SMHI

REPORT OCEANOGRAPHY No. 50, 2014

Oxygen Survey in the Baltic Sea 2014

- Extent of Anoxia and Hypoxia, 1960-2014

Front: The CTD probe and rosette of filled water sampling bottles, which are used to take water measurements and bring back water column samples for analysis. Photo from the December cruise 2014 onboard R/V Aranda. Photo: Martin Hansson.

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Oxygen Survey in the Baltic Sea 2014
- Extent of Anoxia and Hypoxia, 1960-2014

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Summary

A climatological atlas of the oxygen situation in the deep water of the Baltic Sea was first published in 2011 in SMHI Report Oceanography No 42. Since 2011, annual updates have been made as additional data have been reported to ICES. In this report the results for 2013 have been updated and the preliminary results for 2014 are presented. Oxygen data from 2014 have been collected during the annual Baltic International Acoustic Survey (BIAS) and from national monitoring programmes with contributions from Sweden, Poland, Estonia Lithuania, and Germany.

For the autumn period, August to October, each profile in the dataset was examined for the occurrence of hypoxia (oxygen deficiency) and anoxia (total absence of oxygen). The depths of onset of hypoxia and anoxia were then interpolated between sampling stations producing two surfaces representing the depth at which hypoxic respectively 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 updated results for 2013 and the preliminary results for 2014 show that the extreme oxygen conditions in the Baltic Proper after the regime shift in 1999 continue. Both the areal extent and the volume with anoxic conditions have, after 1999, been constantly elevated to levels only observed occasionally before the regime shift. In the Baltic Proper, Gulf of Finland and Gulf of Riga approximately 15% of the bottom area was affected by anoxia and around 25% by hypoxia during 2014.

Sammanfattning

En klimatologisk atlas över syresituationen i Östersjöns djupvatten publicerades 2011 i SMHIs Report Oceanography No 42. Sedan 2011 har årliga uppdateringar gjorts då kompletterande data från länder runt Östersjön har rapporerats till ICES. I denna rapport har resultaten från 2013 uppdaterats. De preliminära resultaten för 2014 baseras på data insamlade under Baltic International Acoustic Survey (BIAS) och nationell miljöövervakning med bidrag från Estland, Litauen, Tyskland, Polen och Sverige.

Förekomsten av hypoxi (syrebrist) och anoxi (helt syrefria förhållanden) under höstperioden, augusti till oktober, har undersökts i varje mätprofil. Djupet där 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 2013 och de preliminära resultaten för 2014 visar att de extrema syreförhållanden som observerats i Egentliga Östersjön efter regimskiftet 1999 fortsätter. Utbredningen av anoxi fortsätter att vara konstant förhöjd till nivåer som bara observerats i Östersjön vid enstaka år före 1999. Under 2013 beräknas ungefär 15 % av bottnarna i Egentliga Östersjön, Finska viken och Rigabukten vara påverkade av anoxiska förhållanden och cirka 25% av hypoxi.

Table of contents

1 Background

The Baltic Sea is characterised by its natural formation as an enclosed estuary with high freshwater input and restricted access to oceanic high saline water. The stratification and fjord-like conditions, in combination with eutrophication and other factors, form the basis for a problematic oxygen situation in the deep areas of the Baltic Sea.

Oxygen depletion or hypoxia occurs when dissolved oxygen falls below the level needed to sustain most animal life. The concentration at which 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, Swedish EPA, 2007]. 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,]. In this report the limit of hypoxia is set to 2.0 ml/l.

Anoxic oxygen conditions are characterised by the total absence of oxygen, only bacteria and fungi can survive during these conditions. When all oxygen is consumed by microbial processes hydrogen sulphide (H_2S) is formed, which is toxic for all higher marine life. During anoxic conditions nutrients, such as phosphate and silicate, are released 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 which can further enhance the oxygen depletion as the bloom sinks to the bottom and use oxygen to decompose.

