Hydrography and oxygen in the deep basins

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Key message

The saline inflows of November 2002 – March 2003 caused major changes to the hydrographic conditions in the deep basins between Arkona and the East Gotland Basin. Deep water salinity in the south eastern Baltic Proper remains higher than in 2002. In the Bornholm and East Gotland Basins, salinity is again close to the 2002 level.

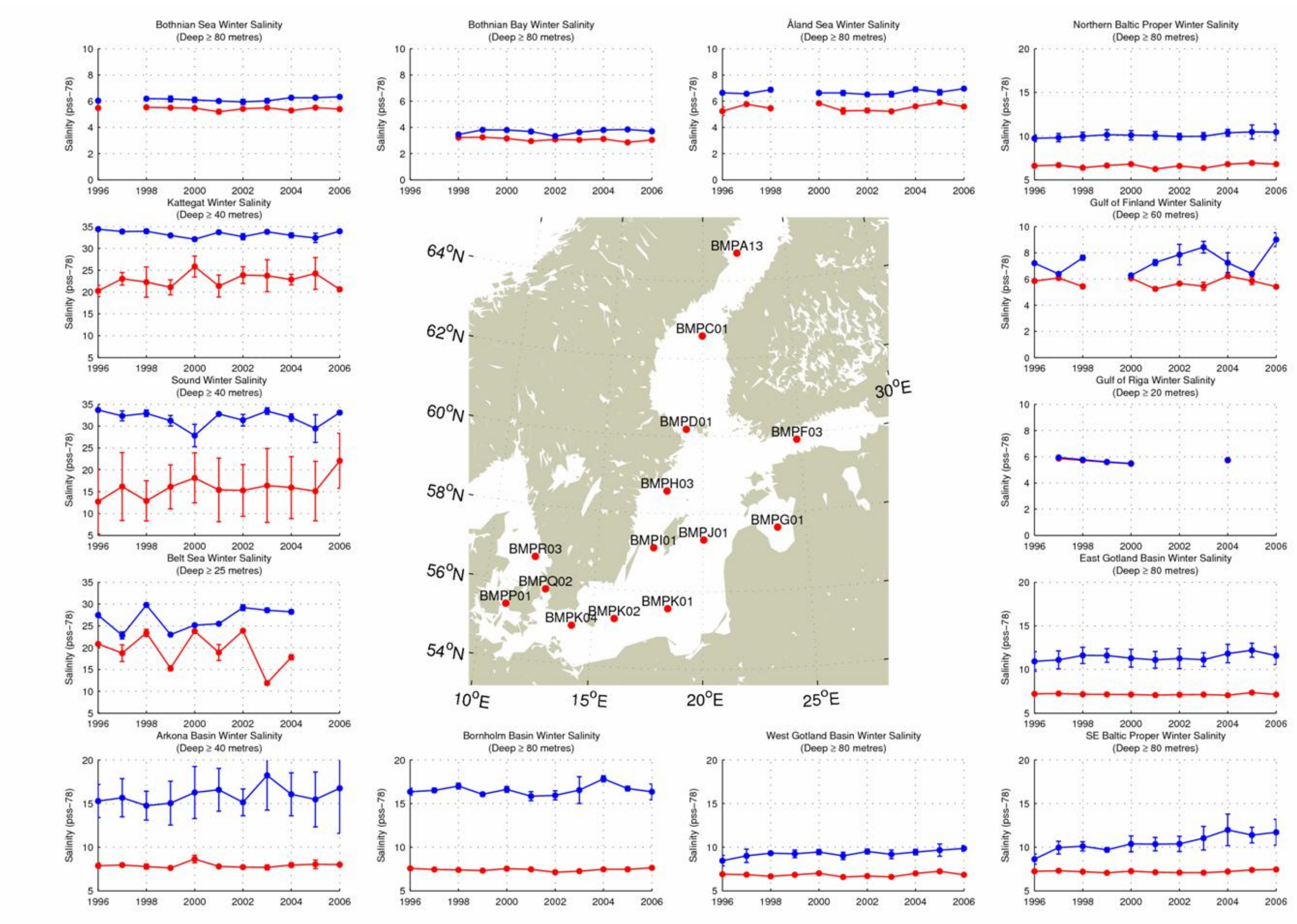
Deep-water oxygen levels, from Arkona to the East Gotland Basin, were significantly better in autumn 2003 than in 2002. Since then, hydrogen sulphide levels have steadily increased again in the East Gotland Basin, though do not yet appear to extend as far as in 2002.

