Eutrophication status of the Baltic Sea 2007-2011
A concise thematic assessment

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Key message

Almost the entire open Baltic Sea was assessed as being eutrophied and only the open Bothnian Bay was assessed as being unaffected by eutrophication (**Figure 1**). Coastal areas in Orther Bucht (Germany) and the outer coastal Quark (Finland) were the only coastal areas assessed by national authorities as being in good ecological status.

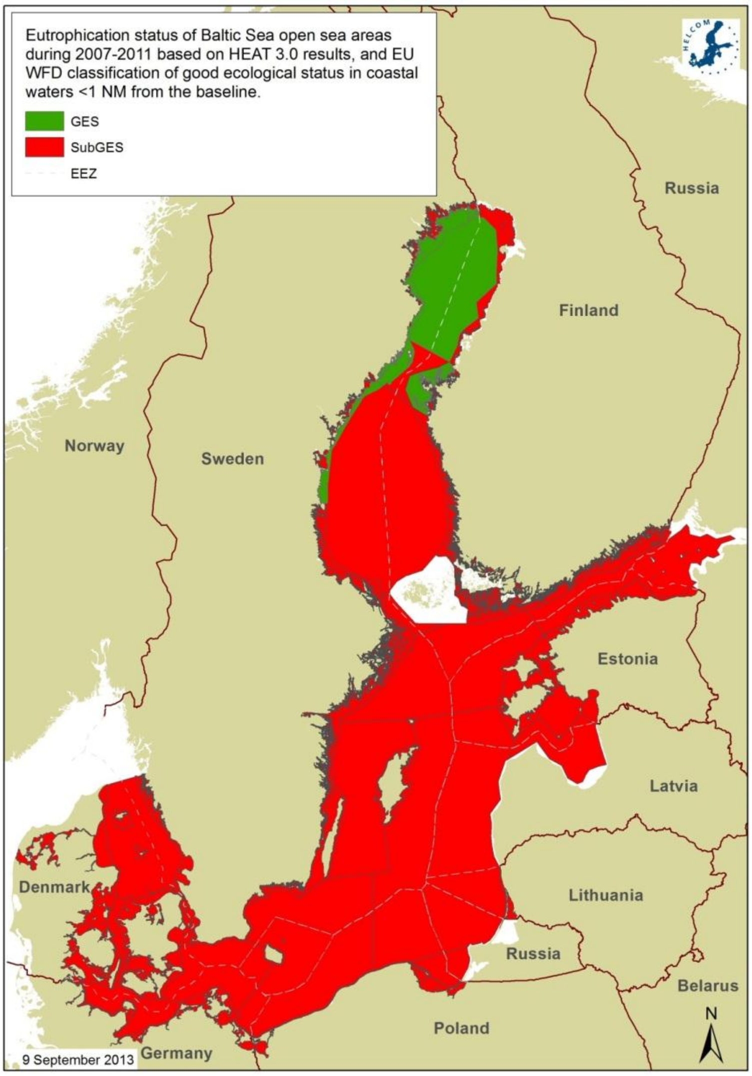

Figure 1. *Eutrophication status in 2007-2011 was assessed as being good (green colour, Good Environmental Status; GES) in the open sea of Bothnian Bay, while the rest of the Baltic Sea was affected by eutrophication (red colour, status less than good; sub-GES). Outer coastal waters of the Quark (Finland) and in Orther Bucht (Germany) were assessed by national experts to be in good ecological status. For methodology, see Technical data section.*

This result indicates that despite measures taken to reduce external inputs of nitrogen and phosphorus to the sea, good status for eutrophication has not been reached yet. Nearly the entire sea area is still affected by eutrophication.

For the open sea areas, the only difference between this core indicator -based assessment and the assessment for years 2001-2006 seems to be the status of the Swedish waters in the northern Kattegat which had good status in 2001-2006 and are now affected by eutrophication (HELCOM 2009). This discrepancy between 2001 and 2006 and this assessment may be a result of methodological differences between the two assessments, or it may be that the northern Kattegat is close to GES."

Eutrophication is driven by a surplus of the nutrients nitrogen and phosphorus in the sea. Nutrient over-enrichment causes elevated levels of algal and plant growth, increased turbidity, oxygen depletion, changes in species composition and nuisance blooms of algae.

The main pathways of nutrients to the sea are riverine inputs, atmospheric deposition of nitrogen to the water surface and direct waterborne discharges to the sea either from coastal point sources, run-off from diffuse sources in coastal areas and discharges from ships. In addition, excess nutrients stored in bottom sediments can enter the water column and enhance primary production of plants.

Outlook for eutrophication

Inputs of nutrients to the Baltic Sea have decreased since the late 1980s. Trends for the whole Baltic Sea show that flow-normalized inputs of total nitrogen and phosphorus to the Baltic Sea have decreased by 16% and 18%, respectively, from 1994 to 2010 (HELCOM, in prep). Changes in individual sub-basins may be greater. Currently, the level of nutrient inputs equals the levels of loads in the early 1960s (Gustafsson et al. 2012).

Despite the reductions in inputs, the concentrations of nutrients have not declined accordingly. There are some recent signs of declining nutrient levels in the Kattegat (total nitrogen; TN, DIN and DIP), Danish Straights (TN, DIN and DIP), Bornholm Basin (DIN), Baltic Proper (DIN), Gulfs of Riga (DIN and DIP) and Finland (DIN) and in the Bothnian Sea (DIN) and Bay (TN, TP and DIP). Despite this chlorophyll *a* trends still show no signs of decline or have increased in recent years (Borhholm Basin, Baltic Proper and Bothnian Sea) (HELCOM 2013a). The long residence time of water in the open Baltic Sea as well as feedback mechanisms such as internal loading of phosphorus from sediments and the prevalence of blooms of nitrogen-fixing cyanobacteria in the main sub-basins of the Baltic Sea are processes that slow down the recovery from a eutrophied state (HELCOM 2009, 2013a, Vahtera et al. 2007).

Model predictions of time-scales of recovery of the Baltic Sea show that nutrient reductions will have an immediate and positive effect on the status of the Baltic Sea ecosystem and that nutrient concentrations will decline rapidly. Nevertheless it will take a long time to reach the target levels of eutrophication status, indicating the urgency of implementing nutrient reduction measures without further delay (**Figure 2**).

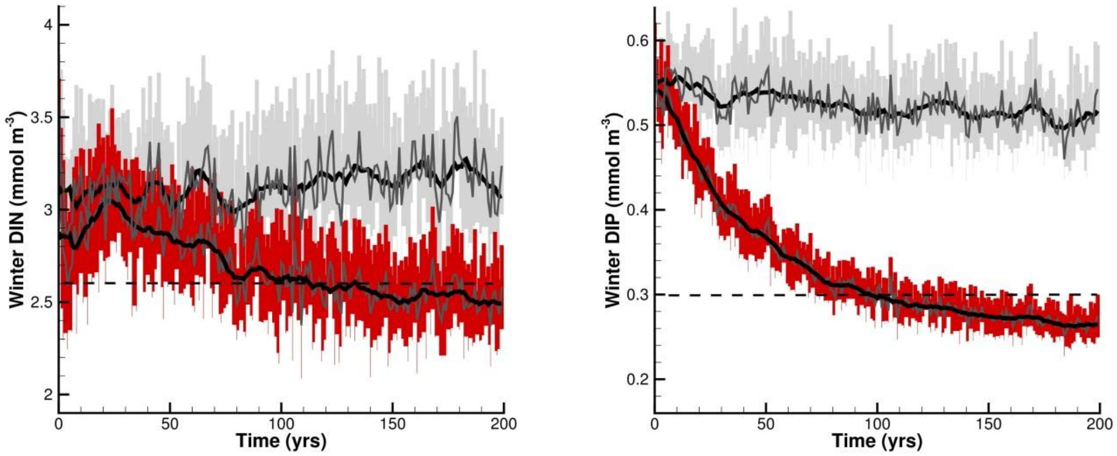

Figure 2. *If nutrient inputs will be reduced to agreed maximum allowable nutrient input levels by year 0, there will be a rapid initial decline of DIP (winter dissolved inorganic phosphorus) and a slightly more delayed initial decline in DIN (winter dissolved inorganic nitrogen) concentrations as indicated with red bars and the 11-years running average indicated with thick lines. If the inputs remain at the level of 1997-2003, DIN and DIP concentrations are not foreseen to decline remarkably between years 0 and 200 (grey bars and 11-years running average). The dotted curves represent the eutrophication targets for DIN and DIP (Gustafsson et al, in prep).*

Reversal of coastal and marine eutrophication is a phenomenon that has not yet been studied much. A recent analysis of monitoring data from 28 locations around the world showed that a unit of nitrogen in coastal waters produces nowadays almost twice the quantity of algal biomass measured as chlorophyll *a* compared to what it did 30-40 years ago (Carstensen et al. 2011). The study suggests that this change could be the result of major shifts in the baselines that stem from the combined effects of climate change, overfishing, other anthropogenic pressures and, possibly, other components of global change.

