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Baltic Marine Environment
Protection Commission

HELCOM
Eutrophication
Assessment Manual

Eutrophication

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1 Introduction

Eutrophication is assessed by HELCOM using regularly monitored data provided by the Contracting Parties to produce an indicator-based quantitative assessment. The Contracting Parties are responsible for producing the assessment, with ICES acting in the role of the data host.

The experts assigned by the HELCOM Contracting Parties as members of the Expert Group on Eutrophication (EG Eutro) are responsible for initiating and following the update of the assessment as well as reviewing and accepting the assessment products. The main aim of the group is to develop and produce eutrophication indicators as a basis for the regularly conducted holistic assessments. The contact persons for the Expert Group on Eutrophication at the HELCOM Secretariat are Susanna Kaasinen (susanna.kaasinen@helcom.fi) and the data manager (data@helcom.fi)

ICES, as the data host, is responsible for the quality assurance and storage of the eutrophication related monitoring data submitted to the ICES database. ICES conducted the changes in the assessment procedure including coding the R script and enabling the free use on GitHub. The contact person at ICES is Hjalte Parner (Hjalte@ices.dk).

The main purpose of this Eutrophication Assessment Manual is to provide instructions for all parties involved in updating the assessment. It also provides detailed information on assessment protocols for the users of the indicator and assessment products. The manual is a living document, which is updated as needed.

Based on the HELCOM HEAT Manual from 2015, this version was updated to document the changes and progress achieved in the eutrophication assessment since HOLAS II. The improvements of the HEAT tool include an enhanced methodology for confidence assessment, altered grouping of indicators, and a new method for indicator scaling based on Environmental Quality Ratios (EQR) to improve comparability between indicators and areas.

2 Eutrophication assessment approach

2.1 Assessment method

The eutrophication assessment was carried out in HOLAS 3 using the HELCOM Eutrophication Assessment Tool (HEAT HOLAS 3). In general, the same process and indicators applied in HOLAS II (Eutrophication Report 2011-2016) were used, with the exception of the 'Shallow-water oxygen' indicator being included as a new pre-core indicator to describe oxygen conditions in the shallow areas of the Baltic Sea. 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 1). In addition, the spatial extent of the total nutrient indicators (TN, TP) has been increased, now covering the whole Baltic Sea. The previously used method for indicator scaling by calculating a eutrophication ratio (ER) was replaced by the use of Environmental Quality Ratios (EQR) making different areas (coastal, offshore) and indicators more comparable, in particular by performing an additional normalisation step to scaled EQR values (EQRS).

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 2017/848), and then further aggregates these into three criteria groups: nutrient levels, direct effects, and indirect effects of eutrophication (Figure 1). 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.

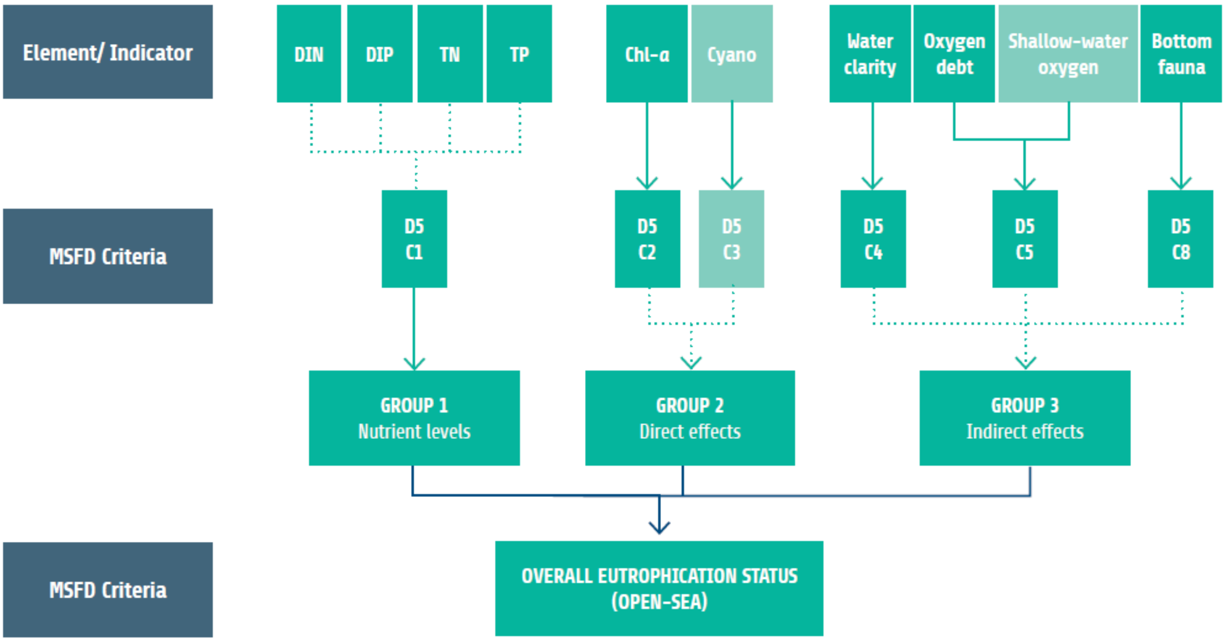


Figure 1. Structure of the eutrophication assessment for open-sea areas. The aggregation of indicators in HEAT HOLAS 3 based on criteria, and subsequent criteria groups, considers the MSFD methodological standards. Pre-core indicators associated with primary criteria are shaded green, whereas core indicators have no shading. Dashed lines indicate a process of weighted averages, and the solid blue line indicates a One-Out-All-Out process is applied.

To assess nutrient levels (group 1), four core indicators on the concentrations of nitrogen and phosphorus were used (dissolved inorganic nitrogen and phosphorus measured in the winter season and year-round measurements of total nitrogen and total phosphorus).

Chlorophyll a concentration was used to assess the direct effects (group 2) 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 (group 3) of eutrophication, the core indicators ‘Oxygen debt’ and ‘Water transparency’ were used. The ’Oxygen debt’ indicator measures the volume-specific oxygen debt below the halocline and 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’ should be used to estimate the bottom area or water volume with oxygen concentrations below area-specific threshold values. 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. Zoobenthos is sensitive to changes in oxygen conditions and nutrient levels, making it valuable indicator of eutrophication. Eutrophication can significantly alter the composition and abundance of macrofauna communities and oxygen depletion (a consequence of eutrophication) can lead to the loss of sensitive species and shifts in community structure. The state of the soft-bottom macrofauna community indicator is applied above the halocline in the open sea, in areas where it responds only or mainly to eutrophication related pressures, especially when an adequate oxygen indicator is missing.

2.2 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 in open sea areas:

- 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

- HELCOM monitoring programme Softbottom fauna

Further HELCOM monitoring programmes are of relevance when corresponding indicators are applied, e.g. in coastal areas:

- HELCOM monitoring programme Softbottom flora
- HELCOM monitoring programme Hardbottom species

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).

Details on the assessment data flow for the eutrophication assessment based on reporting of monitoring data by the Contracting Parties to the HELCOM COMBINE database are provided in chapter 2.4.

2.3 Spatial and temporal assessment scales

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 respective indicator reports 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 as well as reference and threshold 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).

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 been included in the assessment for HOLAS 3 (Figure 2). 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.

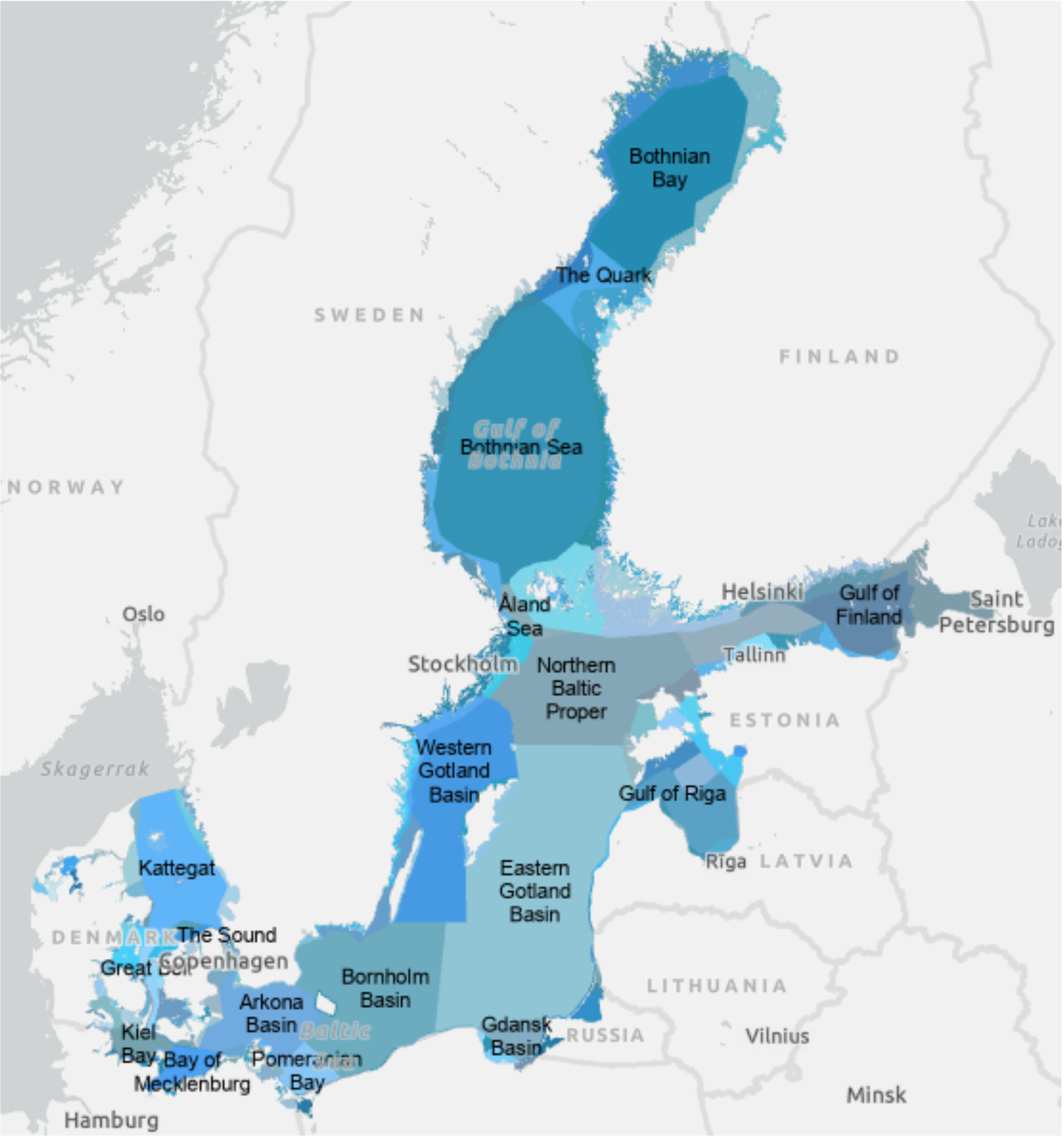


Figure 2. HELCOM eutrophication assessment unit level 4b.

Each holistic assessment covers a timespan of six years, referred to as the assessment period. The current assessment of HOLAS3 focuses on the period 2016-2021. In addition, data for the long-term temporal development has been used in the eutrophication assessment to understand long-term trends and evaluate the direction of ongoing changes.

2.4 Assessment data flow

The eutrophication status assessment results in HOLAS 3 are based on data from the assessment period 2016-2021 obtained through the eutrophication assessment data flow as visualized in Figure 3.

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 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 and pre-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 un-accepted products to the public.

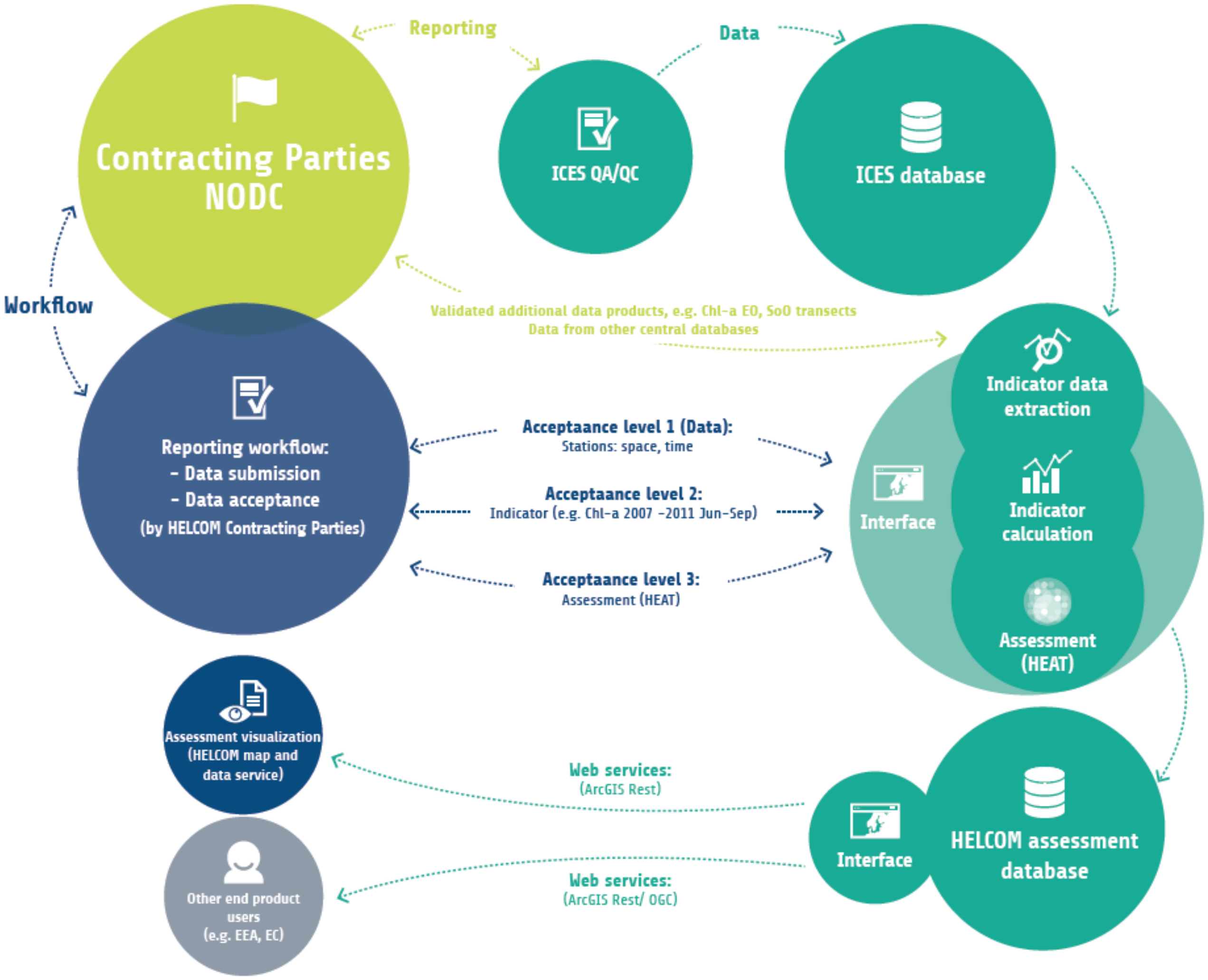


Figure 3. Eutrophication assessment data and information flow. The colour of the items indicates the actor/host: Lime green = Contracting Parties, Blue = HELCOM portal hosted at the HELCOM Secretariat, Turquoise = ICES, Grey = Other end-users, for example European Environment Agency (EEA), European Commission (EC).

3 Eutrophication indicators

This chapter describes the indicator set available for the eutrophication assessment and how they are assessed in the HELCOM process. 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.

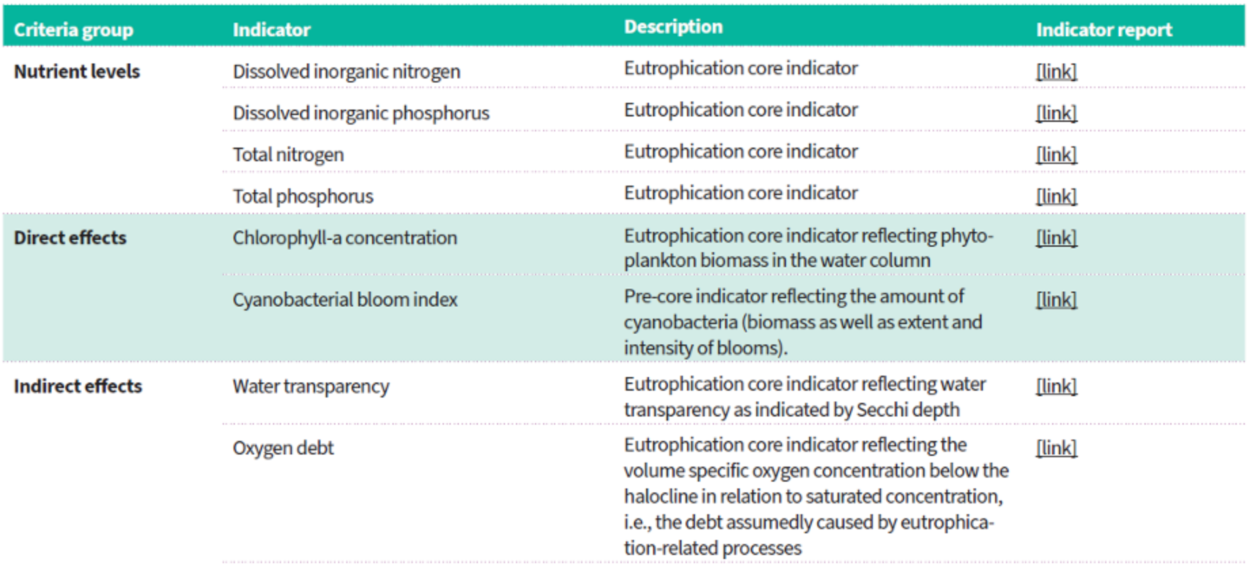
The indicators are divided into three principal classes: core, pre-core and coastal indicators. HELCOM core indicators are used in offshore waters beyond 1 nm seaward from the baseline i.e. beyond coastal waters as defined the Water Framework Directive (WFD). They have been agreed for use in HELCOM with associated threshold values.

The second class is HELCOM pre-core indicators that are further developed towards use in offshore waters but are still not agreed as core indicators. They may also lack e.g. commonly agreed threshold values.

The third class of indicators consists of those used in coastal water assessments under the Water Framework Directive. This indicator group is much more heterogeneous. Some indicators have been intercalibrated between countries through the EU GIG (Geographical Intercalibration Group) process, but many indicators (and particularly those considered as 'physico-chemical supporting parameters' within the WFD) are based on national work. WFD indicators are used nationally to assess ecological status under the WFD during a 6-year cycle and are reported to the European Environment Agency (EEA).

Seven eutrophication core indicators were used as the basis of the assessment in HOLAS 3, covering nutrient levels and direct and indirect effects of eutrophication (**Error! Reference source not found.**). These were complemented with two pre-core indicators, a biodiversity core indicator, and national indicators for coastal areas in order to obtain a more comprehensive assessment for all areas and all relevant aspects.

Table 1. Overview of indicators used in the integrated eutrophication assessment in the open sea areas. Coastal indicators are listed in Table 20 in Annex 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]

Criteria group	Indicator	Description	Indicator report
Indirect effects	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 eutrophication related pressures, especially when an oxygen indicator is lacking.	[link]

3.1 Core indicators

3.1.1 Nutrient indicators (nutrient levels)

Four core indicators for dissolved inorganic and total nitrogen and phosphorus (DIN, TN, DIP, TP) are used in the eutrophication assessment for criteria group 1 on nutrient levels. For the first time, four nutrient indicators could be applied in all Baltic Sea assessment units for HOLAS 3, building on the agreement of threshold values for the areas that were missing in HOLAS II (TN and TP in Kiel Bay, Bay of Mecklenburg, Arkona Basin, Bornholm Basin and TP in Eastern Gotland Basin). All nutrient indicators are utilised for the integrated assessment of eutrophication in the HEAT HOLAS 3 tool. Indicator-specific principles and specifications for dissolved and total nitrogen and phosphorus indicators are summarised in the following tables. Calculations are made both on annual/seasonal and assessment period levels.

Table 2. Specifications of the core indicators dissolved inorganic nitrogen and phosphorus (DIN, DIP)

Indicator	DIN	DIP
Response to eutrophication	Positive	Positive
Parameters	DIN = NO_2 + NO_3 + NH_4 concentration (µmol L^{-1})	DIP = PO_4 concentration (µmol L^{-1})
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016-2021	2016-2021
Assessment season	Winter = December + January + February	Winter = December + January + February
Depth	Surface = average in the 0 – 10 m layer	Surface = average in the 0 – 10 m layer
Removing outliers	No outliers removed	No outliers removed
Removing close observations	No close observations removed	No close observations removed
Indicator level (ES)	Average of winter average values derived as inter-annual winter estimates (December-February), most recent concentrations included are those of January and February 2021)	Average of winter average values derived as inter-annual winter estimates (December-February), most recent concentrations included are those of January and February 2021)

Environmental Quality Ratio (EQR)	EQR = BEST/ ES, where BEST= ET / (1 + ACDEV / 100) ET= threshold (Table 17) ACDEV= acceptable deviation: 50 % for DIN. The final EQR values are scaled after normalisation to five classes of 0.2 width and a Scaled Environmental Quality Ratio is obtained (EQRS)	EQR = BEST/ ES, where BEST= ET / (1 + ACDEV / 100) ET= threshold (Table 17) ACDEV= acceptable deviation: 50 % for DIP. The final EQR values are scaled after normalisation to five classes of 0.2 width and a Scaled Environmental Quality Ratio is obtained (EQRS)

Table 3. Specifications of the core indicators total nitrogen and phosphorus (TN, TP)

Indicator	Total nitrogen	Total phosphorus
Response to eutrophication	Positive	Positive
Parameters	Total nitrogen concentration (µmol L^{-1})	Total phosphorus concentration (µmol L^{-1})
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016-2021	2016-2021
Assessment season	Annual	Annual
Depth	Surface = average in the 0 – 10 m layer	Surface = average in the 0 – 10 m layer
Removing outliers	No outliers removed	No outliers removed
Removing close observations	No close observations removed	No close observations removed
Indicator level (ES)	average of annual/seasonal average values (mostly average = arithmetic mean, in some Contracting Parties the median is used instead to assess status versus threshold)	average of annual/seasonal average values (mostly average = arithmetic mean, in some Contracting Parties the median is used instead to assess status versus threshold)
Environmental Quality Ratio (EQR)	EQR = BEST/ ES, where BEST= ET / (1 + ACDEV / 100) ET= threshold (Table 17) ACDEV= acceptable deviation: 50 % for TN. The final EQR values are scaled after normalisation to five classes of 0.2 width and a Scaled Environmental Quality Ratio is obtained (EQRS)	EQR = BEST/ ES, where BEST= ET / (1 + ACDEV / 100) ET= threshold (Table 17) ACDEV= acceptable deviation: 50 % for TP. The final EQR values are scaled after normalisation to five classes of 0.2 width and a Scaled Environmental Quality Ratio is obtained (EQRS)

The confidence assessment for the nutrient indicators includes aspects of temporal, spatial and accuracy confidence following the description of the general methodology in chapter 4.2.