In this report time series of the bottom areal extent and 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 2014. The time series were first published in 2011 and the results have been updated annually as new additional data have become available at ICES[1]. In the report from 2011 a distinct regime shift in the oxygen situation in the Baltic Proper was found in 1999. During the first regime, 1960-1999, hypoxia affected large areas while anoxic conditions were found only in minor deep areas. After the regime shift in 1999, both areal extent and volume of anoxia have been constantly elevated to levels that only occasionally have been observed before 1999. [Hansson et. al, 2011]

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

For 2014 the results are preliminary and based on oxygen data collected during the annual Baltic International Acoustic Survey (BIAS) complemented by data from national and regional monitoring programmes with contributions from Estonia, Latvia, Lithuania, Poland, Germany and Sweden. 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 results presented for 2014 will be updated when additional data are reported to ICES in 2015.

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

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, almost all parts of the offshore Baltic Proper are monitored.
The surveys are also performed during the autumn period (September/October) when the oxygen situation usually is most severe. Hence, this is an essential contribution of oxygen data, complementing the regular national and regional monitoring performed monthly at fixed stations.

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 the results, the affected area and volume of hypoxia and anoxia have been calculated for each year.

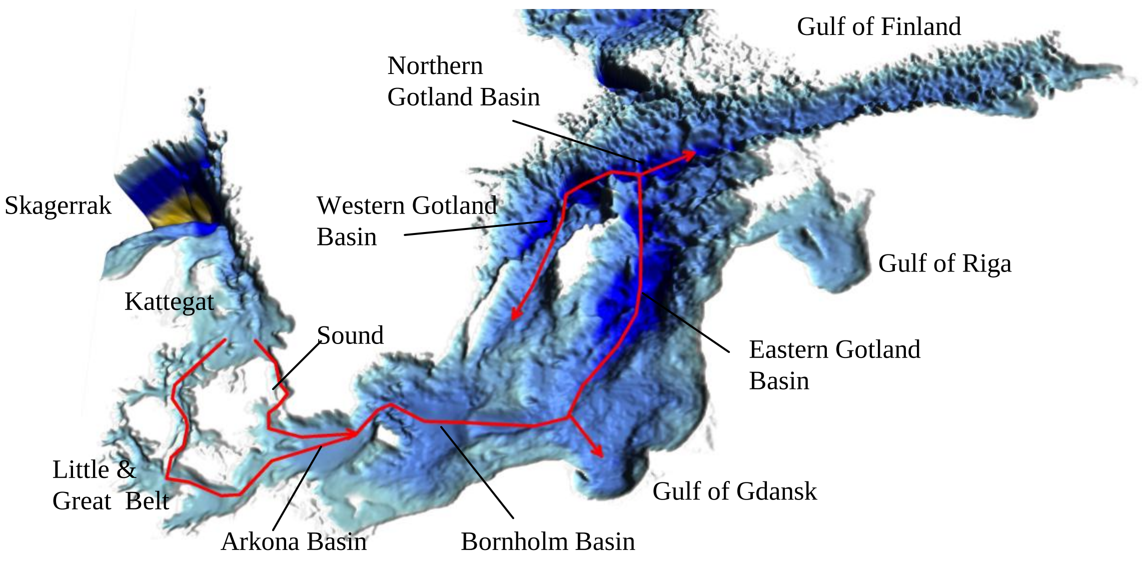

Figure 1. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathway of inflowing deep water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

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, see Figure 1[Fonselius, 1995].