The phenomenon of greater biomass yield per unit of nutrients seems to hold true for the main basins of the Baltic Sea. At least primary production levels in the main basin have not returned to previous levels although phosphorus inputs have decreased to the levels of the 1950s or 1960s (**Figure 3** and Gustafsson et al. 2012). The Baltic Sea is not yet on a path of recovery to its previous state even though inputs of nutrients have decreased. This is due to the exceptionally long time scales of biogeochemical cycles and because the ecosystem structure and functions have changed (Gustafsson et al. 2012, HELCOM 2013b). However, the reductions in nutrient inputs will substantially ease the pressure on the ecosystem, enabling the Baltic Sea to better cope with other pressures, such as climate change. This example concerns the main basin of the Baltic Sea, while nitrogen plays a crucial role especially in the westernmost parts of the Baltic Sea.

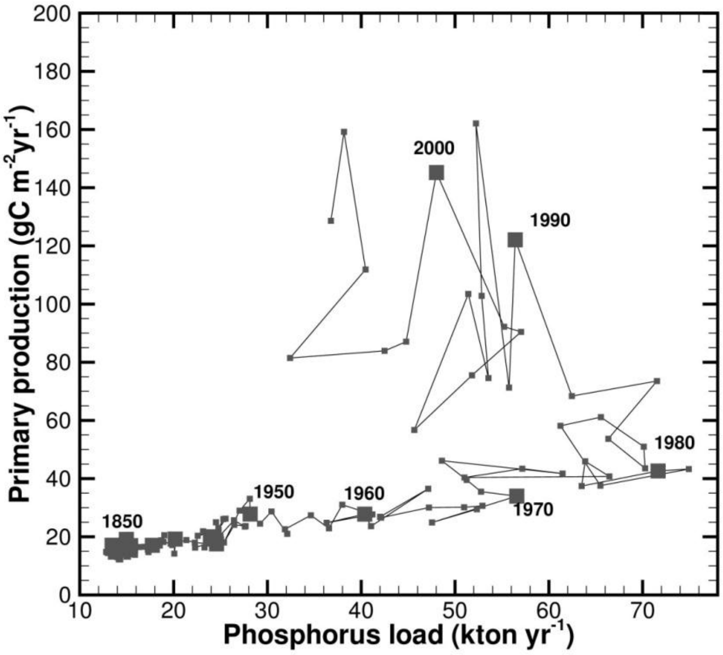

***Figure 3**. Primary production has not decreased in recent years even though phosphorus load has decreased to a level of the 1950s or 1960s in the main basin of the Baltic Sea (based on Gustafsson et al. 2012). However, future scenarios also show that primary production will decrease substantially when the BSAP nutrient input reduction targets have been reached.*

In the Baltic Sea, water temperature has increased by up to 1 ˚C per decade between 1990 and 2009. It is projected that near the end of this century, summer sea-surface temperature will be about 2 ˚C higher in the southern parts of the Baltic Sea and about 4 ˚C higher in the northern parts compared to the present (HELCOM 2013b).

At present, it is not clear how the climate change will influence eutrophication conditions and productivity in the Baltic Sea and it is likely that impacts will vary in different basins (HELCOM 2013b). Climate change may influence eutrophication conditions through changes in runoff and nutrient inputs and shifts in biogeochemical cycles within the system. The results of the new climate change assessment indicate that runoff is explained by temperature and the expected warming will be associated with less runoff in southern Baltic Sea regions and more runoff in the northern regions. A study has shown that the implementation of the BSAP 2007 nutrient input reduction targets in the western Baltic Sea will have a much stronger effect on the ecosystem than climate change (Friedland et al. 2012).

Purpose of the assessment

The main purpose of this eutrophication assessment is to provide background information to the 2013 HELCOM Ministerial Meeting to follow the progress towards reaching the ecological objectives and goals of the Baltic Sea Action Plan. This assessment presents the eutrophication status of the open sea areas of the Baltic Sea calculated for 2007-2011 using the latest available data, new HELCOM eutrophication status targets and the updated HELCOM Eutrophication Assessment Tool (HEAT 3.0).

The results of coastal waters ecological status that indirectly reflect eutrophication conditions are presented where information has been made available. These results are based on WFD status assessments carried out by those Contracting Parties that are also EU member states.

Policy relevance

This integrated report based on core indicators provides an assessment of the eutrophication status in open sea areas of the Baltic Sea based on aggregated data for the years 2007-2011. The assessment was derived using the HELCOM Eutrophication Assessment Tool (HEAT 3.0) and HELCOM Core Set Indicators for eutrophication taking into account the technical work under the EU Marine Strategy Framework Directive (MSFD).

Eutrophication is one of the four thematic segments of the HELCOM Baltic Sea Action Plan (BSAP) with the strategic goal of having a Baltic Sea unaffected by eutrophication (HELCOM 2007).

The EU Marine Strategy Framework Directive (2008/56/EC) requires that "human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters" (Descriptor 5). According to the MSFD, the assessment of eutrophication in marine waters needs to take into account the assessment for coastal and transitional waters under the EU Water Framework Directive (WFD, 2000/60/EC). Russia uses a related water quality grading system under the Scheme for Comprehensive Use and Protection of Water Bodies (SKIOVO).

In this assessment, the results of assessment of coastal waters under the EU WFD wre presented where information has been presented by those Contracting Parties being also EU member states, but for the purposes of harmonising the results across the whole region they are shown according to a MSFD-related two-class classification (good environmental status; GES vs. poorer than good environmental status; sub-GES) instead of the five classes used in the WFD (high, good, moderate, poor and bad). The boundary between GES/Sub-GES is aligned with boundary between good/moderate status.

The HELCOM goal for eutrophication is broken down into five ecological objectives while for the EU MSFD there are three criteria to assess eutrophication (**Table 1**). The HELCOM Ecological Objectives as well as the MSFD Criteria[1] are associated with comparable indicators, such as those used in this assessment: concentrations of nutrients and chlorophyll a, Secchi depth (water transparency) and oxygen concentration. The HEAT 3.0 tool, which aggregates the indicators under the three MSFD Criteria, was used.

The ecosystem approach, which is the basis of the HELCOM BSAP and the MSFD provides an opportunity to comprehensively address all relevant anthropogenic pressures and their interactions with the ultimate aim to restore Baltic Sea ecosystem structures and functions.

[1] European Commission decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (2010/477/EU)

Table 1. *HELCOM eutrophication core indicators from the CORE EUTRO process. The table indicates which HELCOM ecological objectives and MSFD criteria of Descriptor 5 the core indicators can potentially address.*

	HELCOM Ecological objectives					MSFD Criteria for D5		
Core indicator	Clear water	Concentrations of nutrients close to natural levels	Natural level of algal blooms	Natural oxygen levels	Natural distribution and occurrence of plants and animals	D5.1 Nutrient levels	D5.2 Direct effects	D5.3 Indirect effects
Water transparency (Secchi depth)	**X**						**X**	
Concentration of dissolved inorganic nitrogen		**X**				**X**		
Concentration of dissolved inorganic phosphorus		**X**				**X**		
Concentration of chlorophyll a			**X**				**X**	
Oxygen concentration				**X**				**X**

Confidence of the assessment

The confidence of the results was assessed at both indicator and integrated eutrophication status level for each open sea assessment unit. The confidence was rated according to the confidence of the indicator target and the availability and distribution of status data in each assessment unit during the assessment period 2007-2011 (**Figure 4**).

The confidence of the assessment was the highest in the main basins of the Baltic Proper and the southern as well as western parts of the Baltic Sea and the lowest in the Gulf of Riga. The Gulfs of Finland and Bothnia as well as the Gdansk Basin and Western Gotland Sea received a moderate confidence classification. This implies that the targets and data for all indicators and the overall assessment had the best quality in the main basin and the southern as well as western parts of the Baltic Sea. In the Gulf of Riga the confidence level was low particularly due to a lack of data on chlorophyll a and Secchi depth.