Results and assessments

Relevance of the indicator for describing developments in the environment

Salinity, temperature and oxygen are physical background parameters, constraining bio-diversity, fish recruitment and water quality in a semi-enclosed water body such as the Baltic Sea. For example, cod larvae are dependent on water with salinity and oxygen levels above 11 psu and 1 ml/l, respectively. It is only since the most recent inflow that they may survive east of the western Southern Baltic Proper.

Baltic surface waters are strongly influenced by run-off of freshwater from land. Changes in run-off alter the surface salinity while inflows through Öresund and the Belt Sea control the salinity of the deeper waters. Stratification between the upper and lower layers inhibits surface and deep waters mixing together, and thus preventing the oxygenated surface water penetrating to depth, as well as hindering the transfer of phosphorus (which is abundant in the deep water) to the surface waters. Stratification strength can be indicated by the salinity difference between the surface and deepwater, as well as by the buoyancy frequency (a function which incorporates the effects of both salinity and temperature changes) and by the depth of the pycnocline i.e. the volume of the deepwater. Figure 1 shows the difference between surface and deep salinity, while Figure 2 shows the strength of the pycnocline (in terms of the buoyancy frequency) and also its depth.



Time series of winter surface (< 10 m; red) and deep-water (blue) salinity in the Baltic Proper, 1996 – 2006.

Figure 1. Time series of winter surface (< 10 m; red) and deep-water (blue) salinity in the Baltic Proper, 1996 – 2006.

Oxygen depletion is widely used as an indicator for the indirect effects of nutrient enrichment. While oxygen levels above 4.5 ml/l are considered to cause no problems for macroscopic animals, levels below this cause increasing stress to most organisms.

