Hydrography and oxygen in the deep basins

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Key message:

The area of the central Baltic affected by hypoxia (oxygen deficiency) and anoxia (absence of oxygen) remains very high, although a slight improvement (reduction) in the anoxic area has occurred in the last three years.

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 assessments

Surface salinity (Figure 1) has remained fairly constant in the Baltic Proper since 1990, at around 7 [psu] from the Arkona Basin (between Sweden and Germany) to the Northern Baltic Proper (between Gotland and Åland). Salinity has decreased slightly in the Bothnian Sea - from about 6 in 1990 to 5.5 now. Deep water salinity levels in winter 2009 - 10 continue to decrease from the 2003 peak in the Bornholm Basin. In the south eastern Baltic Proper, East Gotland Basin and Northern Baltic Proper deep water salinity remains high, and are higher than after the inflows of 1992 - 1993. The difference between surface and deep water salinity is much greater than at the start of the 1990s, and this can only hinder vertical mixing, which could otherwise have oxygenated at least some of the sea floor.

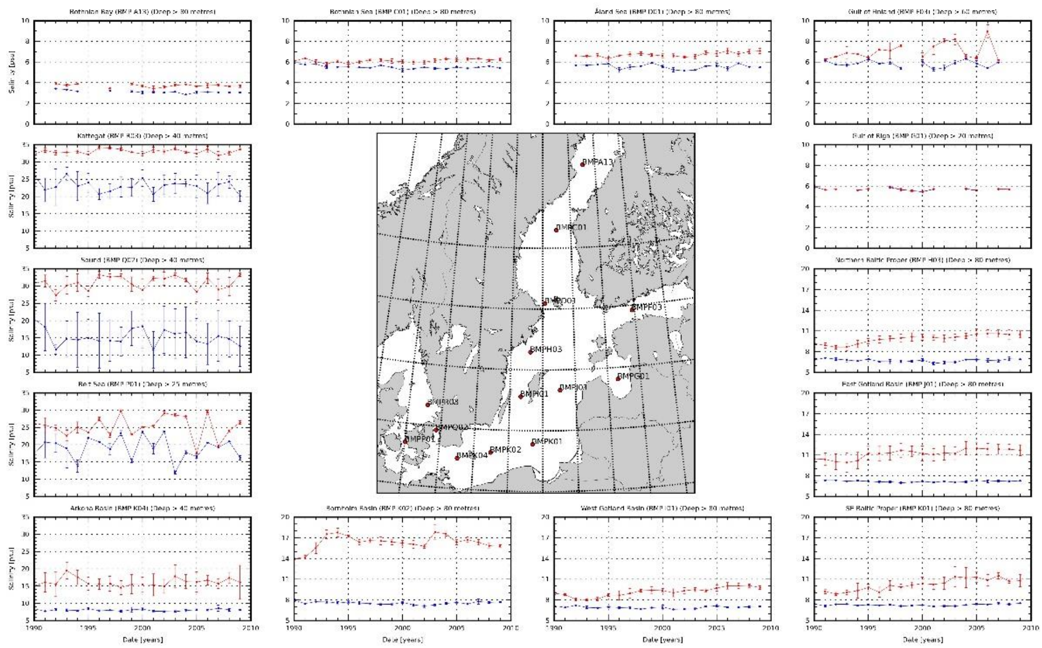

Figure 1. Time series of winter surface (< 10 m; red) and deep-water (blue) salinity in the Baltic, 1990 onwards.

Since 1990, stratification strength (Figure 2) has increased in the Northern Baltic Proper (station BMP H03) and is high in the Eastern Gotland Basin too. In the East Gotland Basin, the depth of the maximum stratification has decreased since 1995, indicating an increase in bottom water volume. The opposite change occurs in the Gulf of Finland, where the deepening pycnocline has reduced the volume of bottom water. The strength of stratification has also increased, hindering vertical mixing. As the deep water of the Gulf of Finland is prone to seasonal hypoxia, this reduction in volume indicates an increasing vulnerability, as the volume of oxygen available in the deep water also decreases.