4 Result

Extent and volume affected by hypoxia and anoxia during the period 1960 - 2014 are presented in Figures 2 and 3, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2013 and 2014 can be found in Appendix 2.The mean areal extent and volume affected by hypoxia and anoxia before and after the regime shift in 1999 (see Background section or [Hansson et. al, 2011]) and the preliminary results for 2014 are 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, 2012 & 2013. Note that the results for 2014 are preliminary.

in %	1960 – 1998		1999 – 2013		2014	
	Hypoxi	Anoxi	Hypoxi	Anoxi	Hypoxi	Anoxi
Mean Areal extent	22	5	29	15	27	17
Max Areal extent (Year)	27 (1968)	14 (1969)	32 (2007)	19 (2011)	-	-
Mean Volume	13	2	18	8	19	11
Max Volume (Year)	19 (1965)	8 (1969)	21 (2011)	12 (2011)	-	-

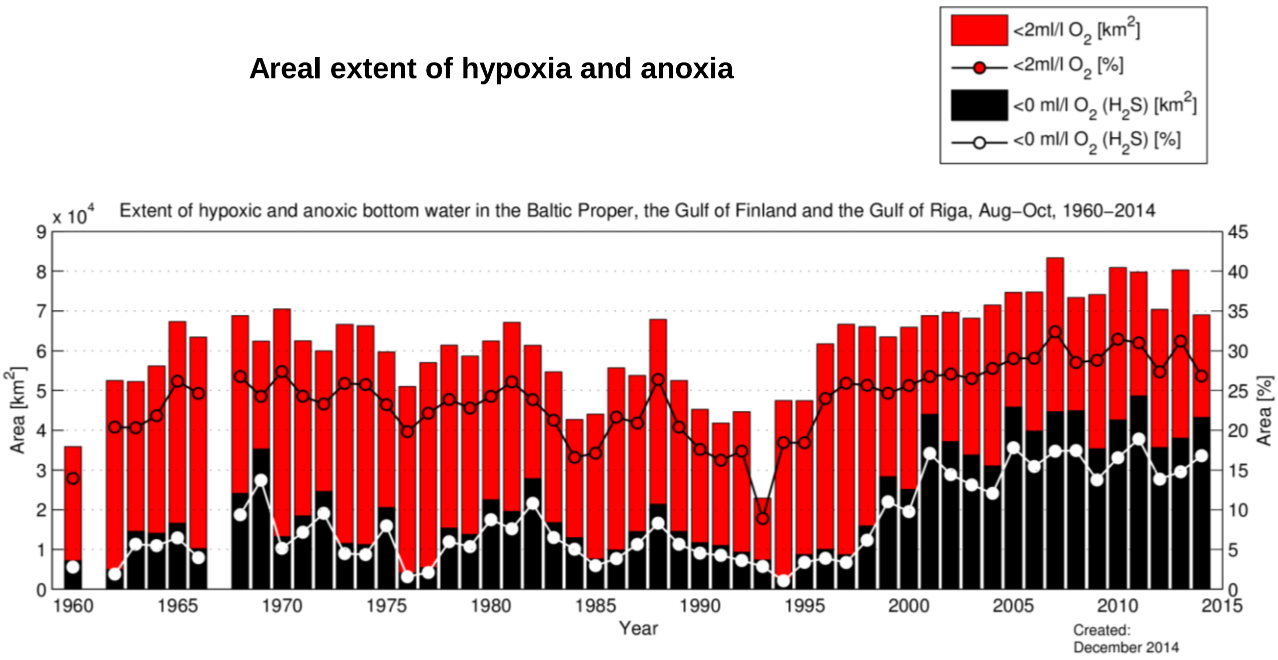

Figure 2. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

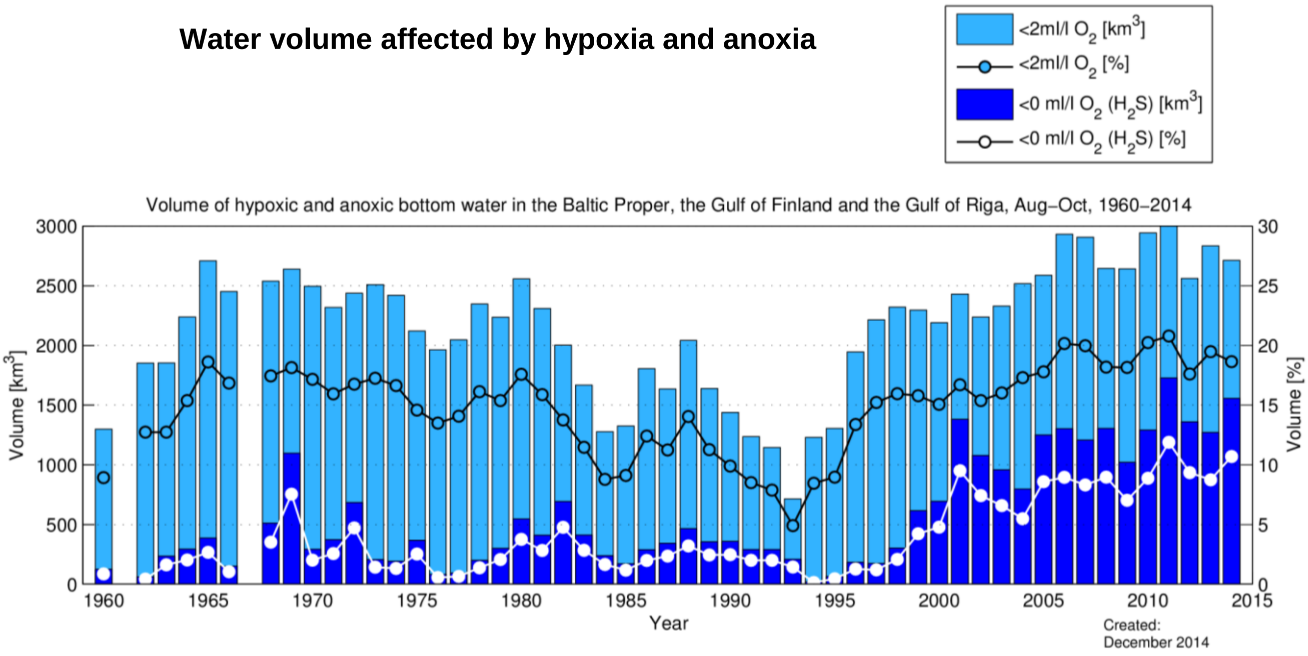

Figure 3. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

5 Discussion

Results for 2013

The updated results for 2013 showed that the anoxic areas where more or less unchanged but that the proportion of areas affected by hypoxia in the Baltic Proper increased from 29% to 31%. Additional areas suffering from hypoxia were found in the Arkona basin and in the south-eastern Baltic Proper. The updated results for 2013 follow the oxygen development that has prevailed since the regime shift in 1999.

A minor inflow of 20 km^3, through the Sound, to the Baltic took place in January. This inflow improved, to some extent, the oxygen conditions in the deep water of the southern Baltic Proper. Thereafter there was a continuous outflow, caused by long-lasting high pressure and north-easterly winds. The accumulated outflow in March was the highest since 1977. At the end of August there was another inflow of 15 km^3 through the Sound.

During the storm Simone, at the end of October, and during the following weeks 40 km^3 entered through the Sound. A smaller inflow, 29 km^3, followed in the beginning of December. However, these inflows were too small to improve the oxygen conditions in the central Baltic Proper and only minor improvements were seen in the southern parts. Inflows have to exceed 100 km^3 through the Sound, while at the same time approximately 200 km^3 has to enter through the Belts, to be considered as major.

The cumulative inflow to the Baltic Sea in 2013 was 301 km^3, while the cumulative outflow was 618 km^3, both somewhat less than normal.

Preliminary results for 2014

The preliminary results for the annual oxygen survey shows that the serious oxygen situation in the Baltic Proper continues. The results are similar to the mean conditions for the period 1999-2013 after the regime shift. Though, in comparison with 2013, the area affected by anoxia in the Eastern Gotland basin has increased and anoxia is again present in the southern parts.