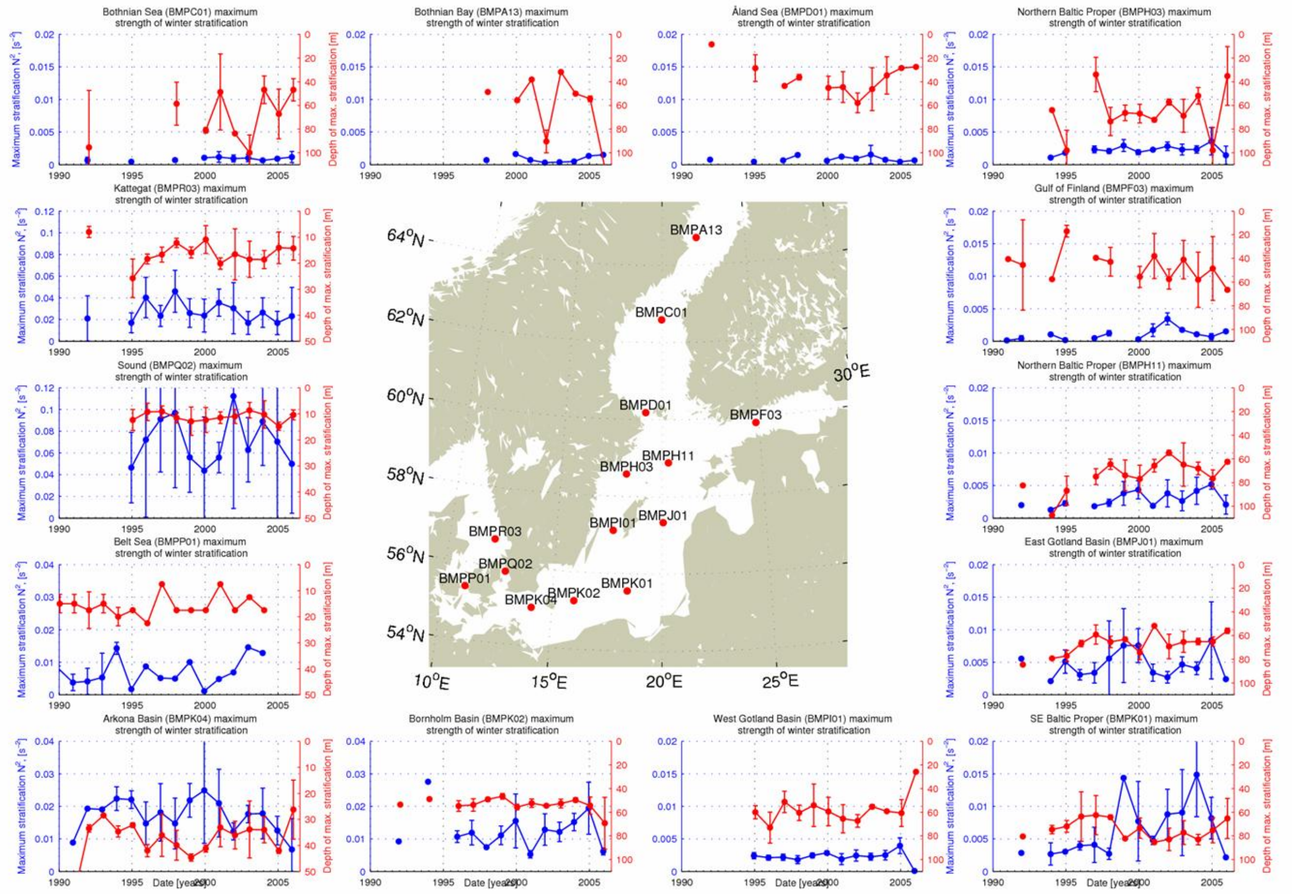
Lowest oxygen levels are experienced at the end of summer, between August and October, when detritus from biological activity in the surface waters has sunk, and is decomposed by bacteria. This process consumes oxygen. When oxygen concentrations fall below about 1 ml/l, bacteria start to use anaerobic processes, producing hydrogen sulphide. Hydrogen sulphide is toxic, and its concentration is described in terms of negative oxygen. In the western Baltic Proper, Danish Straits and Kattegat oxygen depletion is a seasonal phenomenon which occurs during autumn. The deepwater basins in the Baltic Proper however suffer severely from long-term oxygen depletion.

Policy relevance and policy references

Oxygen levels are used as an indicator of eutrophication by both Helcom and OSPAR. It is listed as a core variable of the Helcom COMBINE programme. Oxygen is delivered to the deep waters of the Baltic in the saline inflows that come through the Sound and Belt Sea. Hydrographic measurements (temperature and salinity) allow us to trace these inflows, and other water movements within the Baltic. The vertical stratification, which is governed by the temperature and salinity, inhibits the vertical exchange of heat, salt, nutrients and oxygen, and describes the separation between 'surface' and 'deep' waters.

Assessment

The winter 2002 – 3 inflows led to an increase in deep water salinity from the Arkona Basin to the Northern Baltic Proper. Deep water salinity remains elevated (compared to 2002 levels) in the south-eastern Baltic Proper, Northern Baltic Proper, Åland Sea and even in the Bothnian Sea. In the Bornholm and East Gotland Basins however, the effect of the inflows has almost disappeared, with deep water salinity close to the 2002 level again.

