Hydrography and oxygen in the deep basins

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Key message

There has been a steady worsening of oxygen conditions in the deep basins of the Baltic Proper since the saline inflows of November 2002 – March 2003. Deep water salinity remains higher than the 1990 values in the Bornholm Basin and Baltic Proper.

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.

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.

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

Deep water salinity levels in winter 2006 – 7 in the Bornholm Basin, south eastern Baltic Proper, East Gotland Basin and Northern Baltic Proper remain at the high level that has existed since the early 1990s, the end of the earlier stagnation period. Some of this saline deep water reached the Gulf of Finland and the Åland Sea during winter 2006 -7.

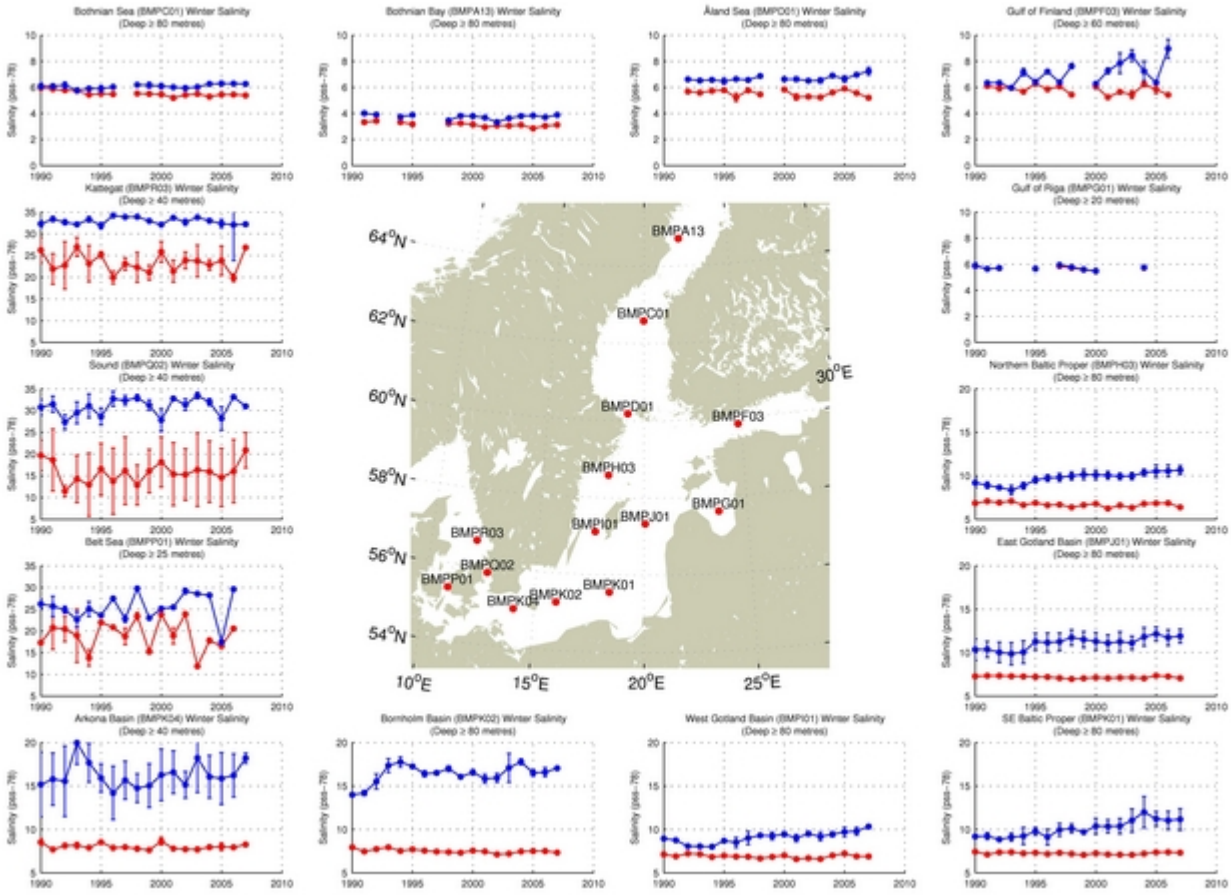

Figure 1 Time series of winter surface (< 10 m; red) and deep-water (blue) salinity in the Baltic Proper, 1990 – 2007.

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.

