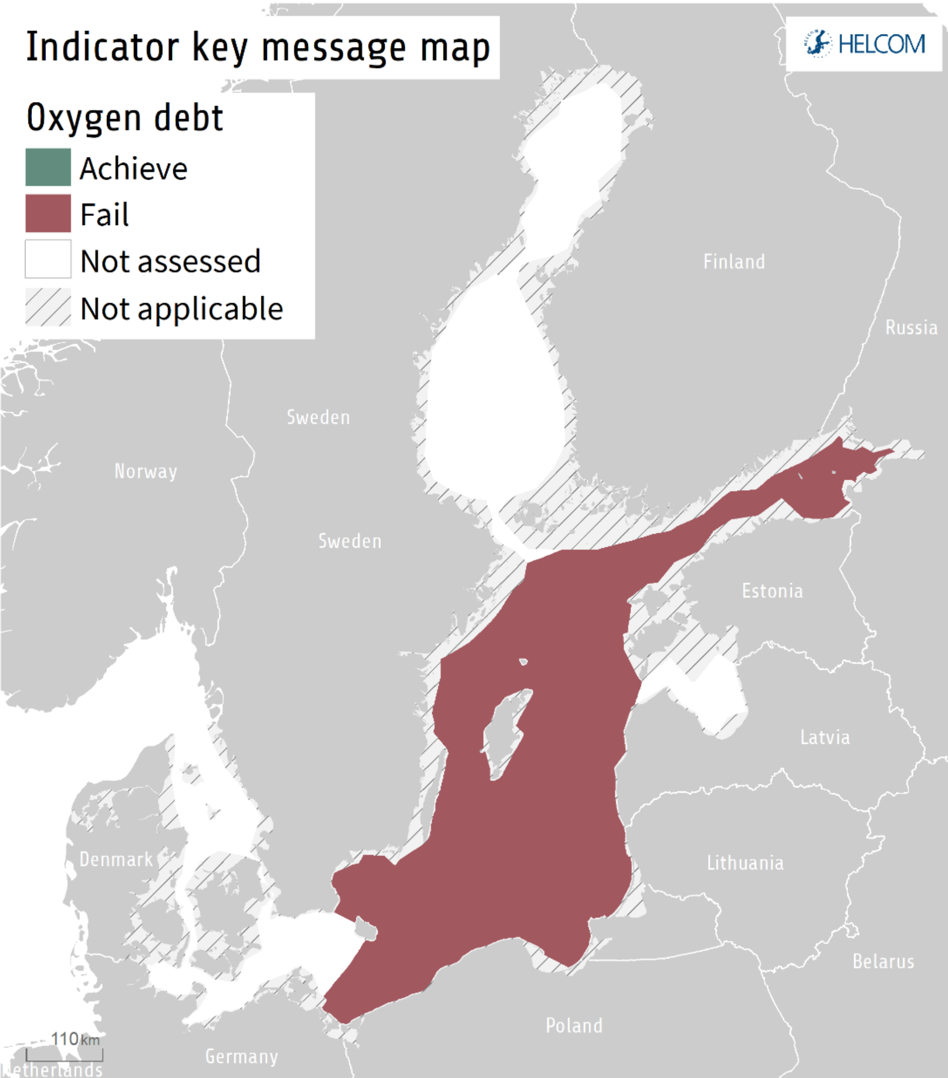
HELCOM core indicator report
July 2018

Oxygen debt

Key Message

This core indicator evaluates average oxygen debt below the halocline that separates deep water from the surface water. Oxygen debt is applied in the Bornholm Basin, Gdansk basin, Western Gotland Basin, Eastern Gotland Basin, Northern Baltic Proper and Gulf of Finland. Oxygen debt values below the threshold value have not been achieved in any of these sub-basins.

Oxygen debt below the halocline has increased in all basins since the early 1900's.



Key message figure 1: Status assessment results based on evaluation of the indicator 'Oxygen debt'. The assessment is carried out using open sea areas of Scale 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4). See Results section below for details. **Click here to access interactive maps at the HELCOM Map and Data Service: Oxygen debt**.

The confidence of the presented oxygen debt status estimate is **high** in all the sub-basins where the indicator was applied.