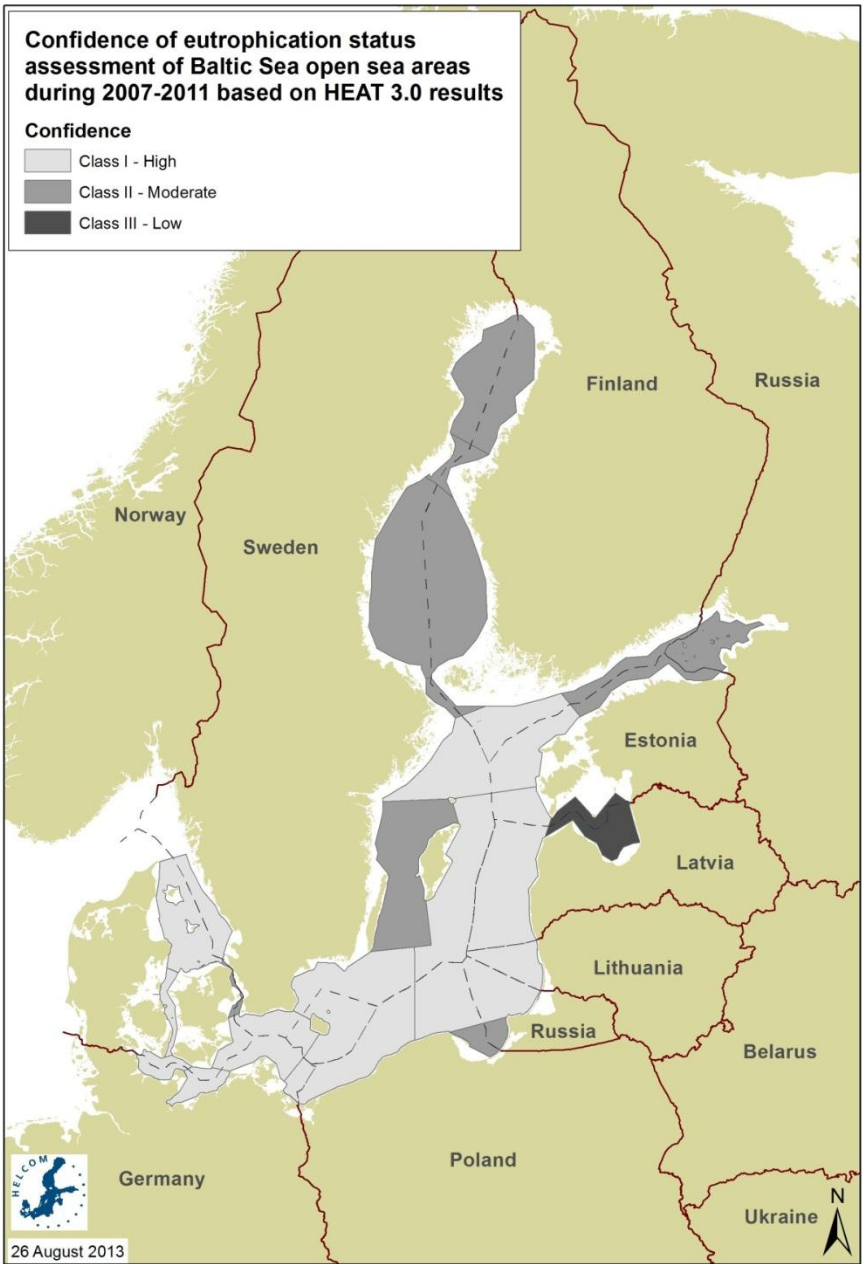

Figure 4. *Confidence of the eutrophication assessment was High (Class I – light grey) in most of the Baltic Sea main basins and southern as well as western areas and Low (Class III – Black) in the Gulf of Riga.*[2]

Indicator status in 2007-2011 by sub-basin

The status of each core indicator varied from one year to another and an average was used to depict the status during the assessment period for each sub-basin. The variation around the target level differed depending on the indicator and sub-basin (**Figures 5 to 9**).

[2] According to Denmark, the confidence for the Sound should be high due to frequent monitoring in the Öresund area. No chlorophyll-a data for 2009-2011 was available from the off-shore assessment unit of Sound for 2009-2011 which comprises a small area at the time of making the assessment, thus the moderate confidence.

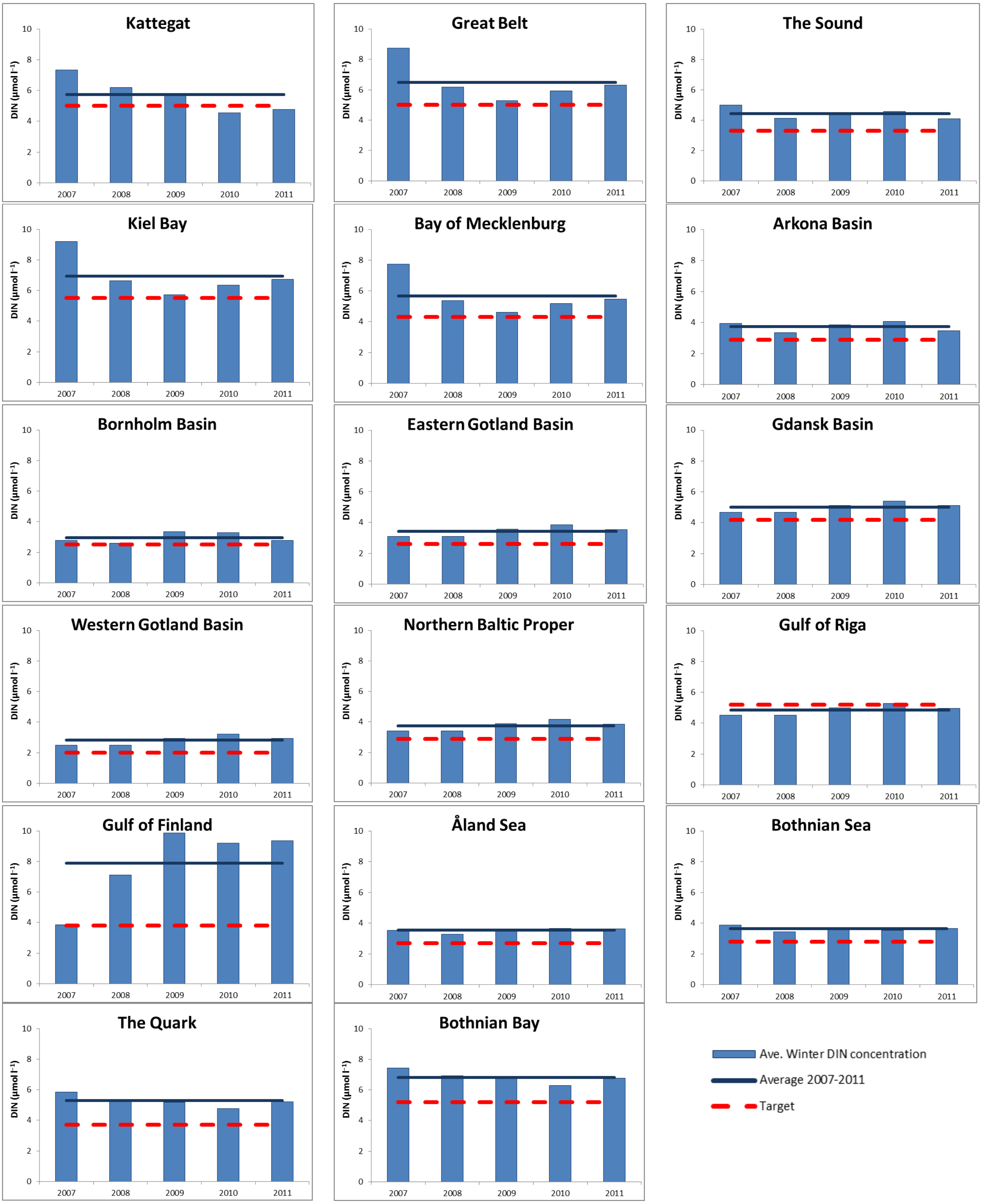

Figure 5. *Winter DIN concentration (black line; average for 2007-2011) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The target was attained only in the Gulf of Riga.*

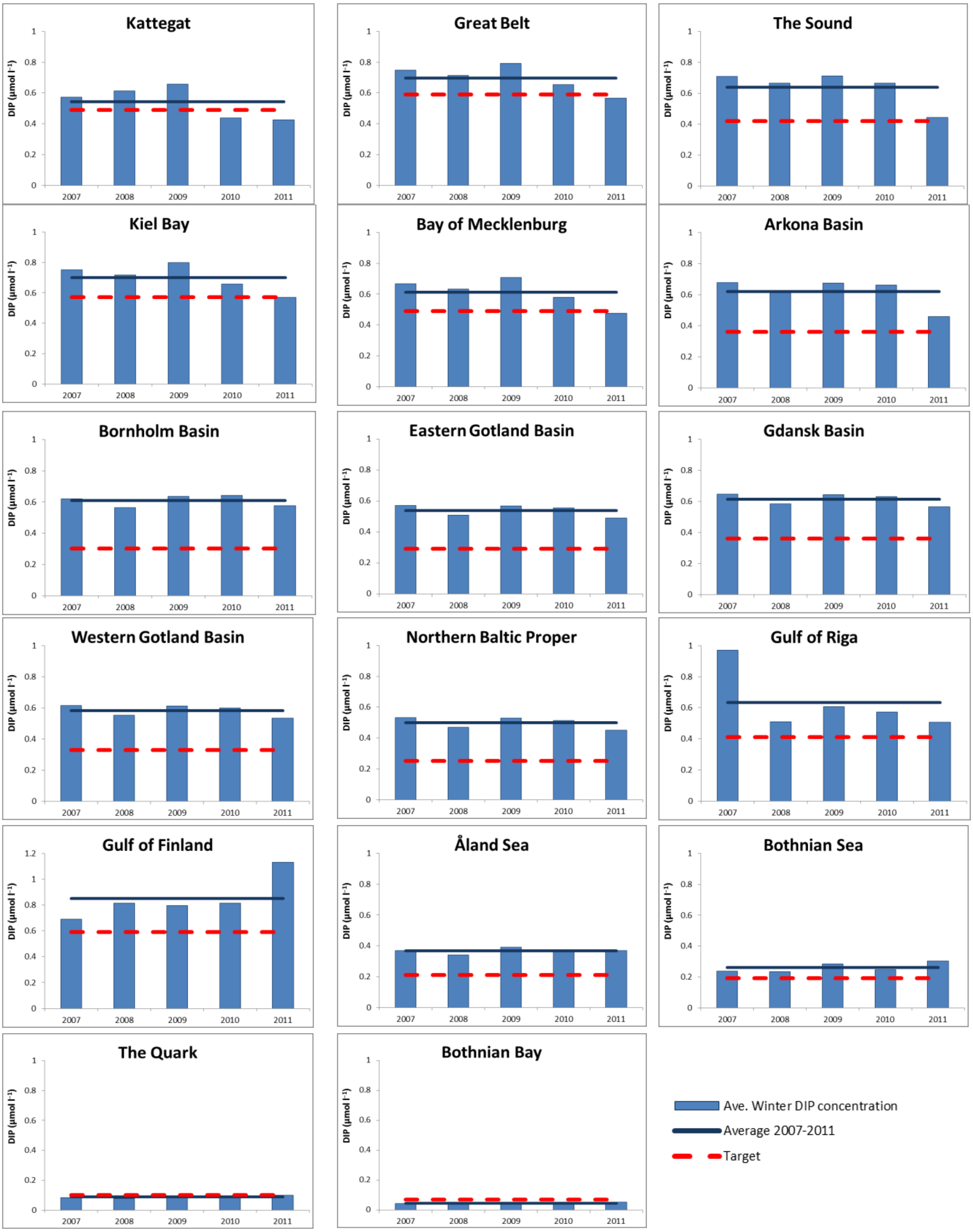

***Figure 6**. Winter DIP concentrations (black line; average for 2007-2011) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The targets were attained in the Quark and the Bothnian Bay and there was positive development in the Kattegat, Great Belt, Kiel Bay and the Bay of Mecklenburg. Note the different scale in the graph for the Gulf of Finland.*