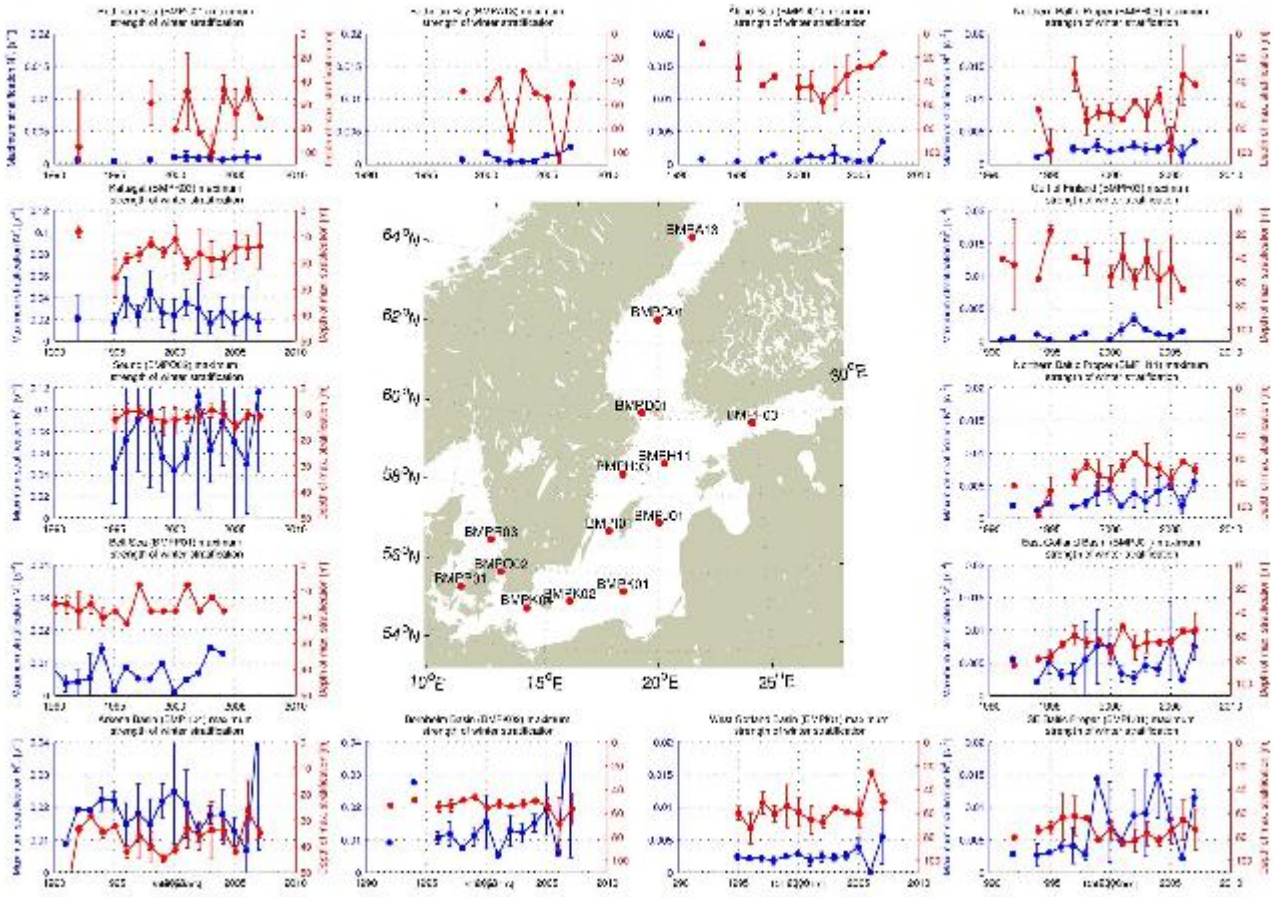

Figure 2. Time series of winter stratification strength (presented as buoyancy frequency N2; blue lines) and also of depth of the strongest stratification (red lines). Error bars represent one standard deviation from the mean of all profiles that season, in that basin. Click image to enlarge.

During winter 2006-7, the pycnocline depth increased in the Gulf of Finland. This indicates a decrease in the volume of the bottom water. This coincided with a strengthening of the pycnocline (to 2003 levels), which inhibits mixing between the deep and surface waters, and can indicate an increased vulnerability to seasonal anoxia. In the northern Baltic Proper and East Gotland Basin, the pycnocline depth has not changed significantly. In the west Gotland Basin, the Bornholm Basin and the Arkona Basin, winter 2006 – 7 was marked by very strong stratification, although the depth of maximum stratification was normal. This strong stratification was caused by stormy conditions during sampling which, in the Arkona Basin led to the water column being well mixed down to 35 metres. In the Bornholm Basin, there was no stratification above 55 metres. This situation is not typical.

