Hydrography and oxygen in the deep basins

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Key message

The saline inflows of November 2002 – March 2003 have caused major changes to the hydrographic conditions in the deep basins of the Baltic Proper. Comparing winter 2001-2, with winter 2002-3, the deep-water (between 80 and 90 m) salinity in the Bornholm Basin and south-eastern Baltic Proper had increased by about 1 psu (or 6%). The deep-water oxygen levels, from Arkona to the East Gotland Basin, are significantly better in autumn 2003 than in 2002, although the West Gotland Basin (and probably the Northern Baltic Proper) is still badly affected by hydrogen sulphide.

Areas suffering oxygen deficiency in the Kattegat and Belt Sea have increased since 1997 and 1998, respectively, and fish kills have occurred. Late summer and autumn 2002 were characterized by particularly severe oxygen depletion in these areas. This was caused, to a great extent, by extremely calm wind conditions, and the resulting lack of water exchange. In summer - autumn 2003, similar calm conditions did not occur for so long, and although the area was still affected by hypoxia, the effects were less severe than in 2002.

Surface salinity has decreased throughout the Baltic Proper since the start of the 1990s. The rate of decrease is greatest along the Swedish coast, and least (though still decreasing) in the south eastern Baltic Proper. Relevance of the indicator for describing developments in the environment.

Relevance of the indicator for describing developments in the environment

Indicators based on salinity, temperature and oxygen are presented in this report. The Indicators represent the average conditions of the Baltic Sea sub-regions, while single stations might show even worse conditions which are not shown here.

Salinity, temperature and oxygen are physical background parameters, constraining bio-diversity, fish recruitment and water quality in a semi-enclosed water body 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 land run-off of freshwater. 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 phosphorous (which is abundant in the deep water) to the surface waters. In some basins this limits the algal productivity. The strength of the stratification is indicated by the salinity difference between the surface and deepwater and by the depth of the pycnocline (**Figure 1**) i.e. the volume of the deepwater.

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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.

Results and assessment

Assessment

The pycnocline depth is an indicator of the deepwater volumes in different basins of the Baltic Sea. **Figure 1** 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. Data from the Baltic Proper are presented, because not all of the most recent (2003) data from outside this area are available yet. The stations shown are considered to be representative of the sub-basins that they lie in.

Between 1990 and 2001, the pycnocline depth decreased in the eastern and northern Baltic Proper, whereas in the southern and western Baltic Proper, it either increased or shows no clear trend (**Figure 1**). In the Arkona Basin and at BCSIII-10 (south-eastern Baltic Proper), the strength of stratification in winter 2002-3 is greater than in the previous winter. While this is probably due to the November 2002 – March ’03 inflows, no clear signal is seen in the Bornholm Deep.

