Hydrography and oxygen in the deep basins

Author: Philip Axe, SMHI

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. Salinity in the Bornholm Basin and south-eastern Baltic Proper increased by about 2 psu.

Deep-water oxygen levels, from Arkona to the East Gotland Basin, were significantly better in autumn 2003 than in 2002. Conditions in the West Gotland Basin, Northern Baltic Proper and Gulf of Finland have worsened, with an increase in the extent of hydrogen sulphide.

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.

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

Time series of winter surface salinity between 1990 and 2004 (Figure 1) show a freshening of the upper 10 metres of the Baltic Proper. During the same period, deepwater salinity shows the opposite trend: Below 80 metres, salinity increased in the Eastern, Northern and Western Gotland basins of the Baltic Proper. The effect of the winter 2002 – 3 inflows is visible in the deep salinity data from Arkona, Bornholm and the eastern Southern Baltic Proper, with increases of up to 2 psu. No effect of the inflow was seen in the winter-averaged data from the East Gotland Deep until the winter 2003 - 2004.

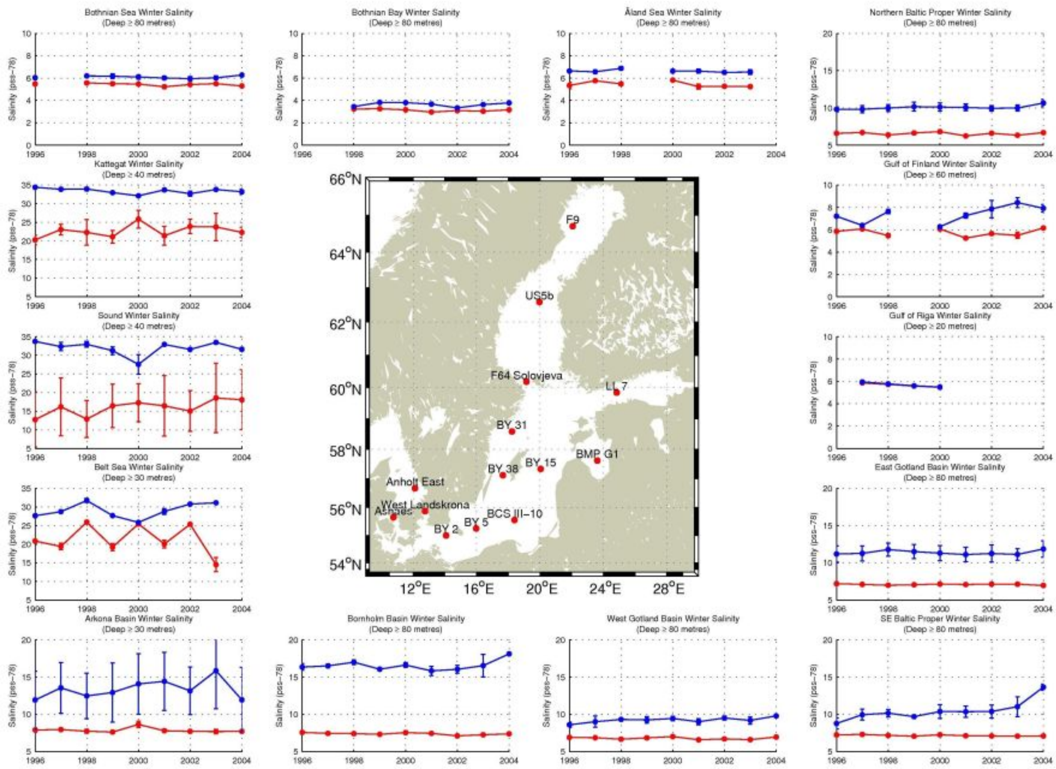

Figure 1. Time series of winter surface (< 10 m; red) and deep-water (blue) salinity in the Baltic Proper, 1996 – 2004. The effects of the winter 2002 – 2003 inflow are apparent in the deep waters from the Arkona Basin to the East Gotland Basin.

Pycnocline depth is an indicator of the deepwater volumes 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 any thermal stratification (present 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.