Relevance of the core indicator

Organic matter deposition to bottom waters increases along with increasing eutrophication. This leads to increasing oxygen consumption and a subsequent decrease in bottom oxygen concentration.

Policy relevance of the core indicator

	BSAP Segment and Objectives	MSFD Descriptors and Criteria
Primary link	A Baltic Sea unaffected by eutrophication	D5 Human-induced eutrophication - D5C5 The concentration of dissolved oxygen is not reduced, due to nutrient enrichment, to levels that indicate adverse effects on benthic habitats (including on associated biota and mobile species) or other eutrophication effects.
Secondary link		
Other relevant legislation: EU Water Framework Directive		

Cite this indicator

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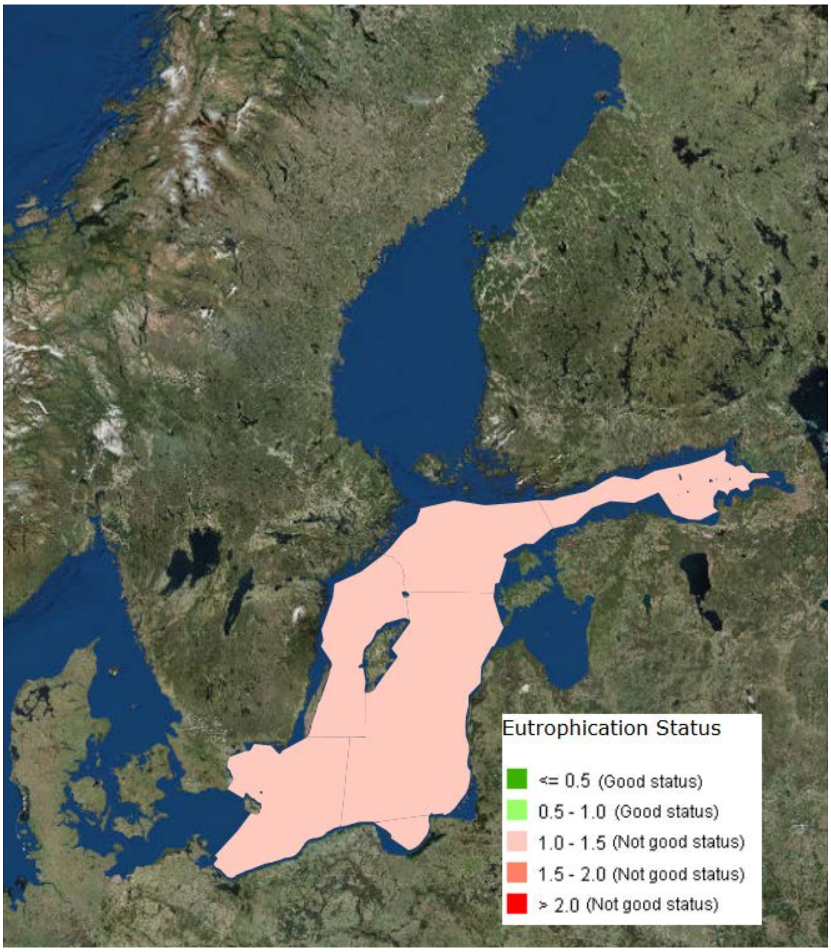
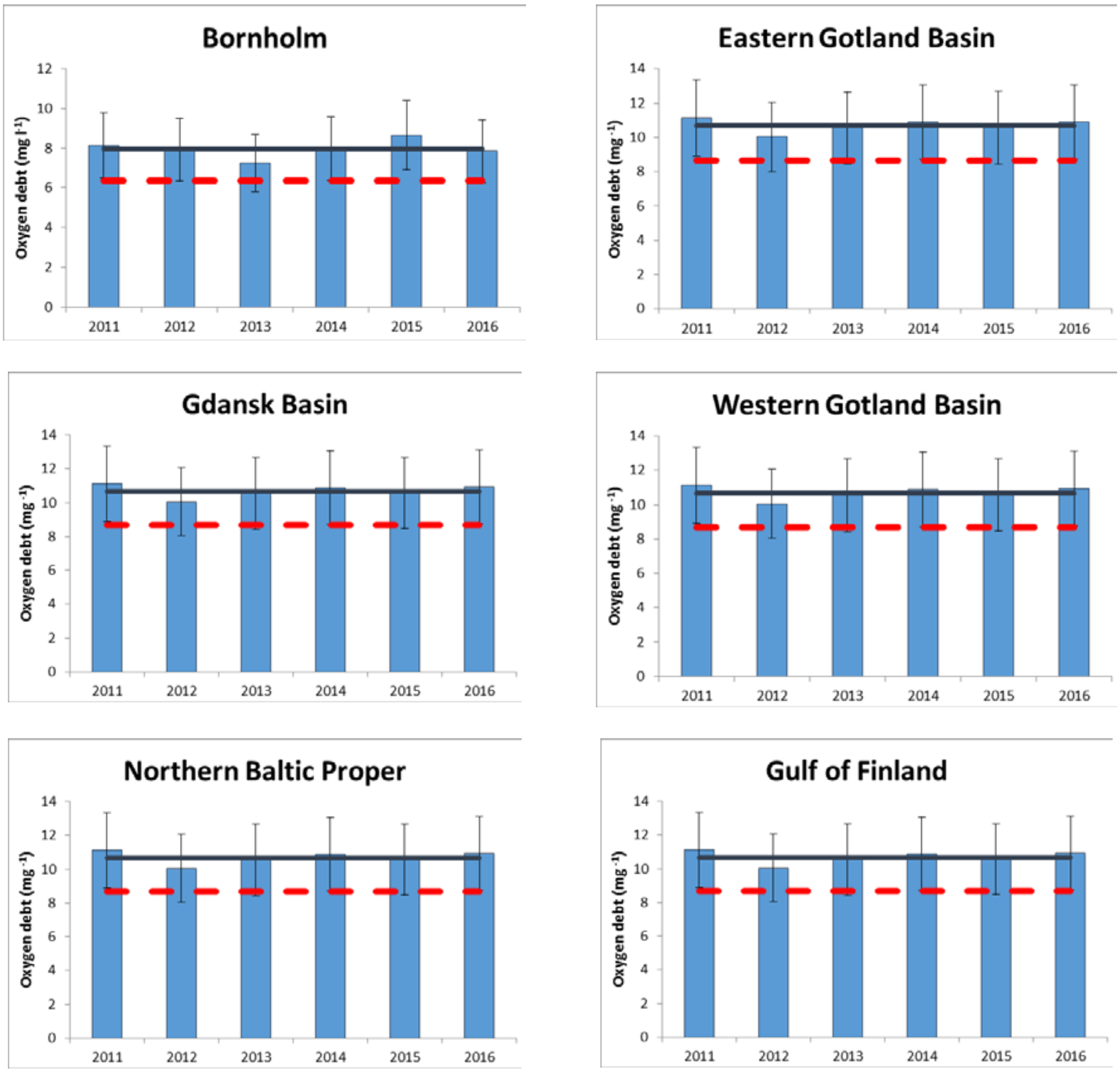
Results and Confidence