Detailed information on indicator-specific confidence class boundaries is provided in Table 19 of Annex 1. The R-code of the HEAT tool for the calculation of the different indicators including confidence rating is available on GitHub as well as explanations on the abbreviations used. Information on the main indicator statistics including abbreviations is also summarised in Table 15 of chapter 4.1.

3.1.2 Chlorophyll-a concentration (direct effects)

Core indicator ‘Chlorophyll-a’ is used in the eutrophication assessment for criteria group 2 on direct effects of eutrophication. The indicator is utilised for the integrated assessment of eutrophication in the HEAT HOLAS 3 tool. The average chlorophyll-a concentration in open sea assessment units is a combined estimate of three types of data (depending on availability, applicability, and regional agreement): 1) *in situ* measurements 2) Earth Observation (EO) remote sensing satellite estimates, and 3) FerryBox flow-through estimates. *In situ* measurements and EO data are available for all open-sea areas, whereas FerryBox data is applied only in agreed open sea areas, the Northern Baltic Proper and Gulf of Finland Western. These data are combined as annual averages, applying weighting based on data availability and confidence. Indicator-specific principles and specifications for chlorophyll-a indicator are summarised in Table 4. Calculations are made both on seasonal and assessment period levels.

The *in situ* chlorophyll-a data (1) is collected in the ship-based monitoring and the samples are handled and analyzed, as explained in the HELCOM Guidelines for monitoring of chlorophyll-a. The satellite-based EO-dataset (2) is calculated at Syke using the Copernicus programme Sentinel-satellite series instrument data. The EO chl-a values for the surface layer depend on the transparency of the water. Cloudy areas have been removed from the dataset. The data is reported as daily statistics of 20K grid cells (Annex 2).

Information based on flow-through system onboard ferrylines (FerryBox data, 3) is collected and validated by Syke and reported to ICES. As selected ferries operating on the Baltic Sea are the platform for FerryBox flow-through systems and only specific routes are followed (https://www.ferrybox.com/routes_data/routes/baltic_sea/index.php.en) the data availability is not evenly distributed across all HELCOM sub-basins. To remove possible spatial bias, which might be considerable in areas with spatial sampling gradients, the Ferrybox-based chl-a estimate is corrected to represent the entire area. This correction is done separately for each HELCOM sub-basin, based on a longer-term reference data, which was achieved using long term statistics on chl-a concentrations derived from satellite instrument MERIS (years 2002-2011). The correction is done separately for each year within the assessment period, according to the following formula:

$$F_{\mathrm{corr}} = \frac{1}{n} \sum_{i=1}^{n} \frac{ref_{\mathrm{ave}}}{ref_{\mathrm{i}}} F_i \text{, where}$$

F_{corr} is the corrected Ferrybox chla estimate in a HELCOM sub-basin,
n is the number of grid cells in the HELCOM sub-basin,
ref_{i} is the grid cell (geometrical) average for the reference data (MERIS 2002-2011),
ref_{ave} is the sub-basin average of the reference data and
F_{i} is the (geometrical) average Ferrybox chla estimate for grid cell ‘i’.

Table 4. Specifications of the core indicator chlorophyll-a

Indicator	Chlorophyll-*a*
Response to eutrophication	Positive
Parameters	Chlorophyll-*a* concentration (µg l^{-1})
Assessment period	2016-2021
Assessment season	Summer = June + July + August + September

<table>
<tr><td>Depth</td><td>Surface:
<i>in situ</i> data: average in the 0-10 m layer
FerryBox data: 3-5 m depth</td></tr>
<tr><td>Removing outliers</td><td>On responsibility of data submitter</td></tr>
<tr><td>Removing close observations</td><td>No close observations removed</td></tr>
<tr><td>Indicator level (ES)</td><td>Defined as using the following data types: 1) water sample measurements from HELCOM COMBINE (<i>in situ</i>), 2) daily earth observation on 20K grid (EO) and in part of the assessment units additionally 3) FerryBox observations (fb). The final ES is defined as an average of the annual estimates, which are defined as weighted averages of data specific ES estimates.

<i>M</i> = datatype weight, agreed by the eutrophication network and State & Conservation 17-2022. Weights are given in table below and <i>M(in situ)</i> + <i>M(eo)</i> + <i>M(fb)</i> = 1

<table>
<tr><td>Sub-basin</td><td>$M_{in\text{-}situ}$</td><td>M_{EO}</td><td>M_{fb}</td></tr>
<tr><td>SEA-001 The Kattegat</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-002 Great Belt</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-003 The Sound</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-004 Kiel Bay</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-005 Bay of Mecklenburg</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-006 Arkona Basin</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-007 Bornholm Basin</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-007B Pomeranian Bay</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-008 Gdansk Basin</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-009 Eastern Gotland Basin</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-010 Western Gotland Basin</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-011 Gulf of Riga</td><td>0.70</td><td>0.30</td><td>0</td></tr>
<tr><td>SEA-012 Northern Baltic Proper</td><td>0.40</td><td>0.30</td><td>0.30</td></tr>
<tr><td>SEA-013A Gulf of Finland Western</td><td>0.40</td><td>0.30</td><td>0.30</td></tr>
<tr><td>SEA-013B Gulf of Finland Eastern</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-014 Åland Sea</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-015 Bothnian Sea</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-016 The Quark</td><td>0.55</td><td>0.45</td><td>0</td></tr>
<tr><td>SEA-017 Bothnian Bay</td><td>0.55</td><td>0.45</td><td>0</td></tr>
</table>

<i>ES(in-situ)</i> = arithmetic average of <i>in-situ</i> observations in assessment unit during assessment season during year <i>y</i>
<i>ES(eo)</i> and <i>ES(fb)</i> = geometric average of EO/fb grid cell data in assessment unit during assessment season during year <i>y</i></td></tr>
<tr><td>Environmental Quality Ratio (EQR)</td><td>EQR = BEST/ ES,
where
BEST= ET / (1 + ACDEV / 100)
ET= threshold (Table 17)
ACDEV= acceptable deviation: 50 % for chlorophyll-a
The final EQR values are scaled after normalisation to five classes of 0.2 width and a Scaled Environmental Quality Ratio is obtained (EQRS)</td></tr>
</table>

The confidence assessment for the chlorophyll-a indicator includes aspects of temporal, spatial and accuracy confidence following the description of the general methodology in chapter 4.2. For chlorophyll-a, the confidence is first calculated separately for the three data types of the indicator (in situ, FerryBox, EO) and the overall indicator confidence is calculated using the weighted average of the data type specific values using the datatype weights in Table 4. The same criteria are used for all data types, based on their n, as described below.

n_y(in situ) = number of observations

n_y(EO), n_y(fb) = the number of 20K grid cells containing data, multiplied with the number of observation days during year y

The confidence assessment for chlorophyll-a is included in the R-code of the HEAT tool. As an exception, the spatial confidence for satellite data was provided by Syke for HOLAS 3, due to the different grids used for the satellite data (20 K) and the confidence assessment in the code for HEAT tool (10-30-60 K).

Detailed information on indicator-specific confidence class boundaries is provided in Table 19 of Annex 1. The R-code of the HEAT tool for the calculation of the different indicators including confidence rating is available on GitHub as well as explanations on the abbreviations used. Information on the main indicator statistics including abbreviations is also summarised in Table 15 of chapter 4.1.

3.1.3 Water transparency (indirect effects)

In the HOLAS 3 eutrophication assessment, the core indicator 'Water transparency (Secchi depth)' was moved from the criteria group direct effects to the indirect effects category (Figure 1). The indicator is utilised for the integrated assessment of eutrophication in the HEAT HOLAS 3 tool. Indicator-specific principles and specifications for water transparency are summarised in Table 5. Calculations are made both on seasonal and assessment period levels.

Table 5. Specifications of the core indicators on water transparency

Indicator	Water transparency
Response to eutrophication	Negative
Parameters	Secchi depth (m)
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016 - 2021
Assessment season	Summer = June + July + August + September
Depth	-
Removing outliers	No outliers removed
Removing close observations	No close observations removed
Indicator level (ES)	average of annual values for the average from June to September
Environmental Quality Ratio (EQR)	EQR = ES/BEST, where BEST= ET / (1 - ACDEV / 100) ET= threshold (Table 17) ACDEV= acceptable deviation: 25 % for water transparency The final EQR values are scaled after normalisation to five classes of 0.2 width and a Scaled Environmental Quality Ratio is obtained (EQRS)

The confidence assessment for water transparency includes aspects of temporal, spatial and accuracy confidence following the description of the general methodology in chapter 4.2.

Detailed information on indicator-specific confidence class boundaries is provided in Table 19 of Annex 1. The R-code of the HEAT tool for the calculation of the different indicators including confidence rating is available on GitHub as well as explanations on the abbreviations used. Information on the main indicator statistics including abbreviations is also summarised in Table 15 of chapter 4.1.

3.1.4 Oxygen debt (indirect effects)

Core indicator ‘Oxygen debt’ is used in the eutrophication assessment for criteria group 3 on indirect effects of eutrophication. This core indicator evaluates average oxygen debt below the halocline that separates deep water from the surface water (Table 6). The oxygen debt is defined as the “missing” oxygen relative to a fully saturated water column. Oxygen debt is applied in the Bornholm Basin and Baltic Proper (containing Gdansk Basin, Western Gotland Basin, Eastern Gotland Basin, Northern Baltic Proper and Gulf of Finland Western assessment units). For more details on the method, see BSEP 133 (BSEP 133) and the derivative R-scripts (https://github.com/ices-tools-prod/HEAT/tree/master/OxygenDebt).

Table 6. Specifications of the core indicator oxygen debt

Indicator	Oxygen debt
Response to eutrophication	positive
Parameters	Oxygen debt (mg l^{-1})
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016 - 2021
Assessment season	All months
Depth	Below halocline
Indicator level (ES)	Reported as ready indicator product, according to details documented in BSEP 133
Environmental Quality Ratio (EQR)	EQR = BEST/ES, where BEST= ET / (1 + ACDEV / 100) ET= threshold (Table 17) ACDEV= acceptable deviation: 50 % for oxygen debt The final EQR values are scaled after normalisation to five classes of 0.2 width and a Scaled Environmental Quality Ratio is obtained (EQRS)

The confidence methods of the indicator results are yet to be developed.

3.1.5 State of the soft-bottom macrofauna community (indirect effects)

In the HOLAS 3 eutrophication assessment, the core indicator ‘State of the soft-bottom macrofauna community’ was used in the indirect effects category (Figure 1) in the following assessment units: Gulf of Riga, Gulf of Finland (Eastern and Western), Åland Sea, Bothnian Sea, The Quark and Bothnian Bay. The indicator is utilised for the integrated assessment of eutrophication in the HEAT HOLAS 3 tool. Indicator-specific principles and specifications are summarised in Table 7.

Table 7. Specifications of the core indicators State of the soft-bottom macrofauna community

Indicator	State of the soft-bottom macrofauna community
Response to eutrophication	negative
Parameters	BQI (index), based on species abundance data
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016-2021
Assessment season	All seasons
Depth	Above halocline in Gulf of Finland. All depths in Bothnian Bay, The Quark, Bothnian Sea, Åland Sea and Gulf of Riga
Indicator level (ES)	Reported as ready indicator product, as described in the indicator report.
Environmental Quality Ratio (EQR)	Scaled based on assessment unit specific maximum and minimum values, and placing the threshold value at 0.6.

The confidence of the indicator results was evaluated using spatial and temporal data coverage and an estimate of the probability that the status is above the threshold derived from the distribution of the 100 000 bootstrapped BQI-values (see indicator report on Soft-bottom macrofauna), as well as methodological confidence. As the confidence assessment for the soft-bottom macrofauna indicator differs from the general confidence assessment for eutrophication indicators, it is not calculated in HEAT, but the confidence results are included in the overall confidence assessment result (see Eutrophication Thematic Assessment 2016-2021).

3.2 Pre-core indicators

Pre-core indicators are included in the eutrophication assessment, acknowledging that they still need further development to achieve standards defined for core indicators, but considering important environmental aspects which would otherwise be missing completely in the assessment.

Two pre-core indicators were used in HOLAS 3, the 'Cyanobacterial bloom index' for direct effects and the 'Shallow-water oxygen' for indirect effects. They are both described in more detail in the following sub-sections and the aim is to reach core status for HOLAS 4.The threshold values applied for pre-core indicators used in the open sea assessment units of HOLAS 3 are listed in Table 17 in Annex 1.

3.2.1 Cyanobacterial bloom index (direct effects)

Pre-core indicator 'Cyanobacterial bloom index (CyaBI)' is used in the eutrophication assessment for criteria group 2 on direct effects of eutrophication. The indicator is utilised for the integrated assessment of eutrophication in the HEAT HOLAS 3 tool.

The indicator is operational in the following open sea assessment units: Bay of Mecklenburg, Arkona Basin, Bornholm Basin, Pomeranian Bay, Gdansk Basin, Eastern Gotland Basin, Western Gotland Basin, Gulf of Riga, Northern Baltic Proper, Gulf of Finland Western, Gulf of Finland Eastern, Åland Sea and Bothnian Sea. The indicator is under development in Kiel Bay, and it is at present not considered relevant for the assessment units Quark, Bothnian Bay, Great Belt, The Sound and Kattegat. The reason is that active growth of cyanobacteria is restricted to salinities below about 12.

The indicator consists of two parameters 1) cyanobacterial surface accumulations (CSA), combining information of volume, length of bloom period and severity of surface accumulations estimated from remote sensing observations and 2) the cyanobacterial biomass in the water column analyzed from in-situ observations. The final indicator value (ES) is the average of the annual estimates, which are defined as averages of the parameter specific ES estimates, normalized between 0-1, with values decreasing with increasing eutrophication (Table 8). When threshold was available only for one of the parameters, the indicator assessment for that assessment unit was also based solely on that parameter. For the assessment period 2016-2021, this was the case for the Gdansk Basin, Pomeranian Bay and Åland Sea, which only had thresholds available for CSA. The normalization and linear models for CSA were updated for HOLAS 3, which affected the normalized CSA threshold values, but the underlying FCA values remain unchanged (IC STATE & CONSERVATION 2-2022 document 5J-27, appendix 2).

Indicator results for cyanobacterial biomass are calculated outside HEAT. Cyanobacterial biomass results are provided by HELCOM EG Phyto and CSA results by Syke.

Parameter 1: Cyanobacterial surface accumulations (CSA)

The main data source utilized by the indicator was satellite observation data derived from the daily algal bloom charts of Syke. The bloom level is estimated utilizing atmospheric-corrected, satellite-observed reflectance signal at 560 nm wavelength (green light band). The method accounts for subsurface and surface blooms. The observations were interpreted to estimate the potentiality of surface algae accumulations in four classes: none (0), potential (1), likely (2), and evident (3). The spatial aggregation of daily Earth Observations (EO) from the assessment units was conducted by calculating an algae barometer value. The algae barometer (AB) value is a weighted sum of the proportion of positive algae observations in the different classes in an assessment area (Eq. 1; Rapala *et al*. 2012).

$$AB = \frac{1}{n_{tot}}(n_{\#cl1} + n_{\#cl2} \times 2 + n_{\#cl3} \times 3) \qquad \text{Eq. 1}$$

where n_{tot} is the total number of algae observations, and $n_{\#cl1}$, $n_{\#cl2}$, and $n_{\#cl3}$ are the number of algae observations in classes 1–3. By definition, AB is in the range of 0 to 3.

Seasonal bloom characteristics were estimated using an empirical cumulative distribution function (ECDF) drawn from seasonal observations of daily algae barometer values from each assessment area. The missing days were interpolated in the AB time series. ECDF gives the cumulative proportion of the seasonal algae barometer values. The bloom characteristics (i.e., the indicative variables of CSA) were defined for each assessment unit as follows: (1) seasonal volume, i.e., the areal coverage above the ECDF functions, (2) length of algal surface accumulation period, i.e., the fraction of the observation period with algae barometer values above bloom limit (taken as 0.5) on as many consecutive days as possible, and (3) bloom severity, i.e., the 90th percentile of the algae barometer observations. The CSA index time series was derived by taking an average from the normalized time series of the indicative variables and grouping all the three EO-based parameters together.

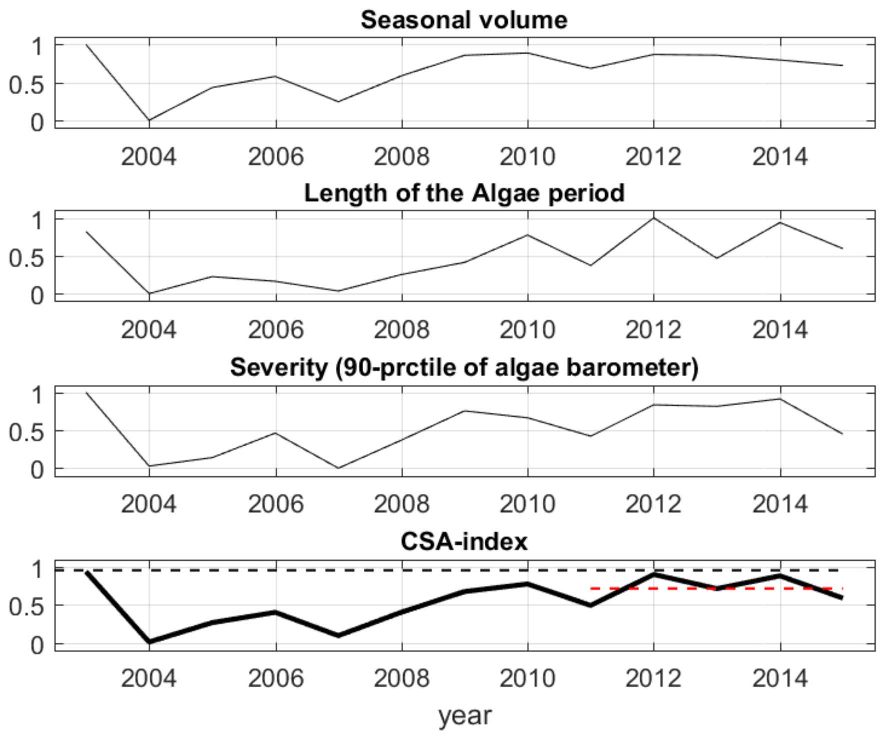


Figure 4. An example (Gulf of Finland) of grouping the normalized EO-based parameters (from top to bottom) (A) seasonal bloom volume, (B) length of bloom period and (C) Severity of blooms, and (D) a combined cyanobacterial surface accumulation (CSA) parameter. As the indicator responds negatively to increased eutrophication, 1 represents the best conditions and 0 the worst. Black dashed horizontal line indicates the parameter-specific target condition, and the red dashed line indicates the estimate for 2011-–2014.

Parameter 2: Cyanobacterial biomass

The annual cyanobacterial biomass values were calculated as described in Kownacka *et al*. 2022. In brief, cyanobacterial biomass was estimated from water samples using microscopy techniques. The data used in the indicator parameter originated from Danish, Estonian, Finnish, German, Latvian, Lithuanian, Polish and Swedish national monitoring data, and was collated by the HELCOM phytoplankton expert group (PEG), for the HELCOM Baltic Sea Environment Fact Sheet, which is updated annually (Kownacka *et al*. 2022).

The cyanobacterial biomass (wet weight in µg/L) was analyzed from integrated water samples (generally 0-10 m, with exceptions described in Kownacka *et al*. 2022). The biomass of the genera *Nodularia*, *Aphanizomenon* and *Dolichospermum* (previously *Anabaena*) was included in the parameter.

National monitoring samples were analyzed and identified by phytoplankton experts, following the HELCOM guidelines for monitoring phytoplankton species composition, abundance and biomass. Sampling frequency was variable and dependent on national monitoring cruises. At least one sample per month had to be available to allow the calculation of the seasonal average. Only in few exceptions data is presented despite missing data from one month out of three, as described in Kownacka *et al*. 2002.

Monthly means were first calculated for each assessment unit, and the seasonal means were then calculated as averages of the monthly values.

Table 8. Specifications of the pre-core indicator cyanobacterial bloom index.