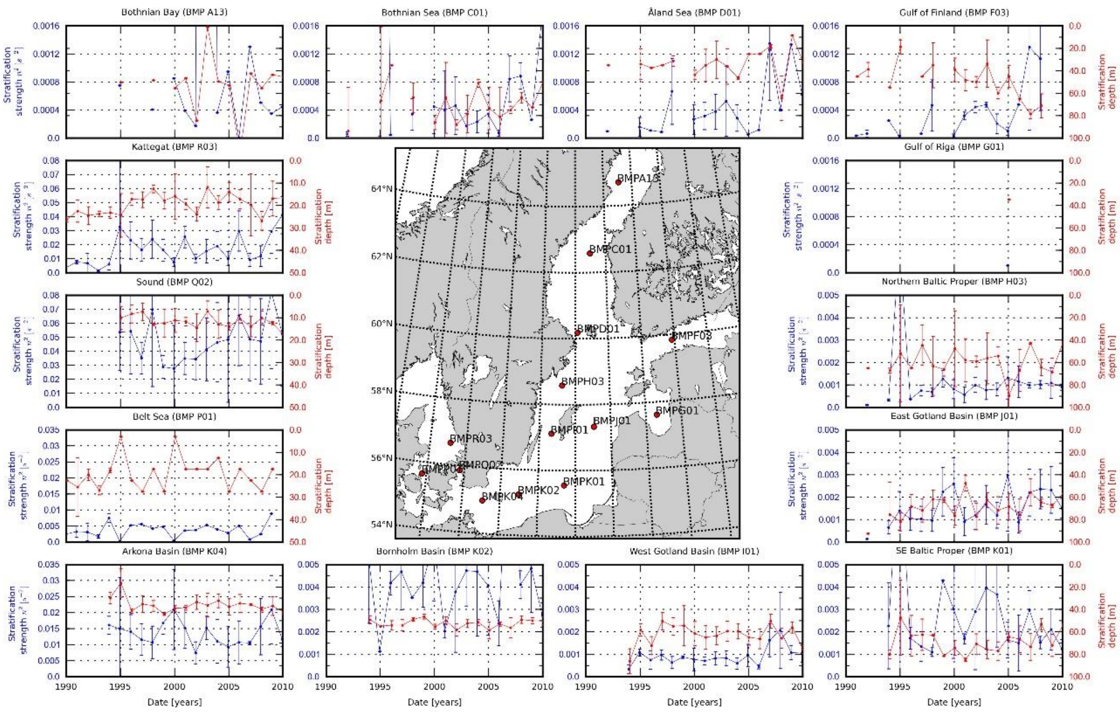

Figure 2. Time series of winter stratification strength (presented as buoyancy frequency N2; blue lines) and also of depth of the strongest stratification (red lines). Error bars represent one standard deviation from the mean of all profiles that season, in that basin**.**

The deepwater 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 also strengthened the stratification of the deep basins however, reducing vertical mixing, and despite the smaller 2002 - 3 inflows, hydrogen sulphide has returned, and now affects more than 10% of both the East and West Gotland Basins and Northern Baltic Proper. At this oxygen concentration, phosphorus is released from bottom sediments, which has the potential to cause even worse eutrophication should it enter the surface waters. In all these basins, around 40% of the water has oxygen levels below 1 ml/l. This is acutely toxic to benthic fauna, and the sea bottoms covered by this water can be considered dead. This has an impact on benthic and demersal fishes, such as cod, which prey upon benthic animals.