The core indicator 'Oxygen debt' is applied in the Bornholm Basin, Gdansk Basin, Western Gotland Basin, Eastern Gotland Basin, Northern Baltic Proper and Gulf of Finland. Values below the threshold values have not been achieved in any of these sub-basins, indicating not good status in all areas where an indicator evaluation has been made (Result figure 1 and Results table 1) and levels have remained relatively constant during the current assessment period (Results figure 2). Oxygen debt is largest in the Baltic Proper, corresponding to hypoxic conditions starting just below the halocline. An oxygen debt threshold value exist for the Åland Sea, Bothnian Sea and Bothnian Bay, but currently the oxygen debt algorithm has not been adjusted and optimized to provide reliable indicator results for those assessment units.



Result and confidence figure 1. Status of the 'Oxygen debt' indicator below the halocline, presented as eutrophication ratio (ER). ER shows the present concentration in relation to the threshold value, increasing along with increasing eutrophication. Good status is achieved when ER ≤ 1.00.



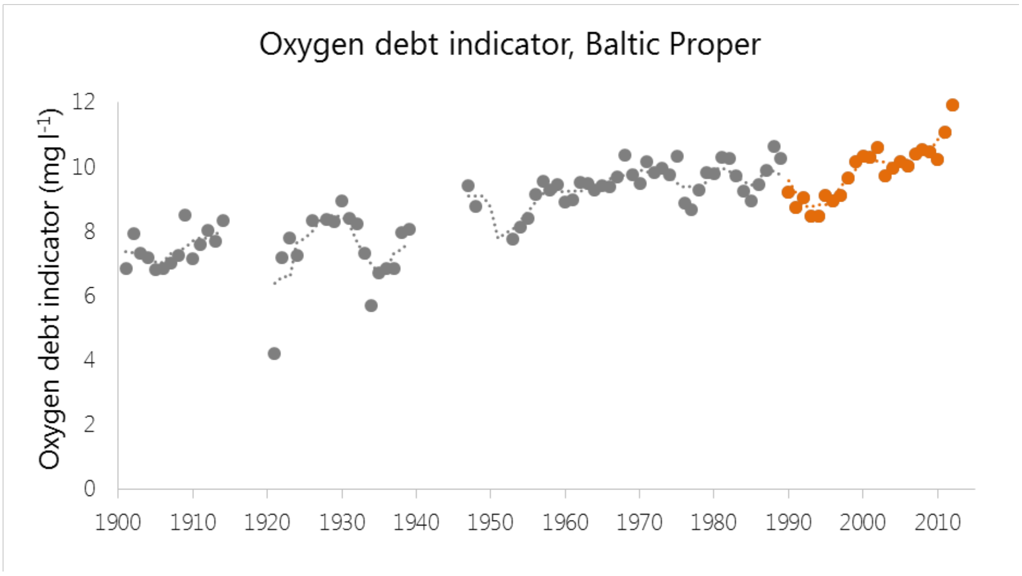
Results figure 2. Average oxygen debt below the halocline (black line; average for years 2011-2016) and threshold values.

Results table 1. Threshold values, present concentration (as average 2011-2016), eutrophication ratio (ER) and status of oxygen debt in the open-sea basins. ER is a quantitative value for the level of eutrophication, calculated as the ratio between the threshold value and the present concentration – when ER > 1, threshold values has not been reached.

Assessment unit (open sea)	Threshold value (mg l^{-1})	Average 2011-2016 (mg l^{-1})	Eutrophication ratio, ER	STATUS (fail/achieve threshold value)
Bornholm Basin	6.37	7.97	1.25	fail
Eastern Gotland Basin	8.66	10.67	1.23	fail
Gdansk Basin	8.66	10.67	1.23	fail
Western Gotland Basin	8.66	10.67	1.23	fail
Northern Baltic Proper	8.66	10.67	1.23	fail
Gulf of Finland	8.66	10.67	1.23	fail
Åland Sea	2.02	NA	NA	not assessed
Bothnian Sea	2.02	NA	NA	not assessed
Bothnian Bay	0.81	NA	NA	not assessed

Long-term trends

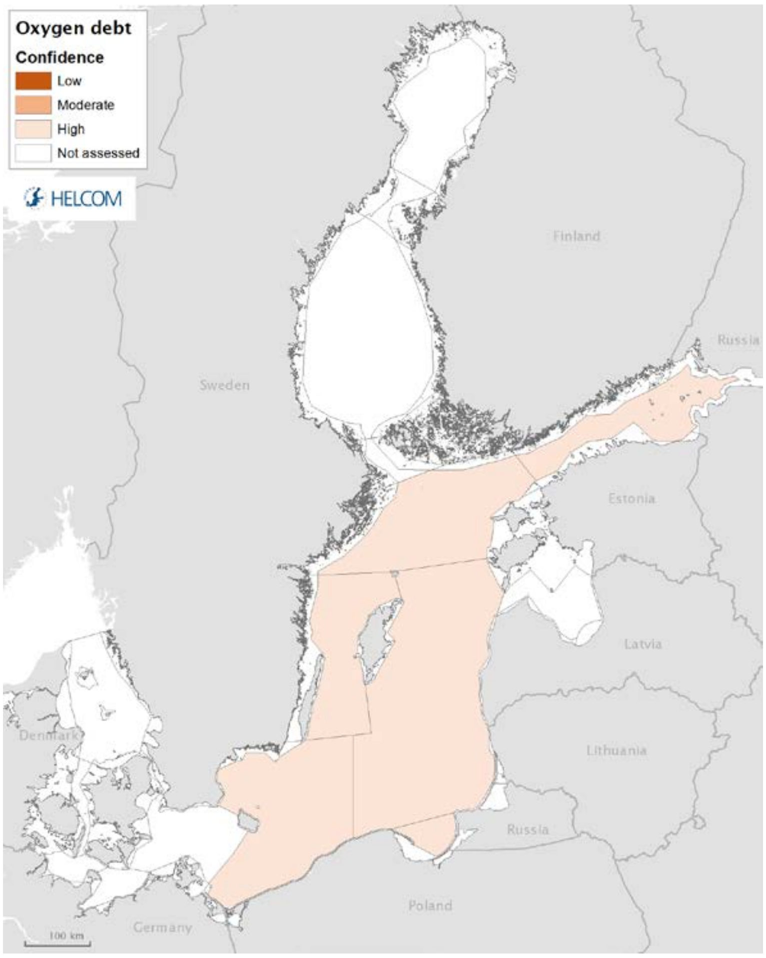
Oxygen debt below the halocline has increased in all basins since the early 1900's. The increase has been strongest in the Baltic Proper (Results figure 3). The Bornholm Basin experiences larger inter-annual variability because of larger variations in the oxygen concentrations, mainly as a result of natural water flows or processes.



