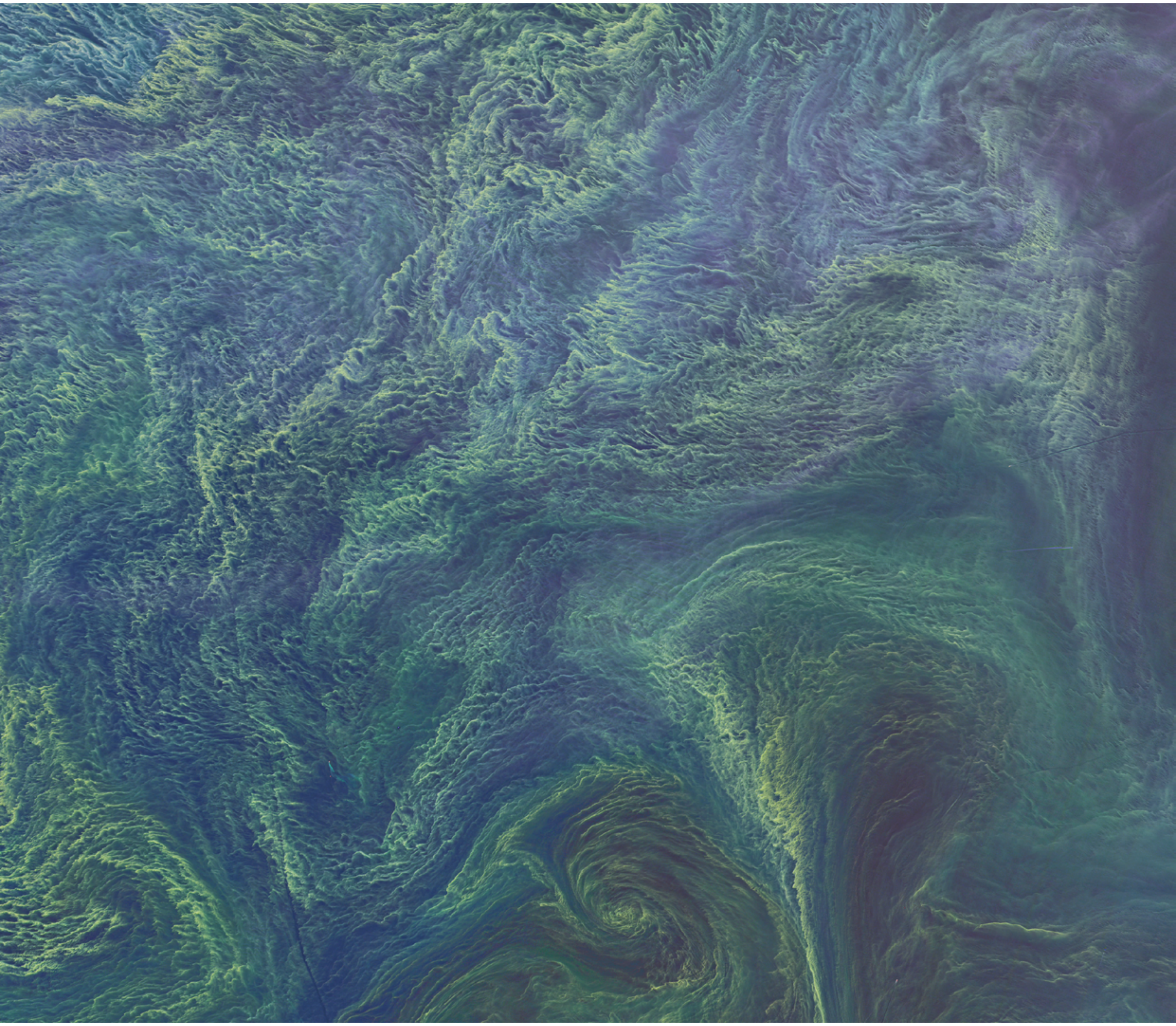
STATE OF THE BALTIC SEA
- HOLISTIC ASSESSMENT -
First version 2017

THE INTEGRATED ASSESSMENT OF EUTROPHICATION

TO BE UPDATED IN 2018

-Supplementary Report to the First Version of the 'State of the Baltic Sea' Report 2017



HELCOM – BALTIC MARINE ENVIRONMENT PROTECTION COMMISSION

The integrated assessment of eutrophication - supplementary report to the first version of the HELCOM 'State of the Baltic Sea' report 2017

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Introductory note

This report contains the method description and summary results for the integrated assessment of eutrophication as presented in the first version of the HELCOM 'State of the Baltic Sea' report, which is available at http://stateofthebalticsea.helcom.fi/about-helcom-and-the-assessment/downloads-and-data/.

The results will be further updated in time for the consolidation and finalization of the 'State of the Baltic Sea' report in June 2018, so that the assessment results will be representative of the assessment period 2011–2016.

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Summary

Eutrophication is one of the most important environmental pressure in the Baltic Sea that has been occurring for a long time. Excessive inputs of nitrogen and phosphorus, which are the main triggers of eutrophication, occur since around the 1950s, enhancing primary productivity, leading to indirect effects also on other parts of the ecosystem.

This report gives the method description and more detailed results of the integrated assessment of eutrophication status in the Baltic Sea 2011-2015, which was carried out as part of the second HELCOM holistic assessment of ecosystem health in the Baltic Sea. The integrated assessment of eutrophication was carried out using the HEAT tool. The key results are presented in the 'State of the Baltic Sea' summary report (HELCOM 2017a). The more detailed results presented here concern the eutrophication ratios and the confidence values for the indicators and for the integrated assessment results, as well as the assessment results presented within national territories.

One key goal of the Baltic Sea Action Plan is to reach a Baltic Sea unaffected by eutrophication (HELCOM 2007). Several eutrophication assessments have been carried out within HELCOM since its agreement (HELCOM 2009, 2010, 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.

The results for the years 2011-2015 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 sea floor (as excessive primary producers are degraded), and a cascade of other ecosystem changes. 97% of the region was assessed as eutrophied according to the integrated status assessment. Nutrient inputs from land have decreased as a result of regionally reduced nutrient loading, but the effect of these measures are not yet detected by the integrated status assessment. Although signs of improvement are seen in some areas, effects of past and current nutrient inputs still predominate the overall status.

Chapter 1. Background

Eutrophication has been evident in the Baltic Sea since the mid-1900s, accompanied by increasing severity of its symptoms in the ecosystem (Larsson *et al.* 1985, Bonsdorff *et al.* 1997). Early symptoms of eutrophication are increased primary production (expressed through increased chlorophyll-a concentrations in the water column or growth of opportunistic benthic algae) and changes in the metabolism of organisms. The increased primary production leads to increased deposition of organic material which in turn leads to increased oxygen consumption. 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).

Concentrations of the main triggers of eutrophication (nitrogen and phosphorus) increased in many areas of the Baltic Sea up until the late 1980s, attributed to increased nutrient loading from land since the 1950s onwards (Figure 1, Gustafsson *et al.* 2012). As a result of locally improved waste water treatment, decreases in nutrient loading occurred in some local areas during the 1980s and 1990s, and in the 1990s the first effects of reducing loss of nutrients from agriculture were also seen. The role of nutrient runoff from cultivated land has been recognised as a highly significant nutrient source in the Baltic Sea (HELCOM 1996). Nutrient inputs to the Baltic Sea have significantly decreased since the late 1990s, and in some sub-basins strong reductions have taken place recently (Figures 1, 2, Box 1).

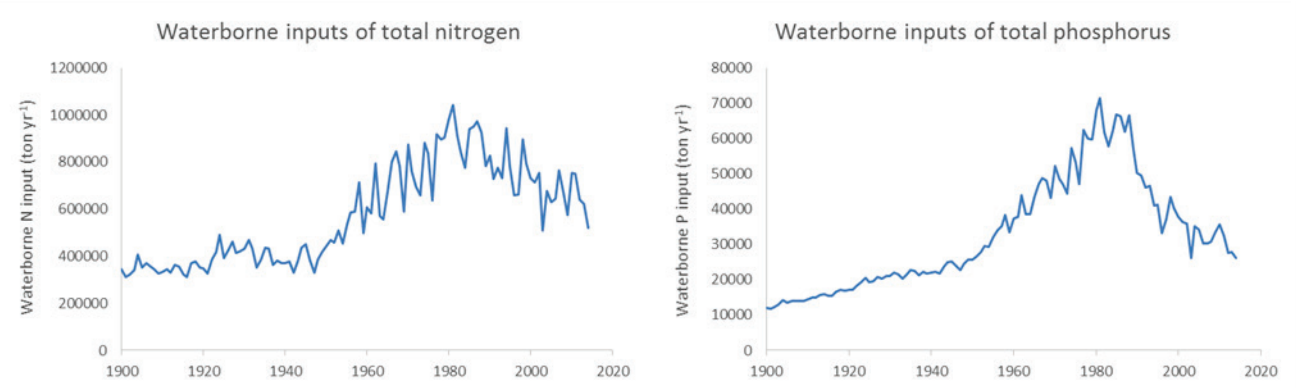

Figure 1. Temporal development of waterborne inputs of total nitrogen (left) and total phosphorus (right) to the Baltic Sea.
Sources: HELCOM (2015a, 2017b), Gustafsson *et al.* (2012), Savchuk *et al.* (2012).

