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Working Group on the State of the Environment and Nature
Conservation

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Document title	Oxygen debt indicator – proposal to extend the indicator to the Bothnian Sea and Bothnian Bay
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Background

The TARGREV project has established a method to assess the oxygen status (in terms of oxygen debt) of the deep basins of the Baltic Sea, excluding the Åland Sea, Bothnian Sea and Bothnian Bay. In document 4J-31, HELCOM IN-Eutrophication reports progress and propose a candidate indicator for shallow water oxygen to be included into the eutrophication assessment. However, as it is dedicated for shallow waters, it does not cover the Åland Sea, Bothnian Sea and Bothnian Bay. An oxygen indicator is necessary for all areas, to evaluate whether the bottom oxygen conditions are expressing impacts of eutrophication.

The TARGREV project calculated oxygen debt for the Bothnian Sea and Bothnian Bay, but did not propose GES boundaries (then called targets), as the areas do not suffer of hypoxia. In this document, we show results on oxygen debt in the Bothnian Bay and Bothnian Sea, and propose extending the indicator to these sub-basins as well as the Åland Sea. The status of oxygen debt can be based on data reported to ICES by the Contracting Parties.

The current version of the '[Oxygen debt](#)' core indicator report is available at the HELCOM web-site.

Action requested

The Meeting is invited to:

- endorse the proposal to extend the core indicator on 'Oxygen debt' to assess oxygen status in the Åland Sea, Bothnian Sea and Bothnian Bay,
- consider the preliminary GES boundaries for the indicator in the Bothnian Sea and Bothnian Bay,
- agree to endorse the final proposals on GES boundaries intersessionally.

A solution for achieving an oxygen core indicator for all open-sea areas

Oxygen debt has been agreed as the HELCOM core indicator for oxygen, and is the only indicator applied for the evaluation of oxygen status in the eutrophication assessment. It covers the open-sea areas connected to the Baltic Proper and consisting of deep waters extending below the halocline – in other words 6 of the 17 open-sea assessment units.

Shallow water oxygen, presently an indicator with candidate status, has been developed further and is proposed in this meeting to be applied as a core indicator of eutrophication for open-sea areas with bottom water above halocline, to be included into the HOLAS II process (see document 4J-31). It is able to cover the remaining open-sea assessment units with water depth ≤ 50 m. It does not however solve the problem of lacking operational oxygen indicator in the Åland Sea, Bothnian Sea and Bothnian Bay.

Oxygen consumption is a candidate indicator still under development. Once finalized, it would be able to provide an oxygen indicator also for these areas. The indicator will however not be finalized in time for use in HOLAS II.

In this document, we propose extending the oxygen debt indicator to the remaining deep sub-basins: the Åland Sea, Bothnian Sea and Bothnian Bay. Oxygen debt is an operational core indicator, and therefore easy to include to the existing indicator update procedures.

Table 1. The oxygen indicators proposed to be applied in HOLAS II in the open Baltic Sea sub-basins. The shallow water oxygen indicator is presented in document 4J-31. The oxygen debt core indicator is presently applied in six sub-basins (highlighted green). We now propose applying the indicator in the three remaining deep sub-basins (highlighted yellow).

HELCOM ID	Assessment unit name	Oxygen indicator	Indicator status
SEA-001	Kattegat	Shallow water oxygen	Candidate
SEA-002	Great Belt	Shallow water oxygen	Candidate
SEA-003	The Sound	Shallow water oxygen	Candidate
SEA-004	Kiel Bay	Shallow water oxygen	Candidate
SEA-005	Bay of Mecklenburg	Shallow water oxygen	Candidate
SEA-006	Arkona Sea	Shallow water oxygen	Candidate
SEA-007	Bornholm Sea	Oxygen debt	CORE
SEA-008	Gdansk Basin	Oxygen debt	CORE
SEA-009	Eastern Gotland Basin	Oxygen debt	CORE
SEA-010	Western Gotland Basin	Oxygen debt	CORE
SEA-011	Gulf of Riga	Shallow water oxygen	Candidate
SEA-012	Northern Baltic Proper	Oxygen debt	CORE
SEA-013	Gulf of Finland	Oxygen debt	CORE
SEA-014	Åland Sea	Oxygen debt	proposed to be extended to CORE
SEA-015	Bothnian Sea	Oxygen debt	proposed to be extended to CORE
SEA-016	The Quark	Shallow water oxygen	Candidate
SEA-017	Bothnian Bay	Oxygen debt	proposed to be extended to CORE