Results figure 3. Temporal development in the core indicator 'Oxygen debt' in the Baltic Proper (containing Eastern Gotland basin, Gdansk basin, Western Gotland basin, Northern Baltic Proper and Gulf of Finland), showing the volume specific oxygen debt below the halocline based on the data and sub-basin division delineation of HELCOM (2017). The dashed line shows the five-year moving average. The significance of the trend was tested for the period 1990-2012 by the Mann-Kendall non parametric test. Orange color indicates significant ($p<0.05$) deteriorating trend: an increasing trend in oxygen debt signifies deteriorating oxygen conditions.

Confidence of the indicator status evaluation

The confidence of the indicator status evaluation is based on the spatial and temporal coverage of data as well as the accuracy of the threshold-setting protocol. **High** confidence was attained in all the sub-basins where the indicator was applicable (Results figure 4).

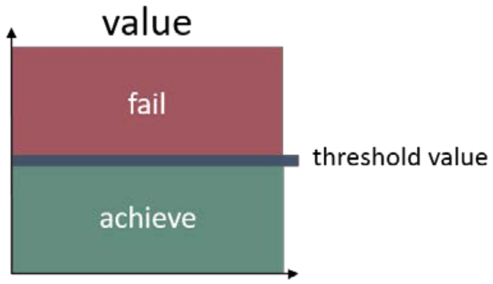


Results figure 4. Indicator confidence, determined by combining information on data availability and the accuracy of the threshold-setting protocol. Low indicator confidence calls for increase in monitoring.

The indicator confidence was estimated through confidence scoring of the threshold (ET-Score) and the indicator data (ES-Score). The ET-Score was rated based on the uncertainty of the threshold value setting procedure. The ES-Score is based on the number as well as spatial and temporal coverage of the observations for the assessment period 2011-2016. To estimate the overall indicator confidence, the ET- and ES-Scores were combined. See Andersen et al. 2010 and Fleming-Lehtinen et al. 2015 for further details.

Thresholds and Status evaluation

Status evaluation is measured in relation to scientifically based and commonly agreed sub-basin specific threshold values, which defines the concentration that should not be exceeded (Thresholds and Status evaluation figure 1).



Thresholds and Status evaluation figure 1. Schematic representation of the threshold value applied in the 'oxygen debt' core indicator, the threshold values are assessment unit specific (see Thresholds and Status evaluation table 1).

These indicator threshold values were based on the results obtained in the TARGREV project (HELCOM 2013a), also taking advantage of the work carried out during the EUTRO PRO process (HELCOM 2009) and national work for EU WFD. The final threshold values were set through an expert evaluation process done by the intersessional activity on development of core eutrophication indicators (HELCOM CORE EUTRO) and the threshold values were adopted by the HELCOM Heads of Delegations 39/2012 (Thresholds and Status evaluation table 1). The threshold values for oxygen debt in Åland Sea, Bothnian Sea and the Bothnian Bay were however endorsed at a later stage by the HELCOM State and Conservation 5E-2017 but the algorithm for calculating the indicator remains to be adjusted and optimized for these areas.

