


Cyanobacterial blooms

INDICATOR TYPE: Pre-core
INDICATOR CATEGORY: State
BSAP SEGMENT: Eutrophication
MSFD CRITERIA: D5C3



Cyanobacterial bloom index

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1 Key message

This indicator is a HELCOM pre-core indicator.

This HELCOM pre-core indicator is evaluated for the purposes of the 'State of the Baltic Sea' report (HOLAS 3) and further development towards a core indicator is expected in the future (threshold values are preliminary). An overview of indicator development is set out in the [HELCOM indicator manual](#).

This pre-core indicator evaluates summer-time (June –August) cyanobacterial surface accumulations and cyanobacteria biomass, summarized in the cyanobacterial bloom index, during the assessment period 2016-2021.

Good status of the cyanobacterial bloom index was not achieved in any of the 13 assessed open sea sub-basins. The indicator status shows a significant deteriorating trend from the levels in 1990 to 2021 in all assessed sub-basins except for Bornholm Basin, Eastern Gotland Basin, Gulf of Finland Eastern and Gdansk Basin.

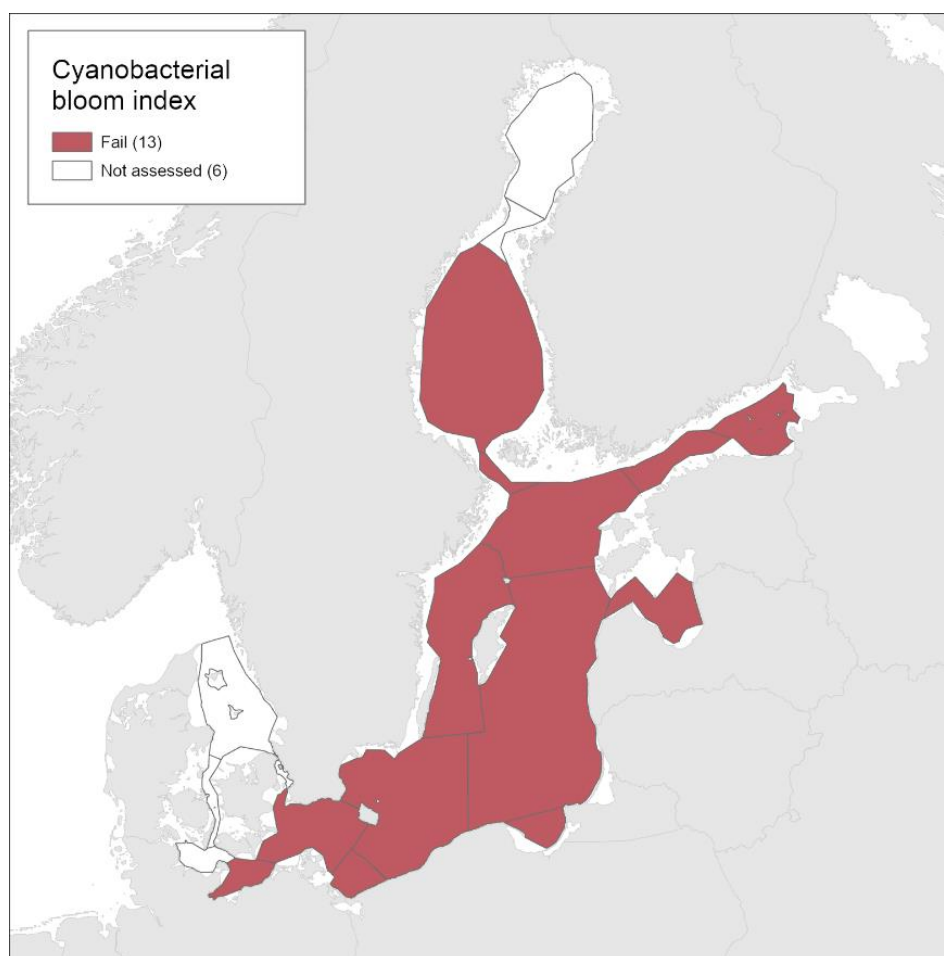


Figure 1. Status evaluation results for the indicator 'Cyanobacterial Bloom Index'. The evaluation is carried out using Scale 4 HELCOM assessment units, applied only in the open sea units at this scale (defined in the [HELCOM Monitoring and Assessment Strategy Annex 4](#)). See Results section below for details. See 'data chapter' for interactive maps and data at the [HELCOM Map and Data Service](#).

The confidence in the indicator status evaluation was high in all assessment units except for moderate in the Pomeranian Bay and the Gdansk Basin. The lower confidence in these assessment units was mainly due to low spatial confidence.

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 at present not considered relevant for the assessment units; Great Belt, The Sound and Kattegat. The reason is that active growth of cyanobacteria is restricted to salinities below about 12.

1.1 Citation

The data and resulting data products (e.g. tables, figures and maps) available on the indicator web page can be used freely given that it is used appropriately and the source is cited. The indicator should be cited as follows:

HELCOM (2023). Cyanobacteria bloom index. HELCOM pre-core indicator report. Online. [Date Viewed], [Web link].

ISSN 2343-2543

2 Relevance of the indicator

This HELCOM pre-core indicator is evaluated for the purposes of the 'State of the Baltic Sea' report (HOLAS 3) and further development towards a core indicator is expected in the future.

The approach and threshold values of this pre-core indicator are yet to be commonly agreed in HELCOM. The results are to be considered as intermediate.

Excess input of nutrients and decreasing N/P ratios of available nutrients enhance the cyanobacterial accumulations, which again contributes to the oxygen depletion in the bottom waters. The potential toxicity of cyanobacteria and the nuisance to recreational use negatively affect the socioeconomic value of the ecosystem.

2.1 Ecological relevance

Surface blooms of nitrogen-fixing cyanobacteria are a natural phenomenon (Bianchi *et al.* 2000) but have become more extensive and frequent in many parts of the Baltic Sea since the 1990s (Finni *et al.* 2001). Phosphorus load into a dominantly nitrogen-limited environment is considered as the main pressure affecting cyanobacterial growth, as many cyanobacteria are capable of fixing molecular nitrogen. The blooms of nitrogen fixing cyanobacteria are central in the main feedback processes that slow down the recovery from eutrophication. They provide nitrogen to the N-limited pelagic system and increase settling of organic matter to the bottom, which leads to more extensive oxygen depletion and release of phosphorus from the sediments (Figure 2, Vahtera *et al.* 2007).

The blooms partly consist of the toxic species *Nodularia spumigena*, which may have negative effects on grazing zooplankton (Engström *et al.* 2000, Sellner *et al.* 1994, Sopanen *et al.* 2009). Cyanobacteria have also been shown to have allelopathic effects on other phytoplankton groups (Suikkanen *et al.* 2004, 2005).

Also other, non-eutrophication related, causes have been suggested to affect the extent of the blooms, such as: hydrographic changes - increased temperature, decreased salinity or stability of the halocline, changes in micronutrients or trace metals, as well as changes in the interaction between phyto- and zooplankton species (Kahru *et al.* 1994).

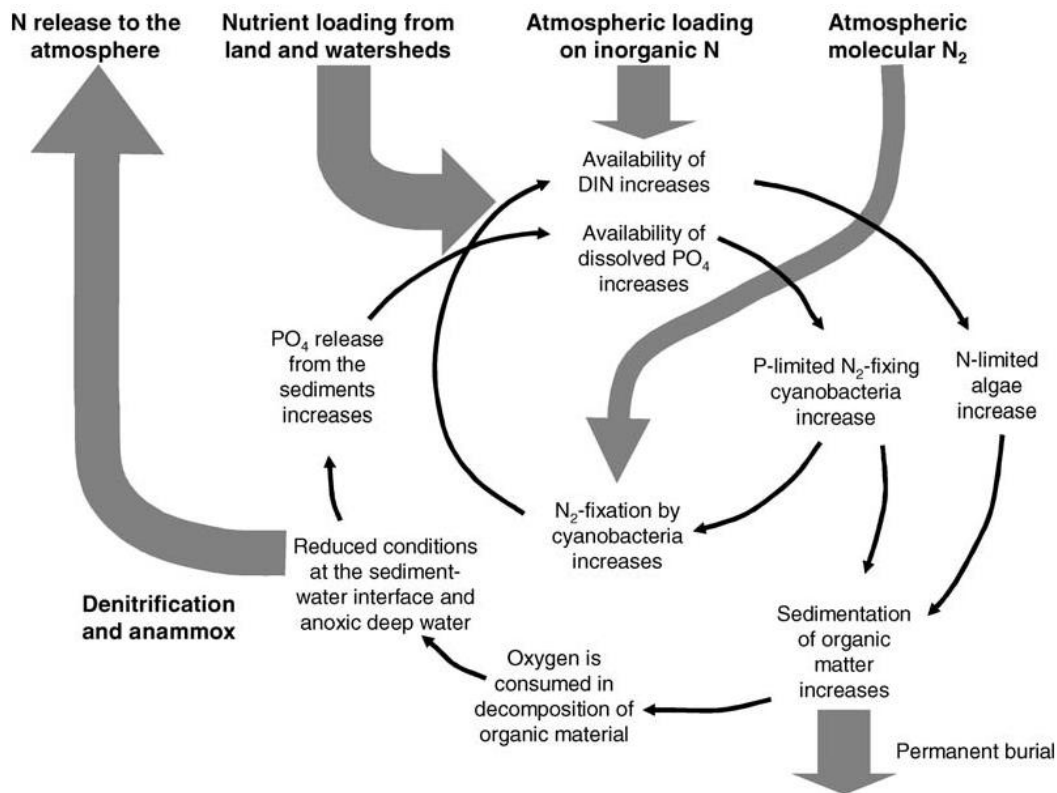


Figure 2. Simplified conceptual model of the vicious circle of eutrophication (from Vahtera *et al.* 2007). See Vahtera *et al.* 2007 for details.

2.2 Policy relevance

Eutrophication is one of the four thematic segments of the HELCOM Baltic Sea Action Plan (BSAP) with the strategic goal of having a Baltic Sea unaffected by eutrophication (HELCOM 2021). Eutrophication is defined in the BSAP as a condition in an aquatic ecosystem where excessive inputs of nutrients stimulate the growth of algae, which leads to imbalanced functioning of the system. The BSAP goal for eutrophication is broken down into five ecological objectives, one of which is "natural levels of algal blooms".

