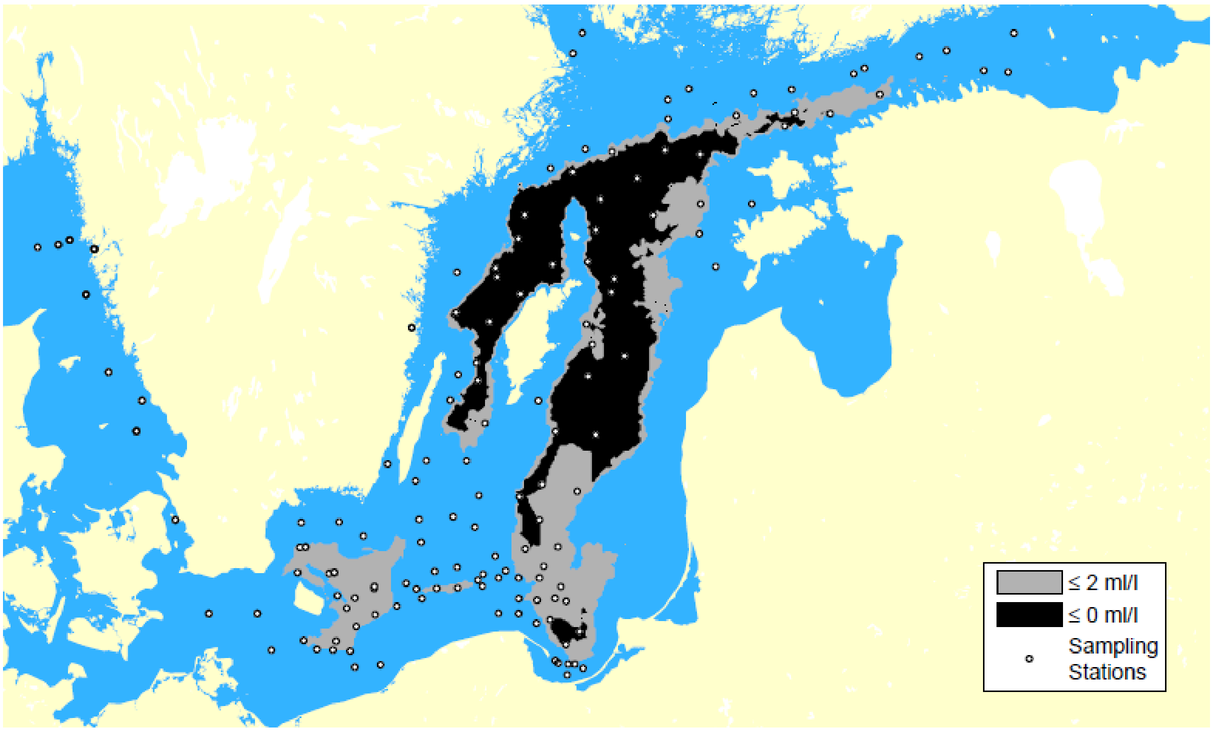
SMHI

REPORT OCEANOGRAPHY No. 46, 2013

Oxygen Survey in the Baltic Sea 2012
- Extent of Anoxia and Hypoxia, 1960-2012



Front: Areal extent of hypoxia (grey), anoxia (black) and sampling stations (dots) in the Baltic Sea during autumn 2012.

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Oxygen Survey in the Baltic Sea 2012
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Summary

A climatology atlas of the oxygen situation in the deep water of the Baltic Sea was published in 2011 in the SMHI Report Oceanography No 42. The results for 2011 were preliminary and have in this report been updated as new additional data have been reported to ICES. The results for 2012 are preliminary and based on oxygen data collected during the annual Baltic International Acoustic Survey (BIAS) with contributions from Sweden, Poland, Estonia and Finland. Data from SMHI own cruises during the autumn have also been included.

For the autumn period, August to October, each profile in the data set was examined for the occurrence of hypoxia (oxygen deficiency) and anoxia (total absence of oxygen). The depths of the onset of hypoxia and anoxia were then interpolated between sampling stations producing two surfaces representing the depth at which hypoxic and anoxic conditions are found. The volume and area of hypoxia and anoxia have been calculated and the results have then been transformed to maps and diagrams to visualize the annual autumn oxygen situation during the analysed period.

