REPORT OCEANOGRAPHY No. 49, 2013

# Oxygen Survey in the Baltic Sea 2013

## - Extent of Anoxia and Hypoxia, 1960-2013

Front: Oxygen samples taken from increasing depths ready for Winkler analysis. Strong yellow colour indicate high oxygen concentrations and transparent low or none oxygen. Photo by Philip Axe.

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# Oxygen Survey in the Baltic Sea 2013
## - Extent of Anoxia and Hypoxia, 1960-2013

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## Summary

A climatology 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 2012 have been updated and the preliminary results for 2013 are presented. Oxygen data from 2013 have been collected during the annual Baltic International Acoustic Survey (BIAS) and from national monitoring programmes with contributions from Sweden, Poland, Finland, Estonia Lithuania, and Latvia.

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 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 updated results for 2012 and the preliminary results for 2013 show that the extreme oxygen conditions in the Baltic Proper after the regime shift in 1999 continue. Both the areal extent and the volume of anoxia have, after the regime shift, been constantly elevated to levels only observed occasionally before the regime shift. In the Baltic Proper, Gulf of Finland and Gulf of Riga ~15% of the bottom areas was affected by anoxia and ~30% by hypoxia during 2013.

## Sammanfattning

En klimatologisk atlas av syresituationen i Östersjöns djupvatten publicerades 2011 i SMHIs Report Oceanography No 42. Sedan 2011 har rapporten uppdateras årligen då kompletterande data från länder runt Östersjön har rapporerats till ICES. I denna rapport har resultaten från 2012 uppdaterats. De preliminära resultaten för 2013 baseras på data insamlade under Baltic International Acoustic Survey (BIAS) och nationell miljöövervakning med bidrag från Finland, Estland, Lettland, Litauen, 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 2012 och de preliminära resultaten för 2013 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 ~15 % av bottnarna i Egentliga Östersjön, Finska viken och Rigabukten vara påverkade av anoxiska förhållanden och ~30% av hypoxi.

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# 1 Background

The Baltic Sea is a sensitive sea area. The region 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 water.

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, 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 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 ($H_2S$) 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 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 2013. The time series was 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

The results for 2013 are preliminary and based on oxygen data collected during the annual Baltic International Acoustic Survey (BIAS) complemented by national and regional monitoring programmes with contributions from Estonia, Finland, Latvia, Lithuania, Poland 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 2013 will be updated when additional data are reported to ICES in 2014.

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.

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

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.