The threshold values for oxygen debt were defined from the 95th percentiles during the pre-eutrophied period before 1940, detected through change-point analysis for all assessment units.

Thresholds and Status evaluation table 1. Assessment unit specific threshold values for the core indicator 'oxygen debt'.

HELCOM_ID	Assessment unit (open sea)	Threshold value (mg l^{-1})
SEA-001	Kattegat	Not applicable
SEA-002	Great Belt	Not applicable
SEA-003	The Sound	Not applicable
SEA-004	Kiel Bay	Not applicable
SEA-005	Bay of Mecklenburg	Not applicable
SEA-006	Arkona Sea	Not applicable
SEA-007	Bornholm Basin	6.37
SEA-008	Gdansk Basin	8.66
SEA-009	Eastern Gotland Basin	8.66
SEA-010	Western Gotland Basin	8.66
SEA-011	Northern Baltic Proper	8.66
SEA-012	Gulf of Riga	Not available
SEA-013	Gulf of Finland	8.66
SEA-014	Åland Sea	2.02
SEA-015	Bothnian Sea	2.02
SEA-016	The Quark	Not available
SEA-017	Bothnian Bay	0.81

Assessment Protocol

The oxygen debt is defined as the "missing" oxygen relative to a full saturated water column, another term often used is the apparent oxygen utilization (AOU). By using the oxygen debt instead of the actual oxygen concentration the variations due to temperature controlled solubility is excluded.

It is preferable if oxygen data from the whole water profile is available but this is often not the case and especially not for older data. To overcome this problem the oxygen profile has instead been modelled with the information from salinity profiles, which typically has a higher vertical resolution than the oxygen in older data.

Generalized additive models (GAM) were applied to describe the temporal, seasonal and spatial variation in each basin. From these models, seasonal and spatial effects can be averaged over providing a time series mostly representing annual variations linked to nutrient inputs. The oxygen debt algorithm is done using the BALTSEM assessment units and the results are afterwards transferred to the HELCOM assessment units. For more details of the method see BSEP 133 and the R-scripts (https://github.com/ices-tools-prod/HEAT/tree/master/scripts/OxygenDebt).

The assessment units for the indicator are the open sea assessment units of the 17 Baltic Sea sub-basins.

The assessment units are defined in the HELCOM Monitoring and Assessment Strategy Annex 4.

Relevance of the Indicator

Eutrophication assessment

The status of eutrophication is assessed using several core indicators. Each indicator focuses on one important aspect of the complex issue. In addition to providing an indicator-based evaluation of the oxygen debt, this indicator also contributes to the overall eutrophication along with the other eutrophication core indicators.

Policy relevance

Eutrophication is one of the four thematic segments of the HELCOM Baltic Sea Action Plan (BSAP) with the strategic goal of having a Baltic Sea unaffected by eutrophication (HELCOM 2007). Eutrophication is defined in the BSAP as a condition in an aquatic ecosystem where high nutrient concentrations stimulate the growth of algae which leads to imbalanced functioning of the system. The goal for eutrophication is broken down into five ecological objectives, of which one is "natural oxygen levels".

The EU Marine Strategy Framework Directive (Anonymous 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). 'Dissolved oxygen in the bottom of the water column' is listed as a criteria element for assessing the criterium D5C5 'The concentration of dissolved oxygen is not reduced, due to nutrient enrichment, to levels that indicate adverse effects on benthic habitats (including on associated biota and mobile species) or other eutrophication effects.

The EU Water Framework Directive (Anonymous 2000) requires good ecological status in the European coastal waters. Good ecological status is defined in Annex V of the Water Framework Proposal, in terms of the quality of the biological community, the hydrological characteristics and the chemical characteristics, including dissolved oxygen.