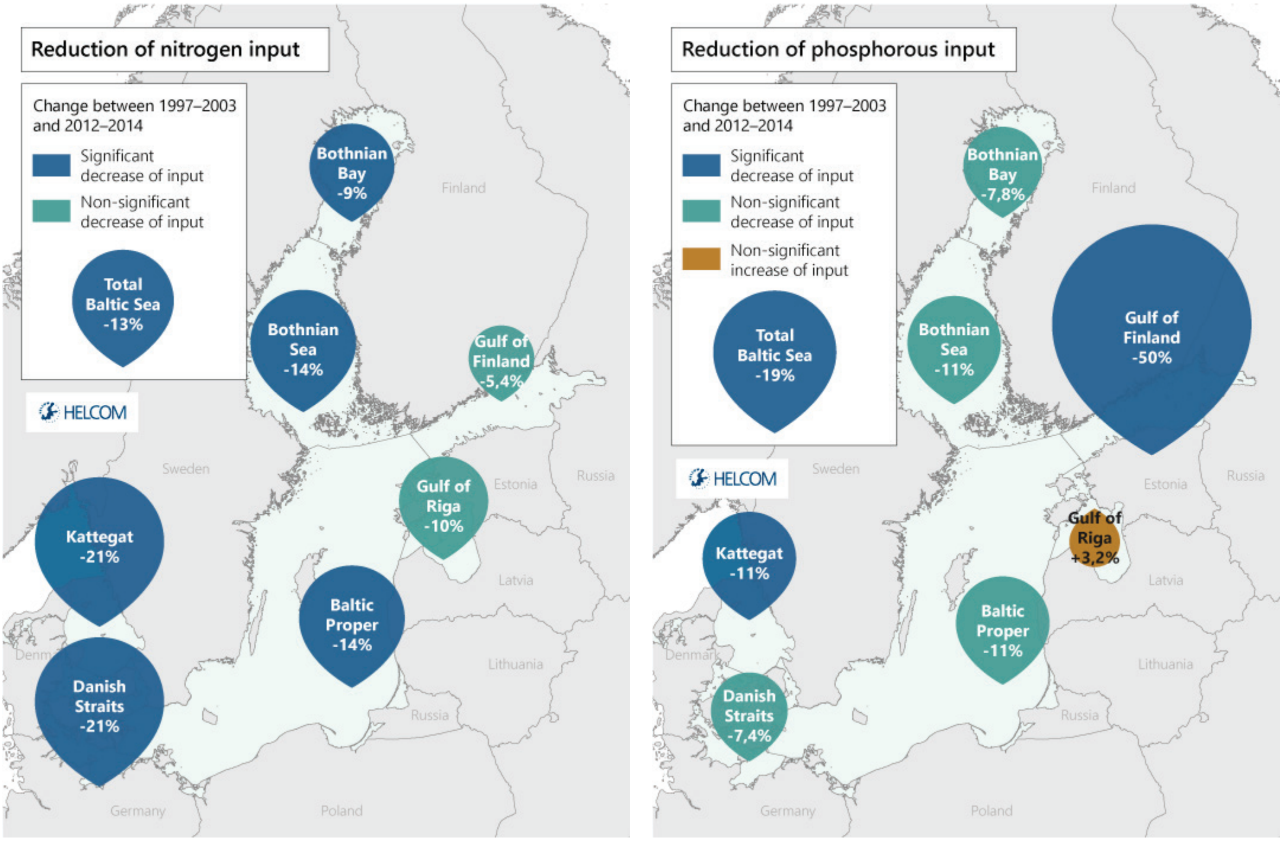

Figure 2. The inputs of nitrogen and phosphorous to the Baltic Sea sub-basins have decreased significantly in recent years. The drop shapes show the relative change in annual average normalised net nutrient input to the sub-basins, including riverine, direct and airborne inputs comparing the years 2012–2014 with the reference period 1997–2003. Drop shapes pointing downwards show sub-basins where inputs have decreased, and the brown shape pointing upwards show sub-basins where inputs have increased. The size of each drop shape is proportional to the amount of change. Significance is determined based on the whole series of observations, starting from 1995. Source: HELCOM 2017b.

Chapter 2. Indicators used in the assessment

Eutrophication status was evaluated in open-sea areas by assessing core indicators within three criteria: nutrient levels, direct effects and indirect effects of eutrophication (Core indicator reports: HELCOM 2017c-k).

To asses nutrient levels, core indicators on the concentrations of nitrogen and phosphorous, which primary producers need for growth, were used. Dissolved inorganic nitrogen and phosphorous are directly utilizable for phytoplankton, and are measured in the winter season when primary productivity is low. Measurements of total nitrogen and total phosphorous also include nutrients that are bound in phytoplankton, or in particles in the water. Thus, they describe the total level of nutrient enrichment in the sea. Including estimates of total nutrients makes it possible to take climate change into account in the assessment, since increased winter temperatures are expected to lead to the production of phytoplankton all year round, and thus to higher shares of nutrients being bound in phytoplankton biomass compared to dissolved forms.

To assess the direct effects of eutrophication, indicators on chlorophyll-a concentrations and water clarity (measured by the indicator 'Secchi depth during summer') were used. In addition, the 'Cyanobacterial bloom index' was included as a test indicator.

To assess indirect effects of eutrophication, the core indicator 'Oxygen debt' was used. This core indicator measures the volume-specific oxygen debt, which is the oxygen debt below the halocline divided by the volume. Hence, the indicator estimates how much oxygen is 'missing' from the Baltic Sea deep water. In addition, the indicator 'State of the soft-bottom macrofauna community' was used to assess indirect effects of eutrophication in the open sea Gulf of Bothnia.

The coastal areas in eight countries were assessed by national indicators used in the Water Framework Directive (EC 2000), used to evaluate biological quality elements such as phytoplankton (chlorophyll-a), benthic invertebrate fauna and macrophytes (macroalgae and angiosperms), and supporting physical and chemical elements such as concentrations of nitrogen, phosphorus, and water clarity. Different indicators were used in different countries.

2.1 THRESHOLD VALUES

The threshold values for HELCOM open sea assessment units have been agreed on by the HELCOM and 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 phosphorous (DIP)', 'Oxygen debt'; HELCOM 38-2017 (outcome para 4.19, Annex 5; HELCOM 2017l): 'Total nitrogen', 'Total phosphorous', 'Cyanobacterial bloom index'.

Threshold values for the coastal areas have been intercalibrated under the Water Framework directive for some indicators (for example chlorophyll-a), or have been set through national decisions (for example nutrient concentrations, secchi depth).

2.2 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. The HELCOM eutrophication core indicators fit well with the MSFD criteria (Table 1). The two primary criteria *Nutrient concentration* and *Chlorophyll* a *concentration*, as well as one secondary criterion are represented by an operational core indicator in all open-sea assessment units. The third primary criterion, *Concentration of dissolved oxygen*, is represented by a core indicator 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.

Regarding all HELCOM core indicators, HELCOM HOD 51-2016 (HELCOM 2016) clarified that 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 EU Commission Decision laying down criteria and methodological standards on good environmental status, but can be used for the purposes of their MSFD obligations by those Contracting Parties being EU Member States that wish to do so.

Table 1. Eutrophication indicators applied in the integrated assessment, listed according to criteria group, and criteria presented in EC 2017/848. The last column indicates whether the criterion is primary or secondary. In coastal areas, national indicators are used, and each of the coastal indicators listed do not necessarily apply for all coastal assessment units. WFD = Water Framework Directive. TN= total nitrogen, TP= total phosphorous.

Criteria group	Indicator name	Coastal/ open sea	MSFD criteria (primary/ secondary)
Nutrient concentration	Dissolved inorganic nitrogen (DIN)	Open sea	D5C1 (primary): Nutrient concentrations are not at levels that indicate adverse eutrophication effects.
	Dissolved inorganic nitrogen (DIP)	Open sea	
	Total nitrogen	Open sea	
	Total phosphorus	Open sea	
	WFD indicators on DIN (EUTRO-OPER)	Coastal	
	WFD indicators on DIP (EUTRO-OPER)	Coastal	
	WFD indicators on TN (EUTRO-OPER)	Coastal	
	WFD indicators on TP (EUTRO-OPER)	Coastal	
Direct effects	Chlorophyll-a	Open sea	D5C2 (primary): Chlorophyll a concentrations are not at levels that indicate adverse effects of nutrient enrichment.
	WFD indicator results on phytoplankton (mostly chlorophyll-a and biovolume) (EUTRO-OPER)	Coastal	
	Cyanobacterial Bloom Index (CyaBI)*,**	Open sea	D5C3 (secondary): The number, spatial extent and duration of harmful algal bloom events are not at levels that indicate adverse effects of nutrient enrichment.
	Water clarity	Open sea	D5C4 (secondary): The photic limit (transparency) of the water column is not reduced, due to increases in suspended algae, to a level that indicates adverse effects of nutrient enrichment
	WFD indicators on water clarity or turbidity (EUTRO-OPER)	Coastal	
Indirect effects	Oxygen debt	Open sea	D5C5 (primary): The concentration of dissolved oxygen is not reduced, due to nutrient enrichment, to levels that indicate adverse effects on benthic habitats (including on associated biota and mobile species) or other eutrophication effects.
	WFD indicators on oxygen concentration or hypoxia (EUTRO-OPER)	Coastal	
	WFD indicators on macrophytes (EUTRO-OPER)	Coastal	D5C6 (secondary): The abundance of opportunistic macroalgae is not at levels that indicate adverse effects of nutrient enrichment. D5C7 (secondary): The species composition and relative abundance or depth distribution of macrophytes communities achieve values that indicate there is no adverse effect due to nutrient enrichment including via a decrease in water transparency.
	State of the soft-bottom macrofauna community*	Open sea	D5C8 (secondary): The species composition and relative abundance of macrofaunal communities, achieve values that indicate that there is no adverse effect due to nutrient and organic enrichment.
	WFD indicators on macrofauna (EUTRO-OPER)	Coastal	

*The indicator has not been adopted in HELCOM yet and is currently tested.
**Pre-core: Denmark has a study reservation on this indicator but has agreed to test it in the 'State of the Baltic Sea' report denoting results as intermediate.

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 is interpreted through statistical analysis. 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 2013). 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).

Chapter 3. Method for the integrated assessment of eutrophication

The integrated assessment of eutrophication was done using the HEAT tool which aggregates the indicator results into a quantitative estimate of overall eutrophication status. 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 elements (indicators) by six criteria, in line with the structure of the MSFD methodological standards on good environmental status (EC 2017), and then further aggregates these into three criteria groups: nutrient levels, direct effects and indirect effects (Figure 3). The indicators within each assigned group are integrated using weighted averaging of the eutrophication ratios which estimate how much different the assessment value is from the threshold value. The weight is evenly distributed unless otherwise justified. No averaging is needed for criteria that consist of only one indicator (element). The overall eutrophication status is determined using one-out-all-out between criteria groups.

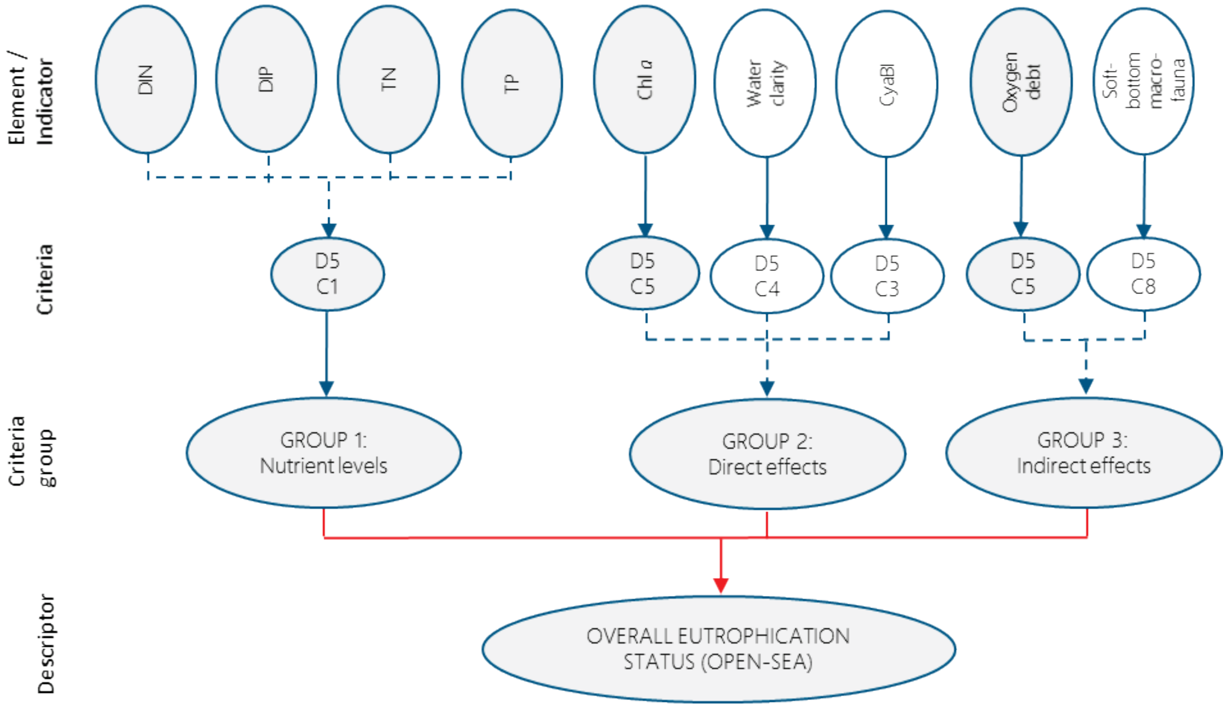

Figure 3. Structure of the eutrophication assessment for open-sea areas. The aggregation of indicators in HEAT 3.0 based on criteria, and subsequently on criteria groups, takes into account the MSFD methodological standards. Primary elements (indictors) associated with primary criteria are shaded grey, whereas the secondary criteria and their elements (indicators) have no shading. Dashed blue lines indicate a process of weighted averages and solid red line indicates where a One-Out-All-Out process is adopted.