Bottom conditions in the Gulf of Bothnia

The Gulf of Bothnia consists of three deep basins, separated by sills from the adjacent assessment units. The Åland Sea is a small but deep sound, extending to a depth of 301 m. The Bothnian Sea, located north from the Åland Sea, is a large basin with a maximum depth of 290 m. The Bothnian Bay is disconnected from the Bothnian Sea by the Quark assessment unit, and has a maximum depth of 146 m (Figure 1).

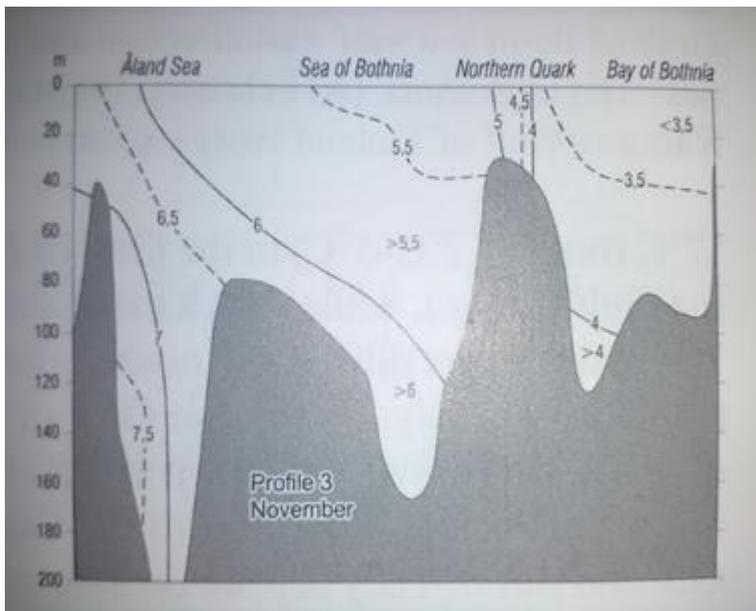
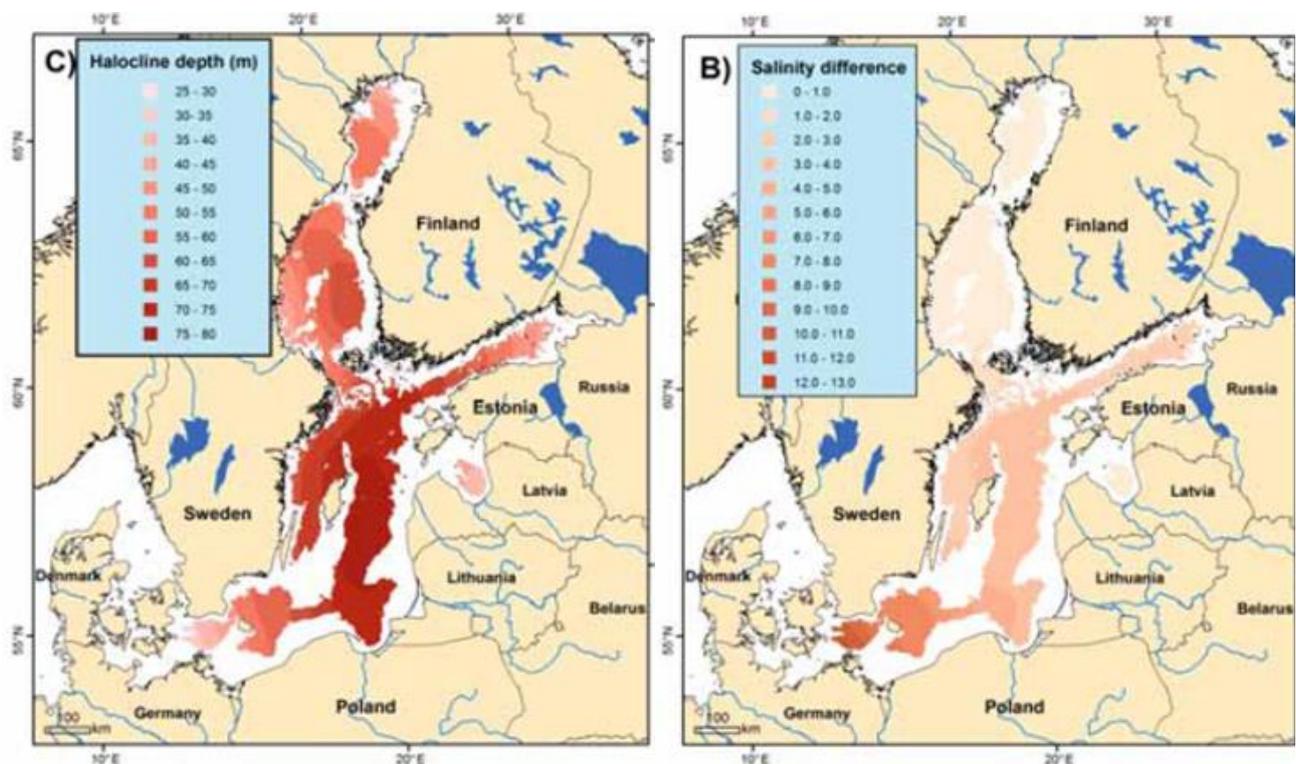


