HOLAS II

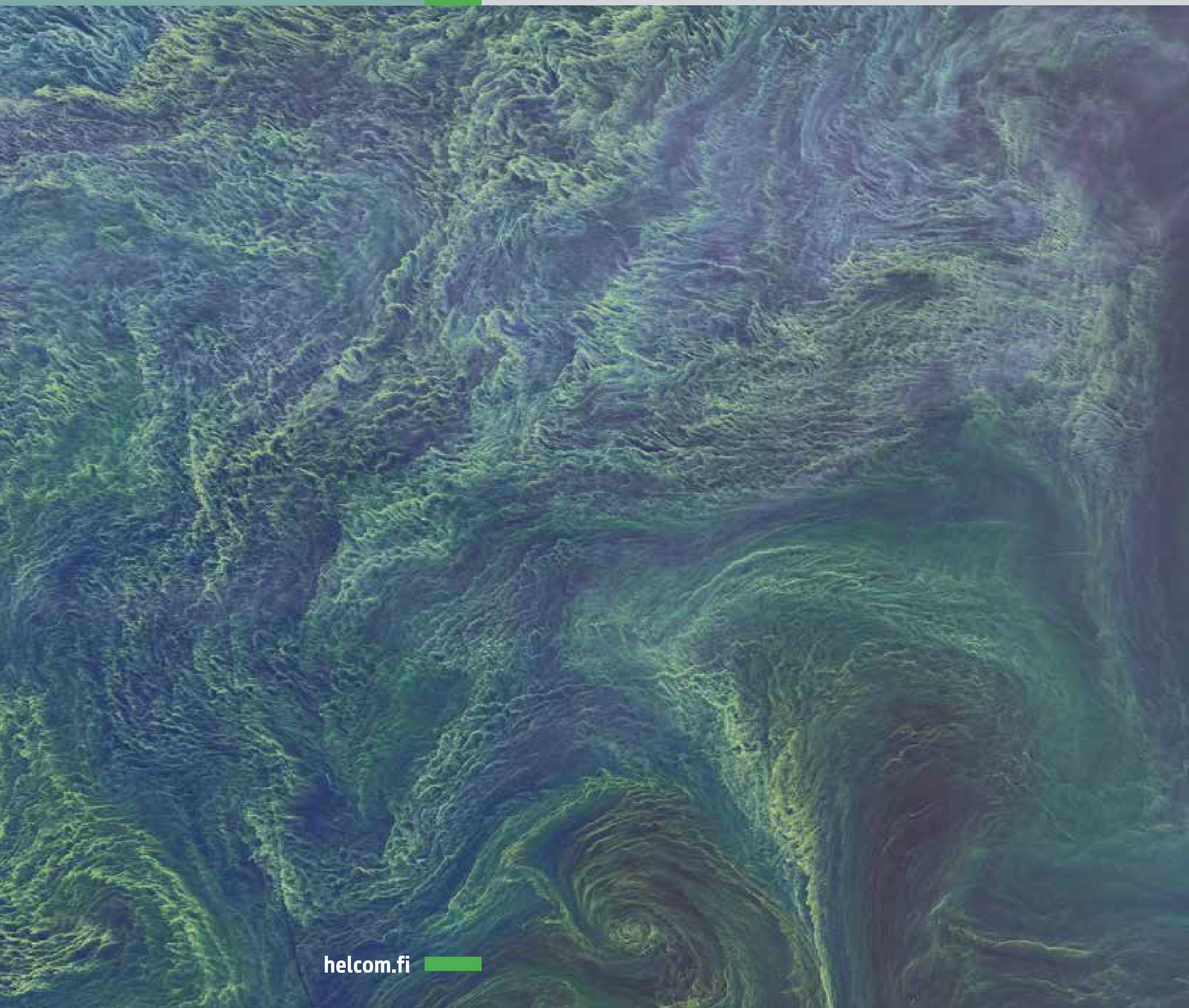
Thematic assessment of eutrophication 2011–2016

Baltic Marine Environment Protection Commission

Supplementary report to the HELCOM 'State of the Baltic Sea' report (PRE-PUBLICATION)

STATE OF THE BALTIC SEA
– HOLISTIC ASSESSMENT –

Eutrophication



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HELCOM Thematic assessment of eutrophication 2011-2016. Supplementary report to the HELCOM 'State of the Baltic Sea' report.

NOTE: This is a pre-publication version. The report will be given a professional layout and then re-published during summer 2018.

The production of this report was carried out through the HELCOM Project for the development of the second holistic assessment of the Baltic Sea (HOLAS II). The implementation of the assessment was managed by the HELCOM SPICE project. The work was financially supported through HELCOM and the EU co-financing of the HELCOM coordinated project SPICE.

The basis for the assessment of status of the Baltic Sea are the HELCOM core indicators and associated threshold values. In this context the following has been agreed:

Regarding threshold values
"At this point in time, HOLAS II indicators and threshold values should not automatically be considered by the Contracting Parties that are EU Member States, as equivalent to criteria threshold values in the sense of Commission Decision (EU) 2017/848 laying down criteria and methodological standards on good environmental status, but can be used for the purposes of their Marine Strategy Framework Directive obligations by those Contracting Parties being EU Member States that wish to do so".

Regarding testing of indicators
Note that some indicators and/or their associated threshold value are still being tested in some countries and may be further developed in HELCOM as a result of the outcome of the testing. In some cases the results may show that the indicator is not suitable for use in a specific sub-basin. These indicators are marked in the assessment report and the results should be considered as intermediate.

Please note that the Danish measurements presented for total nitrogen and total phosphorus are underestimated. This might affect content and conclusions in this report in regard to the status assessment and assessment of nutrient input to Danish waters (See Box 2 page 37). Finnish monitoring open sea estimates of phosphate and total phosphorus in 2011-2014 are in general 10 % lower than in 2015-2017 due to changes in instrumentation and accompanying methodology. This might affect the indicator values in assessment units SEA-012 to -017.

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Acknowledgements: The integrated assessment approach has been developed by the HELCOM Expert intersessional network on eutrophication using the data and information flow developed by EUTRO-OPER. The assessment was carried out with support from the EU co-financed HELCOM SPICE project, and was guided by participants in HELCOM Spice Eutro WS 1-2017, HELCOM HOLAS II Eutro WS 1-2018, the HOLAS II Core team and HELCOM State & Conservation.

For bibliographic purposes, this document should be cited as:

HELCOM (2018): HELCOM Thematic assessment of eutrophication 2011-2016. Available at: http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/

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Summary

Eutrophication is among the most influential and long lasting environmental pressures in the Baltic Sea. Excessive inputs of nitrogen and phosphorus, which are the main triggers of eutrophication, have occurred since around the 1950s, leading to enhanced primary productivity and also to indirect effects on other parts of the ecosystem. One key goal of the Baltic Sea Action Plan is to reach a Baltic Sea unaffected by eutrophication (HELCOM 2007, 2013a).

The status of eutrophication in the Baltic Sea during the years 2011-2016 was assessed to follow up on this objective. The results are presented here and are also summarized in the 'State of the Baltic Sea' report (HELCOM 2018a), which provides a holistic assessment of the ecosystem health of the Baltic Sea during these years. The current supplementary report additionally describes the method for the integrated eutrophication assessment using the HEAT tool. Also, more detailed results are given concerning the eutrophication ratios, the confidence values for the indicators and the integrated assessment results, as well as the proportion of area assessed to be below good status in regards to eutrophication.

Several eutrophication assessments have been carried out within HELCOM since the agreement of the Baltic Sea Action Plan (HELCOM 2009, 2010a, 2014). Compared to previous HELCOM eutrophication assessments, this assessment was conducted with some new indicators and refined threshold values for evaluating status, leading to an approach which increasingly enables evaluation of progress towards improved status.

Integrated assessment results in brief

The results for the years 2011-2016 show that the Baltic Sea still suffers from eutrophication. Excessive input of nutrients to the marine environment enhances the growth of phytoplankton, leading to reduced light conditions in the water, oxygen depletion at the seafloor, and a cascade of other ecosystem changes.

- At least 97 % of the region was assessed to be below good eutrophication status, including all of the open sea area and 86 % of the coastal waters.
- Indicators reflecting nutrient levels were generally furthest away from good status.
- Nitrogen inputs to the sea have decreased in most of the Baltic Sea, and concentrations of nitrogen are predominantly decreasing, with the exception of some sub-basins in the southern Baltic Sea.
- Inputs of phosphorus are also decreasing, but the concentrations of phosphorus at sea are stagnant, with some exceptions.
- Compared to a previously assessed five-year period (2007-2011), the eutrophication status has deteriorated in four of the 17 sub-basins. This can partly be attributed to natural variability in climate and

hydrography, which may cause temporarily deteriorating conditions even when the long term development is positive.

- Long term trends shows signs towards improved eutrophication status in the westernmost Baltic Sea.

- Although signs of improvement are seen in some areas, effects of past and current nutrient inputs still influence the overall status

Indicators included

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

Table 1. Overview of indicators used in the integrated eutrophication assessment in the open sea. The corresponding core indicator reports are identified as HELCOM 2018b-j in the reference list. More detailed information is provided further down in this report. Coastal indicators are listed in Table 12.

Indicator	Description
Nutrient levels	
Dissolved inorganic nitrogen	Eutrophication core indicator
Dissolved inorganic phosphorus	Eutrophication core indicator
Total nitrogen	Eutrophication core indicator
Total phosphorus	Eutrophication core indicator
Direct effects	
Chlorophyll-a concentrations	Eutrophication core indicator reflecting algal biomass in the pelagial
Water clarity	Eutrophication core indicator reflecting water transparency by the Secchi depth
Cyanobacterial bloom index	Pre-core indicator reflecting the amount of cyanobacteria (biomass as well as extent and intensity of blooms). Included as test.
Indirect effects	
Oxygen debt	Eutrophication core indicator reflecting the oxygen concentration below the halocline in relation to saturated concentration, i.e. the debt assumedly caused by eutrophication-related processes.
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.

Chapter 1. Background

Eutrophication, or increase in the supply of organic matter to an ecosystem through nutrient enrichment, is induced by excessive availability of nitrogen and phosphorus for primary producers (algae, cyanobacteria and benthic macrovegetation). Its early symptoms are enhanced primary production, which is expressed through increased chlorophyll-*a* concentrations in the water column and/or the growth of opportunistic benthic algae, as well as changes in the metabolism of organisms. The increased primary production leads to reduced water clarity and increased deposition of organic material, which in turn increase oxygen consumption at the seafloor and may lead to oxygen depletion. These changes may in turn affect species composition and food web interactions (as species that benefit from the eutrophied conditions are favoured directly or via effects on habitat quality and feeding conditions; Cloern 2001).

Inputs of nitrogen and phosphorus have been increasing for a long time in the Baltic Sea, mainly between the 1950s and the late 1980s (Figure 1, Gustafsson *et al*. 2012), causing eutrophication symptoms of increasing severity to the ecosystem (Larsson *et al*. 1985, Bonsdorff *et al*. 1997, Andersen *et al*. 2017). As a response to the deteriorating development, actions to reduce nutrient loading were agreed on by the 1988 HELCOM Ministerial Declaration (HELCOM 1988), and reaching a Baltic Sea unaffected by eutrophication is included as one of the main goals of the Baltic Sea Action Plan (BSAP; HELCOM 2007). Maximum allowable inputs (MAI) for the whole Baltic Sea and each sub-basin, and Country-Allocated Reduction Targets (CART) were set in 2007, and updated in the 2013 HELCOM Ministerial Declaration (HELCOM 2013a).

Several HELCOM eutrophication assessments have been carried out since the agreement of the Baltic Sea Action Plan, to follow-up on the status of eutrophication of the Baltic Sea (HELCOM 2009, 2010a, 2014, See also Box 1). The current assessment covers the situation during years 2011-2016. This report presents the integrated assessment results for this time period, the indicators that were used, and the method for integrated assessment using the HEAT 3.0 tool. A summary of the results is also presented in Chapter 4.1 of the 'State of the Baltic Sea' (HELCOM 2018a), hence providing input to the second holistic assessment of the ecosystem health of the Baltic Sea. In comparison to the State of the Baltic Sea report, the current report shows more detailed assessment outputs with respect to numerical results for assessment units, indicators, and changes over time.

In comparison to previous HELCOM eutrophication assessments, some new indicators are included, enhancing the coverage of assessment criteria. For other indicators, threshold values for evaluating status have been refined, leading to an approach which increasingly enables evaluation of progress towards improved status.

Box 1 HELCOM work on eutrophication

HELCOM has been a major driver in the regional approaches to reduce nutrient loads to the Baltic Sea. The management of the Baltic Sea eutrophication has been advanced with the Baltic Sea Action Plan (HELCOM 2007), which includes a complete management cycle aiming for specified improved conditions in the Baltic Sea, based on the best available scientific information and a model-based decision support system.

Core indicators with associated threshold values representing good status with regard to eutrophication are established primarily from monitoring data, which are interpreted through statistical analysis. The threshold values applied in this assessment were in most cases established based on scientific proposals from the HELCOM TARGREV project (HELCOM 2013b), where statistical breakpoints were identified from historical datasets and hindcast model simulations extending back to the beginning of the 1900s. The scientific proposals were adjusted by HELCOM experts based on other relevant information, such as Water Framework Directive class boundaries in coastal waters, and adopted by the HELCOM Heads of Delegation (HELCOM 2012 and others; see also Chapter 2.2).

In a following step, the relationships between changes in the inputs of nutrients to the Baltic Sea and the core indicators are established by physical-biogeochemical modelling. These relationships differ across sub-basins because of differences in water circulation, ecosystem characteristics, and inputs, for example. The model results give estimates of the maximum allowable input of nutrients to the different sub-basins in order for the core indicators to achieve their threshold values over time, recognizing that this might take many years.

The input reductions necessary to reach the basin-wise maximum inputs of nutrients are allocated to the HELCOM countries as country-wise reduction targets. In addition, certain reduction potential is indicated for upstream countries and distant sources (HELCOM 2013a). The allocation is done according to the 'polluter pays' principle of the Helsinki Convention. Progress in reaching nutrient reduction targets is evaluated based on annual compilations of the nutrient inputs to the Baltic Sea (HELCOM Pollution Load Compilation).

1.1 NUTRIENT INPUTS TO THE BALTIC SEA

Eutrophication was first recognized as a large-scale pressure of the Baltic Sea in the early 1980s, and in part attributed to anthropogenic nutrient loading (HELCOM 1987, 2009). Actions to reduce nutrient loading in the order of 50 % were agreed on by the 1988 HELCOM Ministerial Declaration (HELCOM 1988), and reaching a Baltic Sea unaffected by eutrophication was identified as one of the goals of the Baltic Sea Action Plan in 2007 (HELCOM 2007).

Since the 1980s, nutrient inputs to the Baltic Sea have decreased, and in some sub-basins strong reductions have taken place. For example, waterborne nitrogen inputs to the Baltic Sea are currently at the level that they were in the 1960s, and the phosphorus inputs at the level of 1950s (Figure 1). The total nitrogen input to the Baltic Sea was about 7 % larger than the maximum allowable input in 2015, whereas phosphorus input remained 44 % above this threshold value (HELCOM 2018l).

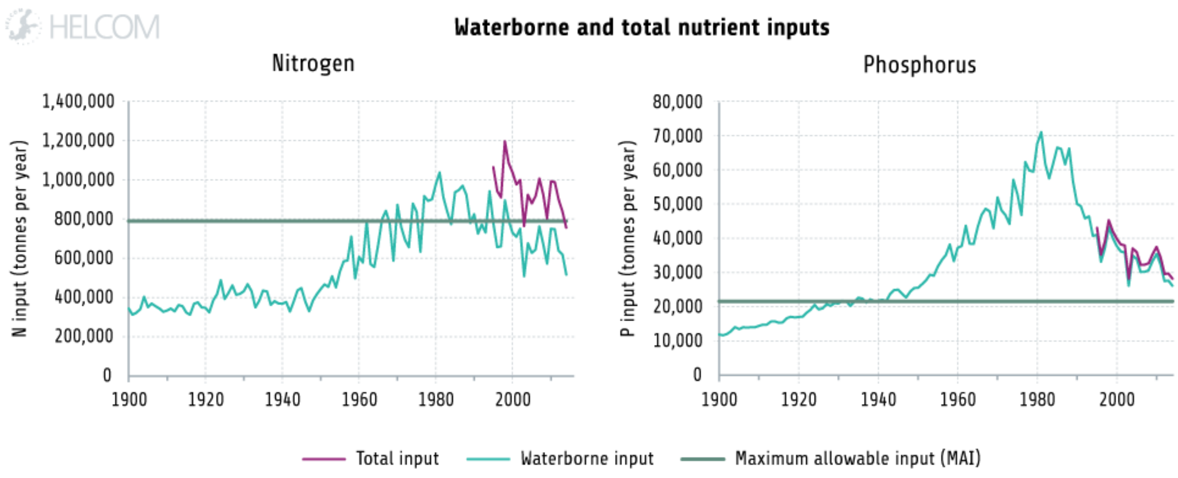

Figure 1. Temporal development of waterborne and total nutrient inputs to the Baltic Sea from 1900 to 2014 with inputs of nitrogen to the left and of phosphorus to the right. The green line shows the maximum allowable inputs (MAI). Sources: HELCOM (2015a), Gustafsson *et al.* (2012), Savchuk *et al.* (2012).

The current annual total input of nutrients to the Baltic Sea amounts to about 826,000 tonnes of nitrogen and 30,900 tonnes of phosphorus (HELCOM 2018k). Most of the input is riverine for both nitrogen and phosphorus (Figure 2). Atmospheric inputs account for about 30 % of the total nitrogen inputs (HELCOM 2018k), originating mainly from combustion processes related to shipping, road transportation, energy production, and agriculture. The largest relative decreases in the inputs of nitrogen and phosphorus over the past decades have occurred in the direct sources, which currently account for 4-5 % of the total loads (Figure 2, HELCOM 2018). The atmospheric input of nitrogen has decreased by between 25 and 31 % during 1995-2014 for all sub-basins, while changes in waterborne nitrogen input are clearly more variable (HELCOM 2018l).

Natural sources constitute about one third of the riverine inputs of nitrogen and phosphorus to the Baltic Sea (Figure 2; HELCOM 2018k). A major part of the anthropogenic part originates from diffuse sources, mainly agriculture, while point sources, dominated by municipal waste water treatment plants, contribute with 12 % and 24 % of the riverine nitrogen and phosphorus loads, respectively.

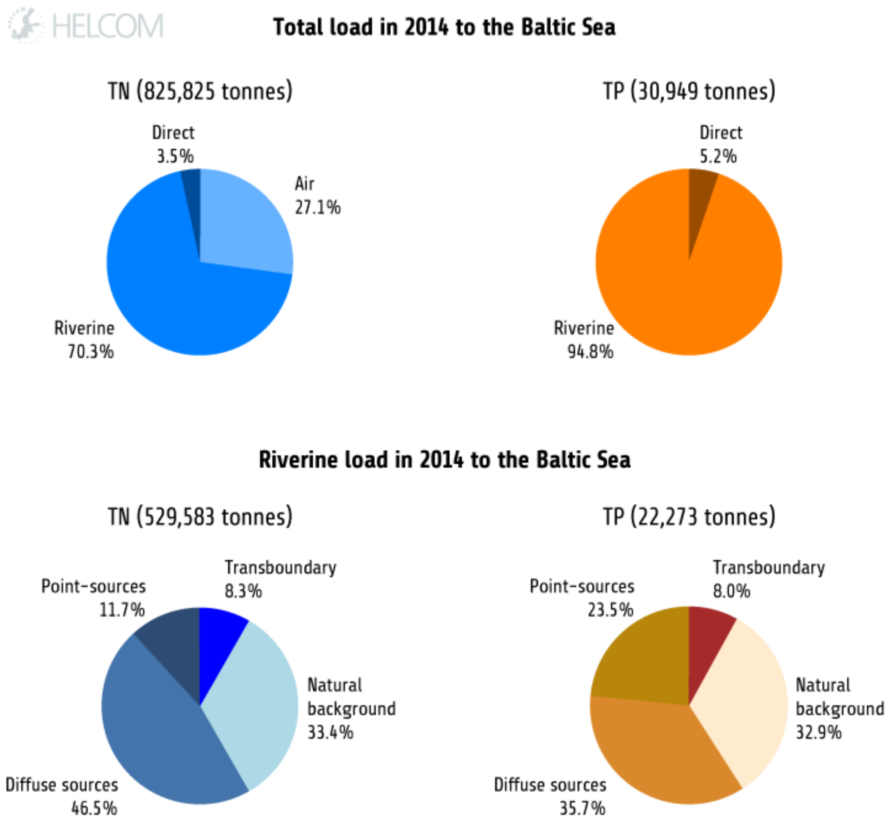

Figure 2. Sources of nitrogen and phosphorus loads to the Baltic Sea in 2014. Source: HELCOM 2018k.

1.2 NUTRIENT REDUCTION TARGETS FOR SUB-BASINS

Based on the revised maximum allowable inputs (MAI) for the seven sub-basins of the Baltic Sea within the HELCOM nutrient reduction scheme, reductions of nitrogen input were needed in three sub-basins (HELCOM 2013a). Of these, the MAI has been fulfilled in the Kattegat, whereas reductions are is still required for nitrogen input to the Gulf of Finland and Baltic Proper (HELCOM 2018l). In the remaining four sub-basins, the input of nitrogen has remained within or close to the maximum allowable input (Figure 3).

Reduction of phosphorus inputs was set for three sub-basins: the Baltic Proper, the Gulf of Finland and the Gulf of Riga (HELCOM 2013a). In all three cases, reductions are seen but notable further reductions are still needed in order to reach the allowable levels (Figure 3). So far, the most pronounced results are seen for the Gulf of Finland, where the phosphorus input has been cut with more than half compared to the reference period (Figure 4). This reduction has been attributed to improved waste water treatment in St. Petersburg and actions to prevent phosphorus release from a fertilizer factory in the catchment of river Luga (Raateoja and Setälä 2016).

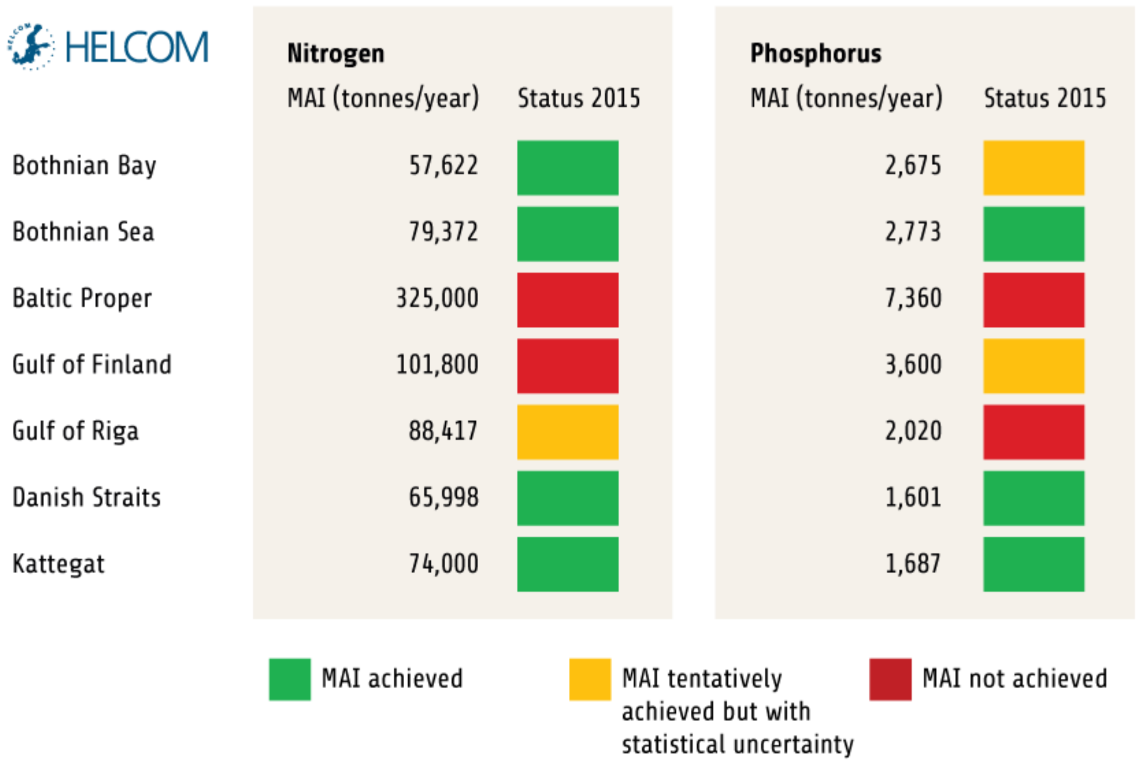

Figure 3. Progress of nutrient reductions in the Baltic Sea in relation to maximum allowable inputs (MAI), based on the evaluation for year 2015 (HELCOM 2018l). The targets are set by sub-basin for nitrogen and phosphorus. The maximum allowable input differs between sub-basins, as shown by the numbers.

Overall, the normalized input of nitrogen was reduced by 12 % and the normalized input of phosphorus by 25 % between the reference period (1997-2003) and 2015 (HELCOM 2018l). The strongest relative changes over the past decades are seen in the Kattegat and the Danish straits for nitrogen input and in the Gulf of Finland for phosphorus input (Figure 4).

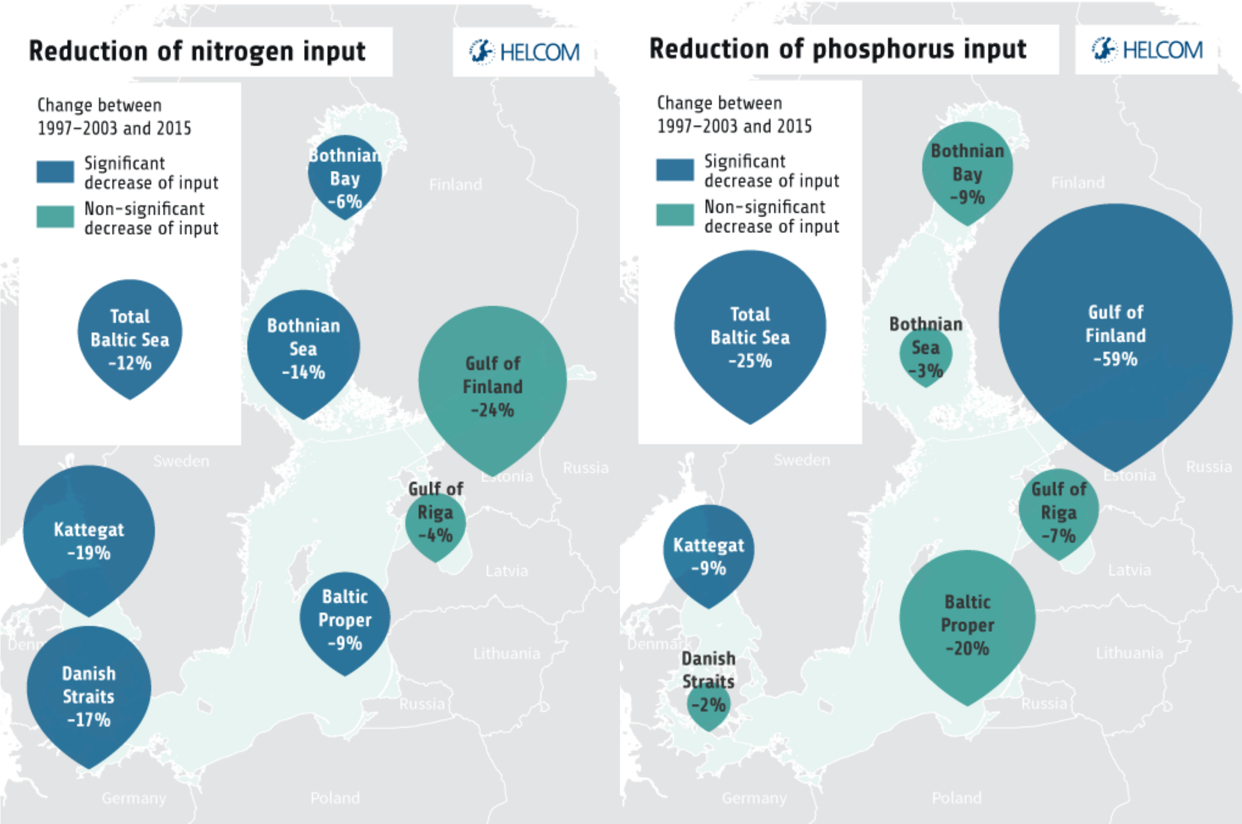

Figure 4. The inputs of nitrogen and phosphorus to the Baltic Sea sub-basins have decreased significantly in recent years. The drop shapes show the relative change in annual average normalised net nutrient input to the sub-basins, including riverine, direct and airborne inputs comparing the year 2015 with the reference period 1997–2003. The size of each drop shape is proportional to the amount of change. Significance is determined based on trend analyses. Source: HELCOM (2018l).

Chapter 2. Indicators used in the assessment

Eutrophication status was evaluated by indicators within three criteria: nutrient levels, direct effects and indirect effects of eutrophication.

HELCOM eutrophication core and pre-core indicators were applied to the assessment of open-sea areas, and were partially supplemented with one biodiversity core indicator (see table 1 for an overview, and table 2 for threshold values). Coastal areas were assessed by national indicators, see Table 3.

To assess nutrient levels in the surface water, eutrophication core indicators on the concentrations of nitrogen and phosphorus were used (HELCOM 2018b-e). Primary producers need both nitrogen and phosphorus for growth. Dissolved inorganic nitrogen and phosphorus, which are directly utilizable by primary producers, are assessed in the winter season when primary productivity is low and the concentrations are largely unaffected by uptake. Hence, these represent the nutrient pool available for phytoplankton growth. Core indicators for total nitrogen and total phosphorus also include dissolved organic nutrients (such as proteins, urea, or humic substances) as well as nutrients that are bound in particulate organic matter (such as phytoplankton and detritus). The inorganic nutrients which enter the sea are rapidly taken up by organisms and bound to their biomass. Via excretion and decay they are then transformed into dissolved organic nitrogen and phosphorus, which again re-mineralise (Markager *et al.* 2011, Knudsen-Leerbeck *et al.* 2017). Hence, the total nutrient indicators provide an estimate of the total level of nutrient enrichment in the sea4.

To assess the direct effects of eutrophication, core indicators on chlorophyll-*a* concentrations in the surface water and water clarity were used (HELCOM 2018f-g). In addition, the 'Cyanobacterial bloom index', which is not yet agreed on as a core indicator, was included as test (HELCOM 2018h).