<table>
<tr><td>Indicator</td><td>Cyanobacterial bloom index</td></tr>
<tr><td>Response to eutrophication</td><td>Negative for the normalized parameters and indicator</td></tr>
<tr><td>Parameters</td><td>Cyanobacterial biomass and Cyanobacterial surface accumulations (CSA)</td></tr>
<tr><td>Assessment period</td><td>2016 - 2021</td></tr>
<tr><td>Assessment season</td><td>Summer
Biomass: June-August, in the Bothnian Sea June-October
CSA: EOs are accounted from 1st of June to 31st of August</td></tr>
<tr><td>Depth</td><td>Surface
Biomass: integrated samples from 0 to up to 20 m (generally 0-10 m), as described below
CSA: the methodology accounts for the detection of both subsurface and surface blooms</td></tr>
<tr><td>Removing outliers</td><td>On responsibility of data submitter</td></tr>
<tr><td>Removing close observations</td><td>No close observations removal</td></tr>
<tr><td>Indicator level (ES)</td><td>Defined using the two parameters: 1) Cyanobacterial surface accumulations (CSA) and 2) cyanobacterial biomass.
The final ES is the average of the annual estimates, which are defined as averages of the parameter specific ES estimates, normalized between 0-1, with values decreasing with increasing eutrophication. If only one parameter is available for an assessment unit, the ES value of that parameter is used as the indicator level.</td></tr>
<tr><td>Environmental Quality Ratio (EQR)</td><td>The normalised estimates (0-1) are directly used as EQR values. The final EQR values are scaled after normalisation to five classes of 0.2 width.
The class boundaries are given in the table below
<table>
<tr><th>Parameter</th><th>Unit ID</th><th>High-good</th><th>Good-moderate</th><th>Moderate-poor</th><th>Poor-bad</th></tr>
<tr><td>biomass</td><td>SEA-005</td><td>0.96</td><td>0.92</td><td>0.613</td><td>0.307</td></tr>
<tr><td>biomass</td><td>SEA-006</td><td>0.97</td><td>0.94</td><td>0.627</td><td>0.313</td></tr>
<tr><td>biomass</td><td>SEA-007</td><td>0.935</td><td>0.87</td><td>0.580</td><td>0.290</td></tr>
<tr><td>biomass</td><td>SEA-009</td><td>0.92</td><td>0.84</td><td>0.560</td><td>0.280</td></tr>
<tr><td>biomass</td><td>SEA-010</td><td>0.91</td><td>0.82</td><td>0.547</td><td>0.273</td></tr>
<tr><td>biomass</td><td>SEA-011</td><td>0.94</td><td>0.88</td><td>0.587</td><td>0.293</td></tr>
<tr><td>biomass</td><td>SEA-012</td><td>0.99</td><td>0.98</td><td>0.653</td><td>0.327</td></tr>
<tr><td>biomass</td><td>SEA-013A</td><td>0.915</td><td>0.83</td><td>0.553</td><td>0.277</td></tr>
<tr><td>biomass</td><td>SEA-013B</td><td>0.92</td><td>0.84</td><td>0.560</td><td>0.280</td></tr>
<tr><td>biomass</td><td>SEA-015</td><td>0.95</td><td>0.90</td><td>0.600</td><td>0.300</td></tr>
<tr><td>CSA</td><td>SEA-005</td><td>0.925</td><td>0.85</td><td>0.567</td><td>0.283</td></tr>
<tr><td>CSA</td><td>SEA-006</td><td>0.875</td><td>0.75</td><td>0.500</td><td>0.250</td></tr>
<tr><td>CSA</td><td>SEA-007</td><td>0.895</td><td>0.79</td><td>0.527</td><td>0.263</td></tr>
<tr><td>CSA</td><td>SEA-007B</td><td>0.905</td><td>0.81</td><td>0.540</td><td>0.270</td></tr>
<tr><td>CSA</td><td>SEA-008</td><td>0.885</td><td>0.77</td><td>0.513</td><td>0.257</td></tr>
<tr><td>CSA</td><td>SEA-009</td><td>0.97</td><td>0.94</td><td>0.627</td><td>0.313</td></tr>
<tr><td>CSA</td><td>SEA-010</td><td>0.94</td><td>0.88</td><td>0.587</td><td>0.293</td></tr>
<tr><td>CSA</td><td>SEA-011</td><td>0.96</td><td>0.92</td><td>0.613</td><td>0.307</td></tr>
<tr><td>CSA</td><td>SEA-012</td><td>0.935</td><td>0.87</td><td>0.580</td><td>0.290</td></tr>
<tr><td>CSA</td><td>SEA-013A</td><td>0.965</td><td>0.93</td><td>0.620</td><td>0.310</td></tr>
<tr><td>CSA</td><td>SEA-013B</td><td>0.985</td><td>0.97</td><td>0.647</td><td>0.323</td></tr>
<tr><td>CSA</td><td>SEA-014</td><td>0.955</td><td>0.91</td><td>0.607</td><td>0.303</td></tr>
<tr><td>CSA</td><td>SEA-015</td><td>0.97</td><td>0.94</td><td>0.627</td><td>0.313</td></tr>
</table>
</td></tr>
</table>

The confidence assessment for the ‘Cyanobacterial bloom index’ includes aspects of temporal, spatial and accuracy confidence following the description of the general methodology in chapter 4.2.

For ‘Cyanobacterial bloom index’, the confidence is first calculated separately for each parameter (biomass, CSA). The overall indicator confidence is calculated using the average of the parameter specific values. The general HEAT confidence methodology was followed as such for the biomass parameter and with slight adjustments to fit the datatype for CSA, as described in Document 5J-27, appendix 3 for IC STATE & CONSERVATION 2-2022. Detailed information on indicator-specific confidence class boundaries is provided in Table 19 of Annex 1. Regarding the confidence for CSA parameter, observation days were used instead of observations for the general temporal confidence, and the share of area represented by CSA was used instead of coverage of sampled grid cells for spatial confidence, to take the data type (satellite) into account.

The confidence assessment for ‘Cyanobacterial bloom index’ was calculated outside of HEAT in Syke. The results were included into the HEAT tool for integrated confidence assessment result. The general methodology of the confidence assessment is described in chapter 4.2. The R-code of the HEAT tool for the calculation of the different indicators including confidence rating is available on GitHub as well as explanations on the abbreviations used. Information on the main indicator statistics including abbreviations is also summarised in Table 15 of chapter 4.1.

3.2.2 Shallow-water oxygen (indirect effects)

The ‘Shallow-water oxygen’ indicator is applied for the first time as pre-core indicator in the Western Baltic Sea, the Pomeranian Bay, the Gulf of Riga, Gulf of Finland Eastern and the Gulf of Bothnia. The ‘Shallow-water oxygen’ indicator is used for the eutrophication assessment in criteria group 3 for indirect effects together with water transparency and soft-bottom macrofauna indicators, where applied. The indicator is utilized for the integrated assessment of eutrophication in the HEAT HOLAS 3 tool.

Different area-specific approaches are used to assess near-bottom oxygen conditions. In the Western Baltic (Kattegat, Great Belt, The Sound, Kiel Bay, Mecklenburg Bay and Arkona Basin) the average area affected by oxygen concentrations below 2, 4 and 6 mg L^{-1} is used, whereas in the Pomeranian Bay and the Gulf of Riga the seasonal minimum oxygen concentration below 4 or 6 mg L^{-1}, depending on seasonally stratified or well-mixed conditions in the water column, is applied. A concentration-based approach is also used in the Gulf of Bothnia (Bothnian Bay, The Quark, Bothnian Sea) to account for deteriorating conditions based on changes in the near-bottom oxygen concentration compared to a reference period. In the Gulf of Finland Eastern a volume-based approach is applied to characterize the water volume under low oxygen conditions by using a threshold of 6 mg L^{-1}.

The confidence assessment is carried out differently in the area-specific approaches and mainly accounts for temporal and spatial confidence aspects of the underlying data. Further details of the different area-specific approaches, including the confidence assessment, can be found in the indicator report for shallow-water oxygen .

Western Baltic Sea

The Western Baltic Sea is strongly affected by seasonal hypoxia, which is partly a natural phenomenon that also occurred in historic times, but to a much lesser extent. In the Western Baltic Sea an area-based approach is used to estimate the areal extent of oxygen depleted waters with oxygen concentrations below 2, 4 and 6 mg L^{-1}. This method is applied in the Kattegat, Great Belt, The Sound, Kiel Bay, Bay of Mecklenburg and Arkona Basin. A non-parametric modelling approach was used to estimate the oxygen concentrations in the past. The areal extent of oxygen depletion for the period 1949-1969 was used to characterize the target conditions in the different sub-basins. To assess the current assessment period, an interpolation model has been used. CTD profiles focused on the month of September (typical peak of seasonal hypoxia with largest areal distribution in the Western Baltic Sea area) are analyzed to determine the depths where the oxygen concentration falls below 2, 4 and 6 mg L^{-1}. An average of the areal extent of the different oxygen concentrations in the assessment period is used for the comparison with the threshold values to assess the status.

Table 9. Specifications of the pre-core indicator shallow-water oxygen in the Western Baltic Sea

Indicator	Shallow-water oxygen
Response to eutrophication	negative
Parameters	Area of oxygen concentration below 2, 4 and 6 mg L^{-1}
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016-2021
Assessment season	August to October (for reference conditions and targets), September (for current assessment period)
Depth	Varying, depending on where the oxygen concentration falls below the required level of 2, 4 and 6 mg L^{-1}
Indicator level (ES)	Reported as ready indicator product according to the area-specific approach (area below defined oxygen concentrations) as described in the indicator report.
Environmental Quality Ratio (EQR)	Scaled based on assessment unit specific maximum and minimum values, and placing the threshold value at 0.6.

Pomeranian Bay and Gulf of Riga

The oxygen minimum approach applied in these two open-sea areas is based on the deepest measured oxygen concentration per station close to the sea floor. The station value is determined as the median of the seasonal minima values for the assessment period. Stations are weighted depending on the number of measurements per season and the number of years with data during the assessment period, to result in an overall weighted mean of the EQRS values per station. The assessment season is defined area-specific using July to November in the Pomeranian Bay and July to September in the Gulf of Riga. Thresholds of 4 and 6 mg L^{-1} are set per station according to seasonally stratified (>15m) or well-mixed conditions (≤15m depth).

Table 10. Specifications of the pre-core indicator shallow-water oxygen for Pomeranian Bay and Gulf of Riga

Indicator	Shallow-water oxygen
Response to eutrophication	negative
Parameters	Near-bottom oxygen concentration in mg L^{-1}
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016-2021
Assessment season	July to November in the Pomeranian Bay July to September in the Gulf of Riga
Depth	Near-bottom (max 4m from seafloor)
Indicator level (ES)	Reported as ready indicator product according to the respective area-specific approach (oxygen concentration, volume or area below defined oxygen concentrations) as described in the indicator report.
Environmental Quality Ratio (EQR)	Scaled based on assessment unit specific maximum and minimum values, and placing the threshold value at 0.6.

Eastern Gulf of Finland

To develop a 'Shallow-water oxygen' indicator for the Gulf of Finland Eastern, all available oxygen water sample analyses from the area were gathered from several databases resulting in a dataset from 1900 until 2021 (Stoicescu et al. manuscript). A volume-based approach was applied and a concentration of dissolved oxygen (DO) <= 6 mg L-1 was selected, to characterize the water volume under low oxygen conditions. This concentration is shown to be a limit below what about 75% of fish will experience stress caused by low oxygen conditions (Vaquer-Sunyer and Duarte, 2008).

To find the volume estimate, a mean profile was compiled for each year in the assessment period. The DO = 6 mg L-1 isoline depth was found for each of these mean profiles, and the average depth for the current assessment period was used for the volume estimate (Stoicescu et al. manuscript).

Because the (eastern) Gulf of Finland is strongly affected by deep-layer advection of saltier and deoxygenated waters, a salinity correction of oxygen concentrations was proposed. This would remove the hydrography effects from the indicator results and allow the estimation of the anthropogenic factor influencing the oxygen conditions.

Table 11. Specifications of the pre-core indicator shallow-water oxygen in the Eastern Gulf of Finland

Indicator	Shallow-water oxygen
Response to eutrophication	positive
Parameters	Volume of oxygen-deficient (<6mg L^{-1}, salinity-corrected) water layer.
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016-2021
Assessment season	July - October
Depth	Varying
Indicator level (ES)	Reported as ready indicator product according to the respective area-specific approach (oxygen concentration, volume or area below defined oxygen concentrations) as described in the indicator report.
Environmental Quality Ratio (EQR)	Scaled based on assessment unit specific maximum and minimum values, and placing the threshold value at 0.6.

Bothnian Bay, Quark and Bothnian Sea

The approach used for the shallow water oxygen indicator in the Bothnian Bay, Quark and Bothnian Sea is concentration-based. In these areas, oxygen hypoxia has not occurred, but oxygen concentrations have decreased. In order to account for the deteriorating development, the indicator is based on changes in near-bottom oxygen concentration from the reference period.

The indicator estimates the temporal change in near-bottom oxygen concentration in July – October, when the oxygen concentrations are lowest, from the reference period to the assessment period. In order to exclude the effect of increasing temperature on oxygen solubility from the observed negative trends in oxygen concentration, the oxygen concentrations were first transformed to oxygen saturation as described in HELCOM COMBINE manual, and the oxygen saturation values where then calculated back to "saturation corrected oxygen concentrations" using oxygen solubility at site specific average near-bottom temperatures and salinities. The effect of saturation correction was small, but consistent.

Table 12. Specifications of the pre-core indicator shallow-water oxygen in Bothnian Bay, Quark and Bothnian Sea

Indicator	Shallow-water oxygen
Response to eutrophication	negative
Parameters	Saturation-corrected near-bottom oxygen concentration in mg L^{-1}
Data source	Monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk)
Assessment period (test assessment)	2016-2021
Assessment season	July to October
Depth	Near-bottom (max 5m from seafloor)
Indicator level (ES)	Reported as ready indicator product according to the respective area-specific approach (oxygen concentration, volume or area below defined oxygen concentrations) as described in the indicator report.
Environmental Quality Ratio (EQR)	Scaled based on assessment unit specific maximum and minimum values, and placing the threshold value at 0.6.

3.3 Coastal indicators

In the HOLAS 3 eutrophication assessment, the coastal areas were assessed using indicator results provided by the HELCOM Contracting Parties. 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 (phytoplankton, macrophytes and benthic fauna), and information on nutrients, oxygen concentration and Secchi depth is used only as supportive to the assessment. If indicator information is only available as EQR, which is often the case for biological quality indices such as macrophytes or the benthic community, this can be included directly in HEAT.

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. Different indicators were used by different Contracting Parties and either individual WFD water bodies have been assessed, or water bodies have been aggregated to larger assessment units.

The national indicators used for the assessment of coastal areas in HOLAS 3 are listed in Table 20 of Annex 3.

4 Integrated assessment

The integrated assessment of eutrophication was carried out using the HELCOM Eutrophication Assessment Tool (HEAT HOLAS 3 version) which integrates the indicator results into a quantitative estimate of the overall eutrophication status as good or not good. 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 (Table 13).

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 1 of chapter 2, and the more detailed specifications on how the assessment is carried out are presented in Annex 1.

Since the last HOLAS II assessment, some changes to the assessment procedure have been agreed, relating to the scaling of indicators and adjustments of the confidence rating as well as a changed grouping of indicators, which were applied for the first time in HOLAS 3.

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 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). 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 equal to and above 0.6 indicate good status, to arrive at a common scaling for all indicators. The scaling procedure is illustrated in Annex 1 using an example. The different steps in the calculation procedure of HEAT are illustrated in Figure 5.

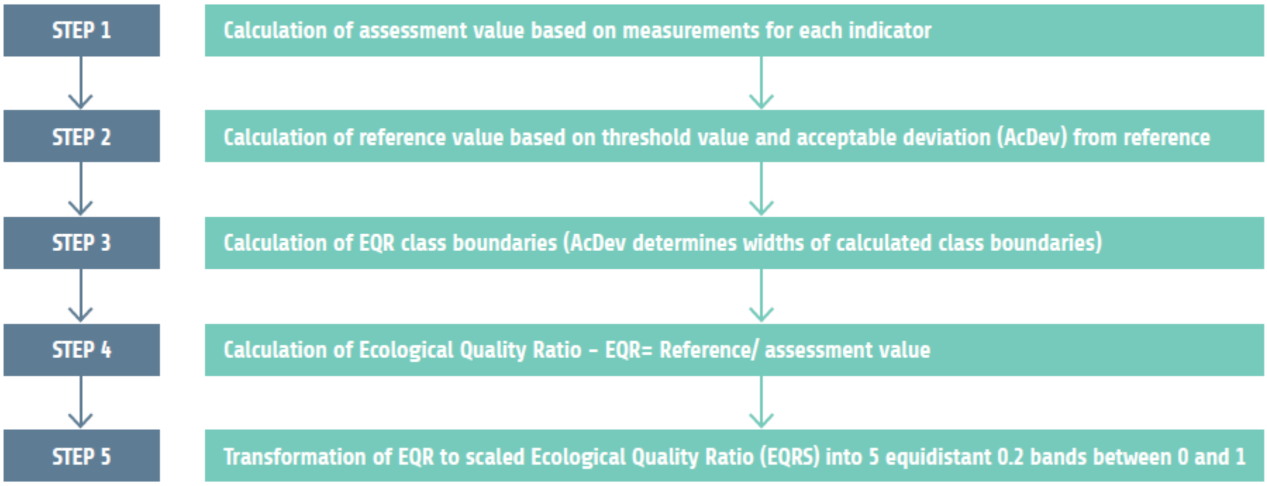
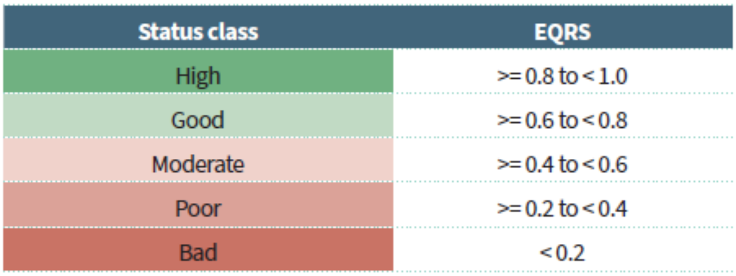


Figure 5. Stepwise approach in the HEAT HOLAS 3 tool to calculate EQR and EQRS values.

The EQRS classes and result categories are shown in Table 13. The weight of the indicators within the different criteria groups is evenly distributed unless otherwise justified (see indicator weights in Table 18 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.

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.

Table 13. Result categories of the assessment using the EQRS values and the colour scheme when presenting the results in maps.



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

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 data view 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 integrated eutrophication status in the HOLAS 3 period 2016-2021 is shown in Figure 6 along with the integrated confidence assessment result as an example for the different output maps of the HEAT HOLAS 3 tool that are provided for the eutrophication status and related confidence on indicator, criteria group and overall level.

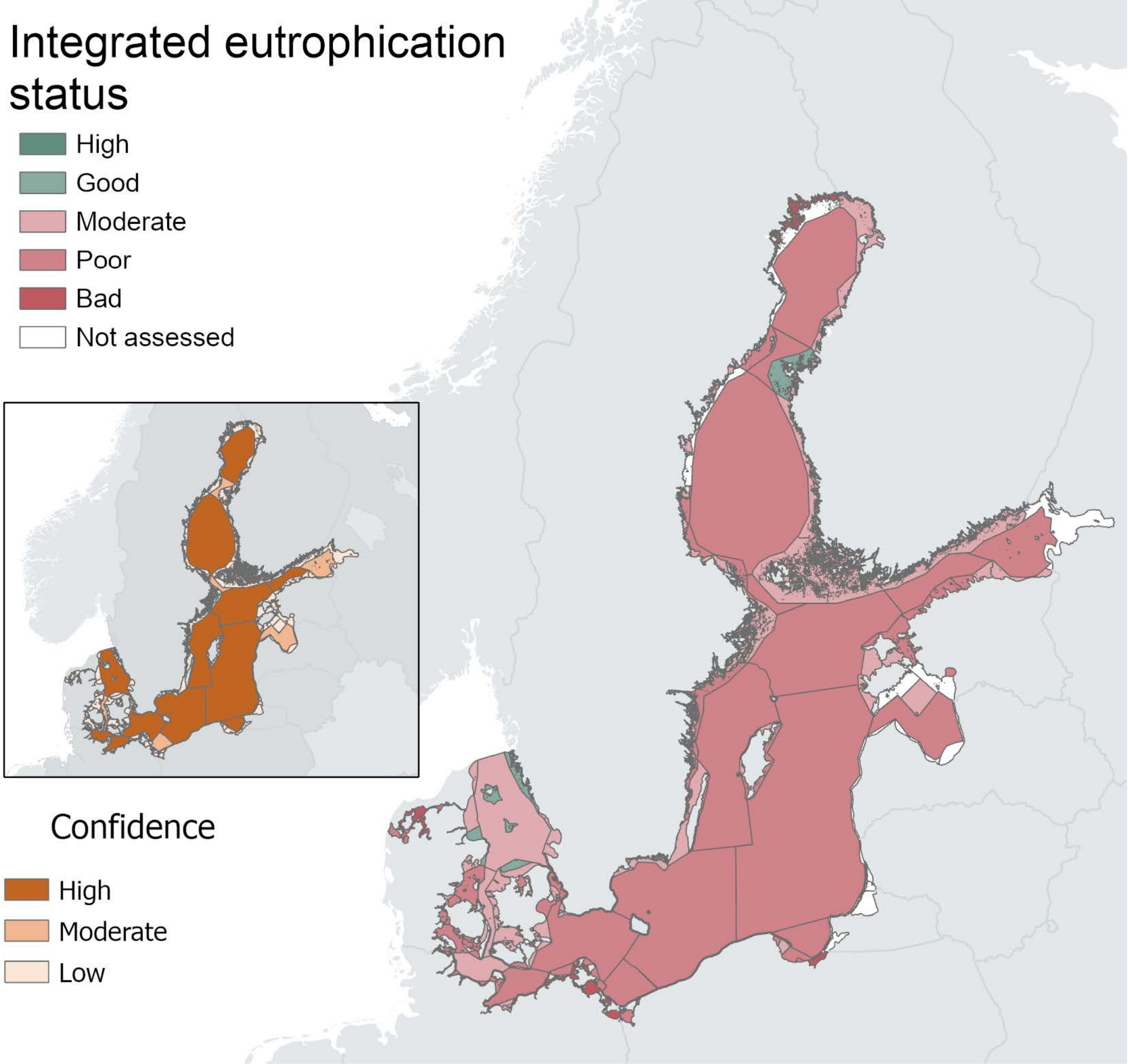


Figure 6. Integrated assessment results for eutrophication in the Baltic Sea 2016-2021 according to the five-class system in respective colours for the status. The inserted map shows the confidence assessment results based on the three classes used with darker colours indicating higher confidence (see HOLAS 3 Eutrophication Thematic Assessment (BSEP 192), 2023).