Figure 1. The salinity profile in the Gulf of Bothnia in November. From Leppäranta & Myrberg 2009.

Despite the strong decreasing northward salinity gradient, all of the basins have a distinct but weak halocline (Figures 1 and 2). Due to the southern sill preventing the flow of Deep Baltic water into the Gulf, the salinity is low in the deep basins; the deep water does thus not originate from the Atlantic inflows (similarly as the deep water in the Baltic Proper), but instead of Baltic mid-layer water flowing over the southern sill (Leppäranta & Myrberg 2009). The area does therefore not suffer of anoxia, although signs of decreasing oxygen concentration have been reported (Raateoja 2015, HELCOM 2013).



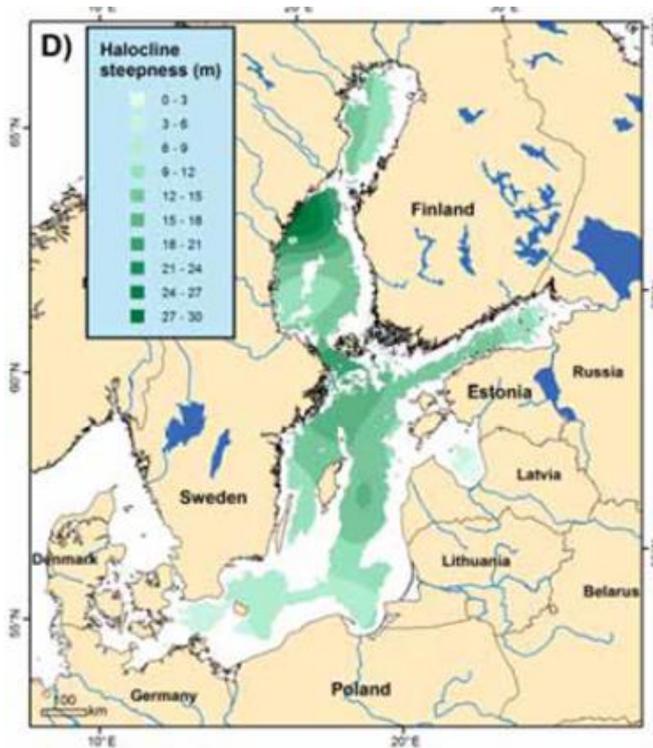


Figure 2. The depth of the halocline (above left), the salinity difference between the water above and below the halocline (above right) and the steepness of the halocline (bottom left) in the Baltic Sea. From HELCOM 2013.