The EU Marine Strategy Framework Directive (2008/56/EC) requires that "human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters" (Descriptor 5). The Commission Decision on GES (2017) defines 'Harmful algal blooms (e.g. cyanobacteria) in the watercolumn' as the criteria element to be assessed using the criteria D5C3 "The number, spatial extent and duration of harmful algal bloom events are not at levels that indicate adverse effects of nutrient enrichment".

Table 1. Eutrophication links to policy.

	Baltic Sea Action Plan (BSAP)	Marine Strategy Framework Directive (MSFD)
Fundamental link	<p>Segment: Eutrophication Goal: “Baltic Sea unaffected by eutrophication”</p> <ul style="list-style-type: none"> • Ecological objective: “Concentrations of nutrients close to natural levels”, “Clear waters”, “Natural level of algal blooms”, “Natural distribution and occurrence of plants and animals”, and “Natural oxygen levels”. • Management objective: “Minimize inputs of nutrients from human activities” 	<p>Descriptor 5 Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters - Macrofaunal communities of benthic habitats.</p> <ul style="list-style-type: none"> • Criteria D5C3 The number, spatial extent and duration of harmful algal bloom events are not at levels that indicate adverse effects of nutrient enrichment. • Feature – Eutrophication. • Element of the feature assessed – Harmful blooms.
Complementary link	<p>Segment: Biodiversity Goal: “Baltic Sea ecosystem is healthy and resilient”</p> <ul style="list-style-type: none"> • Ecological objective: “Natural distribution, occurrence and quality of habitats and associated communities”. • Management objective: “Minimize disturbance of species, their habitats and migration routes from human activities” • The achievement of regional nutrient input targets – Maximum Allowable Inputs (MAI) and Nutrient Input Ceilings (NIC) – for all sub-basins, as identified in this BSAP, is the key prerequisite for achieving the ecological objectives. 	<p>Descriptor 1 Criteria D1C6: The condition of the habitat type, including its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), is not adversely affected due to anthropogenic pressures.</p> <ul style="list-style-type: none"> • Feature – Pelagic broad habitats.
Other relevant policy links	<ul style="list-style-type: none"> • The EU Water Framework Directive. • UN Sustainable Development Goal 14 (Conserve and sustainably use the oceans, seas and marine resources for sustainable development) is most clearly relevant, though SDG 12 (Ensure sustainable consumption and production patterns) and 13 (Take urgent action to combat climate change and its impacts) also have relevance. 	

2.3 Relevance for other assessments

The indicator is included as a test indicator in the integrated assessment of eutrophication and also used in the BEAT tool for pelagic habitats.

Eutrophication assessment

The status of eutrophication is assessed using several core indicators. Each indicator focuses on one important aspect of the complex issue. In addition to providing an indicator-based evaluation of cyanobacterial blooms, this indicator also contributes to the overall eutrophication assessment, along with the other eutrophication indicators. In the integrated assessment, cyanobacterial bloom index is included in the direct effects of eutrophication. Since cyanobacterial blooms are also affected by non-eutrophication related changes (see chapter 'Role of cyanobacterial blooms in the ecosystem'), the indicator has been down-weighted in the integrated assessment.

3 Threshold values

The indicator uses assessment unit specific threshold values that are presented as normalized values. The threshold values of this pre-core indicator are yet to be commonly agreed in HELCOM. The indicator is based on two parameters: (1) cyanobacterial surface accumulations (CSA) and (2) cyanobacterial biomass. A normalized threshold value is set for each parameter for each assessment unit, and the combined indicator threshold value is an average of the two. If either parameter is not applicable or available for a specific assessment unit, then only one parameter is used for the threshold value. Normalized values that are above the threshold value indicate good status (Figure 3).

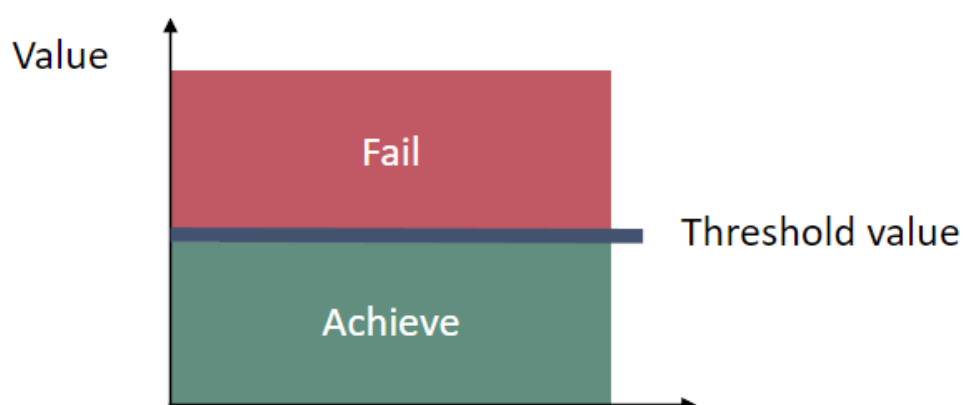


Figure 3 Schematic representation of the averaged and normalized threshold value applied in the cyanobacteria bloom index pre-core indicator, the threshold values are assessment unit specific (see Table 2).

The specific values for each parameter and the proposed overall threshold value are listed in Table 2.

Table 2. Summary table of assessment unit specific threshold values in the open-sea areas. The indicator (Cyanobacterial bloom index, CyaBI) threshold value is the average of the two parameter specific values (Cyanobacterial surface accumulations (CSA) and cyanobacterial biomass). For those assessment units, where threshold value is available only for one of the parameters, the indicator is based solely on that parameter. Threshold values have been updated for HOLAS 3.

HELCOM ID	Assessment unit (open sea)	Parameter threshold: CSA (normalized between 0-1, with 1 expressing good status)	Parameter threshold: Biomass (normalized threshold value between 0-1, with 1 expressing good status)	Indicator Threshold:CyaBI (normalized threshold between 0-1, with 1 expressing good status)	Comments on indicator protocol
SEA-001	Kattegat	Relevance under investigation			
SEA-002	Great Belt	Relevance under investigation			
SEA-003	The Sound	Relevance under investigation			

SEA-004	Kiel Bay	Under development			
SEA-005	Bay of Mecklenburg	0.85	0.92	0.89	Indicator average of CSA and biomass
SEA-006	Arkona Basin	0.75	0.94	0.85	Indicator average of CSA and biomass
SEA-007	Bornholm Basin	0.79	0.87	0.83	Indicator average of CSA and biomass
SEA-007B	Pomeranian Bay	0.81	Under development	0.81	Indicator only based on CSA
SEA-008	Gdansk Basin	0.77	Under development	0.77	Indicator only based on CSA
SEA-009	Eastern Gotland Basin	0.94	0.84	0.89	Indicator average of CSA and biomass
SEA-010	Western Gotland Basin	0.88	0.82	0.85	Indicator average of CSA and biomass
SEA-011	Gulf of Riga	0.92	0.88	0.90	Indicator average of CSA and biomass
SEA-012	Northern Baltic Proper	0.87	0.98	0.93	Indicator average of CSA and biomass
SEA-013A	Gulf of Finland Western	0.93	0.83	0.88	Indicator average of CSA and biomass
SEA-013B	Gulf of Finland Eastern	0.97	0.84	0.91	Indicator average of CSA and biomass
SEA-014	Åland Sea	0.91	Not applicable	0.91	Indicator only based on CSA
SEA-015	Bothnian Sea	0.94	0.90	0.92	Indicator average of CSA and biomass
SEA-016	The Quark	Relevance under investigation			
SEA-017	Bothnian Bay	Relevance under investigation			

3.1 Setting the threshold value(s)

Method description for deriving the threshold values

Parameter specific threshold values for the assessment units were derived based on long-term data series of:

- 1 - cyanobacterial surface accumulations (CSA); the independent satellite-based time series on algae accumulations from 1979-2014 in the Baltic Sea by Kahru and Elmgren (2014) and
- 2 - cyanobacterial biomass; data on *in-situ* observations of cyanobacteria biomass 1990-2015 collated by the HELCOM PEG group (Wasmund *et al.* 2015)

The indicator threshold values for the assessment units were derived as an average of the parameter specific thresholds. When threshold was available only for one of the parameters, this parameter threshold was used as the threshold for the indicator, and 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 threshold values were derived by combining statistical analysis of long-term data with expert judgement. The main concern in proposing threshold values is the lack of sound and consistent historical data. The data starting from 1970s -1990s, which are available in the threshold setting datasets do not correspond to “no, or very little human impact” that could be used as a reference condition. Investigations of stable nitrogen and carbon isotope composition as well as of the organic carbon content of sediments have shown that the increase in nutrients and productivity began already in the 1950s–1960s (Andrén *et al.*, 2000; Struck *et al.*, 2000; Poutanen & Nikkilä, 2001). According to Finni *et al.* (2001), cyanobacterial blooms have become common in the open sea in both the Baltic Proper and the Gulf of Finland since at least the 1960s.

As cyanobacterial blooms are a natural phenomenon in the Baltic Sea, the threshold values should not describe a status with no blooms, but rather a status without extensive and potentially harmful blooms. This status should be consistent with sustainable use of the sea by humans. To meet this aim, the thresholds were derived based on the time periods within the available datasets where the status was already impacted by eutrophication, but the bloom intensity was low. Within the time periods covered by the available datasets, the status covers varying levels of cyanobacterial blooms. To distinguish the shorter periods of low bloom intensity in comparison to the general level, a shift detection method (Rodionov 2004) was used; or if no such periods were distinguished, the thresholds were based on individual low-bloom years using the lowest quartile method ([document 3-5 rev.1 of State & Conservation 5E-2017](#)).

