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Eutrophication status of the Baltic Sea 2007-2011

A concise thematic assessment

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Eutrophication status of the Baltic Sea 2007-2011

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Executive Summary

An assessment of eutrophication status in the Baltic Sea was prepared as background information for the 2013 HELCOM Ministerial Meeting held in Copenhagen, Denmark. The aim of the assessment was to provide information for follow-up of the progress towards reaching the ecological objectives and goals of the HELCOM Baltic Sea Action Plan (BSAP).

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 assessment of the open sea sub-basins was based on an integration of commonly agreed core indicators: inorganic nitrogen (DIN), inorganic phosphorus (DIP) , chlorophyll *a*, water transparency (Secchi depth) and oxygen conditions (oxygen debt, for six sub-basins).

The results of ecological status for coastal waters indirectly reflect eutrophication conditions. These are presented where information was available. These results

are based on WFD status assessments carried out by those HELCOM Contracting Parties that are also EU Member States.

The entire open Baltic Sea was assessed as being affected by eutrophication. The following coastal areas were assessed by national authorities as having good ecological status: Orther Bucht (Germany), outer coastal Quark (Finland) and outer coastal Bothnian Bay, outer coastal Bothnian Sea, inner and outer coastal Quark (Sweden).

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.

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 from coastal point sources, run-off from diffuse sources in coastal areas or discharges from ships. In addition, excess nutrients stored in bottom sediments can enter the water column and enhance primary production.

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. Changes in individual sub-basins are greater. Currently, the level of nutrient inputs equals the levels of loads in the early 1960s.

Despite the reductions in inputs, the concentrations of nutrients have not declined accordingly. Since the previous 2003-2007 assessment, signs of declining nutrient levels have been seen in the Kattegat (dissolved inorganic nitrogen, DIN and dissolved inorganic phosphorus, DIP), Bornholm Basin (DIP), Northern Baltic Proper (DIN) and Gulf of Riga (DIN and DIP). Despite this, chlorophyll *a* trends still show no signs of decline or have increased in recent years (Bornholm Basin, Northern Baltic Proper, Bothnian Sea and Bothnian Bay). The long residence time of water in the open Baltic Sea as well as feedback mechanisms such as phosphorus release from anoxic 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.

Model predictions of recovery of the Baltic Sea show that once the nutrient reduction targets agreed by HELCOM are met, this will have a positive effect on the status of the Baltic Sea ecosystem and that the concentrations of nutrients will decline during the following decades. Nevertheless it will take a long time to reach the target levels of eutrophication status. It is therefore urgent that nutrient reduction measures are implemented without further delay.

1 Introduction

Eutrophication in the Baltic Sea is to a large extent driven by anthropogenic enrichment of the nutrients nitrogen and phosphorus. Nutrient over-enrichment and/or changes in nutrient ratios cause elevated levels of algal and plant growth, increased turbidity, oxygen depletion in bottom waters, 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.

1.1 Purpose of this assessment

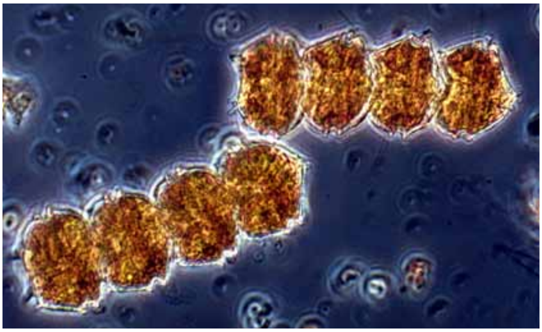
This eutrophication assessment was prepared to serve as background information to the 2013 HELCOM Ministerial Meeting, in order to allow for follow-up on the progress towards reaching the ecological objectives and goals of the HELCOM Baltic Sea Action Plan (HELCOM 2007). This report was originally published as a HELCOM web-based assessment.

The purpose of this assessment was to present the eutrophication status of the open sea areas of the Baltic Sea calculated for 2007-2011 based on 1) the latest available data, 2) new HELCOM eutrophication status targets and 3) the updated HELCOM Eutrophication Assessment Tool (HEAT 3.0). For coastal waters, the results of ecological status, which indirectly reflect eutrophication conditions, were presented where information was available. These results were based on WFD status assessments carried out by those Contracting Parties that are also EU Member States.

1.2 Policy relevance

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

The EU Marine Strategy Framework Directive, MSFD (EC 2008) 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 (EC 2000). Russia uses a related water quality grading system under the Scheme for Comprehensive Use and Protection of Water Bodies (SKIOVO).



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 (EU 2010) 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 (or ecosystem-based 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.

Table 1. HELCOM eutrophication core indicators for open-sea sub-basins 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

2 Methodology

The eutrophication status of seventeen open sea sub-basins (at least one nautical mile from the baseline) defined according to the HELCOM division of the Baltic Sea (**Annex 1**, HELCOM 2013d) was assessed. The status of five eutrophication core indicators, updated with monitoring data from 2007-2011, was integrated into overall eutrophication status using the HEAT 3.0 assessment tool (steps described in **Figure 1**).

The assessment of the open sea sub-basins was based on an integration of status data from core set indicators on inorganic nitrogen (DIN), inorganic phosphorus (DIP) , chlorophyll *a*, water transparency (Secchi depth) and oxygen conditions (oxygen debt, for six sub-basins).

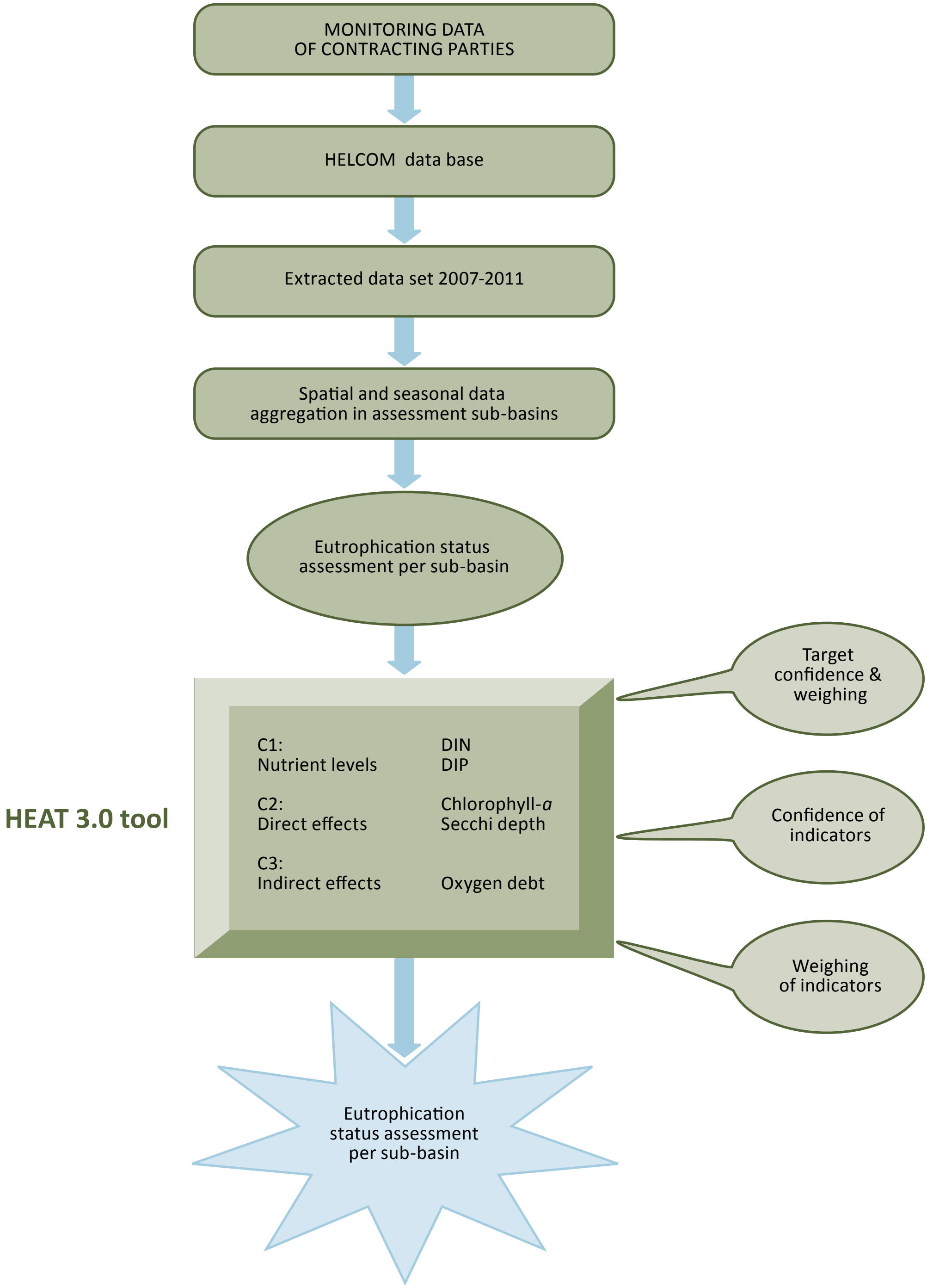


Figure 1. Steps of assessing eutrophication status of the open sea sub-basins of the Baltic Sea from monitoring data to core indicator –based integrated assessment results for each sub-basin.