To assess indirect effects of eutrophication, the eutrophication core indicator 'Oxygen debt' was used (HELCOM 2018i). This core indicator measures the volume-specific oxygen debt, which is the oxygen debt below the halocline divided by the volume of the water mass below the halocline. Hence, is estimates how much oxygen is 'missing' from the Baltic Sea deep water, primarily as a result of degradation of organic matter. In the open sea of the Bothnian Bay, Quark, Bothnian Sea, and Gulf of Riga, where the oxygen debt indicator was not applicable, the biodiversity core indicator 'State of the soft-bottom macrofauna community' was used in order to address indirect effects of eutrophication (HELCOM 2018j). In these areas, the indicator was seen to be suitable for the eutrophication assessment, since it responds only or mainly to eutrophication-related pressures.

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[4] Please note that Danish measurements presented for total nitrogen and total phosphorus are underestimated. This might affect content and conclusions in this report in regard to the status assessment and assessment of nutrient input to Danish waters (See Box 2 on page 37). Finnish monitoring open sea estimates of phosphate and total phosphorus in 2011-2014 are in general 10 % lower than in 2015-2017 due to changes in instrumentation and accompanying methodology. This might affect the indicator values in assessment units SEA-012 to -017

Coastal areas were assessed by national indicators mainly derived from the implementation of the Water Framework Directive (EC 2000). These indicators varied between different national coastal areas. They included indicators describing the level of phytoplankton (mainly via biomass or chlorophyll-*a* concentration), benthic invertebrate fauna, macrophytes (macroalgae and angiosperms), concentrations of nitrogen, concentrations of phosphorus, and water clarity (For more information, see chapter 4.3.3).

2.1 ASSESSMENT SCALE

For purpose of monitoring and assessment the Baltic Sea is sub-divided according to a coherent and agreed structure. Four hierarchical assessment scales are used:

1) HELCOM Marine area. No division: the whole Baltic Sea encompassing the entire HELCOM area.

2) HELCOM Sub-basins. Division of the Baltic Sea into 17 sub-basins.

3) HELCOM Sub-basins with coastal and offshore division. Division of the Baltic Sea into 17 sub-basins and further division into coastal and off-shore areas, including in total 40 coastal areas.

4) HELCOM Sub-basins with coastal WFD water types or water bodies. Division of the Baltic Sea into 17 sub-basins and further division into coastal and off-shore areas and division of the coastal areas by Water Framework Directive (WFD) water types or water bodies, including in total 240 coastal areas.

Detailed maps of the assessment scales are found in attachment four in the HELCOM Monitoring and Assessment Strategy (HELCOM 2013c). The appropriate assessment scale for the respective core indicator is agreed based on ecological relevance. Within an assessment scale the units can be further aggregated i.e. several sub-basins at scale 2 may serve as an assessment unit for an indicator. This is for example the case for indicators representing the abundance and distribution of seal populations.

2.2 THRESHOLD VALUES

The applied threshold values for core and pre-core indicators in the HELCOM open sea assessment units are presented in Table 2, The threshold values have been agreed on by HELCOM and by Heads of Delegation (HOD) as follows ; HOD 39-2012 (outcome para 2.20, HELCOM 2012): 'Chlorophyll-a', 'Water clarity', 'Dissolved inorganic nitrogen (DIN)', 'Dissolved inorganic phosphorus (DIP)', 'Oxygen debt'; HELCOM 38-2017 (outcome para 4.19, Annex 5; HELCOM 2017a): 'Total nitrogen', 'Total phosphorus', 'Cyanobacterial bloom index'.

Threshold values for the coastal areas have been intercalibrated under the Water Framework Directive for some indicators (regarding indicators representing phytoplankton, macrophytes and macrozoobenthos), or are set through national decisions (for example regarding nutrient concentrations and water clarity).

Table 2. Threshold values for eutrophication related core indicators in the open sea, years 2011–2016. (HELCOM 2012, HELCOM 2017a). Blank white cells are shown when there is no regionally agreed threshold value or indicator methodology. Dark grey cells marked 'N' mean that the indicator is not applicable. Indicators marked * have not been adopted in HELCOM yet and are included as test. The indicator 'State of the soft-bottom macrofauna community' (Zoob) was only included in the Gulf of Riga and north from the Åland Sea. It is also available for other sub-basins but is not included there as it is considered to depend markedly also on other pressures than eutrophication (marked 'Not incl.'). Other abbreviations: DIN = 'Dissolved inorganic nitrogen', TN= 'Total nitrogen', DIP= 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chla= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index', and O_2 = 'Oxygen debt'. For more details, see core indicator reports: HELCOM 2018b-j.

	Threshold values for core indicators in the open sea assessment units								
Assessment units	**DIN (µmol l^{-1})**	**TN (µmol l-1)**	**DIP (µmol l^{-1})**	**TP (µmol l^{-1})**	**Chla (µg l^{-1})**	**Water clarity (m)**	**Cyano* (Index, 0-1)**	**O_2 (mg l^{-1})**	**Zoob* (Index)**
Kattegat	5	17.4	0.49	0.64	1.5	7.6	N	N	
Great Belt	5	21	0.59	0.95	1.7	8.5	N	N	
The Sound	3.3	17.3	0.42	0.68	1.2	8.2	N	N	
Kiel Bay	5.5		0.57		2	7.4	N	N	
Bay of Mecklenburg	4.3		0.49		1.8	7.1	0.92	N	Not incl.
Arkona Basin	2.9		0.36		1.8	7.2	0.9	N	
Bornholm Basin	2.5		0.3		1.8	7.1	0.89	6.37	
Gdansk Basin	4.2	18.8	0.36	0.6	2.2	6.5	0.98	8.66	
Eastern Gotland Basin	2.6	16.5	0.29		1.9	7.6	0.84	8.66	Not incl.
Western Gotland Basin	2	15.1	0.33	0.45	1.2	8.4	0.87	8.66	Not incl.
Gulf of Riga	5.2	28	0.41	0.7	2.7	5	0.9	N	0.5
Northern Baltic Proper	2.9	16.2	0.25	0.38	1.65	7.1	0.77	8.66	Not incl.
Gulf of Finland	3.8	21.3	0.59	0.55	2	5.5	0.9	8.66	Not incl.
Åland Sea	2.7	15.6	0.21	0.28	1.5	6.9	N		4
Bothnian Sea	2.8	15.7	0.19	0.24	1.5	6.8	0.58		4
The Quark	3.7	17.3	0.1	0.24	2	6	N	N	1.5
Bothnian Bay	5.2	16.9	0.07	0.18	2	5.8	N		1.5

*Included as test

2.3 CONNECTION TO THE MARINE STRATEGY FRAMEWORK DIRECTIVE

Since HELCOM is the coordinating platform for the regional implementation of the EU Marine Strategy Framework Directive (EC 2017), the HELCOM assessment of eutrophication is aligned with the methodological standards on good environmental status of marine waters laid down by the EU Commission (Table 3). Core indicators representing the two primary criteria *Nutrient concentration* and *Chlorophyll*-a *concentration*, as well as the secondary criterion (*Photic* limit of the water column) have been established and made operational in all open-sea assessment units. The third primary criterion, *Concentration of dissolved oxygen*, is indirectly represented by the core indicator on oxygen debt in 9 of the 17 open sea assessment units. In addition, the secondary criteria *Number*, *extent and duration of harmful algal blooms* and *Species composition and abundance of macrofauna* are applied in some open-sea assessment units.

Table 3. Eutrophication indicators applied in the integrated assessment, listed according to criteria group, and Marine Strategy Framework Directive (MSFD) criteria (EC 2017). The last column indicates whether the criterion is primary or secondary. National indicators are used in coastal areas, primarily as reported under the Water Framework Directive (WFD). The coastal indicators do not necessarily apply for all coastal assessment units. For a further explanation on these, see the HELCOM Eutrophication assessment manual (HELCOM 2015b). For references to core indicator reports, see text

Criteria group	Indicator name	Coastal/ open sea	MSFD criteria (primary/ secondary)
Nutrient concentration	Dissolved inorganic nitrogen (DIN) Dissolved inorganic nitrogen (DIP) Total nitrogen (TN) Total phosphorus (TP) WFD indicators DIN WFD indicators DIP WFD indicators TN WFD indicators TP	Open sea Open sea Open sea Open sea Coastal Coastal Coastal Coastal	D5C1 (primary): Nutrient concentrations are not at levels that indicate adverse eutrophication effects.
Direct effects	Chlorophyll-a WFD indicator results phytoplankton (mostly chlorophyll-a, and biovolume)	Open sea Coastal	D5C2 (primary): Chlorophyll-a concentrations are not at levels that indicate adverse effects of nutrient enrichment.
	Cyanobacterial bloom index*	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.
	Water clarity WFD indicators water clarity or turbidity	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.
Indirect effects	Oxygen debt WFD indicators oxygen concentration or hypoxia	Open sea Coastal	D5C5 (primary): The concentration of dissolved oxygen is not reduced, due to nutrient enrichment, to levels that indicate adverse effects on benthic habitats (including on associated biota and mobile species) or other eutrophication effects.
	WFD indicators macrophytes	Coastal	D5C6 (secondary): The abundance of opportunistic macroalgae is not at levels that indicate adverse effects of nutrient enrichment. D5C7 (secondary): The species composition and relative abundance or depth distribution of macrophytes communities achieve values that indicate there is no adverse effect due to nutrient enrichment including via a decrease in water transparency.
	State of the soft-bottom macrofauna community* WFD indicators macrofauna (EUTRO-OPER)	Open sea Coastal	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.

*Included as test.

Chapter 3. Method for the integrated assessment of eutrophication

The integrated assessment of eutrophication was done using the HELCOM HEAT tool which aggregates the indicator results into a quantitative estimate of overall eutrophication status.

In comparison to previous versions of the tool, HEAT 3.0 was developed to better fit the structure for eutrophication assessment within the Marine Strategy Framework directive. HEAT 3.0 was used also in the assessment of 2007-2011.

The earlier version of HEAT, as used in the assessment of 2001-2006, was developed to fit the Water Framework Directive. One major difference between the versions of the tool lies in how indicators are grouped in the assessment. For example, water clarity was grouped together with nutrient levels into physical-chemical quality elements in HEAT 1.0, but is are assessed in a group of direct effects in HEAT 3.0 (see also the section below).

The applied assessment structure is presented below, and the more detailed specifications on how the assessment is carried out are presented in the HELCOM Eutrophication Assessment Manual (HELCOM 2015b).

3.1 STRUCTURE AND ASSESSMENT APPROACH OF THE HEAT TOOL

The assessment initially integrates indicators (elements) by six criteria, in line with the structure of the Marine Strategy Framework Directive methodological standards on good environmental status (EC 2017), and then further aggregates these into three criteria groups: nutrient levels, direct effects and indirect effects (Figure 5).

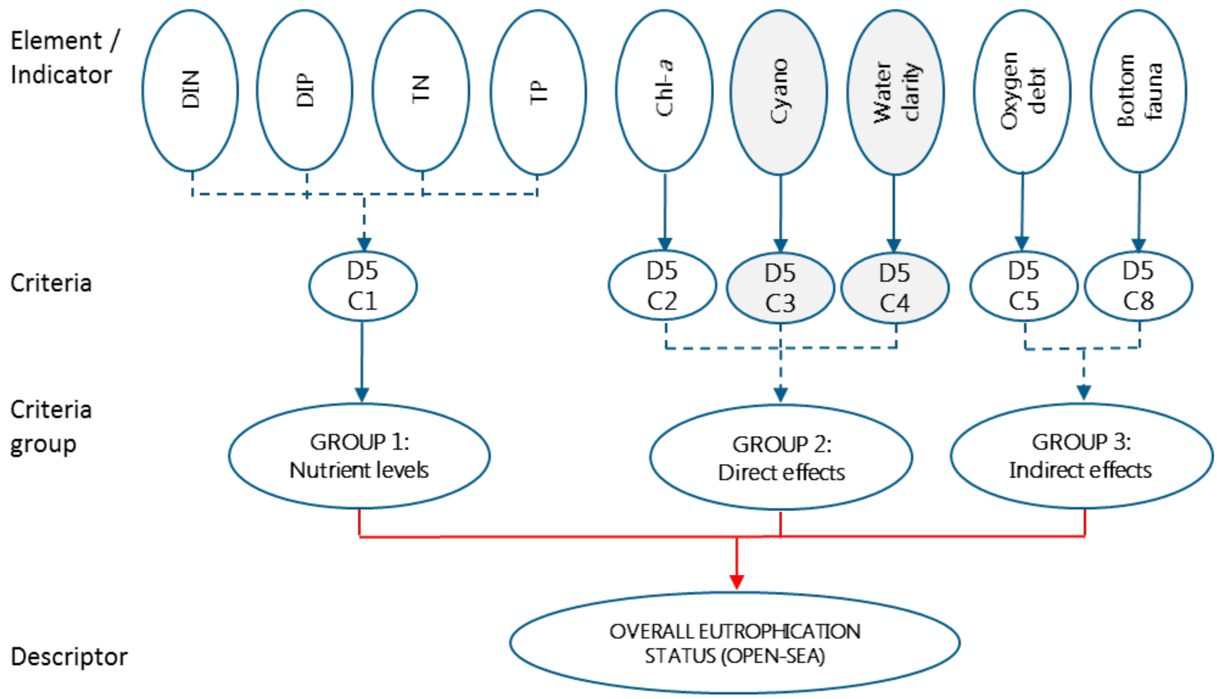


Figure 5. Structure of the eutrophication assessment for open-sea areas. The aggregation of indicators in HEAT 3.0 based on criteria, and subsequently on criteria groups, takes into account the MSFD methodological standards. Primary elements (indicators) associated with primary criteria have no shading, whereas the secondary criteria and their elements (indicators) are shaded grey. Dashed blue lines indicate a process of weighted averages and solid red line indicates where a One-Out-All-Out process is adopted

Indicator results are in the first step integrated within each assigned group, as shown in Figure 5, using weighted averaging. The averaging is based on eutrophication ratios, which are calculated as the assessment value (observed indicator status value) in relation to the threshold value. Hence, the eutrophication ratios estimate how far away the assessment value is from the threshold value. Values above one signify that the threshold value is not achieved, since values are too high, and values below one signify no eutrophication according to that indicator.

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

The results are presented in five status classes according to the result categories presented in table 4.

Table 4. Result categories of the integrated eutrophication assessment. The integrated status is estimated using the eutrophication ratio (ER) to arrive at a common scaling for all indicators. At the indicator level, the eutrophication ratio is calculated as the assessment value (observed indicator status value) divided by the threshold value, and these values are used to calculate the integrated result. The integrated assessment output is presented in result categories, based on the resulting integrated ER scores. The categories are coloured by the scheme shown in the last column when presenting the results in maps.

Integrated eutrophication status		**Result category**
Less than 1.00	≤0.50	Good – Low eutrophication status
	0.50 < ER ≤1.00	Good – Low eutrophication status
Above 1.00	1.00 < ER ≤ 1.50	Not Good – High eutrophication status
	1.50 < ER ≤ 2.00	Not Good – High eutrophication status
	>2.00	Not Good – High eutrophication status

Exceptions to indicators included in the current assessment

In the current assessment, dissolved nitrogen and phosphorus, chlorophyll-*a*, and water clarity were assessed for all sub-basins. Total nitrogen and total phosphorus were not assessed for the Kiel Bay, Bay of Mecklenburg, Arkona Basin and Bornholm Basin, and total phosphorus neither for the Eastern Gotland Basin due to lack of agreed threshold values[5]. 'Cyanobacterial bloom index' is not applicable for the Kattegat, Great Belt, the Sound, Kiel Bay, Åland Sea, Quark and Bothnian Bay. 'Oxygen debt' is not applicable in the Gulf of Riga, the Quark and west from the Arkona Basin, and it was not assessed in the Åland Sea, Bothnian Bay and Bothnian Sea due to lack of agreed threshold values. 'State of the soft-bottom macrofauna community' was included only north from the Åland Sea, as well as in the Gulf or Riga.

[5] For example; In the German parts of these sub-basins, assessment based on national threshold values showed not good status (http://www.meeresschutz.info/oeffentlichkeitsbeteiligung.html)

Applied weights

The weights applied in integrating indicator results to criteria level results are presented in Table 5.

Table 5. Indicator weights used to calculate criteria level results 2011–2016. Blank white cells are shown when there is no regionally agreed threshold value or indicator methodology. Dark grey cells marked 'N' mean that the indicator is not applicable. Indicators marked * are included as test in this assessment. Abbreviations: DIN = 'Dissolved inorganic nitrogen', TN= 'Total nitrogen', DIP= 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chla= 'Chlorophyll-a', 'Cyano = 'Cyanobacterial bloom index', O_2 = 'Oxygen debt' and Zoob= 'State of the soft-bottom macrofauna community'.

Assessment unit	Core indicator results								
	Nutrient levels				Direct effects			Indirect effects	
	DIN	TN	DIP	TP	Chla	Water clarity	Cyano*	O_2	Zoob*
	Dec–Feb	All year	Dec–Feb	All year	Jun– Sep	Jun–Sep	20 Jun–31 Aug	All year	May–Jun
Kattegat	25	25	25	25	50	50	N	N	
Great Belt	25	25	25	25	50	50	N	N	
The Sound	25	25	25	25	50	50	N	N	
Kiel Bay	50		50		50	50	N	N	
Bay of Mecklenburg	50		50		39	39	22	N	
Arkona Basin	50		50		39	39	22	N	
Bornholm Basin	50		50		39	39	22	100	
Gdansk Basin	20	20	30	30	39	39	22	100	
Eastern Gotland Basin	25	25	50		39	39	22	100	
Western Gotland Basin	25	25	25	25	39	39	22	100	
Gulf of Riga	17	17	33	33	55	23	22	N	100
Northern Baltic Proper	25	25	25	25	39	39	22	100	
Gulf of Finland	25	25	25	25	47	31	22	100	
Åland Sea	25	25	25	25	50	50	N		100
Bothnian Sea	25	25	25	25	47	31	22		100
The Quark	25	25	25	25	70	30	N	N	100
Bothnian Bay	17	17	33	33	80	20	N		100

3.2 CONFIDENCE ASSESSMENT

The confidence of the results in open-sea assessment units is assessed at both indicator level and integrated eutrophication status level (HELCOM 2015b). 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 (50-74 %) and low (below 50 %; Table 6).The calculation of confidence is done in three steps:

1. Indicator confidence

Confidence in the indicator-specific threshold value (ET-Score) and indicator-specific status (i) value (ES Score), based on confidence in the data used to calculate the status value (see HELCOM 2015b) are combined by averaging to determine the confidence of each indicator.

The ET-scores in open-sea core indicators were based on the confidence of the target-setting methodology: where historical data could be used, the confidence was higher than where only ecological modelling was applied. A table with justification on ET-scores is presented in the HELCOM eutrophication assessment manual (HELCOM 2015b).

The ES-scores were based on the number of monitoring observations available from the assessment period, describing the temporal representativity of monitoring data. LOW confidence is assigned if there are no more than 5 annual status observations from the assessment season during one or more years. MODERATE confidence is used if more than 5 but no more than 15 status observations are found during the assessment season during the year with least observations. HIGH confidence requires more than 15 spatially non-biased status observations during the assessment season each year.

2. Criteria specific confidence

Criteria-specific confidence is assessed as the (weighted) arithmetic mean of the confidences of the indicators within each criteria. In order to provide an average value, the final confidence rating for each assessment is given a value between 0 and 100 %, and is grouped into three confidence classes: high (100 %), moderate (50 %) and low (0 %).

3. Final 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.

If a criterion is only represented by one indicator, the criteria-specific confidence is reduced by 25 %. If the assessment is based on only a single criterion, the final confidence rating is reduced by 50 %.

Table 6. Confidence categories of the integrated eutrophication assessment. The colours are those used in the confidence maps, which are associated to the integrated eutrophication status assessment

Confidence Score	Confidence Status
High (≥ 75 %)	
Moderate (50- 74 %)	
Low (< 50 %)	

This concept of assessing confidence is not fully in line with that used in the HELCOM integrated assessment of biodiversity using the BEAT tool in that it does not include estimates on spatial representativity, accuracy or methodologic confidence of the monitoring data.

Confidence was not assessed for coastal waters.

3.3 HEAT ASSESSMENT DATA FLOW

The eutrophication status assessment results are based on data obtained through the eutrophication assessment data flow as described below (see also Figure 6).

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

For each eutrophication assessment period, data from the ICES database is extracted and is drawn as such into a separate HELCOM 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 ICES database.

At this stage, indicator aggregation and assessment results are produced dynamically using algorithms specified for the individual core indicators and the overall eutrophication assessment based on the HELCOM eutrophication assessment tool (HEAT 3.0).

Visualized data products are subsequently brought through a review and acceptance procedure, using workflows in the HELCOM Eutrophication workspace. The workflow is established on a share-point based workspace, where it is possible to give tasks to experts taking part in the assessment process, as well as to document the progress. The HELCOM assessment database is being updated continuously until the acceptance at data-, indicator- and assessment levels has been provided by nominated experts of the Contracting Parties.

Final assessment products, such as indicator maps, are produced and visualized from the database and made available through an interface hosted and maintained by ICES. At the HELCOM web portal, the results are presented in the HELCOM core indicator web reports and the HELCOM Map and Data service[6], 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 and data view is restricted to experts named by the Contracting Parties to be responsible for data and assessment product review, in order not to present unaccepted products to the public.

[6] http://maps.helcom.fi/website/mapservice/index.html

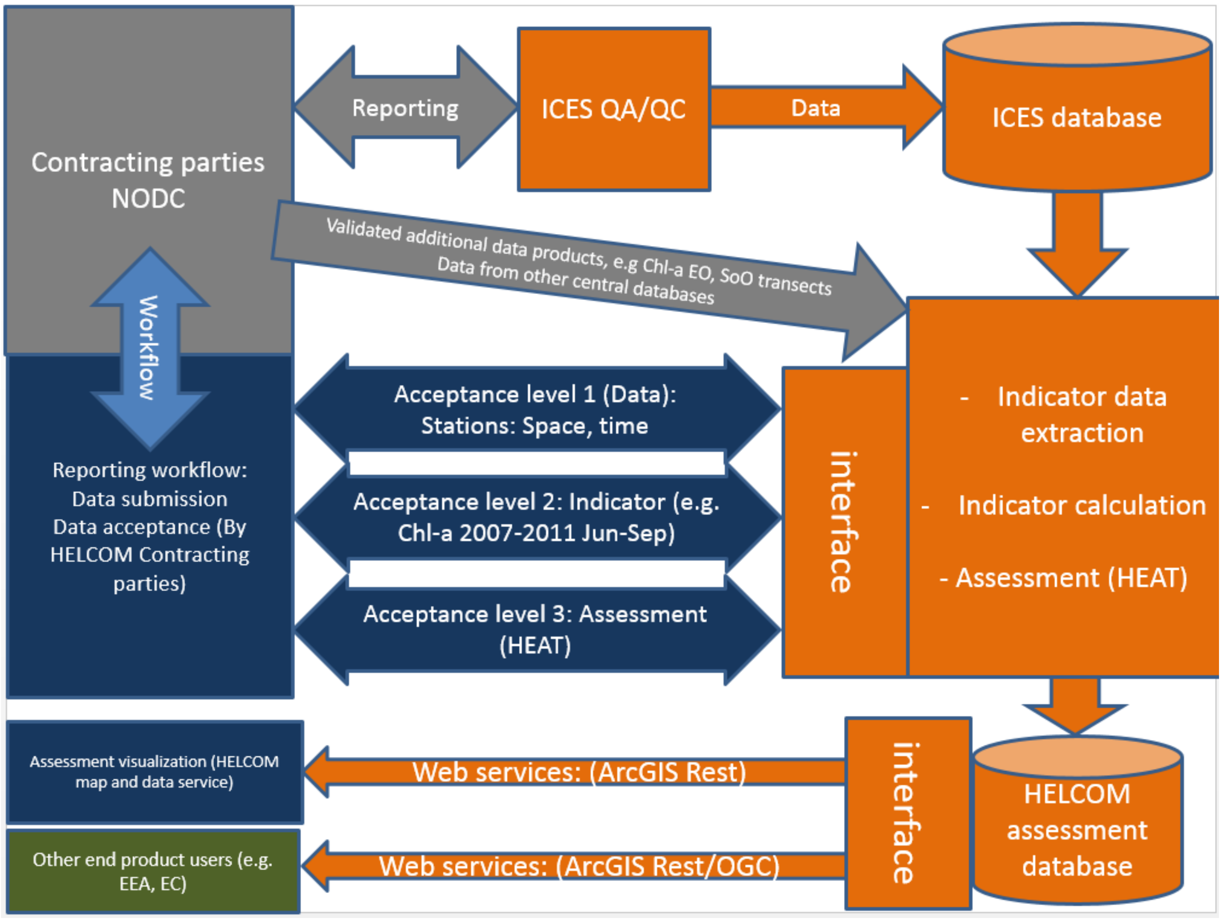


Figure 6. Eutrophication assessment data and information flow. The color of the items indicate the actor/host: Grey = Contracting Parties, Blue = HELCOM portal hosted at the HELCOM Secretariat, Orange = ICES, Green = other end-users, for example European Environment Agency (EEA), European Commission (EC).

Chapter 4. Results from the integrated assessment

The integrated eutrophication status assessment for 2011–2016 shows that the Baltic Sea is still affected by eutrophication (Figure 7). Out of the 247 assessment units included in the HELCOM assessment of coastal and open water bodies, only 17 achieved good status.

In terms of areas covered, 96 % of the surface area in the Baltic Sea, from the Kattegat to the inner bays, is below good status in regards to eutrophication. The assessment results were in the category furthest away from good status in about 12 % of the area. Only a few coastal areas were not affected by eutrophication.

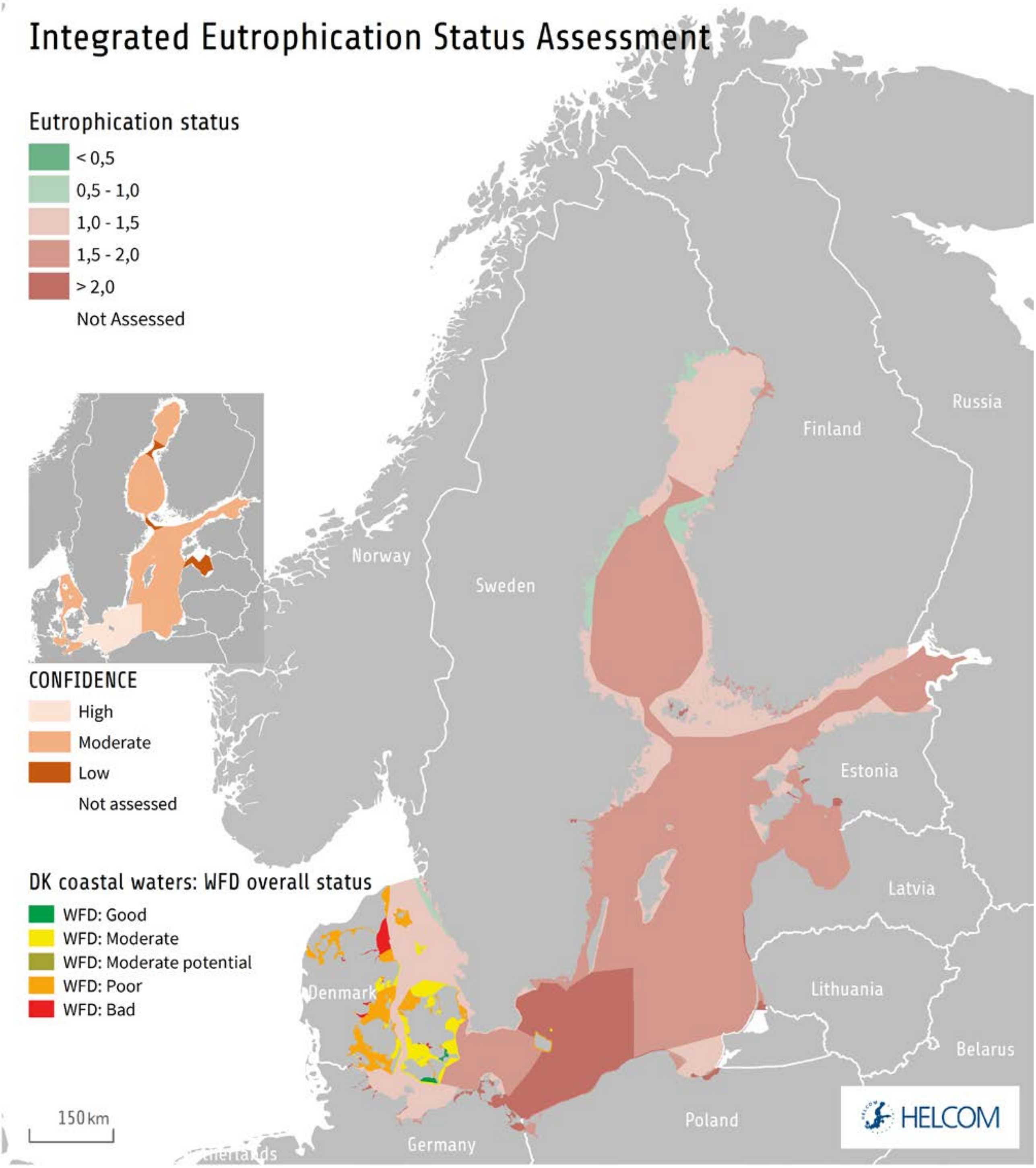


Figure 7. Integrated status of eutrophication in the Baltic Sea 2011-2016. Each assessment unit shows the result for the criteria group furthest away from good status. For results by criteria, see Figure 7. Note that the integrated status of Swedish coastal areas in the Kattegat differs from corresponding results in the OSPAR intermediate assessment. In coastal areas HELCOM utilises national indicators used in the Water Framework Directive to arrive at an assessment of eutrophication status in eight countries. Denmark refers to the assessments made under the WFD due to consideration of the national management of coastal waters. Danish coastal WFD-classification differs from the open sea classification and hence, the colours are not directly comparable. White areas denote that data has not been available for the integrated assessment. The map in the lower corner shows the confidence assessment result, with darker colors indicating lower confidence.

In many open-sea areas, good status was not achieved with respect to any of the assessed criteria; nutrient levels, direct or indirect effects of eutrophication (Figures 8 and 9). Generally, indicators for nutrient levels were furthest away from good status, and thus had highest influence on the integrated assessment results. This was especially evident for Bornholm Basin where shallow stations located in the Pomeranian Bay had significant impact on nutrient level results (Table 7). Nutrient levels were in good status only in the Great Belt, being just below the limit for good status[7], and direct effects were in good status only in the Kattegat. For indirect effects of eutrophication, good status was seen north of and including the Åland Sea, covering 25 % of the total open-sea area.