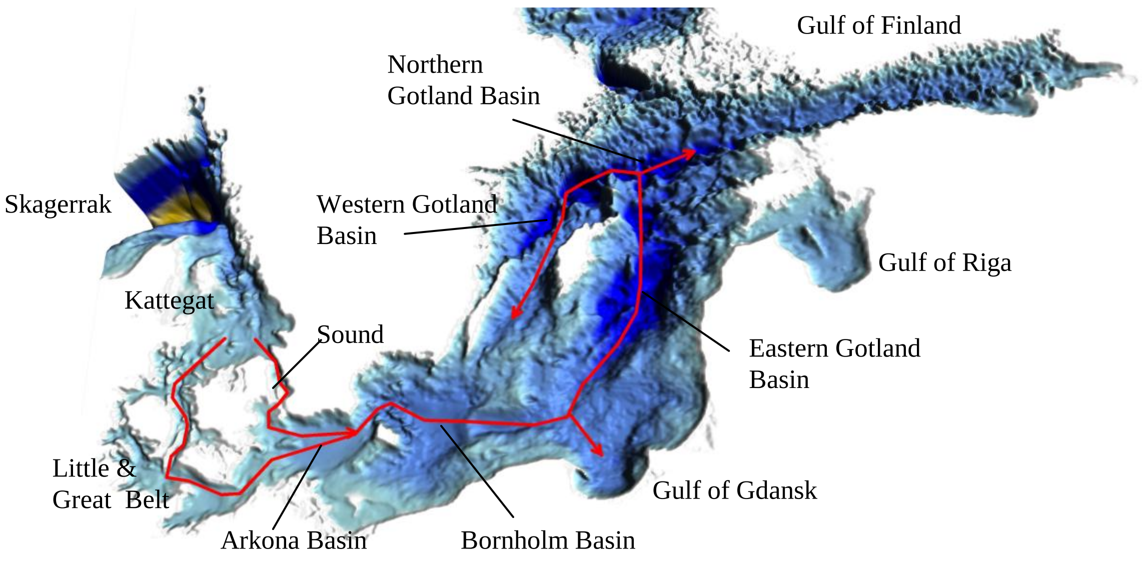


Figure 1. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathway of inflowing deep water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

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

The areal extent and volume affected by hypoxia and anoxia during the period 1960 - 2013 are presented in Figures 2 and 3 respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2012 and 2013 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 2013 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. Note that the results for 2013 are preliminary.

| in % | 1960 – 1998 | | 1999 – 2012 | | 2013 | |
|---|---|---|---|---|---|---|
| | Hypoxi | Anoxi | Hypoxi | Anoxi | Hypoxi | Anoxi |
| Mean Areal extent | 22 | 5 | 28 | 15 | 29 | 15 |
| Max Areal extent (Year) | 27 (1968) | 14 (1969) | 32 (2007) | 19 (2011) | - | - |
| Mean Volume | 13 | 2 | 18 | 8 | 19 | 9 |
| Max Volume (Year) | 19 (1965) | 8 (1969) | 21 (2011) | 12 (2011) | - | - |

