Hydrography and Oxygen in the Deep Basins

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Key Message

The Baltic Sea is a sensitive sea area. The region is characterised by its natural formation as an enclosed estuary with high freshwater input and restricted access to oceanic high saline water. The stratification and fjord-like conditions, in combination with eutrophication and other factors, form the basis for a problematic oxygen situation in the deep water.

Anoxic conditions are characterised by the total absence of oxygen. When all oxygen is consumed by microbial processes hydrogen sulphide (H_2S) is formed, which is toxic for all higher marine life. Anoxic conditions lead to release of phosphate and silicate from the sediments to the water column, which, due to vertical mixing, can reach the surface layer and the photic zone. High concentrations of phosphate favour phytoplankton growth, especially cyanobacteria in the Baltic Sea during summer.

- The area of the central Baltic affected by hypoxia (oxygen deficiency) and anoxia (absence of oxygen) remains very high.
- Deep water salinity remains high in the Baltic Proper, which hampers vertical mixing. Hydrogen sulphide is present in the deep water of the East Gotland Basin, the Northern Baltic Proper and West Gotland Basin.
- The delicate relations between available nutrients, biomass, stratification, water exchange and oxygen levels are not balanced in many of the Baltic Sea sub-regions, leading to reduced bio-diversity, fish recruitment and water quality status.

Results and Assessment

From the end of the 19th century till the 1990s the oxygen situation in the Baltic Sea deep basins was characterized by varying good and bad conditions. In 1999 there was a distinct regime shift and thereafter bottom areas with completely anoxic conditions have increased and are now constantly elevated to levels only observed occasionally before.

The inflows to the Baltic Sea that occurred in recent years have only resulted in temporary improvement of oxygen conditions in the southern Baltic. No inflows have been large enough to reach and improve oxygen levels in the deep-water areas around Gotland, except for a few short lasting events.

The causes and consequences of the extreme oxygen conditions observed since 1999, is currently not fully understood. However, there are several possible causes that may interact such as changing wind conditions, changes in the frequency and nature of inflows, increased load of organic material to the deep water, changes in stratification, vertical mixing and runoff.

Surface winter salinity (Figure 1) has remained fairly constant in the Baltic Proper since 1990, around 7 psu from the Arkona Basin to the Northern Baltic Proper. In the Eastern Gotland Basin there has been a decrease in surface salinity since 2011. In the Gulf of Bothnia salinity in the surface water has decreased slightly. Deep water salinity levels in the Bornholm Basin continue to decrease from the 2004 peak. In the south eastern Baltic Proper, Eastern Gotland Basin and Northern Baltic Proper deep water salinity remains high, and are still higher than after the inflows of 1992 – 1993, partly due to the inflow 2003, although there has been a small decrease during the last few years. In the Western Gotland Basin there has been a continuous increase since 1993. The difference between surface and deep water salinity, in the main part of the Baltic Proper, is much greater than at the start of the 1990s, and this will hinder vertical mixing, which could otherwise have oxygenated at least some of the sea floor. There have been some changes in the strength of the stratification as well as in depth to the halocline. However it is hard to find any significant trends in these parameters since the yearly variations are very large.