The observed relatively poorer status in nutrient values and direct effects in comparison to indirect effects, may be opposite to expectations on how the ecosystem would respond to reduced loading. Under nutrient reduction, it could be expected that nutrient levels improve first, followed by direct effects and that indirect effects react with a time delay. The observed outcome may be due to poorly harmonized threshold values for different indicators, or reflect a need to re-consider the way in which indicators are grouped in the assessment. On the other hand, many of the direct responses can also be expected to respond on a short time-scale to changes in nutrient loading. Indicators representing changes in chlorophyll-*a*, cyanobacteria, water clarity and many annual macroalgae, for example, are likely to respond to changes within the same growth season. In addition, primary productivity may be limited by nutrient composition rather than nutrient concentrations, and may also be regulated by additional factors, such as the level of grazing. Due to the complex relationships involved in the ecosystem responses, however, an explanation cannot be unanimously identified here.

For a discussion of the integrated assessment results for coastal areas see chapter 4.3.3.

[7] Eutrophication ratio 0.99

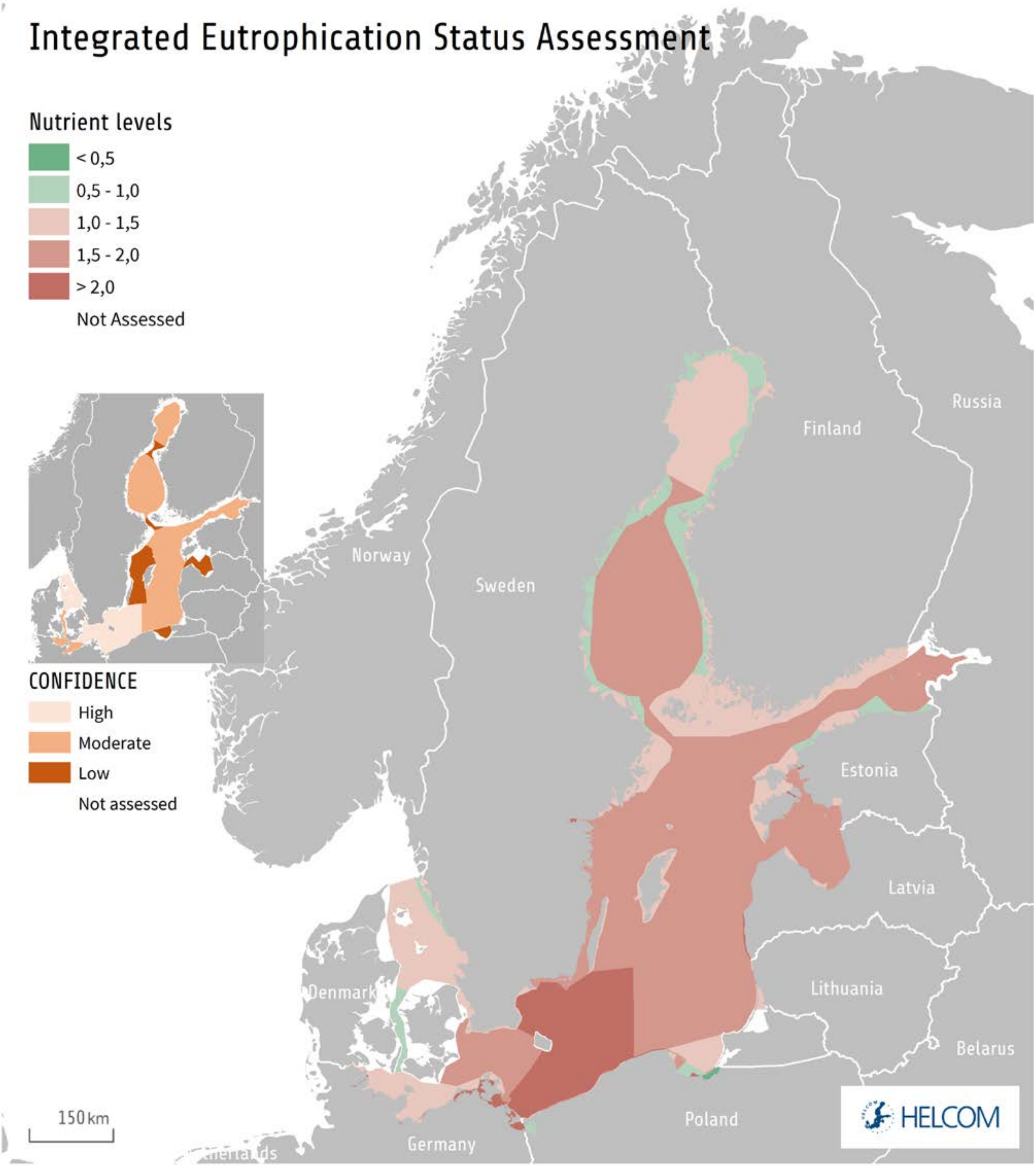


Figure 8a. Integrated assessment results for eutrophication by criteria groups 2011-2016: Nutrient levels. In coastal areas HELCOM utilizes national indicators to assess the eutrophication status. White denote areas that were not assessed due to the lack of indicators. The inserted maps in each lower corner show the confidence assessment result, with darker colour indicating lower confidence. For indicators included, see Table 7.

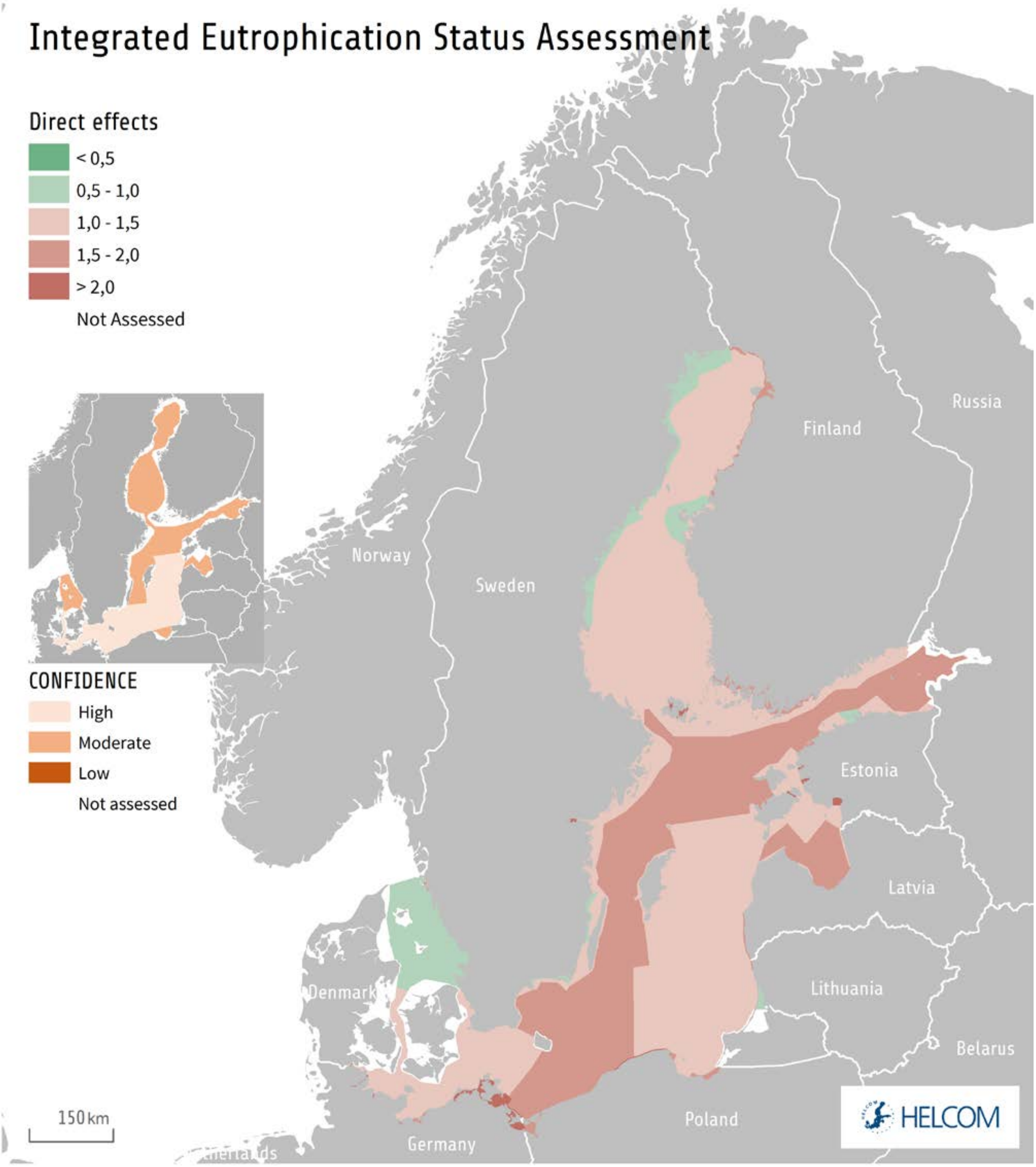


Figure 8b. Integrated assessment results for eutrophication by criteria groups 2011-2016: Direct effects of eutrophication. In coastal areas HELCOM utilizes national indicators to assess the eutrophication status. White denote areas that were not assessed due to the lack of indicators. The inserted maps in each lower corner show the confidence assessment result, with darker colour indicating lower confidence. For indicators included, see Table 7.

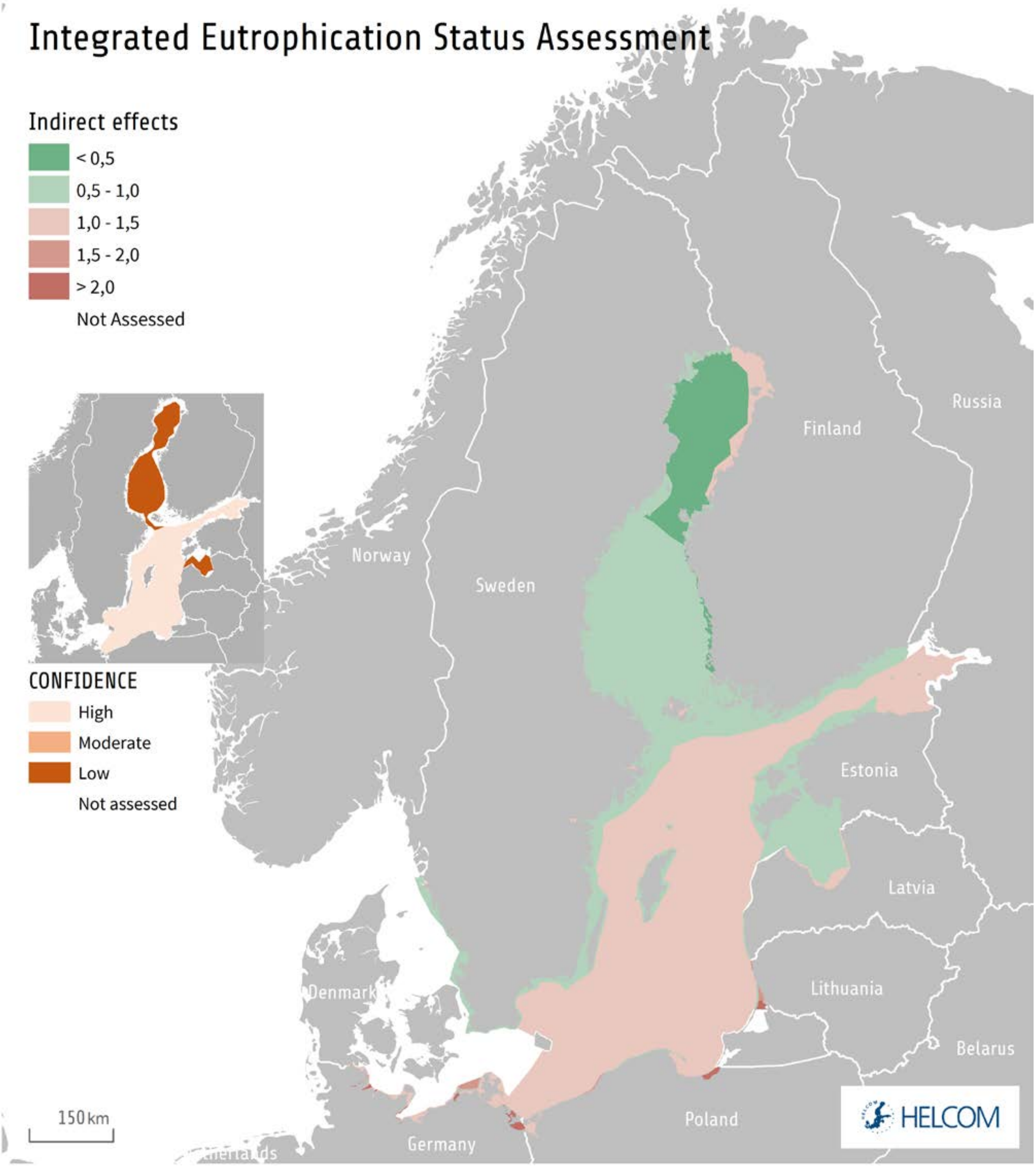


Figure 8c. Integrated assessment results for eutrophication by criteria groups 2011-2016: Indirect effects of eutrophication. In coastal areas HELCOM utilizes national indicators to assess the eutrophication status. White denote areas that were not assessed due to the lack of indicators. The inserted maps in each lower corner show the confidence assessment result, with darker colour indicating lower confidence. For indicators included, see Table 7.

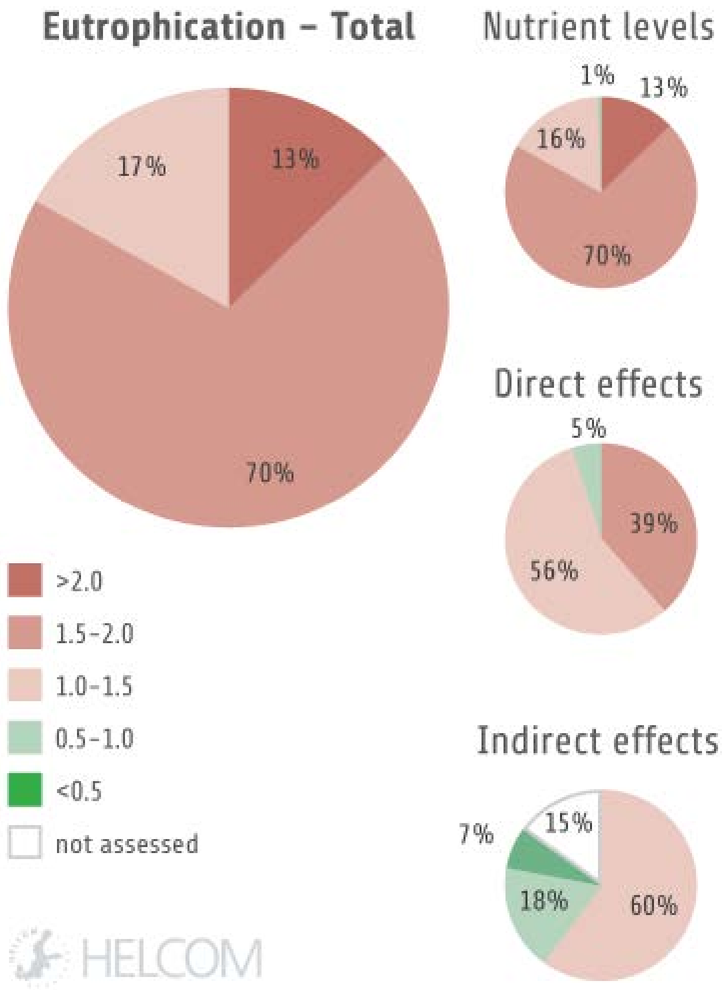


Figure 9. Proportion of open sea area within each of the five status categories of the integrated assessment of eutrophication (based on km2). White denotes areas not assessed due to lack of indicators (see Table 7).

Table 7 shows the numerical integrated status assessment results for each of the open sea sub-basins, together with the corresponding core indicator results. More results on the core indicators are summarized in chapter 5, including an assessment of changes over time.

Table 7. Core indicator results for eutrophication in the open sea 2011–2016. Green cells denote 'good' and red 'not good' status. The last four columns show corresponding integrated status assessment results by criteria groups and for overall status, by the five status categories of the integrated assessment (for results in a map, see figure 7). Values are the eutrophication ratios of each indicator, or the integrated status as estimated in HEAT. White cells denote that the open sea sub-basin was not assessed due to the lack of agreed threshold value or commonly agreed indicator methodology. An 'N' is shown for cases where the indicator is not applicable. The indicator 'State of the soft-bottom macrofauna community' was only included in the Gulf of Riga and north from the Åland Sea. Abbreviations: DIN = 'Dissolved inorganic nitrogen', TN= 'Total nitrogen', DIP= 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chla= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index', O_2 = 'Oxygen debt' and Zoob= 'State of the soft-bottom macrofauna community'. The indicator 'State of the soft-bottom macrofauna community' was only included in the Gulf of Bothnia. For more details, see core indicator reports: HELCOM 2018b-j. See also Box 2.

Assessment unit	Core indicator results									Group results			Integrated status assessment
	Nutrient levels				Direct effects			Indirect effects		Nutrient levels	Direct effects	Indirect effects	
	DIN	TN	DIP	TP	Chla	Water clarity	Cyano*	O_2	Zoob*				
	Dec–Feb	All year	Dec–Feb	All year	Jun–Sep	Jun–Sep	20 Jun–31 Aug	All year	May–Jun				
Kattegat	1.18	0.90	1.09	1.10	0.63	0.81	N	N		1.07	0.72	N	1.07
Great Belt	1.29	0.75	1.11	0.80	1.18	1.12	N	N		0.99	1.15	N	1.15
The Sound	1.82	1.03	1.52	1.16	1.05	0.99	N	N		1.38	1.02	N	1.38
Kiel Bay	1.07		1.13		1.08	1.07	N	N		1.10	1.07	N	1.10
Bay of Mecklenburg	1.48		1.43		1.30	1.34	1.29	N		1.45	1.31	N	1.45
Arkona Basin	1.37		1.72		1.44	1.31	1.06	N		1.54	1.31	N	1.54
Bornholm Basin	3.73		2.19		2.27	1.35	1.12	1.25		2.96	1.66	1.25	2.96
Gdansk Basin	1.09	1.46	1.45	1.35	1.59	1.13	1.19	1.23		1.35	1.32	1.23	1.35
Eastern Gotland Basin	1.36	1.38	1.95		1.53	1.14	1.10	1.23		1.66	1.28	1.23	1.66
Western Gotland Basin	1.64	1.38	2.04	1.66	2.20	1.32	1.11	1.23		1.68	1.62	1.23	1.68
Gulf of Riga	2.00	1.05	2.54	1.34	1.50	1.37	1.71	N	0.91	1.80	1.52	0.91	1.80
Northern Baltic Proper	1.70	1.27	2.54	1.88	2.30	1.38	1.71	1.23		1.85	1.81	1.23	1.85
Gulf of Finland	2.26	1.08	1.62	1.59	2.13	1.23	1.30	1.23		1.64	1.67	1.23	1.67
Åland Sea	1.44	1.15	2.14	1.81	1.72	1.28	N		0.61	1.63	1.50	0.61	1.63
Bothnian Sea	1.36	1.13	1.78	1.75	1.53	1.29	1.55		0.64	1.51	1.46	0.64	1.51
The Quark	1.29	1.03	2.39	1.30	1.24	1.09	N	N	0.48	1.50	1.20	0.48	1.50
Bothnian Bay	1.25	1.11	0.85	1.05	1.17	1.23	N		0.29	1.03	1.18	0.29	1.18

*Included as test.

Box 2. Note on Danish measurements of total nitrogen and total phosphorus

Denmark has discovered that since 2010 two different methods have been used to determine the content of total nitrogen (TN) and total phosphorus (TP) in Danish water samples from both freshwater and marine systems. Traditionally, samples have been analyzed with an autoclave procedure which gives the most precise measurement of TN and TP. However, since 2010, a method using UV light has also been applied in various periods of time.

For both marine and freshwater samples the use of the UV method have resulted in concentrations of total nitrogen being systematically underestimated. This might affect content and conclusions in this report in regard to the status assessment of Danish waters. There are indications that the status of TN in Kattegat and Great Belt might change to "not good" when the data are corrected. In regard to TP, the concentrations seem only to be underestimated in freshwater samples, whereas in marine samples a systematic difference between the two methods could not be proven. As a consequence of the underestimated TN and TP concentrations in freshwater samples, the assessment of nutrient input to Danish basins are probably underestimated as well.

Aarhus University is developing a method to correct the data back in time. When corrected data is available a new dataset for Danish waters will be submitted.

4.1 CONFIDENCE IN THE INTEGRATED ASSESSMENT

The final confidence of the integrated assessment was moderate in most of the open sea (Table 8). It was low in the Gulf of Riga, the Åland Sea and the Quark, and high in the Arkona Basin and Bornholm Basin.

The 'final confidence' is the arithmetic mean of 'criteria specific confidences' of 'nutrient levels', 'direct effects and 'indirect effects' (Chapter 3.2). The confidence of 'nutrient levels' ranged from low to high. 'Direct effects' confidence was moderate in ten and high in seven assessment units, and 'indirect effects' confidence was low in five and high in six assessment units. Low 'final confidence' values in the Gulf of Riga, the Åland Sea and the Quark were due to low 'criteria specific confidences' of both 'nutrient levels' and 'indirect effects'. Lowest 'criteria specific confidences' were encountered for 'nutrient levels'.

The 'criteria specific confidence' is the arithmetic mean of the 'indicator confidences', which again consist of 'status and target confidences' (Chapter 3.2). The 'Status confidence' estimate is only based on the number of observations within the assessed season, not taking into consideration aspects of the spatial representation, statistical accuracy or methodological confidence.

For confidence of 'nutrient levels', the underlying indicator confidences were only available for dissolved inorganic nutrients due to lack of agreed target confidences for total nutrients. For dissolved inorganic nitrogen and phosphorus, the target confidences were moderate in all assessment units (Table 9). Status confidences of both dissolved inorganic nutrients were low in six assessment units (the Sound, the Gdansk Basin, the Western Gotland Basin, the Gulf of Riga, the Åland Sea and the Quark), reflecting the low number of observations during assessed season (≤ 5).

In criteria group 'Direct effects', the 'indicator confidence' of chlorophyll-a was high in all assessment units except for in the Kattegat where it was moderate (Table 8). The 'status confidence' of chlorophyll-a was high in most of the assessment units, reflecting sufficient monitoring, whereas the 'target confidence' was moderate for most of the assessment units (Table 9). The indicator confidence of 'water clarity' was high in the western and southern parts of the Baltic Sea, except for Gdansk Basin and the Western Gotland Basin where it was moderate. North from the Baltic Proper, the indicator confidence of 'water clarity' was moderate or low due to low 'status confidence', reflecting inadequate monitoring during the assessment season. For the indicator 'Cyanobacterial bloom index', 'indicator confidence' is not yet available.

In criteria group 'indirect effects' the confidence value was high in the six assessment units where 'oxygen debt' was assessed, and low in the five assessment units where 'State of the soft-bottom macrofauna community' was included.

Table 8. Confidence of the results at indicator level, criteria group level and the integrated eutrophication status level in the open sea sub-basins. Values show the 'Indicator confidence', which is the average of the 'Status confidence' and 'Target confidence' as estimated in HEAT. The confidence rating is grouped into three confidence classes: High (75-100 %; light color), moderate (50-74 %; medium color) and low (<50 %; darkest color). Empty white cells denote no information due to the lack of agreed threshold value or commonly agreed indicator methodology. An 'N' in a grey cell is shown for cases where the indicator is not applicable. The indicator 'State of the soft-bottom macrofauna community' (Zoob) was only included in the Gulf of Riga and north from the Åland Sea. Confidence of the eutrophication state for the pre-core indicator 'Cyanobacterial bloom index' (Cyano) has not yet been agreed. For the core indicators 'Total nitrogen' (TN) and 'Total phosphorus' (TP), 'Target confidence' was not available for calculation of the 'Indicator confidence'. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', DIP= 'Dissolved inorganic phosphorus', Chla= 'Chlorophyll-a', and O_2 = 'Oxygen debt'. The indicator 'State of the soft-bottom macrofauna community' was only included in the Gulf of Bothnia. For more details, see core indicator reports: HELCOM 2018b-j.

	Confidence of the core indicator results									Criteria specific confidence			
	Nutrient levels				Direct effects			Indirect effects		Nutrient levels	Direct effects	Indirect effects	
Assessment unit	DIN	TN	DIP	TP	Chla	Water clarity	Cyano*	O_2	Zoob*				Integrated confidence assessment
Kattegat	75		75		50	75	N	N		75	63		69
Great Belt	50		50		75	75	N	N		50	75		63
The Sound	25		25		75	75	N	N		25	75		50
Kiel Bay	50		50		75	75	N	N		50	75		63
Bay of Mecklenburg	50		50		75	75		N	Not incl.	50	75		63
Arkona Basin	75		75		75	75		N		75	75		75
Bornholm Basin	75		75		75	75		100		75	75	75	75
Gdansk Basin	25		25		75	50		100		25	63	75	54
Eastern Gotland Basin	50		50		75	75		100	Not incl.	50	75	75	67
Western Gotland Basin	25		25		75	50		100	Not incl.	25	63	75	54
Gulf of Riga	25		25		75	25		N	50	25	50	37	37
Northern Baltic Proper	50		50		75	50		100	Not incl.	50	63	75	63
Gulf of Finland	75		50		75	25		100	Not incl.	63	50	75	63
Åland Sea	25		25		75	25	N		50	25	50	37	37
Bothnian Sea	50		50		75	50			50	50	63	37	50
The Quark	25		25		75	25	N	N	50	25	50	37	37
Bothnian Bay	50		50		75	50	N		50	50	63	37	50

*Included as test.

Table 9. Status and target confidence of the results at indicator level in the open sea sub-basins. The values show the 'Status confidence' and 'Target confidence' as estimated in HEAT. The confidence rating is grouped into three confidence classes: High (100 %; light color), moderate (50; medium color) and low (0; darkest color). Empty white cells denote no information due to the lack of agreed threshold value or commonly agreed indicator methodology. An 'N' in a grey cell is shown for cases where the indicator is not applicable. A method to assess status confidence in the pre-core indicator 'Cyanobacterial bloom index' (Cyano) has not yet been agreed. For the core indicators 'Total nitrogen' (TN) and 'Total phosphorus' (TP), 'Target confidence' was not available for calculation of the 'Indicator confidence'. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', DIP= 'Dissolved inorganic phosphorus', Chla= 'Chlorophyll-a', and O_2 = 'Oxygen debt'. The indicator 'State of the soft-bottom macrofauna community' was only included in the Gulf of Bothnia. For more details, see core indicator reports: HELCOM 2018 b-j.

	Status Confidence of the core indicator results									**Target Confidence of the core indicator results**								
	Nutrient levels				**Direct effects**			**Indirect effects**		**Nutrient levels**				**Direct effects**			**Indirect effects**	
Assessment unit	**DIN**	**TN**	**DIP**	**TP**	**Chla**	**Water clarity**	**Cyano[1]**	**O_2**	**Zoob[1]**	**DIN**	**TN**	**DIP**	**TP**	**Chla**	**Secchi**	**Cyano***	**O_2**	**Zoob***
Kattegat	100	100	100	100	100	100	N	N		50		50		0	50	N	N	
Great Belt	50	100	50	100	100	100	N	N		50		50		50	50	N	N	
The Sound	0	50	0	50	100	100	N	N		50		50		50	50	N	N	
Kiel Bay	50		50		100	100	N	N		50		50		50	50	N	N	
Bay of Mecklenburg	50		50		100	100		N		50		50		50	50		N	
Arkona Basin	100		100		100	100		N		50		50		50	50		N	
Bornholm Basin	100		100		100	100		100		50		50		50	50		100	
Gdansk Basin	0	100	0	100	100	50		100		50		50		50	50		100	
Eastern Gotland Basin	50	100	50		100	100		100		50		50		50	50		100	
Western Gotland Basin	0	100	0	100	100	50		100		50		50		50	50		100	
Gulf of Riga	0	100	0	100	100	0		N		50		50		50	50		N	
Northern Baltic Proper	50	100	50	100	100	0		100		50		50		50	100		100	
Gulf of Finland	100	100	50	100	100	0		100		50		50		50	50		100	
Åland Sea	0	0	0	0	100	0				50		50		50	50			
Bothnian Sea	50	100	50	100	100	50				50		50		50	50			
The Quark	0	50	0	50	100	0		N		50		50		50	50		N	
Bothnian Bay	50	100	50	100	100	0				50		50		50	100			

*Included as test.

4.2 COMPARISON TO PREVIOUS ASSESSMENTS

Compared to previous assessment results (2007-2011; HELCOM 2014, 2015c) the integrated eutrophication status has improved in the Gdansk Basin, but deteriorated in four of the seventeen open-sea assessment units (Figure 11). However, a long-term analysis of integrated assessment results using HEAT 3.0 indicate an improving eutrophication status since the mid-1990s in the westernmost parts of the Baltic Sea: the Kattegat, Danish Straits and Arkona Basin (Andersen *et al.* 2017).

The limited improvement in comparison to the previous assessment could in part be attributed to natural variability acting on top of the human induced eutrophication effects. Past nutrient inputs have enhanced the occurrence of oxygen deficiency and led to an excess of nutrients in deep waters of the central Baltic Sea (Figure 10). Further, inflow events of marine water from the North Sea may have caused intrusions of nutrient-rich deep water from the Central Baltic Sea to adjacent areas leading to enhanced anoxia in the receiving areas and hence an enhanced release of phosphorus from the sediments.

For the coastal waters it was not possible to compare assessment results with previous assessments. Previous assessment has used the WFD results of ecological status while the current assessment used HEAT 3.0 to integrate the WFD indicators and these methodologies are not directly comparable. In addition, for some countries the assessment period of 2007-2012 was used for both assessments.