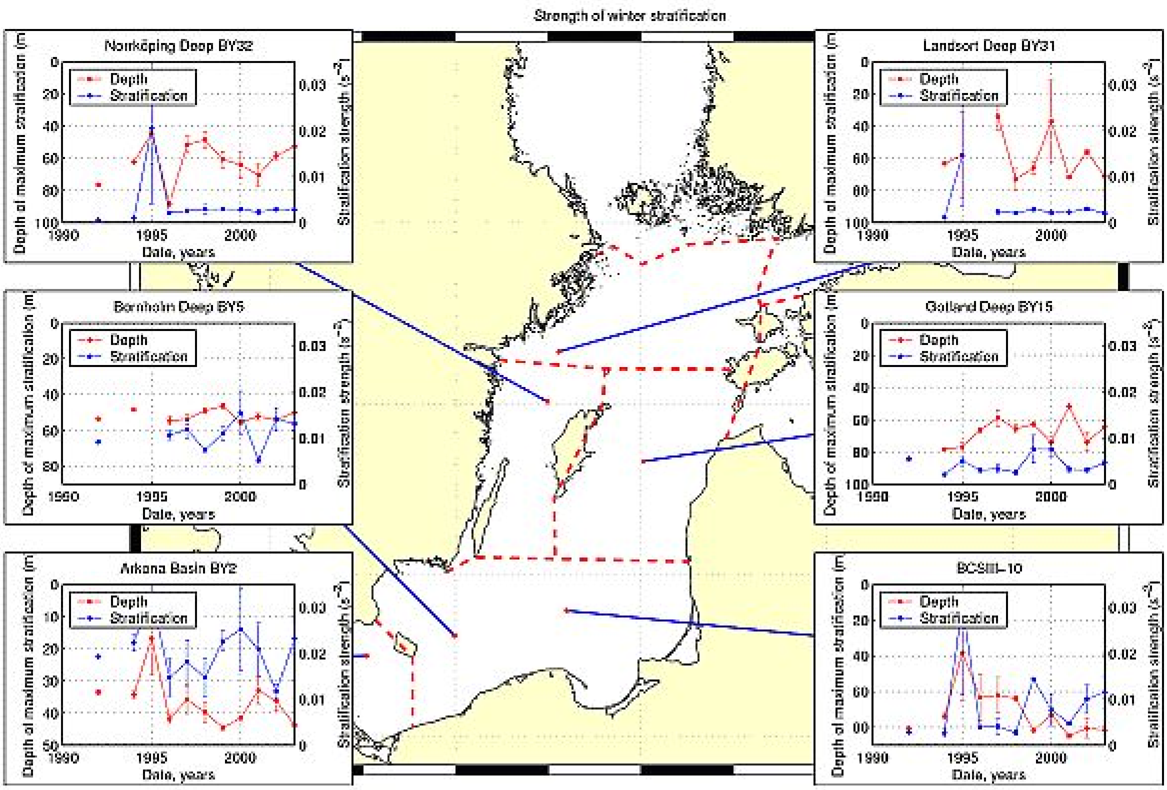

Figure 1 Time series of the pycnocline depth (in red) and strength of the pycnocline (in blue) in winter (December – February)

Time series of winter surface salinity between 1990 and 2003 (**Figure 2**) show a steady freshening of the top surface 10 metres of the Baltic Proper. This trend is strongest along the Swedish coast in the Baltic Proper where surface salinity decreases at an average rate of 0.06 (practical salinity units - psu) per year. Away from the Swedish coast, the rate of decrease in less, at around 0.03 psu.

During the same period, deepwater salinity shows the opposite trend: Below 80 metres, salinity is increasing at a rate of 0.09 psu per year 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 (BCSIII-10), with increases of 0.5, 1.2 and 1.0 psu respectively. No effect of the inflow was seen in the winter-averaged data from the Gotland Deep.

