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Recent developments in assessment methodology reveal that the Baltic Sea eutrophication problem is expanding

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ABSTRACT

This study follows up on a previous assessment of eutrophication status in the Baltic Sea, which covered the period 2001–2006. The updated assessment is based on new eutrophication targets, an improved eutrophication assessment tool (HEAT 3.0) as well as monitoring data for the period 2007–2011. Based on classifications of eutrophication status in all Baltic Sea sub-basins, we reveal that during the assessment period 2007–2011, the entire open Baltic Sea was affected by eutrophication. This is a different conclusion compared to earlier assessments and studies. Whilst the confidence of the assessment was high or moderate in most basins, there were indications of declining confidence in some assessment units and improved confidence in others. The problems in confidence were mainly related to scarcity of in situ monitoring data on chlorophyll-*a* and Secchi depth. The potential implications of our results, e.g. the expansion of the eutrophic zone and declining confidence in the classifications of eutrophication status, are discussed in relation to the existing Baltic Sea-wide nutrient management strategy as well as future assessment activities.

1. Introduction

The Baltic Sea is a brackish water body encompassed by the Scandinavian peninsula and the mainland of northern Europe. Bordering states are Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The environment of the Baltic Sea is affected by intensive use of the sea itself and anthropogenic activities in its catchment area (HELCOM, 2010). The main environmental problems faced by the Baltic Sea are related to excess inputs of nutrients and hazardous substances as well as fishing and other offshore activities, resulting in an impaired status of the marine ecosystem in regard to eutrophication, hazardous substances and biodiversity (HELCOM, 2010; Korpinen et al., 2012). Hence, the Baltic Sea states have agreed on an Action Plan, based on the ecosystem approach, to manage human activities which has the overarching aim of attaining a healthy Baltic Sea environment by 2021 (HELCOM, 2007). This implies an ecosystem with diverse biological components, functioning in balance, supporting a wide range of sustainable human economic and social activities (Backer et al., 2010), including a Baltic Sea unaffected by eutrophication.

In the present study, we assessed eutrophication status in open sea basins of the Baltic Sea for the years 2007–2011, following up on an earlier eutrophication assessment for the period 2001–2006 (HELCOM, 2009; Andersen et al., 2010, 2011). Both assessments

Abbreviations: Chl-*a*, *chlorophyll-a*; DIN, dissolved inorganic nitrogen (NO_X+NH_4-N); DIP, dissolved inorganic phosphorus (PO_4-P); ES, indicator-specific state, based on monitoring data from the assessment period; ET, indicator-specific target/boundary determining lower limit of GES; ER, eutrophication ratio, derived from ET and ES; EQR, ecological quality ratio, derived from ES and reference condition (not used in present assessment); ES-Score, confidence of ES estimate; ET-Score, confidence of ET; FCR, final quality rating of the assessment; GES, good environmental status, referring to an acceptable level of eutrophication; GES-boundary, boundary between GES and sub-GES; HEAT, HELCOM eutrophication assessment tool; MSFD, Marine Strategy Framework Directive of the European Union (Anonymous 2008); Sub-GES, unacceptable level of eutrophication, not meeting the requirements of GES.

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relied on joint efforts of the Baltic Sea states for monitoring, reporting data as well as agreeing on common eutrophication targets and assessment principles. The aim of the eutrophication assessment is to follow the progress towards reaching the ecological quality objectives for eutrophication of the Baltic Sea Action Plan (HELCOM, 2007), which also supports the implementation of the Marine Strategy Framework Directive of the European Union (MSFD, Anon., 2008) in the Baltic Sea region.

The study is more than an update using latest available data. Firstly, we base the assessment on new and recently agreed eutrophication targets which were set through a documented, scientifically-based process (HELCOM, 2013a). Secondly, we base the study on the application of HEAT 3.0, which is a revised version of the HELCOM eutrophication assessment tool (HELCOM, 2014). Thirdly, the study is a fully harmonised and integrated assessment of 17 open sea basins of the Baltic Sea using monitoring data from 2007 to 2011, provided by all the Baltic Sea states for joint and coordinated assessment of the Baltic Sea.

2. Methods

The Baltic Sea was subdivided into 17 open sea basins, referred to as assessment units, characterised by differences in hydromorphology and physical, chemical, and biological conditions (Fig. 1, Table 1). The division took into account the physical and chemical characteristics of the water masses (Feistel et al., 2008; Leppäranta and Myrberg, 2009), aiming at maintaining homogeneity within basins while keeping the number of assessment units low.