Estimating GES boundaries

Oxygen debt was calculated for the Åland Sea, Bothnian Sea and Bothnian Bay during the HELCOM TARGREV project (Figure 3), and time-series were provided for the latter two. The indicator was however not taken into use in these areas, presumably due to them not being hypoxia problem areas. Also the weak halocline might have affected the choice (Jacob Carstensen, personal communication). Yet, oxygen debt does occur in the area, and the indicator could be applied for evaluating the change in bottom oxygen conditions. It could thus have a role in the assessment of eutrophication in the areas that show clear signs of increased eutrophication (HELCOM 2014).

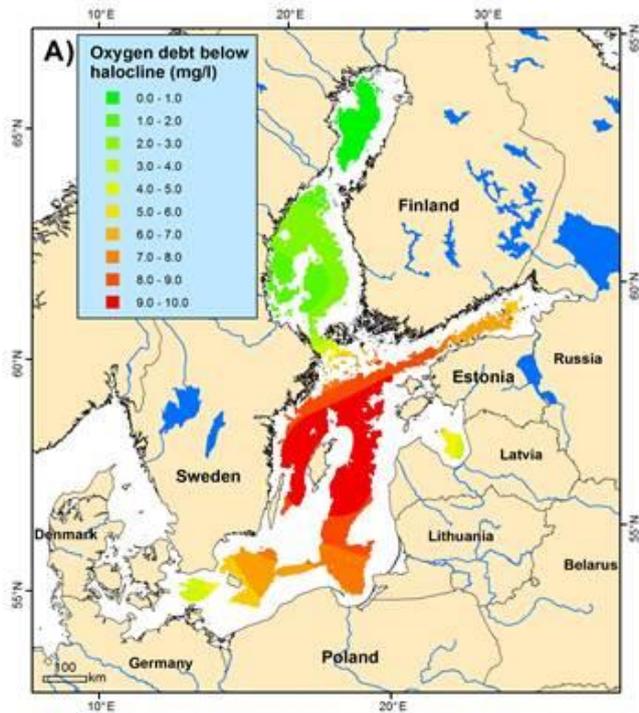


Figure 3. Oxygen debt in the open Baltic Sea sub-basins. From HELCOM 2013.

Oxygen debt was calculated for 1900-2010 by the HELCOM TARGREV project (Figure 4). According to these time-series, oxygen debt has increased in the Bothnian Sea from levels of $1.5 - 2 \text{ mg L}^{-1}$ during the pre-eutrophied period to a level of approximately $3-4 \text{ mg L}^{-1}$ in 2005-2010. A clear change in oxygen debt levels can be timed between 1930 and 1950, with a subsequent period of intense increase after 1990. In the Bothnian Bay, the increase has not been as drastic, but increase was observed since 1950; prior to that, oxygen debt could be estimated to be $1-1.5 \text{ mg L}^{-1}$, and after 2005 above 1.5 mg L^{-1} .

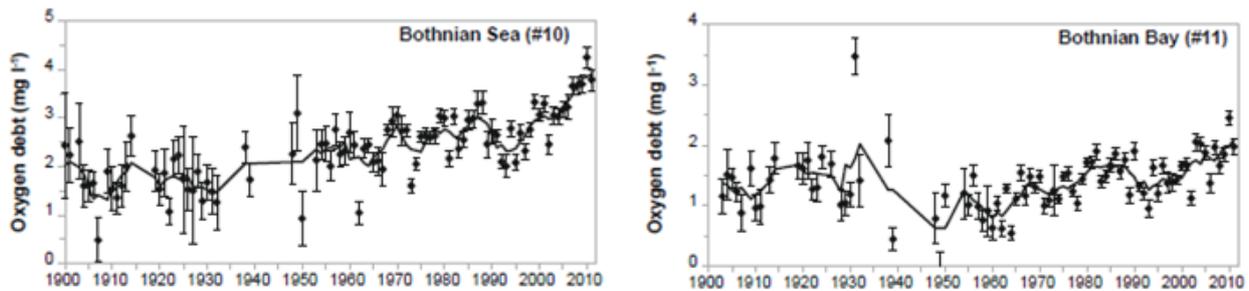


Figure 4. Oxygen debt in the Bothnian Sea (left) and Bothnian Bay (right) between 1900-2010. From HELCOM 2013.