The eutrophication indicators applied in the integrated assessment for open sea and coastal areas are listed in Table 14. The allocation of the indicators to the different criteria groups and MSFD criteria (primary or secondary) is also provided.

Table 14. 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 phosphorus.

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.
Indirect effects	Oxygen debt	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.
	Shallow water oxygen*		
	WFD indicators on oxygen concentration or hypoxia	Coastal	
	Water transparency	Open sea & 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 species composition and relative abundance or depth distribution of macrophyte communities achieve values that indicate there is no adverse effect due to nutrient enrichment including via a decrease in water transparency.
			D5C7 (secondary): The species composition and relative abundance or depth distribution of macrophyte 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

4.1 HEAT HOLAS 3 tool

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, 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.

The open-sea core and pre-core indicators are updated using data reported by Contracting Parties to the HELCOM COMBINE database hosted by ICES, using the algorithms developed for the eutrophication assessment workflow (see chapter 2.4). The oxygen debt indicator is currently an exception to this and reported as ready indicator products. The values are achieved using indicators specifications shown in Table 6. The calculation of the oxygen debt indicator is provided as separate R-script on GitHub.

For open-sea areas, the indicator statistics are produced from data and/or data products submitted and stored at the HELCOM eutrophication assessment data base using the indicator-specific aggregation principles and specifications as described in chapter 3 for core and pre-core indicators. Calculations are made both on annual and assessment-period levels.

For coastal areas, there are two optional ways of producing the indicator statistics. Coastal indicators can be assessed from monitoring data submitted and stored at the HELCOM eutrophication assessment data base, in a similar way as for open sea indicators. Alternatively, ready indicator statistics can be reported by Contracting Parties being also EU Member States based on calculations made in connection with the national Water Framework Directive reporting. The most important indicator statistics used for the assessment, including respective explanations, are summarised in Table 15.

Table 15. For each indicator, the statistics are calculated in each sub-basin, and include:

Statistic	Abbreviation	Explanation
Indicator value (assessment value)	ES	Indicator value during the period of the assessment; calculation is based on the available observation data
Standard deviation	SD	Standard deviation of data used for calculating ES
Standard error	SE	The standard error is calculated from the standard deviation divided by the square root of the sample size (number of observations), the standard error is needed for calculating accuracy confidence
GES boundary (threshold or target)	ET	Commonly agreed boundary for Good Environmental Status (BSEP 143) and recent agreements for additional or adjusted thresholds at HOD 61-2021
Ecological Quality Ratio	EQR	Ratio between reference value and ES (for indicators with positive response to eutrophication) and ratio between ES and reference value (for indicators with negative response to eutrophication)

Scaled Ecological Quality Ratio	EQRS	The final EQR values are scaled after normalisation to five classes of 0.2 width, and a Scaled Ecological Quality Ratio is obtained (EQRS)
Reference value	BEST	For calculation of EQR values, the reference value can be calculated based on the threshold: BEST= ET/(1+ACDEV/100) for indicators responding positive to eutrophication and BEST= ET/(1-ACDEV/100) for indicators responding negative to eutrophication
Acceptable deviation	ACDEV	Acceptable deviation from reference value to define the good/moderate and further boundaries of the five-class system used
Class boundaries	H/G, G/M, M/P, P/B	Different class boundaries of the five-class system: high/good, good/moderate (GES), moderate/poor and poor/bad
Temporal confidence	TC	Differentiated into a general and specific temporal confidence aspect
Spatial confidence	SC	Includes only a specific spatial confidence aspect
Accuracy confidence	ACC	Certainty of the assessment result in terms of being below or above the threshold value

Further details on the calculation within HEAT (R-script HEAT master code) and abbreviations used for the statistics can be found on GitHub.

The HEAT tool generates output tables of the assessment results on indicator (annual and assessment period) and integrated level and produces status and confidence maps for the different indicators, criteria groups and the overall eutrophication assessment result. Besides the different maps for the results of the assessment period, also bar charts for the different indicators in all assessment units are provided including annual assessment results in relation to the respective threshold, the confidence interval of the data and the number of annual observations used for the assessment. Examples for indicator bar charts and confidence maps are shown in Figure 7 and Figure 8.

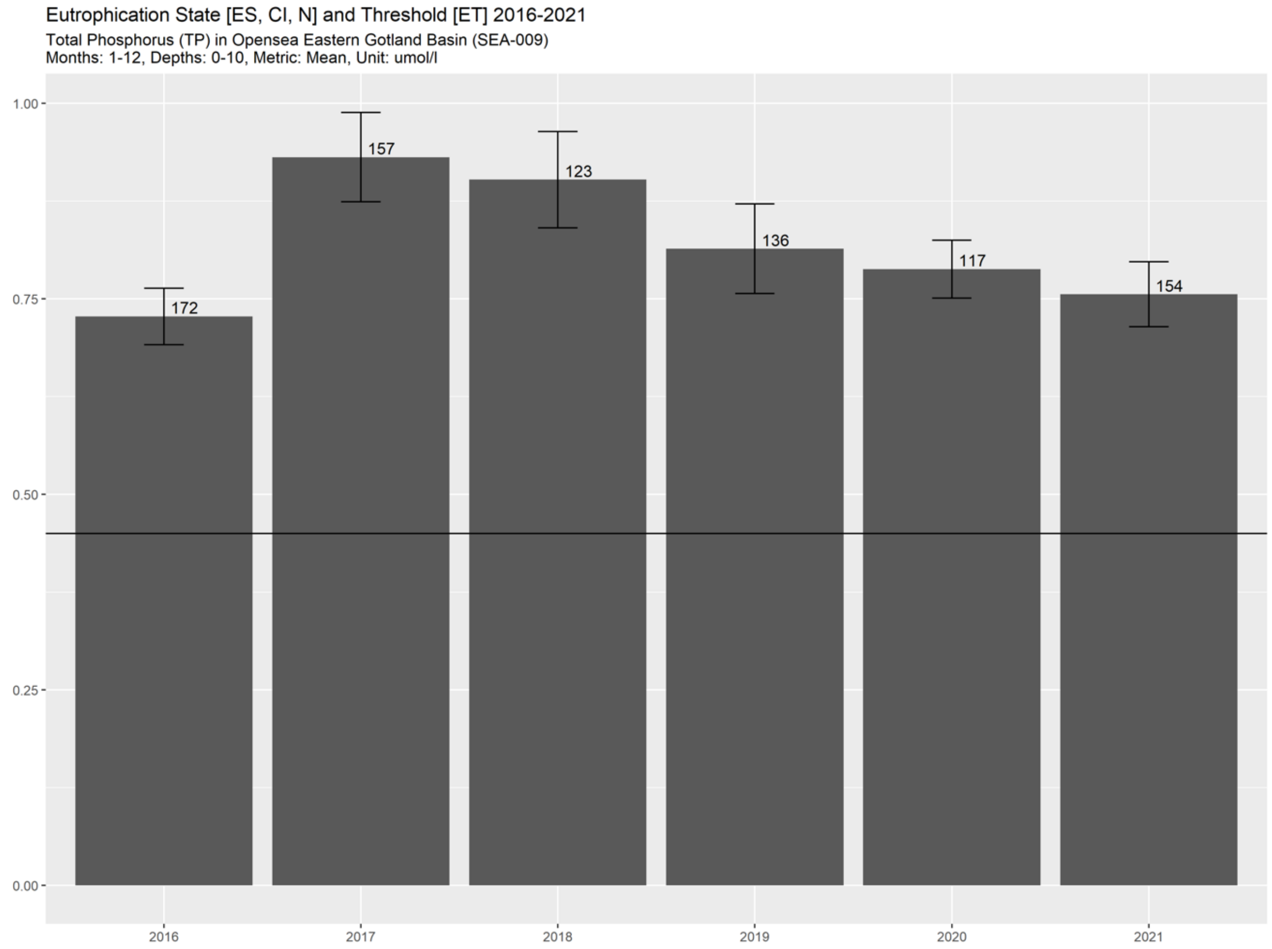


Figure 7. Assessment result of the Total Phosphorus (TP) indicator in the Eastern Gotland Basin 2016-2021 as bar chart provided as output file of the HEAT HOLAS 3 tool. Annual concentrations of TP (ES) in relation to the threshold value (ET) (black line) and additional information on the assessment season, depth of monitoring data considered in the assessment, number of annual observations (N), the metric calculated and the confidence interval (CI).

The output files provided in the HEAT tool are intended for visualisation of assessment results and can also support the interpretation of assessment results in the different assessment units, e.g. for the development of nutrient concentrations during the assessment period, identification of exceptional years and trends in monitoring effort through bar charts or identification of low confidence results in selected assessment units through maps.

In addition to status assessment maps on indicator, criteria group and overall level, also confidence maps are for the different confidence aspects (separately for temporal, spatial and accuracy) produced in the HEAT HOLAS 3 tool. As an example, spatial confidence of TP in the HOLAS 3 period 2016-2021 is shown in Figure 8.

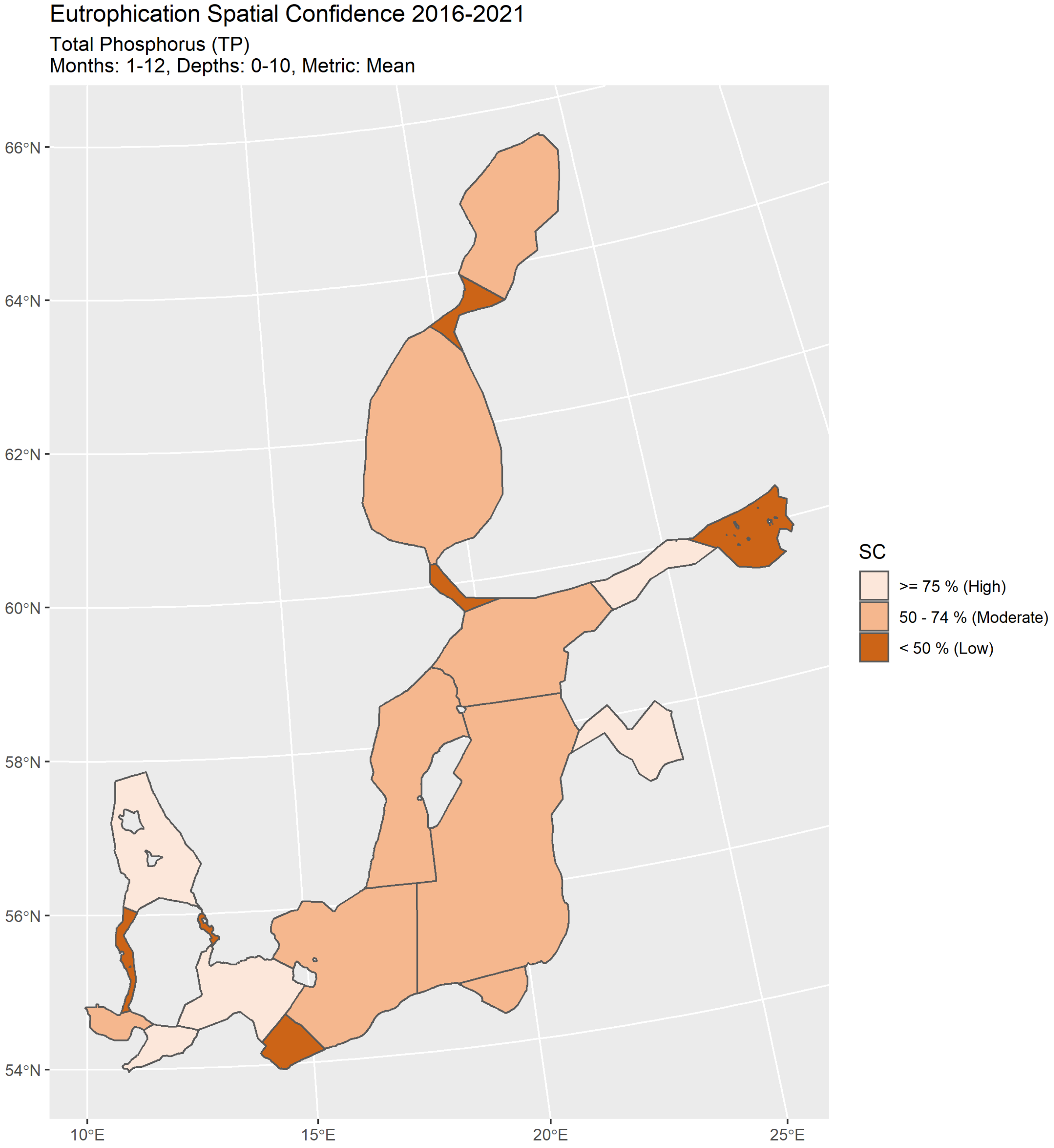


Figure 8. Map of spatial confidence (SC) for TP in all open-sea assessment units 2016-2021 provided as output file of the HEAT HOLAS 3 tool.

In addition to the maps and bar charts in the output folder, the HEAT tool also provides an input folder containing the data used as the basis for the assessment (ICES bottle, pump and CTD data) as well as a configuration file with information on the assessment units, reported assessment results/data products (e.g., for the shallow water oxygen indicator or national WFD indicators in coastal waters), threshold values used, confidence class boundaries and other indicator specifications. Input and output files are produced when running the HEAT master, which can be downloaded from GitHub.

4.2 Confidence assessment

The confidence assessment has been further developed since HOLAS II and includes in addition to temporal confidence also a spatial confidence aspect of the monitoring data as well as an estimate of the accuracy of the assessment result in relation to the threshold. The confidence of the threshold value as such is no longer used in HOLAS 3. In principle, the improved confidence assessment follows the former process with regard to confidence classes (three-class system) and aggregation rules (using mainly the same rules as for the integrated status assessment result). The adjustments made are also intended to achieve harmonisation with the confidence rating in the BEAT tool for the biodiversity assessment.

The general confidence assessment is included in HEAT, and includes aspects of temporal, spatial and accuracy confidence. 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 season (annual/summer). The general temporal confidence (GTC) is assessed based on the number of annual observations during the assessment period, whereas for the specific temporal confidence (STC) the number of missing months in the respective assessment season (annual/summer/winter) determines the classification. The specific spatial confidence (SSC) evaluates the spatial representability of the monitoring data and is based on a gridded approach. Lastly, the accuracy confidence (ACC) indicates how certain the assessment is in relation to the variability of the data to estimate the probability of correct classification for failing or achieving good status. To combine the different confidence assessments GTC and STC are averaged to an overall result for temporal confidence, and this result is then averaged with SSC and subsequently combined with ACC to obtain a result for the indicator.

If needed, indicator-specific adjustments are applied in the confidence assessment as described in the respective indicator chapters, e.g. for chlorophyll-a and softbottom macrofauna.

Detailed information on indicator-specific confidence class boundaries is provided in Table 19 of Annex 1. The R-code of the HEAT tool for the calculation of the different indicators including confidence rating is available on GitHub as well as explanations on the abbreviations used. Information on the main indicator statistics including abbreviations is also summarised in Table 15 of chapter HEAT HOLAS **3 tool**.

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) as illustrated in Table 16. 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.

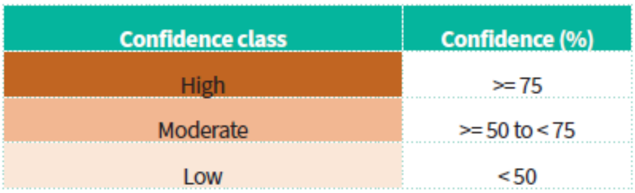
2. Criteria-specific confidence

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. Confidence was not assessed for coastal waters.

Table 16. Confidence classes and related percentages achieved



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

For more details on the confidence assessment methodology, Table 19 in Annex 1 gives a broader comprehension of the different types of confidence that are evaluated including indicator-specific confidence class boundaries applied in the HEAT tool.

5 Visualisation and assessment products

5.1 Indicator reports

Overall status assessment

The overall eutrophication status assessment is published as Eutrophication Thematic Assessment 2016-2021 report for HOLAS 3 (BSEP 192). This publication provides all necessary information related to the assessment, including brief descriptions of the state of each indicator used in the assessment, as well as integrated criteria group and overall results.

Indicator assessment results

All HELCOM indicators are presented on the HELCOM Indicator website and share a similar reporting structure. The front page of the indicator report includes the key message, and the status evaluation results presented in a map. Further sections provide information on the relevance of the indicator, threshold values, results and confidence, the methodology applied, monitoring requirements, data and resulting data products (e.g. tables, figures, maps) as well as contributors and references. Besides the maps showing the current assessment results in the HELCOM area, the temporal development is shown for long-term trends since 1990, highlighting significant increasing or deteriorating developments.

The indicator report is constructed so, that once updating indicator status, it is necessary to update the text and maps according to the latest assessment results following the established structure. The maps and figures are updated with products from the HEAT tool and the assessment work flow, whereas the text is updated by the indicator leads and experts in charge of the assessment.

5.2 HELCOM Maps and Data Service (MADS)

The eutrophication assessment and the indicator evaluations are presented in the HELCOM Map and Data Service (MADS). They may be found under 'Indicators and assessments' >> 'State of the Baltic Sea 2016-2021 HOLAS 3' and 'Eutrophication'. The overall integrated eutrophication status is presented as well as the criteria group results for nutrients, direct and indirect effects and individual indicator assessment results. Examples of the assessment results on different levels are shown in the following figures.

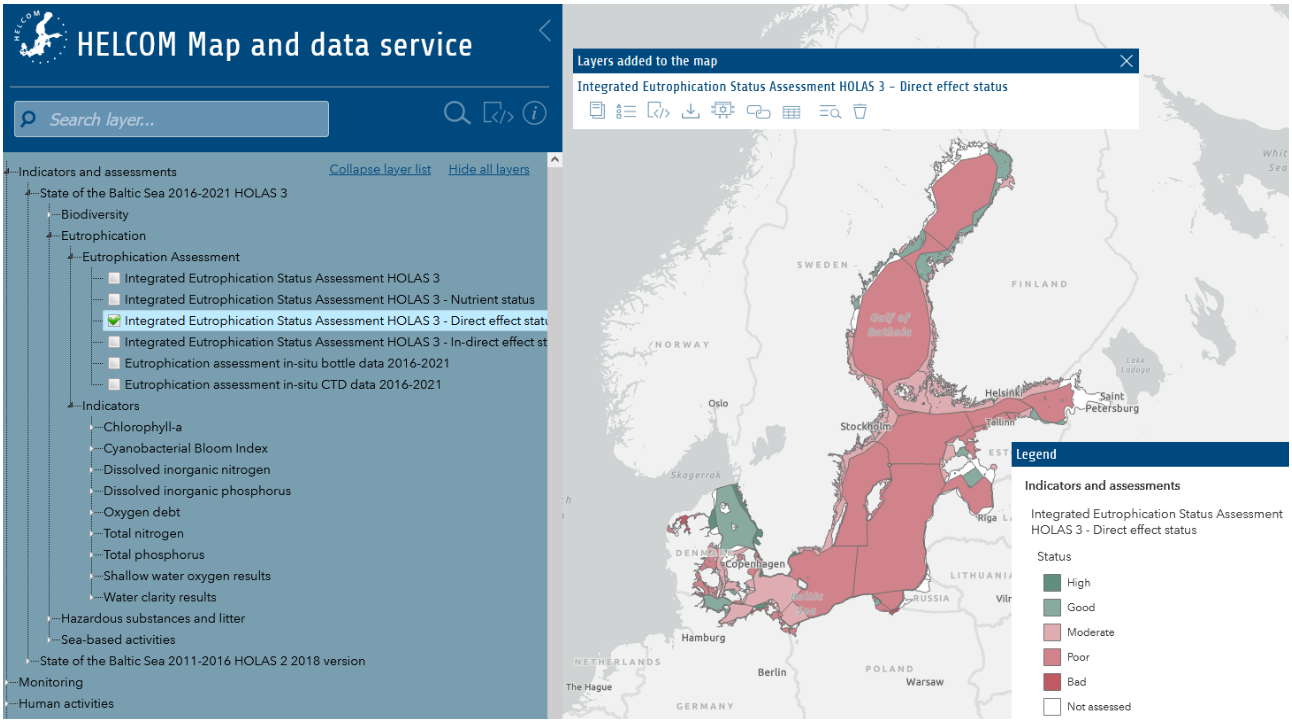


Figure 9. A view from the HELCOM Map and data service showing the eutrophication status of direct effects in HOLAS 3 (2016-2021).