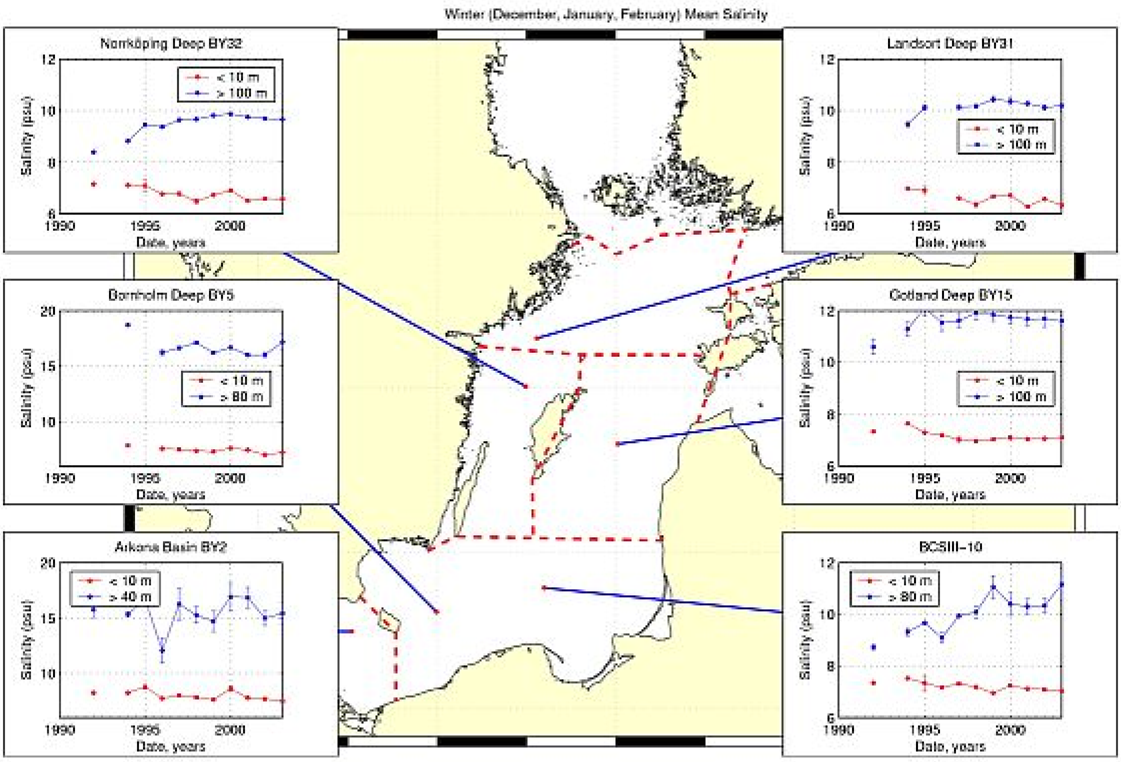

Figure 2 Time series of winter surface (< 10 m) and deep water salinity in the Baltic Proper, 1990 – 2003

For each of the basins, autumn (August, September and October) oxygen profiles from 1990 – 2003 have been examined. Depths at which the oxygen concentration fell below certain levels were calculated, and these data were interpreted in terms of the proportion of water in each basin affected by reduced oxygen levels. These results are presented as time series in **Figure 3**.