Thresholds for CSA

The thresholds for CSA are based on satellite-based time series on algae accumulations (Fraction with Cyanobacterial Accumulations, FCA) from 1979-2014 in the Baltic Sea by Kahru and Elmgren 2014. The shift-detection method was successfully applied to all

assessment units that were assessed in HOLAS II ([State & Conservation 5E-2017, document 3-5 rev.1](#)). Normalized FCA threshold values were transformed into CSA thresholds using a linear model between the two datasets (Anttila *et al.* 2018).

The normalization and linear models have been updated for HOLAS 3, which affects the normalized CSA threshold values, but the underlying FCA values remain unchanged (State & Conservation 17-2022, document 5J-27, appendix 2). New tentative thresholds have been set for Bornholm Basin and Arkona Basin, Pomeranian Bay, Bay of Mecklenburg and Åland Sea. For Bornholm Basin, the same method was used as in HOLAS II, whereas for the smaller basins, FCA data from 1979 - 1997, with higher uncertainty, was excluded from threshold setting, and thresholds were based on the 5th percentile of FCA% from 1998-2021. For the Åland Sea, the CSA threshold was set as an average of the values in adjacent basins Bothnian Sea and Northern Baltic Proper, due to poor dependency between the FCA and CSA time series in this assessment unit.

Thresholds for cyanobacterial biomass

Thresholds for the cyanobacterial biomass were set based on the assessment unit specific timeseries of yearly average cyanobacterial biomasses, as sum of the three main bloom forming genera (*Nodularia*, *Aphanizomenon* and *Dolichospermum*) in summer (generally June-August), collated by HELCOM PEG and presented in the HELCOM Baltic Sea Environment fact sheet for cyanobacterial biomass (Wasmund *et al.* 2015). Periods of low bloom intensity could be identified using the shift detection method only for the Bothnian Sea and the Gulf of Finland in HOLAS II ([document 3-5 rev.1 of State & Conservation 5E-2017](#)). For the rest of the assessment units the lowest quartile method was used. A new tentative threshold has been set for the Western Gotland Basin, using the lowest quartile method, and the threshold for Bothnian Sea has been corrected (State & Conservation 17-2022 document 5J-27, appendix 2). The normalization of the thresholds and data for the Northern Baltic Proper and Bothnian Sea was updated due to notable increase in the cyanobacterial biomass in these assessment units. This does not affect the underlying thresholds in $\mu\text{g L}^{-1}$. Kiel Bay, Gdansk Basin and Pomeranian Bay still lack thresholds for cyanobacterial biomass and there is no data available for the Åland Sea. The non-normalized thresholds are presented in State & Conservation 17-2022 document 5J-27, appendix 2.

4 Results and discussion

The results of the indicator evaluation underlying the key message map and information are provided below. This pre-core indicator and its threshold values are yet to be commonly agreed in HELCOM. The indicator is included as a test indicator for the purposes of the 'State of the Baltic Sea' report, and the results are to be considered as intermediate.

4.1 Status evaluation

Good status was not achieved in any of the assessment units where the indicator was applied. EQRS was highest in the Arkona Sea, Bornholm Sea and Gulf of Finland Eastern (0.43-0.46) and lowest in the Bothnian Sea (0.23) (Figure 4 and table 3). The indicator consists of two parameters, cyanobacterial biomass and cyanobacterial surface accumulations, which provided generally a similar evaluation (Figure 5, figure 6, table 4). Difference in relation to the threshold for good status was found only for the Arkona Sea, where biomass reflects good status and CSA reflects a level below GES.

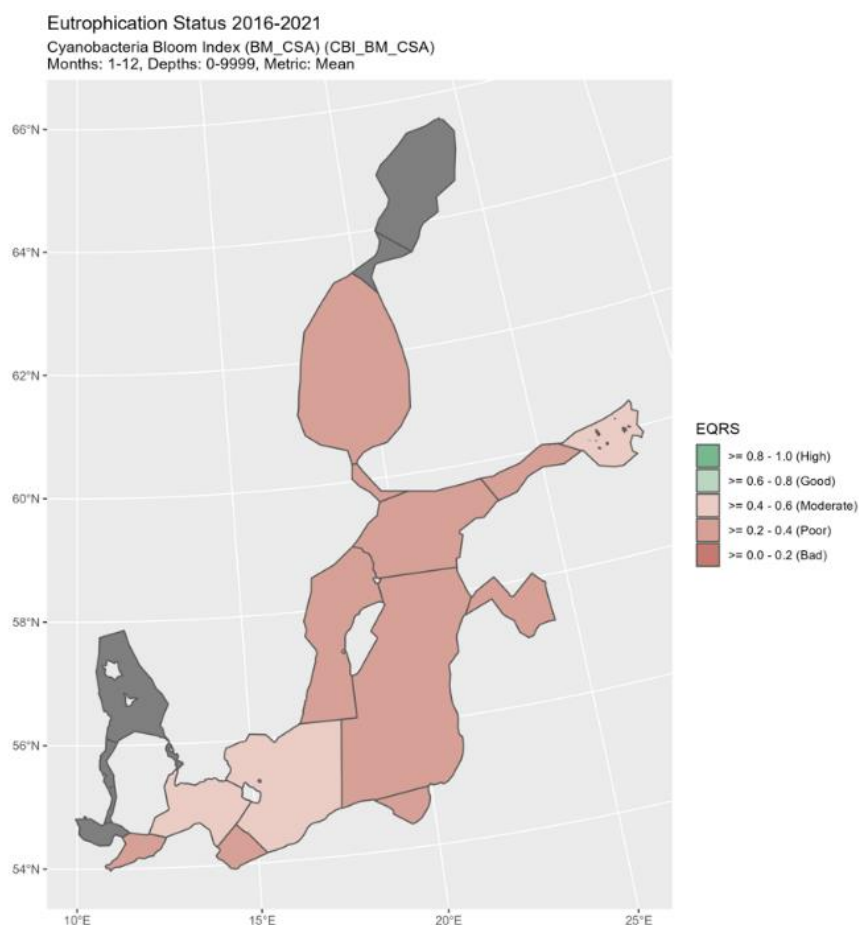


Figure 4. Status of cyanobacterial bloom index, presented as ecological quality ratio scaled (EQRS). EQRS shows the present concentration in relation to the reference value, decreasing along with increasing eutrophication. The threshold value has been achieved when $EQRS \geq 0.6$.

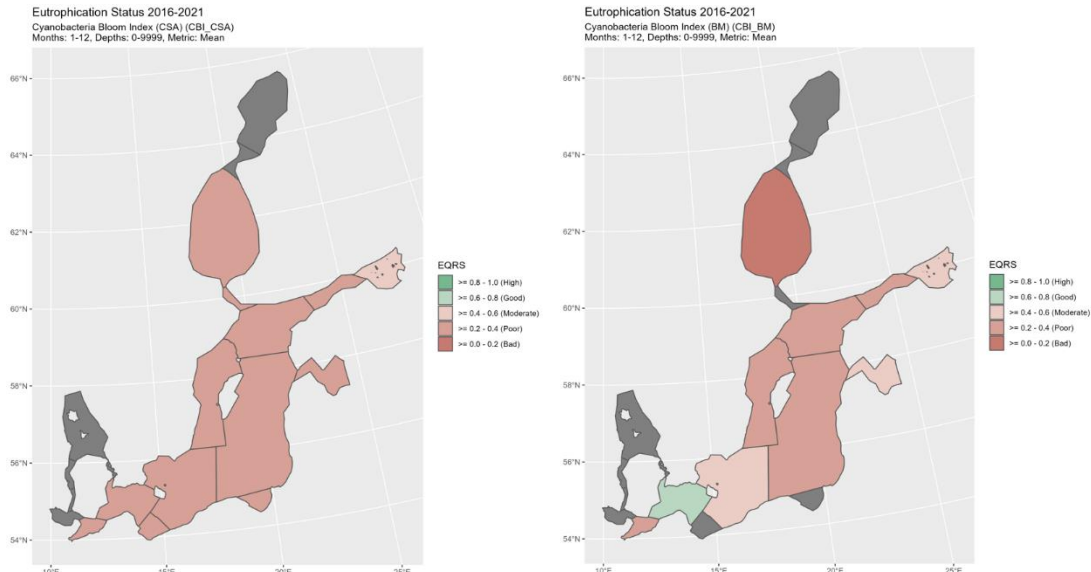


Figure 5. Status of cyanobacterial biomass (BM) presented as ecological quality ratio scaled (EQRS) on the left figure and Status of cyanobacterial surface accumulation (CSA) presented as ecological quality ratio scaled (EQRS) on the right figure. EQRS shows the present concentration in relation to the reference value, decreasing along with increasing eutrophication. The threshold value has been achieved when EQRS \geq 0.6.

Table 3. Information on threshold values, present estimates and status (good status /not good status) of the Cyanobacterial Bloom Index indicator. The indicator values are based on two parameters, Cyanobacterial Surface Accumulations and Cyanobacteria biomass (See **table 2** and Assessment protocol).

HELCOM ID	Name of assessment unit	Proposed threshold value (normalized between 0-1, with 1 expressing good status)	Estimate 2016-2021 (normalized between 0-1, with 1 expressing good status)	Ecological quality ratio (EQRS)	Status (fail/achieve threshold value)
SEA-001	Kattegat	Relevance under investigation			
SEA-002	Great Belt	Relevance under investigation			
SEA-003	The Sound	Relevance under investigation			
SEA-004	Kiel Bay	Under development			
SEA-005	Bay of Mecklenburg	0.89	0.49	0.33	Fail

SEA-006	Arkona Sea	0.85	0.61	0.43	Fail
SEA-007	Bornholm Sea	0.83	0.61	0.46	Fail
SEA-007B	Pomeranian Bay	0.81	0.43	0.36	Fail
SEA-008	Gdansk Basin	0.77	0.45	0.38	Fail
SEA-009	Eastern Gotland Basin	0.89	0.44	0.29	Fail
SEA-010	Western Gotland Basin	0.85	0.41	0.29	Fail
SEA-011	Gulf of Riga	0.90	0.51	0.34	Fail
SEA-012	Northern Baltic Proper	0.93	0.43	0.27	Fail
SEA-013A	Gulf of Finland Western	0.88	0.45	0.31	Fail
SEA-013B	Gulf of Finland Eastern	0.91	0.65	0.43	Fail
SEA-014	Åland Sea	0.91	0.35	0.28	Fail
SEA-015	Bothnian Sea	0.92	0.36	0.23	fail
SEA-016	The Quark	Relevance under investigation			
SEA-017	Bothnian Bay	Relevance under investigation			

Table 4. Parameter specific results for cyanobacterial bloom index for HOLAS 3 period (2016-2021). Cyanobacterial biomass in $\mu\text{g L}^{-1}$ and scaled Ecological quality ratios (EQRS) for cyanobacterial biomass and cyanobacterial surface accumulations (CSA). Note that the EQRS values for Cyanobacterial Bloom Index in Table 3 are based on the indicator estimate values (normalized between 0-1, with 1 expressing good status), and not on the parameter specific EQRS values (See assessment protocol).