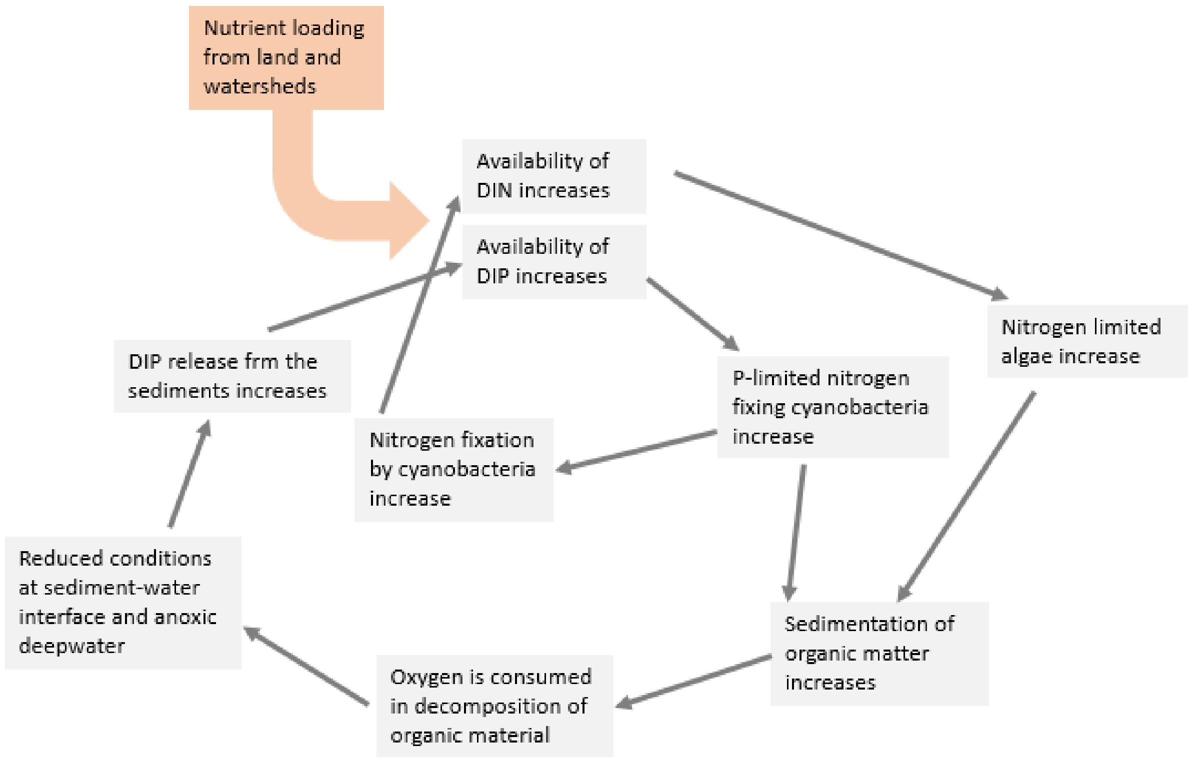
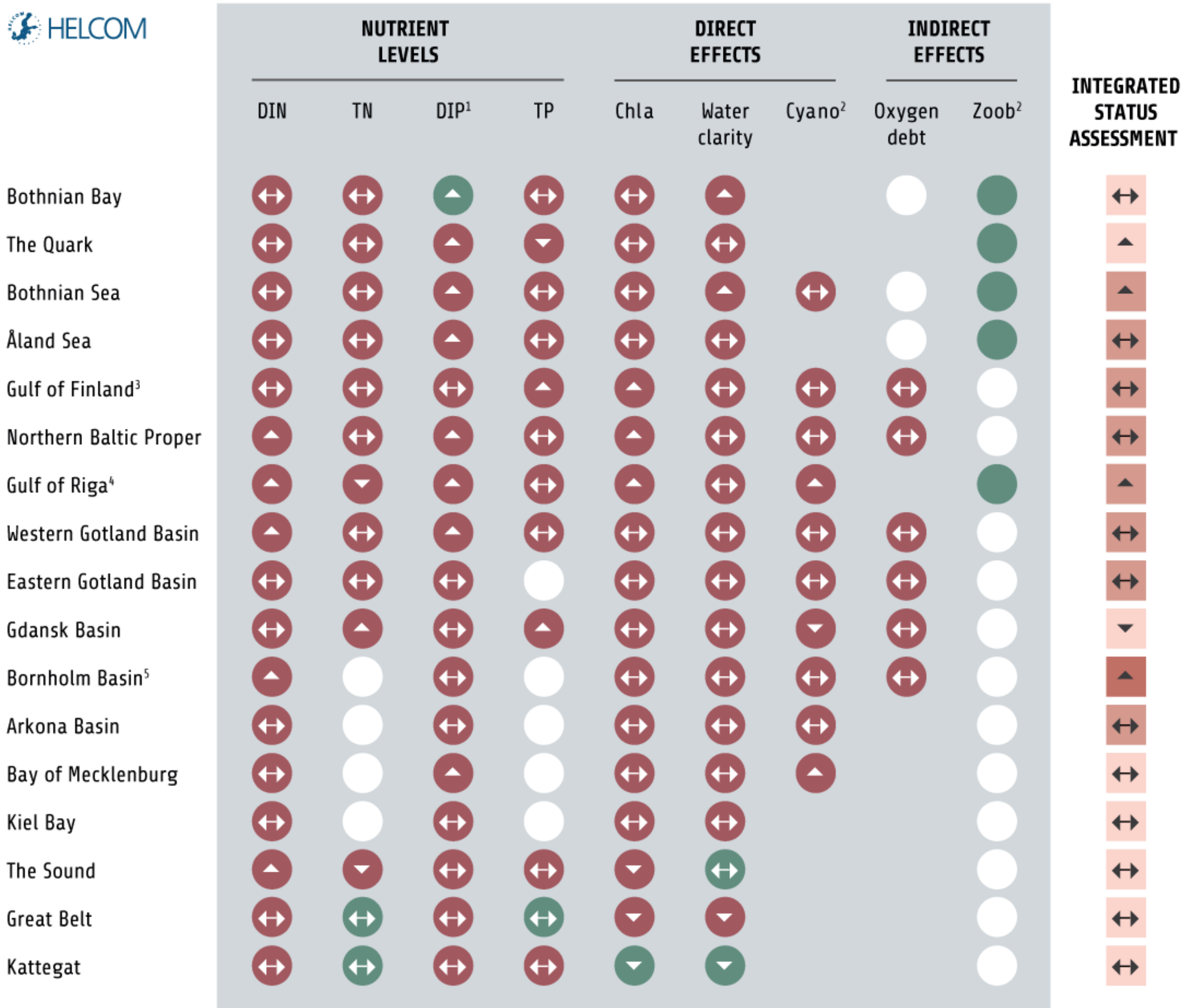


Figure 10. Schematic presentation of the internal feedback processes slowing down the recovery from eutrophication Nutrient loading increases the availability of nutrients for phytoplankton and cyanobacteria, enhancing their growth. The sedimentation of organic matter increases, leading to increased decomposition of organic material and oxygen depletion in bottom waters. In anoxic conditions, release of dissolved inorganic phosphorus (DIP) that has previously accumulated to the sediments is enhanced. The excess availability of DIP increases nitrogen fixation by cyanobacteria and benefits their growth. Nitrogen fixation again increases the availability of dissolved inorganic nitrogen (DIN) for the algae. Simplified from Vahtera *et al.* (2007).



1 For all the northern areas, the increase is due to inflow of saline water which pushes up bottom water with high phosphorus concentrations. This negative development is therefore due to natural variability and temporarily counteracts the efforts to reduce the anthropogenic loadings (Eilola et al. 2014).
2 Included as test
3 The present comparison that shows unchanged conditions does not reflect the positive development in the eastern parts. Reduced phosphorus loading has improved conditions in the eastern part, but this is masked by the inflow of saline water that has increased phosphorus in the western parts of the gulf (Raateoja & Setälä 2016).
4 Lack of monitoring for part of the assessment years increases the uncertainty of the comparison between the two periods.
5 Nutrient concentrations in the Bornholm basin were high due to influence from shallow stations in the Pomeranian Bay and the influence from the plume of river Odra.

Figure 11. Core indicator results for eutrophication 2011-2016, and changes in eutrophication ratios since 2007-2011 by open sea sub-basins. Green circles denote good status and red not good status. The corresponding integrated status assessment result is shown in the last column (see also Figure 7). The symbols indicate if the eutrophication ratio (of the indicator or integrated status as estimated in HEAT) has changed since the last eutrophication assessment in 2007–2011. For the indicator results, a change equal to or more than 15 % was considered to be substantial and is indicated with Δ for an increased eutrophication ratio (deteriorating condition) and with ∇ for a decreased ratio (improving condition). The symbol ↔ indicates a change of less than 15 % between the two compared time periods. For integrated status assessment results (IA status), the symbols reflect if there is a change in the overall status classification on the five-category scale. Empty circles denote no information due to the lack of agreed threshold value or commonly agreed indicator methodology. Absent circles denotes that the indicator is not applicable. Abbreviations used: DIN = 'Dissolved inorganic nitrogen', TN= 'Total nitrogen', DIP= 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chla= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index', O2 = 'Oxygen debt, and 'Zoob'= 'State of the soft bottom macrofauna community' (.Data for comparison was not available for this indicator)'. For more details, see core indicator reports: HELCOM 2018b-j.

4.3 MORE DETAILED RESULTS FROM THE INTEGRATED ASSESSMENT

Proportion of area below good status in regards to eutrophication

The proportion of area below good status in regards to eutrophication for the overall assessment was calculated based on the integrated assessment output shapefile at HELCOM Assessment unit level 4 (2013 Version, with updated coastal areas provided by Estonia and Denmark). The calculations were made using the 'Calculate Geometry' function in ArcGIS, by calculating sum by 'Status' attribute. The results for the whole Baltic Sea as defined by HELCOM marine area are presented in Table 10 part 1. Results for Danish coastal areas was included by adding the area covered by WFD status class "good" as category "Good" and all other WFD status classes as "Not good". Results were also calculated for the Baltic Sea as defined by the MSFD sub-regions (Table 10, part 2), in which case areas which belong to MSFD Region "North Sea" were excluded (Kattegat and the Sound) and only MSFD region "Baltic" was used (See Figure 12).

Table 10.1. Proportion of area **assessed to be below good status** in regards to eutrophication in the whole Baltic Sea, and for open sea and coastal areas, respectively.

HELCOM area	**Area[8] (km2)**			**Percent (%) of area**		
Status	**Baltic Sea**	**Open sea**	**Coastal**	**Baltic Sea**	**Open sea**	**Coastal**
Good	9.900	0	9.900	2	0	9
Not good	40.1000	305.000	96.000	96	100	86
Not assessed	5.900	0	5.900	1	0	5
Total	**416.800**	**305.000**	**111.800**	**100**	**100**	**100**

Table 10.2. Proportion of area assessed to be below good status in regards to eutrophication in the MSFD region "Baltic Sea", and for open sea and coastal areas therein, respectively.

MSFD Baltic	**Area (km2)**			**Percent of area**		
Status	**Baltic Sea**	**Open Sea**	**Coastal**	**Baltic Sea**	**Open Sea**	**Coastal**
Good	8300	0	8300	2.1	0.0	8.1
Not Good	377700	289500	88300	96.4	100.0	86.1
Not Assessed	5900	0	5900	1.5	0	5.8
Total	**391900**	**289500**	**102500**	**100**	**100**	**100**

[8] The areas (km^2) in tables 10.1- 10.2 are rounded and do not necessarily correspond to national estimates

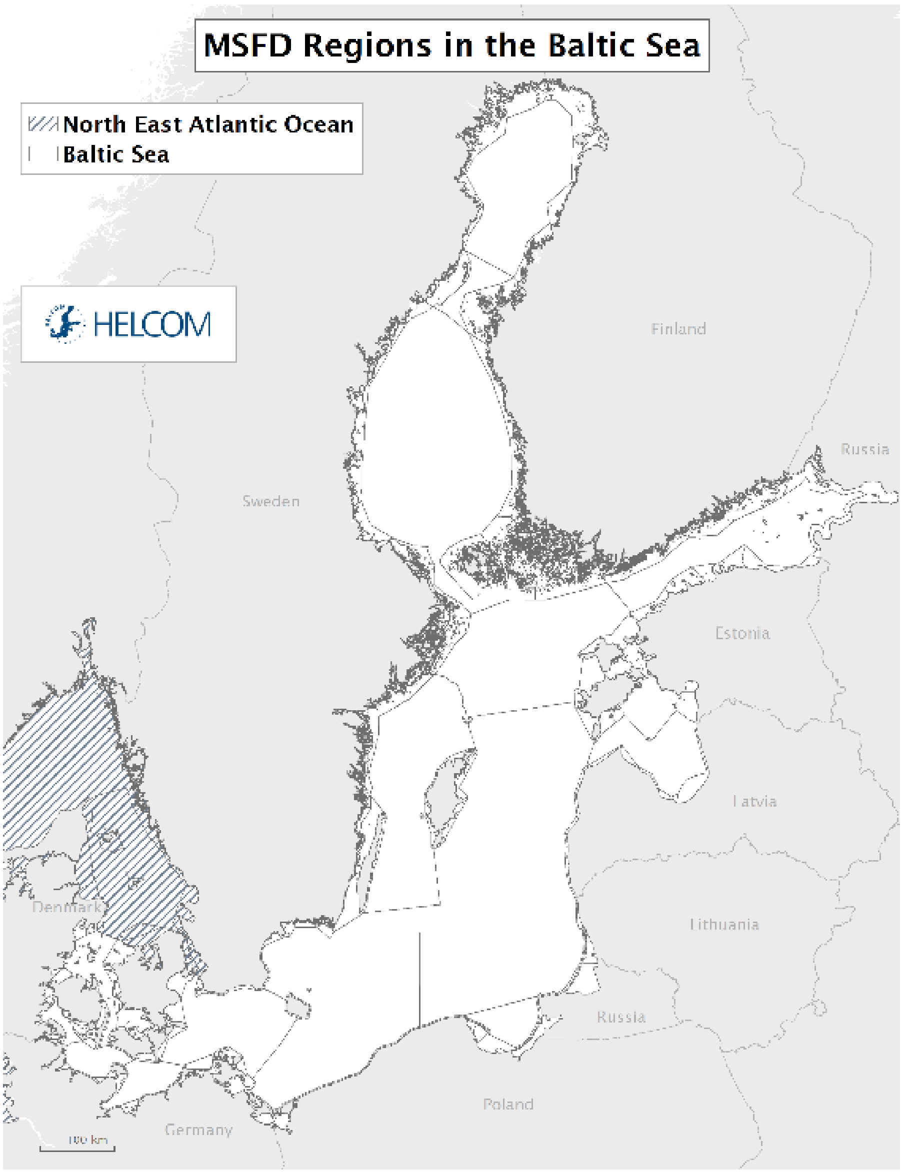


Figure 12. Border between sub-regions North Sea (dashed line) and Baltic Sea (white) according to the Marine Strategy Framework Directive.

Area below good status in regards to eutrophication by country

The proportion of area below good status in regards to eutrophication was calculated by country for the overall assessment by using the assessment shapefile (HELCOM assessment unit level 4 (2013 Version, with updated information on delineation of coastal areas provided by Estonia and Denmark), using the ArcGIS 'Calculate Geometry' function and calculating sum of area by "Status" (Table 11). For coastal areas, the HEAT 3.0 integrated result based on WFD indicators was used in all countries except for Denmark, for which WFD results were used directly. The open sea area of a country was calculated by dividing the open sea assessment units into the national EEZs using HELCOM shapefiles. The results by country are detailed in Table 12, parts 1-9).

Table 11. Overview of proportion of area below good status in regards to eutrophication in the whole Baltic Sea by country (%).

Status	DE	DK	EE	FI	LV	LT	PL	RU	SE
Good	0	1	0	3	0	0	0	0	4
Not good	100	99	100	97	100	100	100	75	96
Not assessed	0	0	0	0	0	0	0	25	0

Table 12.1. Area below good status in regards to eutrophication in Germany given as area and proportion by status class for the open sea and the coastal waters.

Germany				
Status	Open Sea	Area (km2)[9]	% of open sea	% of total
Good		0	0	0
Not Good		11,300	100	73
Not assessed		0	0	0
	Coastal		% of coastal	% of total
Good		0	0	0
Not Good		4,200	100	27
Not assessed		0	0	0
	Total			% of total
Good		0		0
Not Good		15,500		100
Not assessed		0		0

Table 12.2. Area below good status in regards to eutrophication in Denmark given as area and proportion by status class for the open sea and the coastal waters for whole Baltic Sea (HELCOM area) and the MSFD "Baltic subregion".

Denmark: Baltic Sea				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		29000	100	62
Not assessed		0	0	0,0
Status	Coastal	Area (km2)	% of coastal	% of total
WFD: Good		340	2	1
WFD: Moderate		6,600	37	14
WFD: Moderate pot.		17	0	0
WFD: Poor		9,300	53	20
WFD: Bad		1,400	8	3
Not assessed		0	0	0
Status	Total	Area (km2)		% of total
Good		340		1
Not Good		46,700		99
Not assessed		0		0

[9] The areas (km2) in tables 12.1-12.9 are rounded and do not necessarily correspond to national estimates.

Table 12.3 Area below good status in regards to eutrophication in Estonia given as area and proportion by status class for the open sea and the coastal waters.

Estonia				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		22,000	100	60
Not assessed		0	0	0
	Coastal		% of coastal	% of total
Good		0	0	0
Not Good		14,500	100	40
Not assessed		0	0	0
	Total			% of total
Good		0	0	0
Not Good		36,500	100	100
Not assessed		0	0	0

Table 12.4. Area below good status in regards to eutrophication in Finland given as area and proportion by status class for the open sea and the coastal waters.

Finland				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		49,000	100	60
Not assessed		0	0	0
	Coastal	Area (km2)	% of coastal	% of total
Good		2,800	9	3
Not Good		30,000	91	37
Not assessed		0	0	0
	Total			% of total
Good		2,800		3
Not Good		79,000		97
Not assessed		0		0

Table 12.5. **Area below good status in regards to eutrophication in Latvia** given as area and proportion by status class for the open sea and the coastal waters.

Latvia				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		26,000	100	92
Not assessed		0	0	0
	Coastal	Area (km2)	% of coastal	% of total
Good		0	0	0
Not Good		2,300	100	8
Not assessed		0	0	0
	Total			% of total
Good		0		0
Not Good		28,300		100
Not assessed		0		0

Table 12.6. **Area below good status in regards to eutrophication in Lithuania** given as area and proportion by status class for the open sea and the coastal waters.

Lithuania				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		6,200	100	91
Not assessed		0	0	0
	Coastal	Area (km2)	% of coastal	% of total
Good		0	0	0
Not Good		600	100	9
Not assessed		0	0	0
	Total			% of total
Good		0		0
Not Good		6,800		100
Not assessed		0		0

Table 12.7. **Area below good status in regards to eutrophication in Poland** given as area and proportion by status class for the open sea and the coastal waters.

Poland				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		27,000	100	91
Not assessed		0	0	0
	Coastal	Area (km2)	% of coastal	% of total
Good		0	0	0
Not Good		2,600	100	9
Not assessed		0	0	0
	Total			% of total
Good		0		0
Not Good		29,600		100
Not assessed		0		0

Table 12.8. **Area below good status in regards to eutrophication in Russia** given as area and proportion by status class for the open sea and the coastal waters.

Russia				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		17,500	100	75
Not assessed		0	0	0
	Coastal	Area (km2)	% of coastal	% of total
Good		0	0	0
Not Good		0	0	0
Not assessed		5,800	100	25
	Total			% of total
Good		0		0
Not Good		17,500		75
Not assessed		5,800		25

Table 12.9. Area below good status in regards to eutrophication in Sweden given as area and proportion by status class for the open sea and the coastal waters for whole Baltic Sea (HELCOM area) and the MSFD "Baltic subregion".

Sweden: Baltic Sea				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		117,000	100	79
Not assessed		0	0	0
	Coastal	Area (km2)	% of coastal	% of total
Good		5,800	18	4
Not Good		26,100	82	18
Not assessed		0	0	0
	Total			% of total
Good		5,800		4
Not Good		143,100		100
Not assessed		0		0

Sweden: MSFD Baltic region				
Status	Open Sea	Area (km2)	% of open sea	% of total
Good		0	0	0
Not Good		112,400	100	79
Not assessed		0	0	0
	Coastal	Area (km2)	% of coastal	% of total
Good		4,900	17	3
Not Good		24,100	83	17
Not assessed		0		0
	Total			% of total
Good		4,900		0
Not Good		136,500		100
Not assessed		0		0

Coastal waters

The indicators included in the assessment of coastal areas are mainly derived from the assessment of ecological status under the Water framework directive for eight countries. There is variation in what indicators were used in different national waters of the Baltic Sea, decreasing the geographical comparability. Altogether, 37 coastal indicators were reported and used (Table 13).

Table 13. Overview of the coastal indicators used by HELCOM Contracting Parties.

	Indicators	**Denmark**	**Estonia**	**Finland**	**Germany**	**Latvia**	**Lithuania**	**Poland**	**Sweden**
Nutrients	Dissolved inorganic nitrogen					X		X	X
	Total nitrogen		X	X	X		X	X	X
	Dissolved inorganic phosphorus					X		X	X
	Total phosphorus		X	X	X		X	X	X
Direct effects	Chlorophyll-a	X	X	X	X	X	X	X	X
	Water clarity		X	X	X	X	X	X	X
	Phytoplankton biovolume*		X	X	X	X			X
Indirect effects - Macrophytes	Benthic macroflora depth distribution		X						
	Depth limit of eelgrass	X							
	Depth limit of *Fucus vesiculosus*		X						
	Furcellaria lumbricalis depth distribution			X		X	X		
	Macrophytes sheltered			X					
	Macrovegetation Quality Element			X	X			X	X
	Phytobenthos Ecological Quality index					X			
	Proportion of perennial species		X						
Indirect effects – Macrozoobenthos	BBI Index			X					
	Benthic Quality index					X			X
	Large invertebrates FDI		X						
	Large invertebrates KPI		X						
	Zoobenthos Quality Element	X	X		X		X	X	
Indirect effects - Oxygen	Oxygen							X	X

* In Germany biovolume is assessed as part of the national multimetric Phytoplankton index for coastal waters (Sagert *et al.* 2008).

Based on the integrated assessment, 86 % of the coastal waters were not in good status, 9 % were in good status and 5 % were not assessed, while for the open sea, 100 % of the area was not in good status.

In particular, indirect effects achieved good status in many of the coastal areas, including Swedish coastal areas and many Estonian and Finnish coastal areas (see Figure 8). Coastal waters in good integrated status according to the assessment were mainly located in the Bothnian Bay, Quark, Bothnian Sea and the Kattegat.

Given that eutrophication is predominantly caused by excessive riverine nutrient inputs it would be expected that the eutrophication status of the coastal waters would not be better than that of the adjacent open sea areas. According to the current assessment this is not always the case. A reason for this might be the differences in coastal indicators between Contracting Parties, including:

1. Different indicators used for the same criterion. This was the case especially regarding indicators of macrovegetation, macrozoobenthos and nutrients, but to some extent also bottom oxygen and phytoplankton. Some Contracting Parties reported multi-parametric indicators (in practice WFD quality elements), whereas others reported single indicators.

2. Distinctly different assessment seasons for the corresponding indicators. Changes in the indicator evaluation season could alter the ecological relevance of the indicator completely. In some cases the difference was more subtle, differing only by a month or two. This was common for indicators on nutrients, chlorophyll-*a*, and water clarity.

3. Different statistical approaches for the same indicator. For example, the bottom oxygen indicator could be salinity normalized in some areas but not in others.

4. Differences in target-setting principles for the same indicator, especially for indicators that have not been inter-calibrated under the WFD, such as bottom oxygen.

5. Lack of harmonization of the targets used in national waters and in adjacent open sea, for example, nutrient concentration targets in the Finnish part of the Gulf of Bothnia.

6. Different reporting period. The official reporting period for coastal areas was the same as for open sea areas, in other words 2011-2016. However, the previous WFD reporting period 2007-2012 was applied by many Contracting Parties, including also other time periods, depending on indicator and Contracting Party.

For detailed assessment result of coastal areas per indicator and per country see Appendix 1.

Chapter 5. Core indicator evaluations and changes over time

Assessment of longer term trends additionally show possible effects of nutrient reduction efforts over a larger time scale. When assessing a shorter time span, such as when comparing two assessment periods of six year each, as above, natural variability in climate and hydrography may result in temporarily worsened conditions even if the long term development shows a different pattern. A recent example is the major saline inflow which occurred in December 2014, which has caused intrusions of deep sea water with high phosphate concentration into surface waters (Finnish environment institute 2016). Further, the Baltic Sea has a long water residence time, lasting over decades. Hence, pools of nutrients and organic matter which have accumulated over decades with high nutrient inputs are very large and will delay the improvement in environmental conditions.

The year 1990 was chosen as the starting point, as it represents approximately the situation with maximum loadings to the Baltic Sea and hence a potential turning point for environmental conditions. The long term development was assessed using the Mann-Kendall non-parametric test. Data for nutrient levels, chlorophyll-a, and water clarity were provided by HELCOM Contracting Parties via the HELCOM COMBINE database. In addition, trends in the 'Cyanobacterial bloom index' were evaluated for the Eastern Gotland Basin, Northern Baltic Proper and Gulf of Finland, based on data on 'areal fraction with cyanobacteria accumulations' (FCA) and sub-basin division presented in Kahru and Elmgren (2014) and correlation of FCA with 'cyanobacterial surface accumulations' , as presented by Anttila *et al.* (2018). For 'Oxygen debt', the long-term trend is presented for the Baltic Proper based on the data and sub-basin division of HELCOM (2013b).

Analyses of developments since 1990 show an improving eutrophication status in the westernmost parts of the Baltic Sea (Table 14). Levels of nitrogen are predominantly decreasing, with the exception of some sub-basins in the southern Baltic Sea. The results can be viewed as responses to substantial decreases in nitrogen loadings, proving that the nutrient reductions are effective. Phosphorus concentrations do not show the same improvement. For most areas the levels of phosphorus are constant or even increasing, with the exception of a decrease in total phosphorus concentrations in the Great Belt and Kiel Bay. This result reflects that phosphorus is stored in the sediment to a much higher degree than nitrogen, and the present conditions additionally encompass previous high inputs. In addition, the aforementioned major saline inflow has affected the situation in recent years. Ongoing reductions in phosphorus input are expected to lead to decreasing phosphorous concentrations over the coming years.

Table 14. Trends in eutrophication core indicators representing nutrient levels and direct effects in the open sea during 1990-2016. Decreasing trends are presented by downward arrows (↘) and increasing trends are presented by upward arrows (↗), Blue colour indicates a significant improving condition and orange colour a significant deteriorating condition, based on the Mann-Kendall non parametric tests. Two-headed arrows are shown if there was no significant trend at $p<0.05$. Note that for water clarity increasing trend means improving condition.

	Nutrient levels				**Direct effects**	
	Dissolved inorganic nitrogen	**Total nitrogen**	**Dissolved inorganic phosphorus**	**Total Phosphorus**	**Chlorophyll-a**	**Water clarity**
Assessment unit	Dec–Feb	All year	Dec–Feb	All year	Jun– Sep	Jun–Sep
Kattegat	↔	↘	↔	↔	↘	↗
Great Belt	↘	↘	↔	↘	↘	↗
The Sound[10]	↘	↘	↔	↔	↘	↔
Kiel Bay	↘	↘	↔	↘	↘	↔
Bay of Mecklenburg	↘	↔	↔	↔	↔	↔
Arkona Basin	↘	↔	↔	↔	↔	↘
Bornholm Basin[11]	↔	↗	↔	↗	↗	↘
Gdansk Basin	↘	↗	↔	↔	↔	↔
Eastern Gotland Basin	↘	↗	↔	↔	↔	↔
Western Gotland Basin	↘	↔	↔	↗	↔	↘
Gulf of Riga	↔	↘	↔	↔	↔	↔
Northern Baltic Proper	↔	↘	↔	↗	↔	↘
Gulf of Finland	↔	↘	↔	↔	↔	↔
Åland Sea	↘	↘	↗	↔	↔	↔
Bothnian Sea	↘	↘	↔	↔	↔	↔
The Quark	↘	↘	↔	↔	↔	↔
Bothnian Bay	↘	↔	↔	↔	↔	↔

[10] Result may be changed due to planned changes in input data.

[11] Result for the Bornholm Basin may be subject to change, to be clarified.

A summary of the indicator evaluations and evaluation of how they have changed over time is given below, separately for indicators representing nutrient levels, direct and indirect effects. More details about each of the agreed HELCOM core indicators are given in the core indicator reports[12].

5.1 CORE INDICATOR RESULTS: NUTRIENT LEVELS

The concentrations of dissolved inorganic nitrogen and total nitrogen did generally not achieve the threshold value with the exception of Kattegat and Great Belt where the threshold values were achieved for total nitrogen (Table 15)[13]. The highest eutrophication ratios occurred for dissolved inorganic nitrogen in the Gulf of Riga, the Gulf of Finland, and the Bornholm Basin. Average concentrations in the Bornholm Basin were high due to influence from shallow stations in the Pomeranian Bay under influence from the river Odra plume[14].

[12] Available online via the list at http://www.helcom.fi/baltic-sea-trends/indicators/

[13] This refers to the HELCOM threshold values, which are not identical to the OSPAR threshold values.

[14] Reflecting a not uniform distribution of samples, with more sampling in shallow than deeper stations.

Table 15. Core indicator results for nutrient levels in the open sea for years 2011–2016. Values show the eutrophication ratios of the indicators and the criteria group "Nutrient levels", as estimated in HEAT 3.0. Shades of green and red represent the five status categories that are used in the integrated assessment. White cells denote that the sub-basin was not assessed in the open sea, due to the lack of agreed threshold value or commonly agreed indicator methodology. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', TN= 'Total nitrogen', DIP= 'Dissolved inorganic phosphorus', TP = 'Total phosphorus'. For more details, see core indicator reports: HELCOM 2018b-e.