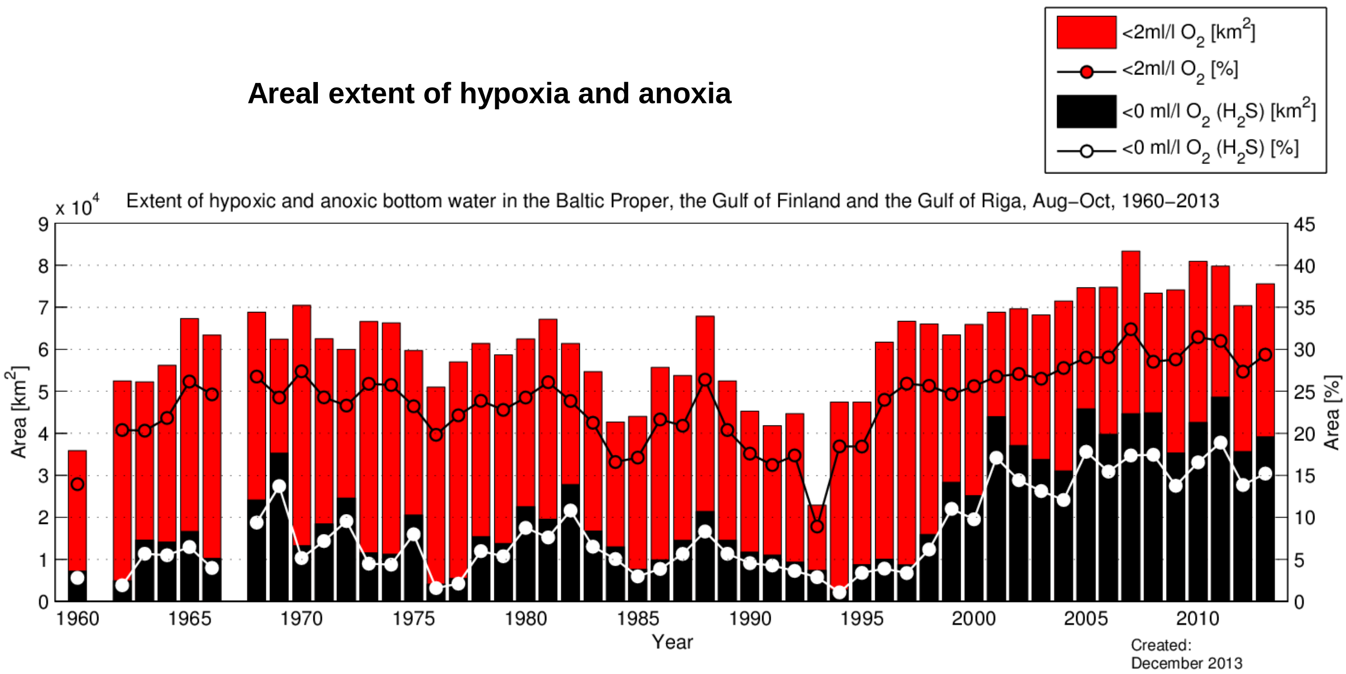


Figure 2. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed since sufficient data from the deep basins are missing.

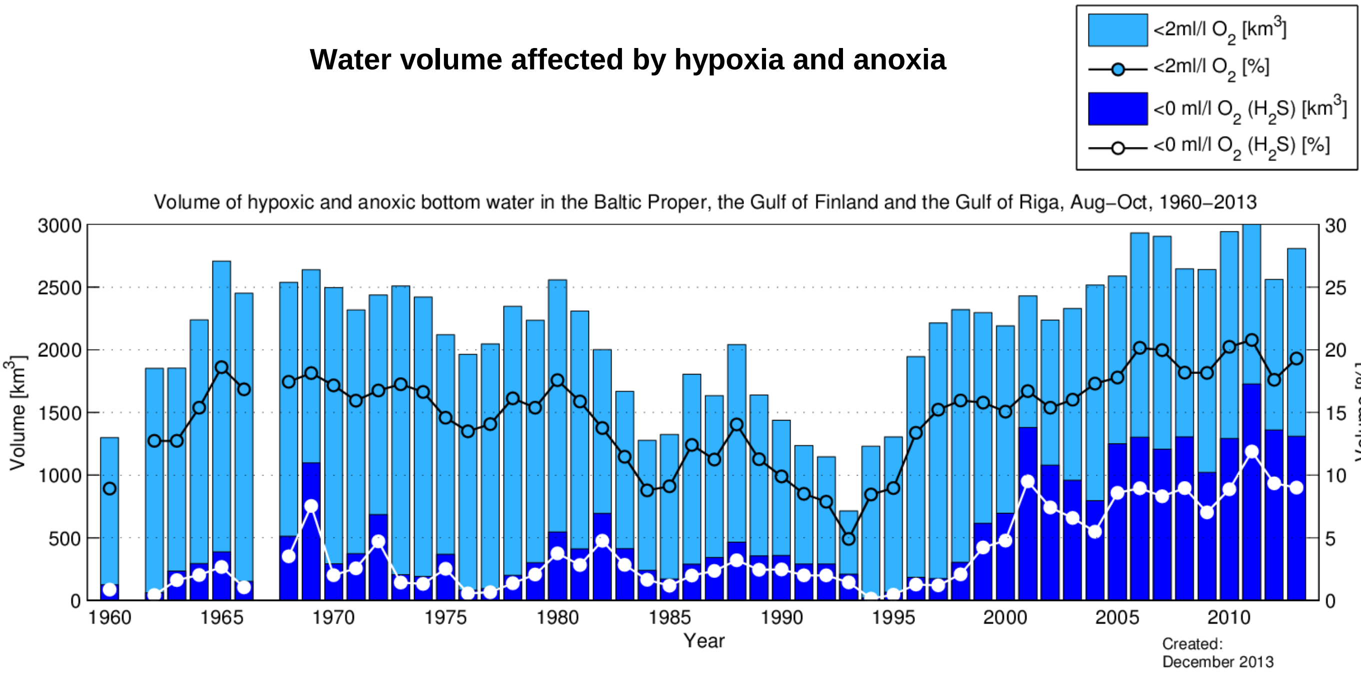


Figure 3. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed since sufficient data from the deep basins are missing.