3.2 CONFIDENCE ASSESSMENT METHODOLOGY OF THE HEAT TOOL

The confidence of the results is assessed at both indicator level and integrated eutrophication status level. The final confidence rating for each assessment unit may range between 100% and 0% and is grouped into three confidence classes: high (100–75%), moderate (74–50%) and low (below 50%).

The calculation of confidence is done in three steps:

1. The indicator-specific confidence: Confidence in the indicator threshold value (referred to as the ET-Score) and in the status value (referred to as the 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. A value of 100 is assigned for high confidence, 50 for moderate and 0 for low confidence.

2. Criteria-specific confidence is assessed as the (weighted) arithmetic mean of the confidences of the indicators within each criteria.

3. 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.

In addition, to ensure at least moderate confidence of the overall eutrophication assessment, the assessment requires that the classification is based on at least two, but preferably three criteria, with ideally not less than two indicators per criterion. 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%.

3.3 ASSESSMENT DATA FLOW

The eutrophication status assessment results presented below are based on data from years 2011-2015[1] obtained through the eutrophication assessment data flow as described below (see also Figure 4).

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 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 achieved from 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[2] and the HELCOM Map and Data service[3], 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 dataview is restricted to experts named by the Contracting Parties to be responsible for data and assessment product review, in order not to present un-accepted products to the public.

[1] the final version will cover data for 2011-2016

[2] http://www.helcom.fi/baltic-sea-trends/eutrophication/indicators/

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

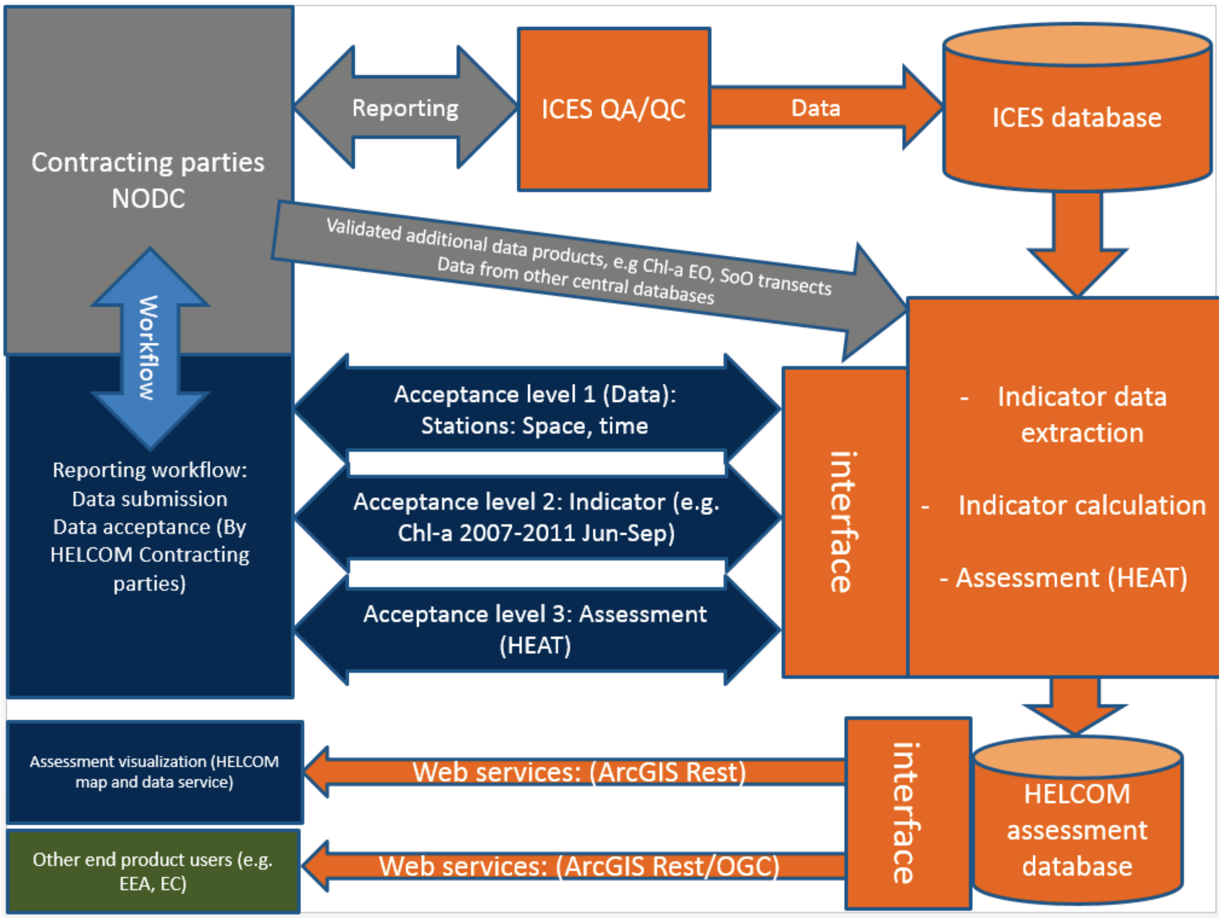

Figure 4. Eutrophication assessment data and information flow. The color of the items indicate the actor/host: Grey = Contracting Parties, Blue = HELCOM portal hosted at the HELCOM Secretariat, Orange = ICES, Green = Other end-users, for example European Environment Agency (EEA), European Commission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

Chapter 4. Results from the integrated assessment

The updated integrated eutrophication status assessment for 2011–2015 shows that the Baltic Sea is still affected by eutrophication (Figure 5). Out of the 247 assessment units included in the HELCOM assessment covering both coastal and open water bodies, only 17 achieved good status, showing that 97% of the surface area in the Baltic Sea, from the Kattegat to the inner bays, is eutrophied. About 15 % of the surface area had eutrophication ratios in the category furthest away from good status. Only a few coastal areas are unaffected by eutrophication.

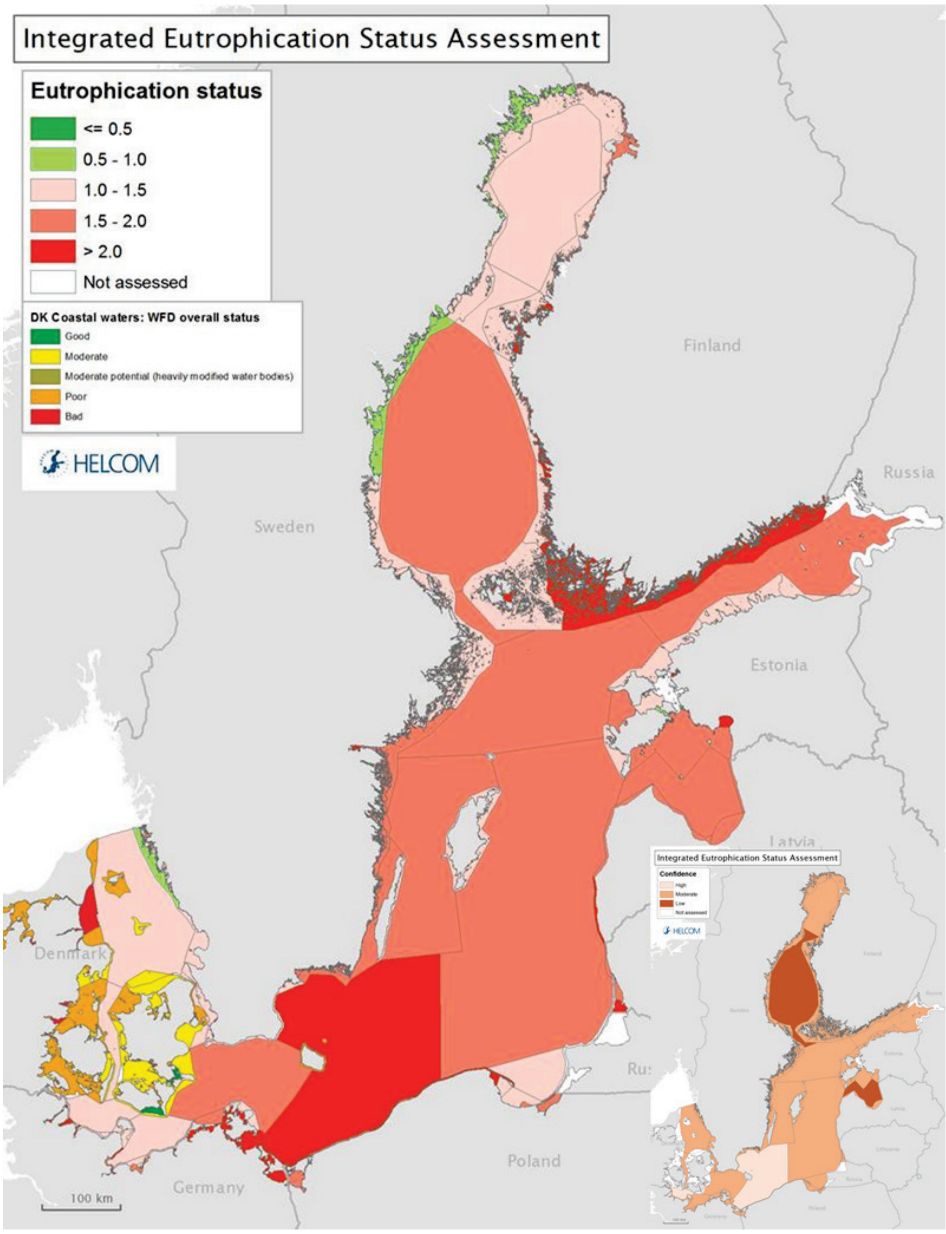

Figure 5. Integrated status assessment of eutrophication. Each assessment unit shows the status of the criteria group in the worst status (see Figure 8 and Table 2). Note that the integrated status of Swedish coastal areas in the Kattegat differs from corresponding results in the OSPAR intermediate assessment. In coastal areas HELCOM utilises national indicators used in the Water Framework Directive to arrive at status of coastal assessment units for eight countries. White areas denote that data has not been available for the integrated assessment. The map in the lower corner shows the confidence assessment result (dark color = low confidence, light color = high confidence).