Role of dissolved oxygen in the ecosystem

Oxygen depletion is a common effect of eutrophication in the bottom waters of coastal marine ecosystems and is becoming increasingly prevalent worldwide (HELCOM, 2002). In the deep basins and other areas of the Baltic Sea which are characterized by vertical stratification and low water exchange, conditions of low oxygen or even anoxia are a natural phenomenon, although enhanced by nutrient loading. Oxygenation of these areas highly depends on inflows of marine water from the North Sea (HELCOM 2017). Oxygen depletion is caused by the consumption of oxygen by the microbial processes responsible for the degradation of organic matter accumulating at the sea floor. Oxygen depletion may result in hypoxia (literally 'low oxygen') or even anoxia (absence of oxygen). These events may be (1) episodic, (2) annually occurring in summer/autumn (most common), or (3) persistent (typical of the deep basins of the Baltic Sea). Oxygen depletion has a clear impact on biogeochemical cycles. Anoxic periods cause the release of phosphorus from sediment. Dissolved inorganic phosphorus (DIP) is significantly negatively correlated with oxygen conditions. The concentration of DIP can vary greatly from year to year depending on the release of phosphorus from sediments under anoxia (Matthäus et al. 2008). Ammonium is also enriched under hypoxic conditions.

The DIP and ammonium from the bottom waters can be mixed into the upper water column and enhance algal blooms. Thus, hypoxia results in large changes in the biogeochemical cycle, which may enhance eutrophication.

Human pressures linked to the indicator

	General	MSFD Annex III, Table 2a
Strong link		Substances, litter and energy - Input of nutrients – diffuse sources, point sources, atmospheric deposition
Weak link		Substances, litter and energy - Input of organic matter – diffuse sources and point sources

Oxygen depletion is an indirect effect of eutrophication, i.e. increase of organic matter descending to the bottom. It also has an indirect link to anthropogenic pressures, through increased anthropogenic nutrient loads and subsequent increase of organic matter descending to the bottom.

Monitoring Requirements

Monitoring methodology

Monitoring of oxygen concentration in the Contracting Parties of HELCOM is described on a general level in the **HELCOM Monitoring Manual** in the **sub-programme: Water column chemical characteristics**.

Specific monitoring guidelines have been agreed in the HELCOM COMBINE guideline. The analytical requirements are specified, including definition of the type and nature of the sample and its environment, concentration range of interest and permissible tolerances in analytical error (Part B Annex B3 in the HELCOM COMBINE manual).

Current monitoring

The monitoring activities relevant to the indicator that are currently carried out by HELCOM Contracting Parties are described in the **HELCOM Monitoring Manual Sub-programme:** monitoring concepts table.

Description of optimal monitoring

Regional monitoring is considered to be sufficient for the purposes of the indicator evaluation.

Data and updating

Access and use

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

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Metadata

Result: Oxygen debt

Data source: The average for 2011-2016 was estimated using monitoring data provided by the HELCOM Contracting Parties, and kept in the HELCOM COMBINE database, hosted by ICES (www.ices.dk). Nominated members of HELCOM STATE & CONSERVATION group were given the opportunity to review the data, and to supply any missing monitoring observations, in order to achieve a complete dataset.

Description of data: The data includes *in-situ* temperature, salinity and oxygen profiles, determined as explained in the HELCOM COMBINE manual. Dissolved oxygen measurements made at the depth below the halocline were used in the assessment.

Geographical coverage: The observations are distributed in the sub-basins according to the HELCOM COMBINE programme, added occasionally with data from research cruises.

Temporal coverage: The raw data includes observations throughout the year, during the assessment period 2011-2016.

Data aggregation: The 2011-2016 averages for each sub-basin were produced as inter-annual estimates, determined using a GLM-GAM procedure to exclude spatio-temporal bias. The oxygen debt calculation algorithm R-script can be accessed at https://github.com/ices-tools-prod/HEAT#oxygen-debt-indicator-calculation-scripts

Contributors and references

Contributors

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HELCOM IN-Eutrophication

Archive

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Additional relevant publications

Eutrophication status of the Baltic Sea 2007-2011 - A concise thematic assessment (2014)

Approaches and methods for eutrophication target setting in the Baltic Sea region (2013)

HELCOM core indicators. Final report of the HELCOM CORESET project (2013)

Eutrophication in the Baltic Sea. An integrated thematic assesment of the effects of nutrient enrichment in the Baltic Sea region (2009)

Development of tools for assessment of eutrophication in the Baltic Sea (2006)

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