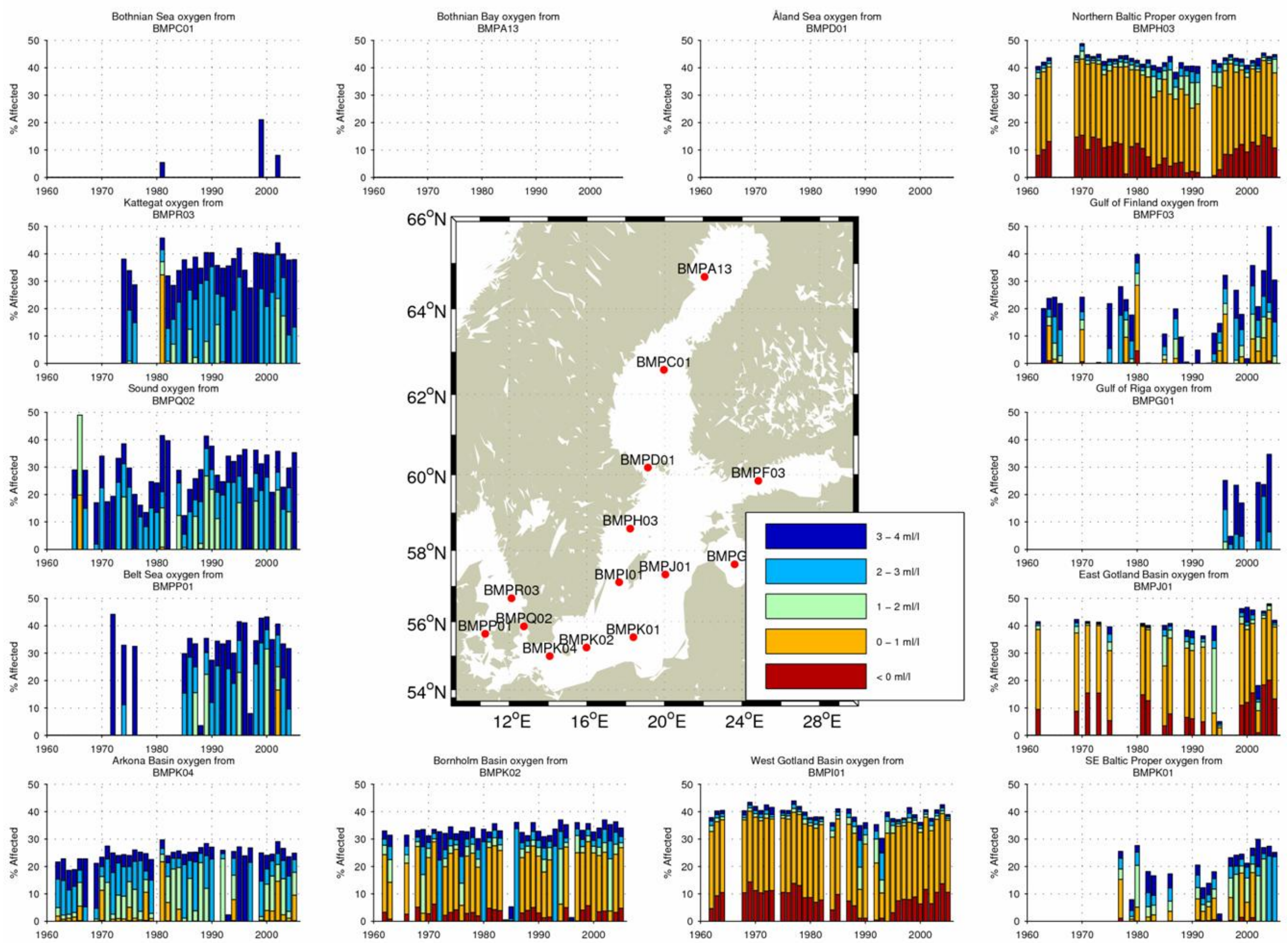


Time series of winter stratification strength (presented as buoyancy frequency N2; blue lines) and also of depth of the strongest stratification (red lines). Error bars represent one standard deviation from the mean of all profiles that season, in that basin.

Figure 2. Time series of winter stratification strength (presented as buoyancy frequency N^2; blue lines) and also of depth of the strongest stratification (red lines). Error bars represent one standard deviation from the mean of all profiles that season, in that basin.

Pycnocline depth is an indicator of the deepwater volume in different basins of the Baltic Sea. Figure 2 presents the depth of maximum winter stratification, and also the strength of that stratification, based on calculations of the buoyancy frequency (a function of the change in density with depth). Winter stratification was used, so that the effect of thermal stratification (strong in summer) would not disturb the signal. Stratification strength is as expected: weakest in the Bothnian Bay and Gulf of Finland, and strongest in the Belt Sea and Öresund. Variability in pycnocline depth is great. The standard deviation of estimates within a season can be more than 20 metres, particularly where the stratification is weak, making it difficult to determine trends with any confidence. In the Baltic Proper however, it appears that stratification during winter 2005-6 was weaker than 2004/5, possibly due to the particularly cold winter.