In most of the open-sea areas, good status was not achieved for the nutrient levels or the direct and indirect effects of eutrophication (Figures 6–7). Nutrient levels were in good status only in the Great Belt, and direct effects in the Kattegat (Figure 6). Indirect effects were in good status in the Bothnian Sea and the Quark, which cover 18 % of the open-sea area (Figures 6–7). The nutrient levels were generally furthest away from good status, and thus had highest overall influence on the integrated assessment results. Integrated eutrophication status had improved in only one but deteriorated in seven of the 17 open-sea assessment units since the last five year period (2007–2011).

Most coastal areas in the Baltic Sea failed to achieve good status based on nutrient levels and direct eutrophication effects, with exceptions mainly in the coastal areas of the Gulf of Bothnia and the Kattegat (Figure 6). Indirect effects achieved good status in many of the coastal areas, including the Swedish and Estonian coasts and Finnish coast of the Bothnian Sea.

Table 2 shows the integrated status assessment result 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.

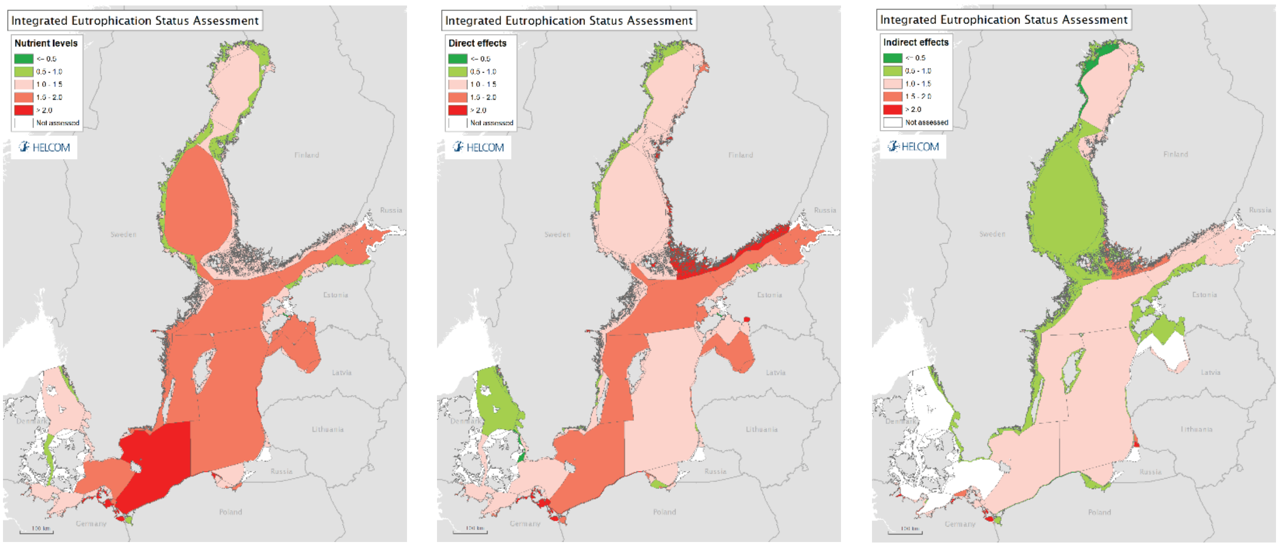

Figure 6. Integrated status assessment results for eutrophication, shown by criteria groups: left: nutrient levels, middle: direct effects, right: indirect effects. Note that the integrated status of Kattegat coastal areas differs from corresponding results in the OSPAR intermediate assessment[4]. In coastal areas HELCOM utilizes national indicators used from the Water Framework Directive to arrive at status of coastal areas assessment units for eight countries. White areas denote areas that were not assessed due to the lack of indicators[5].

[4] Danish coastal water WFD-classification differs from the open sea classification. Hence, the colours are not directly comparable.
[5] The Gdansk Basin has been assessed solely with Polish data.

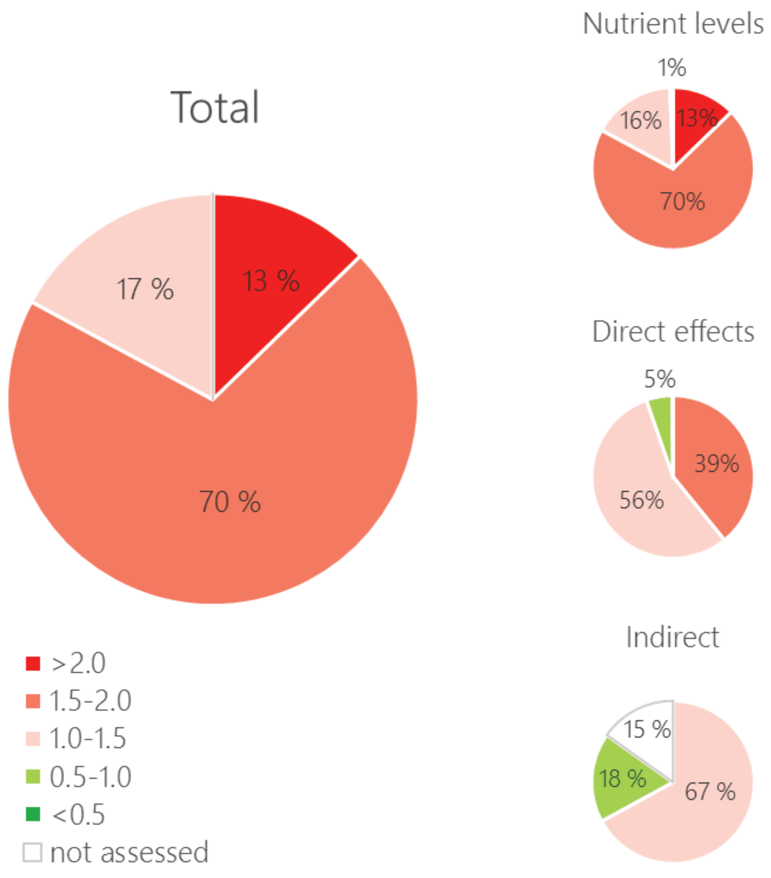

Figure 7. Proportion of open sea areas in the HELCOM region in each of the five status categories of the integrated assessment of eutrophication. White denotes areas not assessed due to lack of indicators (see Table 2).

Table 2. Core indicator results for eutrophication in the open sea for years 2011–2015. Green cells denote good status and red not good status. The last column shows the corresponding integrated status assessment result for open sea sub-basins, similar as in figure 6. Values show the eutrophication ratios of the indicator or integrated status, as estimated in HEAT. 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 in the table: DIN = 'Dissolved inorganic nitrogen', TN= 'Total nitrogen', DIP= 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chla= 'Chlorophyll-a', Secchi= 'Secchi depth during summer', Cyano = 'Cyanobacterial bloom index', and O2 = 'Oxygen debt'. Indicators marked * have not been adopted in HELCOM yet and are currently tested. 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 2017c-k.

	Core indicator results									
	Nutrient levels				Direct effects			Indirect effects		
	DIN	TN	DIP	TP	Chla	Secchi	Cyano*	O_2	Zoob*	
Assessment unit	Dec–Feb	All year	Dec–Feb	All year	Jun–Sep	Jun–Sep	20 Jun–31 Aug	All year	May–Jun	**Integrated status assessment**
Kattegat	1,17	0,87	1,08	1,05	0,63	0,82	N	N		1,04
Great Belt	1,06	0,75	1,11	0,80	1,17	1,13	N	N		1,15
The Sound[6]	1,70	1,01	1,52	1,12	1,01	0,97	N	N		1,34
Kiel Bay	1,07		1,10		1,15	1,06	N	N		1,11
Bay of Mecklenburg	1,49		1,33		1,29	1,24	1,29	N		1,41
Arkona Basin	1,40		1,69		1,45	1,20	1,06	N		1,54
Bornholm Basin[7]	3,63		2,06		2,52	1,26	1,12	1,27		2,84
Gdansk Basin	0,72	1,21	1,06	1,12	1,45	1,11	1,19	1,24		1,26
Eastern Gotland Basin	1,27	1,33	1,83		1,39	1,13	1,10	1,24		1,56
Western Gotland Basin	1,46	1,36	1,99	1,72	1,96	1,37	1,11	1,24		1,63
Gulf of Riga	2,07	1,09	2,31	1,32	1,53	1,32	1,71	N		1,74
Northern Baltic Proper	1,68	1,27	2,53	1,85	2,03	1,17	1,71	1,24		1,83
Gulf of Finland	2,36	1,06	1,61	1,66	2,28	1,31	1,30	1,24		1,76
Åland Sea	1,44	1,16	2,06	1,80	1,57	1,45	N	2,10	0,61	1,61
Bothnian Sea	1,38	1,14	1,71	1,77	1,46	1,30	1,55	2,10	0,63	1,50
The Quark	1,28	1,03	2,23	1,32	1,28	1,04	N	N	0,50	1,46
Bothnian Bay	1,24	1,11	0,77	1,05	1,11	1,29	N	2,26	0,32	1,14

[6] Result may be changed due to planned changes in assessment data.
[7] Result for the Bornholm Basin may be subject to change, to be clarified.

4.1 MORE DETAILED RESULTS FROM THE INTEGRATED ASSESSMENT

Disclaimer: The exact area figures presented below (Tables 3-5.9) are preliminary and subject to change.

Proportion of eutrophied area

The proportion of eutrophied area 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 3, 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 (see Table 5, part 2) as "Not good". Results were also calculated for the Baltic Sea as defined by the MSFD sub-regions (Table 3, 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 8).

Table 3.1. Proportion of eutrophied area in the whole Baltic Sea, and for open sea and coastal areas, respectively.