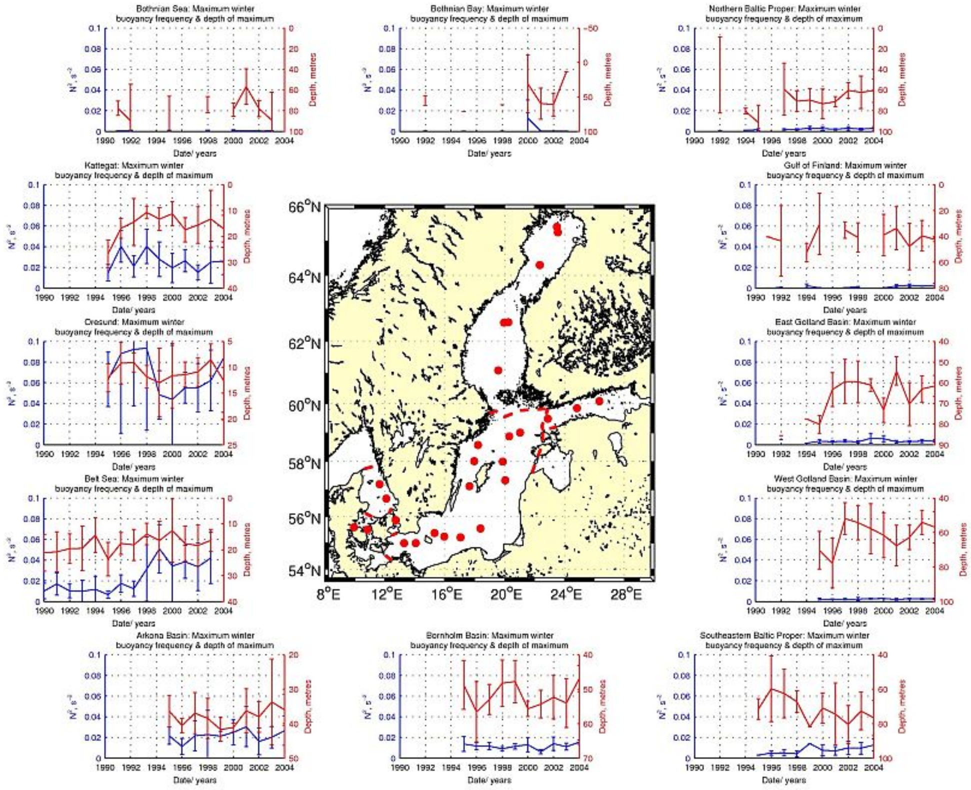

Figure 2. Time series of winter stratification strength (presented as buoyancy frequency N²; blue lines) and also of depth of the strongest stratification (red lines). Error bars represent one standard deviation from the mean of all profiles that season, in that basin.

For each of the basins, autumn (August, September and October) oxygen profiles from 1990 – 2003 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 the volume of each basin affected by reduced oxygen levels. Results are presented as time series in Figure 3. Red dots indicate the position of sampling stations.