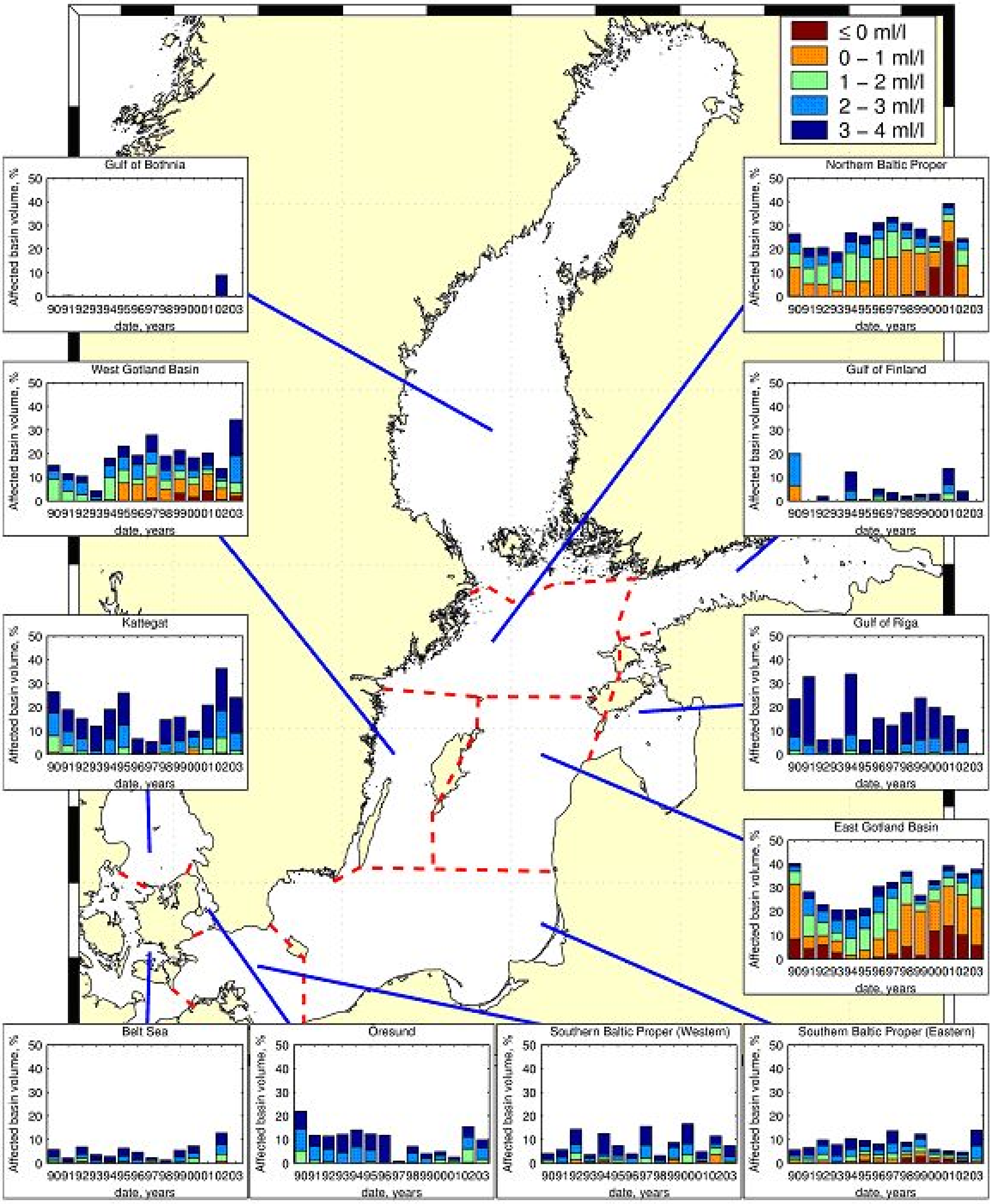

Figure 3 Histograms showing the proportion of basins affected by lowered oxygen levels.

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. Despite this increase, the proportion of the basin affected has not increased greatly.

All basins of the Baltic Sea 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 out first through the Southern Baltic Proper, and then into the deep regions of the other basins. A similar effect from the late 2002 – spring 2003 inflows would be expected, and are visible in the oxygen measurements. Improved deep water oxygen conditions are apparent throughout the Southern Baltic Proper and in the East Gotland Basin.

The basin least affected by oxygen depletion is the Gulf of Bothnia, where there is weak stratification and relatively low biological activity. Despite this, profiles taken in 2002 (the most recent data available) indicate slight oxygen deficiency (below 4 ml/l, or 5.7 mg/l) in the basin.

In the western Baltic Proper, Danish Straits and Kattegat oxygen depletion is a seasonal phenomenom which occurs during autumn.

In the Southern Baltic Proper the deepest 15% was affected by reduced oxygen levels in 2000 and 2002. In 2003, less than 10% of the basin volume is affected, and the severe hypoxia apparent in 2001 is much reduced. The East Gotland Basin was the worst affected basin, with between 30 and 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, but the recent inflows halved this amount in 2003. Hypoxia continues to affect a further 15% of the basin volume.

The proportions of affected water in the Northern Baltic Proper and West Gotland Basin are slightly lower than in the East Gotland Basin. This may be due to the basins having a higher proportion of shallow water than the East Gotland Basin but also could be due to an under-reporting of 'negative' oxygen – or Hydrogen Sulphide - data.

In 2000 and 2001, especially the East Gotland Basin showed a substantial increase in the proportion of water affected by hydrogen sulphide. This may be attributable to high levels of bacterial activity, breaking down carbon introduced either directly from land runoff, or from the surface layer, caused by higher levels of biological productivity. Analysis of the nutrient concentrations, dissolved organic carbon levels and bacterial populations should identify which of these mechanisms was responsible.

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.