In early 2014 (February and March) two inflows occurred through the Sound each of about 30 km^3 [SMHI, 2014]. The two inflows were followed during the monthly sampling performed in the Baltic Proper by SMHI and in July and August these inflows reached the central parts of the Eastern Gotland Basin. At the station BY15 (Gotland Deep) the bottom water was oxygenated, which has not occurred since April 2007 (see temperature, salinity and oxygen at 240m depth at BY15 in Appendix 1). However, the oxygen situation quickly deteriorated and already in September anoxia was again present. The inflow was not strong enough to reach the northern or western parts of the Baltic Proper.

In August and October two inflows, each of about 25 km^3, were recorded that improved the oxygen situation in the Arkona Basin and later in November also improved the oxygen situation in the Bornholm Basin.

In the Western Gotland Basin the stagnation continues. The inflows that reached the Eastern Gotland Basin during the summer did not continue into the Northern and Western Gotland Basin. Since, most likely, no inflows have reached the Western Gotland Basin, hypoxia and anoxia are now found at shallow depths. In December hypoxia was found from ~65 meters depth and anoxia from ~75 meters depth. [SMHI, 2014]

During December, the storm Alexander passed over the Baltic region. This storm resulted in high sea levels in southern Kattegat, and from the 2^{nd} to the 22^{nd} of December an inflow, trough the Sound, of approximately 70 km^3 took place. A total of approximately 200 km^3, including the Belts, is estimated to have entered the Baltic Sea. But the effect of this inflow is uncertain since the temperature of the water is much higher than normal. Exceptional high water temperatures have been recorded in Skagerrak and Kattegat during the autumn [SMHI, 2014]. In Skagerrak, high temperatures were found down to about 100 meters depth which is highly unusual. Water with high temperature contain less oxygen and high temperature in the bottom water can stimulate decomposition rates which further can worsen the oxygen situation in the Baltic Sea.

The latest major inflow occurred in winter 2003-2004 and before that in 1993.

6 Conclusions

- The extreme oxygen conditions in the Baltic Proper continued undiminished during 2014. The areal extent and the volume of anoxia have since the regime shift in 1999 been constantly elevated and there are no signs that inflows, weakening of the stratification or other factors have improved the oxygen conditions in the central deeper parts.

- Preliminary results for 2014 shows that anoxic conditions affect around 17% of the bottom areas in the Baltic Proper, including the Gulf of Finland and the Gulf of Riga and approximately 27% suffer from hypoxia.

- The inflows that occurred in the beginning of 2014 did results in the renewal of the bottom water of the Eastern Gotland basin during July and August. This has not occurred since 2007. However, the oxygen concentration dropped fast and in September anoxic conditions were again present.

- The exceptional high temperatures that have been recorded in the whole water column during the autumn in Skagerrak and Kattegat can worsen the oxygen situation in the Baltic Proper since inflowing water will have a higher temperature than normal. Warm water contains low concentrations of oxygen and increases the decompositions rates in the deep water.

7 Acknowledgement

Data for updating the 2013 results were collected at the web service at the International Council for the Exploration of the Sea (ICES), making the ICES Dataset on Ocean Hydrography available.

Many thanks to:

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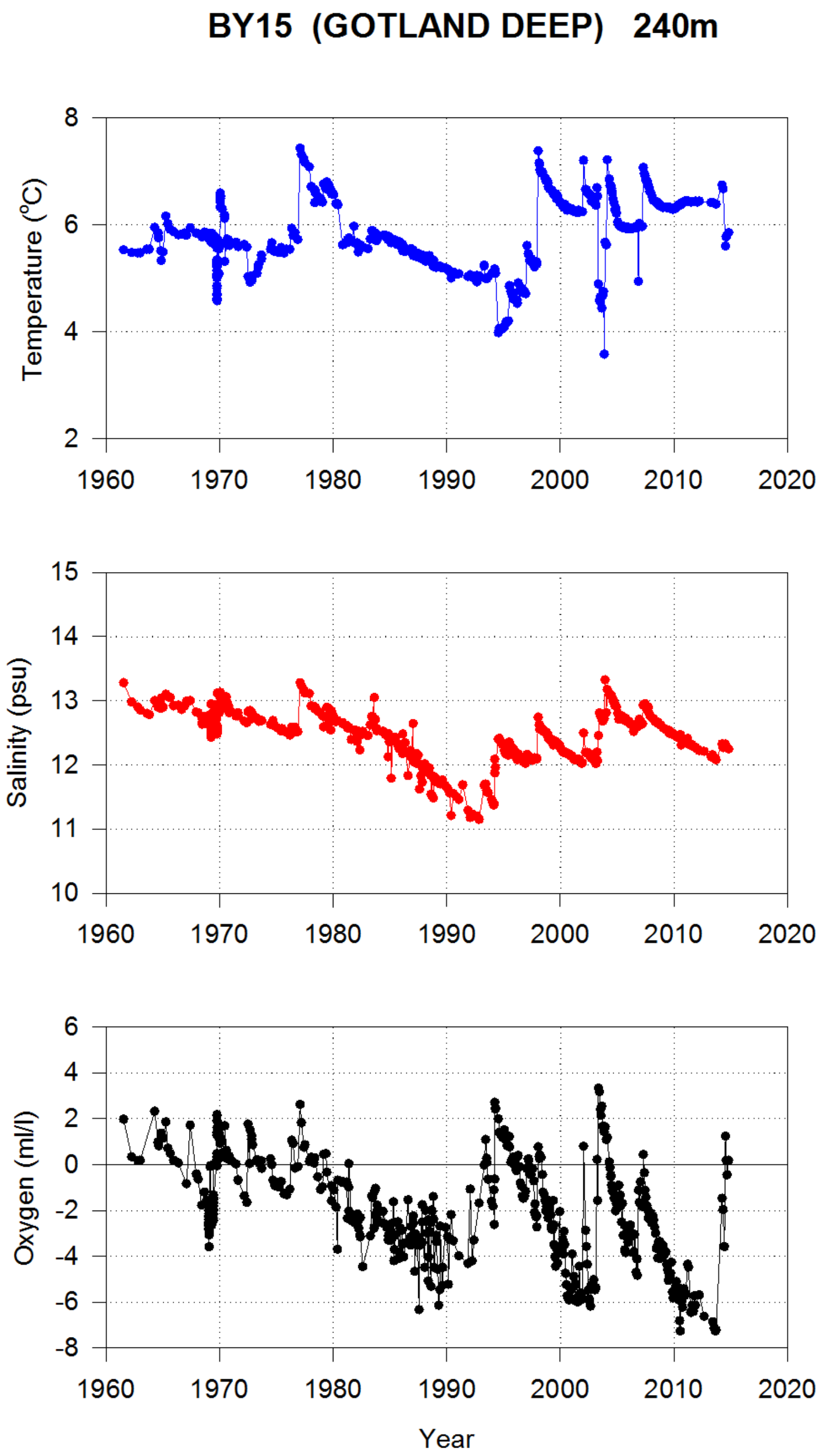