HELCOM ID	Assessment unit	Cyanobacterial biomass $\mu\text{g L}^{-1}$	Cyanobacterial biomass EQRS	CSA EQRS
SEA-005	Bay of Mecklenburg	73	0.34	0.36
SEA-006	Arkona Sea	89	0.69	0.28
SEA-007	Bornholm Sea	85	0.59	0.33
SEA-007B	Pomeranian Bay			0.36
SEA-008	Gdansk Basin			0.38
SEA-009	Eastern Gotland Basin	284	0.28	0.36
SEA-010	Western Gotland Basin	149	0.26	0.37
SEA-011	Gulf of Riga	160	0.42	0.26
SEA-012	Northern Baltic Proper	688	0.29	0.26
SEA-013A	Gulf of Finland Western	412	0.34	0.30
SEA-013B	Gulf of Finland Eastern	334	0.48	0.45
SEA-014	Åland Sea			0.28
SEA-015	Bothnian Sea	83	0.18	0.34

4.2 Trends

Blooms of nitrogen-fixing cyanobacteria are a natural phenomenon in the Baltic Sea (Bianchi *et al.* 2000, Poutanen & Nikkilä 2001, Westman *et al.* 2003), and have been observed in phytoplankton sampling in the early 1900s (Hällfors *et al.* 2013). The blooms became extensive during the 20th century and have occurred commonly in the Baltic Proper and the Gulf of Finland since the 1960s (Finni *et al.* 2001, Poutanen & Nikkilä 2001).

The longest satellite-based time series on algae accumulations from the Baltic Sea is presented by Kahru and Elmgren (2014). According to this satellite-based investigation, cyanobacterial blooms have increased in the Baltic Sea since the late 1970s (Figure 6). Also, the total area covered by the blooms has increased during this time. However, the development has not been linear as the period with the lowest number of blooms occurred in the late 1980s – early 1990s.

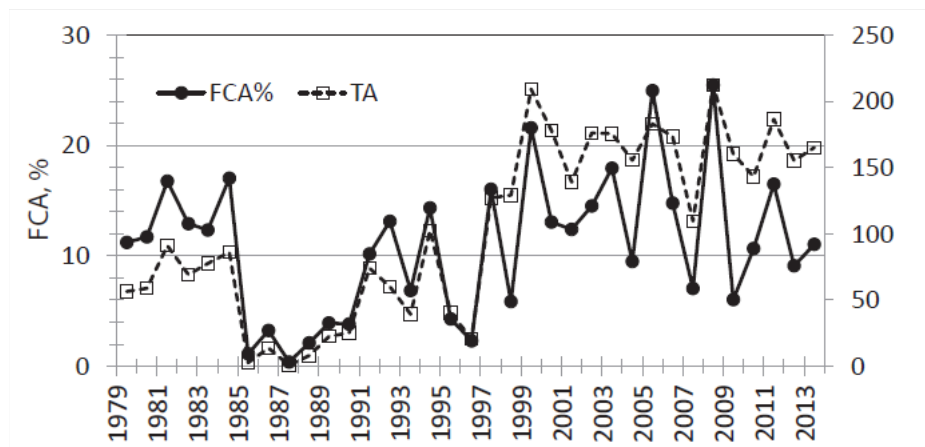
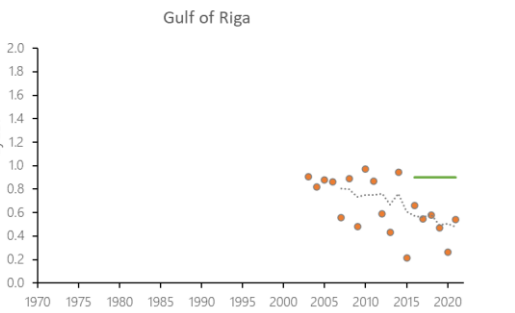
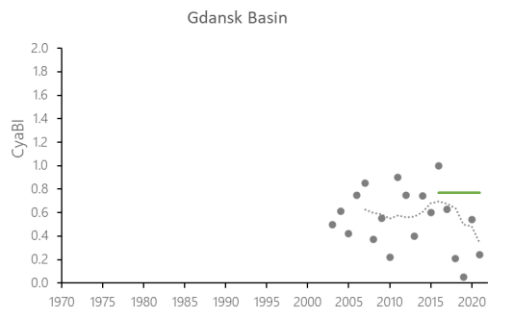
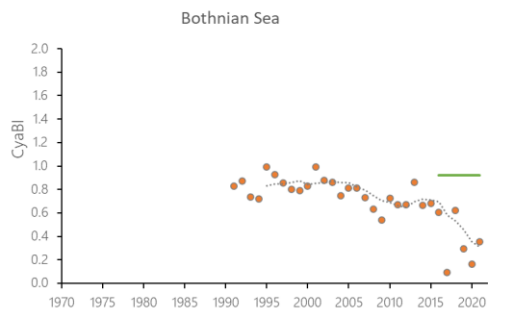
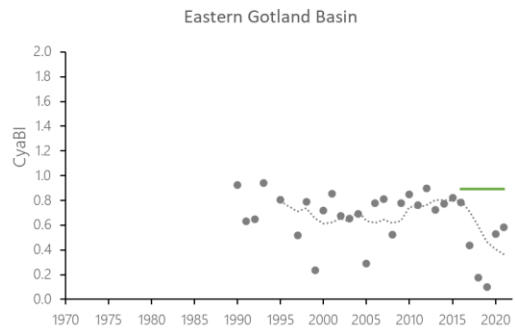
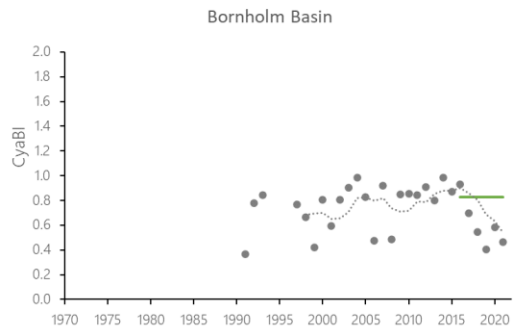
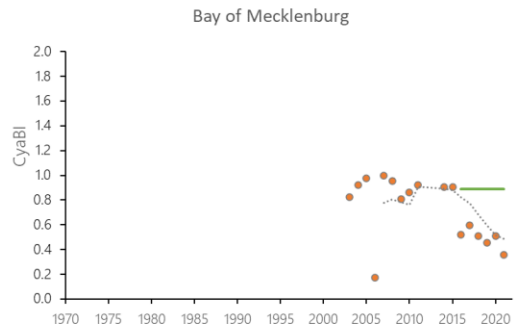
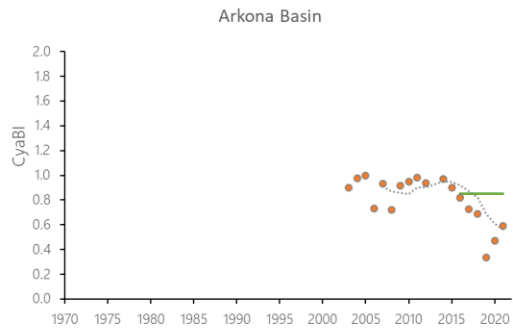


Figure 6. Mean fraction of cyanobacteria accumulations (FCA%) and total accumulated area affected (TA) in the entire Baltic Sea between 1979 and 2013 based on satellite detection (from Kahru and Elmgren, 2014).

The indicator status indicates a worsening trend (i.e. decreasing Cyanobacterial Bloom Index values) from 1990s or early 2000s to 2021 (depending on data availability) for most of the assessed areas (Results figure 3). For the Bornholm Basin, Eastern Gotland Basin, Gulf of Finland Eastern and Gdansk Basin no significant trend was found.