The new results for 2011 and the preliminary results for 2012 show that the extreme oxygen conditions in the Baltic Proper after the regime shift in 1999 continues. Both the areal extent and the volume of hypoxia and anoxia are elevated to levels never seen before.

Sammanfattning

En klimatologisk atlas av syresituationen i Östersjöns djupvatten publicerades 2011 i SMHIs Report Oceanography No 42. Resultaten för 2011 var preliminära och har i denna rapport uppdaterats då ny data har rapporterats till ICES. Resultaten för 2012 är preliminära och är baserade på syredata insamlade under Baltic International Acoustic Survey (BIAS) med bidrag från Sverige, Polen, Estland och Finland. Data från SMHIs egna ordinarie expeditioner har också inkluderats.

Förekomsten av hypoxi (syrebrist) och anoxi (helt syrefria förhållanden) under höstperioden, augusti till oktober, har undersökts i varje mätprofil. Djupet då hypoxi eller anoxi först påträffas i en profil har interpolerats mellan provtagningsstationer och kombinerats med en djupdatabas för beräkning av utbredning och volym av hypoxiska och anoxiska förhållanden. Resultaten har överförts till kartor och diagram för att visualisera syresituationen i Östersjöns djupvatten.

Resultaten för 2011 och de preliminära resultaten för 2012 visar att de extrema syreförhållanden som observerat i Egentliga Östersjön efter regimskiftet 1999 fortsätter. Andelen områden påverkade av hypoxi och anoxi fortsätter att vara förhöjda till nivåer som aldrig tidigare observerats i Östersjöns djupvatten.

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1 Background

Hypoxia is a condition that occurs when dissolved oxygen falls below the level needed to sustain most animal life. The concentration at which various animals are affected varies, but generally effects start to appear when oxygen drops below 2.8-3.4 ml/l (4- 4.8 mg/l) and acute hypoxia is usually defined between 1.4 – 2.1 ml/l (2-3 mg/l) [Rabalais, 2001; Diaz & Rosenberg, 1995; Aertebjerg et al. 2003]. It has also been shown that Baltic cod eggs need at least 2 ml/l oxygen for successful development [MacKenzie et al., 2000; Nissling, 1994; Plikshs et al., 1993; U.S. EPA, 2003; U.S. EPA, 2000, Swedish EPA, 2007]. In this report the limit for hypoxia is set to 2.0 ml/l.

Anoxic conditions are characterised by the total absence of oxygen. When all oxygen is consumed by microbial processes hydrogen sulphide 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.

In this report time series of the bottom areal extent and deep water volume of anoxic and hypoxic autumn conditions of the Baltic Proper, including the Gulf of Finland and the Gulf of Riga, are presented for the period 1960 to 2012. The time series was first published in 2011 [Hansson et. al, 2011] but with preliminary results for 2011. Now as new additional data has become available from ICES[1] the results have been updated.

The report includes maps of bottom areas affected by oxygen deficiencies which can be used as a climatological atlas describing the historical development and the present oxygen situation in the Baltic Proper.

2 Data

The results for 2012 are preliminary and based on oxygen data collected during the annual Baltic International Acoustic Survey (BIAS) with contributions from Sweden, Poland, Estonia and Finland. Data from SMHI own cruises during the autumn have also been included. These data have been subject to initial quality control only (quality assured laboratory procedures; timing and position checks; range checking). The time series and the values presented for 2012 will be updated when additional data are reported to ICES in 2013.

Data from the BIAS cruises are well suited for concurrent oxygen surveys because of the vast spatial distribution of sampling occasions and since cruises are performed by different countries most parts of the offshore Baltic Proper are monitored. The surveys are also performed during the autumn period (September and October) when the oxygen situation usually is most severe. Hence, an essential contribution of oxygen data, complementing the regular national monitoring performed monthly at fixed stations, are obtained.

[1] ICES Dataset on Ocean Hydrography. The International Council for the Exploration of the Sea, Copenhagen 2009.