Furthermore, the assessment included available results of EU WFD classifications of the ecological status in the coastal waters (up to 1 nautical mile from the base-line) carried out by those HELCOM Contracting Parties which are also EU Member States. Reports for coastal waters were received from Denmark, Estonia, Finland, Germany, Lithuania, Poland and Sweden. In coastal areas, the national classifications, according to the WFD (five-class system), were translated into a two class system, with the GES-boundary set at the boundary between Good and Moderate ecological status, for the purpose of comparison with the HELCOM classification.

The assessments of eutrophication and ecological status, though produced through different methodological approaches, both rely on indicators describing eutrophication and can thus be seen to provide an estimation of eutrophication status. However, due to the methodological differences, the results of the coastal and open-sea assessments are not directly comparable.

2.1 Indicators and targets for open sea sub-basins

The indicators were grouped under the following three "Criteria" as described in the Commission Decision (EC 2010): 1) Nutrient levels, 2) Direct Effects and 3) Indirect Effects (**Table 1**). For the concise eutrophication assessment of the open sea sub-basins, the list of indicators comprises:

1. Nutrient levels: winter (December-February) dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations in the surface layer (0 - 10 m depth),
2. Direct effects: summer (June-September) chlorophyll *a* concentration in the surface layer (0 - 10 m depth) and summer (June-September) Secchi depth, and
3. Indirect effects: annual oxygen debt below the halocline (for the Bornholm Basin, Western Gotland Basin, Eastern Gotland Basin, Northern Baltic Proper and Gulf of Finland).

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

For chlorophyll *a* and Secchi depth (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 (Stedmon et al. 2000, Ylöstalo et al. in prep.), 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*. This made Secchi depth a less reliable indicator of eutrophication, and therefore it received a lower weight in those sub-basins (**Annex 2**).

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 weights (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 from the HELCOM TARGREV project (HELCOM 2013b), taking also advantage of the work carried out during the HELCOM EUTRO PRO process (HELCOM 2009) and national work for WFD. The final targets were set through an expert evaluation process under 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 2**).

Table 2. 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 2013b.

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	
The Sound	3.3	0.42	1.2	8.2	
Great Belt	5.0	0.59	1.7	8.5	
Little Belt *	7.1	0.71	2.8	7.3	
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 Basin	2.9	0.36	1.8	7.2	
Bornholm Basin	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	

* Little Belt was not included in the present assessment

2.2 Data processing for HEAT assessment in open sea sub-basins

Estimating target confidence

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

The confidence of the target (EUT_T-score) 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 judged to have high confidence, whereas Group 2 targets (for chlorophyll *a* and nutrients) were derived based on limited historical data supported by modelling, and were given moderate confidence ratings (**Table 3**).

Table 3. Secchi depth and oxygen debt 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 2013b).

Indicator	TARGREV grouping	Confidence (EUT_T-score)
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 open sea sub-basin, all data made available by the Baltic Nest Institute, BNI Denmark (data set for DIN, DIP and oxygen debt described in HELCOM 2013b), BNI Sweden (chlorophyll *a* and Secchi depth) and the International Council for Exploration of the Seas, ICES (for chlorophyll *a* and Secchi depth) as well as experts from Denmark, Finland, Germany, Poland and Sweden, 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 inter-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 2013b) to compensate for 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 2013b, Carstensen et al. 2006).

The confidence of indicator status (EUT_S-score) was rated for each indicator within an assessment unit, according to the availability and distribution of data during the assessment period (**Table 4**).

Table 4. The confidence of the indicator status (EUT_S-Score) in the HEAT assessment was determined for each indicator in all Baltic Sea sub-basins 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 sub-basins (**Table 5**). The confidence was rated low for both indicators in the Gulf of Riga, the Quark and Åland Sea. Chlorophyll *a* indicator received a greater number of low ratings (seven) compared to Secchi depth (four). High confidence ratings were assigned to one or both indicators in the Arkona Basin, Bay of Mecklenburg, Bornholm Basin, Eastern Gotland Basin, Great Belt, Kattegat, Kiel Bay, Northern Baltic Proper and the Sound.

Table 5. The confidence of Secchi depth and chlorophyll a status (EUT_S-score) for each open sea basin, based on data availability for the period 2007-2011.

HELCOM sub-basin	Secchi depth	Chlorophyll a
Kattegat	HIGH	HIGH
The Sound	HIGH	LOW
Great Belt	HIGH	MODERATE
Kiel Bay	HIGH	MODERATE
Bay of Mecklenburg	MODERATE	HIGH
Gdansk Basin	MODERATE	MODERATE
Arkona Basin	MODERATE	HIGH
Bornholm Basin	HIGH	HIGH
Eastern Gotland Basin	HIGH	HIGH
Western Gotland Basin	LOW	MODERATE
Northern Baltic Proper	HIGH	HIGH
Gulf of Riga	LOW	LOW
Gulf of Finland	MODERATE	LOW
Åland Sea	LOW	LOW
Bothnian Sea	MODERATE	LOW
The Quark	LOW	LOW
Bothnian Bay	MODERATE	LOW

2.3 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 2**). If the eutrophication ratio is below 1.00, it reflects good environmental status (GES) and if it is at or above 1.00, it reflects indicator status where GES has not been reached (sub-GES). HEAT 3.0 integration is applied for each open sea basin assessment unit.

It should be noted that the HEAT 3.0 tool divides 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, given agreed class boundaries. However, for the purpose of the present assessment covering the period 2007-2011, only GES or sub-GES status is reported, which is in line with the requirements of the MSFD.