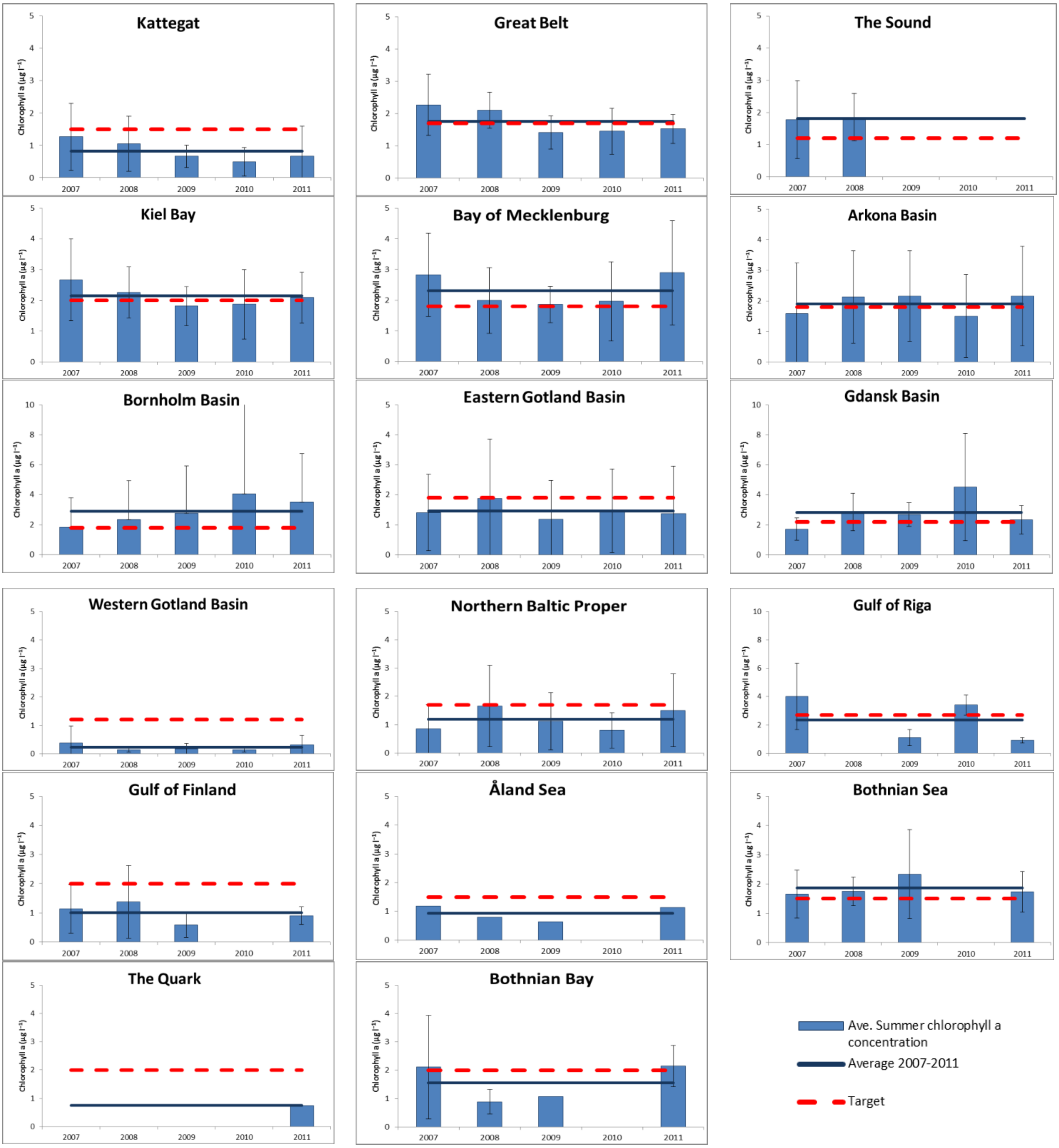

Figure 7*. Summer (June-September) chlorophyll a concentration (black line, average for 2007-2011) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The targets were attained in ten out of 17 sub-basins. Standard Deviations are also shown for each bar whenever available. No data was available for empty spaces. Note the different scales in the graphs for Gdansk Basin and Gulf of Riga.*

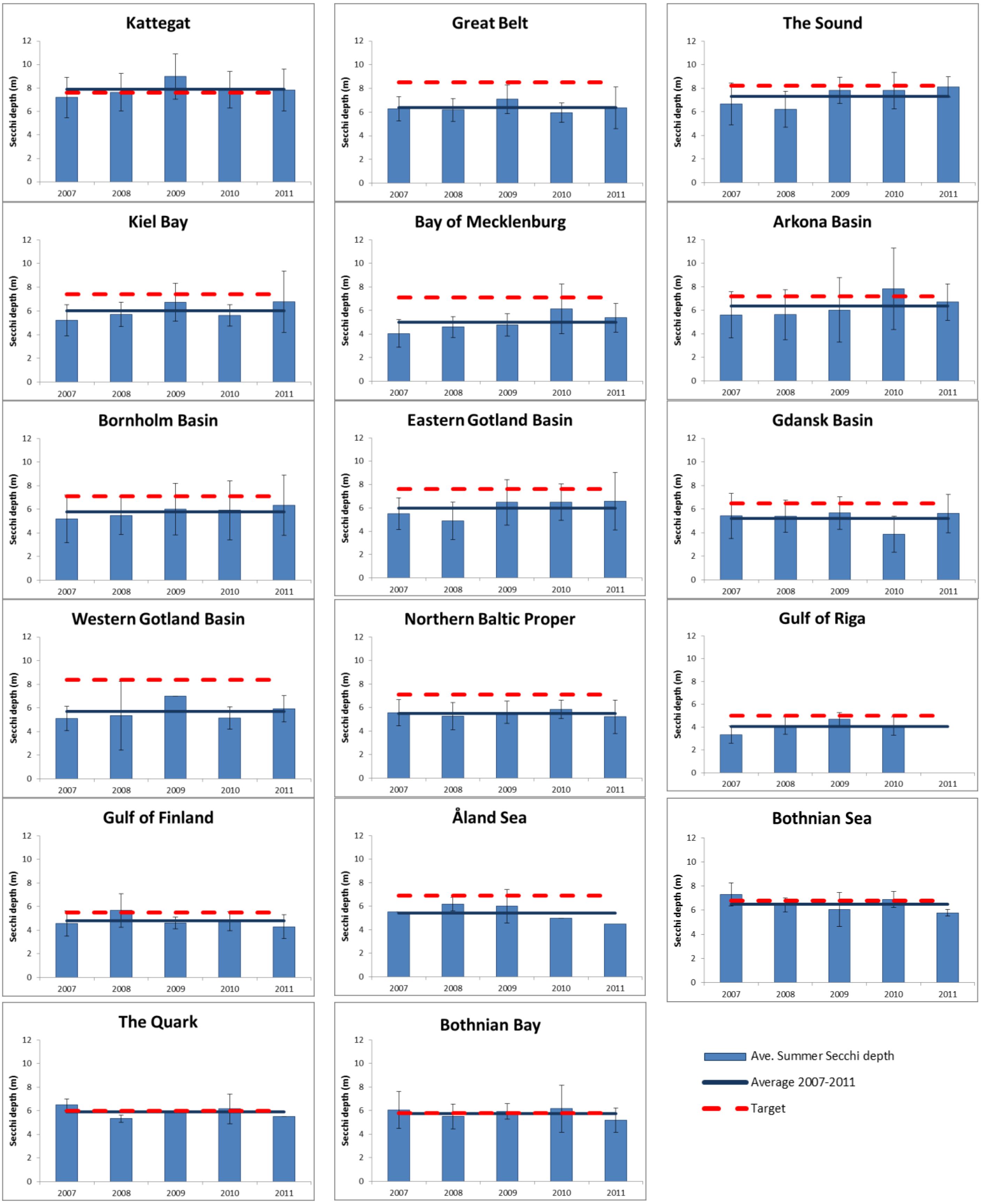

***Figure 8**. Summer (June-September) Secchi depth (black line; average for years 2007-2011) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The targets were attained in the Kattegat and Bothnian Bay. In the Sound, Kiel Bay, Bay of Mecklenburg, Arkona Basin and Eastern Gotland Basin there was positive development towards the targets during 2007-2011. Standard Deviations are also shown for each bar when available.*