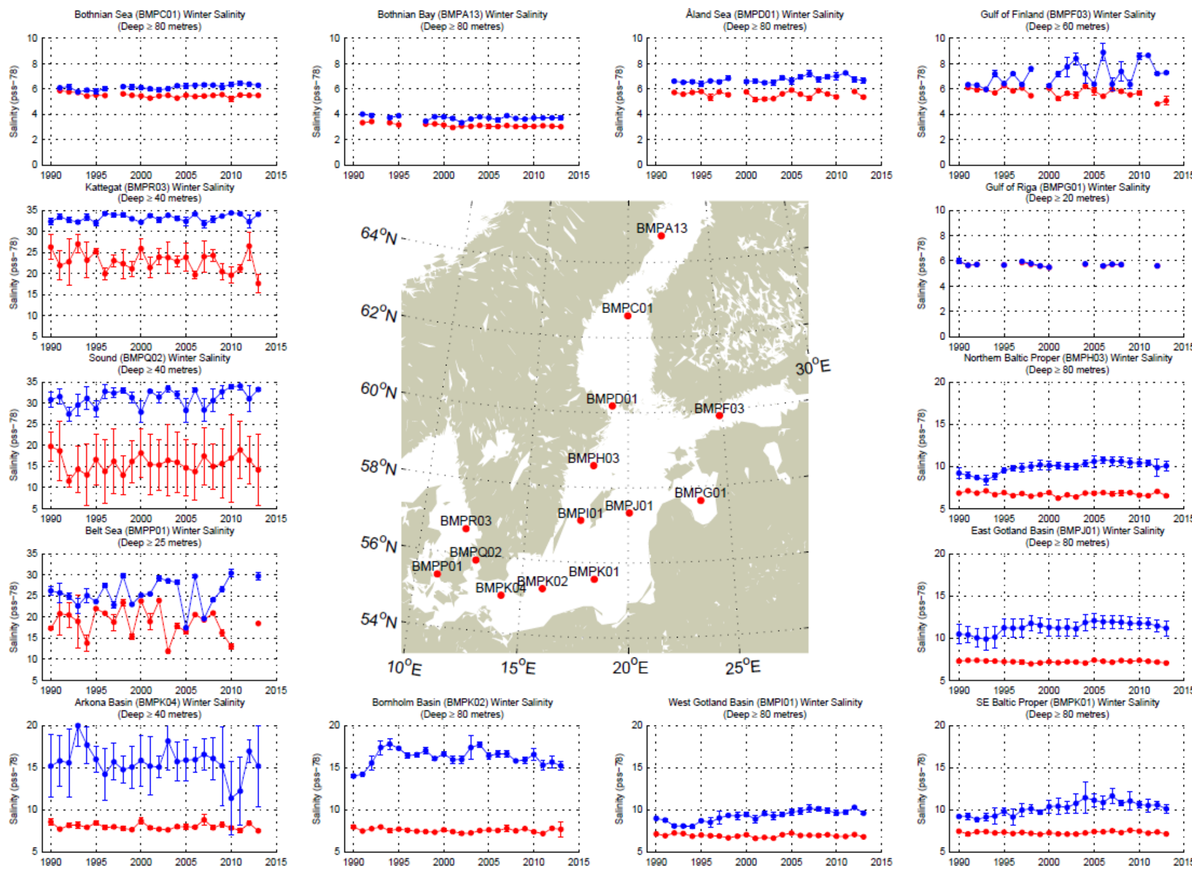

Figure 1. Time series of winter (November – March), surface (< 10 m; red) and deep-water (blue) salinity in the Baltic, 1990 - 2013.

The deep-water basins in the Baltic Proper suffer severely from long-term oxygen depletion. Inflows from the North Sea are currently the principle source of oxygen in the deep water. Between 1991 and 1993, at the end of a long stagnation period, a series of inflows finally oxygenated the deep water, to the extent that hydrogen sulphide had almost disappeared from the deep basins around Gotland. In the Bornholm Basin, levels were above 2 ml/l throughout the water column. This inflow, however, also strengthened the stratification of the deep basins, reducing vertical mixing, and, despite the smaller 2002 - 03 inflows, hydrogen sulphide has returned, and now affects more than 15% of the Baltic Proper including the Gulf of Riga and the Gulf of Finland. In this area, around 30% of the bottom water has oxygen levels below 2 ml/l. This has an impact on benthic and demersal fishes, such as cod, which prey upon benthic animals.

In the Arkona Basin anoxia is a sparse phenomenon, while in the Bornholm Basin it is a more seasonal feature. With the exception of the inflow years 1992 - 93, the basin volume affected by levels below 1 ml/l has remained rather constant since the second half of the 1990s. The offshore Gulf of Bothnia, including the Åland Sea does not suffer from low oxygen levels.

For each of the basins, autumn (August, September and October) oxygen profiles from 1990 - 2013 have been examined. Depths at which the oxygen concentrations were found within certain limits (<0; 0 – 1; 1 – 2; 2 – 3; 3 – 4 ml/l) were calculated, and these values were interpreted in terms of volume of water in each basin affected by reduced oxygen levels as a percentage of the total basin volume. Results are presented as time series in Figure 2.

