SMHI

REPORT OCEANOGRAPHY No. 58, 2016

Oxygen Survey in the Baltic Sea 2016

- Extent of Anoxia and Hypoxia, 1960-2016

Front: Image take of the bottom at the sampling station BY5 in the Bornholm Basin. The oxygen situation at the bottom was almost anoxic, only 0.12 ml/l oxygen, one meter above the bottom. Note the jellyfish passing by. The photo was taken during the SMHI’s December cruise in 2016 with a drop-video rig.

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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 2015 have been updated and the preliminary results for 2016 are presented. Oxygen data from 2016 have been collected during the annual Baltic International Acoustic Survey (BIAS) and from national monitoring programmes with contributions from Sweden, Finland, Poland and Estonia.

For the autumn period 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 2015 and the preliminary results for 2016 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. Despite the frequent inflows to the Baltic Sea since 2014 approximately 17% of the bottom area was affected by anoxia and 28% by hypoxia during 2016. Nevertheless, the amount of hydrogen sulphide has, due to the inflows, decreased in the Eastern and Northern Gotland Basin.

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 2015 uppdaterats. De preliminära resultaten för 2016 baseras på data insamlade under Baltic International Acoustic Survey (BIAS) och nationell miljöövervakning med bidrag från Sverige, Finland, Estland, Tyskland och Polen.

Förekomsten av hypoxi (syrebrist) och anoxi (helt syrefria förhållanden) under höstperioden, 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 2015 och de preliminära resultaten för 2016 visar att de extrema syreförhållanden som observerats i Egentliga Östersjön fortsätter. Utbredningen av anoxi fortsätter att vara konstant förhöjd till nivåer som bara observerats i Östersjön enstaka år före 1999. Trots ett flertal inflöden sedan 2014 beräknas ungefär 17% av bottnarna i Egentliga Östersjön, Finska viken och Rigabukten vara påverkade av anoxiska förhållanden och omkring 28% av hypoxi under 2016. Dock har inflödena påverkat halterna av svavelväte som har minskat kraftigt i Östra och Norra Gotlandsbassängen.

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1 Background

The Baltic Sea is suffering from a lack of oxygen. The oxygen deficiency is most wide spread in deep basins in the Baltic Proper, Gulf of Finland and the Gulf of Riga. The limited inflows of high saline and oxygen rich water from the North Sea and the high freshwater input cause a strong stratification of the water column that prevents ventilation of the deep water. The strong stratification in combination with eutrophication and other factors forms the basis for the problematic oxygen conditions that are found in the Baltic Sea.

Anoxia is the condition when all oxygen is consumed by microbial processes and hydrogen sulphide (H_2S) is formed, which is toxic for all higher marine life. Only bacteria and fungi can survive in a water environment with total absence of oxygen. 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 consume oxygen to decompose.

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 broadly and recent literature studies [Vaquer-Sunyer & Duarte, 2008] show that the threshold for hypoxia range from 0.2 ml/l to 2.8 ml/l. However, the sublethal concentration ranges from 0.06 ml/l to 7.1 ml/l. The mean and median for all experimental assessments was 1.8 +/- 0.12 ml/l and 1.6 ml/l +/- 0.15 respectively. 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.

This report presents a 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, for the period 1960 to 2016. 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 to occur around 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 during 2015 and 2016. The complete and updated time series from 1960 can be found in at; http://www.smhi.se, which can be used as a climatological atlas describing the historical development and the present oxygen situation in the Baltic Proper.

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

2 Data

The calculations for 2016 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, Poland and Sweden. These data have not been fully quality controlled, only preliminary checks have been performed (quality assured laboratory procedures, timing and position checks and range checks). The time series and the results presented for 2016 will be updated when additional data are reported to ICES in 2017. In this report the results for 2015 have also been updated with all available data collected at ICES.

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

3 Method

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. 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.

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.

The calculations do not account for the existence of oxygenated water below an anoxic or hypoxic layer. Hence, during inflow situations when an intermediate layer with low oxygen concentrations or hydrogen sulphide can be found above oxygenated water, the method then overestimates the area and volume. However, these oxygenated zones are still problematic for most benthic animals and fish since they are trapped below an anoxic or hypoxic layer that also prevents migration and recolonization. The oxygenated zones below the intermediary layer, does influence the sediment to water nutrient exchange.

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].

