). Integrated assessment results for coastal assessment units using national indicators. Integrated assessment results for national coastal and open sea assessment units by coastal WFD water type/water body. The table includes information on the assessment unit (CODE, defined in the HELCOM Monitoring and Assessment Strategy Annex 4) and Ecological Quality Ratio Scaled (EQRS). EQRS shows the HOLAS3 2016-2021 periods concentration in relation to the reference value of the Assessment Unit, decreasing along with increasing eutrophication. An 'NA' is shown for cases where the indicator is not applicable. Class estimates the ecological status based on the EQRS value, which has been assigned using more decimals than represented in the table. Note that due to truncated decimals, the status class may vary for identical value with two decimals.

Assessment Unit	Sub basin	EQRS Nutrients	Class	EQRS Direct	Class	EQRS In-direct	Class	Integrated EQRS	Class
GER-019	Pomeranian Bay Basin	0.15	Bad	0.28	Poor	0.57	Moderate	0.15	Bad
GER-020	Pomeranian Bay	0.13	Bad	0.28	Poor	0.40	Poor	0.13	Bad
GER-021	Kiel Bay	0.41	Moderate	0.13	Bad	0.29	Poor	0.13	Bad
GER-022	Kiel Bay	NA	NA	0.56	Moderate	0.39	Poor	0.39	Poor
GER-023	Kiel Bay	0.42	Moderate	0.56	Moderate	0.26	Poor	0.26	Poor
GER-024	Kiel Bay	0.72	Good	0.55	Moderate	0.42	Moderate	0.42	Moderate
GER-025	Kiel Bay	0.09	Bad	0.03	Bad	0.28	Poor	0.03	Bad
GER-026A	Kiel Bay	0.10	Bad	0.02	Bad	0.27	Poor	0.02	Bad
GER-026B	Kiel Bay	0.10	Bad	0.01	Bad	0.27	Poor	0.01	Bad
GER-027	Kiel Bay	NA	NA	0.01	Bad	0.08	Bad	0.01	Bad
GER-028	Kiel Bay	0.39	Poor	0.72	Good	0.45	Moderate	0.39	Poor
GER-029	Kiel Bay	0.52	Moderate	0.59	Moderate	0.33	Poor	0.33	Poor
GER-030	Kiel Bay	NA	NA	0.59	Moderate	0.41	Moderate	0.41	Moderate
GER-031	Kiel Bay	0.48	Moderate	0.56	Moderate	0.21	Poor	0.21	Poor
GER-032	Kiel Bay	0.35	Poor	0.15	Bad	0.27	Poor	0.15	Bad
GER-033	Kiel Bay	0.38	Poor	0.68	Good	0.41	Moderate	0.38	Poor
GER-034	Kiel Bay	NA	NA	0.68	Good	0.39	Poor	0.39	Poor
GER-035	Kiel Bay	0.68	Good	0.77	Good	0.36	Poor	0.36	Poor
GER-036A	Kiel Bay	0.42	Moderate	0.70	Good	0.37	Poor	0.37	Poor
GER-036B	Bay of Mecklenburg	0.42	Moderate	0.69	Good	0.37	Poor	0.37	Poor
GER-037	Kiel Bay	0.48	Moderate	0.64	Good	0.37	Poor	0.37	Poor
GER-038A	Kiel Bay	0.42	Moderate	0.88	High	0.45	Moderate	0.42	Moderate
GER-038B	Bay of Mecklenburg	0.42	Moderate	0.88	High	0.45	Moderate	0.42	Moderate
GER-039	Bay of Mecklenburg	0.64	Good	0.81	High	0.40	Poor	0.40	Poor
GER-040	Bay of Mecklenburg	0.33	Poor	0.52	Moderate	0.33	Poor	0.33	Poor
GER-041	Bay of Mecklenburg	0.34	Poor	0.49	Moderate	0.36	Poor	0.34	Poor
GER-042	Bay of Mecklenburg	NA	NA	0.03	Bad	0.08	Bad	0.03	Bad
GER-043	Bay of Mecklenburg	0.10	Bad	0.04	Bad	0.33	Poor	0.04	Bad
GER-044	Bay of Mecklenburg	0.09	Bad	0.04	Bad	0.04	Bad	0.04	Bad
GER-111	Arkona Basin	0.12	Bad	0.22	Poor	0.36	Poor	0.12	Bad
POL-001	Bornholm Basin	0.79	Good	0.52	Moderate	0.45	Moderate	0.45	Moderate
POL-002	Bornholm Basin	0.79	Good	0.36	Poor	0.44	Moderate	0.36	Poor
POL-003	Gdansk Basin	0.58	Moderate	0.12	Bad	0.40	Poor	0.12	Bad
POL-004	Gdansk Basin	0.28	Poor	0.22	Poor	0.79	Good	0.22	Poor
POL-005	Gdansk Basin	0.68	Good	0.60	Good	0.54	Moderate	0.54	Moderate
POL-006	Gdansk Basin	0.55	Moderate	0.37	Poor	0.49	Moderate	0.37	Poor
POL-007	Bornholm Basin	0.43	Moderate	0.27	Poor	0.58	Moderate	0.27	Poor
POL-008	Gdansk Basin	0.49	Moderate	0.27	Poor	0.56	Moderate	0.27	Poor
POL-009	Bornholm Basin	0.48	Moderate	0.41	Moderate	0.52	Moderate	0.41	Moderate