The indicator GES boundary values are calculated as the upper 95-percentile of the distribution of the yearly means of oxygen debt during the pre-eutrophication phase (HELCOM 2013). These values were estimated for the Bothnian Sea and Bothnian Bay using the dataset collated from the BED database and ICES during the HELCOM TARGREV project (Table 2).

Table 2. The proposed tentative GES boundaries for oxygen debt along with the already agreed and operational oxygen debt GES boundaries for Bornholm Sea, Gdansk Basin, Eastern Gotland Basin, Western Gotland Basin, Northern Baltic Proper and Gulf of Finland.

HELCOM_ID	Assessment unit name	Oxygen debt GES boundary ¹ [mg L ⁻¹]	Status of GES boundary
SEA-007	Bornholm Sea	6.37	Operational
SEA-008	Gdansk Basin	8.66	Operational
SEA-009	Eastern Gotland Basin	8.66	Operational
SEA-010	Western Gotland Basin	8.66	Operational
SEA-012	Northern Baltic Proper	8.66	Operational
SEA-013	Gulf of Finland	8.66	Operational
SEA-014	Åland Sea		Under development
SEA-015	Bothnian Sea	2.8	Tentative proposal
SEA-017	Bothnian Bay	1.8	Tentative proposal

Oxygen status in the Bothnian Bay and Bothnian Sea

Tentative estimates for average oxygen debt in 2007-2011 in the Bothnian Sea and Bothnian Bay was calculated based on the monitoring data collated during HELCOM TARGREV. Estimates for eutrophication ratio (ER) could thus be calculated using the GES boundaries proposed above, and tentative status estimates could be made (Table 3).

Table 3. Estimates of oxygen debt 2007-2011 along with the proposed tentative GES boundaries in the Bothnian Bay and Bothnian Sea, based on the time-series presented in HELCOM 2013. The eutrophication ratio (ER) and status of oxygen debt was calculated based on these values.

Assessment unit name	Tentative GES boundary [mg L ⁻¹]	Estimate 2007-2011 [mg L ⁻¹]	ER [mg L ⁻¹]	Status classification
Bothnian Sea	2.8	3.8	1.35	Sub-GES
Bothnian Bay	1.8	1.7	0.94	GES

According to these tentative values, the oxygen debt status was below GES in the Bothnian Sea and GES in the Bothnian Bay (Table 3, Figure 5). The low status in the Bothnian Sea is a result of increasing oxygen debt since 1930 in the deep water of the area.

¹ previous termed target.