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; 2 – 3; 3- 4 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. Results are presented as time series in Figure 3.

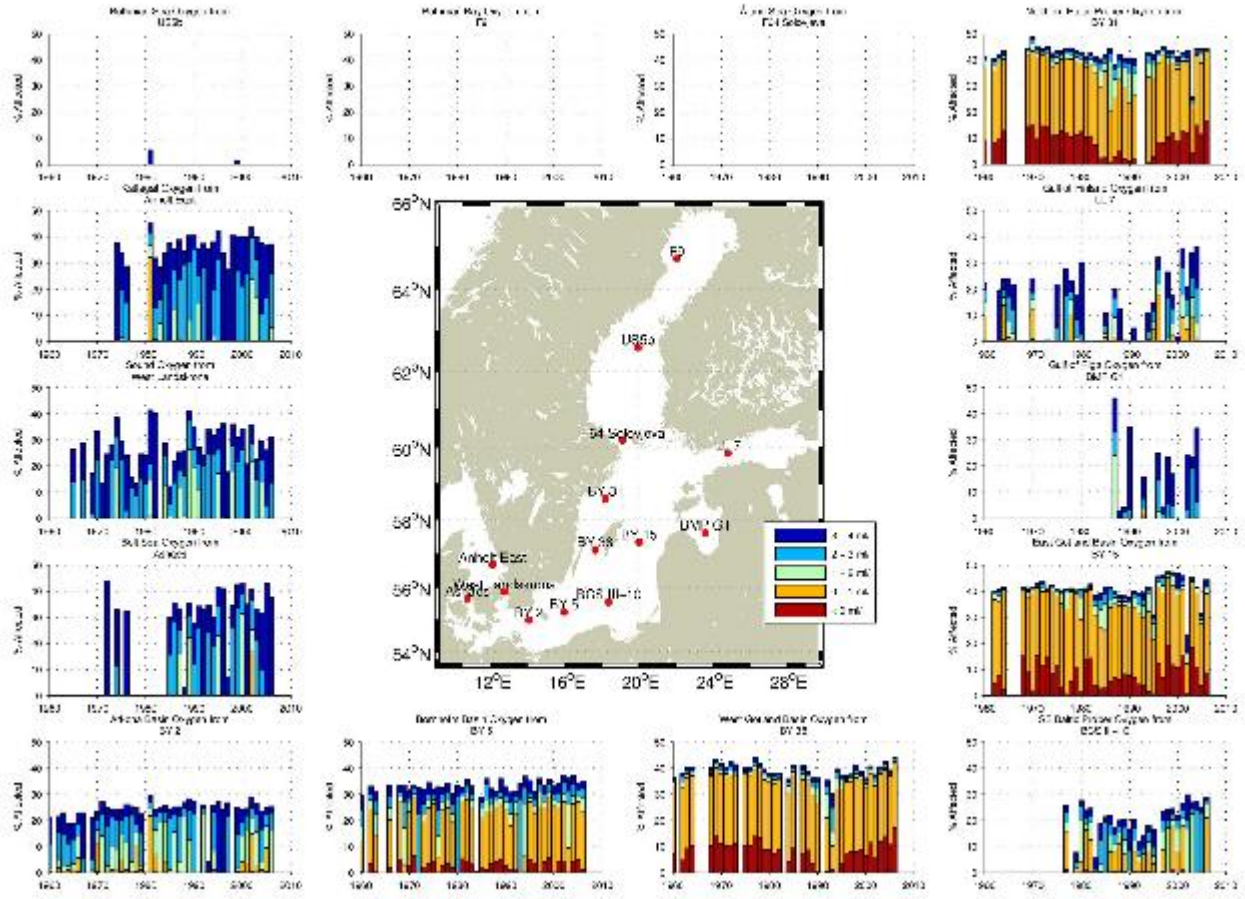

Figure 3. Bar charts showing autumn oxygen concentration as a proportion of the volume of the deep basins. Low oxygen concentrations are not a problem in the Gulf of Bothnia. The effect of the large inflows in 1993 – 1994, and also autumn 2002 – spring 2003 are apparent, particularly in the East Gotland Basin. The 2002-03 inflow only briefly benefited the Northern Baltic Proper. No effect is apparent in the West Gotland Basin. Click image to enlarge.