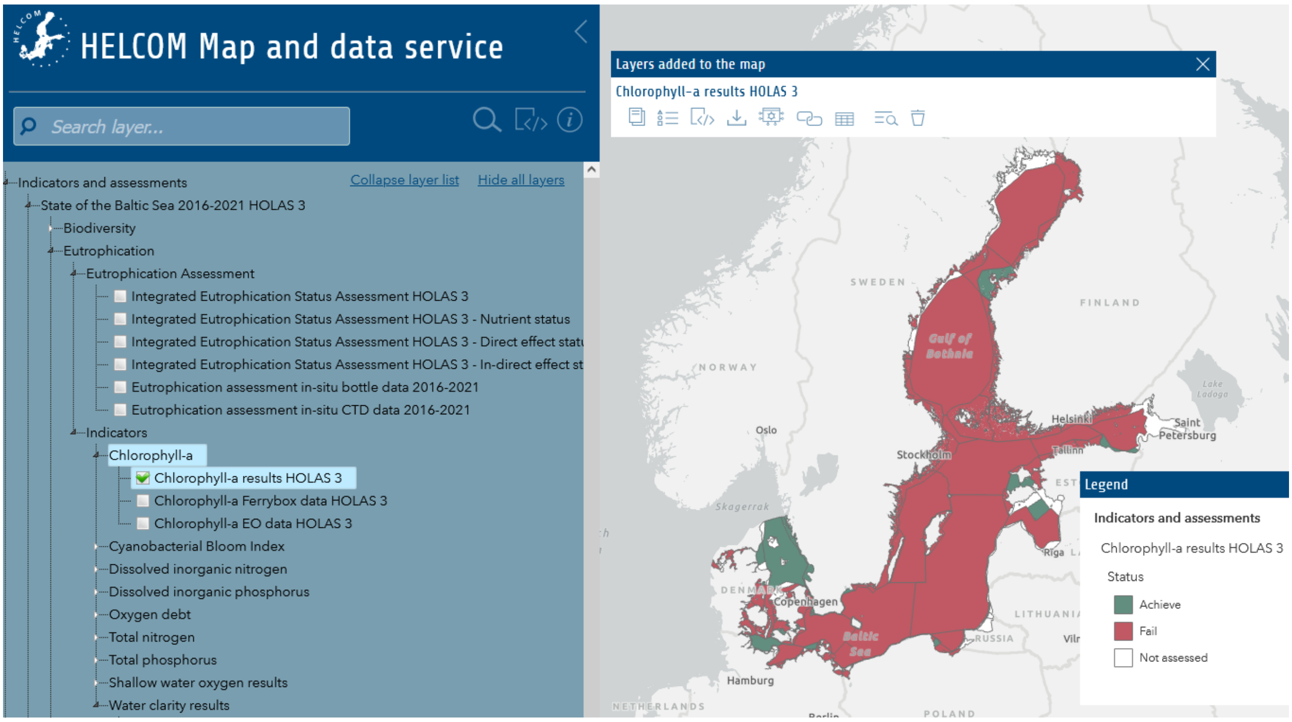


Figure 10. A view from the HELCOM Map and data service showing the assessment results of the chlorophyll-a indicator in HOLAS 3 (2016-2021).

In addition to the assessment results, HELCOM MADS also provides maps showing the distribution of monitoring stations that form the basis for the HOLAS 3 assessments. The following example shows the in-situ CTD datasets reported to ICES by HELCOM Contracting Parties for the HOLAS 3 assessment.

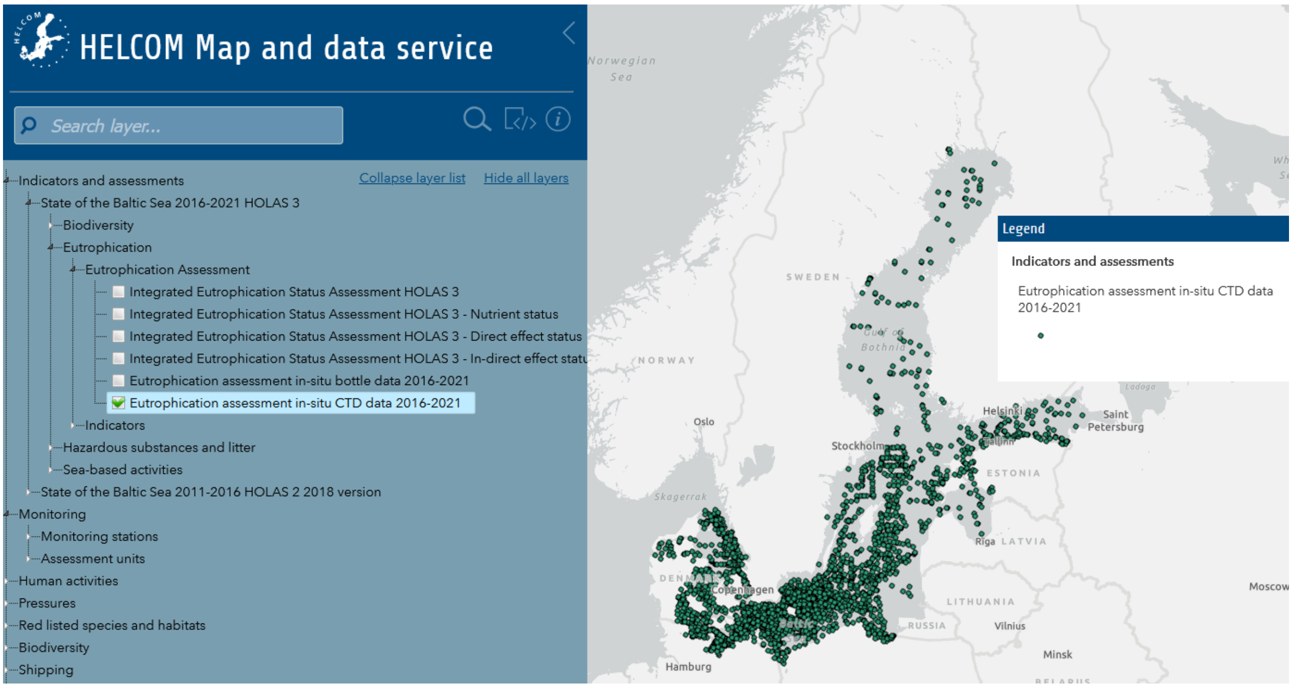


Figure 11. A view from the HELCOM Map and data service showing all in-situ CTD data reported by HELCOM Contracting Parties to ICES for the HOLAS 3 assessment period 2016-2021.

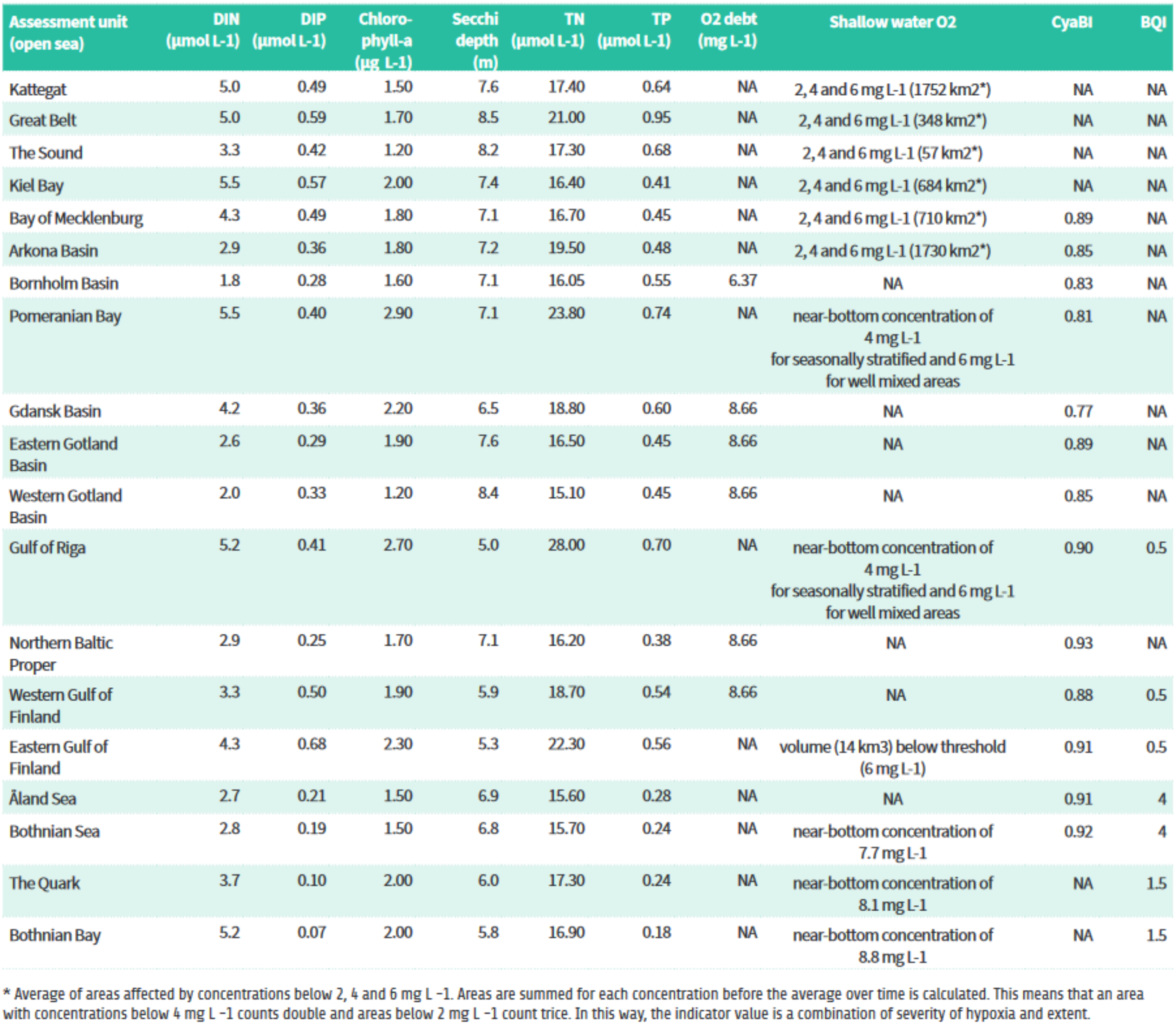
ANNEX 1.

Details of the assessment method (threshold values, indicator weights, confidence class boundaries)

Threshold values for indicators used in open sea assessment units

Threshold values for core and pre-core indicators used in open sea assessment units for HOLAS 3 are compiled in Table 17. Details on threshold value setting and changes since HOLAS II can be found in the respective indicator reports on the HELCOM website (HELCOM indicators).

Table 17. 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.

Calculation of EQR and EQRS values

For each indicator the assessment value (ES) is calculated based on the available observation data. Indicator-specific reference values (BEST) 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, ET) 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 ecological quality ratios (EQRS) into five equidistant 0.2 bands between 0 and 1. The stepwise procedure as calculated in the HEAT tool is illustrated in Figure 12. Details and specific calculation formulas can be found in the HEAT master code available on GitHub.

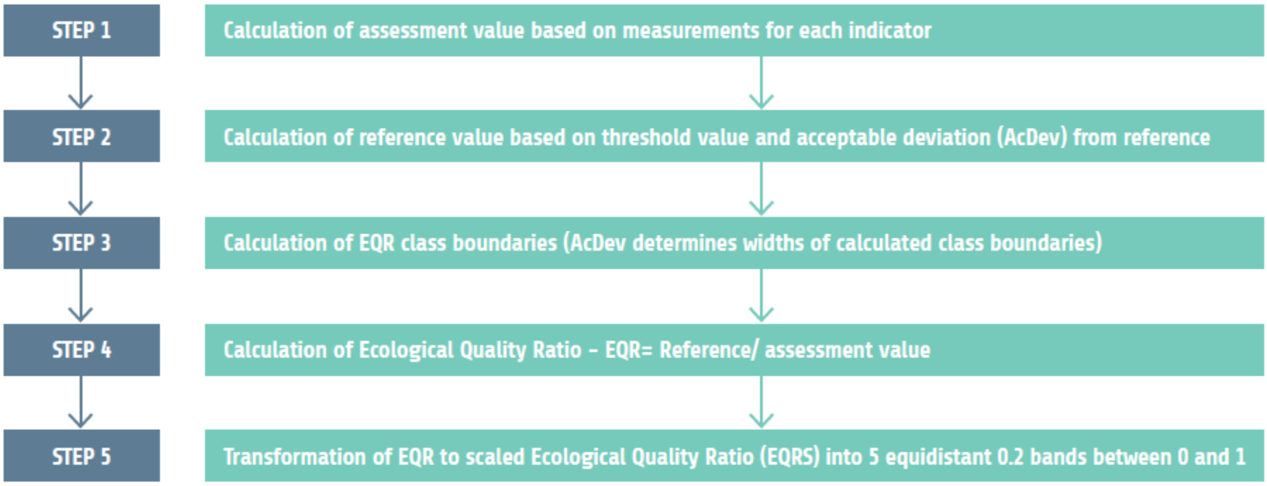


Figure 12. Stepwise approach in the HEAT HOLAS 3 tool to calculate EQR and EQRS values.

First, if the reference value is not provided, then it can be calculated as BEST = ET / (1 + ACCDEV / 100) for indicators, which increase with eutrophication (e.g., nutrient concentrations) or as BEST = ET / (1 – ACCDEV / 100) for indicators like water transparency. Next, the EQR value is found as EQR = BEST / ES for indicators like nutrients, and EQR = ES / BEST for indicators like water transparency.

Next, it is necessary to calculate the EQR class boundaries following these steps:

EQR_GM = 1 / (1+ ACCDEV / 100) (for indicators like nutrient concentrations) or EQR_GM = 1 / (1+ ACCDEV / 100).

EQR_HG = 0.5 * 0.95 + 0.5 * EQR_GM;

EQR_PB = 2 * EQR_GM - 0.95;

EQR_MP = 0.5 * EQR_GM + 0.5 * EQR_PB;

Next, the EQRS is found using a formula, which is selected based on the value of EQR and the class boundaries of EQR:

If EQR <= EQR_PB, then EQRS = (EQR - 0) * (0.2 - 0) / (EQR_PB - 0) + 0.

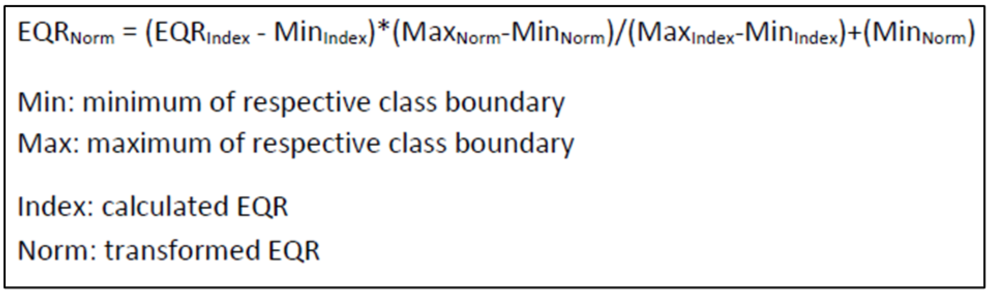
If EQR <= EQR_MP, then EQRS = (EQR - EQR_PB) * (0.4 - 0.2) / (EQR_MP - EQR_PB) + 0.2.

If EQR <= EQR_GM, then EQRS = (EQR - EQR_MP) * (0.6 - 0.4) / (EQR_GM - EQR_MP) + 0.4.

If EQR <= EQR_HG, then EQRS = (EQR - EQR_GM) * (0.8 - 0.6) / (EQR_HG - EQR_GM) + 0.6.

And on all other occasions, EQRS = (EQR - EQR_HG * (1-0.8) / (1 - EQR_HG + 0.8)).

The transformation of EQR values to scaled EQRS values is based on the following formula:

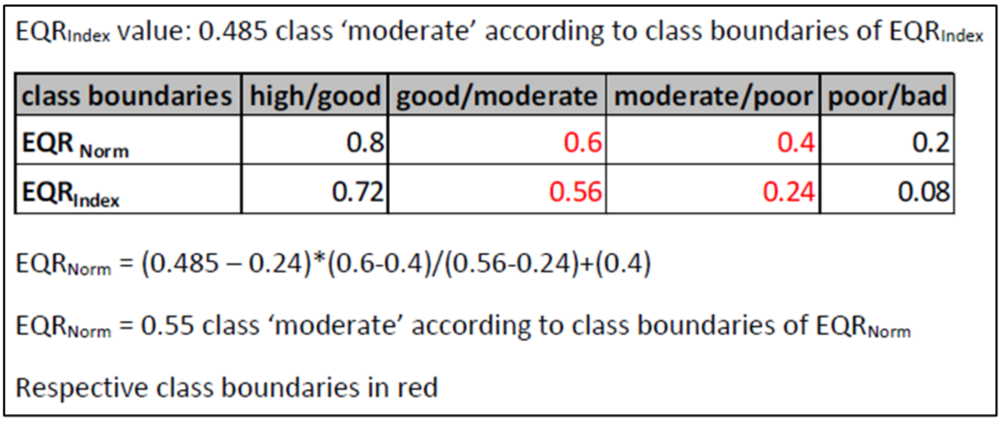


$EQR_{Norm} = (EQR_{Index} - Min_{Index})*(Max_{Norm}-Min_{Norm})/(Max_{Index}-Min_{Index})+(Min_{Norm})$

Min: minimum of respective class boundary
Max: maximum of respective class boundary

Index: calculated EQR
Norm: transformed EQR

The formula uses upper (maximum) and lower (minimum) respective class boundaries for normalizing EQR values to the equidistant scale of 0.2 class width for each class. As EQR and EQRS values are related to different class boundaries, this needs to be considered for the transformation. The calculation according to the above formula is shown in the following example for an EQR value of 0.485 classified as ‘moderate’.



EQR_{Index} value: 0.485 class ‘moderate’ according to class boundaries of EQR_{Index}

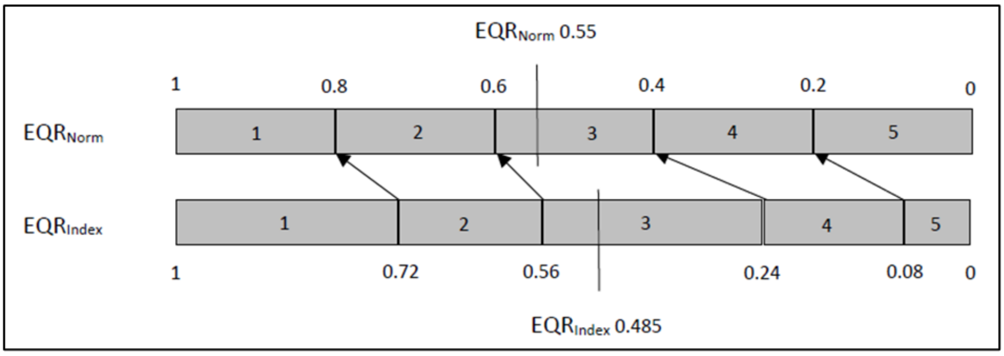
class boundaries	high/good	good/moderate	moderate/poor	poor/bad
EQR_{Norm}	0.8	0.6	0.4	0.2
EQR_{Index}	0.72	0.56	0.24	0.08

$EQR_{Norm} = (0.485 – 0.24)*(0.6-0.4)/(0.56-0.24)+(0.4)$

EQR_{Norm} = 0.55 class ‘moderate’ according to class boundaries of EQR_{Norm}

Respective class boundaries in red

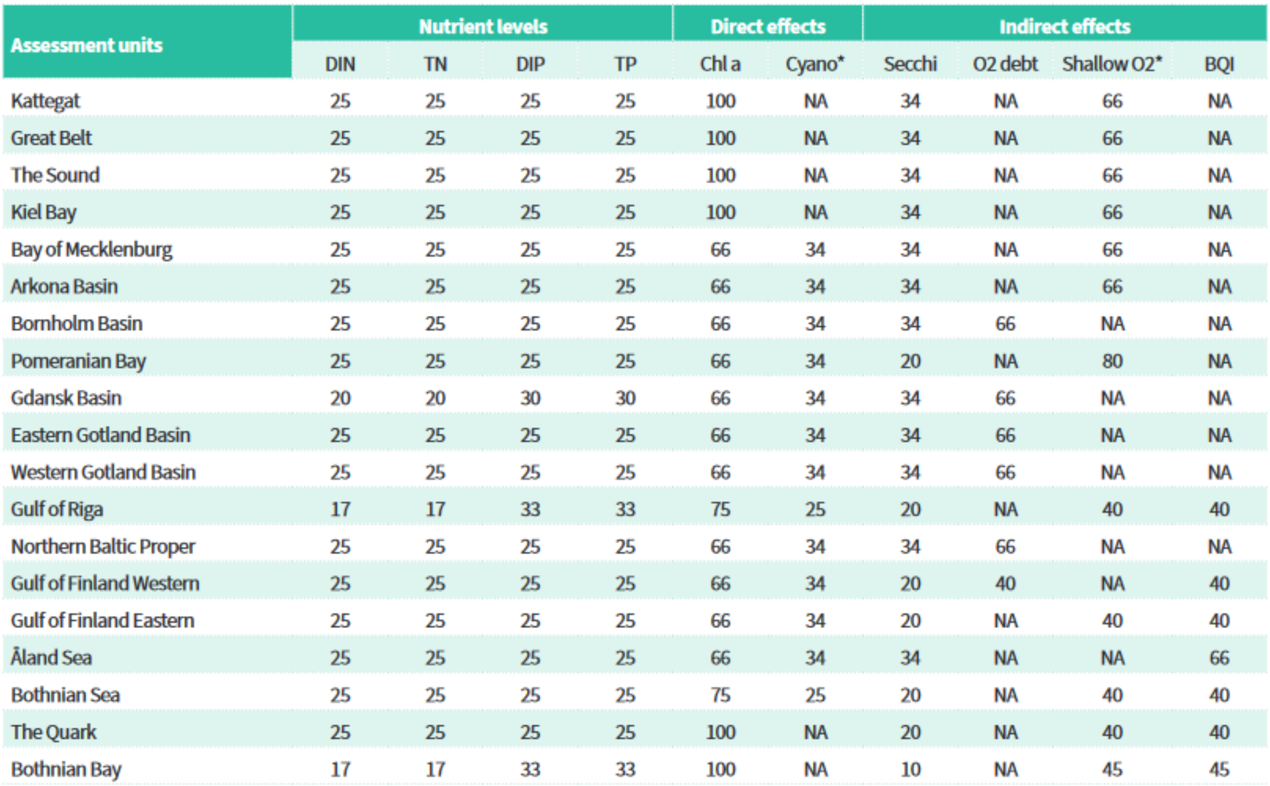
The scaling procedure from EQR to EQRS values within the five-class system is visualized for the calculated example in the following figure for a better understanding and to allow manual calculations outside the HEAT tool if necessary.