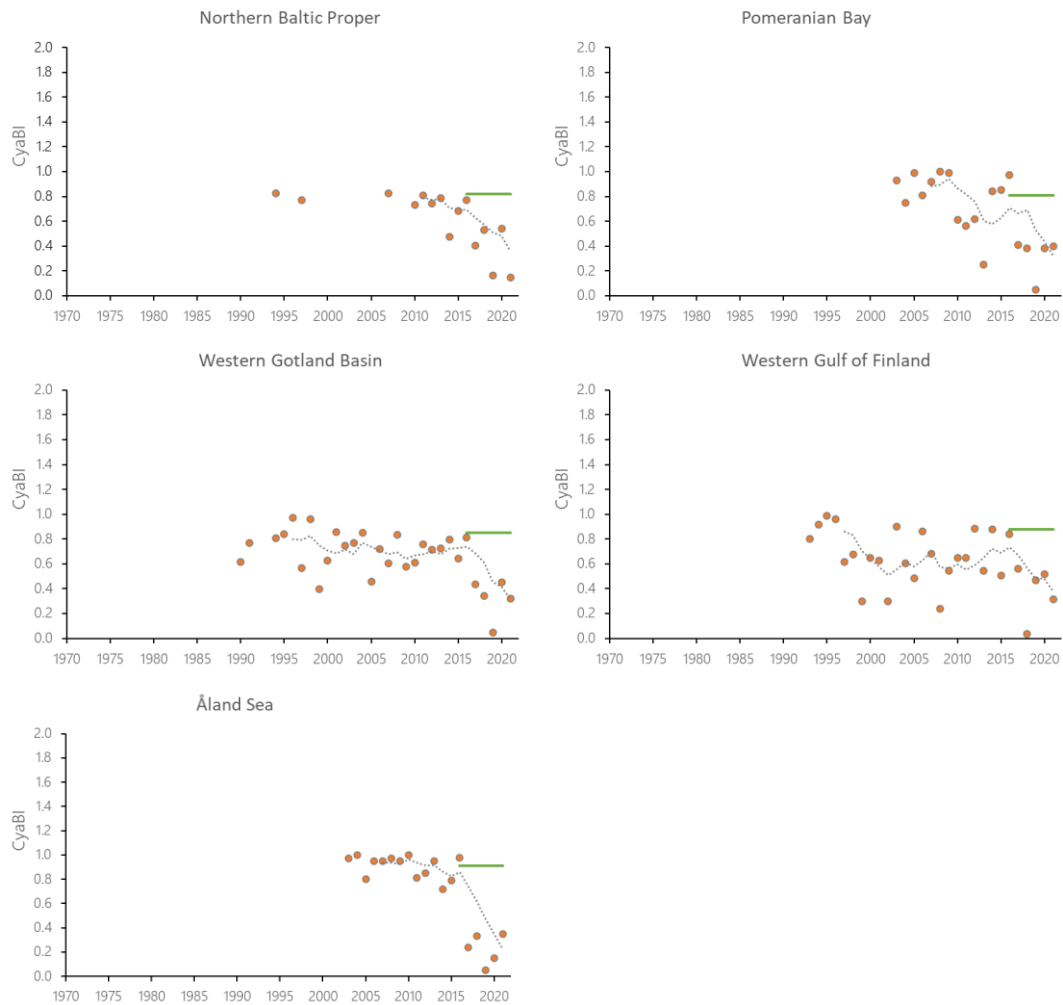


Figure 7. Temporal development of ‘Cyanobacterial bloom index’ in the open-sea assessment units in 1990-2021. Dashed lines show the five-year moving averages of the normalised estimates. Green lines are Assessment Unit (AU) specific threshold values. Significance of trends was assessed with Mann-Kendall non-parametric tests for the individual AUs . Significant ($p < 0.05$) deteriorating trends are indicated with orange data points. No significant improving trends were found in the current data set.

4.3 Discussion text

Evaluation results for cyanobacterial bloom index were compared between the latest two evaluations of HOLAS II and HOLAS 3. All assessed basins remained below good status in HOLAS 3.

Table 5. Status of cyanobacterial bloom index estimates in the HOLAS II (2011-2016) and HOLAS 3 (2016-2021) period coloured red or green whether the sub-basins fails or achieves the threshold, respectively. The last column provides a description of outcome.

HELCOM Assessment Unit name	HOLAS II status	HOLAS 3 status	Description of outcomes, if pertinent
Kattegat			
Great Belt			
The Sound			
Kiel Bay			
Bay of Mecklenburg	Fail	Fail	Remains below GES
Arkona Basin	Fail	Fail	Remains below GES
Bornholm Basin	Fail ¹	Fail	Remains below GES
Pomeranian Bay		Fail	Remains below GES
Gdansk Basin	Fail	Fail	Remains below GES
Eastern Gotland Basin	Fail	Fail	Remains below GES
Western Gotland Basin	Fail	Fail	Remains below GES
Gulf of Riga	Fail	Fail	Remains below GES
Northern Baltic Proper	Fail	Fail	Remains below GES
Gulf of Finland Western	Fail ²	Fail	Remains below GES
Gulf of Finland Eastern		Fail	Remains below GES
Åland Sea		Fail	
Bothnian Sea	Fail	Fail	Remains below GES
The Quark			
Bothnian Bay			

¹⁾ The assessment unit borders have changed. Bornholm Basin and Pomeranian Bay were assessed together in HOLAS II.

²⁾ The assessment unit borders have changed. Gulf of Finland was assessed as one unit in HOLAS II.

5 Confidence

The overall confidence of the indicator status evaluation, based on the spatial and temporal coverage of data and accuracy of the classification result, was high in all assessment units except for the Pomeranian Bay and the Gdansk Basin, where it was moderate (Figure 8). The lower overall confidence in these assessment units was due to low spatial confidence (Annex 1).

The spatial confidence of the indicator was high in most assessment units, but low in the Bay of Mecklenburg, Pomeranian Bay and the Gdansk Basin (Annex 1). The spatial confidence of the biomass parameter was low in all assessment units, whereas the spatial confidence of the CSA parameter was high in all assessment units, except low in the Pomeranian Bay and the Gdansk Basin and moderate in the Bay of Mecklenburg. In areas with lower spatial confidence for CSA, the reason is due to shallow areas in the assessment area. Shallow areas can create overestimation in satellite observed cyanobacteria bloom detection, therefore over these areas satellite observations are excluded.

Temporal confidence of the indicator was high in all assessment units. Temporal confidence was also high for CSA parameter for all assessment units, and for biomass parameter for all assessment units except moderate in the Arkona Basin and Northern Baltic Proper.

The confidence in accuracy of the GES evaluation result was high in all open-sea assessment units. It was also high separately for both parameters.

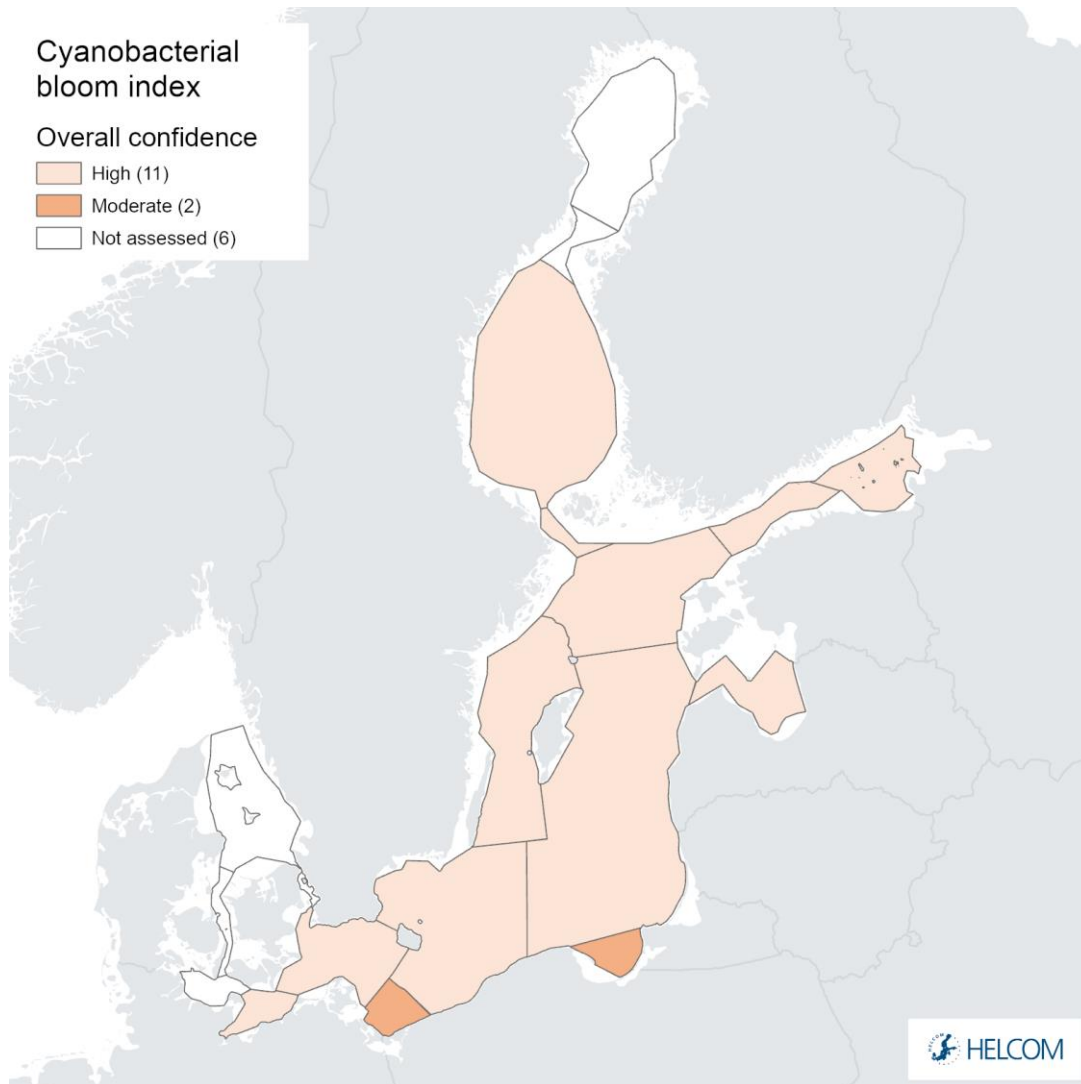


Figure 8. Indicator confidence determined as an average of the parameter specific confidences for cyanobacterial biomass and cyanobacterial surface accumulations.