For each of the basins, autumn (August, September and October) oxygen profiles from 1990 – 2005 were examined. Depths at which the oxygen concentration fell below 2 & 0 ml/l were calculated, and these values were interpreted in terms of the proportion of water in each basin affected by reduced oxygen levels. Results are presented as time series in Figure 3.



Bar charts showing autumn oxygen concentration as a proportion of the volume of the deep basins. Low oxygen concentrations are not a problem in the Gulf of Bothnia. The effect of the large inflows in 1993 – 1994, and also autumn 2002 – spring 2003 are apparent, particularly in the East Gotland Basin. The 2002-03 inflow only briefly benefited the Northern Baltic Proper. No effect is apparent in the West Gotland Basin.

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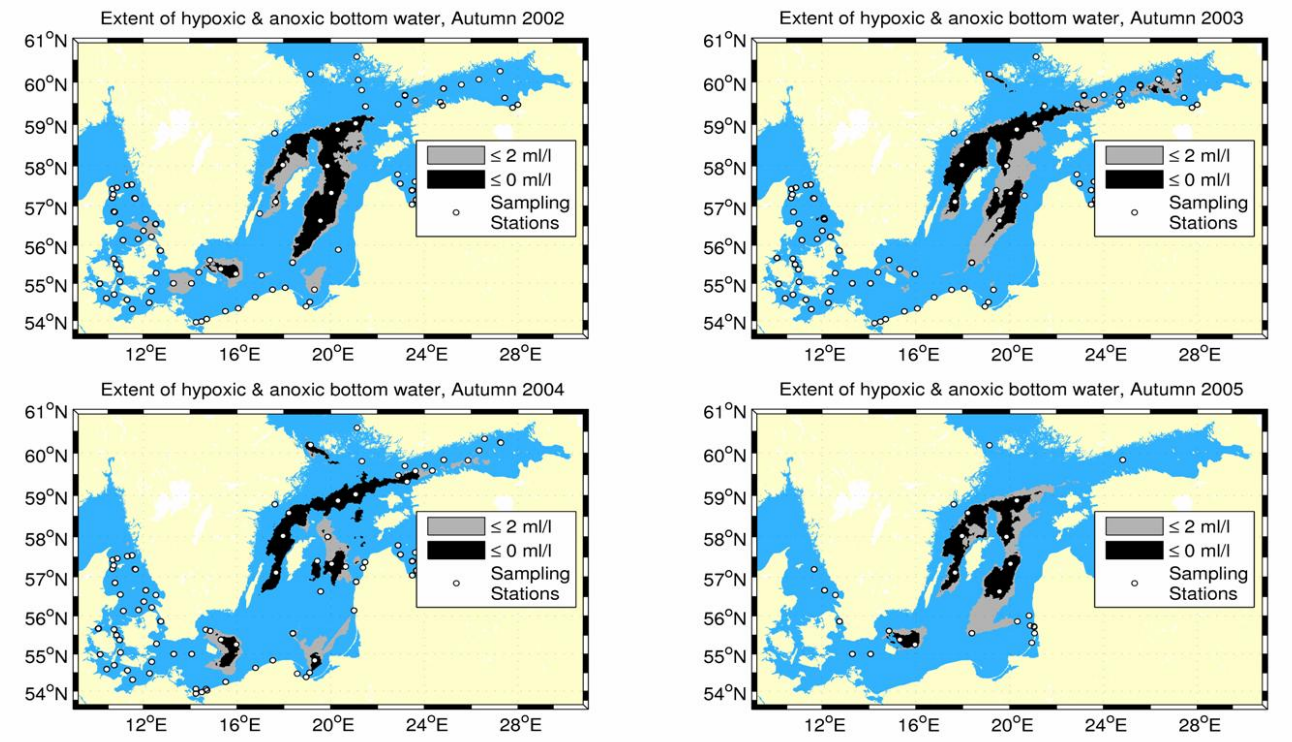
The deepwater basins in the Baltic Proper suffer severely from long-term oxygen depletion. Between 1991 and 1993, oxygen levels were 'only' 50% depleted (equivalent to 3 – 4 ml/l). The level of depletion increased steadily since, and from 1998, the oxygen concentration dropped to acutely toxic levels – with hydrogen sulphide (negative oxygen) observed in three of the four years. The region least affected is the Gulf of Bothnia, where there is weak stratification and relatively little biological activity. Samples taken in 2002 indicated slight oxygen deficiency (below 4 ml/l, or 5.7 mg/l) in the basin, though this was not repeated in 2003.