# 5 Discussion

## Results for 2012

When the preliminary results for 2012 were updated the areal extent and volume were only slightly adjusted. Additional anoxic areas were found in the outer parts of the Gulf of Finland and hypoxia affected large areas in the south-eastern parts of the Baltic Proper. The results for 2012 follow the oxygen development that has prevailed since the beginning of 2000s. Positive effects of the relatively large inflow in November/December 2011, ~50 $km^3$ through the Sound [SMHI, 2013], could be seen in the southern Baltic Proper and in the southern parts of the eastern Gotland Basin but not in the deeper central parts.

The cumulative flow out of the Baltic Sea in 2012 was higher than average and higher than in 2011, mainly due to high precipitation. Some small inflows in February and December led to some oxygenation of the deep water in the southern Baltic. During January, northeasterly winds forced water through the Sound, out of the Baltic Proper. As a result, an inflow, through the Sound, of ~35 $km^3$ during February improved the oxygen conditions in the Arkona- and the Bornholm Basins. The high precipitation and large flows in the watercourses during autumn resulted in continuous outflows through the Sound. At Christmas and the following period water levels rose along the Swedish west coast and gave rise to an inflow of ~30 $km^3$ through the Sound, that again improved the oxygen situation in the southwestern part of the Baltic Proper, but was too small to affect the central parts.

### Preliminary results for 2013

The preliminary results for 2013 are similar to the mean conditions for the period (1999-2012) after the regime shift. Though, in comparison with 2012, the area affected by anoxia in the western Gotland basin has increased and anoxia was again present in the Bornholm Basin. Hypoxic conditions were now also found in the Gulf of Finland.

During 2013, inflows through the Sound were registered in January/February ~30 $km^3$ and together with the minor inflow in December 2012 only a temporary improvement could be seen in the Hanö Bight and in the Bornholm Basin before the oxygen concentrations again dropped below 2 ml/l to almost 0 ml/l. It was first after the inflow in October (~40 $km^3$) that a real improvement could be seen when concentrations increased from 0 ml/l to over 2 ml/l. At the time of writing, the storm Sven had just passed over the southern Baltic region. This storm resulted in high sea levels in south-eastern Kattegat and in the Sound, and in mid-December an inflow was ongoing which had reached ~ 20 $km^3$.

Further into the southeastern Baltic Proper and the southern Eastern Gotland Basin conditions during 2013 have been stable below 2 ml/l, with the exception of two short pulses of oxygenated water, but no hydrogen sulphide have been found in this area.

In the central deep parts of the Eastern Gotland Basin and in the Western Gotland Basin the stagnation continues. At station BY15 in the Gotland deep below 200m, see Appendix 1, there are no signs, in salinity, temperature or oxygen concentrations, of any inflow after 2007. Hence, no inflow that has occurred in later years has been sufficiently large and dense to replace the deep water in the Eastern Gotland basin. Instead, the inflows that have occurred have been set at intermediate depths, between 100-175 meters. Consequently, since most likely no inflows reach the Western Gotland Basin, hypoxia and anoxia are now found at shallow depths. Hypoxia from 60 meters depth and anoxia from 67 meters depth.

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

## 6 Conclusions

- The extreme oxygen condition in the Baltic Proper continues undiminished during 2013. 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.

- Anoxic conditions affected ~15 % of the bottom areas in the Baltic Proper, including the Gulf of Finland and the Gulf of Riga and ~30% suffered from hypoxia during the autumn of 2013. The largest areas of anoxic conditions, ~20 % were found in 2011.

- The inflows that occurred at the end of 2011 and a couple of small inflows that occurred during 2012 have improved the oxygen conditions temporarily in Arkona, Hanö Bight, in the Bornholm Basin and the southern Eastern Gotland Basin. But they did not improve the conditions in the deeper central parts of the Baltic Proper.

- In 2013 an inflow in October improved the oxygen conditions remarkably in the Hanö Bight and the Bornholm Basin. The effects of another inflow in December have still not been registered in monitoring data.