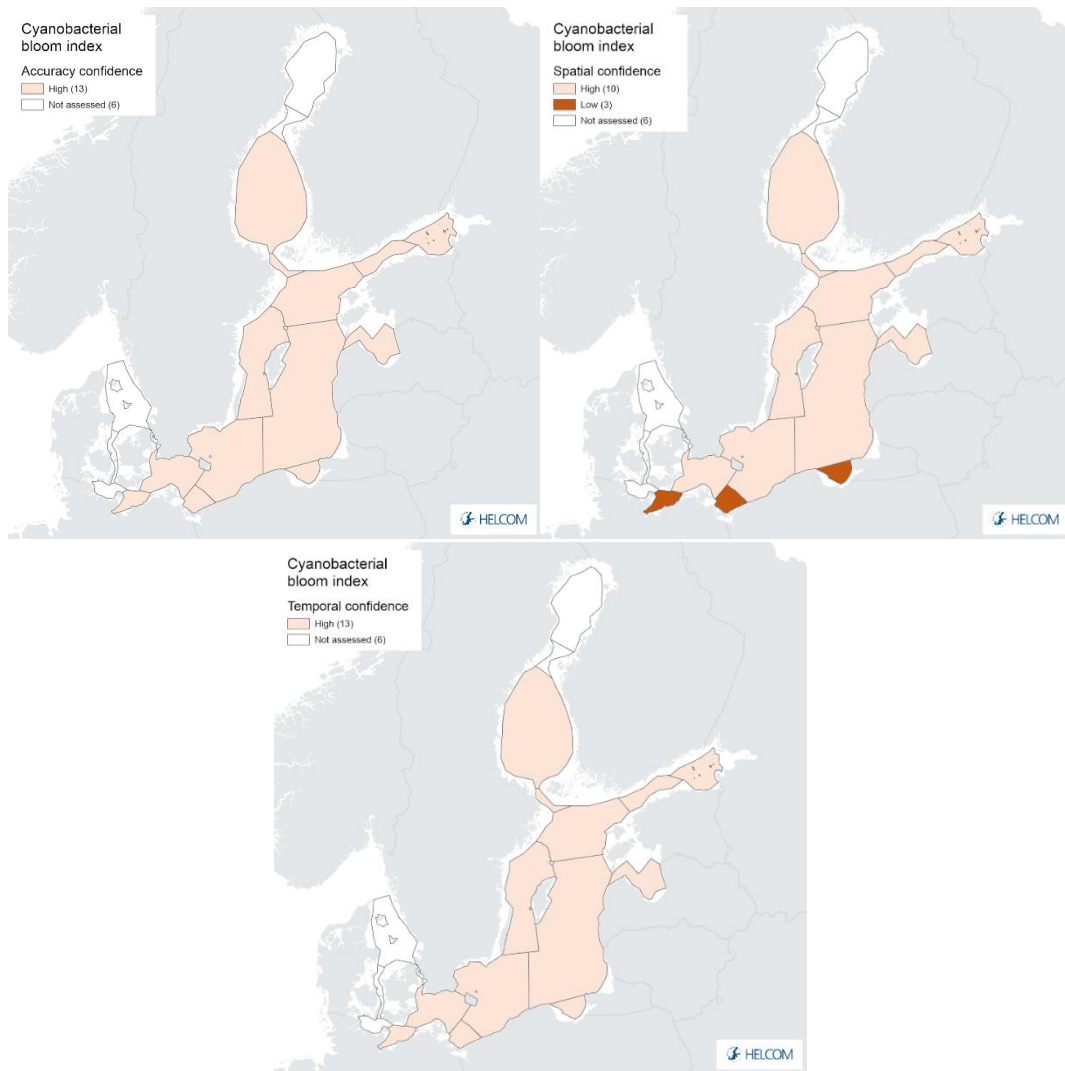


Figure 9. Confidence for cyanobacterial bloom index regarding Accuracy Class (ACC), Spatial Confidence (SC) and Temporal Confidence (TC). Low indicator confidence calls for increase in monitoring.

Parameter-specific confidence maps for CSA and BM are included in Annex 1.

6 Drivers, Activities, and Pressures

For HOLAS 3 initial work has been carried out to explore Drivers (and driver indicators) to evaluate how such information can be utilised within such management frameworks as DAPSIM. Although it is recognised as only addressing a small portion of the drivers (via proxies) of relevance for eutrophication wastewater treatment ([Drivers and driver indicators for Wastewater Treatment](#)) and agriculture ([Drivers and driver indicators for Agricultural Nutrient Balance](#)) have been explored in these pilot studies for HOLAS 3.

Diffuse sources constitute the highest proportion of total nitrogen (nearly 50%) and total phosphorus (about 56%) inputs to the Baltic Sea (HELCOM 2022). For total nitrogen, atmospheric deposition on the sea has the second highest share (24%) followed by natural background loads (20%) and point sources (9%). Natural background loads have the second highest share of total phosphorus inputs to the Baltic Sea (20%), followed by point sources (17%) and atmospheric deposition (7%). Point sources include activities such as municipal wastewater treatment plants, industrial plants and aquacultural plants and diffuse sources consist of anthropogenic sources such as agriculture, managed forestry, scattered dwellings, storm water etc.

A significant reduction of nutrient inputs has been achieved for the whole Baltic Sea. The normalized total input of nitrogen was reduced by 12% and phosphorus by 28 % between the reference period (1997-2003) and 2020 (HELCOM 2023a). The maximum allowable input (MAI) of nitrogen in this period was fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat and the maximum allowable input of phosphorus in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat.

Further developing an overview of such components and the relevant data to be able to better quantify the linkages within a causal framework provide the opportunity for more informed management decisions, for example targeting of measures, and can thereby support the achievement of Good Environmental Status.

Table 6. Brief summary of relevant pressures and activities with relevance to the indicator.

	General	Activity: MSFD Annex III, Table 2b	Pressure: MSFD Annex III, Table 2a
Strong link		Cultivation of living resources; Transport; Urban and industrial uses; Physical restructuring of rivers, coastline or seabed (water management)	Input of nutrients; input of organic matter
Weak link			

7 Climate change and other factors

The current knowledge of the effects of climate change on eutrophication is summarized in the HELCOM fact sheet for climate change (HELCOM and Baltic Earth 2021), and the effects on cyanobacterial blooms are described in more detail in the update of the climate change fact sheet for harmful algal blooms (HELCOM 2023b). The effect of climate change to the nutrient pools is not yet separable from the other pressures, and the future nutrient pools will dominantly be affected by the development of nutrient loading. The cyanobacterial growth season has already prolonged (HELCOM and Baltic Earth 2021). There has been a significant increase both in the frequency and extent of the cyanobacterial blooms, which has been attributed to a decrease in surface salinity and increase in sea surface temperature (HELCOM 2023b).

Climate change is, with medium confidence, considered to increase the stratification, further deteriorate near-bottom oxygen conditions, and increase the internal nutrient loading (HELCOM and Baltic Earth 2021). Warming favours cyanobacteria and is expected to lead to more extensive blooms (HELCOM 2023b). The cyanobacterial accumulations are expected to expand, if the nutrient loads are not reduced (HELCOM and Baltic Earth 2021).

8 Conclusions

The status evaluation fails to achieve good status in all assessed sub-basins.

8.1 Future work or improvements needed

The indicator will be further developed towards the next assessment period, including improving the understandability, especially through reviewing the normalisation and compilation of the CSA variables (severity, duration and volume) as well as combining the CSA and biomass parameters into one indicator. The threshold setting will be re-evaluated.

9 Methodology

9.1 Scale of assessment

The pre-core indicator is operational in 13 open sea assessment units (at least one nautical mile seawards from the baseline).

The indicator is applicable 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 relevance of the indicator in the Kattegat, the Sound, the Bothnian Bay, the Great Belt and the Quark is under investigation. Threshold for the Kiel Bay is under development. In its present form, the indicator is not applicable in the coastal areas.

The indicator is assessed within the HELCOM geographical assessment unit level 4 for eutrophication: open sea sub-basin areas. The assessment units are defined in the [HELCOM Monitoring and Assessment Strategy Annex 4](#).

9.2 Methodology applied

The HELCOM pre-core indicator 'Cyanobacterial bloom index' (CyaBI) evaluates the increase in cyanobacterial blooms, taking into account different aspects of the bloom phenomenon. It responds negatively to increasing eutrophication, i.e. low values indicate increased eutrophication.

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.

Both parameters describe different relevant aspects of the cyanobacterial accumulations: The CSA (parameter 1) relies on high-frequency data, and is optimal for describing the spatial and temporal extent and intensity of the surface blooms. However, this parameter is influenced, in addition to eutrophication, by climate-related variation including wind conditions. The cyanobacterial biomass (parameter 2) supplements CSA by providing information of the actual amount of cyanobacteria in the water column. Combining the two parameters allows for more reliable status estimation than either parameter alone: an indicator expressing the extent of the blooms with high confidence; yet related strongly to changes in the actual amount of cyanobacteria, and subsequently, to eutrophication.

The indicator specifics are presented in Table 7.

Table 7. Specifications of the core indicator cyanobacterial bloom index.

Indicator	Cyanobacterial bloom index																														
Response to eutrophication	negative for the normalized parameters and indicator																														
Parameters	Cyanobacterial biomass and Cyanobacterial surface accumulations (CSA)																														
Assessment period	2016 –2021																														
Assessment season	Summer Biomass: June-August, in the Bothnian Sea June-October CSA: EOs are accounted from 1st of June to 31st of August																														
Depth	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																														
Removing outliers	On responsibility of data submitter																														
Removing close observations	No close observations removed																														
Indicator level (ES)	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.																														
Eutrophication quality ratio (EQR)	The normalized estimates (0-1) are directly used as EQR values. The final EQR values are scaled after normalization to five classes of 0.2 width. The class borders are given in table below <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <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> </thead> <tbody> <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> </tbody> </table>	parameter	Unit ID	High good	- Good-moderate	Moderate-poor	Poor- bad	biomass	SEA-005	0..96	0.92	0.613	0.307	biomass	SEA-006	0.97	0.94	0.627	0.313	biomass	SEA-007	0.935	0.87	0.580	0.290	biomass	SEA-009	0.92	0.84	0.560	0.280
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biomass	SEA-005	0..96	0.92	0.613	0.307																										
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biomass	SEA-009	0.92	0.84	0.560	0.280																										

	biomass	SEA-010	0.91	0.82	0.547	0.273
	biomass	SEA-011	0.94	0.88	0.587	0.293
	biomass	SEA-012	0.99	0.98	0.653	0.327
	biomass	SEA-013A	0.915	0.83	0.553	0.277
	biomass	SEA-013B	0.92	0.84	0.560	0.280
	biomass	SEA-015	0.95	0.9	0.600	0.300
	CSA	SEA-005	0.925	0.85	0.567	0.283
	CSA	SEA-006	0.875	0.75	0.500	0.250
	CSA	SEA-007	0.895	0.79	0.527	0.263
	CSA	SEA-007B	0.905	0.81	0.540	0.270
	CSA	SEA-008	0.885	0.77	0.513	0.257
	CSA	SEA-009	0.97	0.94	0.627	0.313
	CSA	SEA-010	0.94	0.88	0.587	0.293
	CSA	SEA-011	0.96	0.92	0.613	0.307
	CSA	SEA-012	0.935	0.87	0.580	0.290
	CSA	SEA-013A	0.965	0.93	0.620	0.310
	CSA	SEA-013B	0.985	0.97	0.647	0.323
	CSA	SEA-014	0.955	0.91	0.607	0.303
	CSA	SEA-015	0.97	0.94	0.627	0.313
	<hr/>					
Indicator confidence	<p>The confidence assessment for eutrophication indicators is included in HEAT, and includes aspects of temporal, spatial and accuracy confidence. The general methodology of the confidence assessment is described in Document 4.2 of IN-Eutrophication 16-2020 and updates are described in documents 4J-80 of State & Conservation 14-2021 and 4-2 of EG-EUTRO 20-2021. The R-code is available via https://github.com/ices-tools-prod/HEAT.</p> <p>Confidence is calculated separately for each parameter. The overall indicator confidence is calculated using the average of the parameter specific values.</p> <p>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 State & Conservation 17-2022.</p>					

For each parameter, confidence is calculated as the average of the aspects of temporal, spatial and accuracy confidence, and the indicator confidence is the average of the data type specific confidence values.