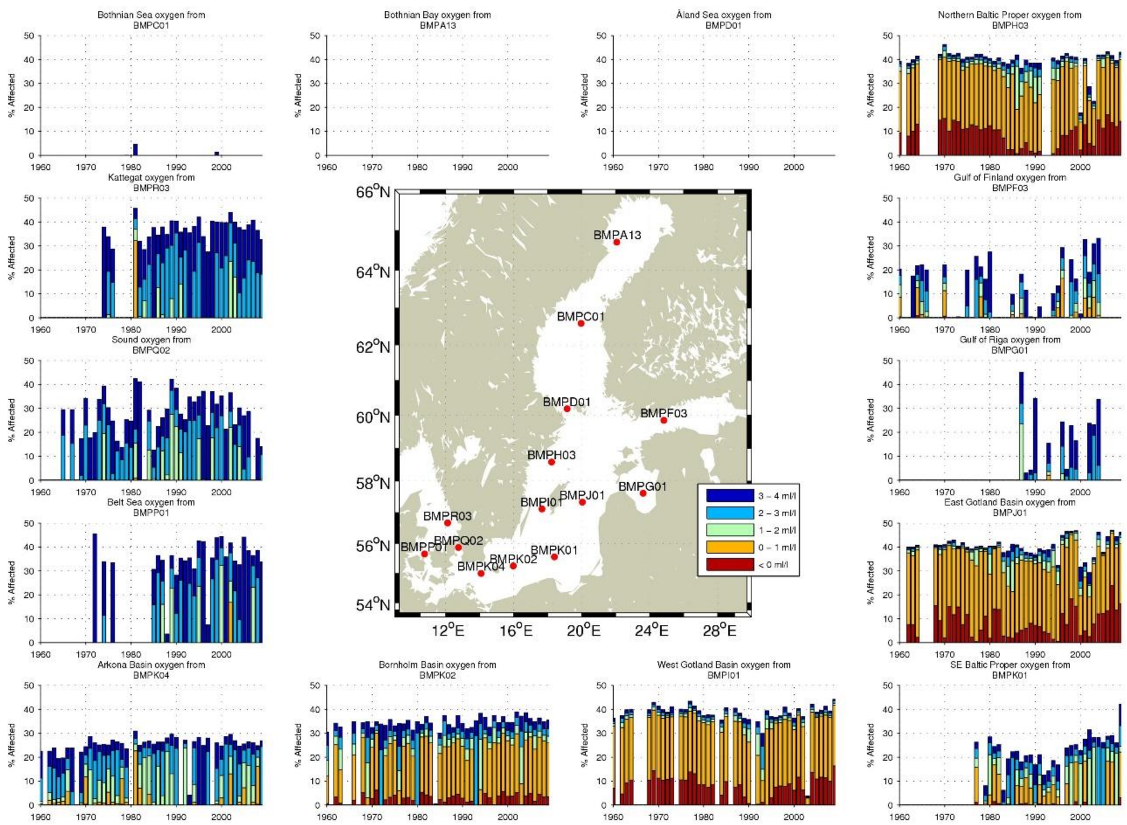

Figure 3. Time series of the development of hypoxia and anoxia at monitoring stations in the Baltic.

In the Bornholm Basin, anoxia is more seasonal. With the exception of the inflow years 1992 - 3, the basin volume affected by levels below 1 ml/l has remained rather constant since the second half of the 1990s. Between the Arkona Basin and the Kattegat, autumn oxygen levels were normal for the autumn, with some depletion (between 1 - 2 ml/l) in Arkona and the Kattegat, though not the Belt Sea and Sound. The offshore Gulf of Bothnia, including the Åland Sea does not suffer from low oxygen levels.