HELCOM area	**Area (km2)**			**Percent (%) of area**		
Status	**Baltic Sea**	**Open sea**	**Coastal**	**Baltic Sea**	**Open sea**	**Coastal**
Good	6 161	0	6 161	1.5	0	5.2
Not good	408 155	305 217	102 938	96.5	100	87.4
Not assessed	8 680	0	8 680	2.1	0	7.4
Total	**422997**	**305217**	**117781**	**100**	**100**	**100**

Table 3.2. Proportion of eutrophied area 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	4960	0	4960	1.2	0	4.6
Not good	383737	289305	94432	96.6	100	87.4
Not assessed	8680	0	8680	2.2	0	8.0
Total	**397377**	**289305**	**108072**	**100**	**100**	**100**

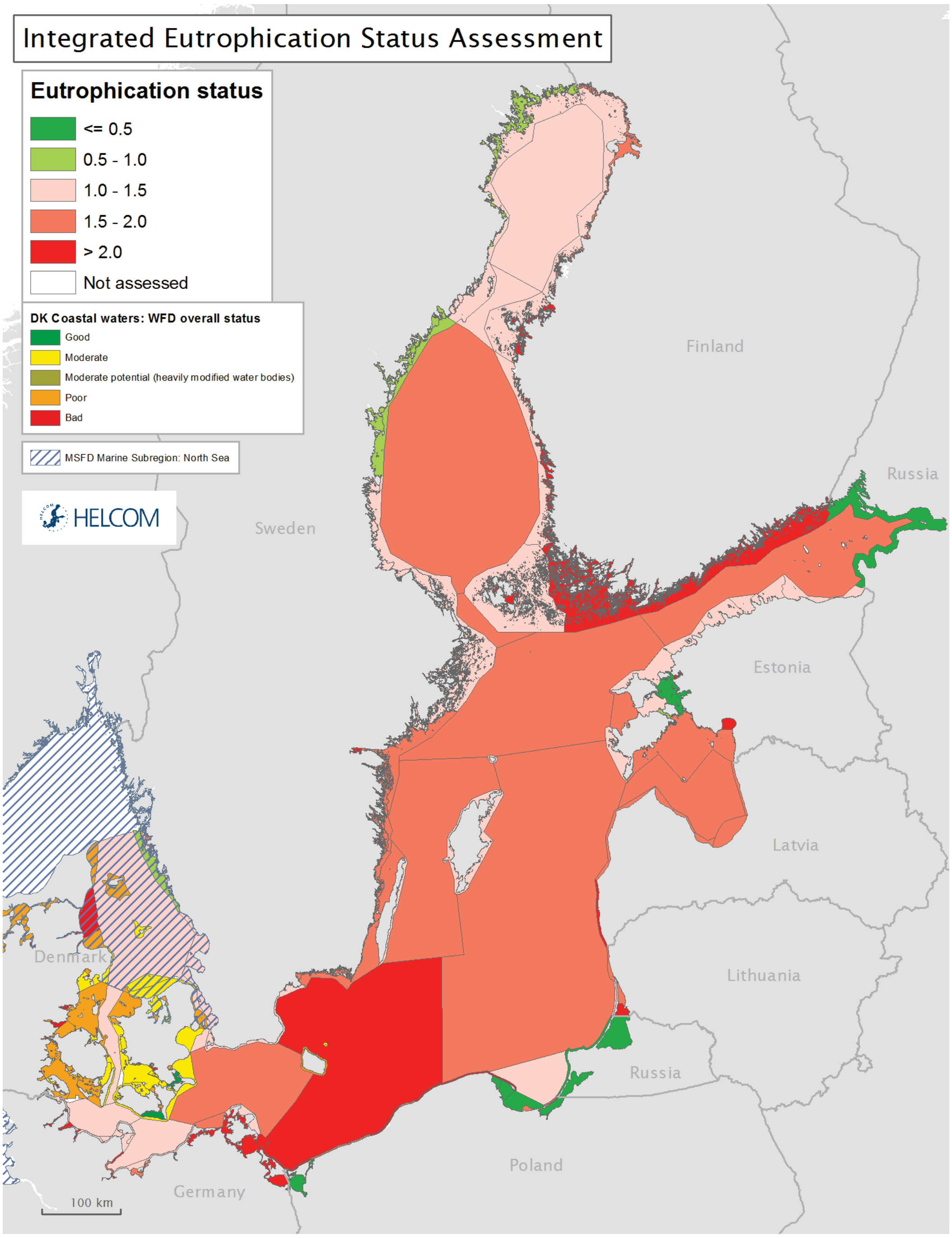

Figure 8. Integrated eutrophication status assessment and border of MSFD sub-region North Sea (dashed line) and Baltic Sea.

Eutrophied area by country

Proportion of eutrophied area 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 4). 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. Open sea area of a country was calculated by splitting the open sea assessment units with EEZ line shapefile used by HELCOM. The results by country are detailed in Tables 5, parts 1 to 9).

Table 4. Overview of proportion of eutrophied area in the whole Baltic Sea by country (%).

Status	DE	DK	EE	FI	LV	LT	PL	RU	SE
Good	0	0.7	0.2	0	0	0	0	0	3.7
Not good	100.0	99.3	97.2	100	100	100	93.7	75.4	96.3
Not assessed	0	0	2.6	0	0	0	6.3	24.6	0

Table 5.1. Eutrophied area in Germany given as area and proportion by status class for the open sea and the coast.

Germany	Open sea areas		Coastal areas	
Status	Area (km2)	% of DE area	Area (km2)	% of DE area
Good	0	0	0	0
Not good	11251	27.6	4293	72.4
Not assessed	0	0	0	0

Table 5.2. Eutrophied area in Denmark given as area and proportion by status class for the open sea and the coast for whole Baltic Sea (HELCOM Area) and MSFD "Baltic subregion".

Denmark: Baltic Sea	Open sea areas		Coastal areas	
Status	Area (km2)	% of DK area	Area (km2)	% of DK area
Good	0	0	na	na
Not good	28 806	62.2	na	na
WFD: Good	na	na	344	0.7
WFD: Moderate	na	na	6 581	14.2
WFD: Moderate pot.	na	na	17	0.0
WFD: Poor	na	na	9 164	19.8
WFD: Bad	na	na	1 384	3.0
Not assessed	0	0	0	0
Denmark: MSFD Baltic	**Open sea areas**		**Coastal areas**	
Status	**Area (km2)**	**% of DK area**	**Area (km2)**	**% of DK area**
Good	0	0	na	na
Not good	17 622	62.5	na	na
WFD: Good	na	na	344	1.2
WFD: Moderate	na	na	4 590	16.3
WFD: Moderate pot.	na	na	5	0.0
WFD: Poor	na	na	5 715	20.3
WFD: Bad	na	na	245	0.9
Not assessed	0	0	0	0

Table 5.3 Eutrophied area in Estonia given as area and proportion by status class for the open sea and the coast.

Estonia	Open sea areas		Coastal areas	
Status	**Area (km²)**	**% of EE area**	**Area (km²)**	**% of EE area**
Good	0	0	64	0.2
Not good	22 469	60.8	13 457	36.4
Not assessed	0	0	981	2.6

Table 5.4. Eutrophied area in Finland given as area and proportion by status class for the open sea and the coast.

Finland	Open sea areas		Coastal areas	
Status	**Area (km²)**	**% of FI area**	**Area (km²)**	**% of FI area**
Good	0	0	0	0
Not good	48 776	59.7	32 967	40.3
Not assessed	0	0	0	0

Table 5.5. Eutrophied area in Latvia given as area and proportion by status class for the open sea and the coast.

Latvia	Open sea areas		Coastal areas	
Status	**Area (km2)**	**% of LV area**	**Area (km2)**	**% of LV area**
Good	0	0	0	0
Not good	26 522	92.0	2 293	8.0
Not assessed	0	0	0	0

Table 5.6. Eutrophied area in Lithuania given as area and proportion by status class for the open sea and the coast.

Lithuania	Open sea areas		Coastal areas	
Status	**Area (km2)**	**% of LT area**	**Area (km2)**	**% of LT area**
Good	0	0	0	0
Not good	5 909	90.5	622	9.5
Not assessed	0	0	0	0

Table 5.7. Eutrophied area in Poland given as area and proportion by status class for the open sea and the coast.

Poland	Open sea areas		Coastal areas	
Status	**Area (km2)**	**% of PL area**	**Area (km2)**	**% of PL area**
Good	0	0	0	0
Not good	27 000	91.2	742	2.5
Not assessed	0	0	1861	6.3

Table 5.8. Eutrophied area in Russia given as area and proportion by status class for the open sea and the coast.

Russia	Open sea areas		Coastal areas	
Status	**Area (km²)**	**% of RU area**	**Area (km²)**	**% of RU area**
Good	0	0	0	0
Not good	17 848	75.4	0	0
Not assessed	0	0	5837	24.6

Table 5.9. Eutrophied area in Sweden given as area and proportion by status class for the open sea and the coast for whole Baltic Sea (HELCOM Area) and MSFD "Baltic subregion".

Sweden: Baltic Sea	Open sea areas		Coastal areas	
Status	**Area (km²)**	**% of SE area**	**Area (km²)**	**% of SE area**
Good	0	0	5753	3.7
Not good	116 634	75.8	31 418	20.4
Not assessed	0	0	0	0
Sweden: MSFD Baltic	**Open sea areas**		**Coastal areas**	
Status	**Area (km2)**	**% of SE area**	**Area (km2)**	**% of SE area**
Good	0	0	4 883	3.3
Not good	111 905	76.5	29 503	20.2
Not assessed	0	0	0	0

4.2 CONFIDENCE IN THE INTEGRATED ASSESSMENT

Open sea assessment units

Confidence in the indicators was high for most open sea assessment units, with respect to all indicators for which confidence values were available (Table 3). The component 'Status confidence' was assessed as high in 94% of the open sea indicator results for assessment units, reflecting comprehensive data sets. For the indicator 'Cyanobacterial bloom index', 'Status confidence' has not yet been agreed. The component 'Target confidence' (confidence in the indicator threshold value) was moderate in 84% of the open sea indicator results for assessment units. Assessment of 'Target confidence' is not yet available for the 'Total nitrogen' and 'Total phosphorus' indicators.

The final confidence rating of the integrated assessment was moderate for most of the open-sea assessment units (Table 6).

Table 6. Confidence of the results at indicator level and the integrated eutrophication status level (shown in the last column) 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 that the sub-basin was not assessed due to the lack of agreed threshold value or commonly agreed indicator methodology. An 'N' in a white cell is shown for cases where the indicator is not applicable. Indicators marked with * have not been adopted in HELCOM yet and are currently tested. 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', Secchi= 'Secchi depth during summer', and O2 = '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 2017c-k.

	Core indicator results									
	Nutrient levels				Direct effects			Indirect effects		
	DIN	TN	DIP	TP	Chla	Secchi	Cyano*	O_2	Zoob*	
Assessment unit	**Dec–Feb**	**All year**	**Dec–Feb**	**All year**	**Jun–Sep**	**Jun–Sep**	**20 Jun–31 Aug**	**All year**	**May–Jun**	**Integrated status assessment**
Kattegat	75	100	75	100	50	75	N	N		50
Great Belt	75	100	75	100	75	75	N	N		56
The Sound[8]	75	100	75	100	75	75	N	N		56
Kiel Bay	75		75		75	75	N	N		75
Bay of Mecklenburg	75		75		75	75		N		67
Arkona Basin	75		75		75	75		N		67
Bornholm Basin[9]	75		75		75	75		100		78
Gdansk Basin	75	100	75	100	75	75		100		65
Eastern Gotland Basin	75	100	75		75	75		100		72
Western Gotland Basin	75	100	75	100	75	75		100		65
Gulf of Riga	75	100	75	100	75	75		N		48
Northern Baltic Proper	75	100	75	100	75	100		100		69
Gulf of Finland	75	100	75	100	75	75		100		65
Åland Sea	50	100	50	100	75	25	N	100	50	42
Bothnian Sea	75	100	75	100	75	75		100	50	49
The Quark	50	100	50	100	75	25	N	N	50	45
Bothnian Bay	75	100	75	100	75	100	N	100	50	56

[8] Result may be changed due to planned changes in assessment data.