Assessment unit	DIN	TN	DIP	TP	Group results
Kattegat	1.18	0.90	1.09	1.10	1.07
Great Belt	1.29	0.75	1.11	0.80	0.99
The Sound	1.82	1.03	1.52	1.16	1.38
Kiel Bay	1.07		1.13		1.10
Bay of Mecklenburg	1.48		1.43		1.45
Arkona Basin	1.37		1.72		1.54
Bornholm Basin	3.73		2.19		2.96
Gdansk Basin	1.09	1.46	1.45	1.35	1.35
Eastern Gotland Basin	1.36	1.38	1.95		1.66
Western Gotland Basin	1.64	1.38	2.04	1.66	1.68
Gulf of Riga	2.00	1.05	2.54	1.34	1.80
Northern Baltic Proper	1.70	1.27	2.54	1.88	1.85
Gulf of Finland	2.26	1.08	1.62	1.59	1.64
Åland Sea	1.44	1.15	2.14	1.81	1.63
Bothnian Sea	1.36	1.13	1.78	1.75	1.51
The Quark	1.29	1.03	2.39	1.30	1.50
Bothnian Bay	1.25	1.11	0.85	1.05	1.03

Winter concentrations of dissolved inorganic nitrogen have shown an increasing trend up until the early 1990s, but the increase has thereafter ceased throughout the Baltic Sea. They have decreased significantly in twelve of the seventeen sub-basins since the 1990s (Table 14, Figure 13, and Appendix 2). Total nitrogen concentrations decreased significantly between 1990 and 2016 in ten of the sub-basins, but they increased in the Bornholm Basin, Gdansk Basin and the Eastern Gotland Basin (Figure 14, Appendix 2). Increasing variability is likely attributed to increased monitoring frequency in several sub-basins. In the Bornholm Basin this also reflects influence from the river Odra.

In more recent time, comparing the last five year assessment period (2007–2011) to the current one (as presented in Figure 11 above), dissolved inorganic nitrogen concentrations have increased substantially in four out of 15 addressed sub-basins. Concentrations of total nitrogen have decreased in the Sound and the Gulf of Riga and increased in the Gdansk Basin compared to the period 2007–2011 (Figure 11).

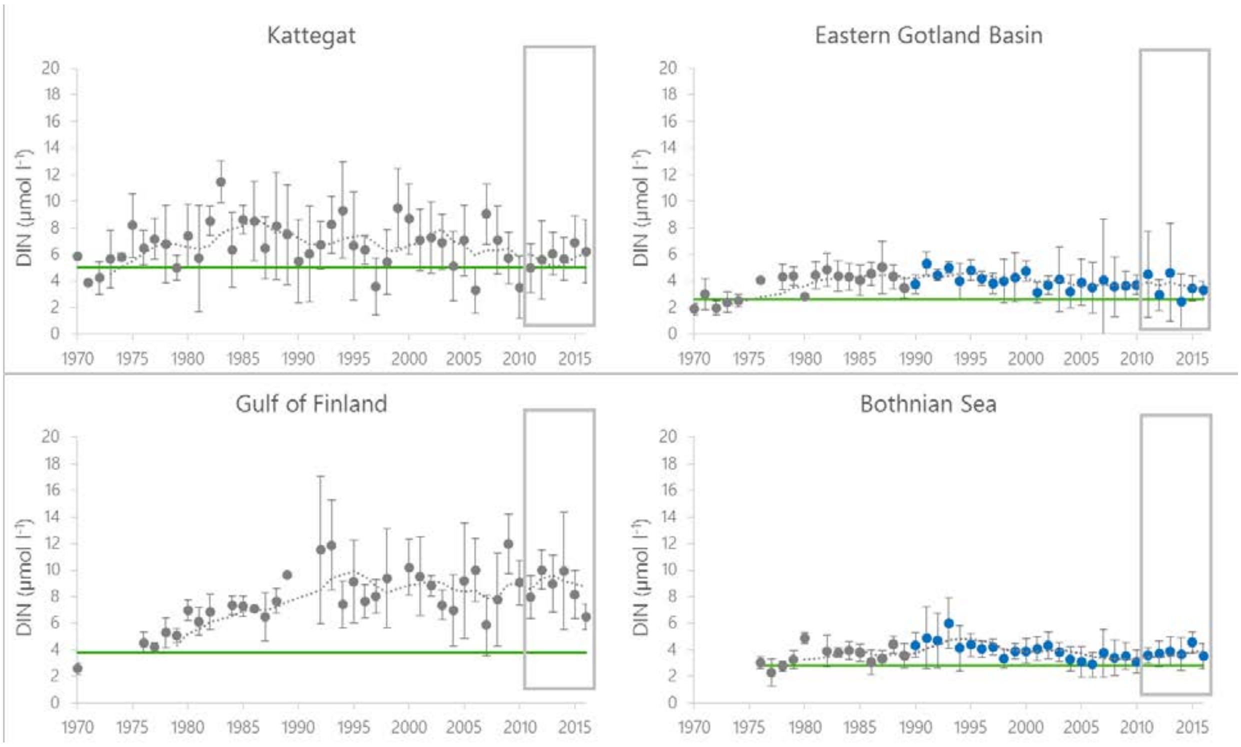


Figure 13. Example of long term trends in nutrient levels in the Baltic Sea: Temporal development of winter dissolved inorganic nitrogen concentrations in the Kattegat, Eastern Gotland Basin, Gulf of Finland and Bothnian Sea. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines indicate the indicator threshold values. Significance of the trends was assessed with the Mann-Kendall tests for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue data points. None of these examples showed significant deteriorating trend. Results for the other sub-basins are shown in Appendix 2.

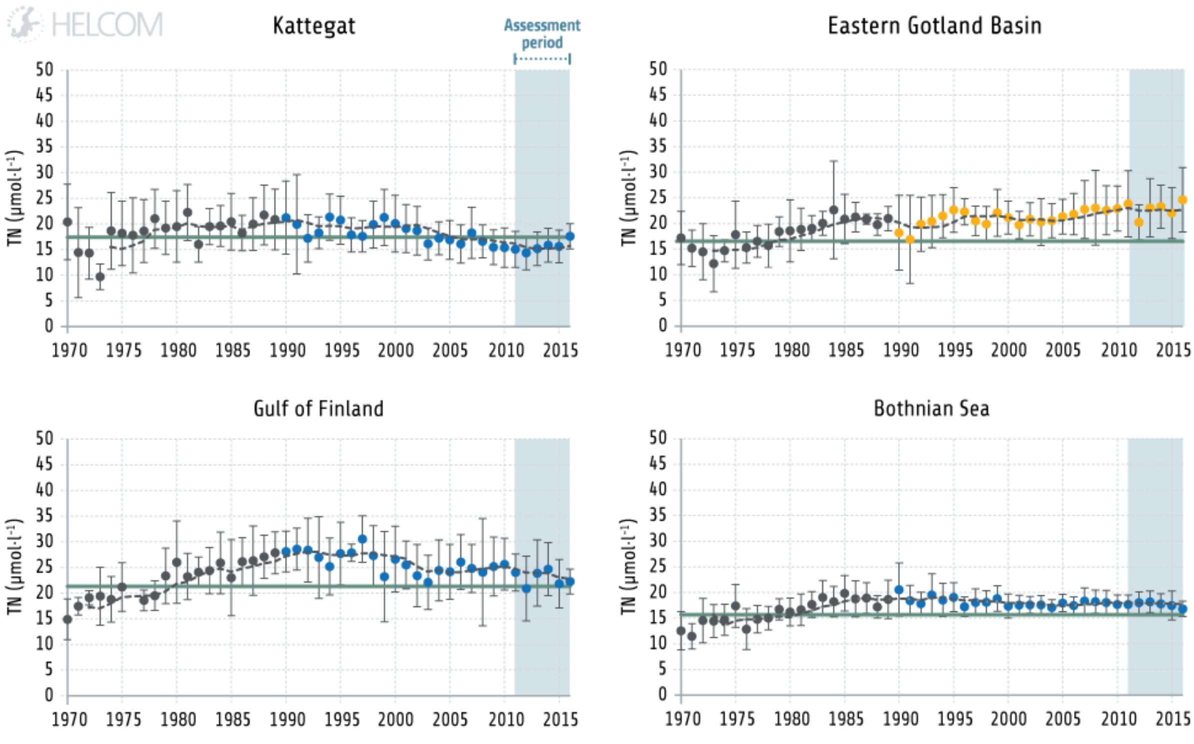


Figure 14. Example of long term trends in nutrient levels in the Baltic Sea: Temporal development of total nitrogen concentrations in the Kattegat, Eastern Gotland Basin, Gulf of Finland and Bothnian Sea. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines indicate the indicator threshold values. Significance of the trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange data points. Results for the other sub-basins are shown in Appendix 2.

The indicator for dissolved inorganic phosphorus achieved the threshold value only in the Bothnian Bay, and total phosphorus achieved it only in the Great Belt (Table 14). A notable increase in total phosphorus was seen in the 1960s and 1970s. This increase ceased around 1990, and relatively large fluctuations have occurred over time (Figure 15). During the assessed time period 1990-2016, an increase in concentrations of dissolved inorganic phosphorus occurred in one sub-basin, the Åland Sea (Table 13, Appendix 2). Concentrations of total phosphorus increased significantly in the Northern Baltic Proper, the Bornholm Basin and the Western Gotland Basin, but decreased in the Great Belt and Kiel Bay (Figure 16).

In comparison to the latest assessment period (2007–2011) the current levels of dissolved inorganic phosphorus are higher (>15 %) in eight of the 17 sub-basins (Figure 11). Total phosphorus concentrations have increased substantially in the Gdansk Bay and the Gulf of Riga and decreased in the Northern Baltic Proper and the Quark. In areas with deep water oxygen deficiency, increases in phosphorus concentrations can at least partly be attributed to release of phosphorus from sediments during transition to anoxic conditions (Conley *et al.* 2002, 2009, Lehtoranta *et al.* 2016).

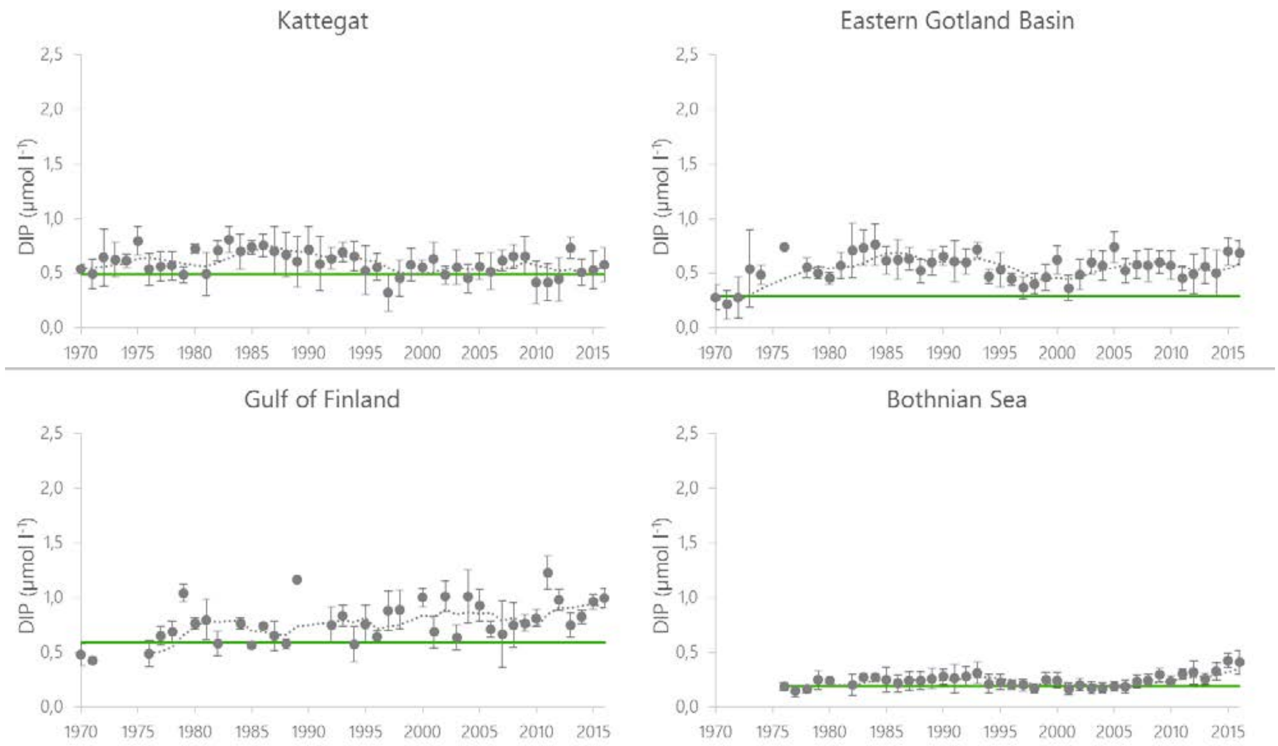


Figure 15. Example of long term trends in nutrient levels in the Baltic Sea: Temporal development of dissolved inorganic phosphorus (DIP) concentrations in winter in the Kattegat, the Eastern Gotland Basin, the Bothnian Sea and the Gulf of Finland. Dashed lines show the five-year moving averages and error bars are the standard deviations. Green lines indicate the indicator threshold values. Significance of the trends was assessed with the Mann-Kendall test for period 1990-2016. None of these examples showed a significant trend ($p> 0.05$). Results for the other sub-basins are shown in Appendix 2.

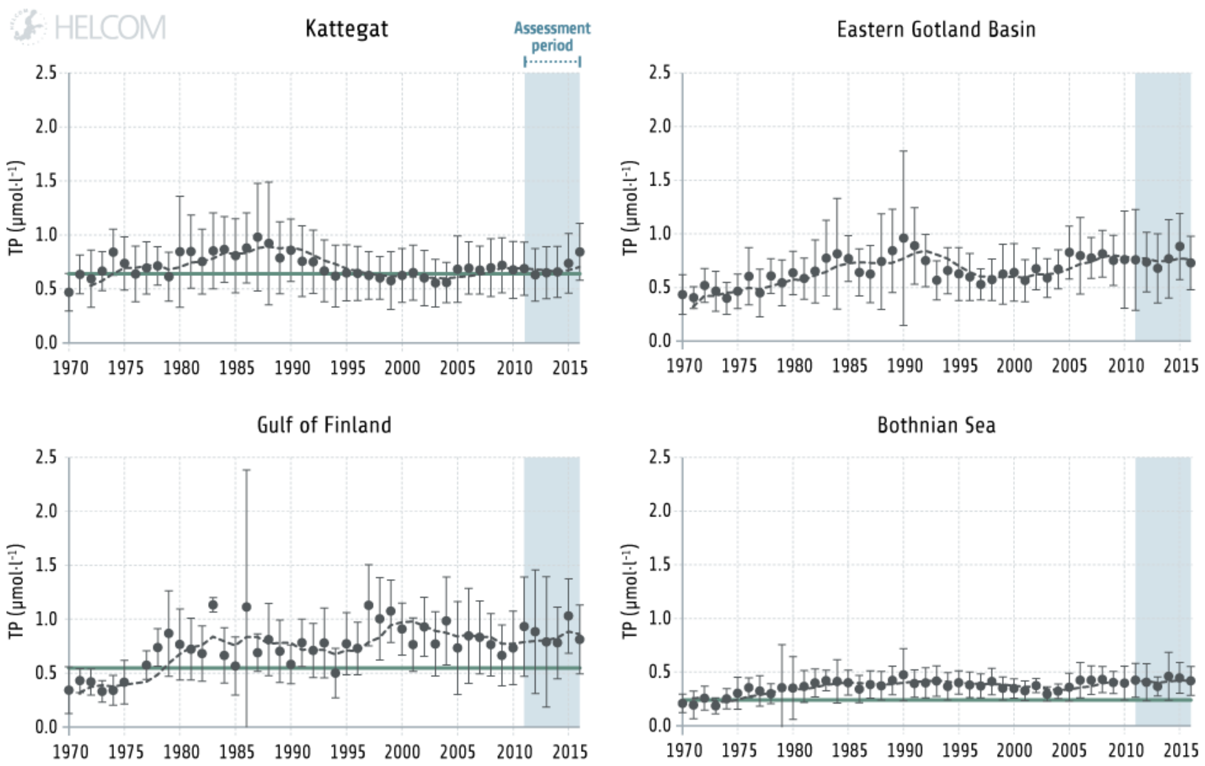


Figure 16. Example of long term trends in nutrient levels in the Baltic Sea: Temporal development of total phosphorus concentrations in winter in the Kattegat, the Eastern Gotland Basin, the Bothnian Sea and the Gulf of Finland. Dashed lines show the five-year moving averages and error bars are the standard deviations. Green lines indicate the indicator threshold values. Significance of the trends was assessed with the Mann-Kendall test for period from 1990-2016. None of these examples showed a significant trend ($p > 0.05$). Results for the other sub-basins are shown in Appendix 2.

5.2 CORE INDICATOR RESULTS: DIRECT EFFECTS

None of the core indicators for direct effects, namely 'Chlorophyll-a' and 'Water clarity', nor the pre-core indicator 'Cyanobacterial bloom index15 achieved the threshold value east of the Sound (Table 16). The indicator for chlorophyll-*a* achieved the threshold value in the Kattegat, and that for water clarity in the Kattegat and the Sound.

The chlorophyll concentrations have remained essentially unchanged during the past few decades (1990-2016), with the exception of the most western parts of the Baltic Sea, where it shows decreasing trends (Table 14, Figure 17, Appendix 2). The result corresponds well with decreases in nitrogen inputs and concentrations in the western parts, where nitrogen is considered the most limiting nutrient for phytoplankton growth. In the central and eastern parts of the Baltic Sea, where summer chlorophyll-*a* concentration is mainly related to phosphorus concentrations the indicator shows no changes. A deteriorating trend was detected only in the Bornholm Basin, which is attributed to influence from measurements at shallow stations in the Pomeranian Bay and outflow from the river Odra.

Compared to the previous five year period (2007–2011), chlorophyll-*a* concentrations have decreased in the Kattegat, Great Belt and the Sound, but increased in the Northern Baltic Proper and the Gulf of Riga (Figure 11).

[15] Included as test.

Table 16. Core indicator results for direct effects of eutrophication in the open sea for years 2011–2016. Values show the eutrophication ratios of the indicator and the criteria group "Direct effects", as estimated in HEAT 3.0. Shades of green and red denote the five status categories applied in the integrated assessment (Table 4). An 'N' is shown for cases where the indicator is not applicable. Abbreviations used: Chla= 'Chlorophyll-a', Cyano = 'Cyanobacterial bloom index'. Asterix denotes that the indicator has not been adopted in HELCOM yet and is currently tested. For more details, see core indicator reports: HELCOM 2018f-h.

Assessment unit	Chla	Water clarity	Cyano*	Group results
Kattegat	0.63	0.81	N	0.72
Great Belt	1.18	1.12	N	1.15
The Sound	1.05	0.99	N	1.02
Kiel Bay	1.08	1.07	N	1.07
Bay of Mecklenburg	1.30	1.34	1.29	1.31
Arkona Basin	1.44	1.31	1.06	1.31
Bornholm Basin	2.27	1.35	1.12	1.66
Gdansk Basin	1.59	1.13	1.19	1.32
Eastern Gotland Basin	1.53	1.14	1.10	1.28
Western Gotland Basin	2.20	1.32	1.11	1.62
Gulf of Riga	1.50	1.37	1.71	1.52
Northern Baltic Proper	2.30	1.38	1.71	1.81
Gulf of Finland	2.13	1.23	1.30	1.67
Åland Sea	1.72	1.28	N	1.50
Bothnian Sea	1.53	1.29	1.55	1.46
The Quark	1.24	1.09	N	1.20
Bothnian Bay	1.17	1.23	N	1.18

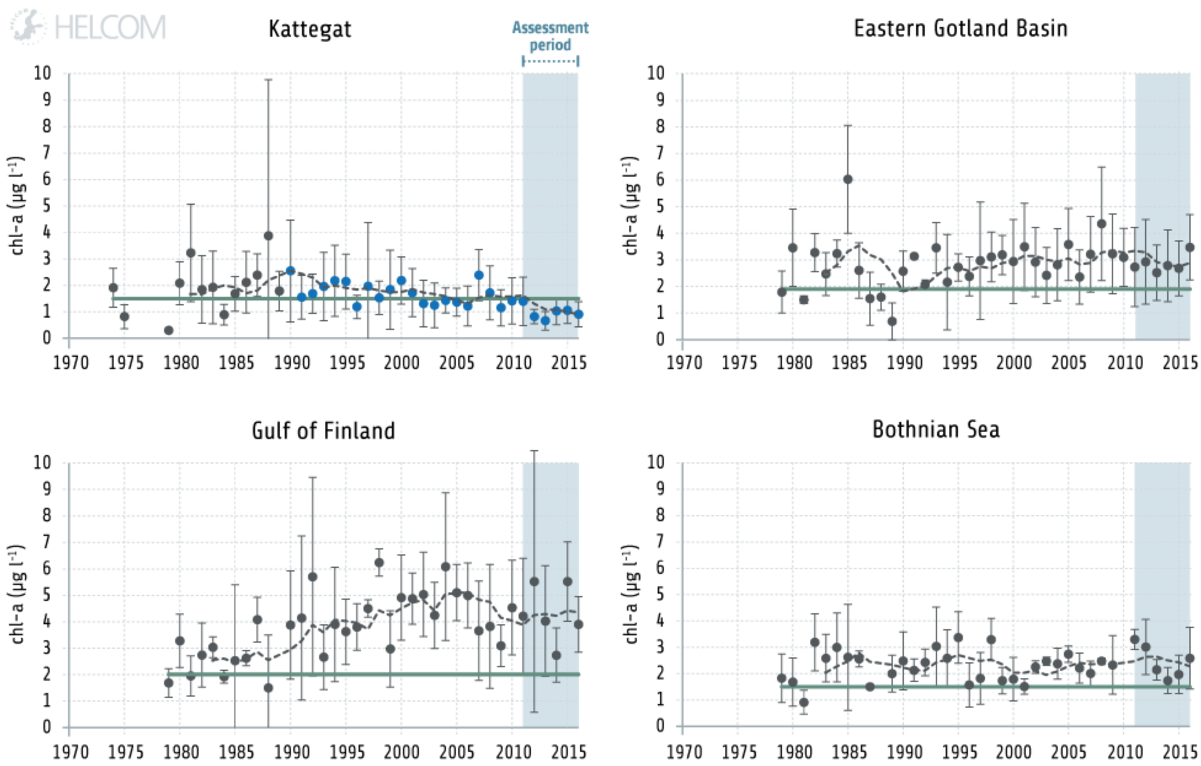


Figure 17. Example of long term trends in direct effects of eutrophication in the Baltic Sea: Temporal development of chlorophyll-a concentrations in summer in the Kattegat, the Eastern Gotland Basin, the Bothnian Sea and the Gulf of Finland. Dashed lines show the five-year moving averages and error bars are the standard deviation. Green lines indicate the indicator threshold values. Significance of the trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue data points. None of these examples showed significant deteriorating trend. Results for the other sub-basins are shown in Appendix 2.

The long-term series for water clarity show a steadily deteriorating situation over several decades, most profoundly in the north-eastern sub-basins (Fleming-Lehtinen and Laamanen 2012). In more recent years, however, the decrease in water clarity has levelled off across most of the Baltic Sea (Figure 18, Appendix 2). Looking over the time period 1990-2016, water clarity has decreased in four of the 17 sub-basins, and has increased (improved) in the Kattegat and the Great Belt.

Water clarity is affected by the abundance of phytoplankton (which is related to eutrophication) but is also affected by the total amount of organic matter in the system. Particulate as well as dissolved organic matter affect the attenuation of light, and both of them have eutrophication and non-eutrophication related components. Eutrophication is attributed to the portion of organic matter and biomass produced within the sea, in the form of either phytoplankton or other organic matter.

As the total amount of organic matter in the system is still at a high level after many decades of elevated nutrient inputs, water clarity is not expected to decrease until the pools of organic matter are degraded or washed out of the Baltic Sea. Recovery is expected to take decades, although improvements in the most northern parts are promising.

In comparison to the period 2007–2011, water clarity has improved in three western sub-basins and decreased (deteriorated) in the Bothnian Bay and the Bothnian Sea under 2011-2016 (Figure 11).

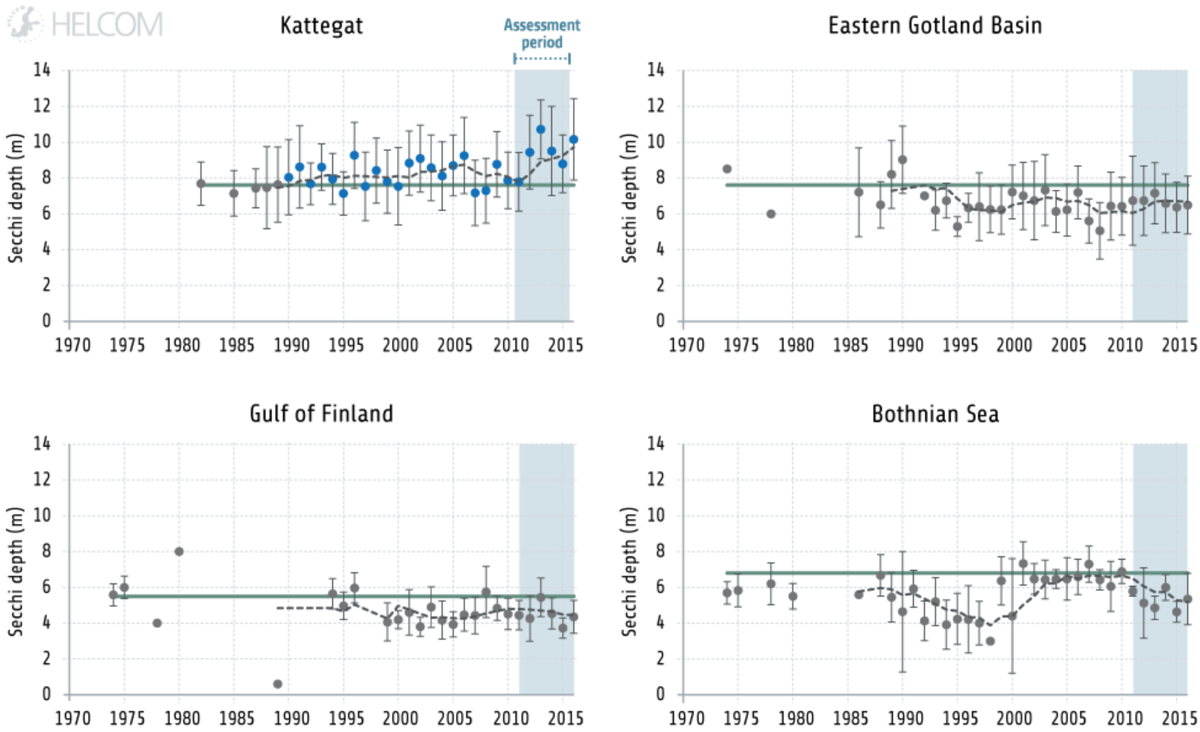


Figure 18. Example of long term trends in direct effects of eutrophication in the Baltic Sea: Temporal development of water clarity in the Kattegat, the Eastern Gotland Basin, the Bothnian Sea and the Gulf of Finland. Dashed lines show the five-year moving averages and error bars the standard deviations. Green lines indicate the indicator threshold values. Significance of the trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue data points. None of these examples showed a significant deteriorating trend. Results for the other sub-basins are shown in Appendix 2.

The 'Cyanobacterial bloom index'[16] did not achieve the threshold value in any of the ten sub-basins where it was tested. The worst status was indicated for the Gulf of Riga, the Northern Baltic Proper and the Bothnian Sea. Long-term data was available for the Eastern Gotland Basin, the Northern Baltic Proper and the Gulf of Finland, showing a deteriorating trend in the northern Baltic Proper during 1990-2016 (Table 14, Figure 19). Compared to the previous five year period 2007–2011, the 'Cyanobacterial bloom index' is further deteriorated in the Gulf of Riga and the Bay of Mecklenburg and improved in the Gdansk Basin during the current assessment period 2011-2016 (Figure 11).

[16] Included as test.

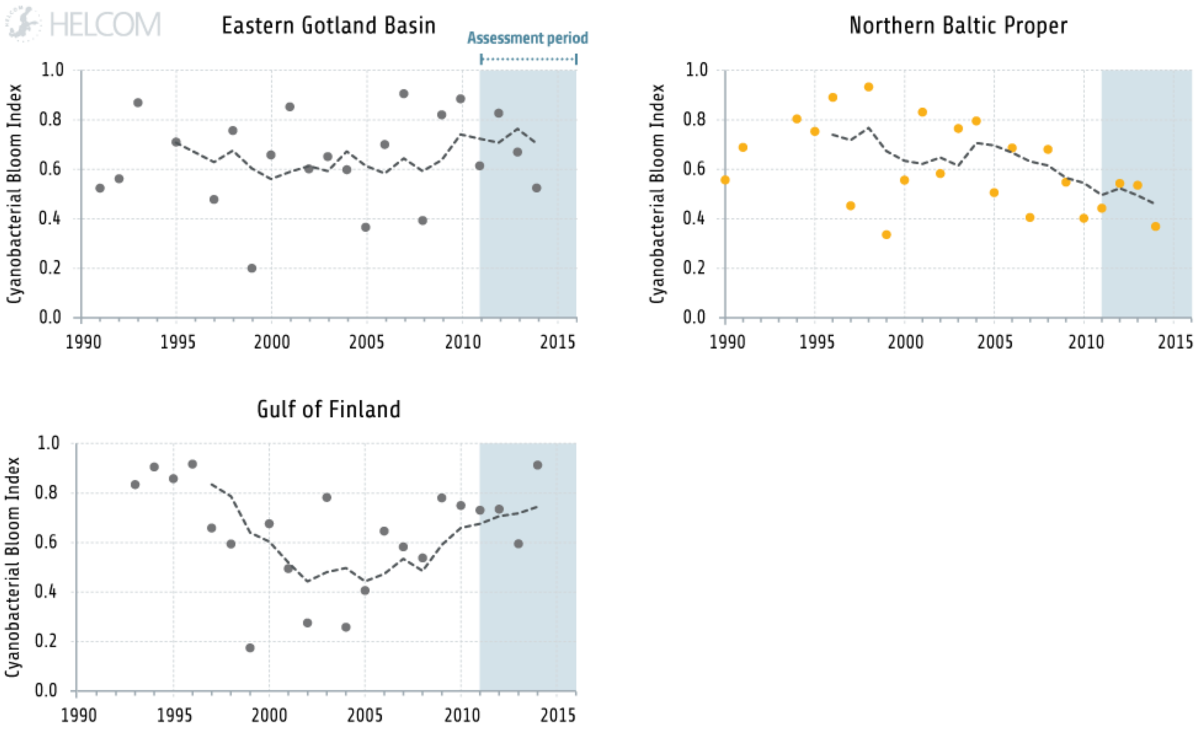


Figure 19. Example of long term trends in the direct effects of eutrophication in the Baltic Sea: Temporal development of the 'Cyanobacterial bloom index' (included as test) in the Eastern Gotland Basin, the Northern Baltic Proper and the Gulf of Finland in 1990-2014. Dashed lines show the five-year moving averages. Significance of the trends was assessed with the Mann-Kendall test. A significant ($p<0.05$) deteriorating trend is indicated with orange data points. None of these examples showed a significant deteriorating trend in 1990-2014. The data represents the areal fraction with cyanobacteria accumulations and the sub-basin delineation of Kahru and Elmgren (2014), and the correlation between areal fraction and cyanobacterial surface accumulations presented by Anttila *et al.* (2018).