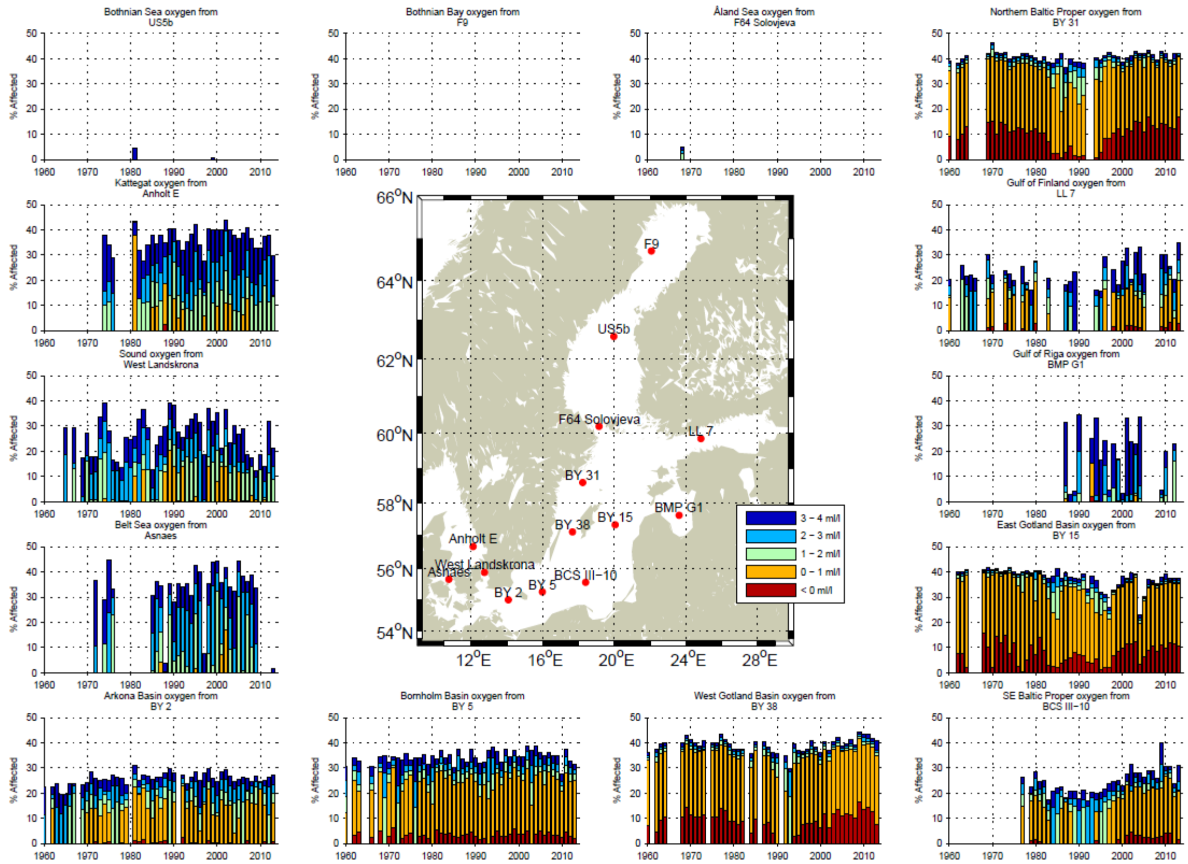

Figure 2. Bar charts showing autumn oxygen concentrations as a proportion of the volume of the deep basins. Low oxygen concentrations are not a problem in the Gulf of Bothnia. The effect of the large inflows in 1993 – 1994, and also autumn 2002 – spring 2003 are apparent, particularly in the East Gotland Basin. The 2002 – 03 inflow only briefly benefitted the Northern Baltic Proper. No effect is apparent in the West Gotland Basin.

Figure 3 shows the regional distribution of the bottom areas where oxygen concentrations are below the critical level of 2 ml/l. Since the inflows of 1992 - 93, there has been no significant ventilation of the deep water in the Baltic Proper. The oxygen has been consumed across an increasing area. Hydrogen sulphide exists in a large area of the East Gotland Basin below about 125 metres, and below 70 to 90 metres in the West Gotland Basin and Northern Baltic Proper. The deep anoxic water even extends into the Gulf of Finland, although the volume of water affected (Figure 2) is not great. This deep, more saline, water does not make it over the sill and into the Gulf of Bothnia. As a result, despite its depth, the stratification is weak and the Åland Sea remains well oxygenated, even during autumn.