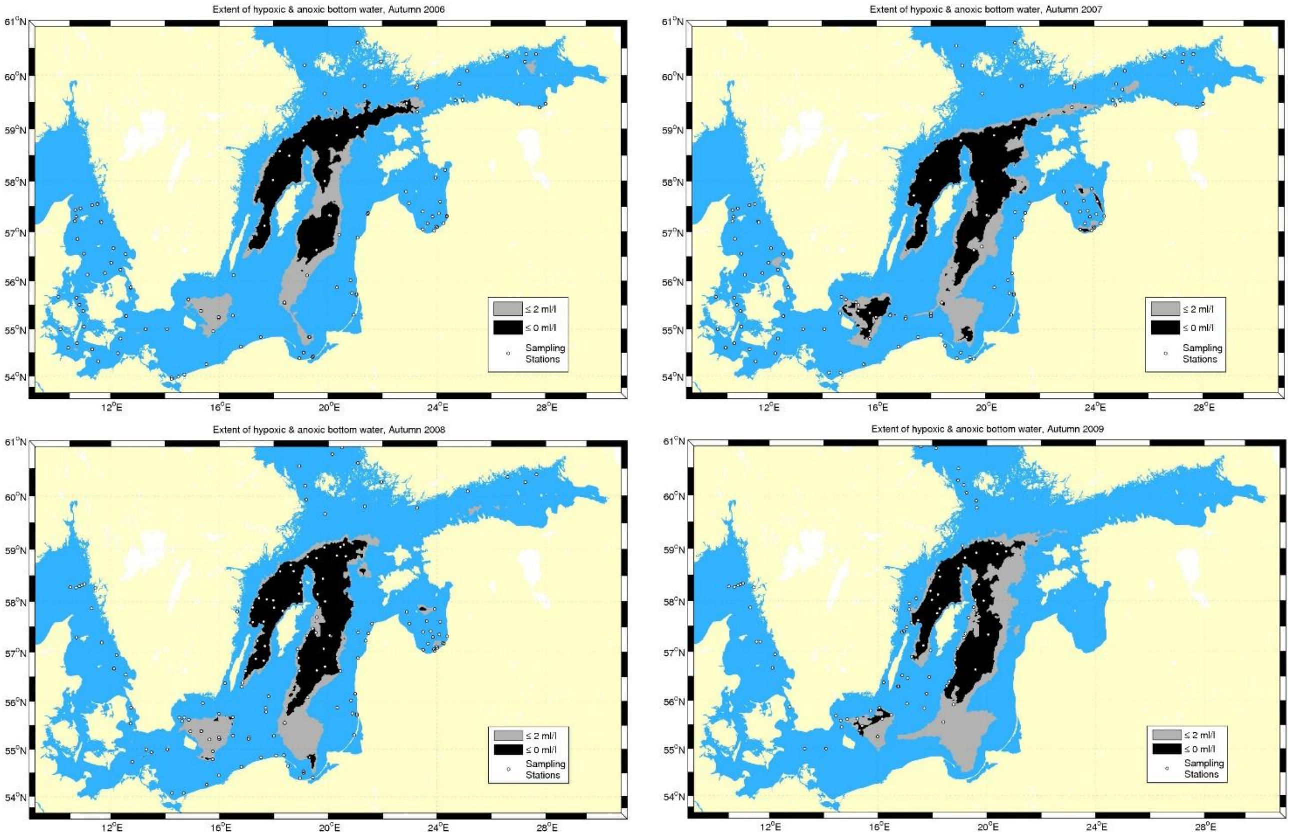

Figure 4. Maps of the extent of hypoxic and anoxic water in the Baltic Proper, 2006 - 2009.

Figure 4 shows the regional distribution of the bottom areas where oxygen concentrations are below the critical level of 2 ml/l since 2006. Since the inflows of 2002 - 3, 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 metres in the West Gotland Basin and Northern Baltic Proper. The deep anoxic water even extends up into the Gulf of Finland, although the volume of water affected (Figure 3) is not great. This deep water does not make it over the sill and into the Gulf of Bothnia. As a result, despite its depth, the Åland Sea remains well oxygenated, even during autumn.

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

Relevance of the indicator for describing developments in the environment

Salinity, temperature and oxygen are physical supporting parameters that help explain other ecosystem changes. "Natural oxygen levels" are a specific Ecological Quality Objective within the Baltic Sea Action Plan.

Temperature, salinity and oxygen constrain biodiversity, fish recruitment and water quality. For example, cod larvae are dependent on water with salinity and oxygen levels above 11 psu and 2.1 ml/l, respectively, which only occur regularly in the Bornholm Basin at present. Oxygen concentrations are in addition both an indicator and driver of nutrient enrichment (eutrophication): A eutrophic system is characterized by excessive primary production. When this production decays, oxygen is consumed. If this oxygen is not replenished, then oxygen levels fall, leading to a degradation of the benthic community structure, possible fish kills and eventually the formation of dead bottoms. With the onset of anoxia, phosphorus is released from bottom sediment, which can favour the formation of cyanobacteria blooms in the surface waters.

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 and depth of the winter stratification. In the period leading up to the large salt water inflow in 1993, weakening stratification in the Baltic caused a reduction in the extent of the Baltic Sea dead zone.
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. Figure 2 shows the strength of the pycnocline (in terms of the buoyancy frequency) and also its depth.

Oxygen depletion is widely used as an indicator for the indirect effects of nutrient enrichment. Eutrophication leads to increased primary productivity. As this production decays, oxygen is consumed. Oxygen levels above 4.5 ml/l are considered to cause little problem; levels below this cause increasing stress to most organisms. Below 2.1 ml/l, cod eggs die. Recurrent episodes of low oxygen concentration leads to the extinction of benthic communities, and their replacement by bacterial mats. At very low oxygen concentrations, large amounts of phosphate are released from bottom sediment, which can worsen eutrophication, stimulate cyanobacterial blooms, and lead to yet lower oxygen concentrations in future.

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.

For each of the basins, autumn (August, September and October) oxygen profiles from 1990 – 2006 were examined. Depths at which the oxygen concentration fell within certain limits (<0; 0 – 1;1 – 2.1; 2.1 – 3.5; 3.5 - 5 ml/l) were calculated, and these values were interpreted in terms of the volume of water in each basin affected by reduced oxygen levels as a percentage of the total basin volume. Figure 3 shows the development of hypoxia with time at monitoring stations in the Baltic.