# 7 Acknowledgement

Data for updating the 2012 results were collected at 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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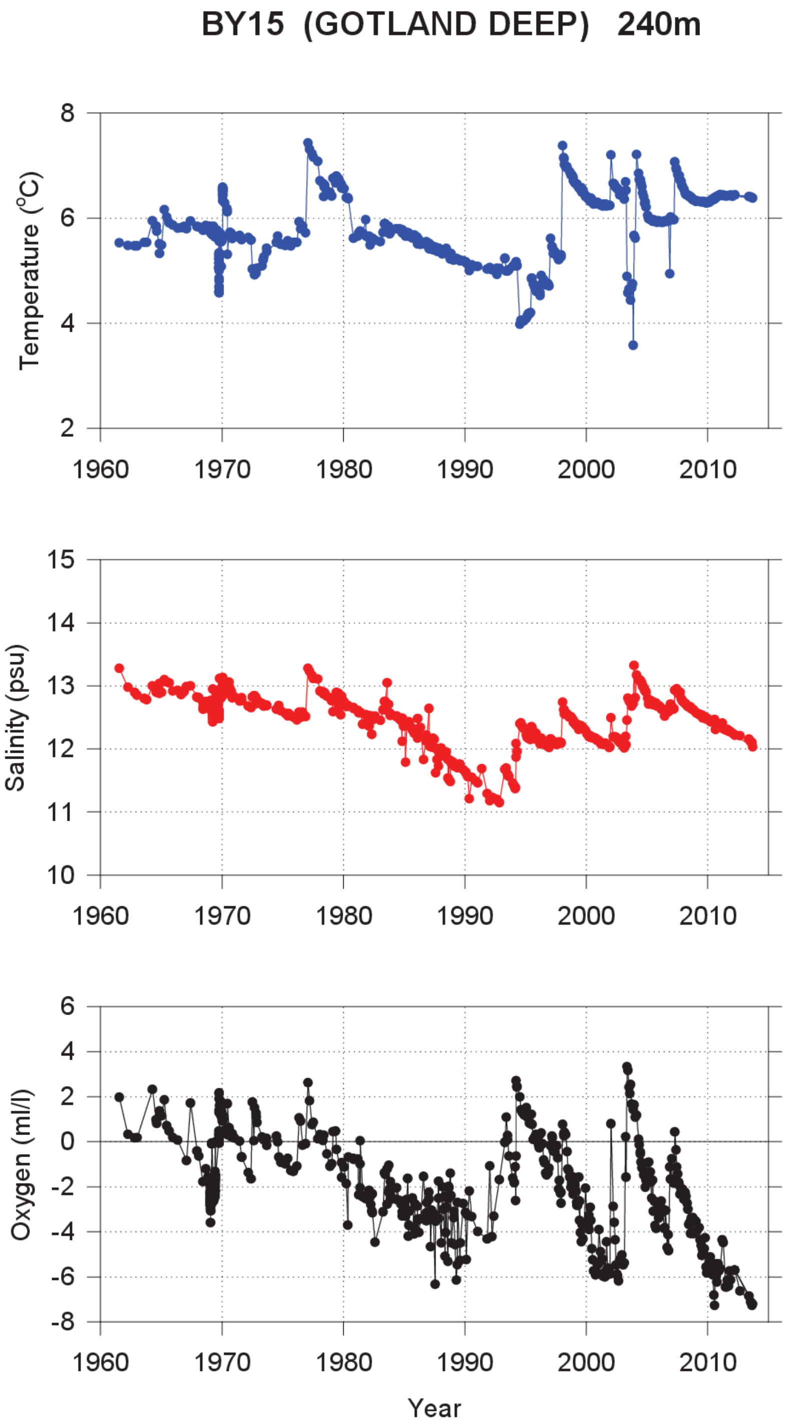
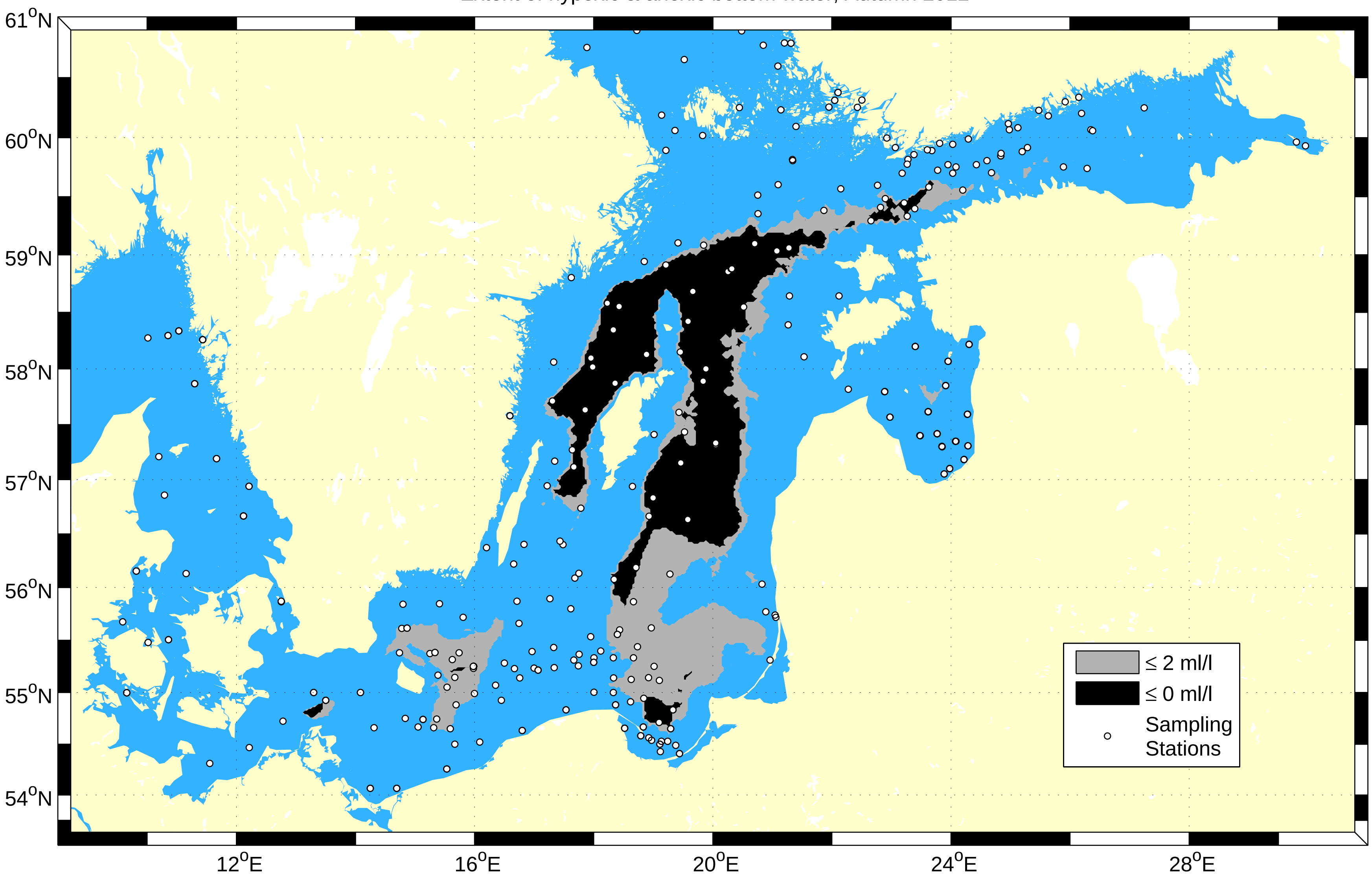
## Appendix 1 – Temperature, salinity and oxygen at BY15, Eastern Gotland Basin, 1960-2013