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

Coastal assessment units[10]

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

The most important differences in the reporting of coastal indicators could be grouped into differences in the following:

1. Different indicators for same function. 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 multiparametric indicators (in practice WFD quality elements), whereas others reported single indicators.

2. In principle same indicator, but with distinctly different assessment season. Using the same indicator in summer, winter or annually could change the function completely. In some cases the difference was more subtle, in differing only by a month or two. This was common in nutrient, chlorophyll-*a*, and Secchi depth indicators.

3. Same indicator with different statistic approach. For example, the bottom oxygen indicator could be salinity normalized in some areas but not in others.

4. Same indicator, but differences in target-setting principles. This seemed to be common especially among indicators that were not inter-calibrated under WFD, such as bottom oxygen.

5. Different reporting period. The assessment period was mostly 2007-2012, determined by the requirements of WFD. Some Contracting Parties were however not able to report this period, but used another period as close as possible. Therefore no time trend information on eutrophication status is given for coastal areas.

[10] To be improved and modified as needed

Chapter 5. Core indicator evaluations

Table 7. Core indicator results for eutrophication and the changes in eutrophication ratios from 2007-2011 to 2011-2015 in the open sea. Green cells denote good status and red not good status. The corresponding integrated status assessment result by open sea sub-basin is shown in the last column, in similar way as for figure 6. The arrows reflect if the eutrophication ratio (of the indicator or integrated status, as estimated in HEAT) has changed since the last eutrophication assessment, comparing years 2007–2011 with 2011–2015. A change equal to or more than 15% was considered to be substantial. Upward arrows ↗ indicate an increased eutrophication ratio between the two periods (deteriorating condition), downward arrows ↘ indicate a decreased ratio (improving condition), and ↔ indicates less than 15 % difference between the two compared time periods. This information is not available for the core indicator 'State of the soft bottom macrofauna community' (Zoob). White cells denote that the sub-basin was not assessed due to the lack of agreed threshold value or commonly agreed indicator methodology. An 'N' in a white cell is shown for cases where the indicator is not applicable. Abbreviations used in the table: DIN = 'Dissolved inorganic nitrogen', TN= 'Total nitrogen', DIP= 'Dissolved inorganic phosphorus', TP = 'Total phosphorus', Chla= 'Chlorophyll-a', Secchi= 'Secchi depth during summer', Cyano = 'Cyanobacterial bloom index', and O2 = 'Oxygen debt'. Indicators marked * have not been adopted in HELCOM yet and are currently tested. 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 2017c-k.

	Core indicator results									
	Nutrient levels				Direct effects			Indirect effects		
	DIN	TN	DIP	TP	Chla	Secchi	Cyano*	O_2	Zoob*	
Assessment unit	Dec–Feb	All year	Dec–Feb	All year	Jun–Sep	Jun–Sep	20 Jun–31 Aug	All year	May–Jun	Integrated status assessment
Kattegat	↔	↔	↔	↔	↘	↔	N	N		↔
Great Belt	↘	↔	↔	↔	↘	↘	N	N		↘
The Sound[11]	↗	↔	↔	↗	↘	↔	N	N		↗
Kiel Bay	↘		↔		↔	↘	N	N		↔
Bay of Mecklenburg	↔		↔		↔	↔	↗	N		↔
Arkona Basin	↔		↔		↔	↔	↔	N		↔
Bornholm Basin[12]	↗		↔		↗	↔	↔	↔		↗
Gdansk Basin	↘	↔	↘	↔	↘	↔	↘	↔		↘
Eastern Gotland Basin	↔	↔	↔		↘	↔	↔	↔		↔
Western Gotland Basin	↔	↔	↔	↔	↘	↔	↔	↔		↔
Gulf of Riga	↗	↔	↗	↗	↗	↔	↗	N		↗
Northern Baltic Proper	↗	↔	↗	↘	↗	↔	↔	↔		↗
Gulf of Finland	↔	↔	↔	↗	↗	↔	↔	↔		↗
Åland Sea	↔	↔	↗	↔	↘	↔	N			↔
Bothnian Sea	↔	↔	↗	↔	↔	↗	↔			↗
The Quark	↔	↔	↗	↔	↔	↔	N	N		↗
Bothnian Bay	↔	↔	↔	↔	↔	↗	N			↔

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

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

5.1 WATER NUTRIENT LEVELS

The concentrations of dissolved inorganic nitrogen and total nitrogen did generally not achieve the threshold with the exception of Kattegat and Great Belt where the threshold values were achieved for total nitrogen[13] and in the Gdansk Basin for dissolved inorganic nitrogen. The eutrophication ratios for dissolved inorganic nitrogen were highest in the Gulf of Riga and the Gulf of Finland. In addition, average concentrations were high in the Bornholm Basin due to influence from shallow stations in the Pomeranian Bay, which is influenced by the Odra plume[14].

Winter concentrations of dissolved inorganic nitrogen showed an increasing trend until the mid-1990s. They started declining in the late 1990's, especially in the southwestern Baltic Sea and Kattegat (Figure 9). Compared to the previous five year period (2007–2011), dissolved inorganic nitrogen concentrations have increased substantially in four and decreased in three out of 17 sub-basins (Table 7). Concentrations of total nitrogen have remained at the same level since the period 2007–2011 in all sub-basins (Table 7).

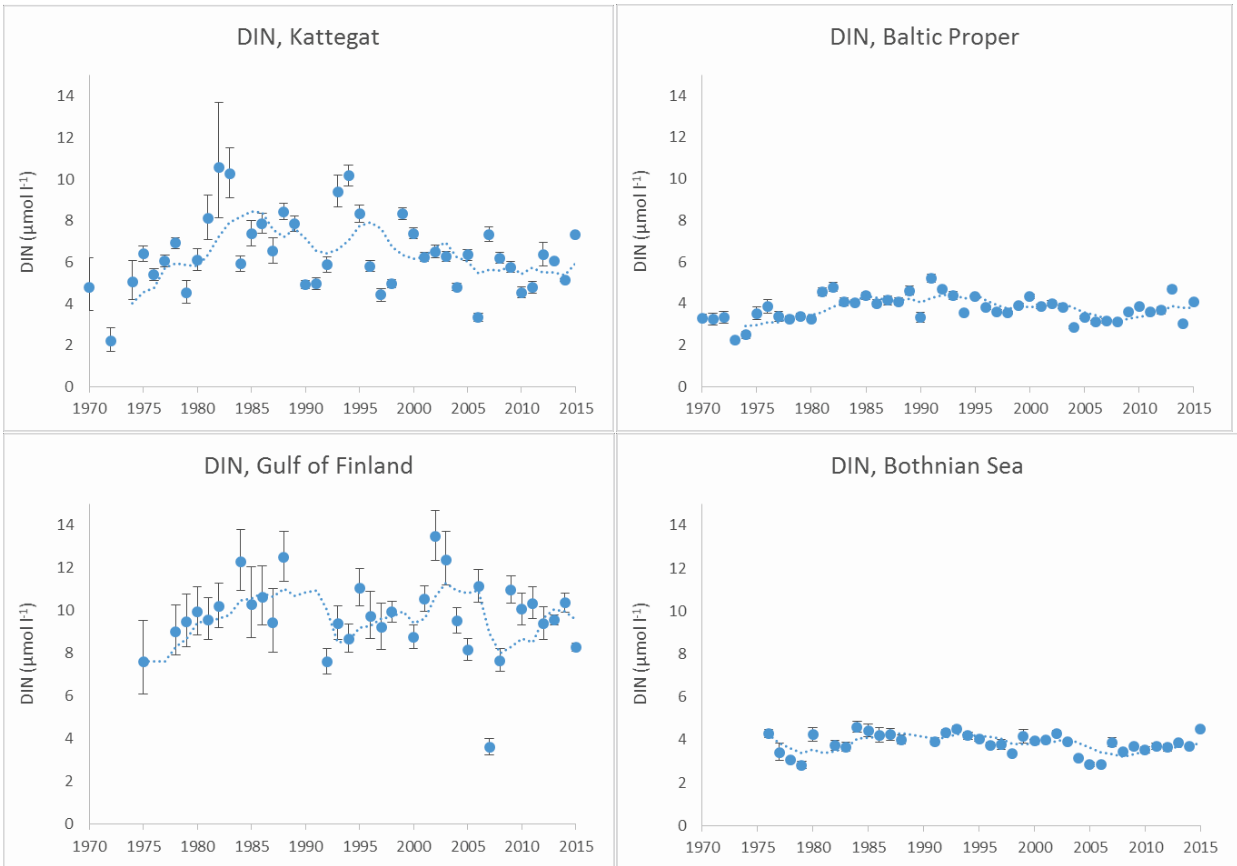

Figure 9. Example of long term trends in nutrient levels in the Baltic Sea: Temporal development of winter dissolved inorganic nitrogen concentrations in the Kattegat, Baltic Proper, Gulf of Finland and Bothnian Sea. Dashed lines show the five-year moving averages and error bars the standard errors.

[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.

For phosphorous, the indicator on dissolved inorganic phosphorous only achieved the threshold value in the Bothnian Bay, and the indicator on total phosphorous achieved it only in the Great Belt

Dissolved inorganic phosphorus concentrations increased notably in the 1960s and 70s, and have shown relatively large fluctuations over time. A decrease from the high values in the mid-1980s to the present has been seen in the Kattegat, Danish Straits, Gulf of Riga and Bothnian Bay, but not in the Gulf of Finland or the Bothnian Sea. In these two sub-basins, dissolved inorganic phosphorus concentrations have increased since the early 2000s (Figure 10), despite decreases in the waterborne inputs from land. In the Baltic Proper, the concentrations decreased in the late 1990s, but increased again since then.

These recent increases probably reflect the release of phosphorus from anoxic sediments (Conley *et al.* 2002, 2009). Since the period 2007–2011, dissolved inorganic phosphorus concentrations have increased substantially in five sub-basins and decreased only in Gdansk Basin (Table 7). Within the same period, total phosphorus concentrations have increased substantially in three sub-basins.