Indicator weights

The HEAT integration is carried out using evenly distributed weights, unless otherwise justified. An example for downweighing an indicator is water transparency, which is dependent on the amount of CDOM (colored dissolved organic matter). High absorption of light by CDOM makes water transparency a less reliable indicator of eutrophication. Therefore, water transparency received a smaller weight in assessment units with high CDOM concentration, e.g. in the Gulf of Riga, Gulf of Finland and Gulf of Bothnia. Another example is the cyanobacterial bloom index indicator, which is also affected by non-eutrophication related changes such as hydrographic changes or changes in the interaction between phyto- and zooplankton species. For this reason, the indicator was down-weighted in the integrated assessment relative to chlorophyll-a. In the Bothnian Bay and the Gulf of Riga, where phosphorus is clearly the limiting element for phytoplankton production, DIN and DIP (group 1, nutrient levels) are weighted to increase the effect of the phosphorus using the same proportional weight (34% and 66%, respectively) as in HOLAS II. No weighted averaging is needed for criteria that consist of only one indicator. The indicator weights applied in the eutrophication assessment for the different indicators and assessment units are summarised in Table 18.

Table 18. 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 and class boundaries used in the HEAT HOLAS 3 tool

The confidence assessment considers 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 is 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.

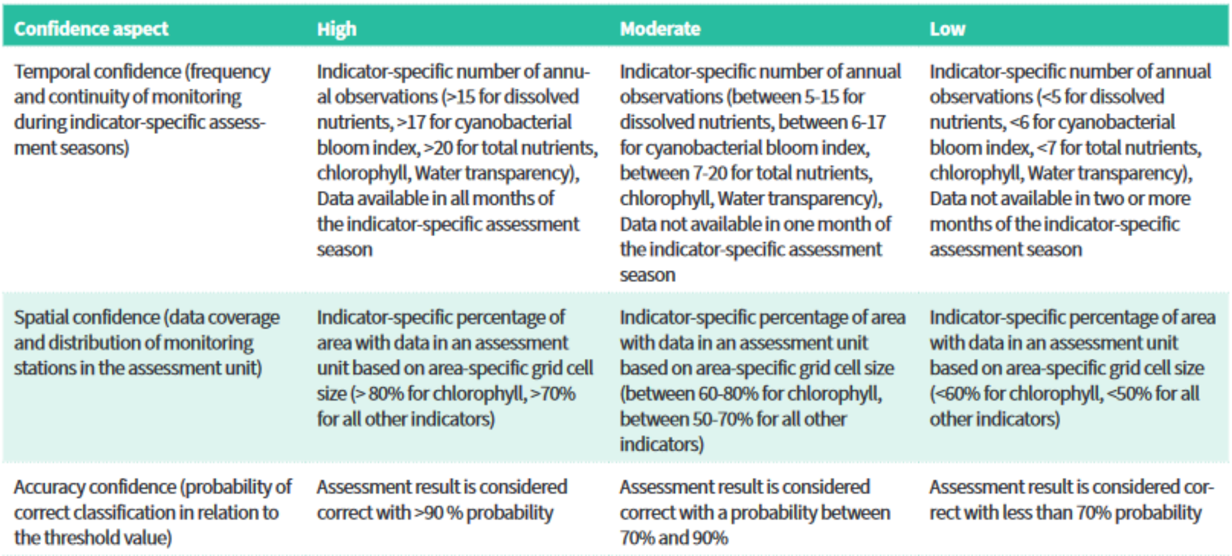
The accuracy of the indicator result indicates how certain the assessment is in relation to the variability of the data. The accuracy aspect of the confidence assessment is considered by calculating variable confidence level per assessment indicator to estimate the probability or certainty of the classification 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 19.

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 soft-bottom macrofauna indicator report).

The different confidence aspects considered in the eutrophication assessment in HEAT including defined boundaries for the classification of 'high', 'moderate' and 'low' confidence are summarised in Table 19. Confidence class boundaries are defined indicator-specific to take into account differences in the length of assessment seasons (winter vs. whole year) and also natural variability.

Table 19. Confidence aspects considered in the integrated assessment using HEAT (including indicator-specific differences in confidence class boundaries) 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.

QA/QC guidelines for different data types (discrete water samples, EO-based information, Ferrybox flow-through information, indicator data)

(Compiled by ICES December 1999, revised August 2001; June 2006; August 2025)

The reporting and QA/QC procedures follow common guidelines for HELCOM eutrophication assessment data. They include instructions on basic requirements of reported data, data standards, formats taken, collection and processing details, quality control and documentation, as well as information on the support of the data host ICES.

The QA/QC guidelines for discrete water sample data, EO-based information, Ferrybox flow-through information and ready indicator products are presented in the following sections.

Discrete water samples

In the context of this guideline, discrete water sample data are considered to be any data that result from a single collection of water and so covers a huge variety of parameters. This collection of water must have a specific, identifiable time, position and depth. Such data could originate from a single bottle attached to a rosette or water drawn from a non-toxic supply.

No integrated samples are considered as part of discrete water sample data. Thus, tows that result in integrated data values are not considered in discrete water sample data. Nor are integrated samples from a pumping system or sediment trap.

Receiving Data

The Data Centres require the following information to be supplied by the data supplier together with the data. When receiving data, the Data Centres of the ICES community shall strive to meet the following guidelines.

Data standard

All parameters must be clearly specified and described. If parameter codes are to be used, then the source data dictionary consistency must be specified. Parameter units must be clearly stated. Parameter scales must be noted where applicable. If computed values are included, the equations used in the computations should be stated.

The data should be fully checked for quality and pre-edited or flagged for erroneous values. An explicit statement should be made of the checks and edits applied to the data.

A brief description, or a reference to the data collection and processing methods (e.g. reference to a specific technique or specific project protocols) must be included and should contain information regarding:

- Describe or reference full laboratory methods and procedures
- If sample was sent out for analysis, give laboratory name and accreditation level Describe or reference any internal or external quality assurance procedures (e.g. QUASIMEME, IAPSO)

A brief description of the data processing procedures must be included and should contain information regarding:

- editing/quality control methods
- how are trace values (values below the detection limit) identified
- how are missing values handled (null vs. zero, or "blanks")
- what is the precision of the methods (e.g. number of significant figures)
- what analyses has been performed (use parameters descriptions as described in the ICES green book)
- what units are used
- whether any duplicate samples were taken
- describe what quality flags are used if any
- comments describing each station
- supply a calibration document

If a cruise/data report is available describing the data collection and processing, this can be referenced. If possible, a copy should be supplied with the data.

Format description

Data should be supplied in a fully documented ASCII format. Data Centres are capable of handling water sample data in a wide variety of user-defined and project formats. If in doubt about the suitability of any particular format, advice from the Data Centre should be sought.

Individual fields, units, etc. should be clearly defined and time zone stated. Time reported in UTC is strongly recommended. Ideally all of the data from the single water source should be stored in a single file. The contents of the data and ancillary information should adhere to the

Formatting Guidelines for Oceanographic Data Exchange at ICES following the recommended format (https://www.ices.dk/data/Documents/ocean/ICES-Oceanography-Data-Submission-Format.zip).

The ICES Data and Information Group (DIG) has developed a set of data type guidelines to assist those involved in the collection, processing, quality control and exchange of various types of physical oceanographic data.

Often different groups or laboratories will analyse a single water sample for a multitude of parameters. In such cases, it is common for the data from the different groups to arrive at the data centre at different times. The receiving data centre may merge those data from a single water source. Thus, it is crucial that the date/time, position and sample identifier accompany the data.

Collection Details

Pertinent information to be included in the data transfer to the Data Centre includes:

- Project, platform, cruise identifier
- Country, organisation, institute, PI

- Station number, site details, sample identifier (or bottle number), type of station (CTD, CTD(NMMP), continuous flow etc.,
- Analyses performed e.g. salinity and nutrients
- Date and time of the start of the sampling and date of analysis (UTC is recommended) Position (latitude and longitude degrees and minutes or decimal degrees can be used. Explicitly state which format is being used. It is recommended that N, S, E and W labels are used instead of plus and minus signs.)
- Description of operational procedures including (where applicable) sampling rate, detection limits, standard analytic procedures, calibration of equipment, quality control of original data, methods of position fixing (e.g. GPS, DGPS)
- Details of the collection instrument and sensor (e.g. manufacturer, model number, serial number, and sampling rate)
- Sounding (station depth and sample depth) should be included for each station. The method and assumptions of determining the sounding should be included.
- Type of analyses undertaken including any nutrient samples analysed
- Range of data values (desirable)

Any additional information of use to secondary users which may have affected the data or have a bearing on its subsequent use.

For additional information on quality control procedures, metadata requirements for particular parameters and collection instrumentation, see UNESCO (1996).

Value Added Service

When processing and quality controlling data, the Data Centres of the ICES community shall strive to meet the following guidelines.

Quality Control

A range of checks are carried out on the data to ensure that they have been imported into the Data Centre's format correctly and without any loss of information. For discrete water sample data, these should include:

- Check header details (vessel, cruise number, station numbers, date/time, latitude/longitude (start and end), instrument number and type, station depth, cast (up and down) data type /no. of data points, platform identifier)
- Plot station positions to check not on land
- Check ship speed between stations to look for incorrect position or date/time
- Automatic range checking of each parameter (e.g. WOD 1998, Maillard 2000)
- Check units of parameters supplied
- Check pressure increasing or decreasing as appropriate
- Check no data points below bottom depth
- Check depths against echo sounder
- Plot profiles (individually, in groups, etc)
- Check for spikes
- Check for vertical stability/inversions
- Check profiles vs. regional climatology

- Check calibration information available
- Compare parameters for predictable relationships (e.g. parameter ratios) Check for consecutive constant values
- Duplicate detection when comparing to archived data
- Flag suspicious data or correct after consultation with Principal Investigator (PI)

Problem Resolution

The quality control procedures followed by the Data Centres will typically identify problems with the data and/or metadata. The Data Centre will resolve these problems through consultation with the originating PI or data supplier. Other experts in the field or other Data Centres may also be consulted.

History Documentation

All quality control procedures applied to a dataset are fully documented by the Data Centre. As well, all quality control applied to a dataset should accompany that dataset. All problems and resulting resolutions will also be documented with the aim to help all parties involved, the Collectors, Data Centre, and Users. A history record will be produced detailing any data changes (including dates of the changes) that the Data Centre may make.

Request for Support

When addressing a request for information and/or data from the User Community, the Data Centres of the ICES community shall strive to provide well-defined data and products. To meet this objective, the Data Centres will follow these guidelines.

Data Description

The Data Centre shall aim to provide to its clients well-defined data or products. If digital data are provided, the Data Centre will provide sufficient self-explanatory series header information and documentation to accompany the data so that they are adequately qualified and can be used with confidence by scientists/engineers other than those responsible for their original collection, processing and quality control. This is described in more detail below:

- A data format description fully detailing the format in which the data will be supplied
- Parameter and unit definitions, and scales of reference
- Definition of additional quality control
- Flagging scheme, if flags are used
- Data history document (as described in 3.2 below)
- Accompanying data (e.g. CTD data at the time of bottle trip)

Data History

A data history document will be supplied with the data to include the following:

- A description of data collection and processing procedures as supplied by the data collector (as specified in Section 1.1 and 1.3)
- Quality control procedures used to check the data (as specified in Section 2.1)
- Any problems encountered with the data and their resolution and modification date

- Any changes made to the data and dates of these changes

Any additional information of use to secondary users which may have affected the data or have a bearing on its subsequent use should also be included.

Referral Service

ICES member research and operational data centres produce a variety of data analysis products and referral services. By dividing ocean areas into regions of responsibility, and by developing mutually agreed guidelines on the format, data quality and content of the products, better coverage is obtained. By having the scientific experts work in ocean areas with which they are familiar, the necessary local knowledge finds its way into the products. Data and information products are disseminated as widely as possible and via a number of media including mail, electronic mail and bulletin boards.

If the Data Centre is unable to fulfil the client's needs, it will endeavour to provide the client with the name of an organisation and/or person who may be able to assist. In particular, assistance from the network of Data Centres within the ICES Community will be sought.

REFERENCES

Maillard, C. And M. Fichaut. 2000. Medar-Medatlas Protocol, Part I : Exchange Format And Quality Checks For Observed Profiles, IFREMER, June 2000 - R.INT.TMSI/IDM/SISMER/SIS00-084.

UNESCO. 1996. IOC-EU-BSH-NOAA-(WDC-A). International Workshop on Oceanographic Biological and Chemical Data Management Hamburg, Germany 20-23 May 1996, IOC Workshop Report 122.

WOD, 1998. World Ocean Database, Documentation and Quality Control, Version 2, Silver Spring, MD, December 1999.

EO-based information

Earth Observation (EO) data are considered to be any data derived from satellite-based optical sensors that provide regular and synoptic overviews of sea areas and give estimates of water-related parameters (such as concentrations of substances, water-leaving reflectance, etc.) on a pixel basis. The term 'pixel' usually refers to the sensor's smallest imaging unit and therefore has a direct link to the spatial resolution of the satellite mission. However, often the effective resolution is coarsened by averaging or binning multiple pixels together to improve the Signal-to-Noise Ratio (SNR) of the data.

EO data are usually extracted, transformed, and reported as distributions or as descriptive statistics over the target area. The target area can be a coastal waterbody, open sea region, individual cell in a regular gridding (HELCOM 10 km, 20 km, 60 km), or the immediate surroundings of a water sampling station or other fixed point of measurement. The typical temporal aggregation period of EO data is one day (i.e., daily data), but they can be aggregated over longer time periods, yielding monthly, seasonal, or annual aggregates. The depth of investigation of EO varies depending on the mapped wavelength and the water's transparency but is usually on the order of magnitude of one optical depth (1 O.D.) [1]. In the open sea, EO usually integrates information from the top 5–10 meters of the water column.

EO data have by nature a well-defined spatial and temporal dimension. Therefore, EO data must always be accompanied by time and position information or, in aggregated outputs, the spatial and temporal extents.

These guidelines do not apply to radar or microwave based EO data (SAR, altimeter, etc.) nor data collected along lines instead of swaths (e.g., spaceborne LiDAR). These guidelines partly apply to infrared sensors, such as those intended for Sea Surface Temperature (SST) measurement.

Basic requirements of EO-data for use in HELCOM eutrophication assessment

A spaceborne sensor collects data from Earth's orbit, where most of the measured signal originates not from the waterbody itself, but from the atmosphere in between. Therefore, EO data submitted to the eutrophication assessment must be processed to minimize disturbances caused by daily variations in atmospheric or environmental conditions. This requires at least removing the effect of absorbing gases (such as ozone), scattering from air molecules and atmospheric aerosols, and sea surface glint (i.e., the enhanced reflection of sunlight from a rough sea surface). For the atmospheric correction (AC) to be effective, the satellite's radiometric properties must be consistent and well-characterised. Recommended platforms with

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[1] At one optical depth, irradiation is reduced to e^{-1} (≈ 0.37) of its surface value.

excellent radiometric properties include, e.g., EU and ESA's Sentinel series (Sentinel-2, Sentinel-3) or USGS's Landsat-8/9.

After atmospheric correction, EO information shall be transformed into the desired target variable and, if it is a physical or biogeochemical variable with a distinctive meaning (e.g., concentration of chl-*a*), it must be validated against a reference, or there must be other assurance of its quality. Typically, the reference comes from in-situ monitoring data such as the ICES database, but flowthrough campaigns can also act as references if they can be traced to laboratory values. The performance of EO may change depending on season and the availability of light, and the data provider may exclude time periods where quality of data cannot be assured. For indicators that rely on non-processed water-leaving reflectances (e.g., the algae barometer used in the pre-core indicator for Cyanobacterial Bloom), the data provider should apply the same AC method as described in the reference implementation (see the indicator report). If the data provider wishes to use a different AC method, an intercalibration must be performed to demonstrate that the alternative approach produces results comparable to the reference implementation.

EO data should be extracted as descriptive daily statistics within the reporting unit required by the indicator. Required statistics depend on the indicator, but usually include at least the arithmetic and geometric means, standard deviations, percentiles (5, 25, 50, 75, 95), class frequencies for categorical or ordinal data, and the number of individual observations that make up the statistics. EO data must be accompanied by information on its effective spatial resolution (after binning) prior to extraction, which may not be too coarse for the variable of interest. A recommended effective spatial resolution is 60 meters for high-resolution sensors (e.g., Sentinel-2) and 300 meters for intermediate resolution sensors (e.g., Sentinel-3).

The data must contain information on the representativeness in terms of coverage within the reporting unit. In particular, it should indicate how many pixels were used to derive the statistics (taking into account cloudiness and the satellite's swath boundaries) and how many pixels could theoretically be retrieved for the same area in ideal observing conditions. The data supplier may exclude from these calculations the areas that are permanently unsuited for the EO method, such as very shallow areas where bottom reflection prevents making accurate water quality determinations.

Receiving data

The Data Centres require the following information to be supplied by the data supplier together with the data. When receiving data, the Data Centres shall strive to meet the following guidelines.

Data standard

All satellite-derived products must be clearly specified and described. Product units must be clearly stated, and the algorithms and transformations used in the computations should be stated. The data should be fully checked for quality and pre-edited or flagged for erroneous values. An explicit statement should be made of the checks and edits applied to the data. A brief description, or a reference to the data collection and processing methods (e.g., reference to a specific technique or specific project protocols) must be included and should contain information regarding:

- Methods and procedures applied to the analysis of original raw data, including the atmospheric correction
- Methods / protocols and dataset(s) used for validation, or refer to their original source

- Internal or external quality assurance procedures (e.g. NASA, ESA protocols, QA4EO guidance[2]) and possible accreditation, if done

A brief description of the data processing procedures must be included and should contain information regarding:

- editing/quality control methods
- how trace values (values below the detection limit) are identified
- how missing values are handled (null vs. zero, or “blanks”)
- what is the precision of the methods (e.g., number of significant figures)
- what units are used
- describe what quality flags are used if any
- supply a validation document

If a report is available describing the data collection and processing, this can be referenced. If possible, a copy should be supplied with the data.

If the submitted data were extracted from a versioned or continuously updated database, the date when the extraction was made or when the source data were fixed for reporting must be known. There must be a log of major revisions on the contents of the database.

Format description

EO data and related metadata should be provided primarily via open and standard machine-readable APIs returning the response in JSON format. In this case, there must be also a machine-readable log of major revisions in the data returned by the APIs. Data deliveries can also be made as Delimited Text Files or other established hierarchical data formats such as NetCDF-4. If in doubt about the suitability of any particular format, advice from the Data Centre should be sought. Individual fields, units, etc. should be clearly defined either in the API metadata or in sidecar documents and files. If precise time stamps are used, they should be in Universal Coordinated Time.

Collection and processing details

Pertinent information to be included in the data transfer to the Data Centre includes:

- Processing responsible: country, organisation, institute, PI
- Satellite instrument(s) and details of the sensor
- Data variables and the indicator the data are intended for
- Spatial resolution of original data and effective resolution used in processing
- Algorithm and processing methods used for deriving the product
- Atmospheric correction scheme and cloud masking strategy
- Possible manual quality control measures that were carried out on the data
- Level of temporal and spatial aggregation used
- Uncertainties on product estimates (see validation details below)
- Temporal extent of the data
- Position estimate in decimal degrees (WGS84 or similar) or a reference to an aerial subdivision recognized by HELCOM
- Any additional information of use to secondary users which may have affected the data or have a bearing on its subsequent use.

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[2] http://qa4eo.org

Validation details

Validation is prerequisite to ensure the distribution of quantitative data products and their subsequent application by the user community. Information on the validation process of the provided data should be able to prove the reliability and consistency of satellite-derived products. Pertinent information includes:

- A reference to the validation protocol used (as an example see, e.g., for ocean colour Mélin and Franz 2014, Pahlevan et al. 2021, Stramski et al. 2023, and MarCoast/CoBiOS validation protocols; CLMS validation protocols for applicable parts, e.g., Stelzer et al. 2020).
- Detailed characteristics of the validation data, i.e. match-up data sets (in case of direct comparison between satellite product and contemporaneous and co-located in-situ measurements of the same quantity)
- Use of existing database (e.g., AERONET, Zibordi et al. 2006; MONOCLE project https://monocle-h2020.eu) and especially ICES for the chlorophyll-a.
- Uncertainties associated with field observations in case these are given (e.g., ICES).
- The data used for validation, their temporal and spatial coverage must be described, and the validation procedure must be described. The validation must conern the Baltic Sea region.
- Information on how other sensor data (e.g., flow-through based water quality measurements) were processed to make sure they are suited for validation. EO data can be at least partially validated with flow-through data if these can be traced back to laboratory values.

When validating EO data, it’s important to consider the different optical characteristics of the target areas. This means that, e.g., coastal areas should be validated separately from the open sea. Even within the open sea, regions with distinct water characteristics (such as different phytoplankton assemblages or varying levels of CDOM) should be treated individually.

Spatial match-ups between EO and in-situ data should avoid overly large EO coverage areas being compared to point-based water samples. Instead, validation should be done using reasonably small spatial units (e.g., HELCOM 20k-grids, coastal WFD-formations) where both EO data and in-situ data are available. Ideally, water samples should be matched with EO data from the same day. If exact matches aren't available, interpolation may be necessary to bridge the time gap. Only water samples taken from depths observable by satellites (e.g., 0–10 m depth for chlorophyll-a) shall be used. The chlorophyll samples should preferably be composite samples, i.e., mixed from subsamples from distinct depths so that it is representative of the whole sunlit layer.

Medians (p50) or geometric means of EO data are recommended to be used in validation when EO is compared against concurrent sampling station data. The geometric mean is the best method to measure the true central tendency of the data distribution because water quality pixel estimates within the region of interest typically follow log-normal distributions which are skewed to the right and therefore exhibit a multiplicative rather than additive nature (see Attila et al. 2019).

There exist multiple validation approaches (e.g., explorative analysis with figures and time series plots, or statistical analysis with metrics like RMSE). A good practice is to perform explorative validation with maps, time series plots (e.g. WFD, station location) (Fig. A2.2.1), and scatterplots. Explorative validation provides a quick overview of data structure, spatial and temporal distribution of data and outliers, potential error sources, and skewness and distribution of data.