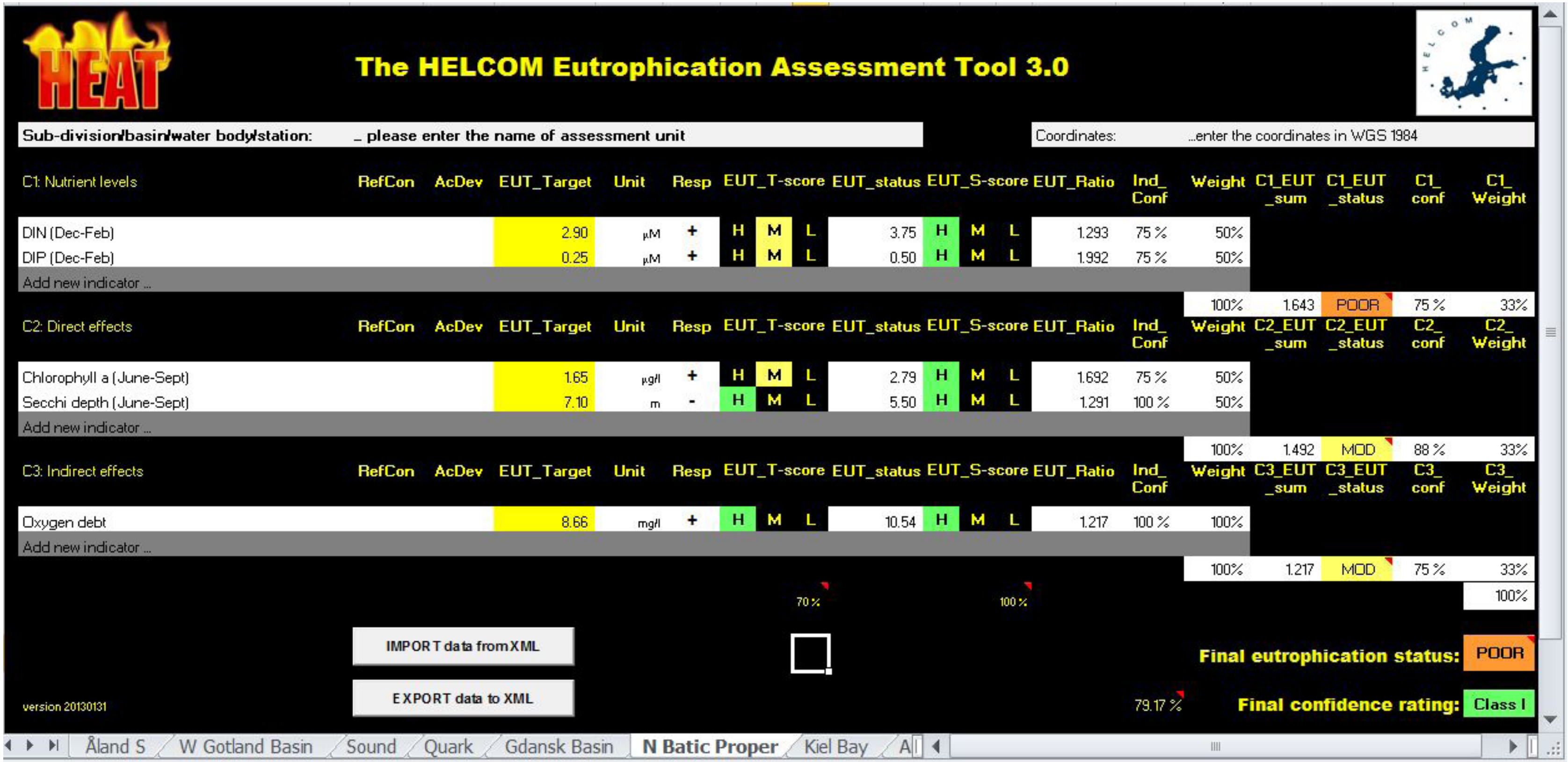


Figure 2. HEAT 3.0 tool runs on MS Excel and displays the core indicators under three criteria and their targets (EUT_Target), status (EUT_status) and the resulting Eutrophication Ratio (EUT_Ratio) which yields the criterion status (C1-C3_EUT_status) and Final eutrophication status. In addition, Confidence 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. For the purpose of this assessment, only a two-step classification showing either GES (high eutrophication status) or sub-GES (moderate or low eutrophication status) was utilized.

For each criterion (i.e. nutrient levels, direct effects and indirect effects) the status was determined as the weighted average of the Eutrophication Ratios (ER) of the individual indicators (e.g. ER for C1, nutrient levels, is given by average of DIP-ER and DIN-ER). The status for the criterion was then assessed as GES where ER≤1 and sub-GES where ER>1.

In the final step, the one-out-all-out principle was used between the criteria status classifications to determine the overall eutrophication status for each basin; i.e. the worst of the three results on criterion level determined the final status classification.

2.4 Comparability of the current assessment with the 2003-2007 assessment of open sub-basins

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 direct one-to-one comparison between the two assessments is not possible. Yet, according to evaluation described below, the overall eutrophication status classification in the present and previous assessments is comparable. Methodological aspects of the present as well as earlier assessments are summarized in **Table 6**.

Table 6. Comparison of the present eutrophication status assessment and previous HELCOM assessments.

Assessment	Time period from which data were used	HEAT version used	Baltic Sea divided into geographical units (number of units)	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 website (www.helcom.fi), updated 12 May 2010
Updated Baltic Sea open sea area assessment	2007-2011	HEAT 3.0	17 sub-basins (only open sea areas 1 NM seaward from the baseline) and coastal water assessments based on national WFD classifications	Present assessment

Comparison of indicators and targets

In the previous assessments on eutrophication status, 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 sub-basins where depths exceeded the limits for vegetation. 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 (NO2+NO3+NH4), winter DIP, summer/annual TN or summer/annual TP.

In the current assessment, the indicators were grouped in a new way into Criteria (as in the EU Commission Decision 477/2010, see Chapter 3.1 'Indicators and targets'), indicating the main cause-effect relationships in the eutrophication process (Cloern 2001). In the present assessment, only Criterion 2, 'Indirect effects', consists of a single indicator - oxygen debt. The possibility of a single indicator being able to dominate the overall eutrophication status increases along with decreasing number of indicators per criterion. The likelihood of this happening in the current assessment, where only one criterion is expressed through a single indicator, is smaller than in the previous one.

Due to scarcity of monitoring data and lack of progress in target revision, the benthic fauna indicator was not applied in the present assessment of open sea areas, whereas in the previous assessment it was present in 9 out of 13 open

sea 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 determine the overall eutrophication status in the Bornholm Basin, Western Gotland Basin, Eastern Gotland Basin, Northern Baltic Proper and Gulf of Finland, had it been the indicator showing worst status in the assessment unit.

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, when a change greater than +/-15% of the target was considered to be substantial (with the +/-15% change having been chosen arbitrarily) (**Table 7**). A greater number of targets changed towards a more ambitious level, i.e. to a stricter target. The targets that changed considerably (>+/-15%) were considered to have had an additional effect on the indicator status, i.e. the Eutrophication Ratio of an indicator may have changed even in cases where the monitored level (i.e. average concentration, Secchi depth or oxygen debt) in 2007-2011 remained the same as during the previous assessment period.

Table 7. 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 a change of ≥15% was considered to be substantial. ↗ = 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	Chl *a*	Secchi
Kattegat		↗	↘	↘
The Sound	↗			
Great Belt	↘	↘	↘	
Kiel Bay	↗	↘		
Bay of Mecklenburg	↘	↘		
Gdansk Basin	↗		↘	
Arkona Basin				↗
Bornholm Basin	↗	↗		
Eastern Gotland Basin			↘	↗
Western Gotland Basin	↗		↗	↗
Northern Baltic Proper		↗		
Gulf of Riga	↗			↗
Gulf of Finland		↗		
Åland Sea		↗		
Bothnian Sea		↗		
The Quark		↘		
Bothnian Bay		↗		

A crude evaluation of the impact of methodological changes in assessment and targets (grouping indicators into Criteria, excluding zoobenthic indicators, including oxygen debt indicator and updating targets) on the assessment revealed that the changes did not affect the final eutrophication classification, e.g. the final classification (GES or sub-GES / Good or Moderate) remained unchanged regardless of change in methodology. No change in distance to GES (Good/Moderate) boundary within the two classes could be observed, as would have been the case had intermediate class boundaries been used (e.g. the five-class classification used in the 2003-2007 assessments).

Comparison of data processing

In the present assessment, data for all seasons were used for the DIN, DIP and oxygen debt indicators to produce the seasonal estimates (December-February for nutrients, annual for oxygen debt, as defined for the indicators), using a combined spatial and seasonal model, "the TARGREV model" for extracting the seasonal data (see section on "Data aggregation" in Chapter 3.2) (HELCOM 2013b, 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 assessments, 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.

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), in the HELCOM Initial Holistic Assessment (HELCOM 2010a) and in the demonstration set of core eutrophication indicators (HELCOM 2010b). A second version (HEAT 2.0) has been developed but never used in the HELCOM context.

As described above, HEAT 1.0 differs from HEAT 3.0 in the way indicators are grouped (**Figure 3**). In HEAT 1.0, four ecological quality elements were used to group the indicators. These ecological quality elements corresponded with WFD requirements and consisted of plankton (phytoplankton and chlorophyll *a*), submerged aquatic vegetation, benthic invertebrates and physico-chemical features.