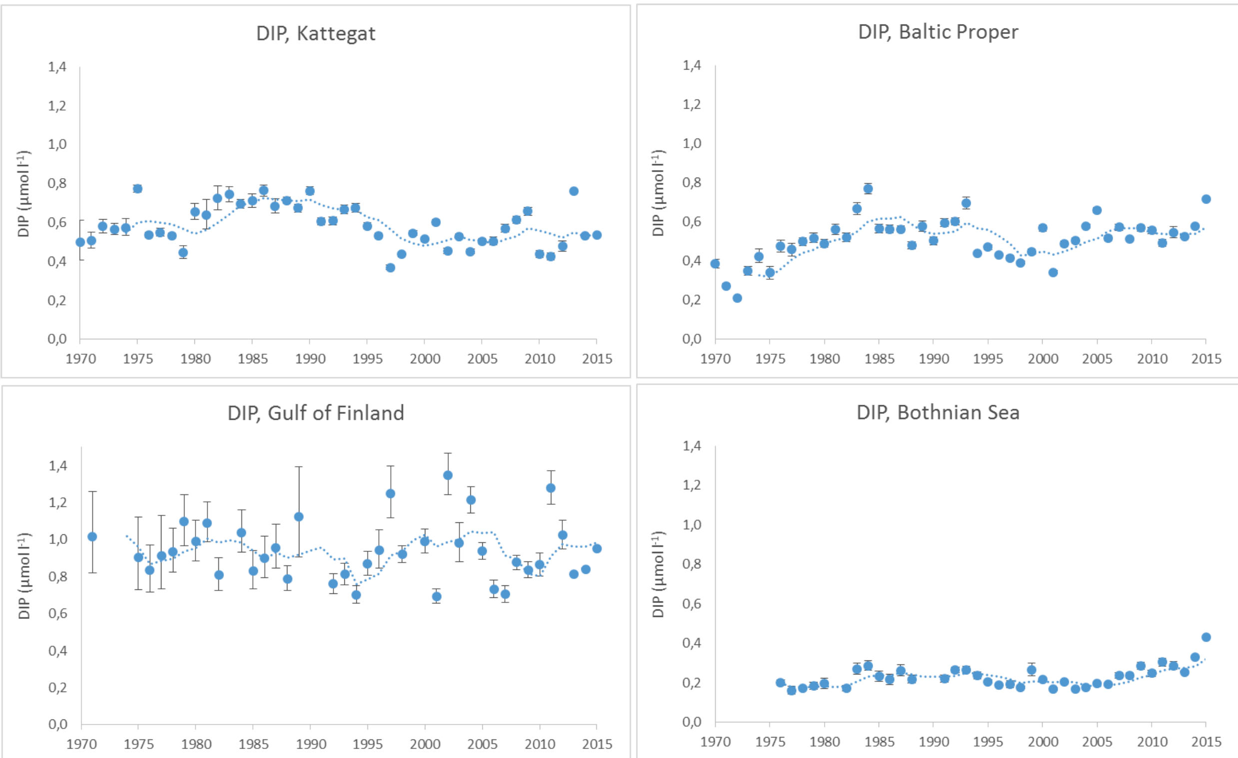

Figure 10. Example of long term trends in nutrient levels in the Baltic Sea: Temporal development of dissolved inorganic phosphorus concentrations in winter in the Kattegat, the Baltic Proper, the Bothnian Sea and the Gulf of Finland. Dashed lines show the five-year moving averages and error bars are the standard errors.

5.2 DIRECT EFFECTS

The core indicators for direct effects ('Chlorophyll-a' and 'Secchi depth during summer' and additionally 'Cyanobacterial bloom index'[15]) did not achieve the threshold value in any open sea sub-basin east of the Sound. West of the Sound, the chlorophyll-a core indicator achieved the threshold value in the Kattegat, and water clarity in the Kattegat and the Sound.

The longer term trend shows that chlorophyll-a concentrations have increased from the 1970's to the present in most of the inner Baltic Sea (Figure 10). In the Kattegat and the Danish Straits, the chlorophyll-a concentration has been decreasing since the late 1980s (Figure 11). Compared to the previous five year period (2007–2011), the chlorophyll-a concentrations have decreased in seven sub-basins, but increased in the Bornholm Basin, Northern Baltic Proper, Gulf of Finland and Gulf of Riga (Table 7).

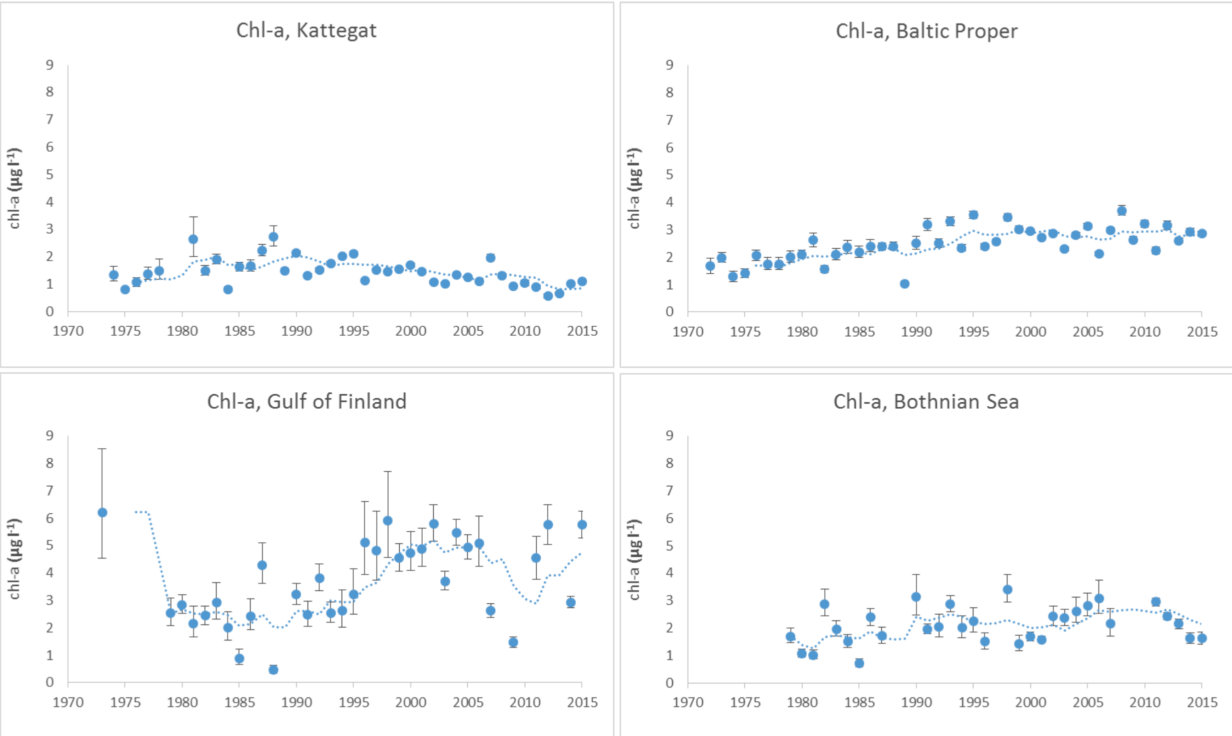

Figure 11. Example of long term trends in the direct effects of eutrophication in the Baltic Sea: Temporal development of chlorophyll-a concentrations in summer in the Kattegat, the Baltic Proper, the Bothnian Sea and the Gulf of Finland. Dashed lines show the five-year moving averages and error bars are the standard errors.

The longest time series available for water clarity have been recorded since the early 1900s in the Baltic Proper. The results show a steadily deteriorating situation over several decades (Figure 12). In more recent years, however, the decrease in water clarity has levelled off across most of the Baltic Sea, and the water clarity has remained on the same level since the period 2007–2011 in most of the sub-basins (Table 7). The water clarity reflects changes in the

[15] Included as a test indicator.

eutrophication-related abundance of phytoplankton, but is also affected by the presence of coloured dissolved organic matter and suspended particles.

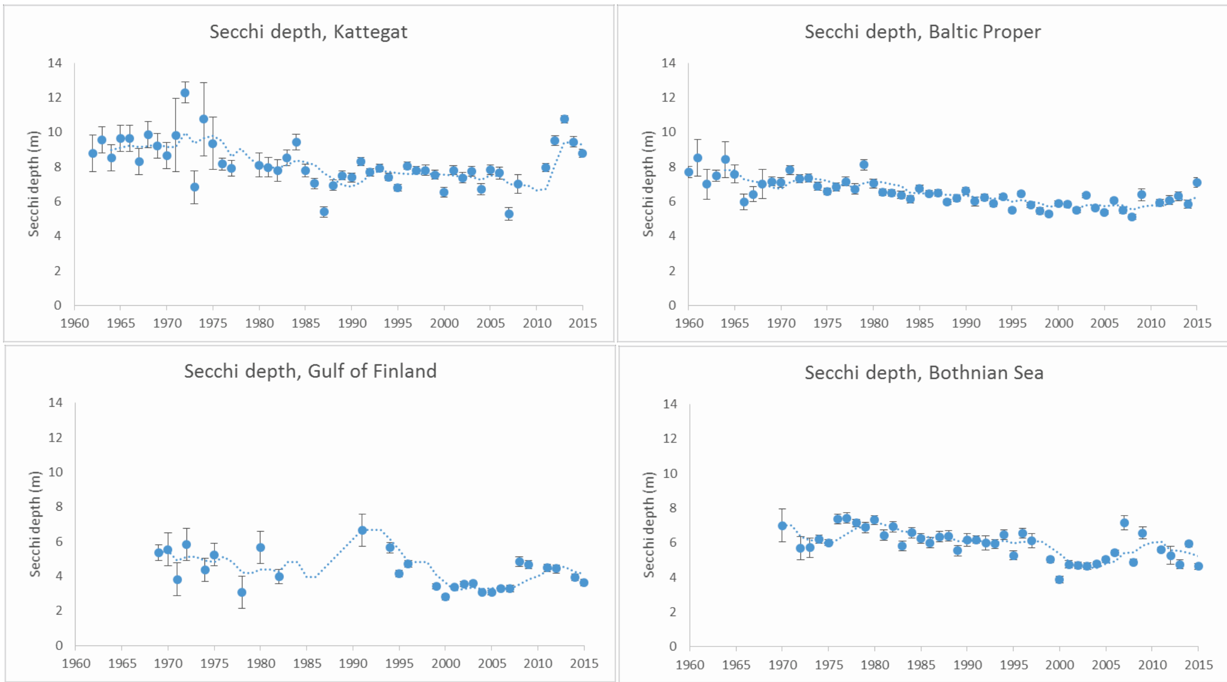

Figure 12. Example of long term trends in the direct effects of eutrophication in the Baltic Sea: Temporal development of water clarity (measured as Secchi depth in summer) in the Kattegat, the Baltic Proper, the Bothnian Sea and the Gulf of Finland. Dashed lines show the five-year moving averages and error bars the standard errors.

The cyanobacterial bloom index was used as a test indicator in ten sub-areas, showing the worst status in the Gulf of Riga, the Northern Baltic Proper and the Bothnian Sea. The index has remained at the same level since the previous five year period 2007–2011 in most of the sub-basins (Table 7).

5.3 INDIRECT EFFECTS

The core indicator 'Oxygen debt' did not achieve the threshold values in any open sea sub-basin. Oxygen debt has increased over the past century (Figure 13). It plateaued from the early 1980's to the early 1990's, but has subsequently increased again. Since the last assessment period (2007–2011), the oxygen debt has remained at the same level (Table 7). North of the Baltic Proper, the indicator 'State of the soft-bottom macrofauna community' was also included, to estimate the condition of the animal community at the seafloor[16]. The core indicators achieved the threshold value in these areas showing the bottom fauna to be in good condition.