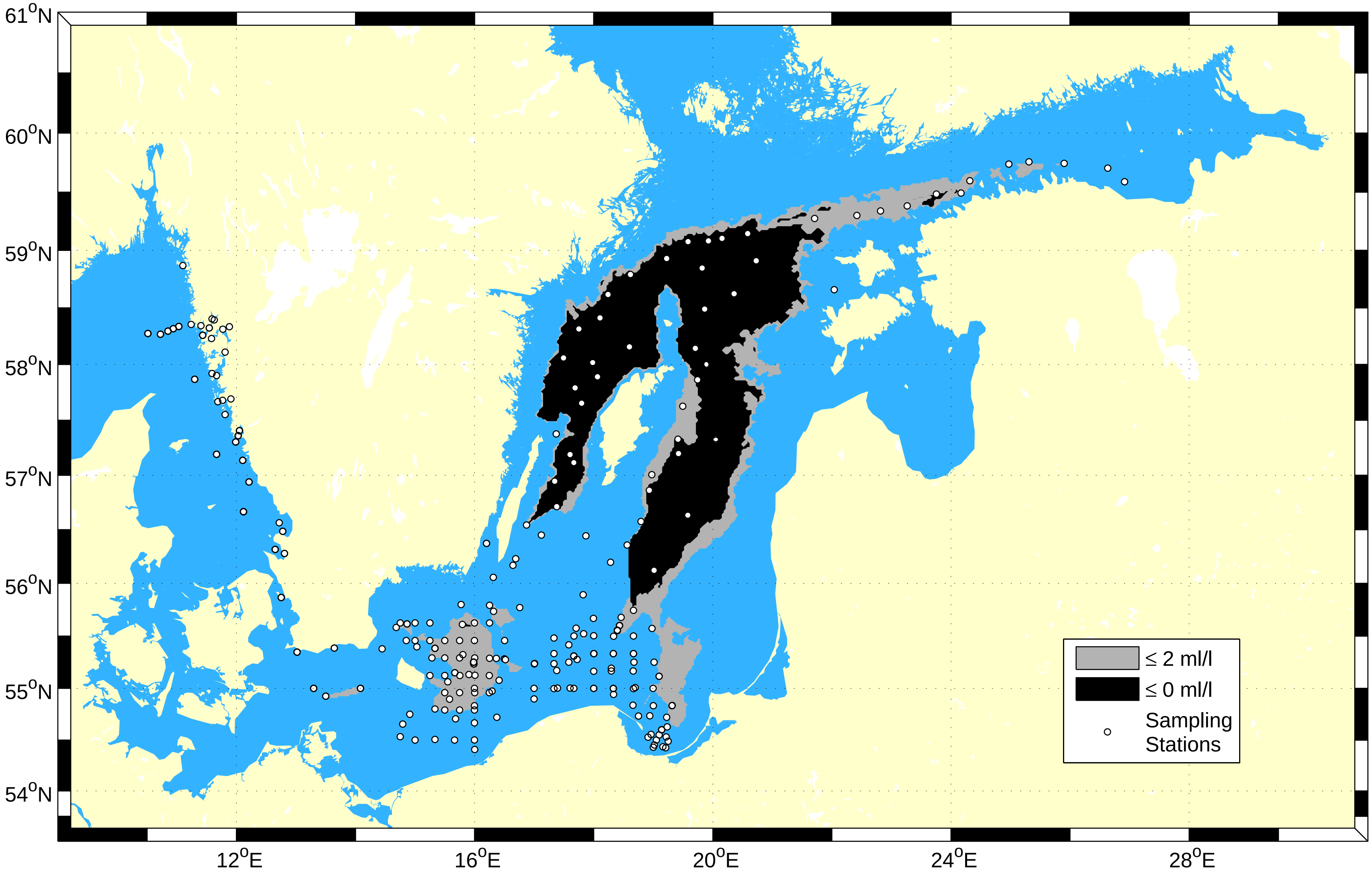
Appendix 1 – Temperature, salinity and oxygen at BY15, Eastern Gotland Basin, 1960-2014



Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea, 2012-2013

(The complete and updated time series can be found in on www.smhi.se)

Extent of hypoxic & anoxic bottom water, Autumn 2014



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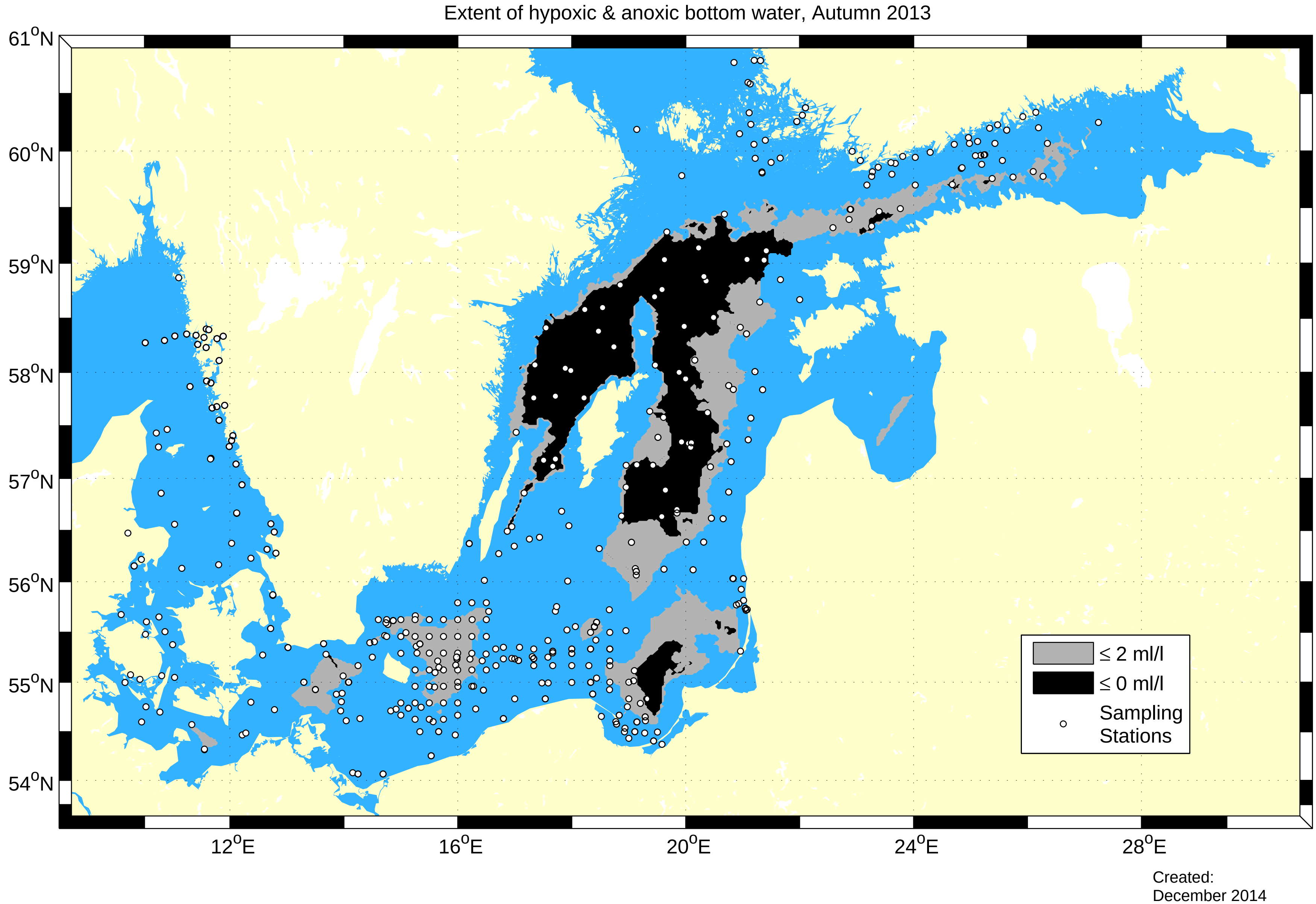
December
2014


Extent of hypoxic & anoxic bottom water, Autumn 2013
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
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations
Created:
December 2014

9 SMHI Publications

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