The deepwater basins in the Baltic Proper suffer severely from long-term oxygen depletion. Inflows from the North Sea are the principle source of oxygen in the deep water. Between 1991 and 1993, a series of inflows had oxygenated the deep water, so that hydrogen sulphide had almost gone from the deep basins around Gotland. In the Bornholm Basin, levels were above 2 ml/l throughout the water column. Since then, despite the smaller 2002 – 3 inflows, hydrogen sulphide has returned, and now affects almost 10% of the East Gotland Basin and 17% of the West Gotland Basin and Northern Baltic Proper (by volume). At this oxygen concentration, phosphorus is released from bottom sediments.

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.

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.

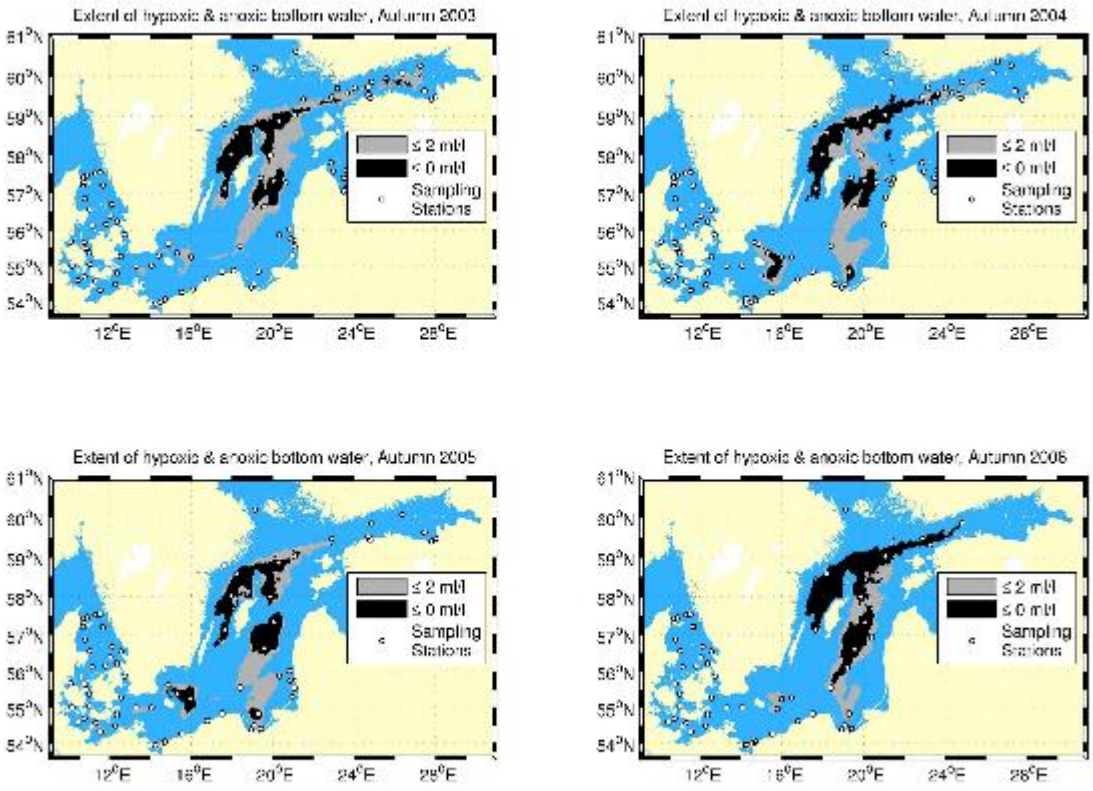

Figure 4. Estimates of the extent of hypoxic (oxygen content less than 2 ml/l) and anoxic (oxygen content nil; often with presence of hydrogen sulphide) in Autumn 2003 - 2006. There has been a steady increase in the area affected by hydrogen sulphide in the East and West Gotland Basins, the Norhtern Baltic Proper and the outer Gulf of Finland. Click image to enlarge.

Figure 4 shows the regional distribution of the bottom areas where oxygen concentrations are below the critical level of 2 ml/l. 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, 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

Summary
Deep water salinity remains high in the Baltic Proper. Hydrogen Sulphide is present in the deep water of the East Gotland Basin, the Northern Baltic Proper and West Gotland Basin, and even affects the western deep areas of the Gulf of Finland.

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)

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