3 Method

To process the dataset a few station profiles had to be filtered out: for example when data was missing in the deep water or when questionable data were found.

For the autumn period, August to October, each vertical profile including at least three data points, was examined for the occurrence of hypoxia (<2 ml/l) and anoxia (<0 ml/l). To find the depth of the onset of hypoxia and anoxia in each vertical profile, interpolation between discrete measurements in the profile was used. If hypoxia or anoxia was not found in the profile, the two deepest measurements in the profile were used to linearly extrapolate the oxygen concentration down towards the bottom. If two or more profiles were found at the same position an average profile was calculated for that position.

The depths of the onset of hypoxia and anoxia were gridded with linear interpolation (Delaunay triangulation) between sampling stations, producing a surface representing the depth at which hypoxic and anoxic conditions are found. The surface has then been compared with bathymetry data [Seifert, 2001], see Figure 1, to exclude profiles where the hypoxic and anoxic depths were greater than the actual water depth. After filtering of the results, the affected area and volume of hypoxia and anoxia have been calculated for each year.

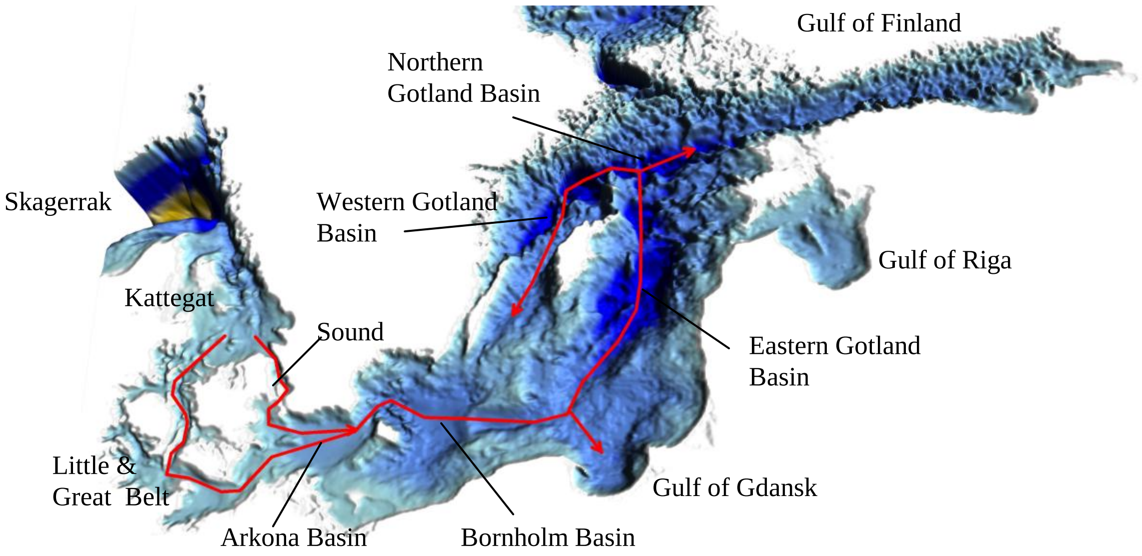

Figure 1. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathway of inflowing deep water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

Areal extent and volumes are presented in relation to the area and volume of the Baltic Proper, including the Gulf of Finland and the Gulf of Riga according to the sub-basins commonly used, see Figure 1 [Fonselius, 1995].

4 Result

The areal extent and volumes affected by hypoxia and anoxia during the period 1960 - 2012 are presented in Figures 2 and 3 respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2011 and 2012 can be found in Appendix 1.The mean areal extent and volume affected by hypoxia and anoxia before and after the regime shift in 1999 is presented in Table 1.