The evaluation criteria for temporal confidence are given in the table below.

Confidence class	Evaluation criteria for general temporal confidence	Evaluation criteria for specific temporal confidence
cyanobacterial biomass		
High (100)	The evaluation is based on > 17 annual observations during the given assessment period	0 missing months per year
Medium (50)	The evaluation is based on 6-17 annual observations	1 missing month per year
Low (0)	The evaluation is based on < 6 annual observations	≥ 2 missing months per year
CSA		
High (100)	The evaluation is based on > 17 annual observation days during the given assessment period	0 missing months per year
Medium (50)	The evaluation is based on 6-17 annual observation days	1 missing month per year
Low (0)	The evaluation is based on < 6 annual observation days	≥ 2 missing months per year

If the specific temporal confidence is high (100) for at least half of the assessed years, it is set as high (100) for the assessment period. The total temporal confidence is the average of the general and specific temporal confidence aspects.

The evaluation criteria for spatial confidence are given in the table below.

Confidence class	Evaluation criteria for spatial confidence
cyanobacterial biomass	
High (100)	Sampled grid cells cover > 80 % of the assessment-unit area
Medium (50)	Sampled grid cells cover 60-80 % of the assessment-unit area
Low (0)	Sampled grid cells cover < 60 % of the assessment unit area
CSA	
High (100)	CSA represents > 80 % of the assessment-unit area
Medium (50)	CSA represents 60 % to 80 % of the assessment-unit area

	Low (0)	CSA represents < 60 % of the assessment-unit area
The accuracy aspect assesses the probability of the correct classification (classification being below or above the threshold for good status). The evaluation criteria for accuracy aspect are given in table below.		
	Confidence class	Evaluation criteria for accuracy confidence
	High (100)	GES has been/ not been achieved by ≥ 90 % probability
	Medium (50)	GES has been/ not been achieved by 70 - < 90 % probability
	Low (0)	GES has been/ not been achieved by < 70 % probability

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 the Finnish Environment Institute (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).

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

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.

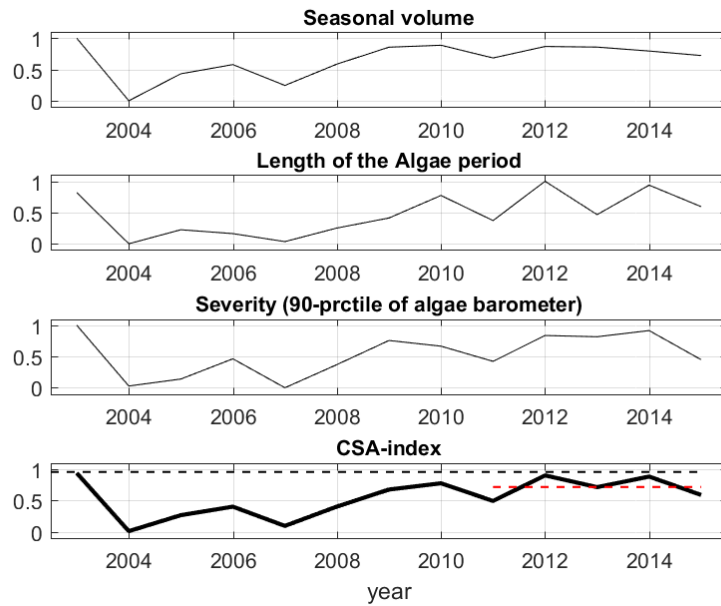


Figure 10. An example (Gulf of Finland) of grouping the normalized EO-based parameters (from top to bottom) (A) seasonal bloom volume, (B) length of bloom period and (C) Severity of blooms, and (D) a combined cyanobacterial surface accumulation (CSA) parameter. As the indicator responds negatively to 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 main sampling locations are presented in Figure 11.

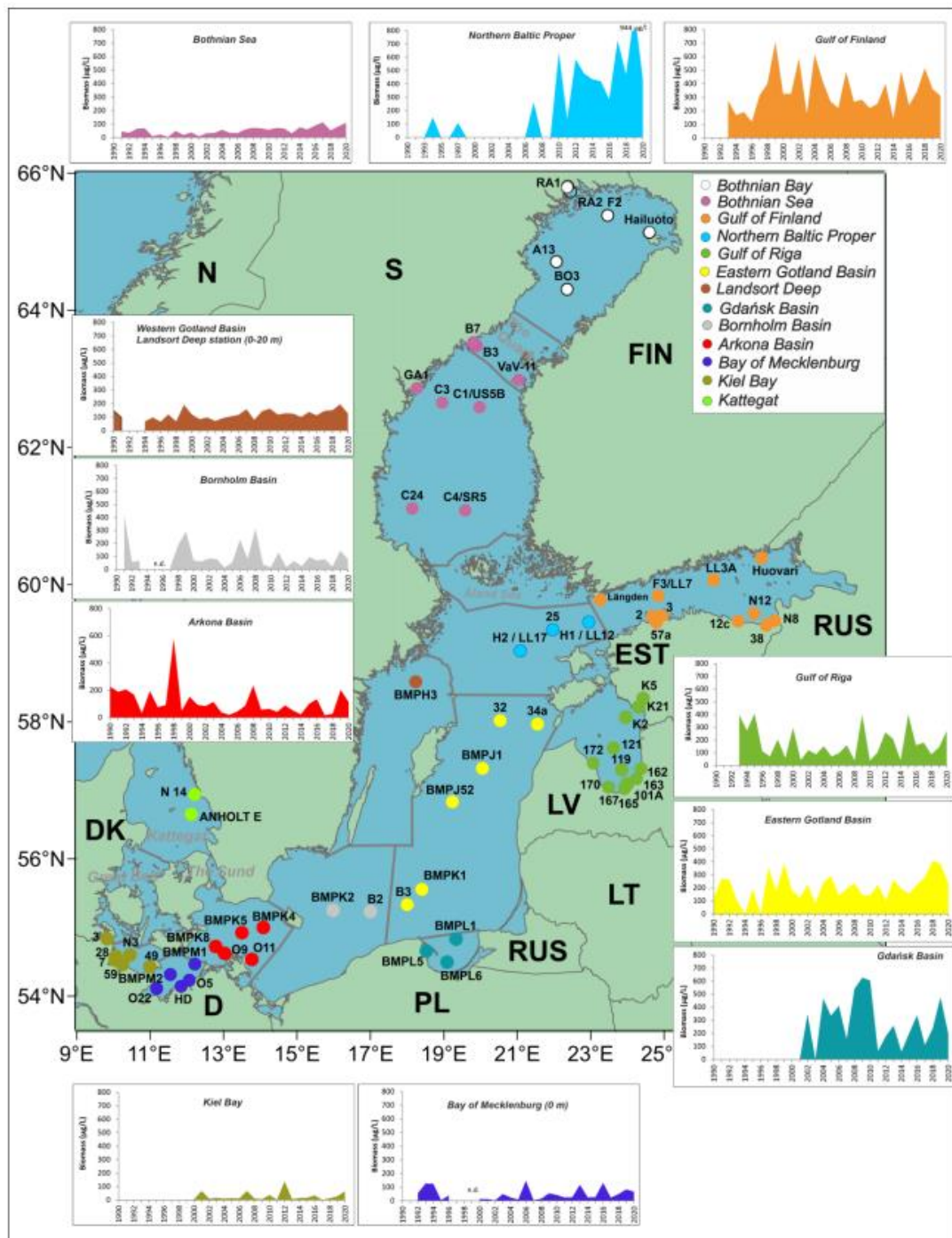


Figure 11. Map of the regularly sampled stations, containing assessment unit specific graphs on diazotrophic cyanobacteria biomass (seasonal mean biomass $\mu\text{g/L}$). Names of some Finnish coastal stations are abbreviated. Stations in Bothnian Bay and Kattegat have been tested but the results are not presented. Figure from: Kownacka *et al.* 2022.

The cyanobacterial biomass (wet weight in $\mu\text{g/L}$) 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.

9.3 Monitoring and reporting requirements

Monitoring methodology

Monitoring of cyanobacteria in the Contracting Parties of HELCOM is described on a general level in the HELCOM Monitoring Manual in the [sub-programme phytoplankton species composition, abundance and biomass](#).

Specific monitoring guidelines are under development with the aim to be included in the HELCOM Monitoring Manual at a later stage.

Current monitoring

The monitoring activities relevant to the indicator that are currently carried out by HELCOM Contracting Parties are described in the HELCOM Monitoring Manual Sub-programme [sub-programme phytoplankton species composition, abundance and biomass](#).

The temporal and spatial coverage of the satellite remote sensing data used can be considered high in the open sea areas as well as in the outer coastal assessment areas of the Baltic Sea.

Cyanobacterial biomass monitoring takes place according to the national monitoring programmes.

Description of optimal monitoring

For remote sensing data, annually at least 30 daily spatial aggregates from valid bloom observations in an assessment area should be applied from the period between June 1st – August 30th in order to derive the annual bloom characteristics information. The compilation of observations is expected to be distributed spatially within the assessment unit in a non-biased way.

For biomass data, at least one sample per month has to be available to allow the calculation of seasonal averages.