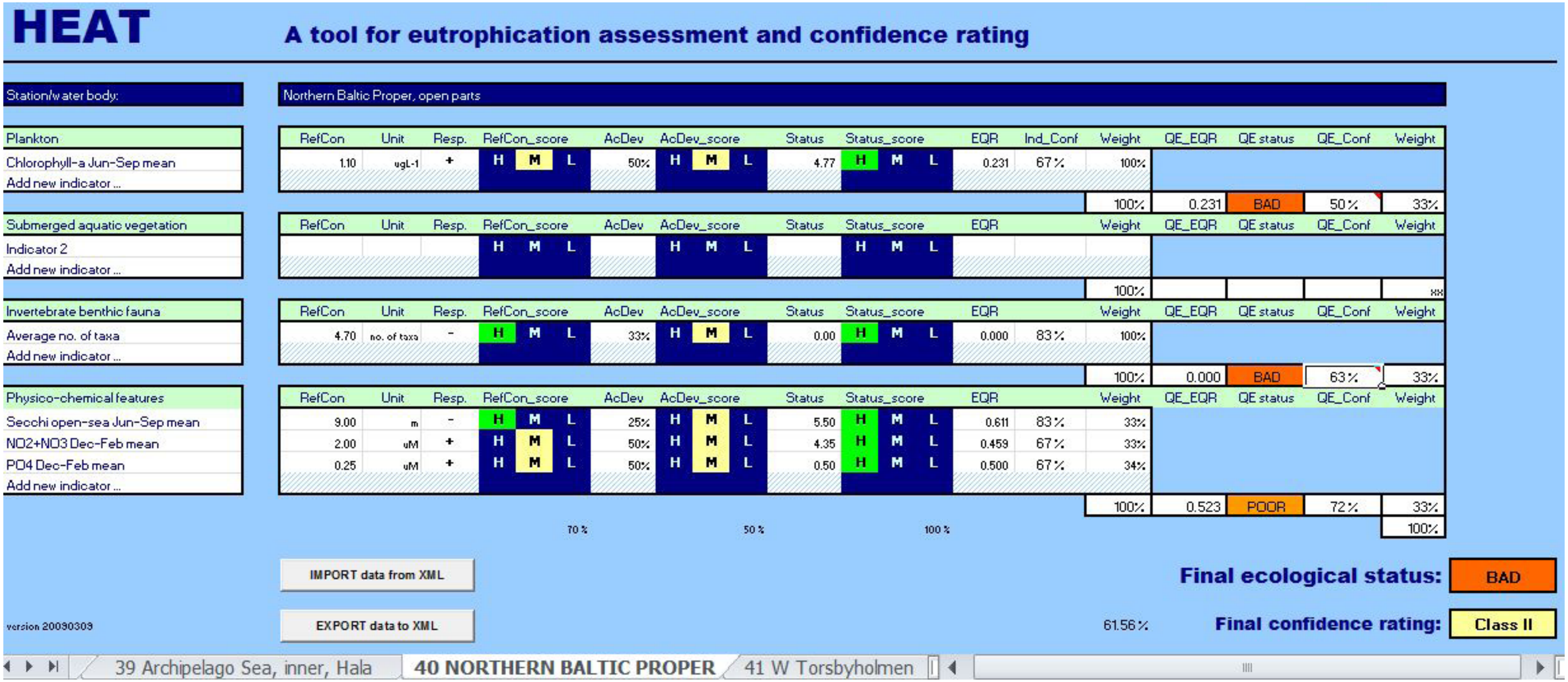


Figure 3. Snapshot of the HEAT 1.0 tool displaying the grouping of indicators under four quality elements, and the application of Reference Conditions (RefCon) and Acceptable Deviations (AcDev) for determining quality element status (QE_status).

The assessment principle of HEAT 1.0 was based on reference values (RefCon) and acceptable deviation (AcDev) which, when combined, produced preliminary targets. At the time of applying HEAT 3.0, HELCOM had strengthened the scientific background of target setting (HELCOM 2013b) 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 through the RefCon and AcDev (Andersen et al 2011). In most Baltic sub-regions, the acceptable deviation was set arbitrarily at 50 % (25 % for Secchi depth). For the overall assessment of a sub-basin or coastal assessment unit, 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. 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 *a* 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.

Comparison of assessment units

The division of the Baltic Sea into open sea sub-basins remained basically the same, except that in the current assessment slight adjustments have been made in the southern boundary of the Quark and the northern boundary of the Gulf of Riga have slightly changed. Some areas assessment units considered coastal areas previously have been assessed as open sea basins in the present assessment (e.g. the 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.

For the previous assessment, the Baltic Sea was divided into 189 assessment units consisting of 17 open sea sub-basins and 172 coastal assessment sites. The current assessment was based on 17 open sea sub-basins agreed targets, and status of coastal waters is based on WFD classification status, where such information had been made available by HELCOM Contracting Parties that are also EU Member States.

3 Eutrophication status 2007-2011

3.1 Main results

The entire open Baltic Sea was assessed as being affected by eutrophication (**Figure 4**). The following coastal areas were assessed by national authorities as being in good ecological status according to WFD requirements (EC 2000): Orther Bucht (Germany), outer coastal Quark (Finland) and outer coastal Bothnian Bay, outer coastal Bothnian Sea, inner and outer coastal Quark (Sweden).

This result indicates that despite measures taken to reduce external inputs of nitrogen and phosphorus to the sea, good status for eutrophication was reached yet.

For the open sea areas, the only differences between this core indicator-based assessment and the previous assessment carried out for the years 2001-2006 (HELCOM 2009) were the status of the open Bothnian Bay and the Swedish waters in the north-eastern Kattegat, which both had good status in 2001-2006, and were in the present assessment classified as affected by eutrophication. When comparing the two assessments, the changes in sub-basin division for the Kattegat must be taken into account, since they may have affected the result.

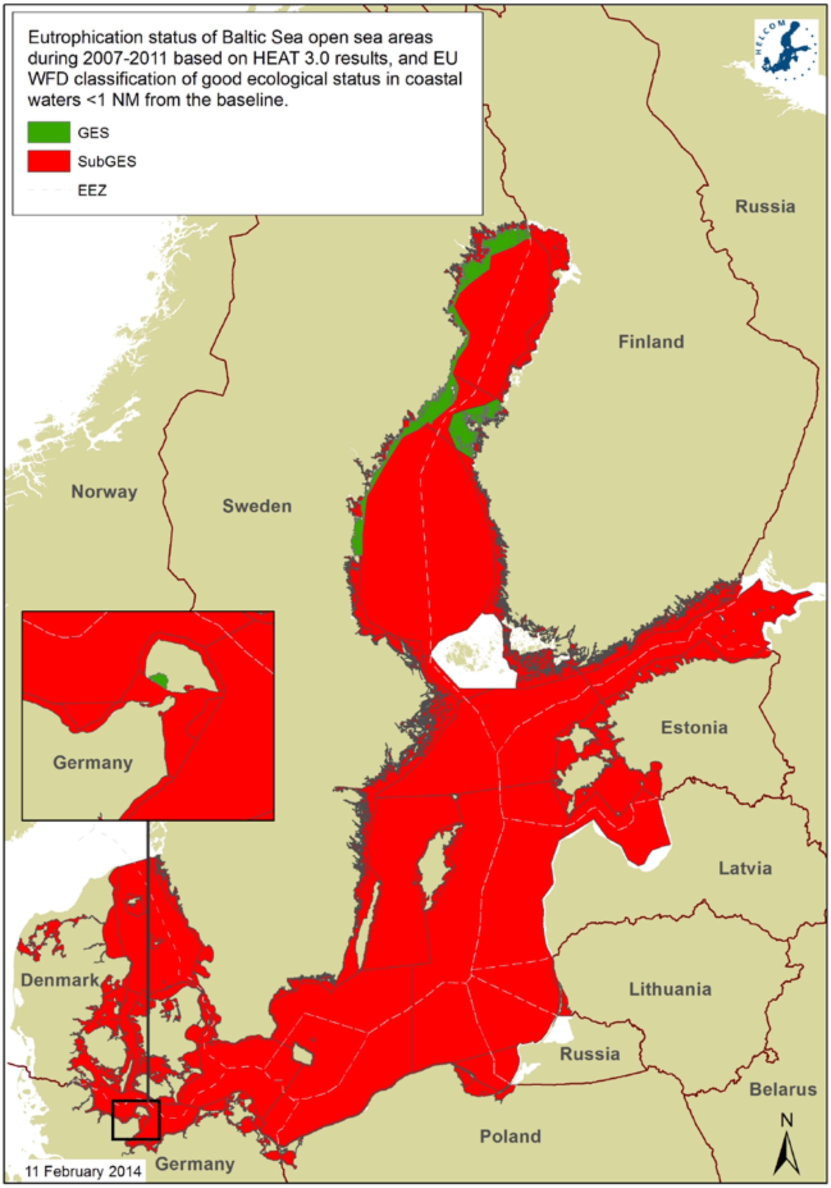


Figure 4. Eutrophication status in 2007-2011 was assessed as affected by eutrophication (red colour, status less than good; sub-GES) in all the open Baltic Sea sub-basins.

3.2 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 5**).