Table 1. Mean and maximum areal extent and volume of anoxia and hypoxia before and after the regime shift. Results are given as part (%) of the area and volume of the Baltic Proper, including the Gulf of Finland and the Gulf of Riga. Updated table from Hansson et. al., 2011. The results for 2012 are preliminary.

in %	1960 – 1998		1999 – 2011		2012	
	Hypoxi	Anoxi	Hypoxi	Anoxi	Hypoxi	Anoxi
Mean Areal extent	22	5	28	15	27	14
Max Areal extent (Year)	27 (1968)	14 (1969)	32 (2007)	19 (2011)	-	-
Mean Volume	13	2	18	8	17	9
Max Volume (Year)	19 (1965)	8 (1969)	21 (2011)	12 (2011)	-	-

The updated results for 2011 show that the anoxic conditions this year are the highest ever observed. Almost 20% of the bottom areas in the Baltic Proper, including the Gulf of Finland and the Gulf of Riga are affected by anoxic conditions, which correspond to a water volume of 12%.

The areal extent of hypoxia increased from about 9% in 1993 to 32% in 2007. The widespread hypoxia during 2007, the largest noted, corresponds to a water volume of one fifth (20%) of the investigated area. In 2011 the largest volume of hypoxic bottom water was observed (21%), though the areal extent of hypoxia this year was 27%. The discrepancy between the largest noted areal extent and volume is due to the fact that different areas, with different hypsographic conditions, are affected.

Preliminary results for 2012 show that the areal extent and volume of both anoxia and hypoxia remain on an elevated level like all years after the regime shift in 1999 [Hansson et. al., 2011].

In the Bornholm Basin and the southern parts of the Eastern Gotland Basin the oxygen situation improved during 2012 as a result of the inflow that occurred in November and December 2011. Hypoxia was widespread in these areas but no anoxic conditions were present as in 2011. The inflow was studied during the SMHI cruises during 2012 [SMHI cruise reports, 2012] and already in March the Bornholm Basin was filled up to the sill level and the inflow continued through the Slupsk Channel into the Eastern Gotland Basin. The inflow in November and December 2011 through the Sound was estimated by SMHI to ~50 km^3 [SMHI, 2012], while the total inflow, including the Belt Sea, to the Baltic Sea was approximated by IOW to ~300 km^3 [Nausch et. al., 2012].

However, at the time of writing (January 2013) the inflow has not affected the deep water in Eastern Gotland Basin. No signs of the inflow have been observed below 200 meters depth at BY15 (See time series of temperature, salinity and oxygen at 240 meter depth at BY15 in Appendix 1). Higher up in the water column, at intermediate depth, only traces of the inflow have been found. Hence, this inflow will not improve the conditions of the deep water in central Baltic Proper.