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

(The complete time series can be found in RO report 42)

Extent of hypoxic & anoxic bottom water, Autumn 2012

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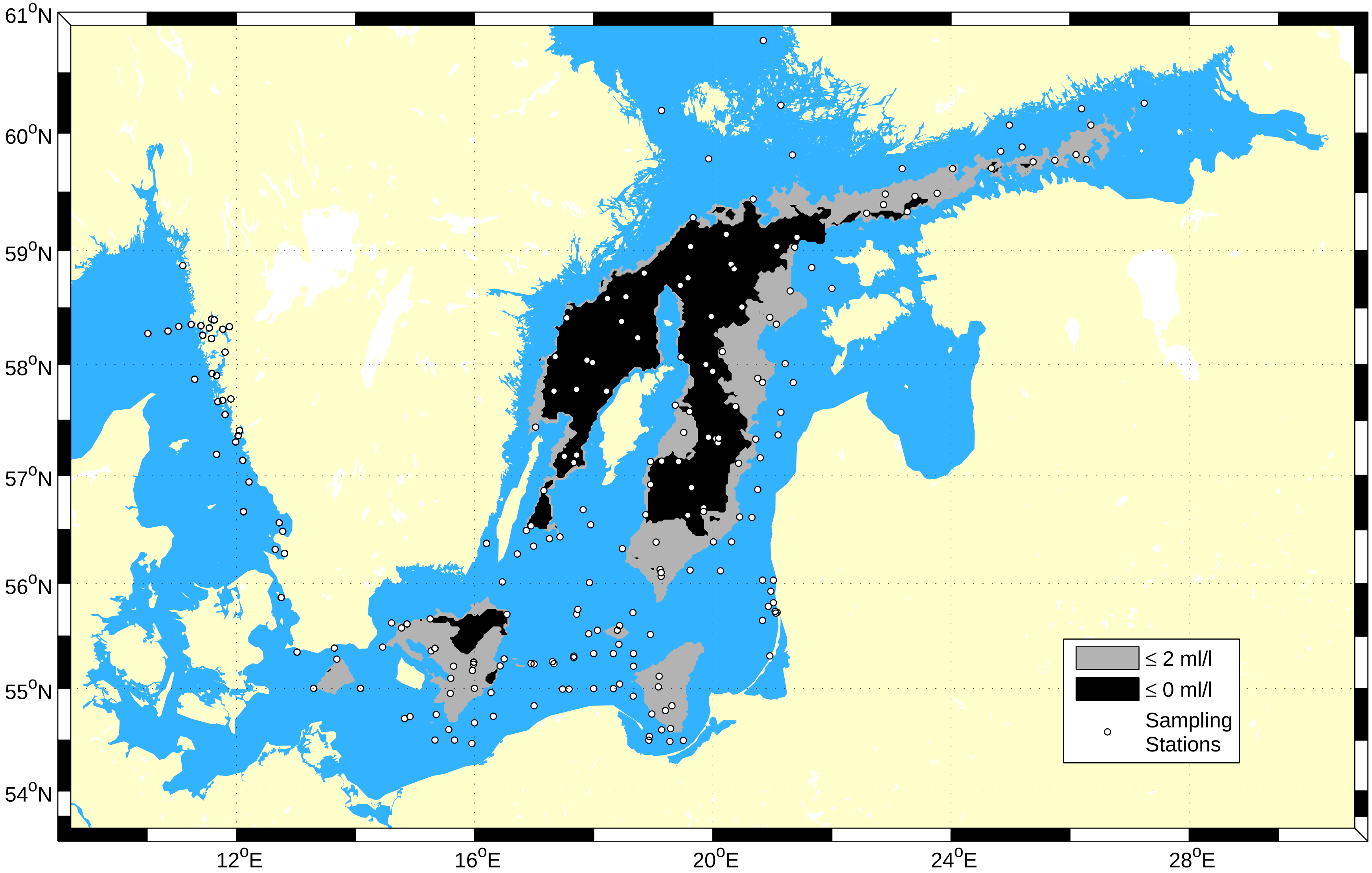
Extent of hypoxic & anoxic bottom water, Autumn 2013

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