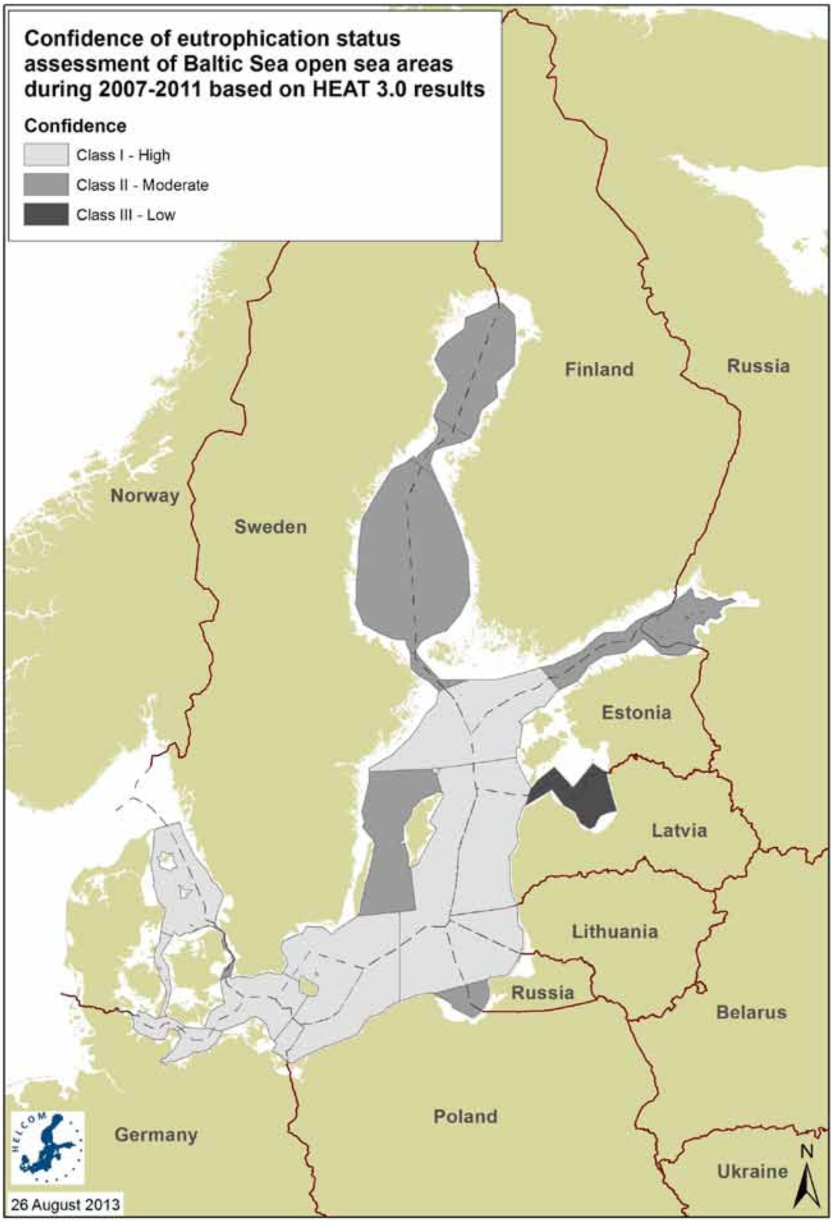


Figure 5. Confidence of the eutrophication assessment was High (Class I – light grey) in most of the Baltic Sea main basins and southern as well as western areas and Low (Class III – Black) in the Gulf of Riga.[1]

1 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.

The confidence of the assessment was highest in the Baltic Proper and the southern and western parts of the Baltic Sea. The Gulf of Finland, Åland Sea, Bothnian Sea, Quark and Bothnian Bay received a moderate confidence classification, particularly due to a lack of data on chlorophyll *a* and Secchi depth (**Table 5**). The Gdansk Basin and Western Gotland Basin also received a moderate confidence classification. The assessment confidence was lowest in the Gulf of Riga.

3.3 Indicator status in 2007-2011 by open sea sub-basin

The status of each core indicator varied from year to year. An average was used to calculate 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 6 to 10**).

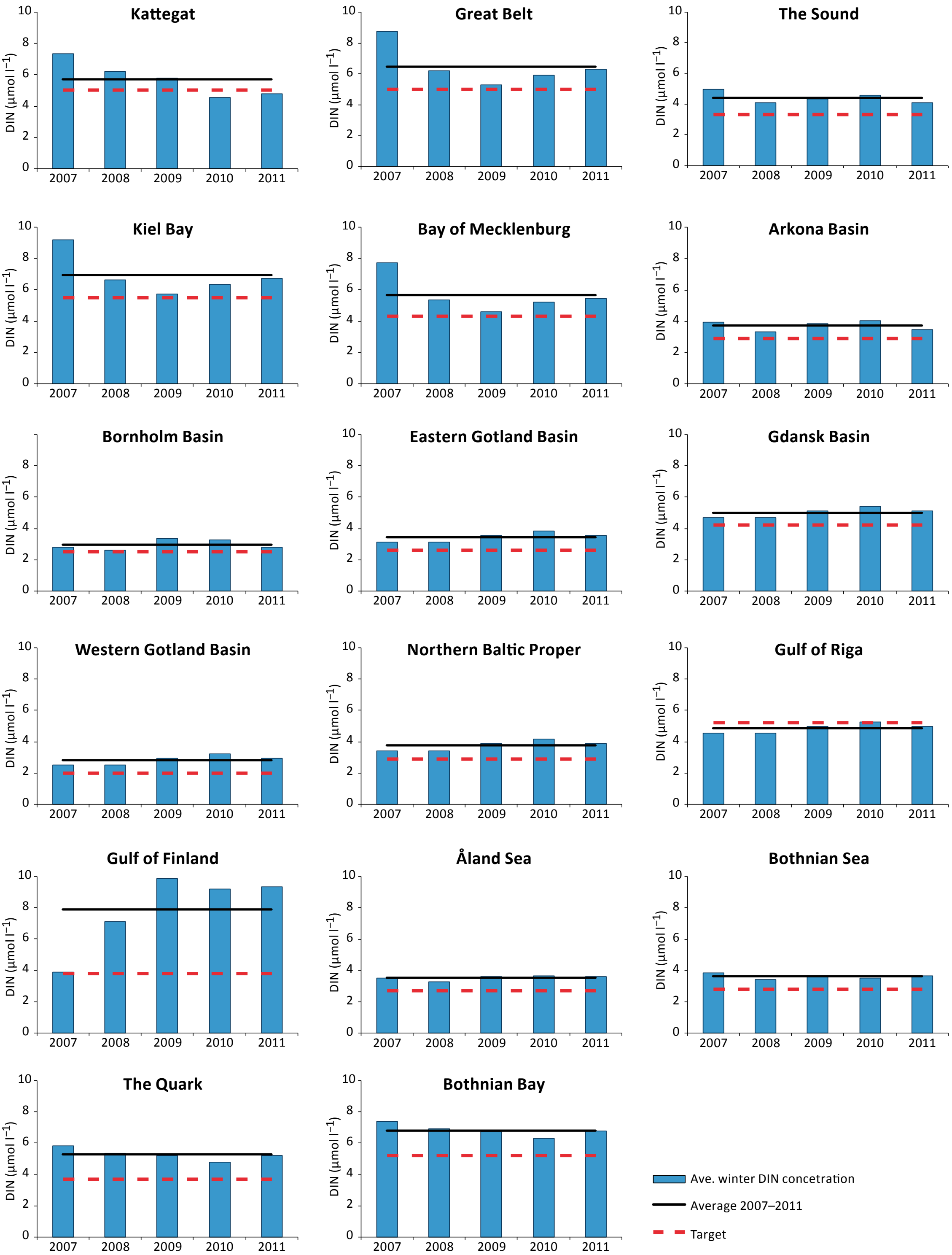


Figure 6. Winter (December-February) DIN concentration yearly average (blue columns), average for 2007-2011 (black line) and target levels as agreed by HELCOM HOD 39/2012 (red broken line).The averages were aggregated using a combined spatial and seasonal model (as applied in the TARGREV project, HELCOM 2013b), and standard deviations could not be provided. The target was attained only in the Gulf of Riga, and there was positive development (in the form of status being above GES during the last two assessment years) in the Kattegat.