Areal extent of hypoxia and anoxia

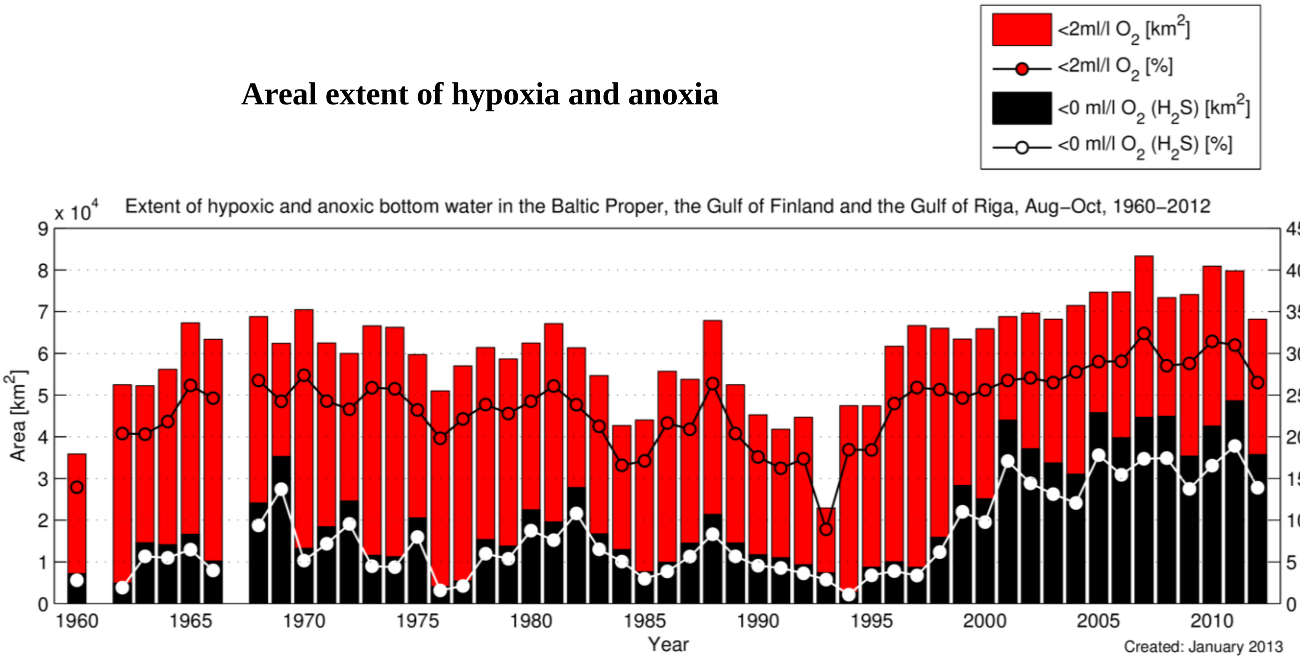

Figure 2. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed since sufficient data from the deep basins are missing.

Water volume affected by hypoxia and anoxia

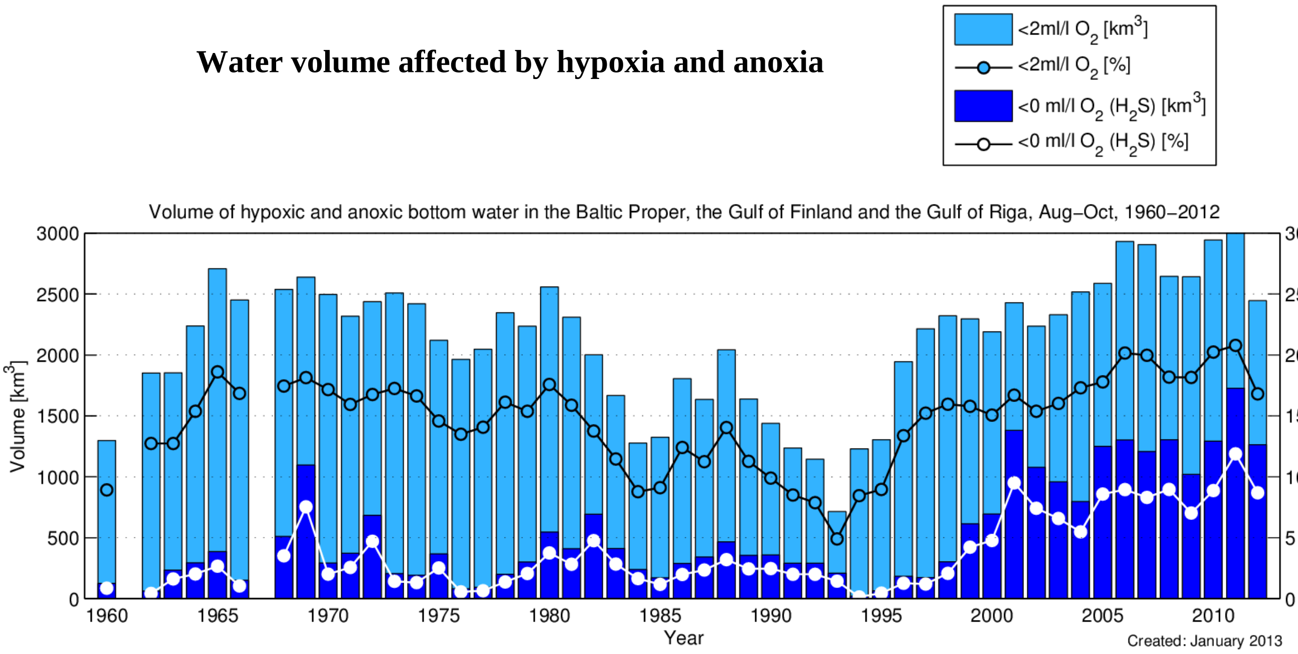

Figure 3. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed since sufficient data from the deep basins are missing.

5 Conclusions

- The updated results for 2011 and the preliminary results for 2012 show that the extreme oxygen conditions in the Baltic Proper continue. Both the areal extent and the volume of hypoxia and anoxia are elevated to levels never seen before.