Table A2.1. (Continued). Integrated assessment results for coastal assessment units using national indicators. Integrated assessment results for national coastal and open sea assessment units by coastal WFD water type/water body. The table includes information on the assessment unit (CODE, defined in the HELCOM Monitoring and Assessment Strategy Annex 4) and Ecological Quality Ratio Scaled (EQRS). EQRS shows the HOLAS3 2016-2021 periods concentration in relation to the reference value of the Assessment Unit, decreasing along with increasing eutrophication. An 'NA' is shown for cases where the indicator is not applicable. Class estimates the ecological status based on the EQRS value, which has been assigned using more decimals than represented in the table. Note that due to truncated decimals, the status class may vary for identical value with two decimals.

Assessment Unit	Sub basin	EQRS Nutrients	Class	EQRS Direct	Class	EQRS In-direct	Class	Integrated EQRS	Class
POL-010	Gdansk Basin	0.52	Moderate	0.29	Poor	0.64	Good	0.29	Poor
POL-011	Gdansk Basin	0.47	Moderate	0.15	Bad	0.74	Good	0.15	Bad
POL-012	Gdansk Basin	0.28	Poor	0.10	Bad	0.45	Moderate	0.10	Bad
POL-013	Bornholm Basin	0.33	Poor	0.18	Bad	0.52	Moderate	0.18	Bad
POL-014	Bornholm Basin	0.47	Moderate	0.15	Bad	0.67	Good	0.15	Bad
POL-015	Bornholm Basin	0.53	Moderate	0.16	Bad	0.68	Good	0.16	Bad
POL-016	Eastern Gotland Basin	0.49	Moderate	0.16	Bad	0.72	Good	0.16	Bad
POL-017	Gdansk Basin	0.51	Moderate	0.43	Moderate	0.66	Good	0.43	Moderate
POL-018	Bornholm Basin	0.43	Moderate	0.30	Poor	0.60	Moderate	0.30	Poor
POL-019	Bornholm Basin	0.34	Poor	0.24	Poor	0.51	Moderate	0.24	Poor
SWE-001	Kattegat	0.76	Good	0.95	High	0.76	Good	0.76	Good
SWE-003	Kattegat	0.83	High	0.81	High	0.64	Good	0.64	Good
SWE-004	Kattegat	0.61	Good	0.85	High	0.58	Moderate	0.58	Moderate
SWE-005	The Sound	0.47	Moderate	0.83	High	0.54	Moderate	0.47	Moderate
SWE-006	Arkona Basin	0.54	Moderate	0.80	High	0.72	Good	0.54	Moderate
SWE-007	Western Gotland Basin	0.39	Poor	0.51	Moderate	NA	NA	0.39	Poor
SWE-008	Western Gotland Basin	0.53	Moderate	0.60	Moderate	NA	NA	0.53	Moderate
SWE-009	Eastern Gotland Basin	NA	NA	0.39	Poor	0.38	Poor	0.38	Poor
SWE-010	Western Gotland Basin	NA	NA	0.41	Moderate	0.40	Moderate	0.40	Moderate
SWE-011	Northern Baltic Proper	0.55	Moderate	0.47	Moderate	0.57	Moderate	0.47	Moderate
SWE-012	Western Gotland Basin	0.51	Moderate	0.47	Moderate	0.63	Good	0.47	Moderate
SWE-013	Western Gotland Basin	0.54	Moderate	0.37	Poor	0.48	Moderate	0.37	Poor
SWE-014	Western Gotland Basin	0.38	Poor	0.56	Moderate	0.63	Good	0.38	Poor
SWE-015	Northern Baltic Proper	0.57	Moderate	0.48	Moderate	NA	NA	0.48	Moderate
SWE-016	Bothnian Sea	0.43	Moderate	0.41	Moderate	0.55	Moderate	0.41	Moderate
SWE-017	Bothnian Sea	0.33	Poor	0.48	Moderate	0.55	Moderate	0.33	Poor
SWE-018	Bothnian Sea	0.46	Moderate	0.61	Good	0.82	High	0.46	Moderate
SWE-020	The Quark	0.52	Moderate	0.42	Moderate	NA	NA	0.42	Moderate
SWE-021	The Quark	0.40	Poor	0.61	Good	NA	NA	0.40	Poor
SWE-022	Bothnian Bay	NA	NA	NA	NA	0.15	Bad	0.15	Bad
SWE-024	Northern Baltic Proper	0.63	Good	0.41	Moderate	NA	NA	0.41	Moderate
SWE-025	Kattegat	0.53	Moderate	NA	NA	NA	NA	0.53	Moderate