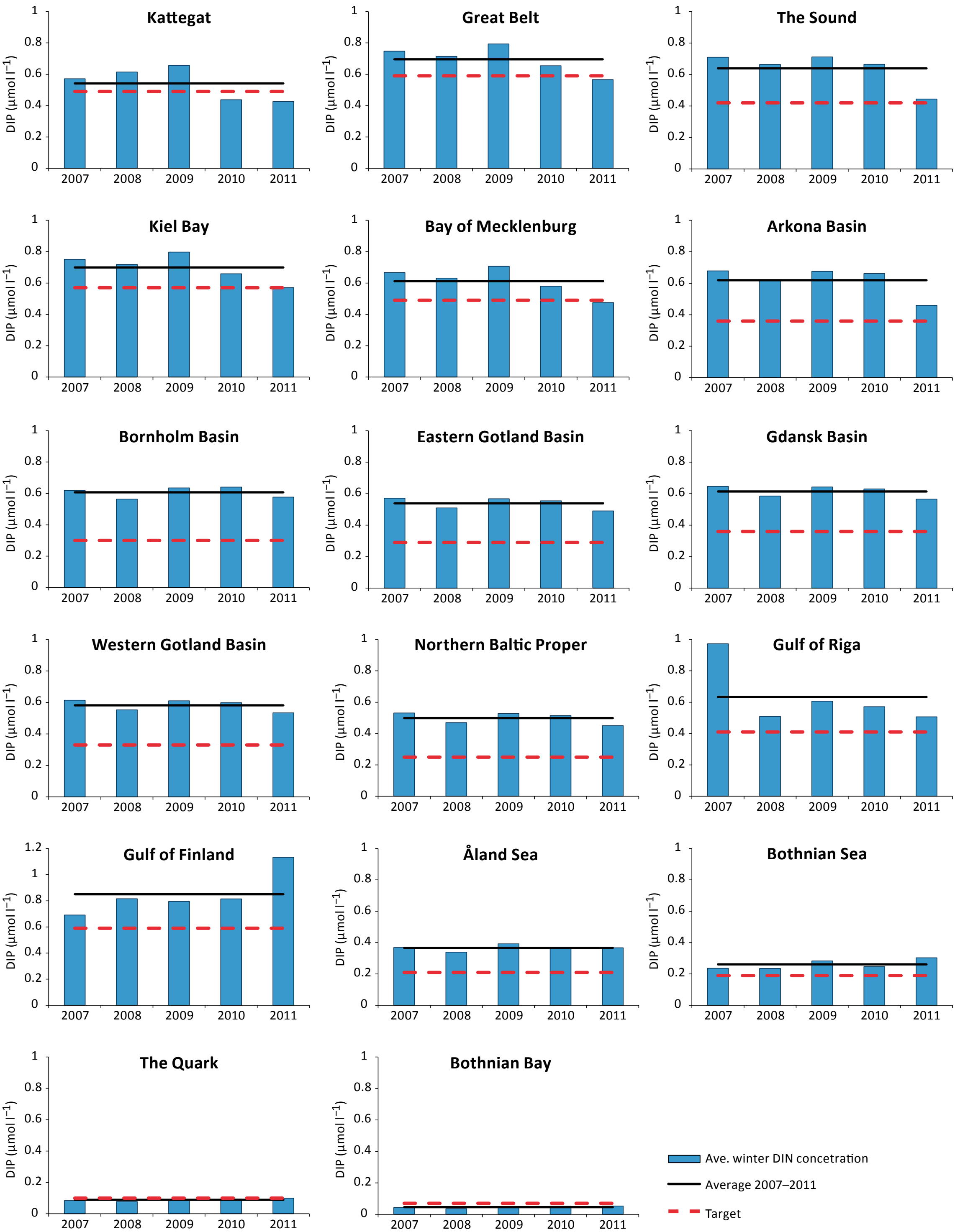


Figure 7. Winter (December-February) DIP concentrations yearly average (blue columns), average for 2007-2011 (black line) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The averages were aggregated using a combined spatial and seasonal model (as applied in the TARGREV project, HELCOM 2013b), and standard deviations could not be provided. The targets were attained in the Quark and the Bothnian Bay, and there was positive development (in the form of status being above GES during the last assessment year) in the Kattegat, Great Belt, Kiel Bay and the Bay of Mecklenburg. Note the different scale in the graph for the Gulf of Finland.

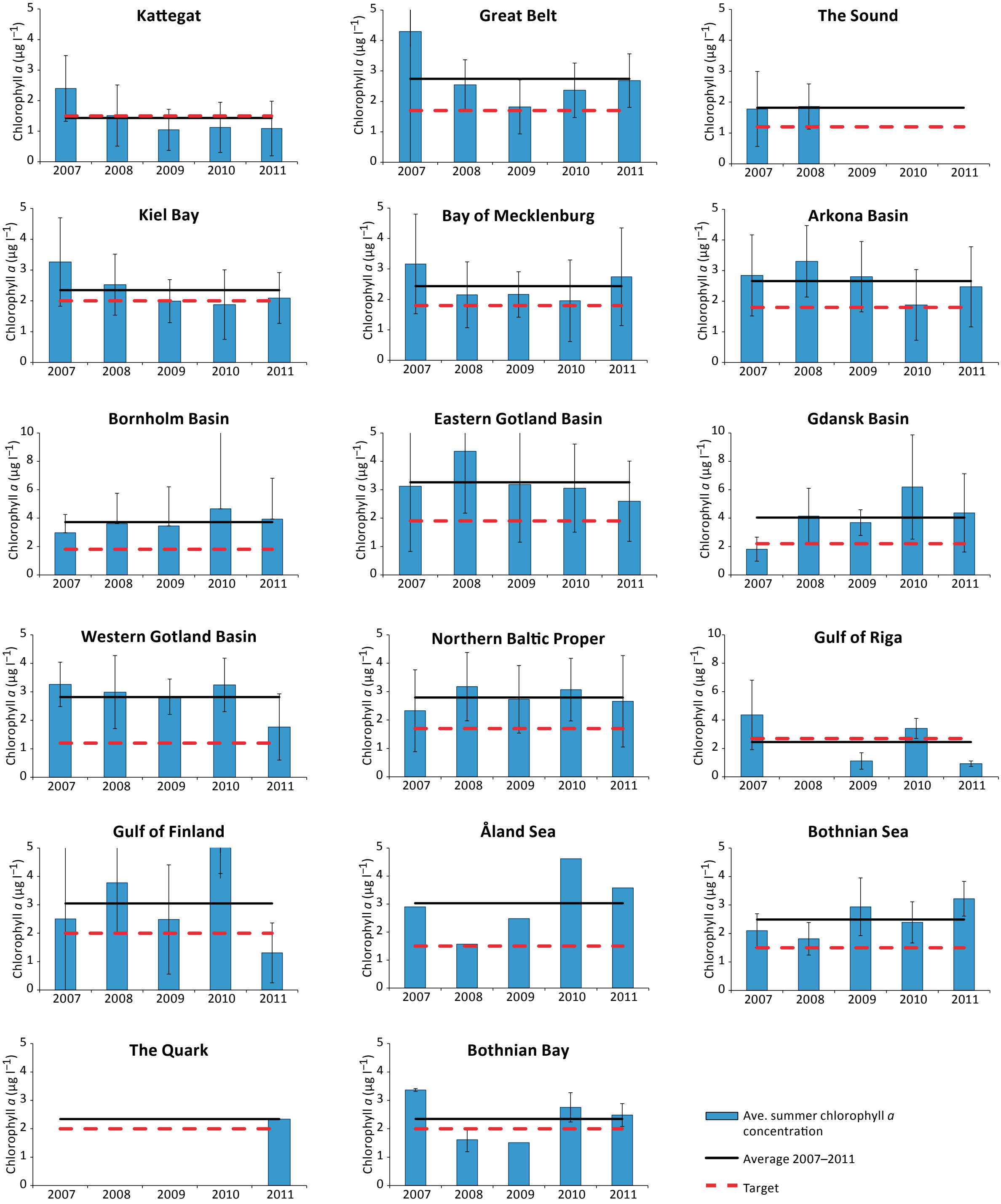


Figure 8. Summer (June-September) chlorophyll a concentrations yearly average (blue columns), average for 2007-2011(black line) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The targets were attained in the Kattegat and Gulf of Riga. Standard Deviations are also shown for each bar whenever available. No data were available for empty spaces. Note the different scales in the graphs for Bornholm Basin, Gdansk Basin and Gulf of Riga.