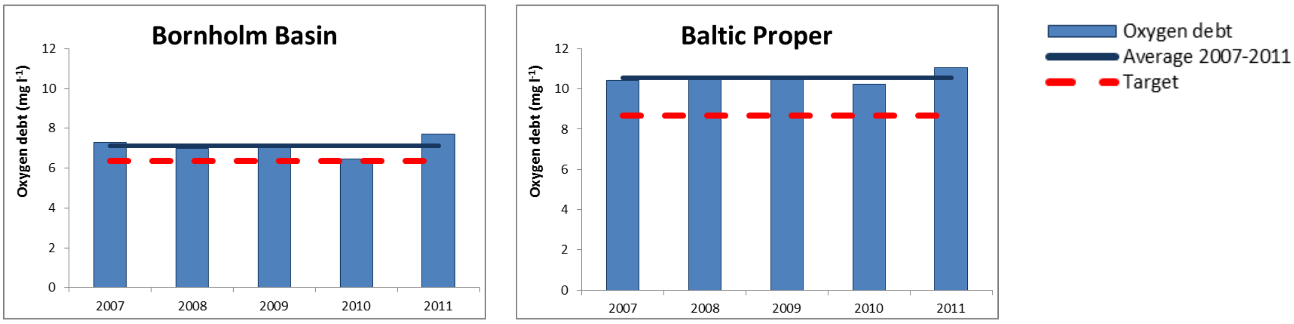

***Figure 9**. Oxygen debts (black line; average for 2007-2011) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). Oxygen debt targets were not reached in either of the assessed sub-basins. Plese note that for oxygen debt, the Baltic Proper consists of the following sub-basins: Northern Baltic Proper, Western Gotland Basin, Easter Gotland Basin and Gdansk Basin and the data from all these sub-basins were aggregated (cf. HELCOM 2013a). This result for the Baltic Proper was also included in the HEAT 3.0 integration of core indicators of each of these sub-basins.*

Technical data

Eighteen open sea area sub-basins (at least one nautical mile seawards from the baseline) were assessed using the HEAT 3.0 tool according to the HELCOM[3] division of the Baltic Sea.

The assessments of the open sea areas were based on an integration of state data from core set indicators on winter inorganic nitrogen (DIN) and phosphorus (DIP) concentrations, chlorophyll a concentrations, water transparency (Secchi depth) and oxygen conditions below halocline (oxygen debt, only for Bornholm Basin and Baltic Proper [“TARGREV data” distributed over the following sub-basins: Western and Eastern Gotland Basin, Gdansk Basin, Northern Baltic Proper and Gulf of Finland]).

Furthermore, the assessment included available results of EU WFD classification of the ecological status in the coastal waters (up to 1NM from the baseline) carried out by the Contracting Parties which are also EU member states. Reports for coastal waters were received from Denmark, Estonia, Finland, Germany and Lithuania. In coastal areas, the national classifications, according to the WFD (five-class system), were translated into a two class system (GES or sub-GES) for the purpose of comparison with the HELCOM classification.

Finnish expert, Ms. Vivi Fleming-Lehtinen, was appointed to fill in the spreadsheets of the HEAT 3.0 tool for the 18 assessed open sea area sub-basins based on aggregated data made available by BNI Denmark (original TARGREV data set for DIN, DIP and oxygen debt), BNI Sweden and ICES (for chlorophyll a and Secchi depth).

Indicators and targets

The indicators were grouped under the following three “criteria” as described in the Commission Decision (2010/477/EU): 1. Nutrient levels, 2. Direct Effects, 3. Indirect Effects (EC 2010) (**Table 1**). For this concise eutrophication assessment, the list of indicators comprises under nutrient levels: winter (December-February) dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations,

[3] The sub-basin division of the Baltic Sea follows that of the HELCOM Monitoring and Assessment Strategy agreed by HELCOM HOD 41/2013.

under direct effects: summer (June-September) chlorophyll a concentration and summer (June-September) Secchi depth, as well as annual oxygen debt below halocline (for the main sub-basins) under indirect effects.

The indicators within the criteria were weighted according to their relevance for eutrophication in each sub-basin. The weight was evenly distributed within the criterion, unless there was a justification to do otherwise.

For Secchi depth and chlorophyll a (criterion 2, direct effects), the weight was assigned according to the available information on the light absorption by colored dissolved organic matter (CDOM) and the relationship between CDOM absorption and chlorophyll a concentration in the sub-basin (Ylöstalo et al. in prep., Stedmon et al. 2000), respectively. The weight was distributed equally (50% / 50%) for most sub-basins but in the Gulf of Finland and especially in the Gulf of Bothnia chlorophyll a received a greater weight due to higher absorption of light by CDOM in relation to chlorophyll a (**Table 2)**. This made Secchi depth a less reliable indicator of eutrophication, and therefore it received a smaller weight in those basins.

Table 2. *Secchi depth and chlorophyll a have been weighted according to available information on CDOM absorption of light and the relationship between CDOM light absorption and chlorophyll a (chl-a) concentration in the sub-basin.*

Basin	**Weight Secchi**	**Weight chla**	**CDOM light absorption / chlorophyll a (chla)**
Kattegat	50 %	50 %	
The Sound	50 %	50 %	Low CDOM absorption (Stedmon et al. 2000)
Great Belt	50 %	50 %	Low CDOM absorption (Stedmon et al. 2000)
Little Belt	50 %	50 %	Low CDOM absorption (Stedmon et al. 2000)
Kiel Bay	50 %	50 %	Assumed similar as in the Belts and Arkona Sea
Mecklenburg Bight	50 %	50 %	Assumed similar as in the Belts and Arkona Sea
Arkona Sea	50 %	50 %	Low CDOM absorption (Ylöstalo et al. 2012), medium in relation to chl-a
Bornholm Sea	50 %	50 %	Low CDOM absorption (Ylöstalo et al. 2012), medium in relation to chl-a
Eastern Gotland Basin	50 %	50 %	Assumed similar as in the Northern Baltic ProperB
Western Gotland Basin	50 %	50 %	Low CDOM absorption (Ylöstalo et al. 2012), medium in relation to chl-a
Gdansk Basin	50 %	50 %	No info
Northern Baltic Proper	50 %	50 %	Medium CDOM absorption (Ylöstalo et al. 2012), medium in relation to chl-a
Gulf of Finland	40 %	60 %	High CDOM absorption (Ylöstalo et al. 2012), medium in relation to chla
Gulf of Riga	30 %	70 %	Extremely high CDOM absorption (Ylöstalo et al. 2012), high in relation to chla.
Åland Sea	50 %	50 %	Interpolated between Bothnian Sea and Northern Baltic Proper
Bothnian Sea	40 %	60 %	Medium CDOM absorption (Ylöstalo et al. 2012), medium-high in relation to chla
Quark	30 %	70 %	Interpolated between Bothnian Bay and Bothnian Sea
Bothnian Bay	20 %	80 %	High CDOM absorption (Ylöstalo et al. 2012), extremely high in relation to chla.

In the Bothnian Bay and the Gulf of Riga, where phosphorus is clearly the limiting element for phytoplankton production, DIN and DIP (criteria 1, nutrient levels) were weighted to increase the effect of the phosphorus using the same proportional weight (33.3% and 66.7%, respectively) as in the previous thematic assessment of eutrophication (HELCOM 2009).

The indicator targets were based on the results obtained in the TARGREV project (HELCOM 2013a), taking also advantage of the work carried out during the EUTRO PRO process (HELCOM 2009) and national work for WFD. The final targets were set through an expert evaluation process done by the intersessional activity on development of core eutrophication indicators (HELCOM CORE EUTRO) and the targets were adopted by the HELCOM Heads of Delegations 39/2012 (**Table 3**).

Table 3: *Eutrophication indicator targets for the Baltic Sea sub-basins agreed by HELCOM HOD 39/2012 and with national background information updated by HELCOM GEAR 3/2013. For scientific basis of target setting, see HELCOM 2013a.*

Basin	Winter DIN (μmol l^{-1})	Winter DIP (μmol l^{-1})	Summer Chl *a* (μg l^{-1})	Summer Secchi depth (m)	Oxygen debt (mg l^{-1})
Kattegat	5.0	0.49	1.5	7.6	>2*
The Sound	3.3	0.42	1.2	8.2	>2*
Great Belt	5.0	0.59	1.7	8.5	>2*
Little Belt	7.1	0.71	2.8	7.3	>2*
Kiel Bay	5.5	0.57	2.0	7.4	
Bay of Mecklenburg	4.3	0.49	1.8	7.1	
Gdansk Basin	4.2	0.36	2.2	6.5	8.66
Arkona Sea	2.9	0.36	1.8	7.2	
Bornholm Sea	2.5	0.30	1.8	7.1	6.37
Eastern Gotland Basin	2.6	0.29	1.9	7.6	8.66
Western Gotland Basin	2.0	0.33	1.2	8.4	8.66
Northern Baltic Proper	2.9	0.25	1.7	7.1	8.66
Gulf of Riga	5.2	0.41	2.7	5.0	
Gulf of Finland	3.8	0.59	2.0	5.5	8.66
Åland Sea	2.7	0.21	1.5	6.9	
Bothnian Sea	2.8	0.19	1.5	6.8	
The Quark	3.7	0.10	2.0	6.0	
Bothnian Bay	5.2	0.07	2.0	5.8	

*2mg/l is the Danish MSFD target for oxygen concentration.