5.3 CORE INDICATOR RESULTS: INDIRECT EFFECTS

The core indicator 'Oxygen debt' did not achieve the threshold values in any assessed open sea sub-basin (Table 17). The indicator has increased over the past century (Figure 20). It levelled off between the early 1980s and the early 1990s, but has subsequently increased again. In comparison with the most recent previous assessment period (2007–2011), oxygen debt during 2011-2016 has remained at the same level (Figure 11).

North of the Baltic Proper, the indicator 'State of the soft-bottom macrofauna community'[17]was included to evaluate the condition of the animal community at the seafloor. The indicator achieved the threshold value in these areas.

[17] Included as a test

Table 17. Core indicator results for indirect effects of eutrophication in the open sea during 2011–2016. Values show the eutrophication ratios of the indicator and criteria group “Indirect effects” as estimated in HEAT 3.0. The shades of green and red denote the five status categories used in the integrated assessment. White cells denote that the sub-basin was not assessed in the open sea, due to the lack of agreed threshold value or commonly agreed indicator methodology An ‘N’ is shown for cases where the indicator is not applicable. Abbreviations used: O_2= ‘Oxygen debt’ and Zoob= ‘State of the soft-bottom macrofauna community’. ‘State of the soft-bottom macrofauna community’ was only included in the Gulf of Bothnia. For more details, see core indicator reports: HELCOM 2018i-j.

Assessment unit	O_2	Zoob[18]	Group results
Kattegat	N		N
Great Belt	N		N
The Sound[19]	N		N
Kiel Bay	N		N
Bay of Mecklenburg	N		N
Arkona Basin	N		N
Bornholm Basin[20]	1.25		1.25
Gdansk Basin	1.23		1.23
Eastern Gotland Basin	1.23		1.23
Western Gotland Basin	1.23		1.23
Gulf of Riga	N	0.91	0.91
Northern Baltic Proper	1.23		1.23
Gulf of Finland	1.23		1.23
Åland Sea		0.61	0.61
Bothnian Sea		0.64	0.63
The Quark	N	0.48	0.48
Bothnian Bay		0.29	0.29

[18] Included as test
[19] Result may be changed due to planned changes in assessment data.
[20] Result for the Bornholm Basin may be subject to change, to be clarified.

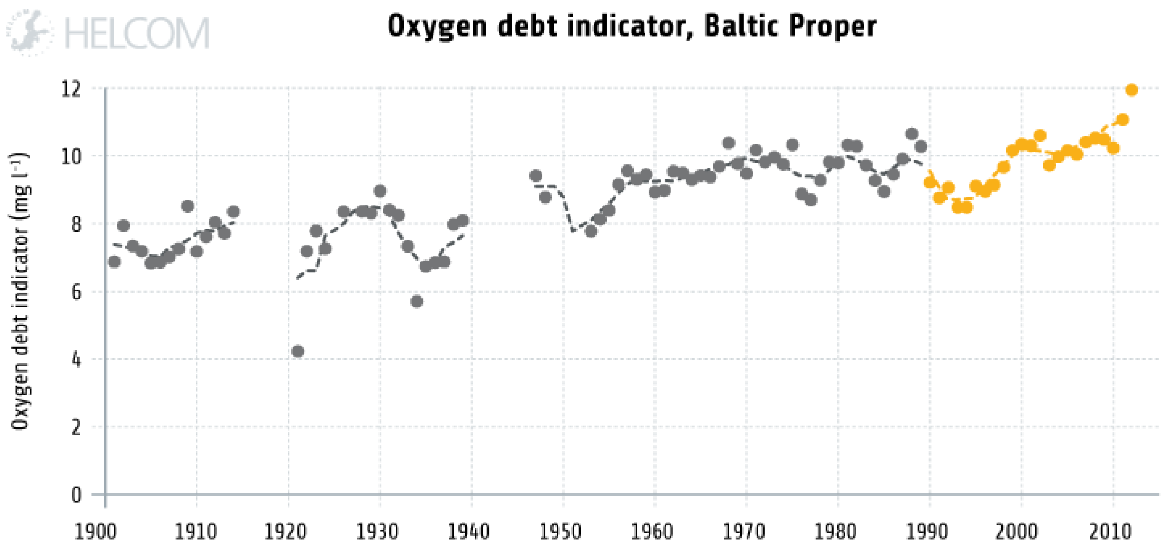


Figure 20. Example of long term trends in the indirect effects of eutrophication in the Baltic Sea: Temporal development in the core indicator 'Oxygen debt' in the Baltic Proper, showing the volume specific oxygen debt below the halocline based on the data and sub-basin division delineation of HELCOM (2013b). The dashed line shows the five-year moving average. The significance of the trend was tested for the period 1990-2012 by the Mann-Kendall test. Orange colour indicates significant ($p<0.05$) deteriorating trend: An increasing trend in oxygen debt signifies deteriorating oxygen conditions.

Chapter 6. Implications

Impacts and future perspective

Primary production is a key process in the ecosystem as it provides energy for all organisms. On the other hand, excessive primary production leads to eutrophication symptoms and reduces the function of the food web in many cases, as well as socioeconomic effects (HELCOM 2018a, HELCOM 2018i). An increased intensity and frequency of phytoplankton blooms typically leads to decreased water clarity and increased sedimentation. These conditions further limit the distribution of submerged vegetation, such as macroalgae and macrophytes, and reduce the habitat quality of coastal areas. Increased sedimentation and microbial degradation of organic matter increases oxygen consumption and depletes oxygen conditions in areas with poor water exchange, including deep water areas. The extent of oxygen-deficient waters has increased more than ten-fold over the past 115 years (Carstensen *et al.* 2014). After a stagnation period, the oxygen deficiency has expanded again over the last two decades (Carstensen *et al.* 2014). Also in the coastal areas, hypoxia has steadily increased since the 1950s (Conley *et al.* 2011).

By the 1960s the soft bottom fauna was already disturbed in some parts of the Baltic Sea, attributed to eutrophication. Human induced nutrient inputs have contributed to the enhanced distribution of areas with poor oxygen conditions seen today, including deep waters. In areas with vertical stratification and low water exchange, eutrophication acts on top of naturally low oxygen levels further enhancing these conditions. Life in deep water habitats is also highly dependent on aeration provided by inflows of marine water from the North Sea.

Some positive development in the eutrophication status is seen in the current assessment, such as a decrease in nitrogen concentrations in most of the Baltic Sea and improved water clarity and a decreased chlorophyll concentrations in some western parts of the Baltic Sea. Moreover, the intensity of the spring blooms is seen to have been reduced from 2000 to 2014 due to reductions in nutrient loading (Groetsch *et al.* 2016). However, the results show that the Baltic Sea is still highly affected by eutrophication and that the impacts on organisms and human well-being will continue. Large scale responses to reduced loading are slow, and recently achieved reductions are not visible in the short time frame of the assessments.

The recovery of the Baltic Sea from eutrophication depends on the continuing efforts to reduce nutrient loading. Ongoing and agreed reductions of nutrient inputs according to the HELCOM Baltic Sea Action Plan (Figures 1-3) are foreseen to be effective in decreasing the eutrophication symptoms in the long term. Based on modelling simulations of the Baltic Sea biogeochemistry under different nutrient reduction schemes, implementation of the BSAP nutrient reductions will lead to significantly improved eutrophication state of the Baltic Sea within this century, including reduced primary productivity, nitrogen fixation and hypoxia (Saraiva *et al.* 2018).

Climate change is foreseen to amplify eutrophication symptoms, with biogeochemical responses depending on the implemented nutrient reductions (Box 3), hence enhancing the importance of nutrient reductions (Saraiva *et al.* 2018).

Box 3 Effects of climate change on eutrophication

Adaptation to climate change is a central issue for the planning and implementation of measures to reduce nutrient inputs, as well as for adjusting the level of nutrient input reductions to ensure protection of the Baltic Sea marine environment in a changing climate. For example, the maximum allowable inputs are calculated under the assumption that Baltic Sea environmental conditions are in a biogeochemical and physical steady-state. This assumes that the environment will reach a new biogeochemical steady state under the currently prevailing physical steady state, after some time when the internal sinks and sources have adapted to the new input levels. This assumption is not likely to last with a changing climate, as the physical environment is also changing and will feedback upon the biogeochemical cycling, for example by enhancing growth and mineralization rates. Simulations indicate that climate change may call for additional nutrient input reductions to reach the targets for good environmental status of the Baltic Sea Action Plan (Meier *et al.* 2012). Effects from climate change and input reductions will both take substantial time, and a deepened understanding of the development is needed to support management.

Monitoring development

The eutrophication assessment methodology has been under constant improvement during the previous decades, responding to increased knowledge in eutrophication-related processes as well as developments in monitoring methods as well as modelling, among others. However, experiences from the present assessment, combined with information provided by recent research projects, revealed a need for further development in the future: 1) Indicator threshold values should be developed for those indicators lacking a threshold, and the need for further alignment and revision of existing threshold values should be estimated, 2) the set of core indicators should be complemented, to express the spring bloom period and to better cover the benthic habitats, 3) the confidence assessment should be improved to take into account also the spatial coverage of the monitoring data, 4) the assessment tool should be complemented with procedures introducing indicator scaling and 5) a solution for assessing sub-basins with considerable spatial gradients (for example in the Gulf of Finland) should be identified. Furthermore, 6) the assessment and indicators should be quantitatively linked to specific pressures, besides those related to nutrient loading, also to changes arising from climate change.

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Appendix 1. Assessment results for eutrophication in coastal areas

This appendix contains three tables. Table A.1.1 contains the Output table from HEAT 3.0 showing results from the integrated assessment of eutrophication in coastal areas. The following tables show the corresponding indicator results for nutrient levels and direct effects (Table 1.2.2) and indirect effects (Table 1.2.3).

Table A1.1. Output table from HEAT 3.0 showing results from the integrated assessment of eutrophication in coastal waters. The first column gives the codes for each of the applied spatial assessment unit (SAU). 'ER'= Eutrophication ratio. Columns 2-4 show the ER scores for the three criteria groups: nutrient levels, direct effects and indirect effects. The integrated values for these three criteria groups were combined into the integrated ER score shown in column 5, using one-out-all-out between criteria groups.

SAU	Nutrient levels	Direct effects	Indirect effects	ER
EST-001	0.98	1.28	1.03	1.28
EST-002	0.70	1.09	0.72	1.09
EST-003	1.27	0.92	0.77	1.27
EST-004	1.06	0.98	0.81	1.06
EST-005	1.08	1.31	0.81	1.31
EST-006	0.99	1.55	0.95	1.55
EST-007	1.50	1.28	0.80	1.50
EST-008	3.47	2.34	0.93	3.47
EST-009	1.71	2.19	0.66	2.19
EST-010	1.33	1.64	0.75	1.64
EST-011	1.36	1.08	0.95	1.36
EST-012	1.50	1.35	0.77	1.50
EST-013	1.39	2.24	0.82	2.24
EST-014	1.26	1.05	0.82	1.26
EST-015	2.99	3.42	0.87	3.42
EST-016	1.84	1.18	0.92	1.84
FIN-001	1.39	1.53	0.66	1.53
FIN-002	1.22	1.25	0.76	1.25
FIN-003	1.22	1.37	0.92	1.37
FIN-004	1.07	1.19	0.64	1.19
FIN-005	1.41	1.19	0.72	1.41
FIN-006	1.36	1.16	0.94	1.36
FIN-007	0.96	0.71	0.29	0.96
FIN-008	1.23	1.10	0.35	1.23
FIN-009	0.99	1.16	0.67	1.16
FIN-010	1.18	1.61	1.10	1.61
FIN-011	0.96	1.34	1.12	1.34
FIN-012	1.45	3.26	1.22	3.26
FIN-013	1.01	1.43	0.95	1.43
FIN-014	1.03	1.40	0.95	1.40

GER-001	1.21	2.60	1.05	2.60
GER-002	1.21	1.76	1.06	1.76
GER-003	1.59	1.58	1.19	1.59
GER-004	1.15	1.23	1.38	1.38
GER-005	2.61	3.09	1.75	3.09
GER-006	1.18	1.29	1.46	1.46
GER-007	3.80	7.84	6.61	7.84
GER-008	3.08	5.27	1.25	5.27
GER-009	4.71	12.33	1.42	12.33
GER-010	1.38	1.47	1.97	1.97
GER-011	2.08	3.62	1.06	3.62
GER-012	2.50	4.82	1.34	4.82
GER-013	2.44	4.39	1.19	4.39
GER-014	6.67	19.97	2.31	19.97
GER-015	1.28	1.44	1.44	1.44
GER-016	2.46	3.47	3.00	3.47
GER-017	2.68	4.04	3.08	4.04
GER-018	1.67	2.19	1.43	2.19
GER-019	2.83	3.38	1.46	3.38
GER-020	2.67	3.43	2.30	3.43
GER-021	1.49	2.58	1.85	2.58
GER-022	1.29	1.35	1.19	1.35
GER-023	1.18	1.35	1.22	1.35
GER-024	1.19	1.27	1.01	1.27
GER-025	3.65	6.86	1.71	6.86
GER-026	3.39	15.75	3.43	15.75
GER-027	3.39	15.75	5.71	15.75
GER-028	1.19	1.27	1.23	1.27
GER-029	1.15	1.39	2.14	2.14
GER-030	1.16	1.09	1.16	1.16
GER-031	1.17	1.25	3.75	3.75
GER-032	1.55	3.05	1.43	3.05
GER-033	1.16	1.09	1.08	1.16
GER-034	1.16	1.21	1.17	1.21
GER-035	1.06	1.21	1.09	1.21
GER-036	1.29	1.14	1.33	1.33
GER-037	0.93	1.31	1.05	1.31
GER-038	1.31	1.12	1.13	1.31
GER-039	1.19	1.12	0.98	1.19
GER-040	1.29	1.24	2.26	2.26
GER-041	1.38	1.32	1.78	1.78
GER-042	4.59	4.03		4.59
GER-043	3.05	5.04	1.60	5.04
GER-044	3.31	7.65	3	7.65

GER-111	2.76	8.18	1.45	8.18
LAT-001	2.10	1.53	0.85	2.10
LAT-002	1.61	1.18		1.61
LAT-003	1.23	1.68	1.13	1.68
LAT-004	1.56	1.44	1.26	1.56
LAT-005	1.56	1.56	1.33	1.56
LIT-001	1.36	1.57		1.57
LIT-002	1.10	1.24	0.96	1.24
LIT-003	1.46	1.89	1.92	1.92
LIT-004	1.22	0.97	2.27	2.27
LIT-005	1.01	0.90	1.77	1.77
LIT-006	1.58	1.45	1.30	1.58
POL-001	0.63	1.55	1.21	1.55
POL-002	0.67	1.72	1.26	1.72
POL-003	0.48	1.45	2.17	2.17
POL-004	1.14	1.65	1.13	1.65
POL-005	1.72	1.02	1.16	1.72
POL-006	0.96	1.04	1.19	1.19
POL-007	1.66	2.54	0.99	2.54
POL-008	2.38	1.76	1.24	2.38
POL-009	1.37	1.84	1.08	1.84
POL-010	1.92	1.43	0.75	1.92
POL-011	1.64	1.48	1.00	1.64
POL-012	2.43	2.88	1.11	2.88
POL-013	1.69	1.95	1.39	1.95
POL-014	1.77	1.99	0.90	1.99
POL-015	1.22	2.12	0.94	2.12
POL-016	2.00	2.24	0.77	2.24
POL-017	1.97	1.79	0.81	1.97
POL-018	1.32	1.88	1.15	1.88
POL-019	1.35	1.76	1.59	1.76
SWE-001	1.01	0.93	0.92	1.01
SWE-003	0.96	0.82	0.83	0.96
SWE-004	1.07	0.82	0.87	1.07
SWE-005	1.48	1.09	0.84	1.48
SWE-006	1.28	1.17	0.78	1.28
SWE-007	1.55	0.99	0.68	1.55
SWE-008	1.62	1.08	0.63	1.62
SWE-009	1.25	1.47	0.74	1.47
SWE-010	1.26	1.29	0.81	1.29
SWE-011	1.46	1.34	0.67	1.46
SWE-012	1.60	1.35	0.74	1.60
SWE-013	2.16	2.21	1.10	2.21
SWE-014	1.55	1.31	0.83	1.55

SWE-015	1.14	1.32	0.61	1.32
SWE-016	1.09	1.06	0.94	1.09
SWE-017	0.92	1.19	0.74	1.19
SWE-018	0.89	0.92	0.88	0.92
SWE-019	0.90	0.80	0.78	0.90
SWE-020	1.15	0.94	0.90	1.15
SWE-021	0.88	1.04	0.69	1.04
SWE-022	0.93	0.74	0.73	0.93
SWE-023	1.28	0.87	0.50	1.28
SWE-024	1.26	1.20	1.19	1.26
SWE-025	1.23	1.53	1.02	1.53

Table A1.2. Indicator results for nutrient levels and direct effects of eutrophication in coastal waters. The first column gives the codes for each of the applied spatial assessment unit (SAU). Columns 2-5 show the eutrophication ratios for indicators in criteria group 'nutrient levels' and columns 6-8 eutrophication ratios for indicators in criteria group 'Direct effects'.

	Nutrient levels				Direct effects		
SAU	**Dissolved Inorganic Nitrogen**	**Dissolved Inorganic Phosphorus**	**Total Nitrogen**	**Total Phosphorus**	**Water clarity**	**Chloro-phyll a**	**Phytoplankton biovolume***
DEN-001						2.52	
DEN-002						1.14	
DEN-003						0.88	
DEN-005							
DEN-006						0.48	
DEN-007						0.71	
DEN-008						1.24	
DEN-009						1.48	
DEN-010						0.67	
DEN-011						0.88	
DEN-012						0.81	
DEN-013						0.81	
DEN-014						2.00	
DEN-015						0.62	
DEN-016						0.90	
DEN-017						1.67	
DEN-018						1.27	
DEN-019						1.12	
DEN-020						1.13	
DEN-021						0.94	
DEN-022						1.76	
DEN-023						0.76	
DEN-024						6.24	
DEN-025						1.59	
DEN-027						2.14	
DEN-028						0.47	
DEN-029							
DEN-030						1.33	
DEN-031						1.05	
DEN-032							
DEN-033						0.57	
DEN-034						2.79	
DEN-035						6.26	
DEN-036						3.54	

DEN-037						0.71	
DEN-038						7.39	
DEN-039						2.25	
DEN-040						122.86	
DEN-041						24.56	
DEN-042						1.38	
DEN-043						4.38	
DEN-044						7.86	
DEN-045						3.72	
DEN-046						0.75	
DEN-047						2.14	
DEN-048						0.61	
DEN-049						1.81	
DEN-050						0.90	
DEN-051						1.60	
DEN-052						1.11	
DEN-053						1.61	
DEN-054						1.29	
DEN-055						1.05	
DEN-056							
DEN-057						1.48	
DEN-059							
DEN-060						1.67	
DEN-061						14.00	
DEN-062						3.76	
DEN-063						4.05	
DEN-064						2.10	
DEN-065						1.81	
DEN-066						0.95	
DEN-067						0.64	
DEN-068						0.97	
DEN-069						2.03	
DEN-070						0.47	
DEN-071						0.33	
DEN-072						1.50	
DEN-074						1.23	
DEN-075						1.36	
DEN-076						0.94	
DEN-077						1.13	
DEN-078						1.05	
DEN-079						0.95	
DEN-080						0.90	
DEN-081							
DEN-082						0.57	

DEN-083						1.64	
DEN-084						0.71	
DEN-085						0.31	
DEN-086						2.33	
DEN-087						1.85	
DEN-088						4.94	
DEN-089						3.25	
DEN-090							
DEN-091						2.62	
DEN-092						0.69	
DEN-093						0.88	
DEN-094							
DEN-095						1.25	
DEN-096						0.87	
DEN-097						0.86	
DEN-098						1.40	
DEN-099						0.62	
DEN-100						1.29	
DEN-101						0.90	
DEN-102						1.93	
DEN-103						1.80	
DEN-104						2.13	
DEN-105						1.06	
DEN-106						0.69	
DEN-107						1.06	
DEN-108						1.00	
EST-001			0.87	1.10	1.29	1.21	1.12
EST-002			0.78	0.62	1.01	1.41	1.30
EST-003			0.93	1.61	0.99	0.98	0.86
EST-004			0.86	1.26	0.99	1.24	0.74
EST-005			0.91	1.25	1.18	1.44	1.52
EST-006			0.86	1.11	1.26	1.47	2.02
EST-007			1.09	1.90	1.88	1.43	1.20
EST-008			1.70	5.23	2.88	2.93	2.53
EST-009			1.26	2.17	3.06	1.18	2.20
EST-010			1.31	1.36	1.20	2.59	1.59
EST-011			1.27	1.45	1.12	1.53	0.73
EST-012			1.12	1.88	1.61	1.49	1.52
EST-013			1.11	1.67	2.52	1.47	
EST-014			1.02	1.50	1.11	1.07	1.60
EST-015			1.69	4.30	2.61	1.21	9.33
EST-016			0.95	2.73	1.46	1.05	1.60
FIN-001			1.34	1.43	1.89	2.80	
FIN-002			1.21	1.23	1.45	2.04	3.11

FIN-003			1.19	1.25	1.59	2.57	
FIN-004			1.07	1.07	1.26	2.32	2.35
FIN-005			1.17	1.65	1.84	1.88	2.00
FIN-006			1.43	1.29	1.05	2.03	
FIN-007			0.96	0.95	0.88	1.18	1.04
FIN-008			1.39	1.06	1.27	2.07	
FIN-009			0.85	1.13	0.98	1.33	1.18
FIN-010			1.10	1.25	1.14	1.73	
FIN-011			0.98	0.95	0.97	1.36	1.58
FIN-012			1.54	1.36	2.31	4.20	
FIN-013			1.02	1.00	1.61	1.25	
FIN-014			1.00	1.07	1.40		
GER-001			1.07	1.36	2.22	1.59	4.00
GER-002			1.07	1.36	2.22	1.59	1.46
GER-003			1.84	1.34	1.89	1.49	1.36
GER-004			1.02	1.28	1.67	0.94	1.09
GER-005			2.59	2.64	3.59	3.46	2.22
GER-006			1.04	1.32	1.80	1.01	1.05
GER-007			4.87	2.73	8.50	9.56	5.45
GER-008			3.78	2.38	5.67	7.28	2.86
GER-009			5.44	3.98	13.56	16.77	6.67
GER-010			1.15	1.61	2.52	0.87	1.02
GER-011			2.29	1.88	4.15	4.78	1.94
GER-012			2.70	2.31	6.10	6.23	2.14
GER-013			2.42	2.46	4.59	6.52	2.07
GER-014			7.06	6.27	20.33	34.13	5.45
GER-015			1.12	1.44	1.62	1.24	1.46
GER-016			2.90	2.02	3.27	5.07	2.07
GER-017			3.01	2.35	3.40	6.64	2.07
GER-018			1.62	1.73	2.80	2.35	1.43
GER-019			3.32	2.34	3.66	4.53	1.94
GER-020			2.76	2.59	2.88	5.64	1.76
GER-021			1.13	1.86	2.12	3.04	
GER-022			1.20	1.39	1.41	1.28	
GER-023			1.14	1.22	1.41	1.28	
GER-024			1.14	1.23	1.44	1.10	
GER-025			3.89	3.41	4.24	9.49	
GER-026			3.27	3.51	8.71	22.79	
GER-027			3.27	3.51	8.71	22.79	
GER-028			1.14	1.23	1.44	1.11	
GER-029			1.12	1.18	1.53	1.25	
GER-030			1.09	1.23	1.24	0.95	
GER-031			1.13	1.20	1.31	1.18	
GER-032			1.41	1.70	2.12	3.97	

GER-033			1.09	1.23	1.24	0.95	
GER-034			1.09	1.23	1.47	0.95	
GER-035			1.04	1.08	1.47	0.95	
GER-036			1.21	1.37	1.64	0.64	
GER-037			0.87	0.99	2.06	0.56	
GER-038			1.23	1.39	1.29	0.96	
GER-039			1.15	1.22	1.29	0.95	
GER-040			1.25	1.32	1.38	1.11	
GER-041			1.40	1.37	1.50	1.14	
GER-042			5.11	4.07	3.00	5.06	
GER-043			3.83	2.27	2.90	7.18	
GER-044			4.04	2.58	4.69	10.62	
GER-111			2.84	2.68	6.78	13.14	4.62
LAT-001	2.74	1.47			1.18	2.14	1.25
LAT-002	1.86	1.37			1.00	2.14	0.39
LAT-003	1.14	1.32			1.38	2.05	1.61
LAT-004	1.85	1.28			1.29	2.05	0.98
LAT-005	1.93	1.19			1.15	2.01	1.51
LIT-001			1.60	1.13		1.57	
LIT-002			1.44	0.77	1.32	1.17	
LIT-003			1.76	1.15	1.67	2.10	
LIT-004			1.30	1.14		0.97	
LIT-005			1.15	0.88		0.90	
LIT-006			2.00	1.15		1.45	
POL-001	0.34	0.51	0.81	0.85	1.73	1.37	
POL-002	0.42	0.47	0.87	0.91	1.73	1.71	
POL-003	0.27	0.22	0.92	0.52	1.25	1.65	
POL-004	1.38	0.69	1.37	1.10	0.81	2.50	
POL-005	0.83	2.56	1.22	2.29	1.07	0.98	
POL-006	0.65	1.33	0.88	0.97	0.96	1.13	
POL-007	1.72	0.60	2.86	1.48	2.37	2.72	
POL-008	3.58	2.31	1.62	2.00	1.58	1.95	
POL-009	1.56	0.71	1.58	1.64	2.21	1.48	
POL-010	1.23	3.00	1.64	1.80	1.22	1.64	
POL-011	1.88	1.58	1.12	1.97	0.78	2.17	
POL-012	1.36	4.00	1.75	2.60	2.15	3.61	
POL-013	1.85	2.40	1.22	1.30	1.70	2.19	
POL-014	3.68	0.67	1.76	0.97	1.44	2.54	
POL-015	0.96	0.47	2.74	0.73	1.27	2.96	
POL-016	0.63	3.33	1.78	2.27	1.40	3.08	
POL-017	0.72	2.87	1.68	2.60	1.17	2.41	
POL-018	0.82	0.88	1.74	1.83	1.65	2.10	
POL-019	1.17	1.87	1.13	1.23	1.65	1.88	
SWE-001	1.21	0.91	1.09	0.97	1.09	0.76	

SWE-003	1.21	0.91	0.94	0.95	1.15	0.76	0.54
SWE-004	1.40	1.13	0.97	1.10	1.16	0.89	0.42
SWE-005	2.30	1.36	1.15	1.71	1.25	0.94	
SWE-006	1.27	1.53	1.04	1.66	1.24	1.10	
SWE-007	1.04	1.98	1.14	2.76	1.03	0.95	
SWE-008	1.28	1.43	1.81	2.37	1.19	0.96	
SWE-009	0.83	1.50	1.23	1.69	1.42	1.52	
SWE-010	0.78	1.81	1.17	1.62	1.27	1.31	
SWE-011	1.46	1.81	1.17	1.86	1.36	1.50	1.15
SWE-012	1.36	2.00	1.20	1.95	1.49	1.19	1.37
SWE-013	1.74	2.90	1.43	3.46	2.55	2.68	1.40
SWE-014	1.84	1.81	1.16	1.86	1.27	1.26	1.40
SWE-015			1.15	1.14	1.25	1.31	1.40
SWE-016	1.52	0.93	0.98	1.22	1.23	1.24	0.71
SWE-017	1.04	0.85	0.88	1.02	1.36	1.21	0.99
SWE-018	1.13	0.78	0.92	0.86	0.69	1.04	1.02
SWE-019	1.20	0.74	0.90	0.90	0.79	0.81	
SWE-020	1.59	0.94	1.18	1.28	0.79	1.22	0.80
SWE-021	1.21	0.76	0.91	0.83	0.79	1.29	
SWE-022	1.20	0.78	1.01	0.87	0.60	0.98	0.65
SWE-023	1.21	0.74	3.33	0.84	0.62	1.11	
SWE-024			1.22	1.30	1.22	1.62	0.77
SWE-025	1.84	0.91	1.15	1.17	1.20	1.86	

* For German water bodies, the quality element result based on the national phytoplankton index for coastal waters was applied.

Table A.1.3. Indicator results for indirect effects of eutrophication in coastal waters. The first column gives the codes for each of the applied spatial assessment unit (SAU). Columns 2-15 show the eutrophication ratios for indicators in criteria group 'Indirect effects'.