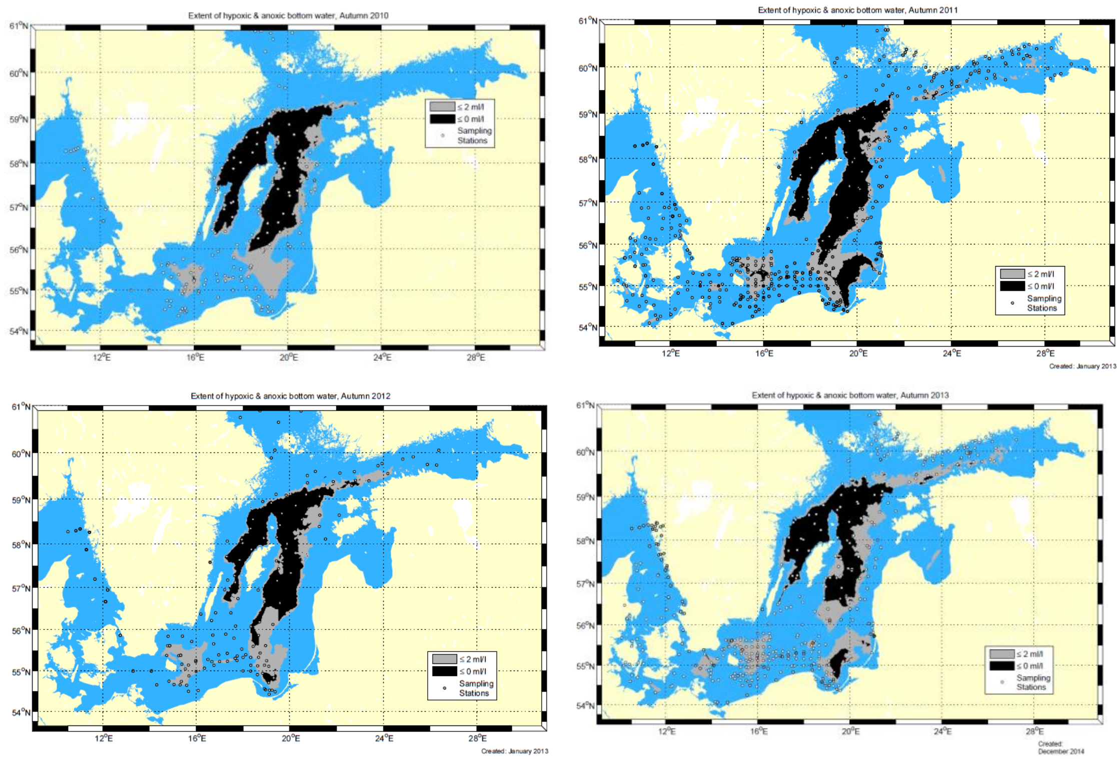

Figure 3. Estimates of the extent of hypoxic (oxygen content less than 2 ml/l) and anoxic (oxygen content nil; often with presence of hydrogen sulphide) in autumn 2011 – 2014. There has been a steady increase in the area affected by hydrogen sulphide in the East and West Gotland Basins, the Northern Baltic Proper and the outer Gulf of Finland.

For more information on oxygen depletion in the deep waters of the Baltic Sea, see Hansson and Andersson 2013.

Relevance of oxygen depletion and stratification as indicators 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 eggs and larvae are dependent on water with salinity and oxygen levels above 11 psu and 2 ml/l, respectively.
Baltic surface waters are strongly influenced by run-off of freshwater from land. Changes in run-off alter the surface salinity while inflows through the Belt Sea and Öresund control the salinity of the deep waters. The density difference between the upper and lower layers inhibits mixing between surface and deep water, thus preventing the oxygenated surface water penetrating to depths, as well as hindering the transfer of phosphorus (which is abundant in the deep water) to the surface waters. The strength of the stratification is indicated by the salinity difference between the surface and deep water. Figure 1 shows the difference between surface and deep water winter salinity.

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 water has sunk, and is decomposed by bacteria. This process consumes oxygen. When oxygen concentrations fall below 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 south-western Baltic Proper, Danish Straits and Kattegat oxygen depletion is a seasonal phenomenon which occurs during autumn. The deep-water basins in the inner Baltic Proper suffer, however, 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 transported to the deep waters of the Baltic by the saline inflows that come through the Sound and Belt Sea. Hydrographic measurements (temperature and salinity) make it possible 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.

References

Hansson M. and L. Andersson, 2013, Oxygen Survey in the Baltic Sea 2013 -Extent of anoxia and hypoxia, 1960 - 2013, SMHI Report No. 49, 2013. Available online at http://www.smhi.se/polopoly_fs/1.35317!Oxygen_timeseries_1960_2013_final.pdf

Data

This study has made use of HELCOM data provided by the Baltic marine institutions through ICES.