Statistical validation refers to the use of numerical metrics to describe the match between EO and field sampled value. While mandatory error metrics, such as R-squared (R^2), Mean Absolute Error (MAE), Mean Bias Error (MBE), and Root Mean Square Error (RMSE) against the 1:1 model, are necessary to validate the data, they may leave out useful information or be biased in strongly skewed base distributions. Optional error metrics such as Median Bias, Median Absolute Percentage Difference, and Median Symmetric Accuracy can provide more detail into data distribution (Stramski et al. 2023).

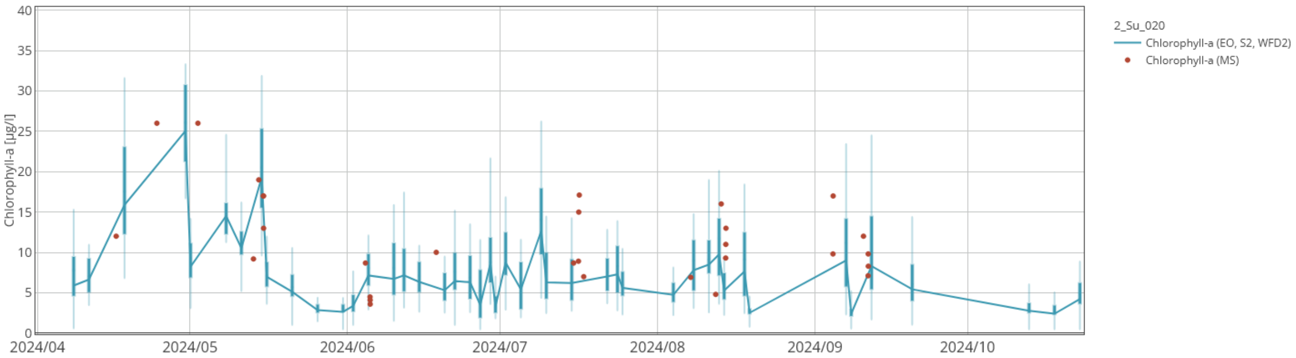

Figure A2.2.1. Explorative validation is often performed by looking at time series of EO against station sampling data. The plot shows chlorophyll-a concentration in Finnish coastal waterbody with EO data (blue line) plotted against in-situ measurements (red dots). The vertical error bars represent the distribution of pixel-level estimates within the waterbody (thicker bar: P25 to P75 or interquartile range, thinner bar: P05 to P95).

Value added service

When processing and quality controlling data, the Data Centres of the ICES community shall strive to meet the following guidelines.

Quality control

A range of checks are carried out on the data to ensure that they have been imported into the Data Centre's format correctly and without any loss of information. For EO data, these should include:

- Check header details / metadata (satellite platform, instrument, effective resolution, spatial and temporal aggregation, area identifiers, timestamp format)
- Automatic range checking of each parameter (e.g. WOD 1998, Maillard 2000)
- Automatic flagging of the dates where the coverage of EO data is less than 25% of the area of interest
- Check units of parameters supplied
- Flag suspicious data or correct after consultation with Principal Investigator (PI)

Problem resolution

The quality control procedures followed by the Data Centres will typically identify problems with the data and/or metadata. The Data Centre will resolve these problems through consultation with the originating PI or data supplier. Other experts in the field or other Data Centres may also be consulted.

History documentation

All quality control procedures applied to a dataset are fully documented by the Data Centre. As well, all quality control applied to a dataset should accompany that dataset. All problems and resulting resolutions will also be documented with the aim to help all parties involved, the Collectors, Data Centre, and Users. A history record will be produced detailing any data changes (including dates of the changes) that the Data Centre may make.

Request for support

When addressing a request for information and/or data from the User Community, the Data Centres shall strive to provide well-defined data and products. To meet this objective, the Data Centres will follow these guidelines.

Data description

The Data Centre shall aim to provide to its clients well-defined data or products. If digital data are provided, the Data Centre will provide sufficient self-explanatory series header information and documentation to accompany the data so that they are adequately qualified and can be used with confidence by scientists/engineers other than those responsible for their original collection, processing and quality control. This is described in more detail below:

- A data format description fully detailing the format in which the data will be supplied
- Parameter and unit definitions, and scales of reference
- Definition of additional quality control
- Flagging scheme, if flags are used
- Data history document (as described below)
- Accompanying data

Data history

A data history document will be supplied with the data to include the following:

- A description of data collection and processing procedures as supplied by the data collector (as specified earlier)
- Quality control procedures used to check the data (as specified earlier)
- Any problems encountered with the data and their resolution and modification date
- Any changes made to the data and dates of these changes

Any additional information of use to secondary users which may have affected the data or have a bearing on its subsequent use should also be included.

References

Attila, J. (2019). Water quality monitoring and assessment of the Northern Baltic Sea using Earth Observation. Doctoral thesis 229/2019. Department of Built Environment, Aalto University. ISBN 978-952-60-8867-9.

Maillard, C. And M. Fichaut. 2000. Medar-Medatlas Protocol, Part I: Exchange Format And Quality Checks For Observed Profiles, IFREMER, June 2000 - R.INT.TMSI/IDM/SISMER/SIS00-084.

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Pahlevan, N., et al. (2021). ACIX-Aqua: A global assessment of atmospheric correction methods for Landsat-8 and Sentinel-2 over lakes, rivers, and coastal waters. Remote Sensing of Environment, 258: 112366. Doi: 10.1016/j.rse.2021.112366

Stelzer, K. and the C-GLOPS Lot-2 consortium (2020). Copernicus Global Land Operations "Cryosphere and Water": Quality assessment report. Lake Water Quality 300 m and 1 km products, version 1.3.1. Issue I1.11.

Stramski, D. et al. (2023). Adaptive optical algorithms with differentiation of water bodies based on varying composition of suspended particulate matter: A case study for estimating the particulate organic carbon concentration in the western Arctic seas. Remote Sensing of Environment, 286: 113360. Doi: 10.1016/j.rse.2022.113360

WOD, 1998. World Ocean Database, Documentation and Quality Control, Version 2, Silver Spring, MD, December 1999.

Zibordi G. Et al. (2006). A network for standardized ocean colour validation measurements. EOS Trans. AGU 87: 293-297.

Ferrybox flow-through information

In this guideline, Ferrybox information is considered to be information derived from automatic flow-through systems implemented on board ships of opportunity. The observations are either original or in validated form and may be aggregated temporally and spatially to a specific level.

The data must include a distinct time and position. In the case of aggregated information, these may be estimates.

Basic requirements of Ferrybox flow-through data for use in HELCOM eutrophication assessment

Ferrybox-based flow-through data used in the HELCOM eutrophication assessment and submitted to the eutrophication assessment database must fulfil the following basic requirements.

Data are validated aggregated estimates of a core indicator parameter, i.e. not raw flow-through observations. The validation must be based on in-situ monitoring data. The data submitter is responsible for quality control procedures as described below (value added services), since the database holder will not go through such procedures after receiving the data.

The data product may be aggregated at two alternative levels:

1) Large scale
- spatial: HELCOM assessment unit, following the HELCOM sub-division into 19 open sub-basins and 42 coastal areas (shapefile may be retrieved at www.helcom.fi)
- temporal: annual assessment period (e.g. summer months)

2) Small scale
- spatial: HELCOM 20K grid (shapefile may be retrieved at www.helcom.fi)
- temporal: daily

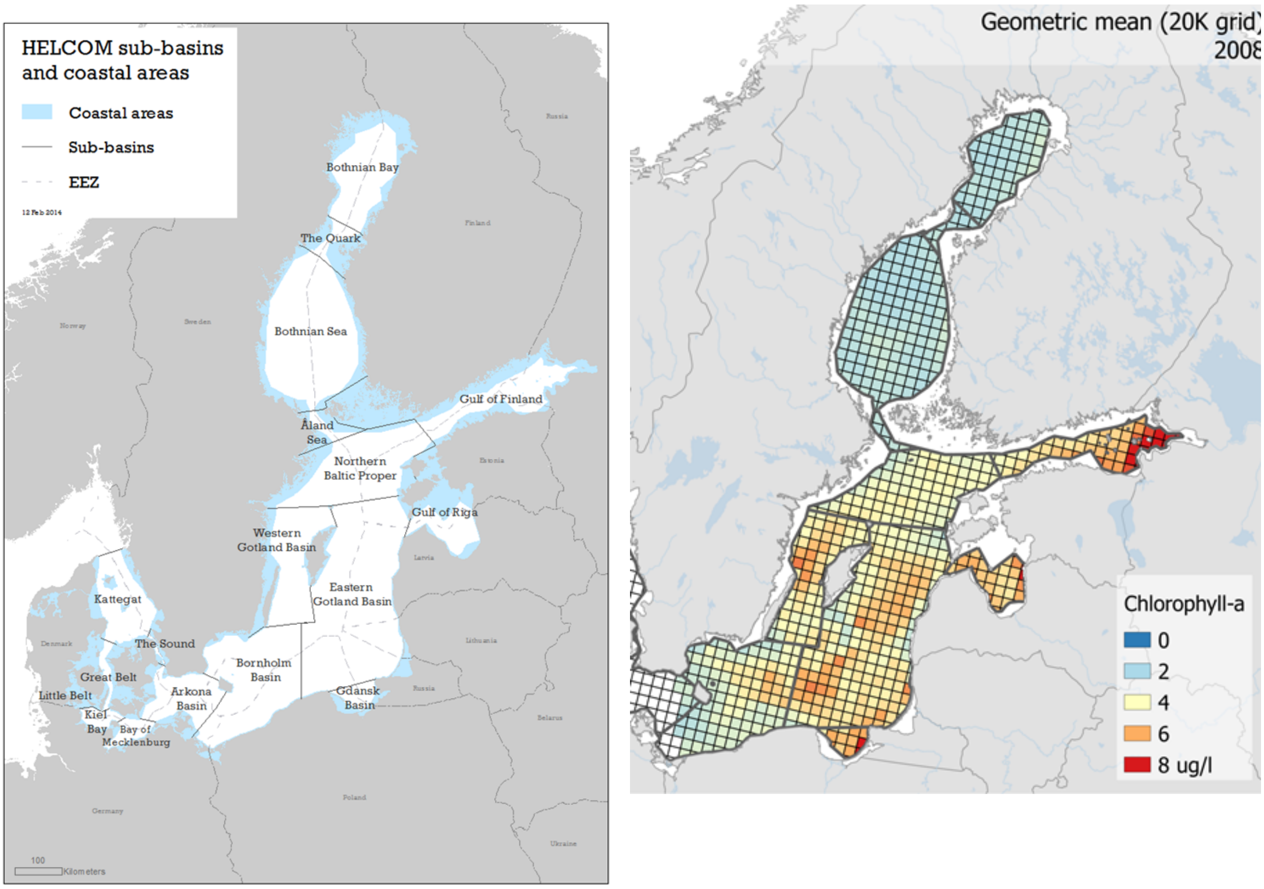


Figure A2.3.1. Map illustrating the large (HELCOM assessment units, left panel) and small (HELCOM 20K grids, right panel) spatial scales.

Receiving data

The Data Centres require the following information to be supplied by the data supplier together with the data. When receiving data, the Data Centres shall strive to meet the following guidelines.

Data standard

All parameters must be clearly specified and described. If parameter codes are to be used, then the source data dictionary consistency must be specified. Parameter units must be clearly stated. If computed values are included, the equations used in the computations should be stated. The data should be fully checked for quality and pre-edited or flagged for erroneous values. An explicit statement should be made of the checks and edits applied to the data. A brief description, or a reference to the data collection and processing methods (e.g. reference to a specific technique or specific project protocols) must be included and should contain information regarding:

- Methods and procedures applied to the analysis of raw data
- Methods / protocols and dataset(s) used for validation, or refer to their original source
- Description or reference any internal or external quality assurance procedures

A brief description of the data processing procedures must be included and should contain information regarding:

- editing/quality control methods
- how are missing values handled (recommended as "blanks")
- what is the precision of the methods (e.g. number of significant figures) green book)
- what units are used
- describe what quality flags are used if any
- supply a validation document

If a report is available describing the data collection and processing, this can be referenced. If possible, a copy should be supplied with the data.

Format description

Data should be supplied in a fully documented format (e.g. ASCII, NetCDF). If in doubt about the suitability of any particular format, advice from the Data Centre should be sought. Individual fields, units, etc. should be clearly defined and time zone stated. Time reported in UTC is strongly recommended. The contents of the data and ancillary information should adhere to the Formatting Guidelines for Oceanographic Data Exchange (http://ocean.ices.dk/formats/GETADE_Guidelines.aspx) prepared by the IOC's Group of Experts on the Technical Aspects of Data Exchange (GETADE) and available from RNODC Formats.

Collection and processing details

Pertinent information to be included in the data transfer to the Data Centre includes:

- Processing responsible: country, organisation, institute, PI
- Description of flow-through system and measuring instruments / sensors
- Measured parameters
- Products derived through validation procedures
- Resolution of original data
- Details of validation data
- Conversions used for deriving chlorophyll *a* concentration from chlorophyll *a* fluorescence data
- Level of temporal and spatial aggregation used
    - spatial: either raw data, HELCOM 20 km grid or HELCOM assessment area
    - temporal: either raw data or daily / annual assessment period
- Uncertainties on product estimates
- Date and time of the start and end of the sampling (UTC is recommended)
- Position estimate (latitude and longitude degrees and minutes or decimal degrees can be used. Explicitly state which format is being used. It is recommended that N, S, E and W labels are used instead of plus and minus signs.)
- Description of procedure for checking spikes

Any additional information of use to secondary users which may have affected the data or have a bearing on its subsequent use. For additional information on quality control procedures, metadata requirements for particular parameters and collection instrumentation, see UNESCO (1996).

Value added service

When processing and quality controlling data, the Data Centres of the ICES community shall strive to meet the following guidelines.

Quality control

A range of checks are carried out on the data to ensure that they have been imported into the Data Centre's format correctly and without any loss of information. For discrete water sample data, these should include:

- Check header details (platform, date/time, latitude/longitude, water intake depth).
- Plot measurement positions to check not on land
- Automatic range checking of each parameter (e.g. WOD 1998, Maillard 2000)
- Check units of parameters supplied
- Flag suspicious data or correct after consultation with Principal Investigator (PI)

Problem resolution

The quality control procedures followed by the Data Centres will typically identify problems with the data and/or metadata. The Data Centre will resolve these problems through consultation with the originating PI or data supplier. Other experts in the field or other Data Centres may also be consulted.

History documentation

All quality control procedures applied to a dataset are fully documented by the Data Centre. As well, all quality control applied to a dataset should accompany that dataset. All problems and resulting resolutions will also be documented with the aim to help all parties involved, the Collectors, Data Centre, and Users. A history record will be produced detailing any data changes (including dates of the changes) that the Data Centre may make.

Request for support

When addressing a request for information and/or data from the User Community, the Data Centres shall strive to provide well-defined data and products. To meet this objective, the Data Centres will follow these guidelines.

Data description

The Data Centre shall aim to provide to its clients well-defined data or products. If digital data are provided, the Data Centre will provide sufficient self-explanatory series header information and documentation to accompany the data so that they are adequately qualified and can be used with confidence by scientists/engineers other than those responsible for their original collection, processing and quality control. This is described in more detail below:

- A data format description fully detailing the format in which the data will be supplied
- Parameter and unit definitions, and scales of reference
- Definition of additional quality control
- Flagging scheme, if flags are used

- Data history document (as described below)
- Accompanying data

Data history

A data history document will be supplied with the data to include the following:

- A description of data collection and processing procedures as supplied by the data
- collector / data provider (as specified earlier)
- Quality control procedures used to check the data (as specified earlier)
- Any problems encountered with the data and their resolution and modification date
- Any changes made to the data and dates of these changes

Any additional information of use to secondary users which may have affected the data or have a bearing on its subsequent use should also be included.

References

UNESCO (1996)
WOD 1998
Maillard 2000

Indicator data

In the context of this guideline, indicator data are considered to be ready eutrophication indicator products. Examples of such product would be coastal indicator results, or core indicators not being processed from monitoring observations through algorithms in the HELCOM eutrophication assessment work flow.

The information must be spatially and temporally aggregated to suit the requirements of the assessment. Optimally, the information should be reported in the measuring units of the original indicator parameter. If this is not possible, also information reported as EQR is accepted.

Indicator data is reported directly to the HELCOM secretariat (data@helcom.fi).

Receiving data

Data standard and format description

The data is reported using a specific reporting template for WFD results in coastal waters, according to the information required in HEAT for the calculation of integrated assessment results. The template has been tailored for each Contracting Party separately to contain the relevant coastal assessment units.

The indicator data template includes four types of sheets, which require the following information.

Units: Coastal assessment units (HELCOM Level 4b) and their UnitIDs for respective country
Indicators: National WFD indicators and associated information should be filled in here. Mandatory attributes are indicated in Green and recommended attributes in yellow.

IndicatorUnits: ET and ACDEV **or** EQR_HG, EQR_GM, EQR_MP, EQR_PB should be reported for each indicator in each assessment unit. Reference conditions (RefCon) can be reported in addition. Mandatory attributes are indicated in Green and conditional mandatory attributes in orange. Weighting of indicators per indicator and assessment unit can be reported here, if relevant. Leaving weight empty results in equal weights of indicators within criteria.

IndicatorUnitResults: If ET and ACDEV are reported in IndicatorUnits, **ES should be reported**. If EQR_HG, EQR_GM, EQR_MP, EQR_PB are reported in IndicatorUnits, **EQR should be reported**. If IndicatorUnits are empty, **EQRS should be reported**. Mandatory attributes are indicated in Green and conditional mandatory attributes in orange.

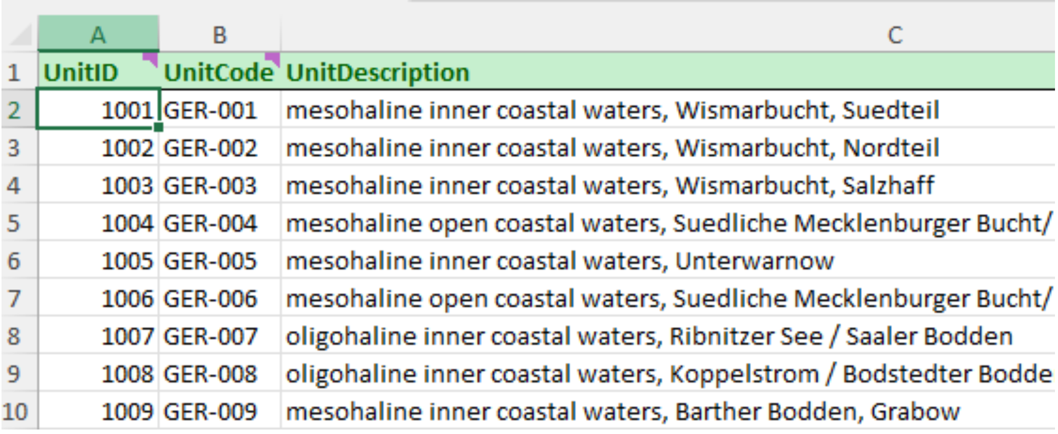
The template contains column descriptions in comments as guidance on how to report WFD results and filled in example rows that can be overwritten. It is possible to report WFD results in following approaches:

1. **ET, ES, ACDEV** is reported for each coastal indicator in each coastal assessment unit. This approach requires filling in sheets **Indicators, IndicatorUnits** and **IndicatorUnitResults.**
2. **EQR, ACDEV** is reported for each coastal indicator in each coastal assessment unit. This approach requires filling in sheets **Indicators, IndicatorUnits** and **IndicatorUnitResults.**
3. **EQR, EQR_HG, EQR_GM, EQR_MP, EQR_PB** is reported for each coastal indicator in each coastal assessment unit. This approach requires filling in sheets **Indicators, IndicatorUnits** and **IndicatorUnitResults.**
4. **EQRS** is reported for each coastal indicator in each coastal assessment unit. This approach requires filling in sheets **Indicators** and **IndicatorUnitResults.**
5. **Data-driven approach** by utilizing coastal monitoring data reported to ICES. Only ET and AccDev should be reported for each indicator in each coastal assessment unit. This approach requires filling in sheets **Indicators** and **IndicatorUnits.**

Regarding temporal aspects, it is possible to report annual results (e.g. 2016) or period (e.g. 20162021). Annual results will be integrated in the HEAT assessment.

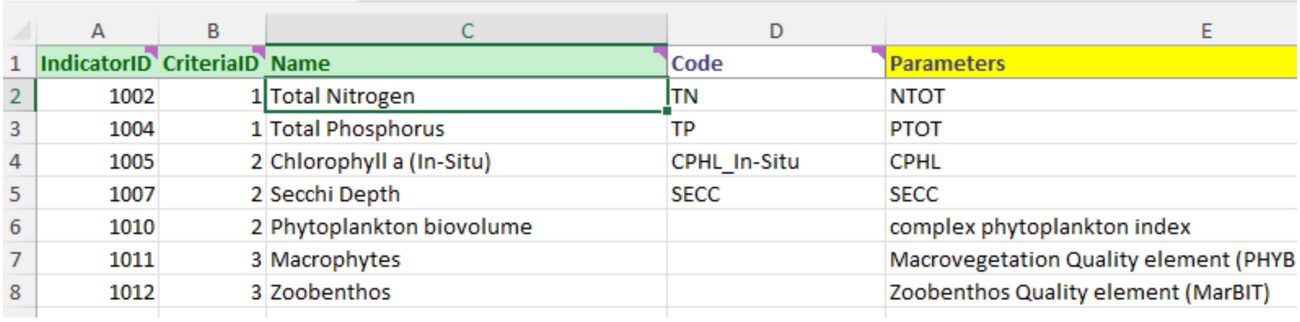
The following tables show the different sheets of the reporting template, illustrated with filled in examples for Germany.

Table A2.4.1 The first sheet from the indicator data template: units (example Germany).