2.1. Data sources

A total of five indicators, representing nutrient levels as well as direct and indirect effects of eutrophication (see Anon., 2010) were used to produce the assessment (Fig. 2). Nutrient level indicators were dissolved inorganic nitrogen (or DIN, average $NO_X + NH_4$-N concentration at 0–10 m depth between December and February) and dissolved inorganic phosphorus (or DIP, average PO_4-P concentration at 0–10 m depth between December and February). Chlorophyll-*a* (or Chl-*a*, average chlorophyll-*a* concentration at 0–10 m depth between June and September) and Secchi depth (average Secchi depth between June and September) were used as indicators representing direct effects of eutrophication. Indirect effects of eutrophication were represented by an oxygen debt indicator (annual oxygen debt below halocline).

In order to evaluate the level of eutrophication, targets for good eutrophication status (ET) were set for each indicator (Table 2). Separate targets were set for each assessment unit, taking into account the regional differences between the basins. These targets, representing the boundary between good and less-than-good eutrophication status (or good environmental status (GES) boundary), were set in a two-step procedure: (1) scientific estimation of target levels (HELCOM, 2013a; Carstensen et al., 2014) and (2) finalising targets through expert group work (HELCOM, 2012). The scientific approach employed in the first phase of the target setting was based on identifying thresholds of ecosystem change by means of data mining and ensemble modelling. Although this approach differed from the earlier approach used for setting targets, where tentative targets were set through reference conditions and acceptable deviations (HELCOM, 2006, 2009), the targets resulting from the two approaches were compatible in that they both aimed to describe the boundary between an acceptable and unacceptable eutrophication status. During the second phase, a group of eutrophication experts from the Baltic Sea region convened to review the scientifically estimated targets for each basin, with the objective to achieve harmonised targets between

Table 1
Characteristics of the 17 assessment units used in the study: surface area (calculated using GIS); maximum bottom depth (Leppäranta and Myrberg, 2009); typical level of salinity at the surface (Leppäranta and Myrberg, 2009); approximate depth of permanent halocline, if present (HELCOM, 2013a); typical surface temperature in July (Leppäranta and Myrberg, 2009); major rivers flowing into the sub-basin (Kulinski and Pempkowiak, 2011; HELCOM, 2013c) as well as average (2008–2010) annual inputs of total nitrogen and total phosphorus to the basin, including adjacent coastal areas (HELCOM, 2013c). Nutrient inputs are calculated using different basin subdivisions and have therefore been combined for some assessment units.

Assessment unit	Surface area (km^2)	Depth, max (m)	Salinity, typical surface	Permanent halocline depth, approx. (m)	Temperature, typical surface summer (°C)	Major rivers flowing to area	N input, avg 2008–2010 ($t\,y^{-1}$)	P input, avg 2008–2010 ($t\,y^{-1}$)
Kattegat	15,670	130	18–26	10–20	16–17	Göta Älv	69,170	1550
The Sound	600	53	9–16	10–15	16–17	(no major rivers)	53,970	1470
Great Belt	1940	81	8–24	15–20	16–17	(no major rivers)		
Kiel Bay	2760	20	7–8	15–20	16–18	(no major rivers)		
Bay of Mecklenburg	3480	20	9–14	15–20	16–18	(no major rivers)		
Arkona Sea	13,110	53	7.3–8.5	25–35	16–17	(no major rivers)		
Bornholm Sea	38,840	105	7.3–8.5	55–60	16–17	Oder	413,680	16,510
Gdansk Basin	3650	114	5.0–7.3	70–75	18–22	Vistula		
Eastern Gotland Basin	70,750	249	6.5–7.5	70–80	15–17	Nemunas		
Western Gotland Basin	21,930	459	6.5–7.5	65–75	15–17	(no major rivers)		
Northern Baltic Proper	31,570	150	5–7	65–75	16–17	(no major rivers)		
Gulf of Riga	8670	51	4.5–6	(not present)	17–18	Daugava	89,060	2810
Gulf of Finland	16,590	123	0–6	45–65	15–18	Neva, Narva	125,050	6810
Åland Sea	1900	301	5–6	50–60	13–15	(no major rivers)	74,530	2660
Bothnian Sea	49,580	293	4–6	45–60	13–15	Ångerman, Indal		
The Quark	2870	40	3.5–6	(not present)	13–15	Ume	55,780	2580
Bothnian Bay	21,350	146	2–4	40–55	13–15	Lule, Torne, Kemijoki		