Data processing for HEAT assessment

Estimating target confidence

The present targets are based on work done in the TARGREV project, through a procedure combining data mining and/or hindcast modelling (HELCOM 2013a), modified to suit the HELCOM sub-basin division.

The target confidence was rated based on the approach developed in the TARGREV project, where the indicators were grouped according to the availability of historical data. Group 1 - targets (for oxygen debt and Secchi depth) were derived based on historical data and were acknowledged to have high confidence, whereas Group 2 - targets (for chlorophyll *a* and nutrients) wereare derived based on limited historical data supported by modeling, and were given moderate confidence (**Table 4**).

Table 4. Oxygen debt and Secchi depth have targets rated as high confidence (Group 1 according to TARGREV), while chlorophyll a, DIN and DIP targets have moderate confidence (Group 2 TARGREV grouping). The target confidence is based on the classification in the HELCOM TARGREV report (table 3.14 in HELCOM 2013a).

Indicator	**TARGREV grouping**	**Target confidence**
Oxygen debt	Group 1	HIGH
Secchi depth	Group 1	HIGH
Chlorophyll *a*	Group 2	MODERATE
DIN	Group 2	MODERATE
DIP	Group 2	MODERATE

Data aggregation

For each sub-basin, the data from all of the relevant Contracting Parties were pooled for the assessment.

The aggregated average 2007-2011 indicator values were estimated as an inter-annual winter (December-February) average for inorganic nutrients, inter-annual summer (June-September) average for chlorophyll *a* and Secchi depth and as an annual average for oxygen debt. For the DIN, DIP and oxygen debt indicators, the data representing the period of 2007-2011 were aggregated using a combined spatial and seasonal model (as applied in the TARGREV project, HELCOM 2013a) to compensate for possible uneven distribution of stations and inadequate seasonal coverage of measurements in order to overcome shortcomings of the monitoring station networks of the Contracting Parties (HELCOM 2013a, Carstensen et al. 2006).

The confidence was rated for each indicator within an assessment unit, according to the availability and distribution of data during the assessment period (**Table 5**).

Table 5. *The confidence (EUT S-Score) of the indicators in the HEAT assessment was determined according to the availability and temporal distribution of data during the assessment period.*

Data availability	Confidence (EUT S-Score)
During one or several years, no more than 5 status observations are found annually.	LOW
During one or several years, more than 5 but no more than 15 assessment observations are found annually.	MODERATE
During all years, more than 15 assessment observations are found, and their spatial distribution is not clearly biased.	HIGH

For chlorophyll *a* and Secchi depth, the data were scarce or missing for some years and basins (**Table 6**). The confidence was rated low for both indicators in the Gulf of Riga, Little Belt, the Quark and Åland Sea. Chlorophyll *a* indicator received a greater number of low ratings (eight) compared to Secchi depth (five). High confidence ratings were assigned to Arkona Sea, Bornholm Sea, Eastern Gotland Basin, Gdansk Basin and the Kattegat.

Table 6. The confidence of Secchi depth and chlorophyll *a* averages for each open sea sub-basin, based on data availability for the period 2007-2011.

Sub-basin	Secchi depth	Chlorophyll *a*
Arkona Basin	Moderate	High
Bay of Mecklenburg	Moderate	High
Bornholm Basin	High	Moderate
Bothnian Bay	Moderate	Low
Bothnian Sea	Moderate	Low
Eastern Gotland Basin	High	High
Gdansk Basin	Moderate	Moderate
Great Belt	High	Moderate
Gulf of Finland	Moderate	Low
Gulf of Riga	Low	Low
Kattegat	High	High
Kiel Bay	High	Moderate
Northern Baltic Proper	High	Moderate
The Quark	Low	Low
The Sound	High	Low
Western Gotland Basin	Low	Moderate
Åland Sea	Low	Low

High
Moderate
Low

Description of the HEAT 3.0 tool

The new HELCOM Eutrophication Assessment Tool 3.0 compares an agreed eutrophication target for the selected indicator with the current status value derived from monitoring data. For each of these indicators a “Eutrophication Ratio” is calculated (**Figure 10**). If the eutrophication ratio is below 1.00, it reflects good environmental status (GES) and if it is above 1.00, it reflects indicator status where GES has not been reached (sub-GES). HEAT 3.0 integration is applied for each sub-basin assessment unit.

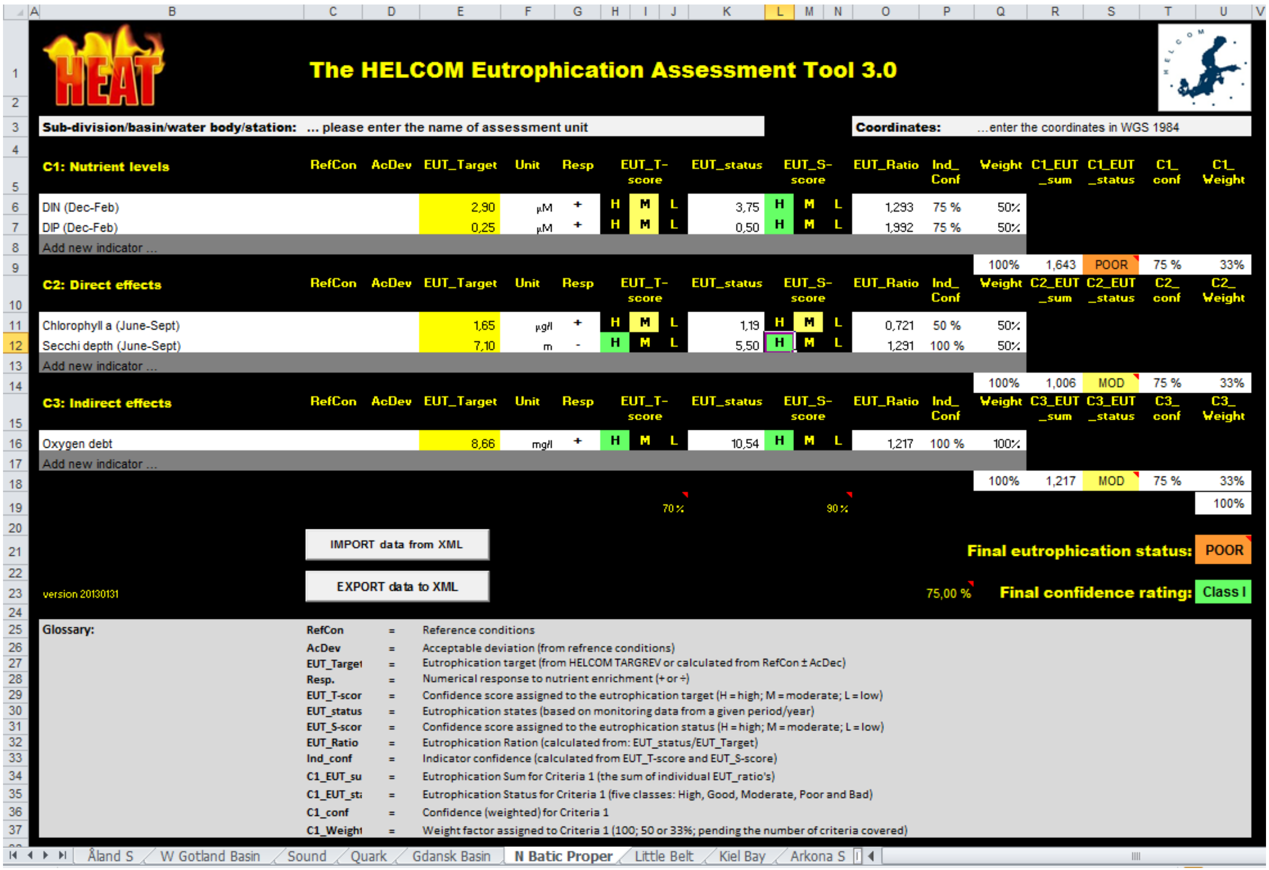

***Figure 10**. HEAT 3.0 tool runs on excel and displays the core indicators under three criteria and their targets (EUT_Target), status (EUT_status) and the resulting Eutrophication Ratio (EUT_Ratio) which yields the Final eutrophication status. In addition, Confidence rating of each target (EUT_T_score), status data (EUT_S_score) as well as of each criterion (C1-C3_conf) and the Final confidence rating are given.*

In each criterion (i.e. nutrient levels, direct effects and indirect effects) the status was determined as a weighted average of the Eutrophication Ratios of the individual indicators grouped under each of the three criteria (e.g. average of DIP-ER and DIN-ER). The status was assessed according to the outcome, where GES≤1 and sub-GES>1.

In the final step, the one-out-all-out principle was used between the 'criteria status' to determine the overall eutrophication status for each sub-basin; i.e. the worst of the three results on criterion level determined the final status classification. While the Marine Strategy neither excludes nor specifies the use of the 'one-out-all-out principle' its use solves the problem of combining the results from different MSFD criteria and is consistent with earlier assessments.