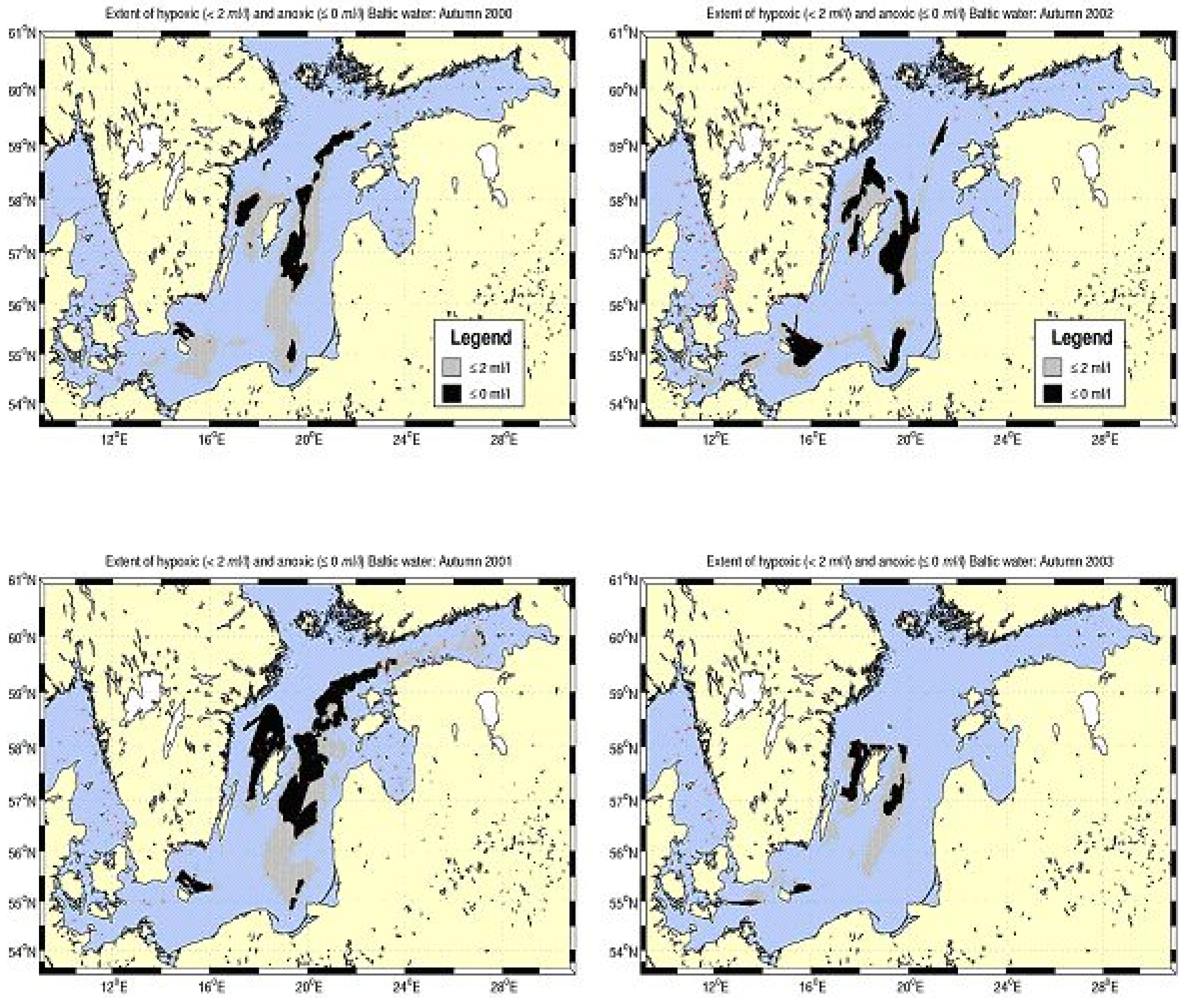

Figure 4 Oxygen concentrations (2 ml/l and 0 mg/l shaded) in bottom water, 2000-2003. The severity of the anoxia in 2002 and 2003 in the Northern Baltic Proper appears underestimated, as not all data are available yet.

References

This study has made use of data provided by the following institutes:

- Swedish Meteorological and Hydrological Institute (SMHI)
- Finnish Institute for Marine Research (FIMR)
- International Council for the Exploitation of the Sea (ICES)
- Danish Environmental Research Institute (DMU)
- Polish Maritime and Water Institute (IMGW)
- Institute of Aquatic Ecology (IAE)
- Estonia is Estonian Marine Institute (EMI)
- Estonian Meteorological and Hydrological Institute

Summary

The Autumn 2002 – Spring 2003 saline inflows have had a posive 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,

shortly after the last inflow. Hydrogen sulphide is still present in the East Gotland Basin, though in smaller amounts than in 2000 – 2002. The Western Baltic Proper is still 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.

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/.