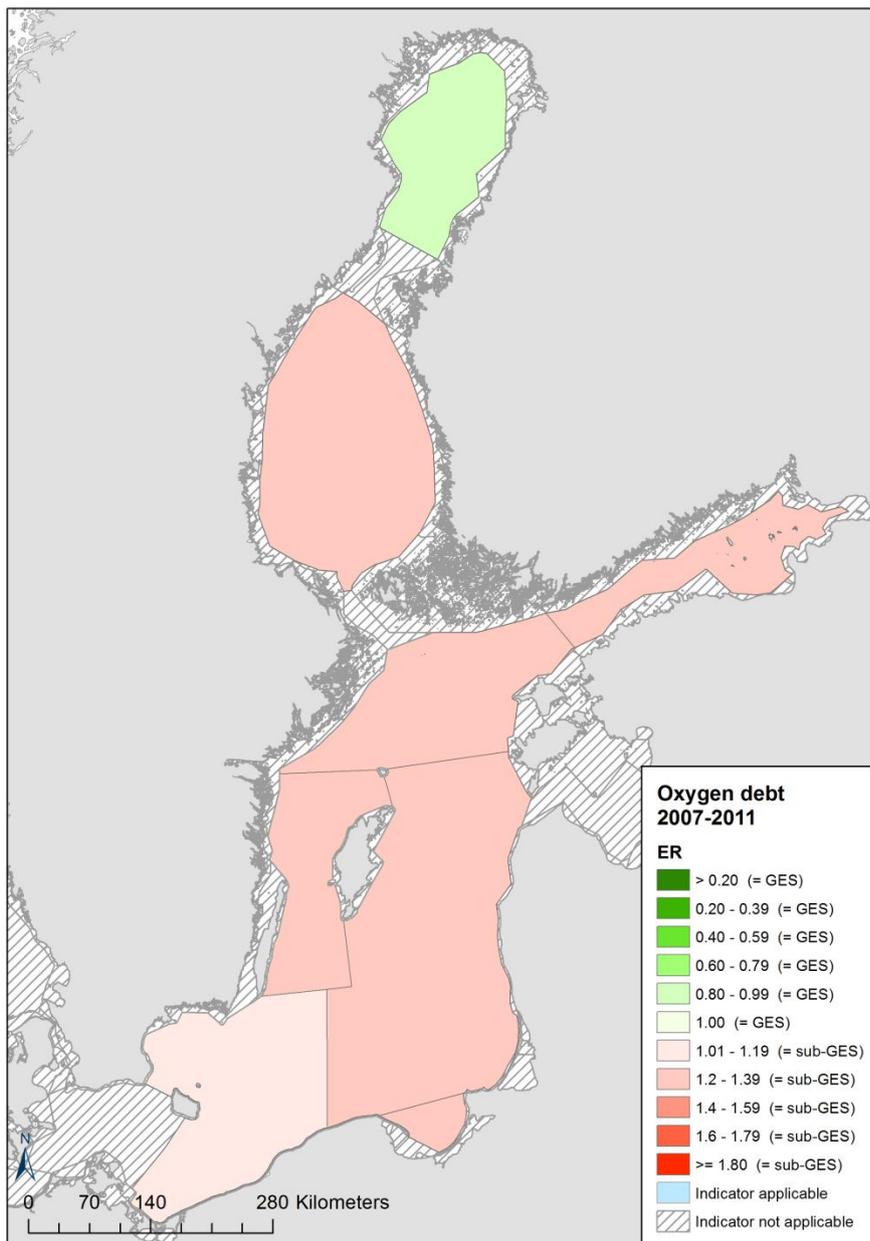


Figure 5. The tentative status of oxygen debt in the open Baltic Sea in 2007-2011. The status estimates for Bothnian Sea and Bothnian Bay are not a HELCOM status evaluation, but based on the tentative estimates and proposed tentative values presented in this document.

The status of oxygen debt can be updated for HOLAS II, based on monitoring data 2011-2016 reported to ICES by the Contracting Parties. Oxygen debt is presently being included into the HELCOM eutrophication assessment database algorithms by ICES, in order to automatize the indicator development in the same way as has been done for the other core indicators (HELCOM 2015). Updating the indicator will not require additional statistical input from the national experts of IN-Eutrophication, but will be accomplished through the algorithms in connection with the HELCOM Eutrophication Assessment Database hosted by ICES.

References

HELCOM 2013. Approaches and methods for eutrophication target setting in the Baltic Sea region. BSEP 133.

HELCOM 2014. Eutrophication status of the Baltic Sea 2007-2011 – A concise thematic assessment. BSEP 143.

HELCOM 2015. Final report of the project, Making HELCOM Eutrophication Assessments Operational (HELCOM EUTRO-OPER).

Leppäranta M & Myrberg K 2009. Physical oceanography of the Baltic Sea. Springer.

Raateoja M 2013. Deep-water oxygen conditions in the Bothnian Sea. Boreal Environment Research 18:00-00.