- The anoxic conditions during 2011 are the highest ever observed. Almost 20% of the bottom areas in the Baltic Proper, including the Gulf of Finland and the Gulf of Riga were affected, which corresponds to a water volume of 12%.

- The inflow in November/December 2011 improved the oxygen conditions during 2012 in the Bornholm Basin and the southern Eastern Gotland Basin, but did not improve the conditions in the deeper central parts of the Baltic Proper.

6 Acknowledgement

This study was possible due to the excellent web service at The International Council for the Exploration of the Sea, ICES, making the ICES Dataset on Ocean Hydrography available.

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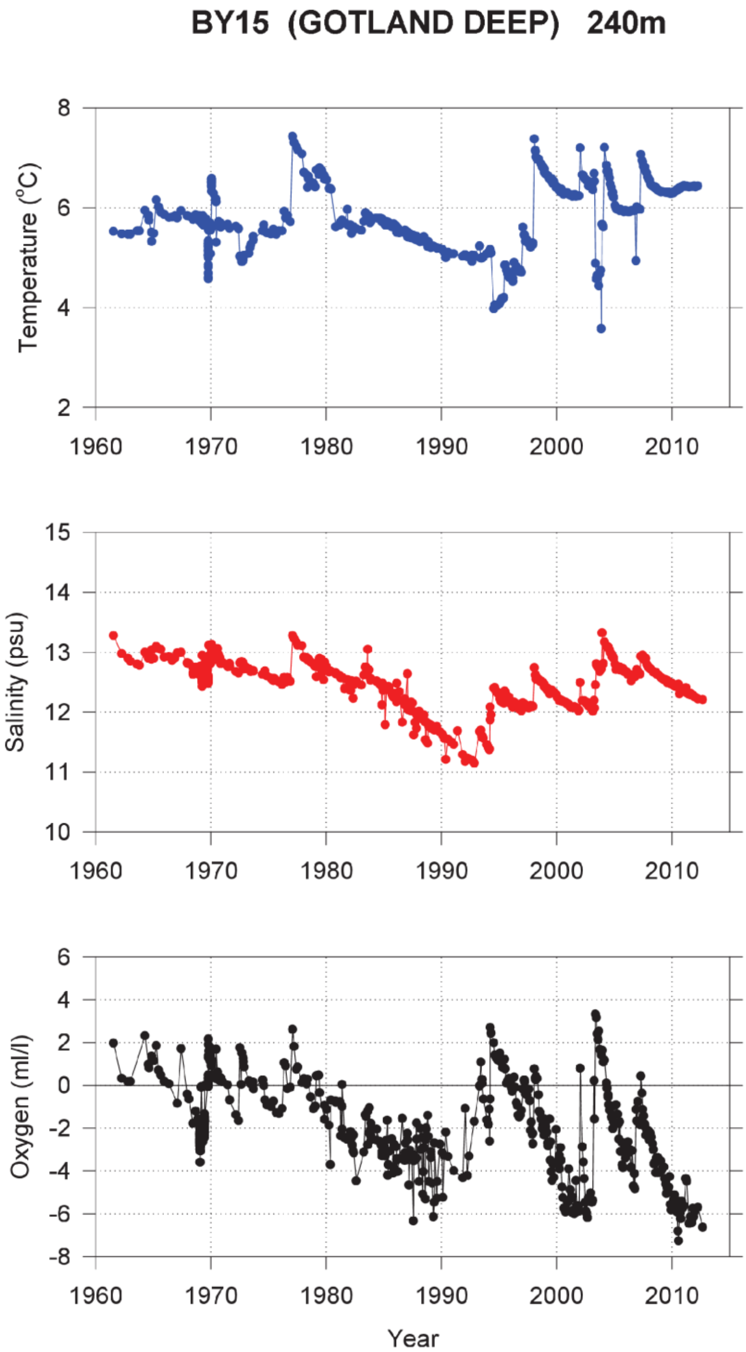
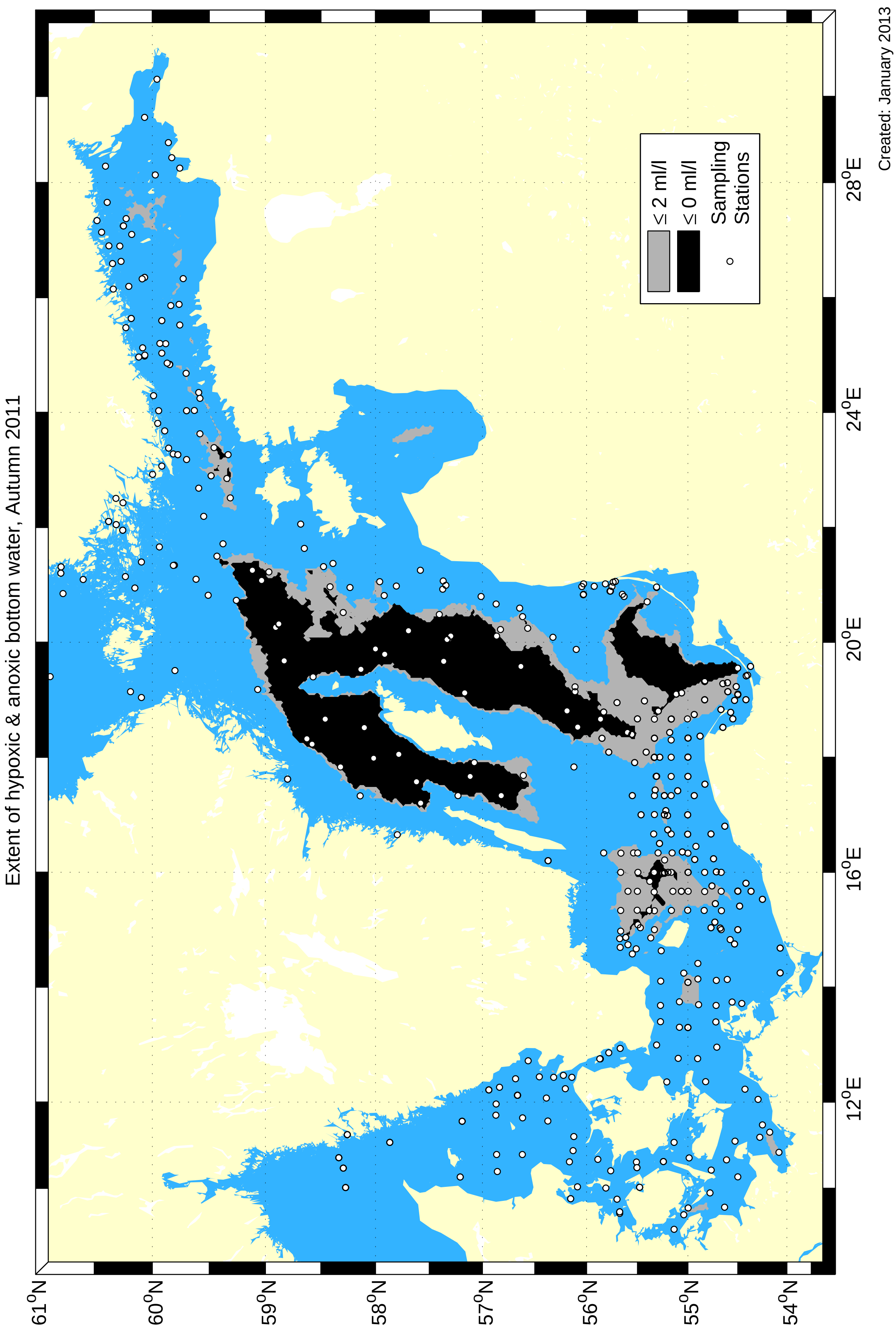
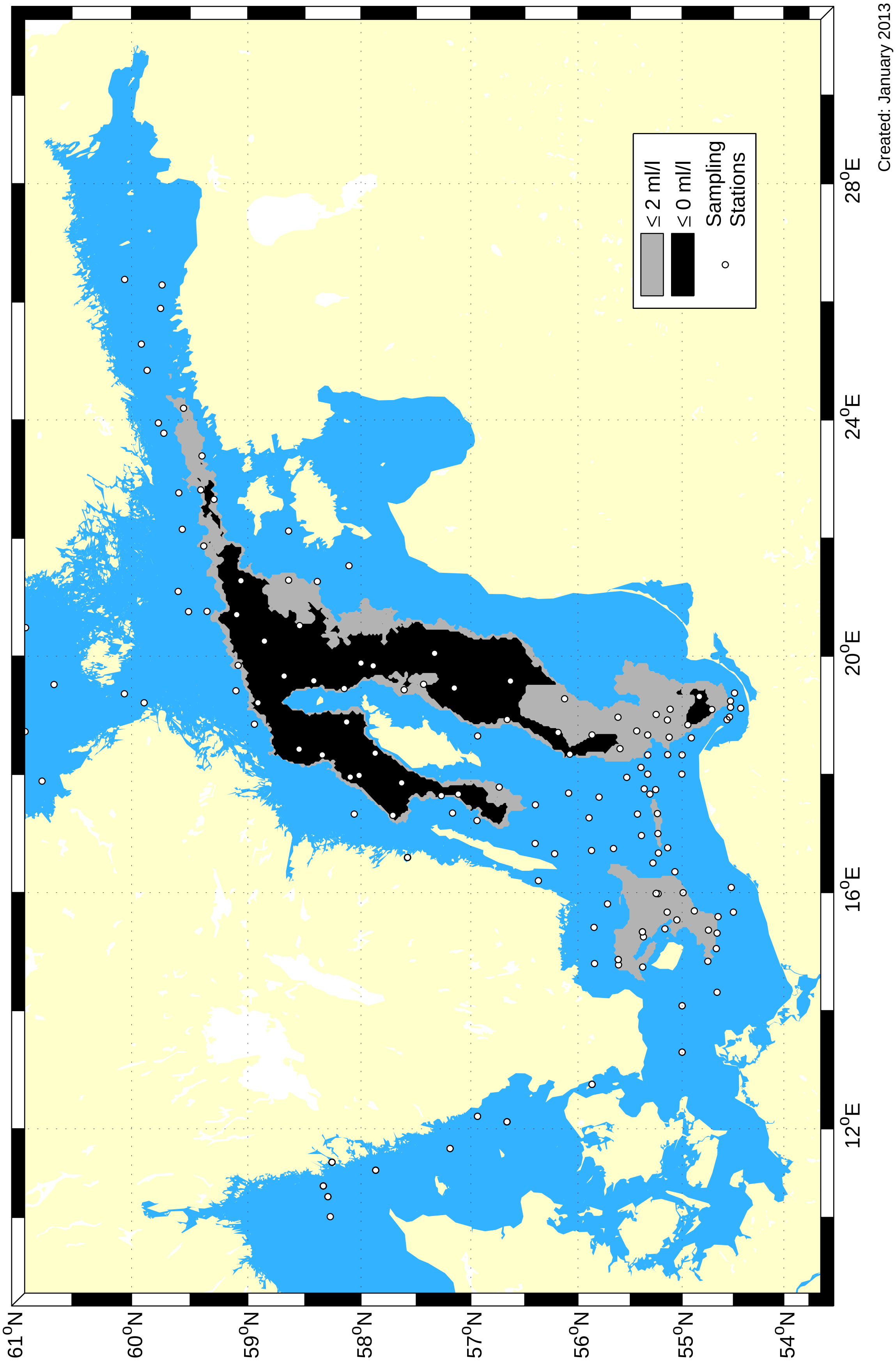
Appendix 1 – Temperature, salinity and oxygen at BY15, Eastern Gotland Basin, 1960-2012



Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea, 2011-2012


Extent of hypoxic & anoxic bottom water, Autumn 2011
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
Created: January 2013



Extent of hypoxic & anoxic bottom water, Autumn 2012

8 SMHI Publications

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[1] Rossby Centre, SMHI [2] James Rennell Division, Southampton Oceanography Centre, [3] Department of Meteorology, Stockholm University

27 H. E. Markus Meier (1999)
First results of multi-year simulations using a 3D Baltic Sea model.

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