10 Data

The data and resulting data products (e.g., tables, figures and maps) available on the indicator web page can be used freely given that it is used appropriately and the source is cited.

[Result: Cyanobacterial bloom index](#)

[Data: Cyanobacterial bloom index](#)

The Earth Observation (EO) data source was the daily surface algae interpretations of the Finnish Environment Institute (operative version of the [algae bloom annual composites](#) can be found in SYKE's open EO-service [TARKKA](#)). The cyanobacteria biomass was collected and analysed by the HELCOM PEG group.

Geographical coverage:

- EO data collection took place over the bulk of the Baltic Sea from Danish straits up to the Quark (the narrow passage between Bothnian Sea and Bothnian Bay). EO data collection was systematic owing to the fixed satellite overpass tracks. During HOLAS 3, the method yielded 70 to 170 usable EOs for the average unit grid cell of an open sea assessment area (see Appendix 2 on CSA confidence), with a coefficient of variation in the range of 4 to 70 %.
- Cyanobacterial biomass was observed at HELCOM COMBINE stations situated in the Bay of Mecklenburg, Arkona Basin, Bornholm Basin, Eastern Gotland Basin, Western Gotland Basin, Northern Baltic Proper, Gulf of Riga, Gulf of Finland Western, Gulf of Finland Eastern and Bothnian Sea.

Temporal coverage:

- EOs yielded an algal barometer estimate for each basin of the Baltic Sea on 15 to 70 individual dates each year. Observations were only made in the date range 1 June to 31 August.
- The estimates are based on observations made between June – August for all covered assessment units, except for the Bothnian Sea, where observations were made between June – October. Estimates include observations made during 2016-2021.

Data aggregation:

- The 2016-2021 values for each sub-basin were estimated as an inter-annual summer (1st of June – 31st of August) averages.

11 Contributors

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12 Archive

This version of the HELCOM core indicator report was published in April 2023:

The current version of this indicator (including as a PDF) can be found on the [HELCOM indicator web page](#).

Earlier versions of the core indicator report include:

[Cyanobacterial bloom index HELCOM pre-core indicator 2018](#) (pdf)

[HOLAS II component – Pre-core indicator report – web-based version July 2017](#) (pdf)

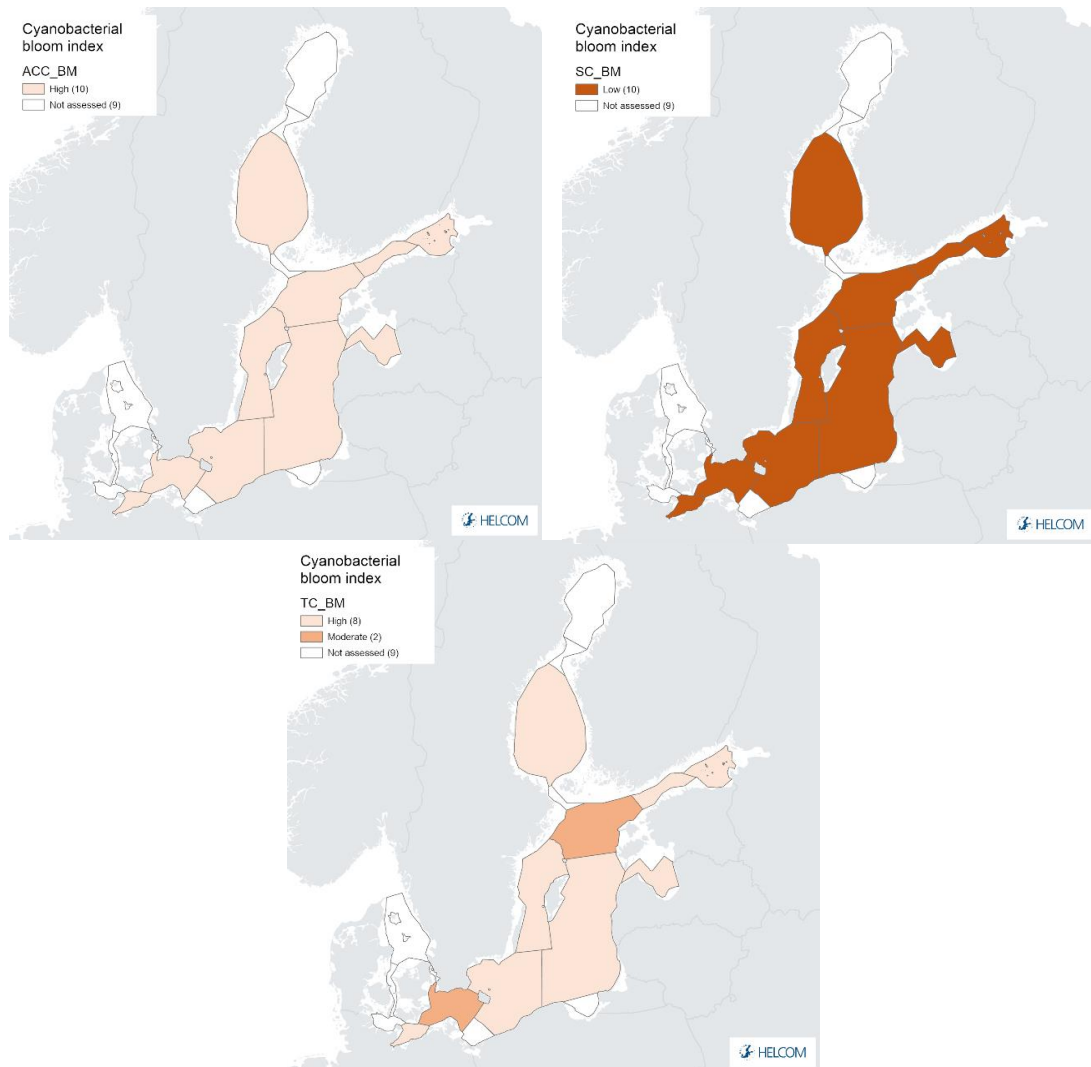
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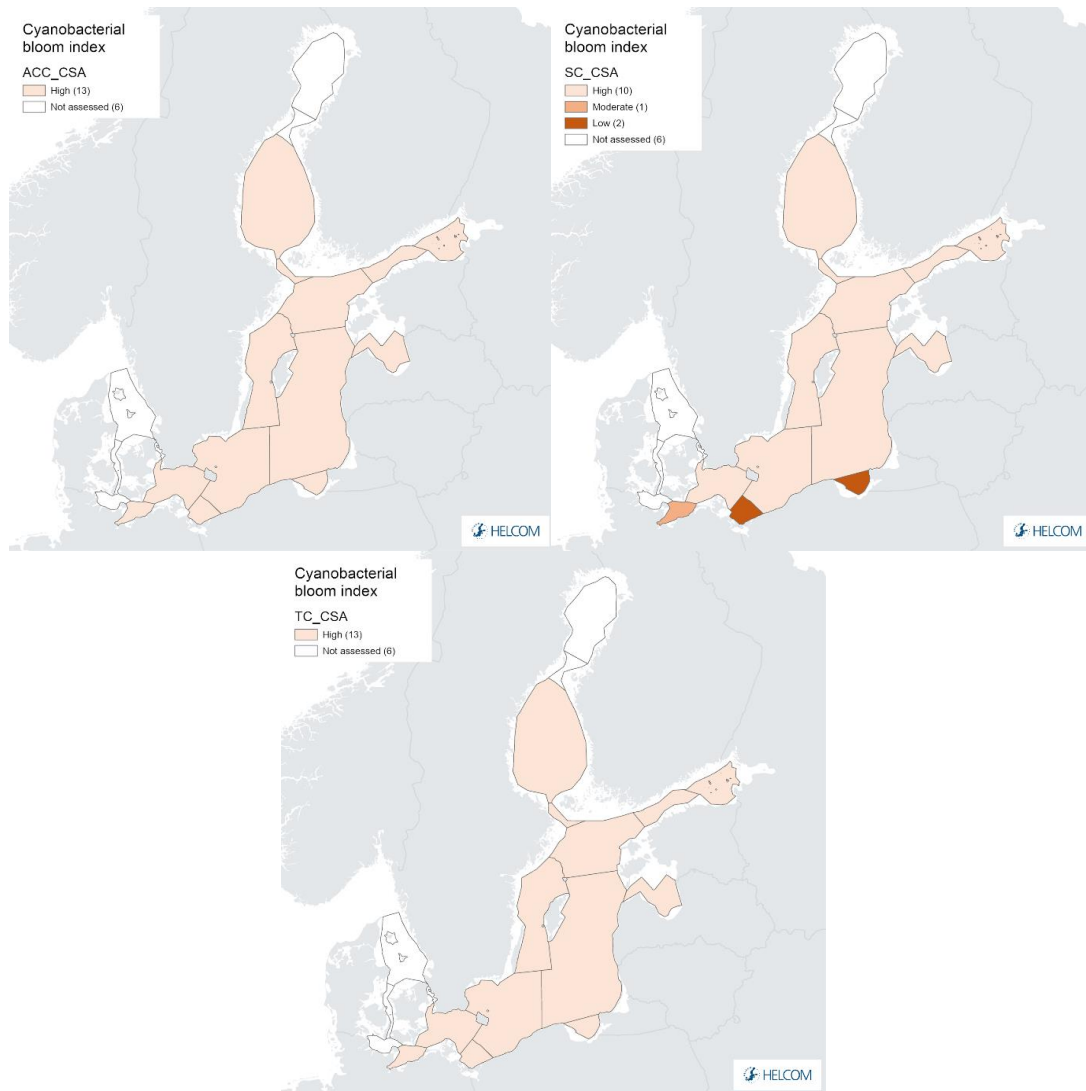
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14 Other relevant resources

Annex 1. Confidence maps



Annex figure 1. Confidence for biomass parameter of the cyanobacterial bloom index regarding Accuracy Class (ACC), Spatial Confidence (SC) and Temporal Confidence (TC). Low indicator confidence calls for increase in monitoring.



Annex figure 2. Confidence for CSA parameter of the cyanobacterial bloom index regarding Accuracy Class (ACC), Spatial Confidence (SC) and Temporal Confidence (TC).