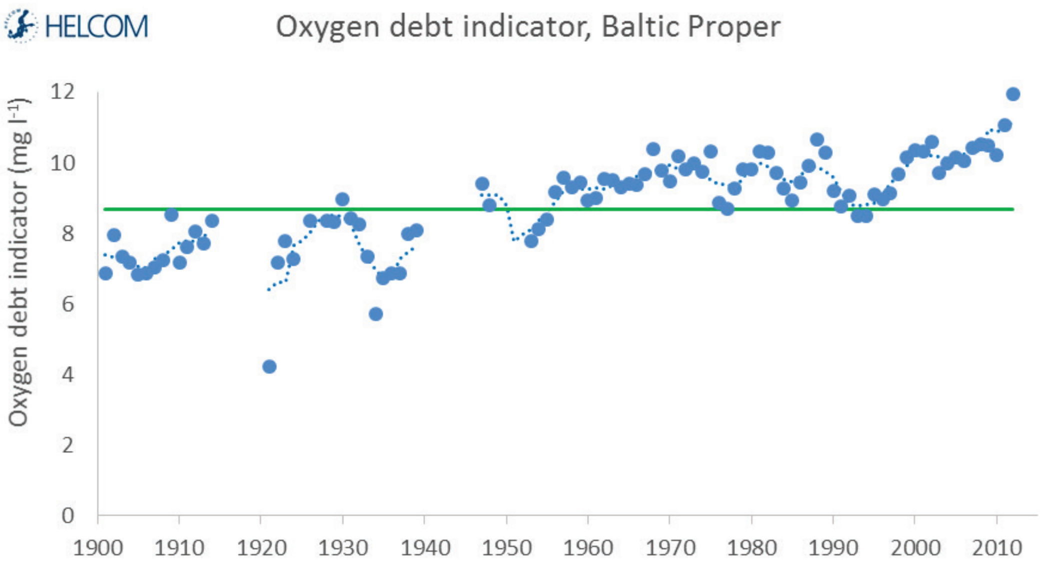

Figure 13 Example of long term trends in the indirect effects of eutrophication in the Baltic Sea: Temporal development in the core indicator 'Oxygen debt' in the Baltic Proper, showing the volume specific oxygen debt below the halocline. Dashed line shows the five-year moving average and green line the threshold for good status. The increasing trend in oxygen debt signifies deteriorating oxygen conditions.

[16] Included as a test indicator.

Chapter 6. Impacts and recovery

Primary production is a key process in the ecosystem as it provides energy for all organisms, but nutrient-enhanced excessive primary production leads to eutrophication symptoms and reduces the function of the food web in many cases. 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 reduces 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.

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. It should be noted, however, that in areas with vertical stratification and low water exchange, eutrophication acts on top of naturally low oxygen levels. Life in these deep water habitats is also highly dependent on aeration provided by inflows of marine water from the North Sea.

Even though some positive development in the eutrophication status is seen in the current assessment, such as a decrease in nutrient concentrations, improved water clarity in parts of the Baltic Sea, and a decrease in chlorophyll concentrations in some areas, 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. The reductions of nutrient inputs according to the HELCOM Baltic Sea Action Plan are foreseen to be effective in decreasing the eutrophication symptoms in the long term (Figure 2). Large scale responses to reduced loading are slow, and recently achieved reductions are not visible in the assessments over the short time frame. In addition, future development is foreseen to be dependent on changes in climate (Box 2).

Box 2 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. Within a changing climate this assumption will not hold, as the physical environment is also changing and will feedback upon the biogeochemical cycling, for example by enhancing growth and mineralization rates. Simulations also 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.

References

Bonsdorff, E, E.M. Blomqvist, J. Mattila & A. Norkko (1997): Long-term changes and coastal eutrophication. Examples from the Aland Islands and the Archipelago Sea, northern Baltic Sea. Oceanologica Acta 20(1): 319- 329.

Cloern, J. (2001): Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210:223–253.

Conley, D.J., C. Humborg, L. Rahm, O.P. Savchuk & F. Wulff (2002): Hypoxia in the Baltic Sea and Basin-Scale changes in phosphorus and biogeochemistry. Environmental Science and Technology 36: 5315-5320.

Conley, D.J., S. Björck, E. Bonsdorff, J. Carstensen, G. Destouni, B. Gustafsson, S. Hietanen, M. Kortekaas, H. Kuosa, M. Meier, B. Müller-Karuli, K. Nordberg, G. Nürnberg, A. Norkko, H. Pitkänen, N.N. Rabalais, R. Rosenberg, O. Savchuk, C.P. Slomp, M. Voss, F. Wulff & L. Zillén (2009): Hypoxia-related processes in the Baltic Sea. Environmental Science and Technology 43:3412-3420.

EC (2000): Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy. OJ L 327

EC (2017): Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU

Gustafsson, B.G., F. Schenk, T. Blenckner, K. Eilola, H.E.M. Meier, B. Müller-Karulis, T. Neumann,T. Ruoho-Airola, O.P. Savchuk & E. Zorita (2012): Reconstructing the Development of Baltic Sea Eutrophication 1850–2006. Ambio, 41(6), 534–548. DOI 10.1007/s13280-012-0318-x

HELCOM (1996): Third Periodic Assessment of the State of the Marine Environment of the Baltic Sea area, 1989-1993; Executive Summary. Baltic Sea Environment Proceedings 64A.

HELCOM (2007): Baltic Sea Action Plan. Adopted at HELCOM Ministerial Meeting in Krakow, Poland on 15 November 2007.

HELCOM (2009): Eutrophication in the Baltic Sea – An integrated thematic assessment of the effects of nutrient enrichment and eutrophication in the Baltic Sea region. Baltic Sea Environment Proceedings 115B.

HELCOM (2010): Ecosystem Health of the Baltic Sea 2003–2007: HELCOM Initial Holistic Assessment. Baltic Sea Environment Proceedings 122.

HELCOM (2012): HELCOM HOD 39/2012. Online. 11.7.2017, https://portal.helcom.fi/Archive/Shared%20Documents/HOD%2039-2012_Minutes%20of%20HELCOM%20HOD%2039%202012.pdf#search=HOD%2039/2012%20outcome

HELCOM (2013): Approaches and methods for eutrophication target setting in the Baltic Sea region. Baltic Sea Environment Proceedings 133.

HELCOM (2014): Eutrophication status of the Baltic Sea 2007-2011 - A concise thematic assessment. Baltic Sea Environment Proceedings 14.

HELCOM (2015a): Updated Fifth Baltic Sea pollution load compilation (PLC-5.5). Baltic Sea Environment Proceedings 145.

HELCOM (2015b): HELCOM Eutrophication assessment manual. Updated: 31.12.2015 http://www.helcom.fi/Documents/Eutrophication%20assessment%20manual.pdf

HELCOM (2016): Outcome of the 51st Meeting of the Heads of Delegation. Online. 11.7.2017, https://portal.helcom.fi/meetings/HOD%2051-2016-400/MeetingDocuments/Outcome_HOD%2051-2016.pdf

HELCOM (2017a): First version of the 'State of the Baltic Sea' report – June 2017 – to be updated in 2018State of the Baltic Sea: The second HELCOM holistic assessment of the ecosystem health of the Baltic Sea – first version (June 2017). Available at: http://stateofthebalticsea.helcom.fi/about-helcom-and-the-assessment/downloads-and-data/

HELCOM (2017b): Inputs of nitrogen and phosphorus to the Baltic Sea. HELCOM core indicator report. Online 6.7.2017. http://www.helcom.fi/Core%20Indicators/Nutrient%20inputs%20-%20Core%20indicator%20report-HOLAS%20II%20component%202017.pdf

HELCOM (2017c): Dissolved inorganic nitrogen (DIN). HELCOM core indicator report. Online 6.7.2017, http://helcom.fi/Core%20Indicators/DIN%20-%20HELCOM%20core%20indicator%20report%20-%20HOLAS%20II%20component.pdf

HELCOM (2017d): Total nitrogen. HELCOM core indicator report. Online 6.7.2017, http://www.helcom.fi/Core%20Indicators/Total%20Nitrogen%20-%20HELCOM%20core%20indicator%20report%20-%20HOLAS%20II%20component.pdf

HELCOM (2017e): Dissolved inorganic phosphorus (DIP). HELCOM core indicator report. Online 6.7.2017, http://www.helcom.fi/Core%20Indicators/DIP%20-%20HELCOM%20core%20indicator%20report%20-%20HOLAS%20II%20component.pdf

HELCOM (2017f): Total phosphorus. HELCOM core indicator report. Online 6.7.2017, http://www.helcom.fi/Core%20Indicators/Total%20Phosphorous-%20HELCOM%20core%20indicator%20report%20-%20HOLAS%20II%20component.pdf

HELCOM (2017g): Chlorophyll *a*. HELCOM core indicator report. Online 6.7.2017, http://helcom.fi/Core%20Indicators/Chlorophyll%20a%20-%20updated%20core%20indicator%20report_HOLAS%20II%20component.pdf

HELCOM (2017h): Water clarity. HELCOM core indicator report. Online 6.7.2017, http://www.helcom.fi/Core%20Indicators/Water%20clarity%20-HELCOM%20core%20indicator%20report%20-%20HOLAS%20II%20component.pdf

HELCOM (2017i): Cyanobacteria bloom index. HELCOM pre-core indicator report. Online 6.7.2017, http://www.helcom.fi/Core%20Indicators/Cyanobacterial%20bloom%20index%20-%20precore%20indicators%20-%20HOLAS%20II%20component.pdf

HELCOM (2017j): Oxygen debt. HELCOM core indicator report. Web link to be added, for most recent version, see http://www.helcom.fi/Core%20Indicators/Oxygen%20debt%20-%20core%20indicator%20report%202015_web%20version.pdf

HELCOM (2017k): State of the soft-bottom macrofauna community. HELCOM core indicator report. Online 6.7.2017, http://www.helcom.fi/Core%20Indicators/State%20of%20the%20soft-bottom%20macrofauna%20community%20-%20HELCOM%20core%20indicator%20report%20-%20HOLAS%20II%20component.pdf

HELCOM (2017l): Outcome of the 38th meeting of Baltic Marine Environment Protection Commission (HELCOM). Online. 11.7.2017, https://portal.helcom.fi/meetings/HELCOM%2038-2017-401/MeetingDocuments/Outcome%20of%20HELCOM%2038-2017.pdf

Larsson, U., R. Elmgren & F. Wulff (1985): Eutrophication and the Baltic Sea - causes and consequences. Ambio 14:9–14.

Meier, H. E. M., H.C. Andersson, B. Arheimer, T. Blenckner, B. Chubarenko, C. Donnelly, K. Eilola, B.G. Gustafsson, A. Hansson, J. Havenhand, A Höglund, I. Kuznetsov, B.R. MacKenzie, B. Müller-Karulis, T. Neumann, S. Niiranen, J. Piwowarczyk, U. Raudsepp, M. Reckermann, T. Ruoho-Airola, O.P. Savchuk, F. Schenk, S. Schimanke, G. Väli, J.-M. Weslawski & E. Zorita. (2012): Comparing reconstructed past variations and future projections of the Baltic Sea ecosystem—first results from multi-model ensemble simulations. Environmental Research Letters 7: 034005.

Savchuk, O.P., K. Eilola, B.G. Gustafsson, M. Rodriguez Medina &T. Ruoho-Airola (2012): Long-term reconstruction of nutrient loads to the Baltic Sea 1850-2006. Baltic Nest Institute Technical report 6:9. www.balticnest.org