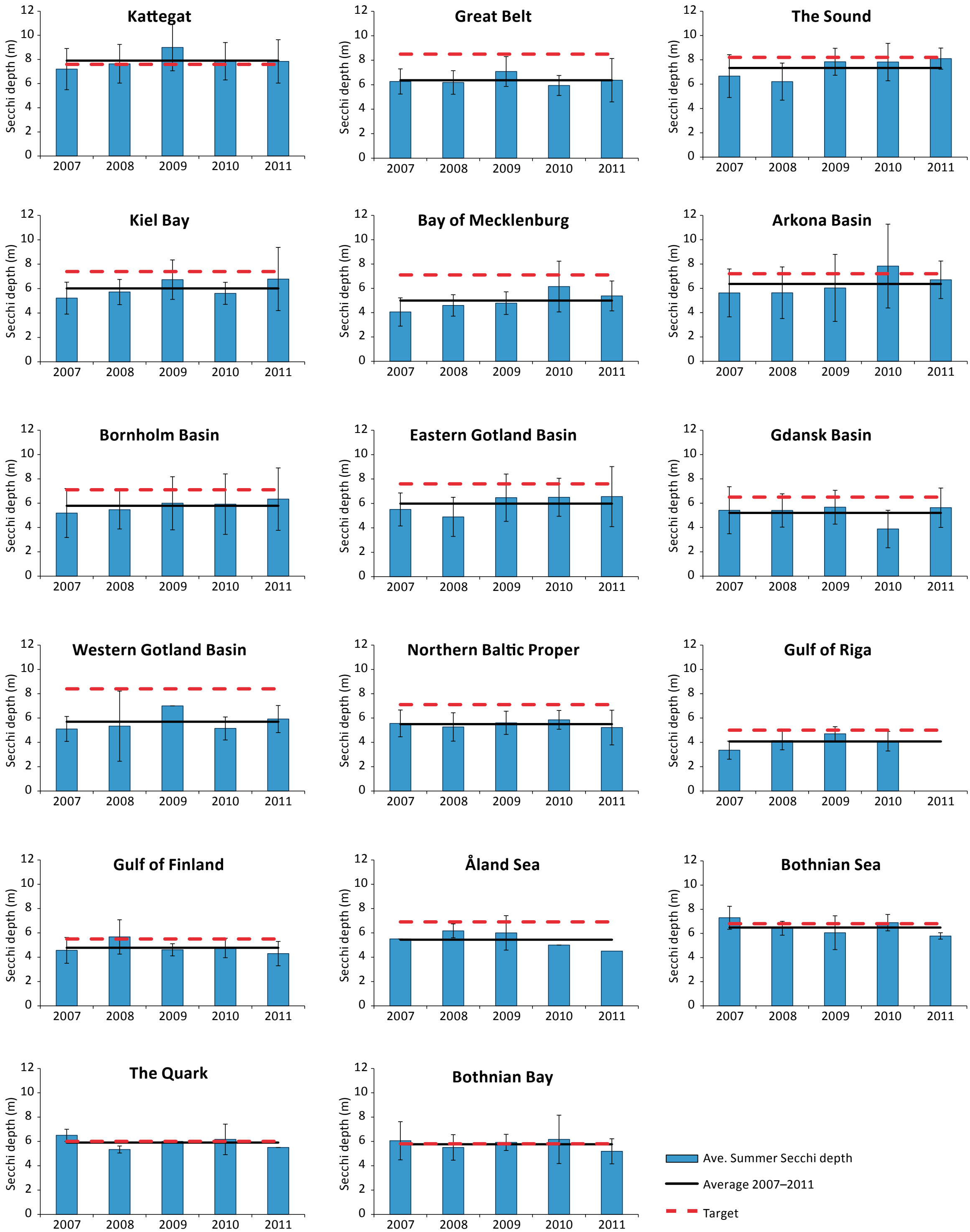


Figure 9. Summer (June-September) Secchi depth yearly average (blue columns), average for years 2007-2011 (black line) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The targets were attained in the Kattegat and Bothnian Bay. Standard Deviations are also shown for each bar when available.

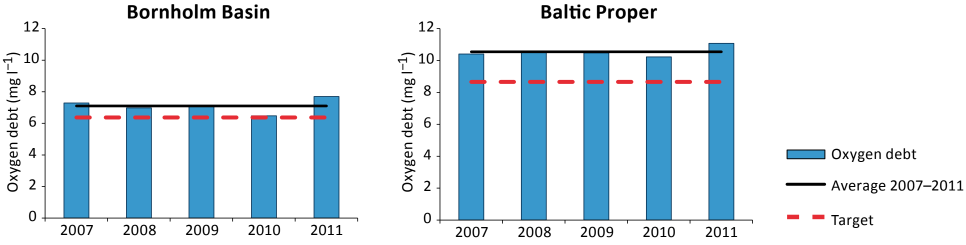
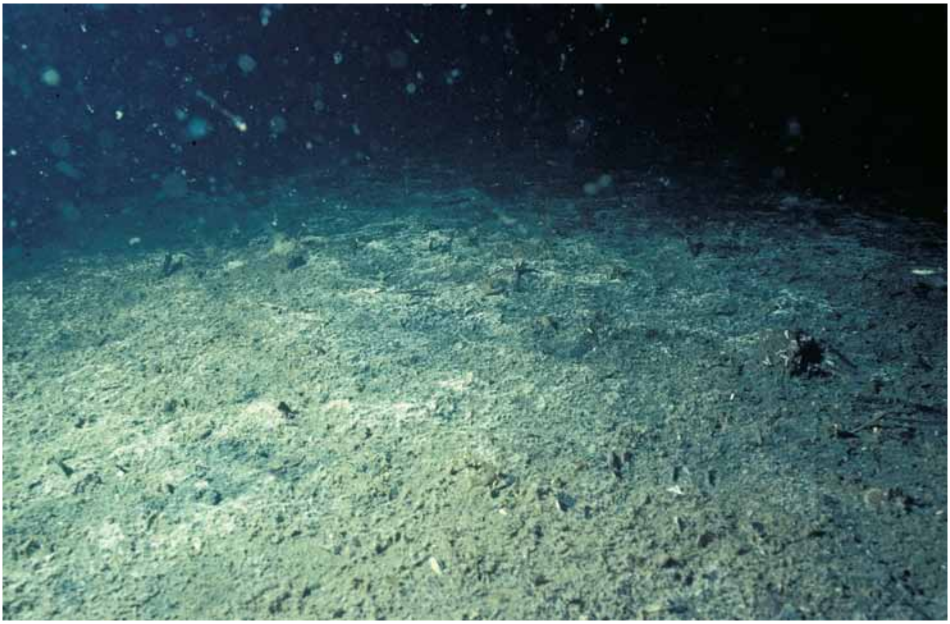


Figure 10. Oxygen debt yearly average (blue columns), average for 2007-2011 (black line) and target levels as agreed by HELCOM HOD 39/2012 (red broken line). The averages were aggregated using a combined spatial and seasonal model (as applied in the TARGREV project, HELCOM 2013b), and standard deviations could not be provided. Oxygen debt targets were not reached in either of the assessed sub-basins. Please note that for oxygen debt, the Baltic Proper consists of the following sub-basins: Northern Baltic Proper, Western Gotland Basin, Eastern Gotland Basin and Gulf of Finland and the data from all these sub-basins were combined (cf. HELCOM 2013b). This result for the Baltic Proper was also included in the HEAT 3.0 integration of core indicators of each of these sub-basins.



4 Discussion and conclusions

Despite measures taken to reduce external inputs of nitrogen and phosphorus to the sea, the entire open Baltic Sea is still affected by eutrophication. According to the present integrated assessment on eutrophication, based on data covering the period 2007-2011, the entire open Baltic Sea was eutrophied during the period 2007-2011. The following coastal areas were assessed by national authorities as being in good ecological status according to WFD criteria (EU 2000): Orther Bucht (Germany), outer coastal Quark (Finland) and outer coastal Bothnian Bay, outer coastal Bothnian Sea, inner and outer coastal Quark (Sweden).

4.1 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, although changes in individual sub-basins may be greater (HELCOM 2013a). Currently, the level of nutrient inputs equals that in the early 1960s (Gustafsson et al. 2012).

Despite the reductions in inputs, the concentrations of nutrients have not declined accordingly. Since the assessment period 2003-2007 (HELCOM 2010b), signs of declining nutrient levels have been observed in the Kattegat (DIN and DIP) Bornholm Basin (DIP), Eastern Gotland Basin (DIP), Northern Baltic Proper (DIN), Gulf of Riga (DIN and DIP). Despite this, chlorophyll *a* trends still show no signs of decline or have increased in recent years (Bornholm Basin, Northern Baltic Proper, Bothnian Sea and Bothnian Bay, HELCOM 2010b). On the other hand, increasing nutrient levels have been observed in the Western Gotland Basin (DIP), Eastern Gotland Basin (DIN), Gulf of Finland (DIN) and Bothnian Sea (DIP). The long residence time of water in the open Baltic Sea as well as feedback mechanisms such as release of phosphorus from anoxic 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, 2013b, Vahtera et al. 2007).