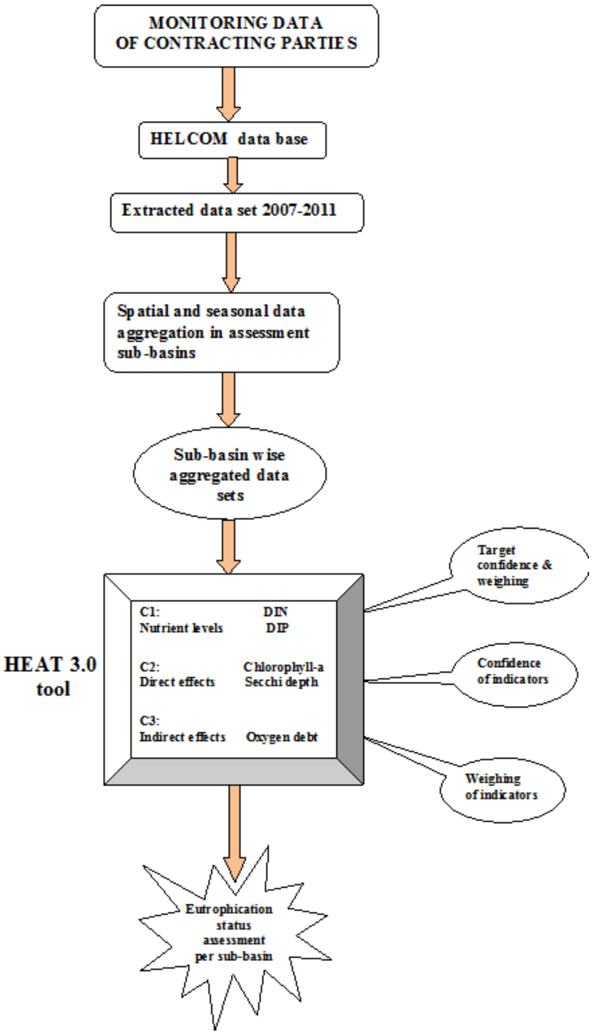

Figure 11. *Steps of assessing eutrophication status of the open sea sub-basins of the Baltic Sea from monitoring data to core indicator –based integrated assessment results for each sub-basin.*

It should be noted that the HEAT tool is able to divide GES status into high and good classes and sub-GES status into moderate, poor and bad classes, as in the WFD classification of ecological status, once class boundaries have been agreed on. However, for the purpose of the present assessment covering the period 2007-2011, only GES and sub-GES are applied, which is in line with the requirements of the MSFD.

Comparability of the current assessment with the 2003-2007 assessment

This section explains the differences between the approaches of the present eutrophication assessment and the previous HELCOM thematic assessment on eutrophication (HELCOM 2010b) and explains why the comparability of assessment results is limited.

Comparison of indicators and targets

In the previous assessments, covering the years 2001-2006 (HELCOM 2009) and 2003-2007 (HELCOM 2010b), the indicators were grouped into four quality elements (as in the EU WFD), which often included only a single indicator in the open sea sub-basins. The quality element (1) 'Plankton' comprised only the summer chlorophyll *a* indicator. The quality element (2) 'Submerged aquatic vegetation' could not be applied in the open basins for the obvious reasons. In most of the open sub-basins, the quality element (3) 'Invertebrate benthic fauna' included an indicator, such as average number of taxa, presence/absence, or

Danish Quality Index (DKI). Only the last quality element, (4) 'Physico-chemical features' included several indicators, varying by sub-basin: summer/annual Secchi depth, winter DIN (NO_2+NO_3+NH_4), winter DIP, summer/annual TN or summer/annual TP.

In the current assessment, the indicators were grouped in a different way into criteria (as in the EU Commission Decision, see chapter 'Indicators and targets' under Technical data). Only Criterion 2, 'Indirect effects', consisted of a sole indicator - oxygen debt. Thus, the possibility of a single indicator being able to dominate the overall eutrophication status is smaller in the current assessment. As a consequence, the likelihood of "bad status" is lower in sub-basins where the variation between indicators status is high.

In the current assessment, the benthic fauna indicator was not applied in the assessment of open sea units, whereas in the previous assessment it was present in most of the open sea areas (in 9 out of 13 assessment units). The overall eutrophication status in the previous assessment was determined as 'bad' in the Bornholm Basin, Gdansk Deep and Eastern Gotland Basin due to the benthic fauna indicator alone being in bad status.

On the other hand, the oxygen debt indicator was not used in the previous assessment. As the only indicator under its criterion "indirect effects", the oxygen debt indicator had the potential to dominate the overall eutrophication status in the basins related to the deep basins of the Baltic Proper. However, oxygen debt did not end up determining the overall eutrophication status in any of these assessment units as it was never the indicator showing the worst status (**Figure 9**).

In the current assessment, new eutrophication targets as agreed by HELCOM HOD 39/2012 were implemented. Some of the targets had changed considerably from the preliminary targets used in previous assessments and a change greater than +/-15% of the target was considered to be a considerable change (with the +/-15% change having been chosen arbitrarily) (**Table 8**). A greater number of targets changed towards a more ambitious level, i.e. to a stricter target. The targets that had changed considerably (>+/-15%) were considered to have had an additional effect on the indicator status, i.e. even in the case where the actual state of the parameter had not changed the final Eutrophication Ratio would have changed.

Table 8. *Change in targets for DIN, DIP, chlorophyll a and Secchi depth indicators from the previous assessments (2001-2006 and 2003-2007) to the current assessment (2007-2011), where ≥15% ↗ = increased level of ambition, ↘ = decreased level of ambition. (The 2001-2006 and 2003-2007 assessments results are presented in HELCOM 2009 and 2010b, respectively). In the absence of an arrow in the table, the change was smaller than ≥15%.*

HELCOM basin	DIN	DIP	Chla	Secchi
Arkona Sea				↗
Meclenburg Bight	↘	↘		
Bornholm Sea	↗	↗		
Bothnian Bay		↗		
Bothnian Sea		↗		
Eastern Gotland Basin			↘	↗
Great Belt	↘	↘	↘	
Gulf of Finland		↗		
Gulf of Riga	↗			↗
Kattegat		↗	↘	↘
Kiel Bay	↗	↘		
Little Belt				
Northern Baltic Proper		↗		
Gdansk Basin	↗		↘	
Quark		↘		
Sound	↗			
Western Gotland Basin	↗		↗	↗
Åland Sea		↗		

An evaluation of the impact of removal of zoobenthic indicators, the use of oxygen debt indicator, changes in the targets and grouping of indicators did not yield any changes in the final eutrophication classification. The shift from a five class system to a two class system (GES/sub-GES) made the results crude in the sense that any impact of the above changes should have taken place across the GES/sub-GES boundary.

Comparison of data processing

In the present assessment, data for all seasons were used for the DIN, DIP and oxygen debt indicators to produce seasonal estimates, using a combined spatial and seasonal model, “the TARGREV model” for extracting the seasonal data (see “Data aggregation”) (HELCOM 2013a, Carstensen et al. 2006).

In the 2009 (HELCOM 2009) and 2010 (HELCOM 2010b) assessments, data for each assessment unit were averaged over the assessment period without applying the modeling step to even out seasonal and spatial differences.

In the previous assessment, national experts used the HEAT 1.0 tool individually and the indicator averages did not take into account the uneven spatial and temporal distribution of the data which might have biased the figures. However, the assessment results were jointly evaluated in a workshop after the integration step and any spatial discrepancies between assessment units were processed.

Comparison between HEAT 3.0 and HEAT 1.0

The first version of the HEAT tool was developed in the HELCOM EUTRO process (see HELCOM 2006) and documented by Andersen et al. 2010 and 2011. It was applied in the HELCOM thematic assessment of eutrophication in the Baltic Sea (HELCOM 2009), core indicator integration of 2010 (HELCOM 2010b), as well as in the HELCOM Initial Holistic Assessment and demonstration set of core eutrophication indicators (HELCOM 2010a and HELCOM 2010b). A second version (HEAT 2.0) has been developed but never used in the HELCOM context.

HEAT 1.0 differs from HEAT 3.0 not only in the set of indicators and targets used, but also in the way indicators are grouped and also in the assessment principles as well as to some extent in the division of sub-basins (**Figure 12**).

In HEAT 1.0, four ecological quality elements were used to group the indicators, instead of the three criteria used in HEAT 3.0. These ecological quality elements corresponded with WFD requirements and consisted of plankton (phytoplankton and chlorophyll), submerged aquatic vegetation, benthic invertebrates and physico-chemical features.