All basins of the Baltic Proper show a minimum in oxygen deficiency between 1992 and 1994. This may be correlated with the inflow of new, oxygenated saline water from the Kattegat, spreading through the Southern Baltic Proper, and then into the deep regions of the other basins. The late 2002 – spring 2003 inflows had a similar effect. Deep-water oxygen levels were improved throughout the Southern Baltic Proper and into the East Gotland Basin.

The East Gotland Basin was the worst affected by hypoxia/anoxia, with between almost 40% of the total basin volume suffering reduced oxygen levels, and almost 30% having acute toxicity between 1998 and 2001. Hydrogen sulphide was present in 10% of the water in 2001. The 2002-3 inflows halved this amount. Hypoxia continues to affect a further 15% of the basin volume. The ventilation of the East Gotland Basin has not extended further however. Anoxia affects almost 30% of the Northern Baltic Proper, and 5% of both the West Gotland Basin and the Gulf of Finland.

Figure 4 shows the regional distribution of the bottom areas where oxygen concentrations are below the critical level of 2 ml/l. The spatial change over time follows the changes discussed above. The large saltwater inflows during 1993 and 1994 oxygenated the bottom waters in the Baltic Proper. However, due to the lack of any further inflow events and the strong stratification built up by the inflows, the oxygen levels decrease again due to a too large sedimentation of organic material in comparison to the oxygen transported into the deep waters. This process was repeated with the winter 2002-3 inflows, though at a smaller scale. The Northern Baltic Proper and Gulf of Finland now appear to have benefited from this ventilation (although this judgment is based on few data points). Conditions in both the East and West Gotland Basins have worsened.



Estimates of the extent of hypoxic (oxygen content less than 2 ml/l) and anoxic (oxygen content nil; often with presence of hydrogen sulphide) in Autumn 2002 - 2005. The East Gotland Basin shows a dramatic improvement in Autumn 2003 compared with 2002, though the amount of hydrogen sulphide in the East Gotland Basin has subsequently increased.

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For oxygen in the deep waters and water exchange between the Baltic Sea and the North Sea, see also Indicator Report: Water exchange between the Baltic Sea and the North Sea and conditions in the deep basins

Summary

The Autumn 2002 – Spring 2003 saline inflows had a positive effect on the oxygen conditions in the deep basins of the Baltic Proper, though the effect appears to be coming to an end, with conditions returning to their previous status. Hydrogen sulphide has returned to the Bornholm Basin (though at present only during autumn) and is spreading in the East Gotland Basin. The Northern Baltic Proper and West Gotland Basin are badly affected by hydrogen sulphide.

The delicate relations between available nutrients, biomass, stratification, water exchange and oxygen levels is unfortunately not well balanced in many of the Baltic Sea sub-regions, leading to reduced bio-diversity, fish recruitment and water quality status.

Data

This study has made use of HELCOM data provided by the Baltic marine institutions through ICES. These have been complemented with additional data (particularly after 1999), kindly supplied by the following institutes:

- Swedish Meteorological and Hydrological Institute (SMHI)
- Finnish Institute for Marine Research (FIMR)
- Danish Environmental Research Institute (DMU)

For reference purposes, please cite this Baltic Sea environment fact sheet as follows:

[Author's name(s)], [Year]. [Baltic Sea environment fact sheet title]. HELCOM Baltic Sea Environment Fact Sheets. Online. [Date Viewed], http://www.helcom.fi/baltic-sea-trends/environment-fact-sheets/.