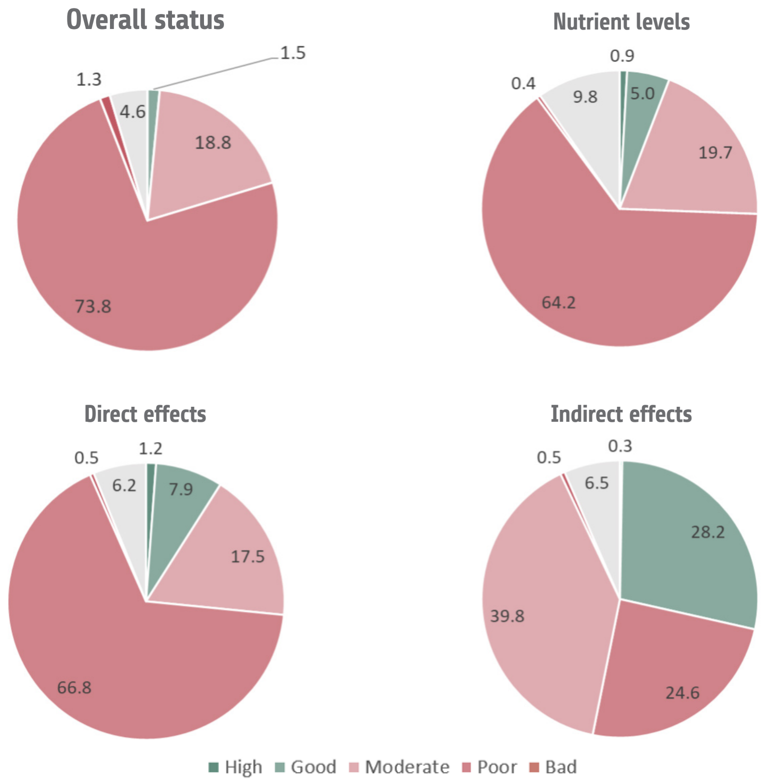

Figure A2.1. Proportional division (% of total area) of coastal- and open sea assessments (overall and the criteria) in the HELCOM region. NA – not assessed.