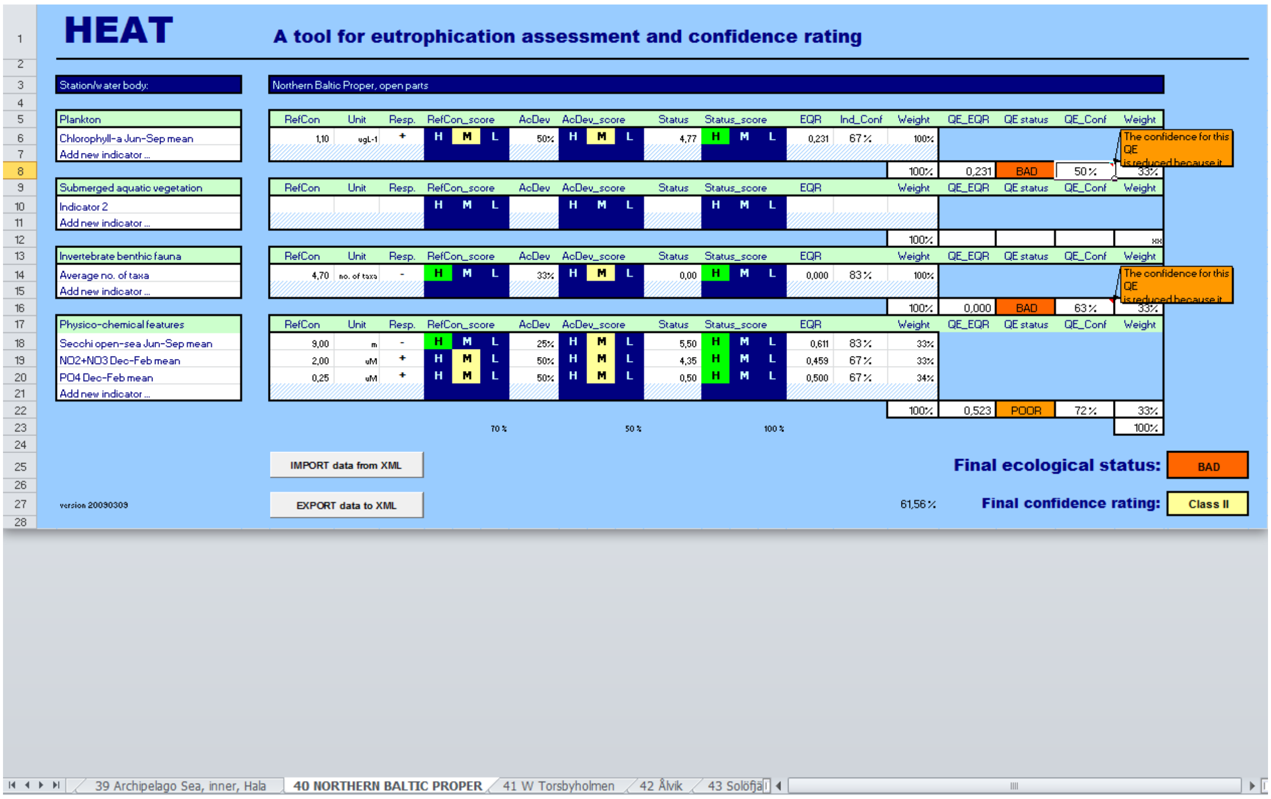

***Figure 12**. Snapshot of the HEAT 1.0 tool displaying the grouping of indicator under four quality elements, and the application of Reference Conditions (RefCon) and Acceptable Deviations (AcDev).*

The assessment principle of HEAT 1.0 was based on reference values (RefCon) and acceptable deviation (AcDev) which, when combined, produced preliminary targets. By the time of applying HEAT 3.0, HELCOM has strengthened the scientific background of target setting (HELCOM 2013a) and agreed on a set of targets. The HEAT 1.0 classification comprised five status classes (high, good, moderate, poor and bad). The boundary between good and moderate was defined by RefCon + AcDev. In most Baltic sub-regions, the acceptable deviation was set arbitrarily at 50 % (25 % for Secchi depth). For the overall assessment of a sub-region, the one-out-all-out-principle was used on quality element level, meaning that the quality element with the worst result determined the final status classification of the sub-region or basin assessed. The assessment results differ also because the indicators were grouped differently in HEAT 1.0 compared to

HEAT 3.0 (e.g. Secchi depth being one of the indicators under "physico-chemical features" in HEAT 1.0, while appearing together with chlorophyll under "direct effects" in HEAT 3.0). As a result, the assessments based on HEAT 1.0 and HEAT 3.0 are not fully comparable.

The division of the Baltic Sea into open sea sub-basins is in general the same for both assessments but in the current assessment slight adjustments have been made to sub-basin boundaries, e.g. in the Quark, and in this assessment some areas have been assessed as open sea sub-basins, while they were considered as coastal areas in the previous assessment (e.g. Little Belt, Kiel Bay, Bay of Mecklenburg and Åland Sea). Furthermore, in 2009 the Kattegat was divided into three assessment units, while it comprised only one unit in the present assessment. Otherwise, the main sub-basin boundaries have remained the same for most sub-basins.

For the HEAT 1.0 assessments, the Baltic Sea was divided into 189 assessment units consisting of 17 open sea basins and 172 coastal assessment sites. The current HEAT 3.0 assessment was applied to 18 open sea sub-basins for which targets have been agreed and it included WFD classification status for coastal areas, where such information had been made available by HELCOM Contracting Parties that are also EU member states.

Table 10. *Comparison of this eutrophication status assessment and previous HELCOM assessments.*

Assessment	**Time period from which data were used**	**HEAT version used**	**Baltic Sea divided into n geographical assessment units, n =**	**Published**
Thematic Eutrophication assessment 2009	2001-2006	HEAT 1.0	189 "areas" (17 open sea and 172 coastal areas)	Baltic Sea Environmental Proceedings (BSEP) No. 115, 2009
Initial Holistic Assessment (HOLAS) 2010	2001-2006	HEAT 1.0	189 areas" (17 open sea and 172 coastal areas)	Baltic Sea Environmental Proceedings (BSEP) No. 122, 2010 - eutrophication assessment based on Andersen et al. 2011
Update of the 2010 assessment for the time period 2003-2007	2003-2007	HEAT 1.0	189 areas (17 open sea and 172 coastal areas)	HELCOM webpage (www.helcom.fi), updated 12 May 2010
Updated Baltic Sea open sea area assessment	2007-2011	HEAT 3.0	18 sub-basins (only open sea 1 NM seaward from the baseline) and coastal water assessments based on national WFD classifications	Present assessment

Need for further development

Indicators and targets

There is a need to set up a process (i.e. expert group) for continuous work on the indicators and targets.

Regular review of agreed targets to take into account e.g. new scientific knowledge and development of GES targets for new core indicators should be carried out by the expert group. This group should have responsibility for QA/QC guidance of the full eutrophication assessment process from monitoring to assessment products, and indicators and targets should be reviewed and revised, if necessary.

There is a need to elaborate a description of parameters and data used for the set of core eutrophication indicators and to develop a manual for monitoring of each core indicator, including QA/QC requirements and procedures. Data aggregation products needed for regular updating of indicators should be identified; methods and scripts for modelling (e.g. spatial, seasonal and long-term aspects) for data aggregation should be specified and a manual for data aggregation for core eutrophication indicators, including a description for producing graphs and maps of single indicator reports should be developed.

The list of indicators needs to be supplemented as the following indicators are missing (e.g. compared to former assessments): phytoplankton biomass or taxonomic indicator, aquatic vegetation, coastal oxygen conditions and macrozoobenthos. There needs to be a discussion over whether macrozoobenthos should be treated as an eutrophication indicator as it was done in the former assessments or whether it should be used as an indicator of sea floor integrity in accordance with European Commission Decision 2010/477/EU on criteria and methodological standards on good environmental status of marine waters or whether it could have multiple uses (i.e. be used under various ecological objectives and descriptors).

Operationalization of the assessment process

There is a need to make operational regional assessments of eutrophication for the Baltic Sea, including defining and streamlining the full process that leads from data to assessment products. Operationalization should encompass development of a system within which the data from the Contracting Parties will be channeled to a common data pool, used for predefined data aggregation, production of core eutrophication indicator reports and finally eutrophication assessments for the Baltic Sea. All assessment products, manuals and data should be designed to be available on the HELCOM web portal.

The data products, i.e. core indicator reports and eutrophication assessments for the Baltic Sea need to be designed so as to serve the follow-up of the implementation of the HELCOM Baltic Sea Action Plan, and for those Contracting Parties being also EU Member States, the reporting needs for the Marine Strategy Framework Directive, especially Descriptor 5 for good environmental status. HELCOM Map and Data service also need to be developed to fully support the production of assessment products also needed by the Contracting Parties for their national reporting purposes, as well as to allow access to the data behind them.

Development of HEAT

There is a need to develop further the HEAT assessment tool. A user-friendly handbook, describing the function and giving guidance on the use of HEAT 3.0 is needed. Classification algorithms, agreed criteria for setting confidence levels and rules for the aggregation of data should be contained in the handbook as well.

Class boundaries need to be further elaborated on. If more than two classes (GES and sub-GES) are of interest, it should be determined how the other boundaries should be set; how the boundaries fit with WFD class boundaries; whether the treatment of increasing (e.g. chlorophyll) and decreasing (e.g. Secchi depth) parameters by simply inverting the Eutrophication Ratio is appropriate or if this method introduces a bias in the classification; and whether a cause-effect-relationship can be established between Eutrophication Ratio and indicator/criterion so that boundaries do not need to be set equi-distantly as done up to now.

There is a need to further evaluate and develop proposals for methods used for eutrophication assessment in the coastal zone (inter alia WFD indicators) as well as open sea (Baltic Sea Action Plan and Marine Strategy Framework Directive) in order to coordinate harmonization of coastal and open sea assessments.

For the future, it would be desirable that more Contracting Parties commit themselves to the further refinement of the assessment tools and methods as well as data delivery in order to obtain reliable assessment results.

Datasets

[Integrated eutrophication assessment for 2007-2011 (HEAT 3.0)]

[Seasonally aggregated data for each year (2007-2011) and sub-basin]

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