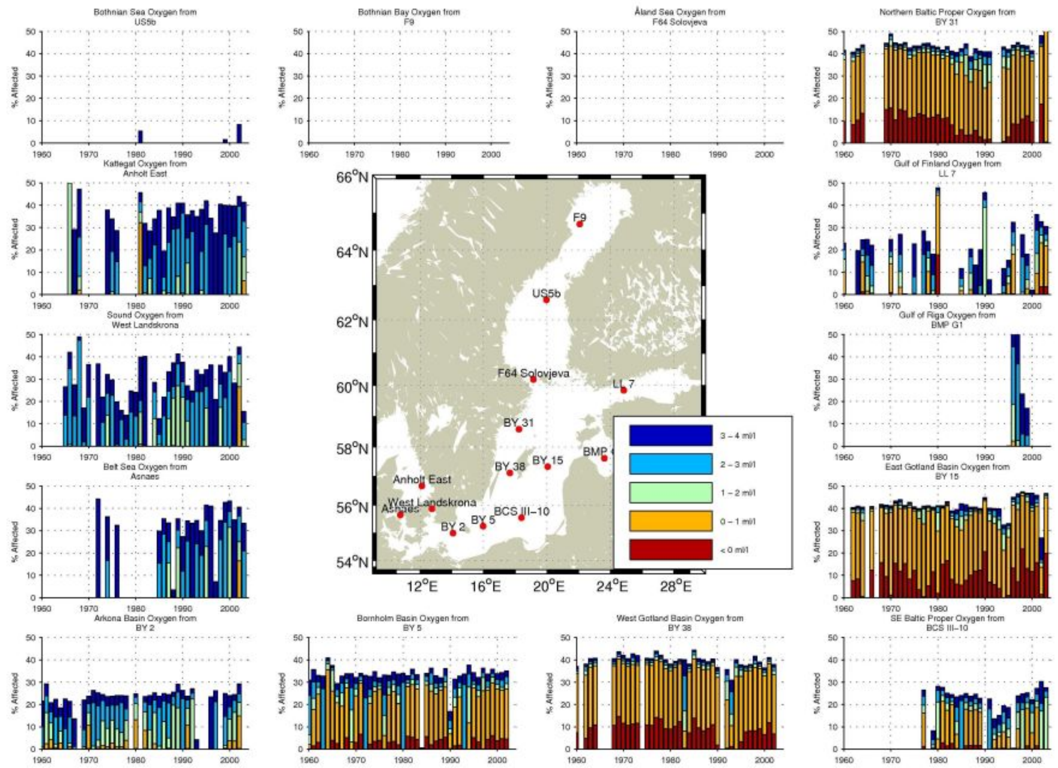

Figure 3. Bar charts showing autumn oxygen concentration as a proportion of the volume of the deep basins. The effect of the large inflows in 1993 – 1994, and also autumn 2002 – spring 2003 are apparent, particularly in the East Gotland Basin (Station BY15).

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 basin 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 has been repeated with the winter 2002-3 inflows, though ventilation of the deep basins has not extended beyond the East Gotland Basin.

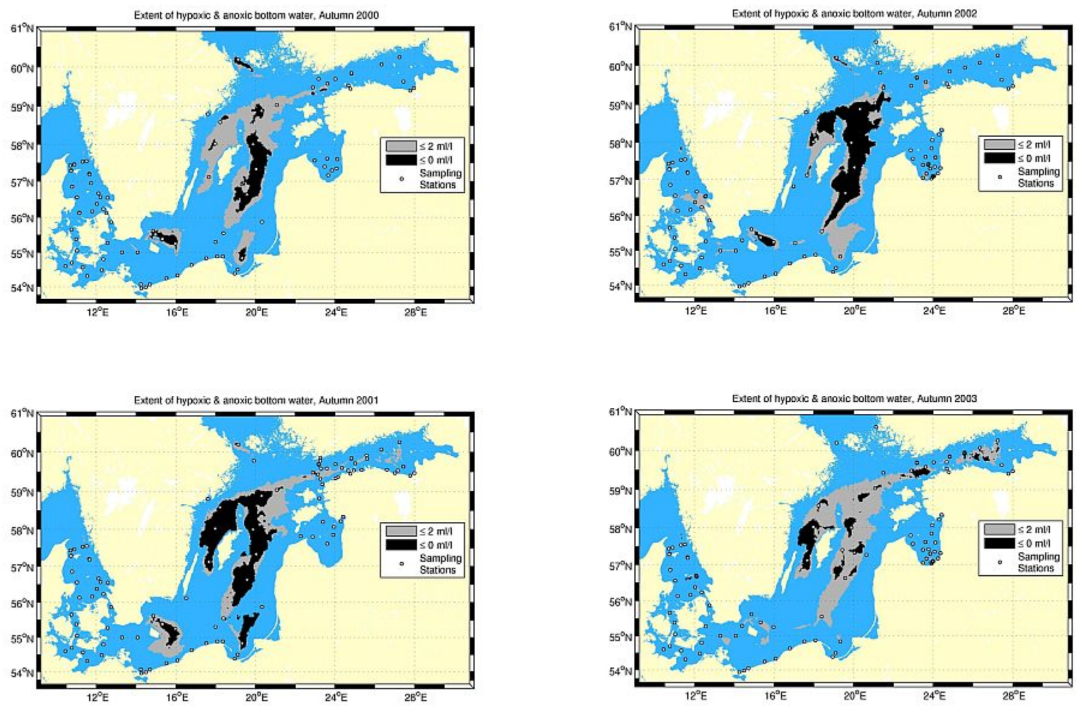

Figure 4. Extent of hypoxic and anoxic bottom water (oxygen content below 2 ml/l and 0 ml respectively) in Autumn 2000 - 2003.

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 have had a positive effect on the oxygen conditions in the deep basins of the Southern and Eastern Baltic. In the Southern Baltic Proper, oxygen levels are close 1995 levels, shortly after the last inflow. Hydrogen sulphide is still present in the East Gotland Basin, though in smaller amounts than in 2000 – 2002. The Northern Baltic Proper, West Gotland Basin and Gulf of Finland 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 the official HELCOM COMBINE-programme dataset (1996 - 2004) supplied by ICES. In addition, long time series (1960 -) came from the ICES data bank.

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/.