Model predictions of recovery of the Baltic Sea show that once the BSAP nutrient reduction targets (HELCOM 2007[1]) are met, this will have a positive effect on the status of the Baltic Sea ecosystem and that nutrient concentration levels will decline during the following decades. Nevertheless, it will take a long time to reach the target levels of eutrophication status. It is therefore urgent that nutrient reduction measures are implemented without further delay (**Figure 11**).

1 Revised maximum allowable nutrient inputs and country-wise allocation of nutrient reduction targets were adopted by the 2013 HELCOM Copenhagen Ministerial Declaration (HELCOM 2013e)

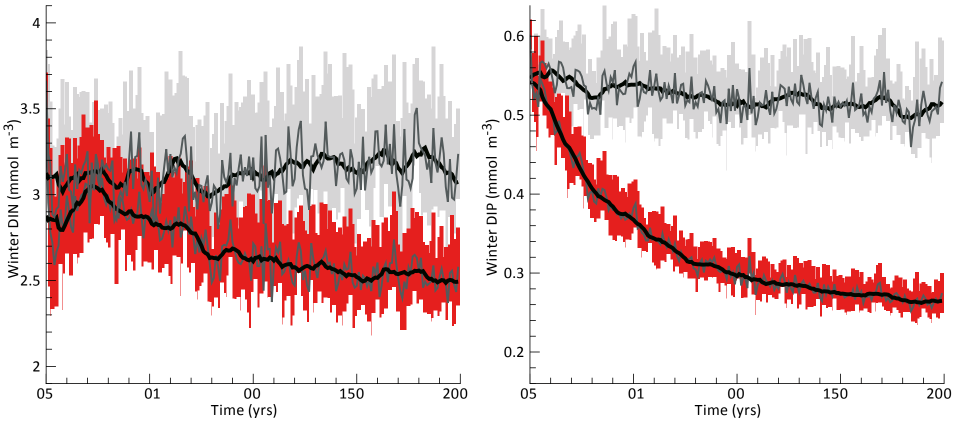


Figure 11. If nutrient inputs are reduced to agreed maximum allowable nutrient input levels by year 0, there will be a rapid initial decline of DIP (winter dissolved inorganic phosphorus) and a slightly more delayed initial decline in DIN (winter dissolved inorganic nitrogen) concentrations as indicated 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 lines represent the eutrophication targets for DIN and DIP (Gustafsson et al, in prep).

Reversal of coastal and marine eutrophication is a phenomenon that has been the subject of very few studies. A recent analysis of monitoring data from 28 locations around the world showed that nowadays a unit of nitrogen in coastal waters produces almost twice the quantity of algal biomass measured as chlorophyll *a* concentration than it did 30-40 years ago (Carstensen et al. 2011). The study suggests that this change could be the result of major shifts 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. Certainly primary production levels in the main basins have not returned to previous levels even though phosphorus inputs have decreased to the levels of the 1950s or 1960s (**Figure 12** 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 long time-scales of biogeochemical cycles and because the ecosystem structure and functions have changed (Gustafsson et al. 2012, HELCOM 2013c). 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.

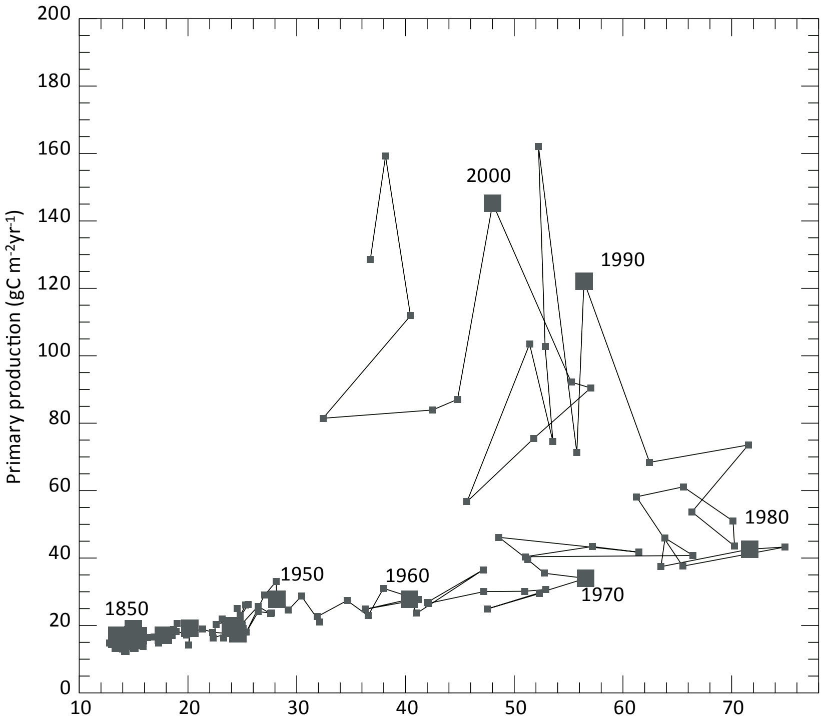


Figure 12. Primary production has not decreased in recent years even though phosphorus load has decreased to a level of the 1950s or 1960s in the Baltic Proper (based on Gustafsson et al. 2012). However, future scenarios also show that primary production will decrease substantially when the BSAP nutrient input reduction targets have been reached.

In the Baltic Sea, water temperature 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 than present (HELCOM 2013c).

At present, it is not clear how climate change will influence productivity and subsequent eutrophication signals in the Baltic Sea and it is likely that impacts will vary in different sub-basins (HELCOM 2013c). 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 (HELCOM 2013c) indicate that runoff is related to temperature and that the expected warming will be associated with reduced runoff in southern parts of the Baltic Sea catchment area and greater 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).

4.2 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 quality assurance (QA) and quality checking (QC) guidance of the entire eutrophication assessment process from monitoring to final 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.

Operationalization of the assessment process

There is a need to make the regional assessment of eutrophication for the Baltic Sea operational, including defining and streamlining the entire process 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 (Eutrophication). The HELCOM Map and Data service should also 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 further define the methodology used in the HEAT assessment tool. A user-friendly handbook, describing the functionality 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 also be contained in the handbook.

Definition of class boundaries needs further work. If more than two classes (GES and sub-GES) are of interest, they should be commonly agreed upon. It should be investigated 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. If a cause-effect-relationship can be established between Eutrophication Ratio and indicator/criterion then boundaries do not need to be set equidistantly 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 is desirable that all Contracting Parties commit themselves to the further refinement of the assessment tools and methods as well as data delivery.

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Annex 1

The 17 open sub-basins used in the present assessment were adopted by the HELCOM Copenhagen Ministerial meeting, along with the HELCOM Monitoring and Assessment Strategy (HELCOM 2013d)[2]. The open sub-basins are indicated as a white area, separated from each other by a black line. The coastal zone is indicated as a blue area. Little Belt, which is not included in the present assessment, is also indicated.

2 In some cases, the HELCOM sub-basin division is not fully consistent with national assessment units (e.g. for he Kattegat and in the Western Baltic Proper.

Annex 2

Secchi depth and chlorophyll *a* have been weighing for the HEAT 3.0 assessment was done 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 chl *a*	CDOM light absorption / chlorophyll *a* (chl *a*)
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)
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. *in prep.*), medium in relation to chl *a*
Bornholm Sea	50 %	50 %	Low CDOM absorption (Ylöstalo et al. *in prep.*), medium in relation to chl *a*
Eastern Gotland Basin	50 %	50 %	Assumed similar as in the Northern Baltic Proper
Western Gotland Basin	50 %	50 %	Low CDOM absorption (Ylöstalo et al. *in prep.*), medium in relation to chl *a*
Gdansk Basin	50 %	50 %	No info
Northern Baltic Proper	50 %	50 %	Medium CDOM absorption (Ylöstalo et al. *in prep.*), medium in relation to chl *a*
Gulf of Finland	40 %	60 %	High CDOM absorption (Ylöstalo et al. in prep.), medium in relation to chl *a*
Gulf of Riga	30 %	70 %	Extremely high CDOM absorption (Ylöstalo et al. *in prep.*), high in relation to chl *a*.
Åland Sea	50 %	50 %	Interpolated between Bothnian Sea and Northern Baltic Proper
Bothnian Sea	40 %	60 %	Medium CDOM absorption (Ylöstalo et al. *in prep.*), medium-high in relation to chl *a*
Quark	30 %	70 %	Interpolated between Bothnian Bay and Bothnian Sea
Bothnian Bay	20 %	80 %	High CDOM absorption (Ylöstalo et al. *in prep.*), extremely high in relation to chl *a*

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