Figure 4 shows the extent of anoxic (water totally free of oxygen) and hypoxic bottoms in the Baltic during the past four years, while figure 5 provides a summary of this information, showing the development of the anoxic and hypoxic areas since the 1960s.

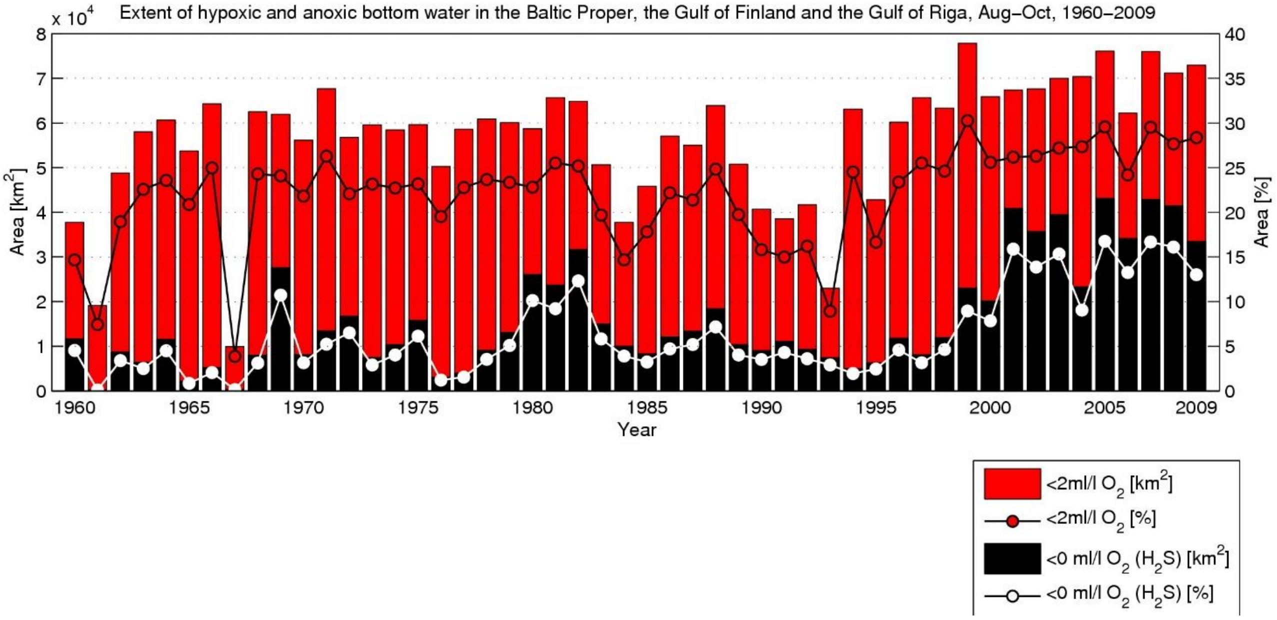

Figure 5. Extent of hypoxic and anoxic bottom water in the Baltic Proper, Gulf of Finland and Gulf of Riga, August to October 1960 - 2009

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, these inflows strengthen the stratification of the Baltic Proper however, which hinders the vertical transport of oxygen to the deep water. Hydrographic measurements (temperature and salinity) allow us to trace the 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.

Data

This study has made use of HELCOM data provided by the Baltic marine institutions through ICES. These have been complemented with additional data harvested through the EU project SeaDataNet.

Oxygen concentrations are measured by water sample titration, in a way that is essentially unchanged since the 1880s. Among the skilled operators within the HELCOM Combine programme, each observation should be within about 1% of the 'true' oxygen concentration. Temperature and salinity are measured with reversing thermometers, salinometers and in-situ with CTD probes. Temperature samplers are required to be accurate to within +/-0.05°C, while salinity observations should be within +/-0.05 [psu], although in practice with modern equipment and laboratory procesures, better accuracies are obtained.

References

Hansson M., P. Axe and L. Andersson, 2009, 'Extent of anoxia and hypoxia in the Baltic Sea, 1960 - 2009', SMHI Report Mo 2009-214, available online at http://www.smhi.se/polopoly_fs/1.10354!Oxygen_timeseries_1960_2009.pdf

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