	Indirect effects													
SAU	**BBI**	**Benthic macrofl depth distrib.**	**Benthic QI**	**Depth limit of eelgrass macrophyte**	**Fucus vesiculosus depth distrib**	**Furcellaria lumbricalis depth distrib**	**Large inverter-brates FDI**	**Large inverter-brates KPI**	**Macro-phyt. sheltered**	**Macro-veg QE**	**Oxy-gen**	**Phyto-benthos Ecological QI**	**Proportion of perennial species**	**Zoo-benthos QE**
DEN-001				0.98										1.00
DEN-002				1.25										1.00
DEN-003				1.55										
DEN-005														0.96
DEN-006														1.05
DEN-007														
DEN-008				0.98										1.31
DEN-009				1.11										
DEN-010				1.37										
DEN-011				1.53										0.85
DEN-012				2.03										1.08
DEN-013				1.01										
DEN-014														0.99
DEN-015														
DEN-016				0.84										
DEN-017				1.08										0.87
DEN-018														
DEN-019				1.19										
DEN-020														
DEN-021				1.42										0.89
DEN-022				1.32										0.81
DEN-023				1.00										0.82
DEN-024														

DEN-025														
DEN-027														1.10
DEN-028				1.27										
DEN-029				1.46										
DEN-030				1.02										
DEN-031														
DEN-032				2.93										
DEN-033														
DEN-034														
DEN-035														
DEN-036														
DEN-037				1.00										
DEN-038														
DEN-039														
DEN-040														
DEN-041														
DEN-042				2.43										
DEN-043														
DEN-044														
DEN-045														
DEN-046														
DEN-047				1.64										
DEN-048				1.63										1.01
DEN-049				1.04										0.93
DEN-050				1.35										
DEN-051				1.35										1.13
DEN-052				1.45										1.06
DEN-053				1.91										1.06
DEN-054				1.25										
DEN-055				1.76										0.89

DEN-056				3.56										
DEN-057				2.22										
DEN-059				1.63										
DEN-060				3.15										3.09
DEN-061														
DEN-062														
DEN-063														
DEN-064				1.84										
DEN-065				3.75										
DEN-066				1.71										1.62
DEN-067				3.50										
DEN-068				2.65										1.31
DEN-069				2.56										1.24
DEN-070				3.48										
DEN-071				2.83										
DEN-072				3.05										1.15
DEN-074														1.06
DEN-075														1.06
DEN-076				1.91										1.11
DEN-077														0.91
DEN-078														
DEN-079				1.22										1.13
DEN-080														0.93
DEN-081				2.12										3.78
DEN-082				2.59										
DEN-083														
DEN-084				1.46										1.01
DEN-085				1.61										1.01
DEN-086				1.52										1.39
DEN-087				2.28										1.17

DEN-088				20.50										
DEN-089				3.87										1.45
DEN-090				4.50										1.19
DEN-091				1.42										
DEN-092														0.83
DEN-093				1.23										0.84
DEN-094														0.86
DEN-095														1.08
DEN-096				1.21										1.29
DEN-097				1.10										0.89
DEN-098														
DEN-099				0.89										
DEN-100				1.03										
DEN-101				1.17										0.85
DEN-102				1.35										
DEN-103				2.53										1.33
DEN-104				2.38										1.14
DEN-105				2.25										
DEN-106				3.75										1.08
DEN-107				2.43										
DEN-108				1.96										1.10
EST-001		0.74			1.95		0.98	0.65					1.50	0.84
EST-002		0.55			0.56		0.94	0.66					0.64	0.91
EST-003		0.77			0.55		0.98	0.70					0.88	0.83
EST-004		0.91			0.78		0.91	0.61					0.97	0.85
EST-005		0.81			0.73		0.88	0.64					1.11	1.00
EST-006		0.82			1.40		0.75	0.69					1.45	1.11
EST-007		0.74			0.92		0.85	0.67					0.61	0.81
EST-008					1.16		0.69	0.86					1.02	1.01
EST-009							0.55	0.71					2.33	0.71

EST-010		0.54			0.88		0.84	0.65					1.15	0.86
EST-011		0.56			1.94		0.72	0.67					0.95	0.85
EST-012		0.70			0.71		0.80	0.68					0.79	0.99
EST-013		0.80					0.85	0.62					2.73	1.01
EST-014					0.88		0.80	0.72					0.43	0.89
EST-015					1.17		0.67	0.78					0.51	0.84
EST-016					1.35		0.77	0.64					0.63	0.94
FIN-001	1.04								1.68	1.89				
FIN-002	0.83								2.37	1.74				
FIN-003	1.04								2.94	2.02				
FIN-004	1.19								1.80	1.63				
FIN-005	0.77								1.69	2.22				
FIN-006	0.94													
FIN-007	0.97									0.89				
FIN-008	0.79									1.89				
FIN-009	0.67													
FIN-010	1.10													
FIN-011	1.12													
FIN-012	1.36					1.07								
FIN-013	0.94					0.97								
FIN-014	0.93					0.98								
GER-001														1.05
GER-002										1.15				0.98
GER-003										1.15				1.22
GER-004										1.62				1.15
GER-005										2.40				1.09
GER-006														1.46
GER-007										1.22				12.00
GER-008										1.11				1.40
GER-009										1.25				1.58

GER-010										3.00				0.95
GER-011										1.09				1.03
GER-012										1.50				1.18
GER-013										1.30				1.07
GER-014										1.46				3.16
GER-015										1.62				1.25
GER-016										3.00				3.00
GER-017										3.00				3.16
GER-018										1.76				1.09
GER-019														1.46
GER-020										2.00				2.61
GER-021										1.94				1.76
GER-022										1.20				1.18
GER-023														1.22
GER-024										0.90				1.13
GER-025										2.50				0.92
GER-026										6.00				0.86
GER-027										10.00				1.43
GER-028										1.36				1.09
GER-029														2.14
GER-030										1.18				1.15
GER-031														3.75
GER-032										1.71				1.15
GER-033										1.07				1.09
GER-034										1.25				1.09
GER-035														1.09
GER-036										1.46				1.20
GER-037										1.00				1.09
GER-038										1.00				1.25
GER-039														0.98

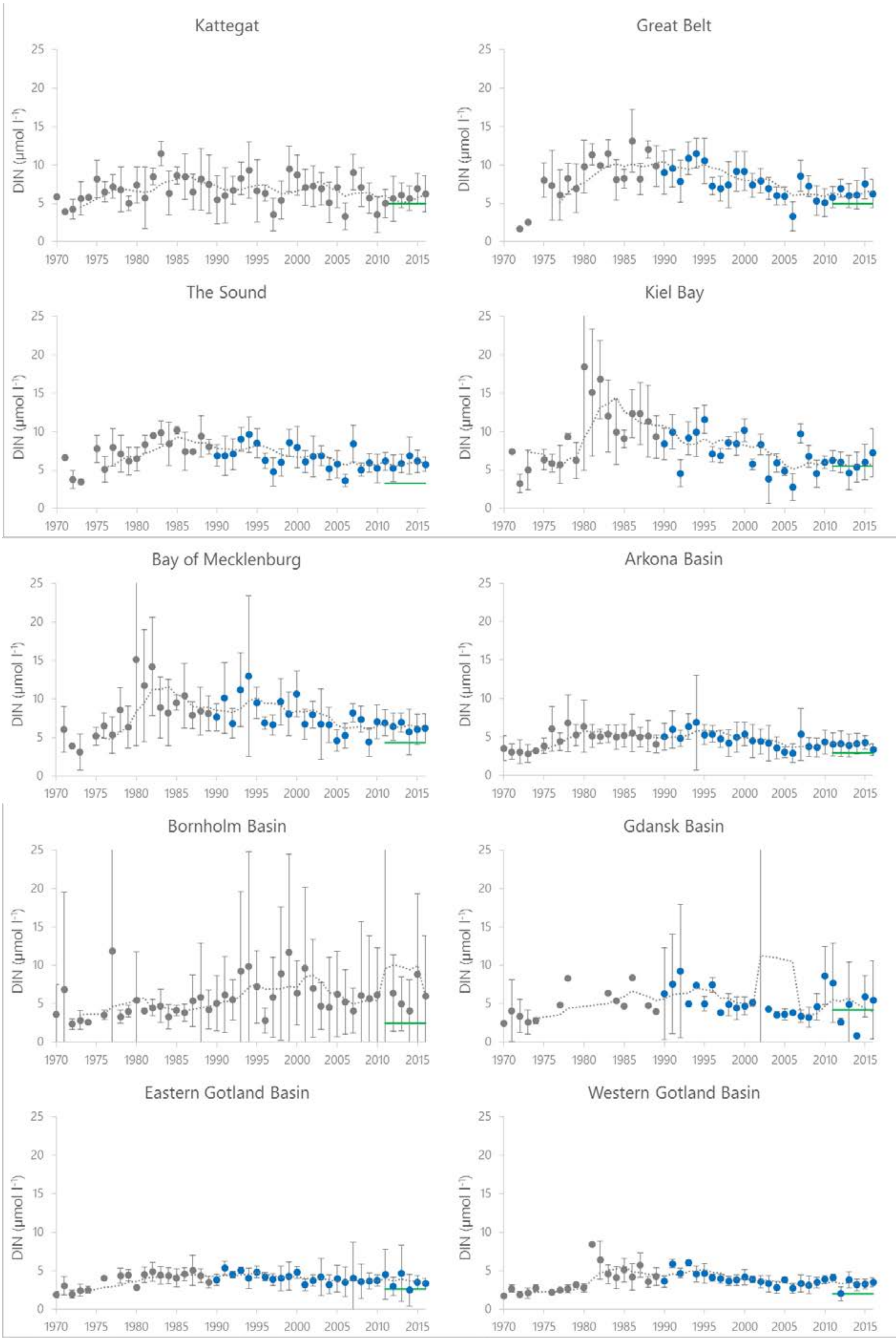
GER-040										3.33				1.20
GER-041										2.22				1.33
GER-042														
GER-043										1.94				1.25
GER-044										3.00				
GER-111										1.50				1.40
LAT-001						0.68						1.01		
LAT-002														
LAT-003			1.13											
LAT-004			1.25									1.27		
LAT-005			1.33											
LIT-001														
LIT-002														0.96
LIT-003						2.03								1.81
LIT-004														2.27
LIT-005														1.77
LIT-006						1.77								0.83
POL-001											0.78			1.65
POL-002											0.95			1.57
POL-003											1.45			2.89
POL-004										1.33	0.72			1.33
POL-005										1.13	1.14			1.21
POL-006											1.20			1.19
POL-007											0.72			1.26
POL-008											1.24			1.24
POL-009											0.79			1.37
POL-010											0.61			0.89
POL-011											0.66			1.35
POL-012											0.71			1.50
POL-013											0.81			1.98

POL-014											0.60			1.20
POL-015										1.07	0.60			1.15
POL-016											0.63			0.92
POL-017											0.62			1.00
POL-018											0.93			1.36
POL-019											0.91			2.27
SWE-001			1.25							0.86	0.65			
SWE-003			1.20							0.67	0.63			
SWE-004			1.11							0.69	0.81			
SWE-005			1.03							0.75	0.74			
SWE-006			0.90							0.83	0.60			
SWE-007			0.66							0.78	0.60			
SWE-008			0.59							0.71	0.60			
SWE-009			0.66							0.94	0.61			
SWE-010			0.67							0.72	1.03			
SWE-011			0.67							0.75	0.60			
SWE-012			0.82							0.73	0.66			
SWE-013			1.13							1.43	0.75			
SWE-014			0.55							0.67	1.27			
SWE-015			0.55							0.67				
SWE-016			1.28							0.94	0.61			
SWE-017			0.94							0.67	0.60			
SWE-018			1.24							0.79	0.60			
SWE-019			1.04							0.71	0.60			
SWE-020			1.19								0.60			
SWE-021			0.78								0.60			
SWE-022			0.86								0.60			
SWE-023			0.39								0.60			
SWE-024			1.19											
SWE-025			1.20								0.83			

Appendix 2. Temporal development of indicators in the open sea

The development over time in the open-sea indicators used in the eutrophication assessment representing ‘nutrient levels’ and ‘direct effects’ are given below in figures A2.1-7. Trends in nutrient levels, chlorophyll-*a* concentrations and water clarity are assessed for the period of 1990-2016 for all sub-basins based on monitoring data provided by HELCOM Contracting Parties via the HELCOM COMBINE database.

Trends in the ‘Cyanobacterial Bloom Index’ were evaluated for the Eastern Gotland Basin, Northern Baltic Proper and Gulf of Finland for 1990-2014 (for sub-basins division: see Kahru and Elmgren 2014). The indicator component ‘cyanobacterial surface accumulations’ (CSA) was estimated from data on ‘areal fraction with cyanobacteria accumulations’ (FCA) (Kahru and Elmgren 2014), based on correlation of FCA with CSA presented in Anttila *et al*. (2018). The time-series data used in the indicator component ‘Cyanobacterial biomass’ was collated by the HELCOM phytoplankton expert group (PEG) for the annually updated HELCOM Baltic Sea Environmental Fact Sheet (HELCOM 2017b) based on Estonian, Finnish, German, Latvian, Lithuanian, Polish and Swedish national monitoring data.


Kattegat
Great Belt
The Sound
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Gdansk Basin
Eastern Gotland Basin
Western Gotland Basin
DIN (µmol l⁻¹)
0
5
10
15
20
25
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

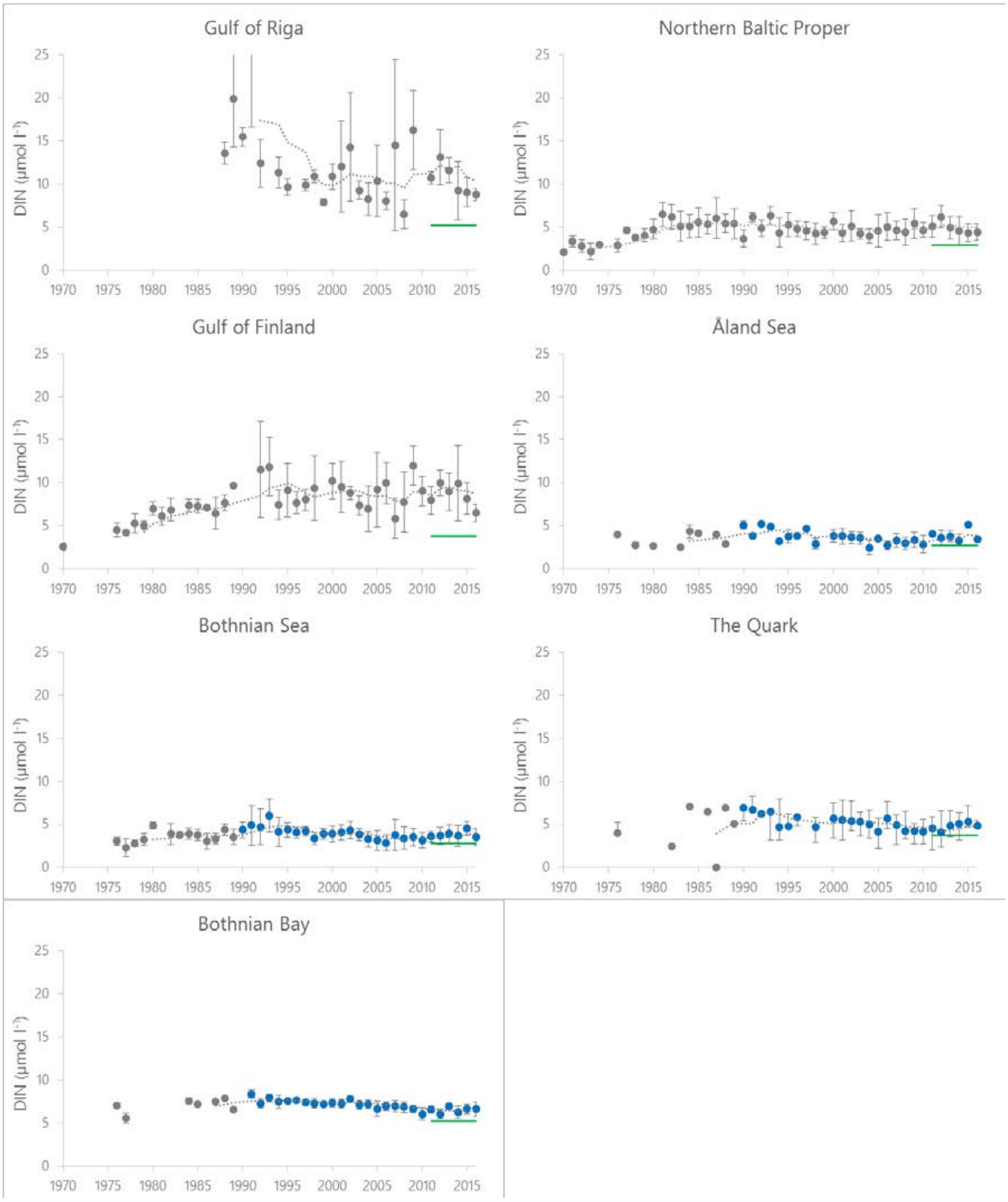
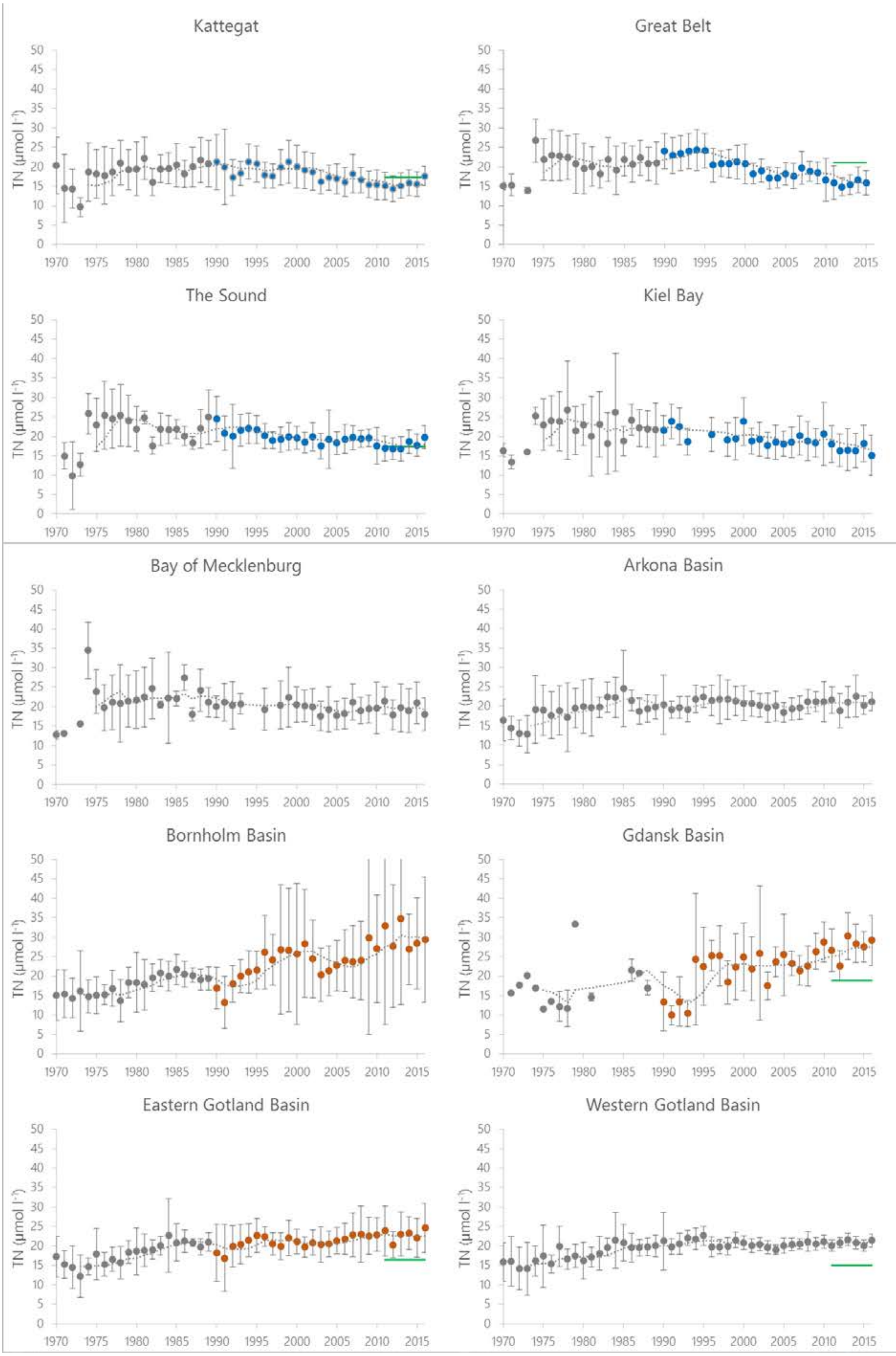


Figure A2.1. Temporal development of winter dissolved inorganic nitrogen (DIN) concentrations in the open-sea assessment units in 1970-2016. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold value. Significance of trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue data points. No significant deteriorating trends were detected.


Kattegat
Great Belt
The Sound
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Gdansk Basin
Eastern Gotland Basin
Western Gotland Basin
TN (µmol l⁻¹)

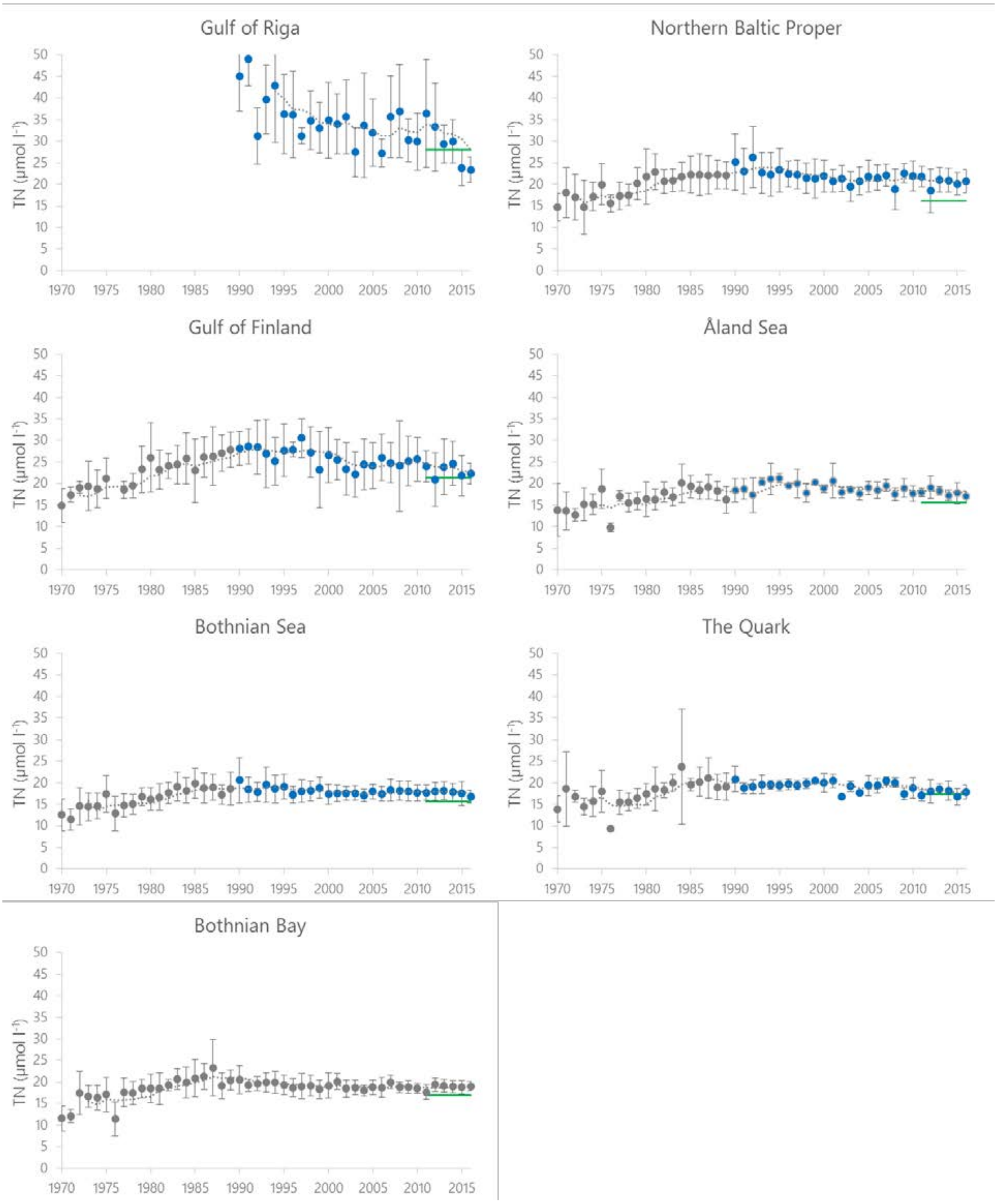
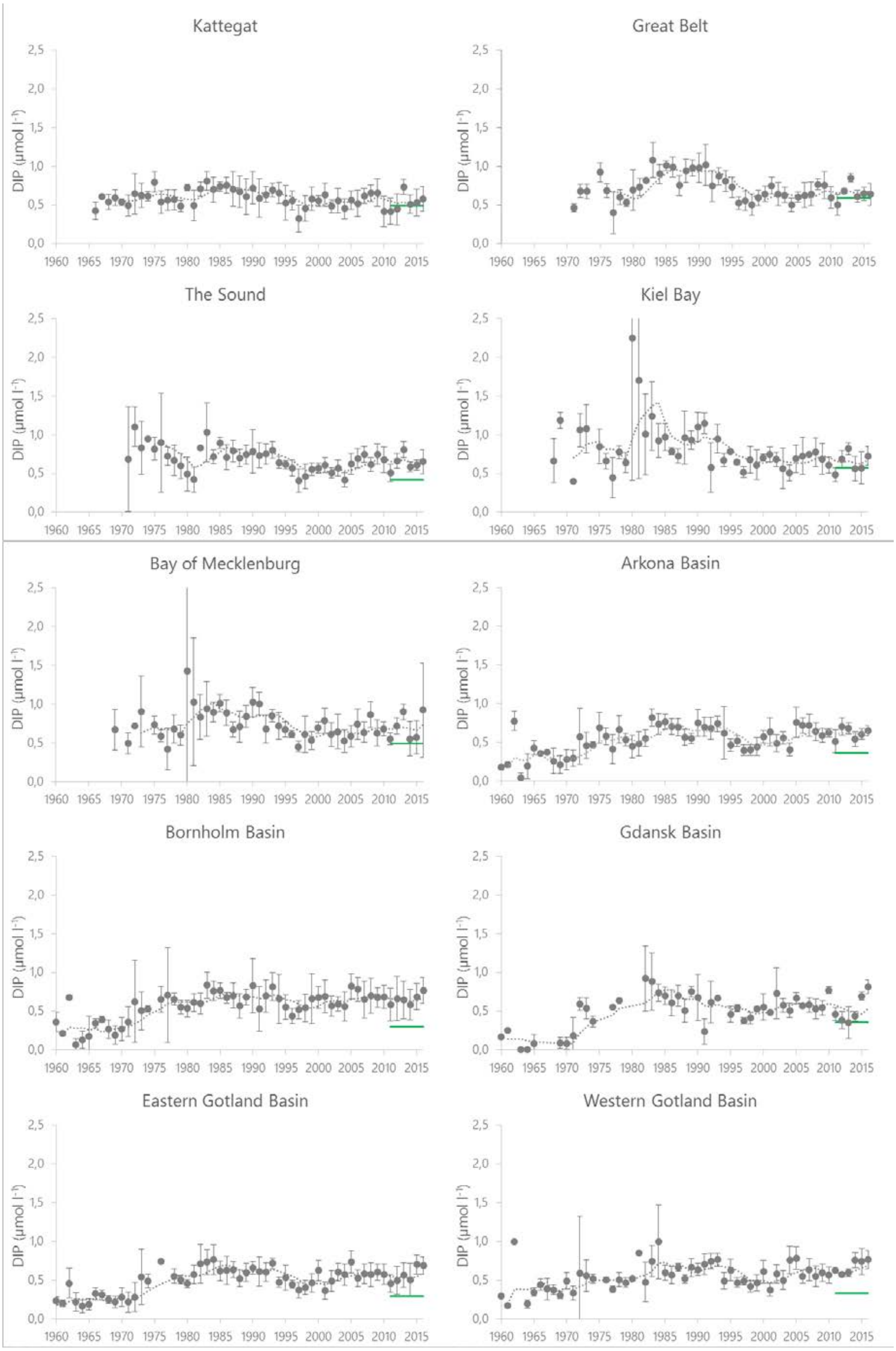


Figure A2.2. Temporal development of total nitrogen (TN) concentrations in the open-sea assessment units in 1970-2016. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold values. Significance of trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange data points.