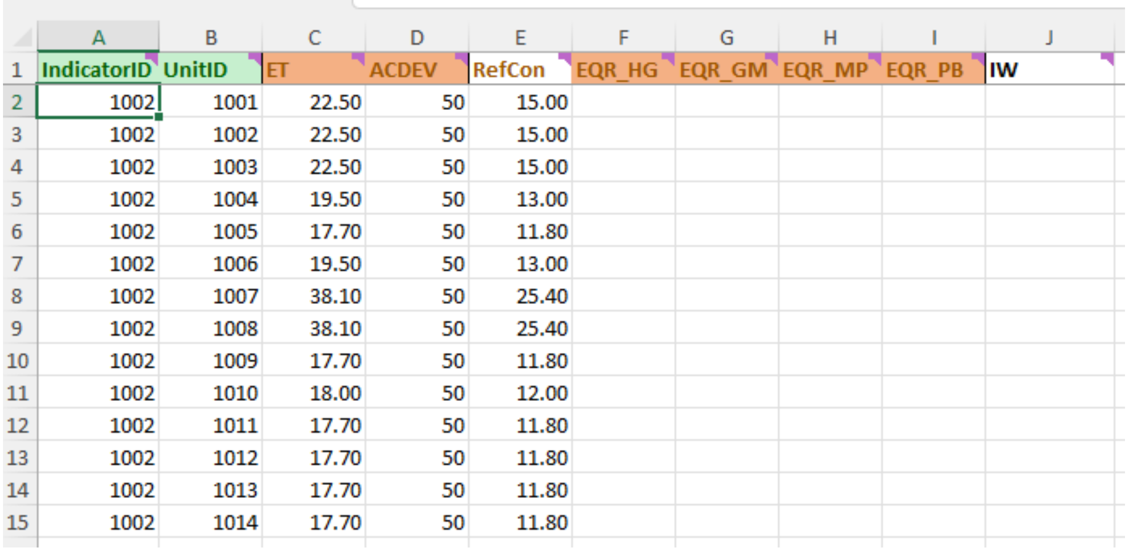
UnitID	UnitCode	UnitDescription
1001	GER-001	mesohaline inner coastal waters, Wismarbucht, Suedteil
1002	GER-002	mesohaline inner coastal waters, Wismarbucht, Nordteil
1003	GER-003	mesohaline inner coastal waters, Wismarbucht, Salzhaff
1004	GER-004	mesohaline open coastal waters, Suedliche Mecklenburger Bucht/
1005	GER-005	mesohaline inner coastal waters, Unterwarnow
1006	GER-006	mesohaline open coastal waters, Suedliche Mecklenburger Bucht/
1007	GER-007	oligohaline inner coastal waters, Ribnitzer See / Saaler Bodden
1008	GER-008	oligohaline inner coastal waters, Koppelstrom / Bodstedter Bodde
1009	GER-009	mesohaline inner coastal waters, Barther Bodden, Grabow

Table A2.4.2. The SECOND sheet from the indicator data template: indicators (example Germany).



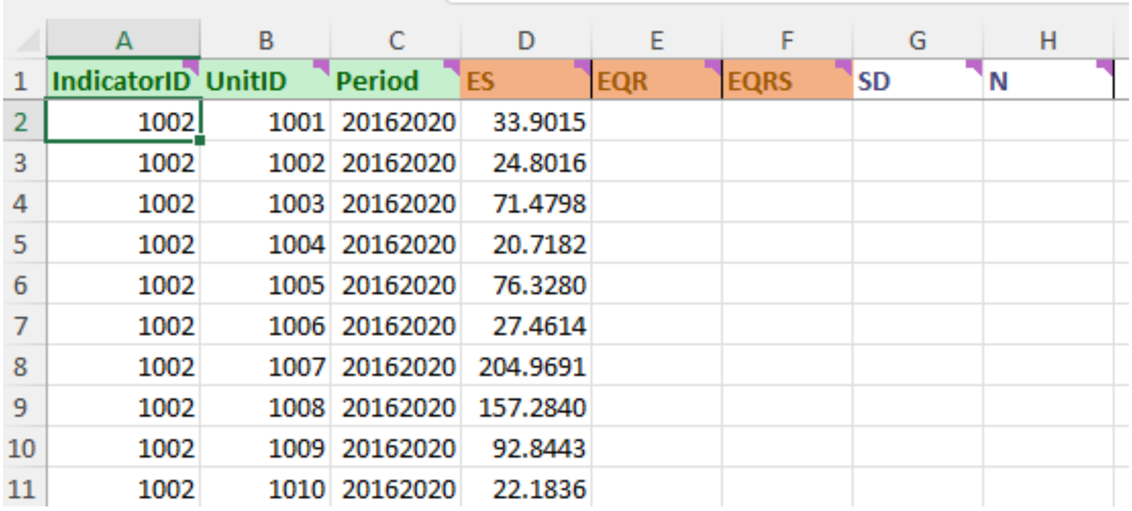
	A	B	C	D	E
1	IndicatorID	CriteriaID	Name	Code	Parameters
2	1002	1	Total Nitrogen	TN	NTOT
3	1004	1	Total Phosphorus	TP	PTOT
4	1005	2	Chlorophyll a (In-Situ)	CPHL_In-Situ	CPHL
5	1007	2	Secchi Depth	SECC	SECC
6	1010	2	Phytoplankton biovolume		complex phytoplankton index
7	1011	3	Macrophytes		Macrovegetation Quality element (PHYB
8	1012	3	Zoobenthos		Zoobenthos Quality element (MarBIT)

Table A2.4.3. The third sheet from the indicator data template: IndicatorUnits (example Germany).



	A	B	C	D	E	F	G	H	I	J
1	IndicatorID	UnitID	ET	ACDEV	RefCon	EQR_HG	EQR_GM	EQR_MP	EQR_PB	IW
2	1002	1001	22.50	50	15.00					
3	1002	1002	22.50	50	15.00					
4	1002	1003	22.50	50	15.00					
5	1002	1004	19.50	50	13.00					
6	1002	1005	17.70	50	11.80					
7	1002	1006	19.50	50	13.00					
8	1002	1007	38.10	50	25.40					
9	1002	1008	38.10	50	25.40					
10	1002	1009	17.70	50	11.80					
11	1002	1010	18.00	50	12.00					
12	1002	1011	17.70	50	11.80					
13	1002	1012	17.70	50	11.80					
14	1002	1013	17.70	50	11.80					
15	1002	1014	17.70	50	11.80					

Table A2.4.4. The fourth sheet of the indicator data template: IndicatorUnitResults (example Germany).



	A	B	C	D	E	F	G	H
1	IndicatorID	UnitID	Period	ES	EQR	EQRS	SD	N
2	1002	1001	20162020	33.9015				
3	1002	1002	20162020	24.8016				
4	1002	1003	20162020	71.4798				
5	1002	1004	20162020	20.7182				
6	1002	1005	20162020	76.3280				
7	1002	1006	20162020	27.4614				
8	1002	1007	20162020	204.9691				
9	1002	1008	20162020	157.2840				
10	1002	1009	20162020	92.8443				
11	1002	1010	20162020	22.1836				

ANNEX 3.
Detailed list of indicators used in coastal waters

The coastal areas in six countries were assessed by national indicators used in the Water Framework Directive (EC 2000) and their respective threshold values. 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. An overview of the indicators that were applied in coastal waters of the different countries for the HOLAS 3 assessment is given in Table 20.

Table 20. Overview table on WFD indicators used in different countries for the assessment of coastal waters (based on CPs reporting and information from HEAT configuration file).

	Indicators	Denmark	Estonia	Finland	Germany	Poland	Sweden
Nutrient levels	Dissolved inorganic nitrogen					x	x
	Dissolved inorganic phosphorus					x	x
	Total nitrogen		x	x	x	x	x
	Total phosphorus		x	x	x	x	x^1
Direct effects	Chlorophyll-a	x	x	x	x	x	x
	Phytoplankton biomass		x	x			
	Phytoplankton-Index				x		
	Total phytoplankton biomass						x
Indirect effects - macrophytes	Coastal water phytobenthos index (EPI)		x				
	Red algae depth limit			x			
	Fucus depth limit			x			
	Macrophytes				x		
	Macrophyte index			x		x	x
Indirect effects - macrozoobenthos	Macrozoobenthos community index (ZKIZ)		x				
	Benthic Quality Index (BQI)						x
	Brackish water benthic index (BBI)			x			
	Zoobenthos (DKI, MarBIT, Multimetric Index B)	x			x	x	
Indirect effects - others	Water transparency (Secchi depth)	x	x	x	x	x	x
	Oxygen debt						x
	Oxygen concentration					x	x

[1] In Sweden, summer mean and winter mean concentrations are used specifically, while in other countries annual mean values are used for the assessment of total nutrients.

Indicators used in Danish coastal waters

Indicator	Applied (yes/no)	Intercalibrated (yes/no)	Description of indicator	Unit	Response to increasing eutrophication	Assessment months (1…12)	Parameters used in indicator
Chlorophyll-a	yes			µg/l	pos	5-9	chlorophyll-a
Depth limit of eelgrass	yes			m	neg	6-9	
DKI (zoobenthos)	yes			None (index)	neg	3-5	Species and group of species

Indicators used in Estonian coastal waters

Indicator	Applied (yes/no)	Intercalibrated (yes/no)	Description of indicator	Unit	Response to increasing eutrophication	Assessment months (1…12)	Parameters used in indicator
Total nitrogen	yes	no	Summer concentration of total nitrogen in seawater. Water samples are gathered 6-7 times during monitoring period from the depths 1, 5 and 10 metres in every station, totN is analysed on different depths. Assessment value is the average of all measured values.	µmol/l	pos	6-9	Summer concentration of total nitrogen in seawater
Total phosphorus	yes	no	Summer concentration of total phosphorus in seawater. Water samples are gathered 6-7 times during monitoring period from the depths 1, 5 and 10 metres in every station, totP is analysed on different depths. Assessment value is the average of all measured values.	µmol/l	pos	6-9	Summer concentration of total phosphorus in seawater
Chlorophyll-a	yes	no	Summer chlorophyll-a concentration in seawater. Water samples are gathered 6-7 times during monitoring period from the depths 1, 5 and 10 metres in every station. Chlorophyll-a concentration determined from an integrated sample. Assessment value is the median of all monitored values.	µg/l	pos	5-9	Summer chlorophyll-a concentration
Phytoplankton biomass	yes	no	Summer phytoplankton wet weight biomass. Water samples are gathered 6-7 times during monitoring period from the depths 1, 5 and 10 metres in every station. Phytoplankton biomass is determined from an integrated sample. Assessment value is the median of all monitored values.	mg/l	pos	6-9	Summer phytoplankton wet weight biomass
Transparency Secchi depth	yes	no	Summer-time Secchi depth transparency. Secchi depth is measured 6-7 times in the monitoring period in every station.	m	neg	6-9	Summer-time Secchi depth
Benthic macroflora depth distribution	yes	yes	Depth distribution of phytobenthos is measured by visual observations (diving or video). Data on species coverage and appearance is gathered from a transect which is crosswise to the beach. Monitoring is done by 1 meter depth interval to depth where no phytobenthos appears. In every monitoring point 3-4 meter wide seabed area is used to give coverage assessments.	m	neg	7-9	Coverage of phytobenthos and depth distribution of phytobenthos
Fucus vesiculosus depth distribution	yes	yes	Depth distribution of F. vesiculosus is measured by visual observations (diving or video). Data on species coverage and appearance is gathered from a transect which is crosswise to the beach. Monitoring is done by 1 meter depth interval to depth where no phytobenthos appears. In every monitoring point 3-4	m	neg	7-9	Coverage of F. vesiculosus and depth distribution of F. vesiculosus

			meter wide seabed area is used to give coverage assessments.				
Proportion of perennial species	yes	no	Proportion of perennial species in benthic vegetation. Quantitative benthic vegetation samples are gathered by a diver on a transect from 5-7 depths using a 20x20 cm metal frame. 3 duplicate samples are gathered on each depth. Samples are analysed in the laboratory to species level and dried at 60 degrees Celsius. Perennial species percentage in an area is determined by perennial species biomass.	%	neg	7-9	Perennial species biomass and total biomass of erect vegetation
Large invertebrates ZKI	yes	yes	The structure of zoobenthos community reacts to different stressors, because there are species in the community which have different physiological tolerance, feeding habitats and trophic relations. Zoobenthos species are divided into three sensitivity classes using this information. Index is calculated on the basis of biomass proportions of species belonging to the sensitivity classes and total biomass.	-	neg	5-8	Zoobenthos species biomass

Indicators used in Finnish coastal waters

Indicator	Applied (yes/no)	Intercalibrated (yes/no)	Description of indicator	Unit	Response to increasing eutrophication	Assessment months (1…12)	Parameters used in indicator
Total nitrogen	yes	no	total nitrogen concentration in water surface water layer (0-8 m)	µg/l	pos	7-9*	total nitrogen in water
Total phosphorus	yes	no	total phosphorus concentration in water surface water layer (0-8 m)	µg/l	pos	7-9*	total phosphorus in water
Secchi depth	yes	no	Secchi depth	m	neg	7-9*	Secchi depth
Chlorophyll-a	yes	yes	chlorophyll-a concentration in surface layer (0-10 m, lower depth limit of composite samples generally based on Secchi depth)	µg/l	pos	7-9*	chlorophyll-a
Phytoplankton biomass	yes	no	phytoplankton biomass in surface layer (0-10 m, lower depth limit of composite sample generally based on Secchi depth)	mg/l	pos	7-9*	Biomass of phytoplankton
Fucus depth limit	yes	yes	Lower depth limit of Fucus vesiculosus. Determined for sheltered and open sites.	m	neg	75-9	Lower depth limit of Fucus vesiculosus
Red algae depth limit	yes	no	Average of lower depth limits of red algae species Furcellaria lumbricalis, Rhodomela confervoides, Phyllophora pseudoceranoides andPolysiphonia fucoides	m	neg	5-9	Lower depth limits of red algae Furcellaria lumbricalis, Rhodomela confervoides, Phyllophora pseudoceranoides and Polysiphonia fucoides
Brackish water benthic index (BBI)	yes	yes	Index is calculated from species composition of benthic macro fauna and accounts for species tolerance, diversity and abundance		neg	5-6, 8-10	Species abundance data

*1.7.- 7.9., except for Bothnian Bay 7.7.-7.9.

Indicators used in German coastal waters

Indicator	Applied (yes/no)	Intercalibrated (yes/no)	Description of indicator	Unit	Response to increasing eutrophication	Assessment months (1…12)	Parameters used in indicator
Total nitrogen	yes	no	total nitrogen concentration in surface water layer (0-10 m)	µmol/l	pos	1-12	total nitrogen in water
Total phosphorus	yes	no	total phosphorus concentration in surface water layer (0-10 m)	µmol/l	pos	1-12	total phosphorus in water

Chlorophyll-a	yes	partly	chlorophyll-a concentration in surface water layer (0-10 m)	µg/l	pos	5-9	chlorophyll-a
Secchi depth	yes	no	Secchi depth	m	neg	5-9	Secchi depth
Phytoplankton biovolume	yes	no	complex phytoplankton index, accounts for chlorophyll-a concentration, total biovolume and biovolume of Chlorophyceae and Cyanophyceae using a weighted approach for the integration	EQR (normalised)	neg	5-9	phytoplankton
Macrophytes	yes	yes	Macrovegetation quality element (PHYBIBCO/BALCOSIS), complex indicator for inner and outer coastal areas, accounts for habitat-specific species (soft-bottom, hard-bottom) and their depth limit	EQR (normalised)	neg	6-9	
Zoobenthos	yes	yes	Zoobenthos quality element (MarBIT), complex Index calculated from species composition of benthic macro fauna and accounts for sensitive and tolerant species, diversity and abundance	EQR (normalised)	neg	1-12	Species abundance data

Indicators used in Polish coastal and transitional waters

Indicator	Applied (yes/no)	Intercalibrated (yes/no)	Description of indicator	Unit	Response to increasing eutrophication (pos/neg)	Assessment months (1...12)	Parameters used in indicator
Chlorophyll-a(VI-IX)			Indicator used in coastal and transitional waters excluding lagoons. Measurements from the 0-10 m depth are used.	ug/l	pos	6-9	chlorophyll-a
Chlorophyll-a (a.m.)			Indicator used in lagoons. Measurements from the 0-10 m depth are used.	ug/l	pos	1-12	chlorophyll-a
Macrophyte state indicator (SM_1)	yes	no	The indicator used to assess the environmental status based on macrophytes in coastal and transitional waters (except for water type BT1 - Lagoon with mud and sand substrate, including: the Vistula Lagoon, the Szczecin Lagoon and the Kamieński Lagoon, defines the ratio of positive taxa biomass to the total macrophyte biomass.	index	neg	6-9	Species biomass and coverage
Ecological status macrophyte index (ESMIz)	yes	no	This is a multimetric indicator consisting of two indexes describing the taxonomic composition (the Pielou eveness index, Shannon-Wiener diversisty) and abundance of macrophytes, adjusted to the environmental status assessment of lagoons, such as the Szczecin Lagoon, the Kamieński Lagoon and the Vistula Lagoon.	index	neg		Species composition and coverage

Multimetric Index B			Index for the assessment of the state of macrozoobenthos.The algorithm of this index includes taxonomic diversity, expressed number of identified taxa and abundance of individuals of each taxon and qualitative information on the ecological sensitivity/tolerance of individual taxa. The index value increases with the increase of taxonomic diversity, share of sensitive taxa and eveness of taxa in the entire abundance structure.	index	neg		abundance and sensitivity of species
DIN (I-III)			Indicator used in coastal and transitional waters excluding lagoons. Measurements from the whole water column are used.	mg/l	pos	1-3	nitrates+nitrites+ ammonium
DIN (a.m.)			Indicator used in lagoons. Measurements from the whole water column are used.	mg/l	pos	1-12	nitrates+nitrites+ ammonium
DIP (I-III)			Indicator used in coastal and transitional waters excluding lagoons. Measurements from the whole water column are used.	mg/l	pos	1-3	phosphate
DIP (a.m.)			Indicator used in lagoons. Measurements from the whole water column are used.	mg/l	pos	1-12	phosphate
TN (VI-IX)			Indicator used in coastal and transitional waters excluding lagoons. Measurements from the whole water column are used.	mg/l	pos	6-9	total nitrogen
TN (a.m.)			Indicator used in lagoons. Measurements from the whole water column are used.	mg/l	pos	1-12	total nitrogen
TP (VI-IX)			Indicator used in coastal and transitional waters excluding lagoons. Measurements from the whole water column are used.	mg/l	pos	6-9	total phosphorus
TP (a.m.)			Indicator used in lagoons. Measurements from the whole water column are used.	mg/l	pos	1-12	total phosphorus
Secchi (VI-IX)			Indicator used in coastal and transitional waters excluding lagoons.	m	neg	6-9	secchi depth
Secchi (a.m.)			Indicator used in lagoons.	m	neg	1-12	secchi depth
Oxygen (min. VI-IX)			Minimal oxygen concentration at the bottom in the VI-IX months.	mg/l	neg	6-9	oxygen

Indicators used in Swedish coastal waters

HEAT	Criteria	Indicator	Applied (yes/no)	Intercalibrated (yes/no)	Description of indicator	Unit	Response to increasing eutrophication	Assessment months (1…12)	Parameters used in indicator
Causative factors	D5C1	Winter total nitrogen	yes	no	total nitrogen concentration in surface water layer (0-max 10 m)	µmol/l	pos	12,.2 in Baltic Proper, 12..3 in	total nitrogen in water

		Winter total phosphorus	yes	no	total phosphorus concentration in surface water layer (0-max 10 m)	µmol/l	pos	Kattegat and Sound 11..2 in Bothnian Bay	total phosphorus in water
		Winter dissolved inorganic nitrogen	yes	no	Dissolved inorganic nitrogen concentration in surface water layer (0 – max 10 m)	µmol/l	pos		Dissolved inorganic nitrogen in water
		Winter dissolved inorganic phosphorus	yes	no	Dissolved inorganic phosphorus concentration in surface water layer (0 – max 10 m)	µmol/l	pos		Dissolved inorganic phosphorus in water
		Summer total nitrogen	yes	no	total nitrogen concentration in surface water layer (0-max 10 m)	µmol/l	pos	6..8 in Kattegat and Sound; 7..8 in Baltic	total nitrogen in water
		Summer total phosphorus	yes	no	total phosphorus concentration in surface water layer (0-max 10 m)	µmol/l	pos		total phosphorus in water
Direct effects	D5C2	Chlorophyll-a	yes	partly	chlorophyll-a concentration in surface water layer (0-10 m)	µg/l	pos	6-8	chlorophyll-a
		Phytoplankton biovolume	yes		Biovolume is determined from the biomass of autotrophic and mixotrophic phytoplankton and expressed as the mean value from integrated samples (o-10 m) or discrete samples (0,5 m) if water depth is < 12 m. Data from deviating samples depths can be corrected to represent the above intervals and depths. SWE-007, SWE-011, SWE-013 and SWE-024 need to be corrected with observed salinity.	mm^3/l	neg	6-8	Biomass of autotrophic and mixotrophic phytoplankton, salinity
	D5C7	Macrovegetation	yes	yes	A transect shall be classified only if maximal depth distribution of a minimum of three species is included. Each	points	neg	7-9	Index based on maximum depth of occurrence and species sensitivity

					species get a water type specific point. All points within the transect are summarized and averaged and the result is divided with the “reference point” five. Within a water body a minimum of three transects shall be included. The final status for a water body is thus 1-5 points.				
Indirect effects	D5C4	Secchi depth	yes	no	Secchi depth from June to August, if these months are missing, September may be used. Accuracy shall not be higher than 0.5 m. SWE-007, SWE-011, SWE-013 and SWE-024 need to be corrected with observed salinity.	m	neg	6-8	Secchi depth
	D5C5	Bottom oxygen	yes	no	Oxygen concentration in bottom water	mg/l	neg	1-12	Oxygen concentration in water
	D5C8	Zoobenthos	yes	yes	Zoobenthos quality element (BQI), complex Index calculated from species composition of benthic macro fauna and accounts for sensitive and tolerant species, diversity and abundance	EQR (normalised)	neg	1-12	Species abundance data