Kattegat
Great Belt
The Sound
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Gdansk Basin
Eastern Gotland Basin
Western Gotland Basin
DIP (µmol l-1)
0,0
0,5
1,0
1,5
2,0
2,5
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

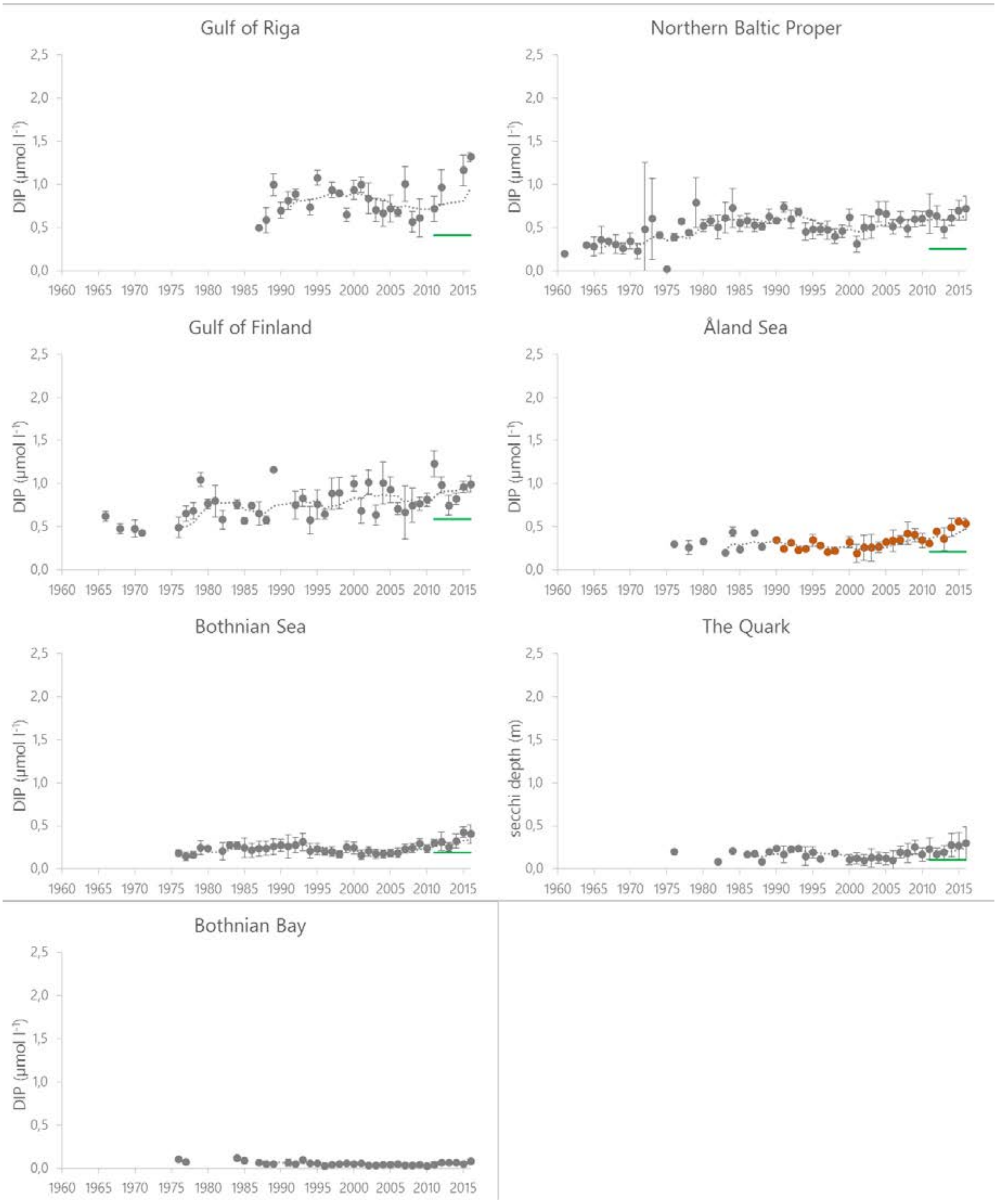
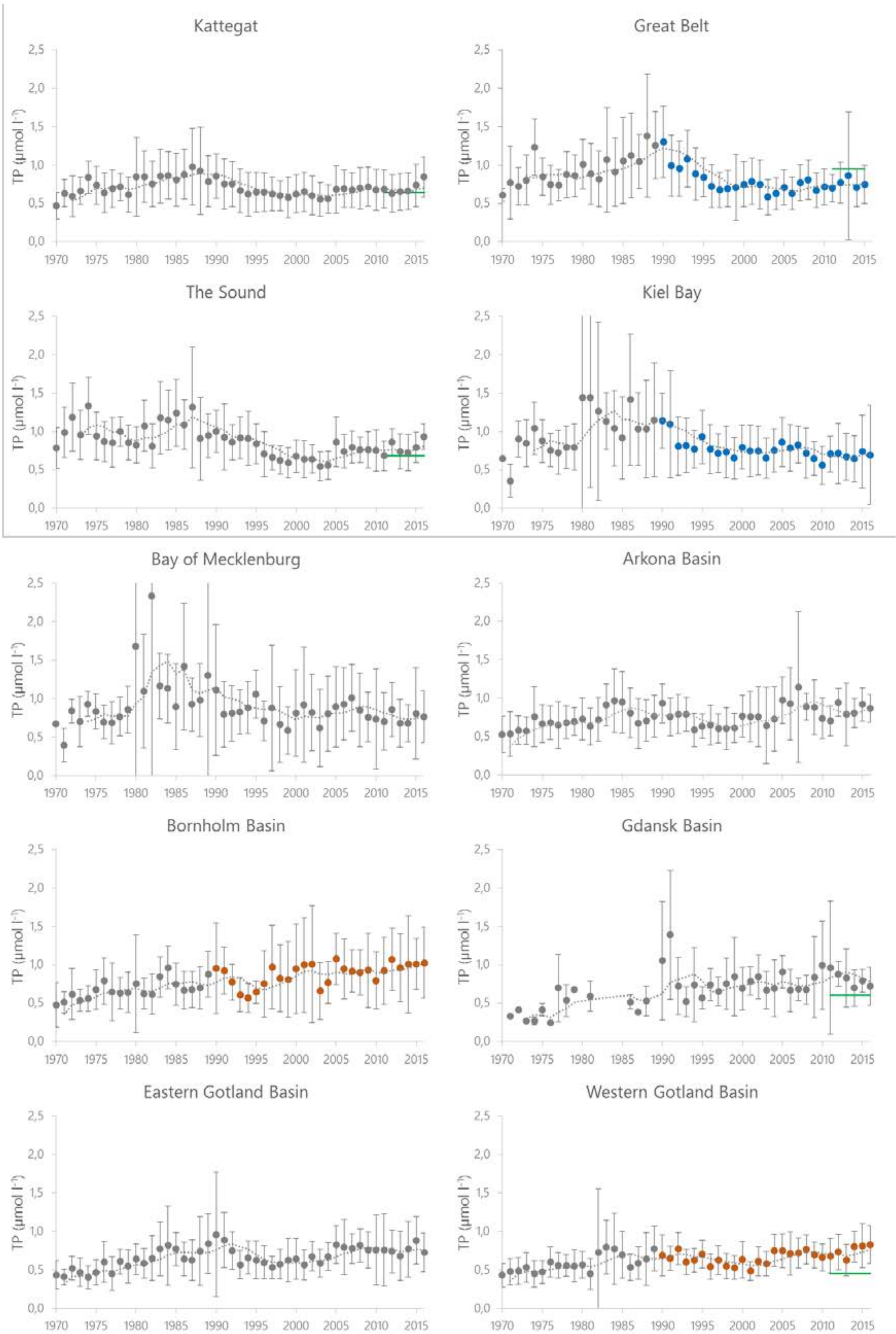


Figure A2.3. Temporal development of winter dissolved inorganic phosphorus (DIP) concentrations in the open-sea assessment units from 1960s to 2016. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold values. Significance of trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) deteriorating trends are indicated with orange data points. No significant improving trends were detected.


Kattegat
Great Belt
The Sound
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Gdansk Basin
Eastern Gotland Basin
Western Gotland Basin
TP (µmol l⁻¹)
2,5
2,0
1,5
1,0
0,5
0,0
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

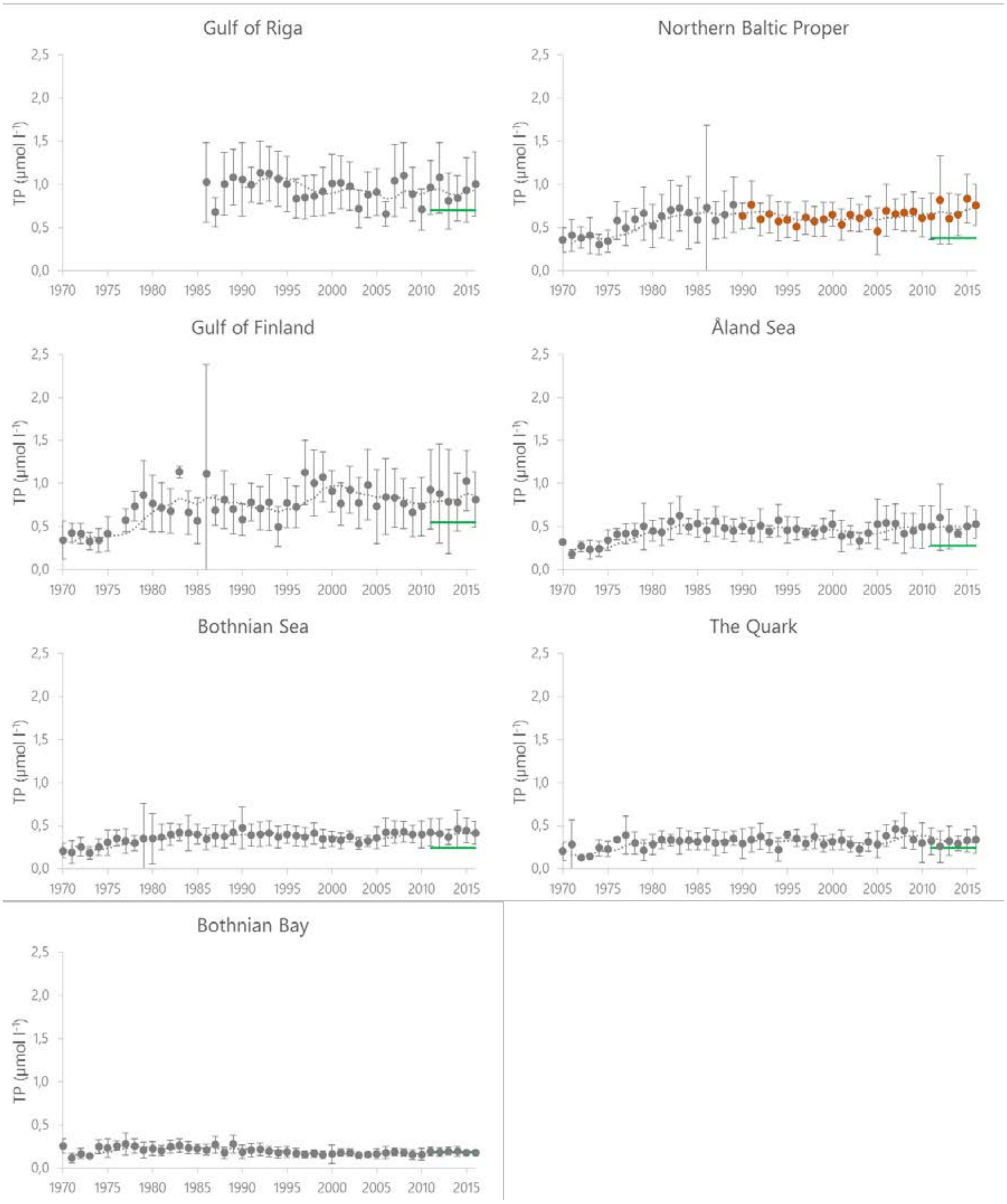
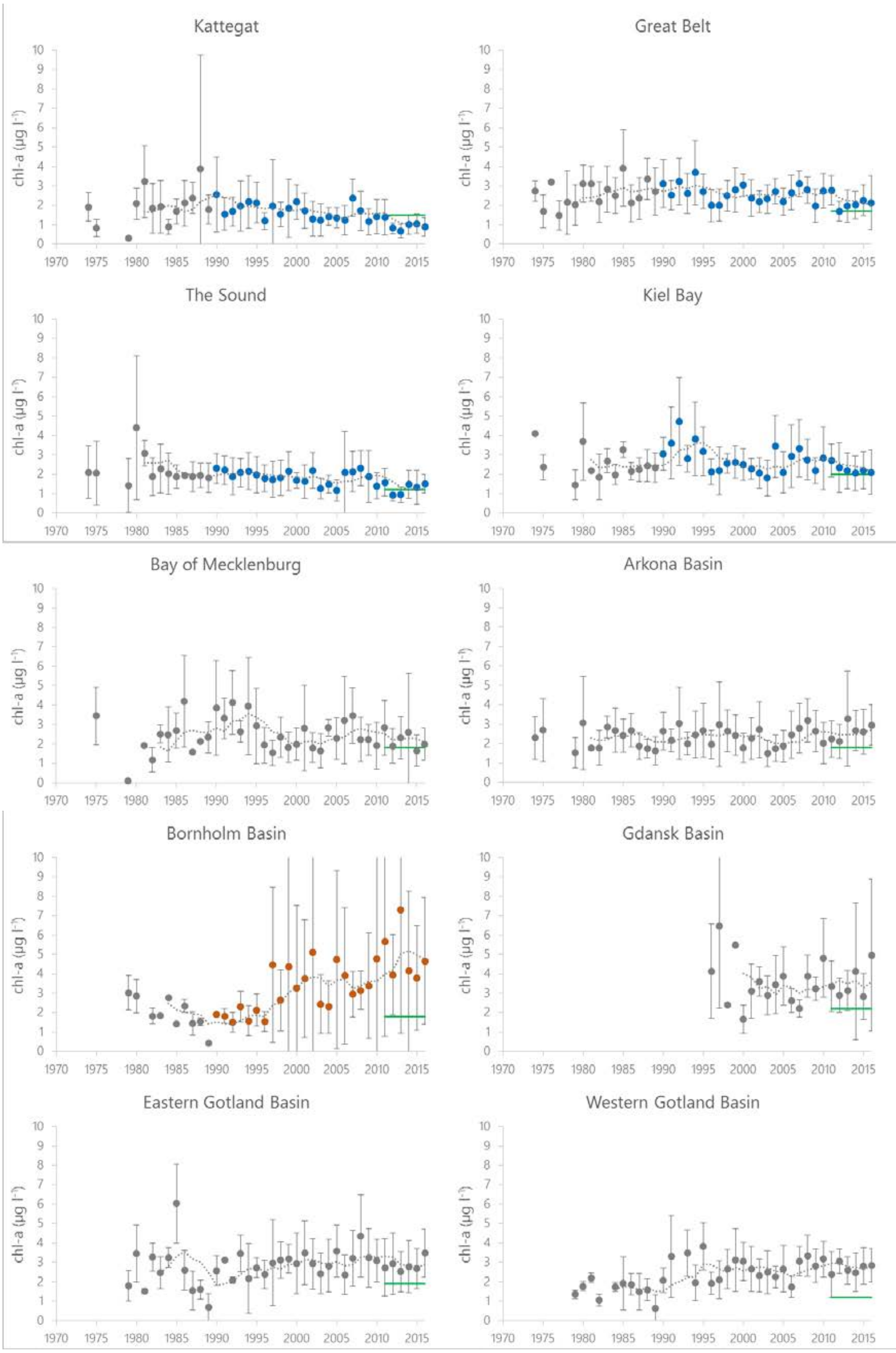


Figure A2.4. Temporal development of total phosphorus (TP) concentrations in the open-sea assessment units from 1970s to 2016. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold values. Significance of trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange data points.


Kattegat
Great Belt
The Sound
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Gdansk Basin
Eastern Gotland Basin
Western Gotland Basin
chl-a (µg l-1)

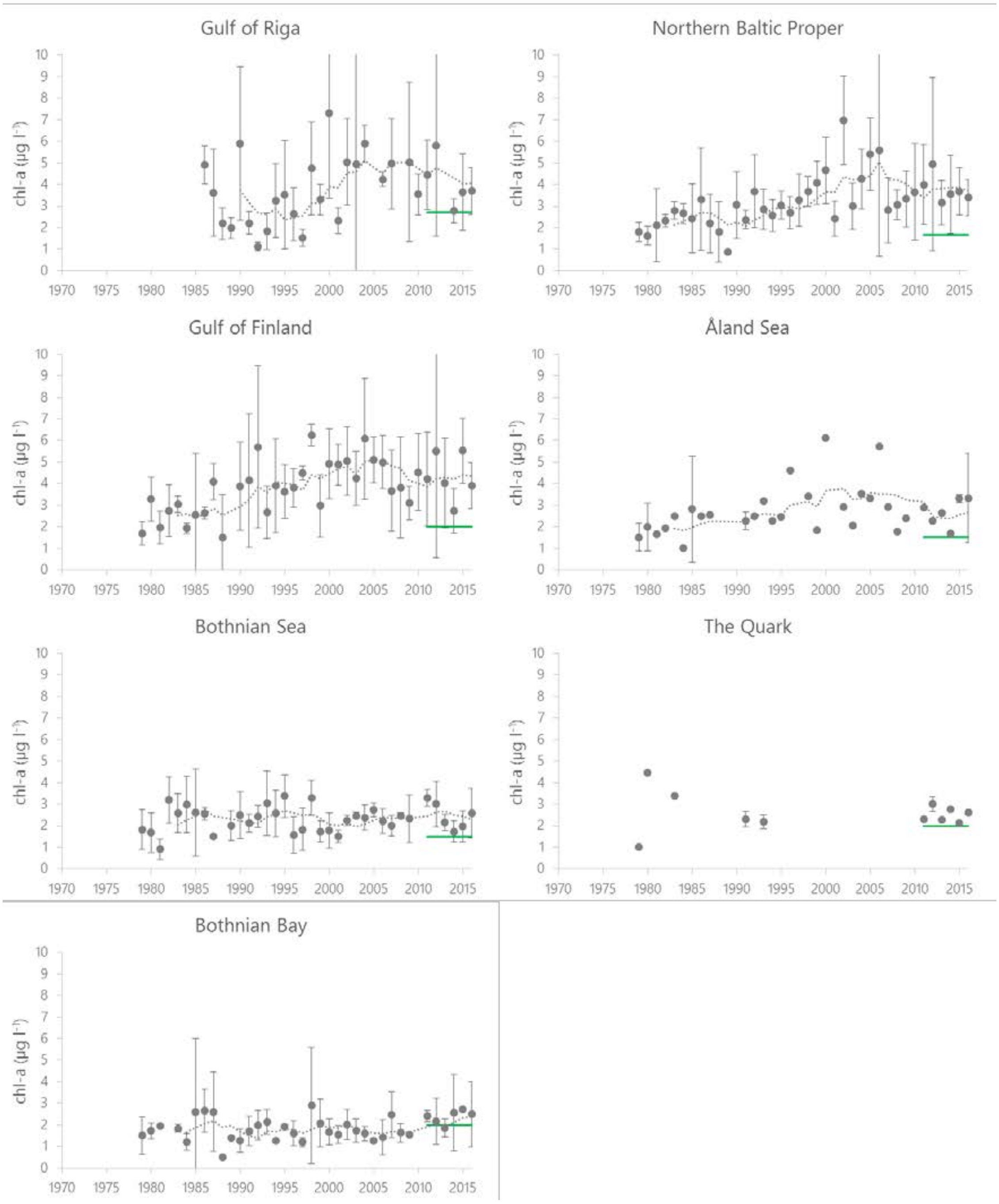
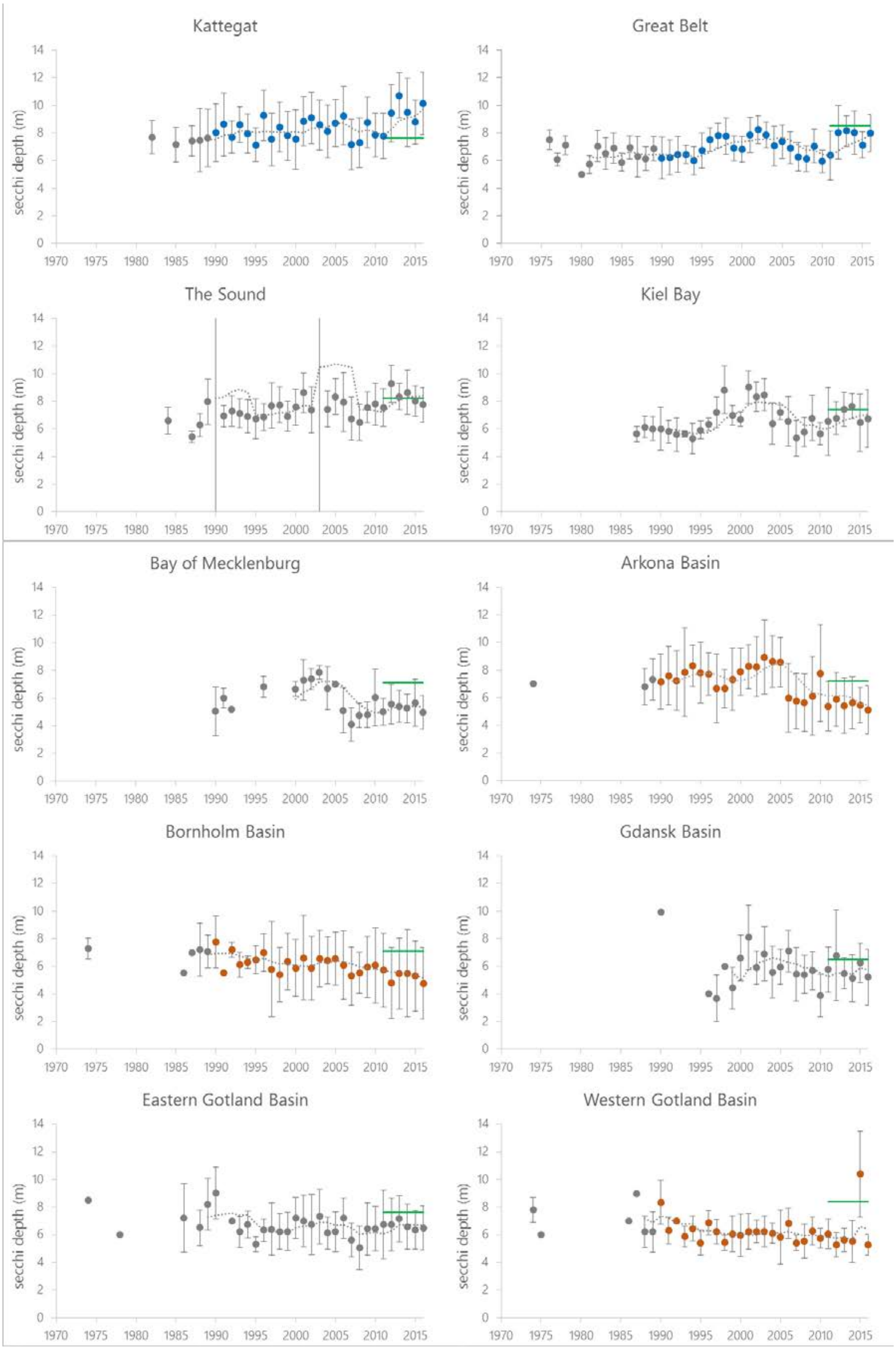


Figure A2.5. Temporal development of chlorophyll-a (Chl-a) concentrations in the open-sea assessment units from 1970s to 2016. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold values. Significance of trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange data points.


Kattegat
Great Belt
The Sound
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Gdansk Basin
Eastern Gotland Basin
Western Gotland Basin
secchi depth (m)
0
2
4
6
8
10
12
14
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

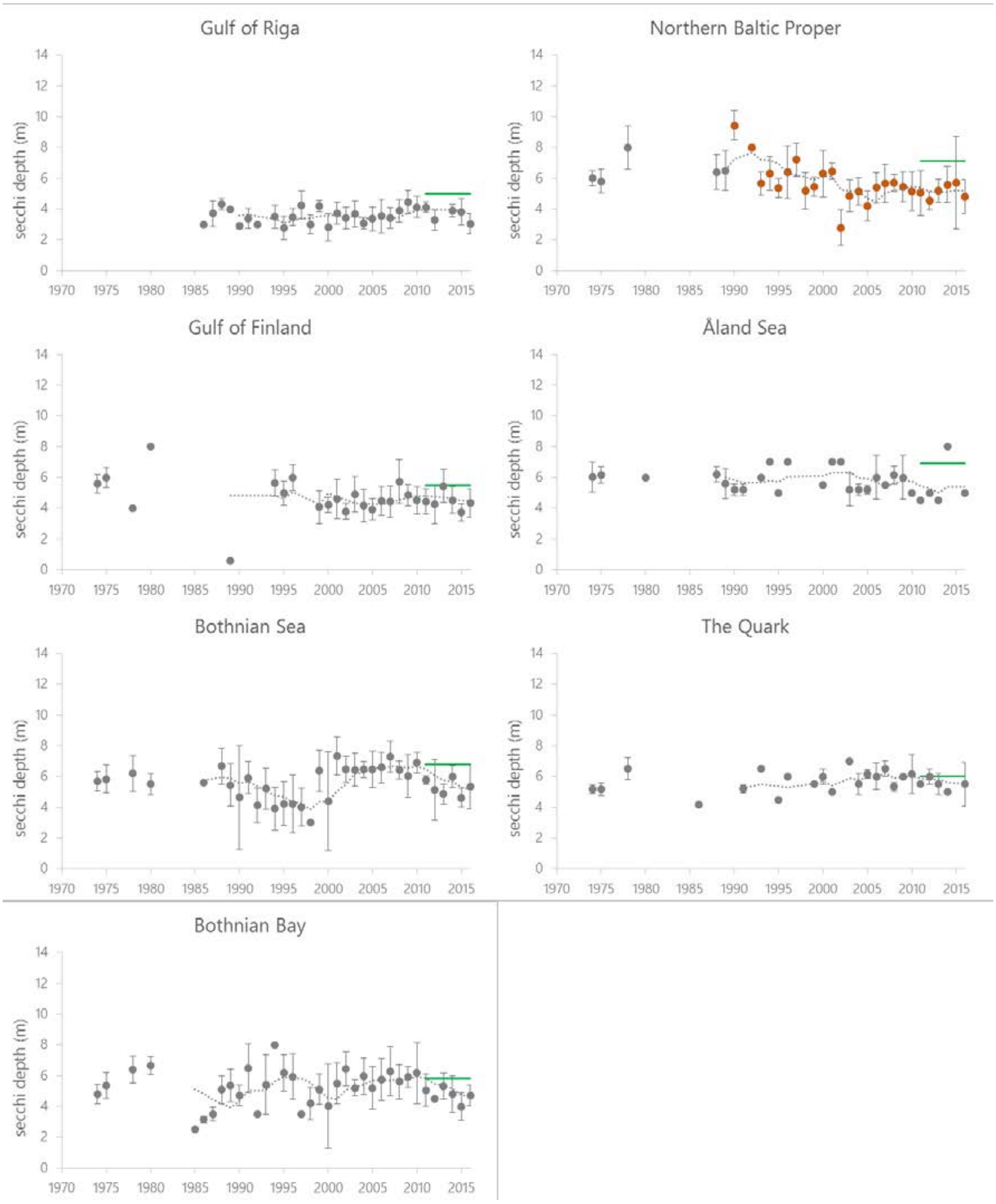
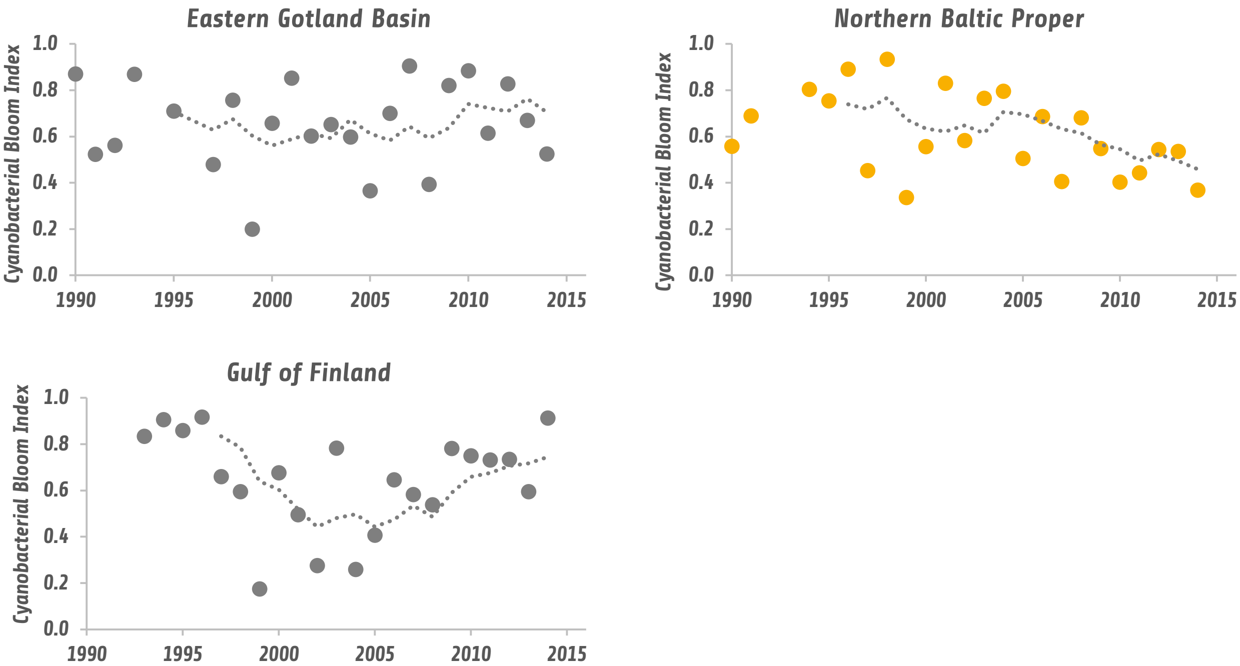


Figure A2.6. Temporal development of water clarity in the open-sea assessment units from 1970s to 2016. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines denote the indicator threshold values. Significance of trends was assessed with the Mann-Kendall test for period from 1990-2016. Significant ($p<0.05$) improving trends are indicated with blue and deteriorating trends with orange data points.

A



B

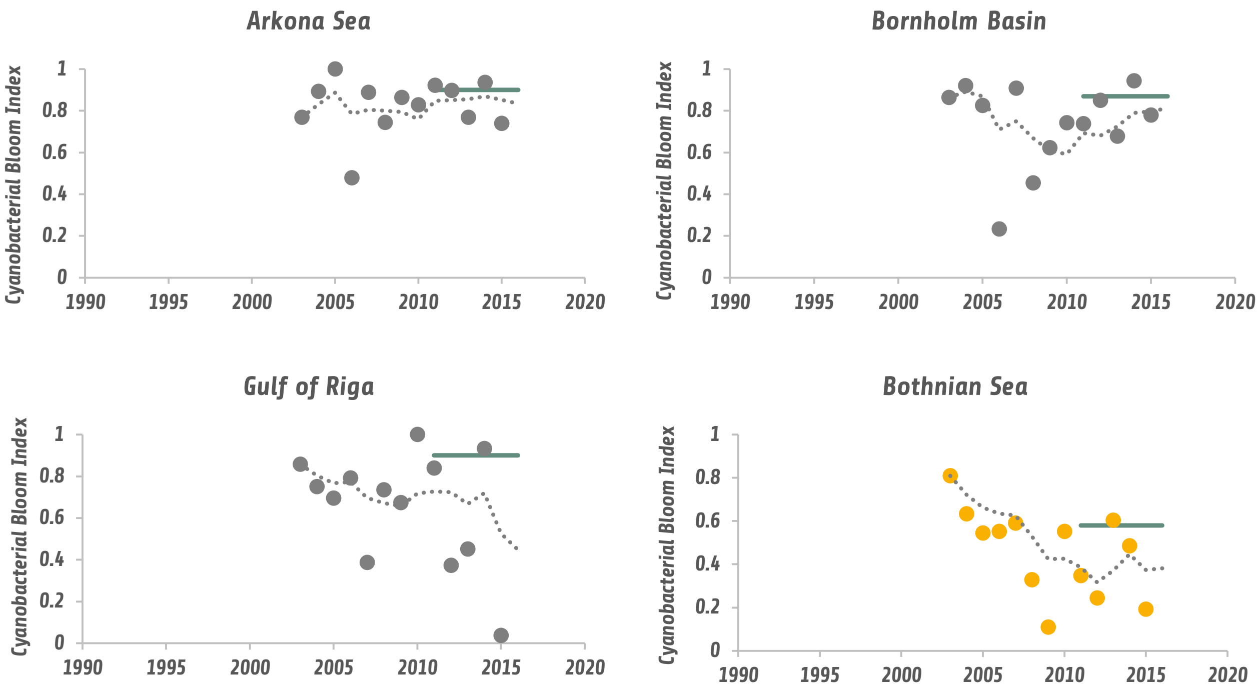


Figure A2.7. Temporal development of 'Cyanobacterial bloom index' in the open-sea assessment units: A) In the Eastern Gotland Basin, the Northern Baltic Proper and the Gulf of Finland in 1990-2014, and B) in the Arkona Basin, the Bornholm Basin, the Gulf of Riga and the Bothnian Sea in 2003-2015. Dashed lines show the five-year moving averages and error bars the standard deviation. Green lines in B denote the indicator threshold values. Threshold values are not included in panel A due to differences in sub-basin division (sub-basin division given in Kahru and Elmgren 2014). Significance of trends was assessed with the Mann-Kendall test for the whole data sets. Significant (p<0.05) improving trends are indicated with blue and deteriorating trends with orange data points.