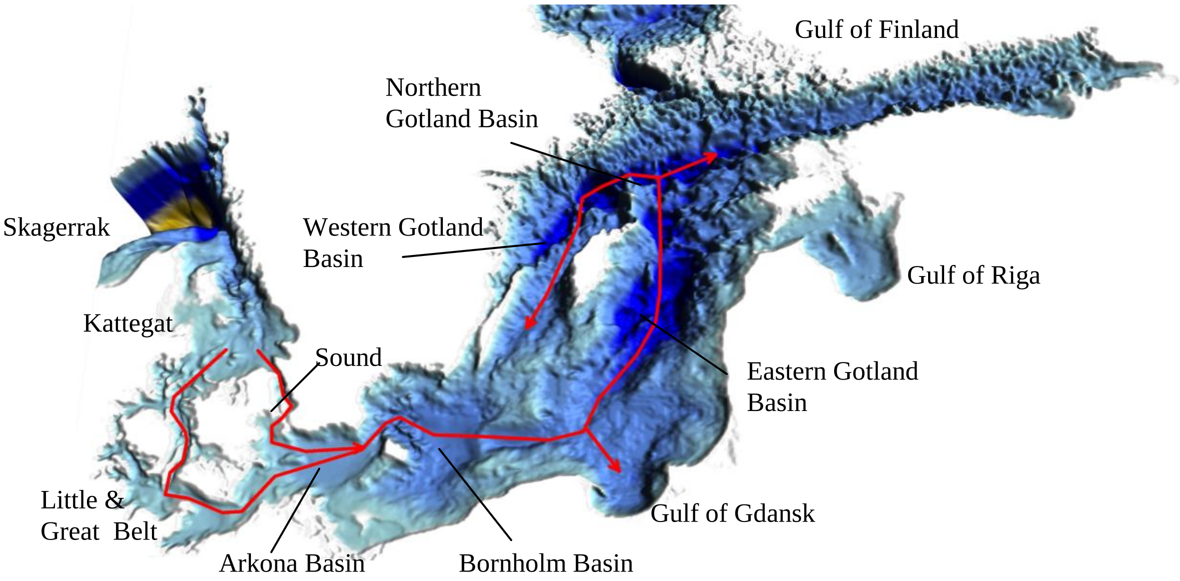

Figure 1. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathways of inflowing deep water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

4 Result

Extent and volume affected by hypoxia and anoxia during the period 1960 - 2016 are presented in Figures 2 and 3, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2015 and 2016 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 2016 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., 2011-2015. Note that the results for 2016 are preliminary.

in %	1960 – 1998		1999 – 2015		2016	
	Hypoxi	Anoxi	Hypoxi	Anoxi	Hypoxi	Anoxi
Mean Areal extent	22	5	29	15	28	17
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)	-	-

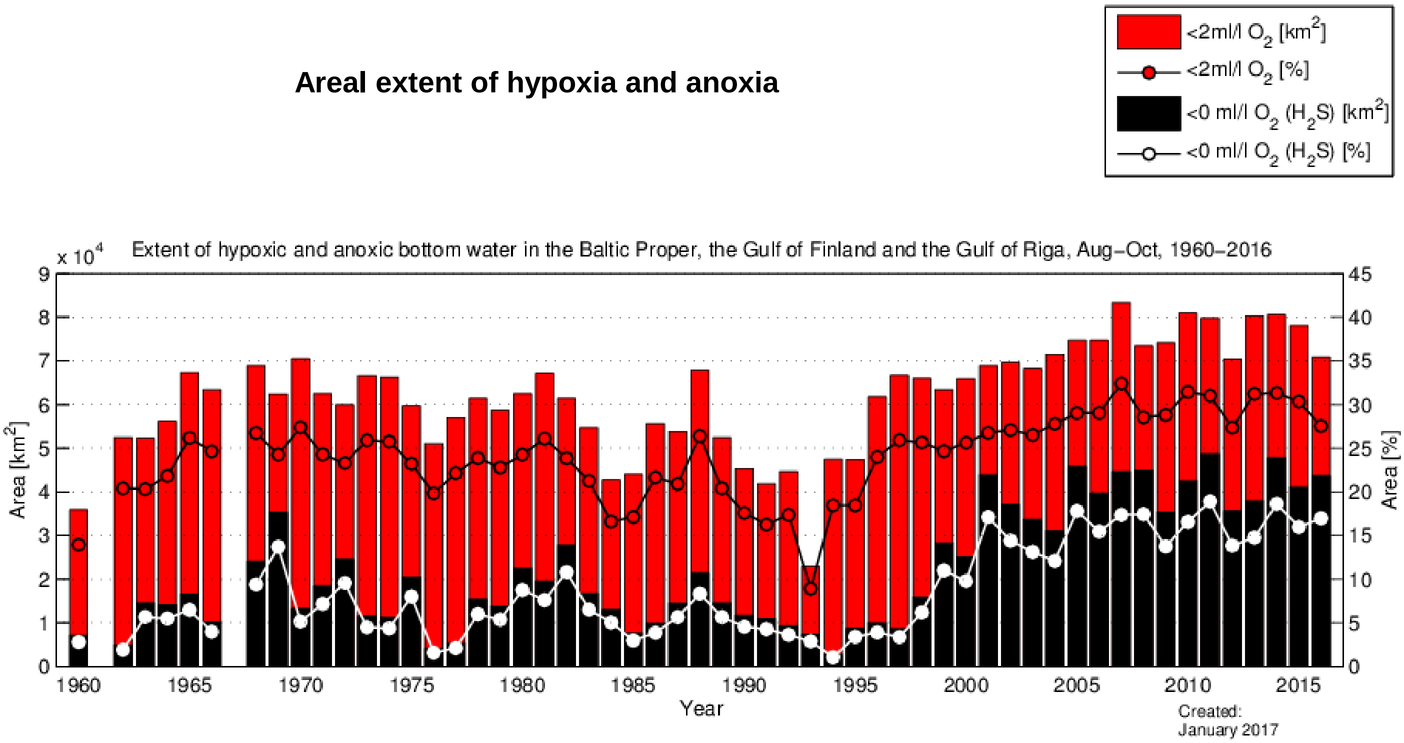

Figure 2. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

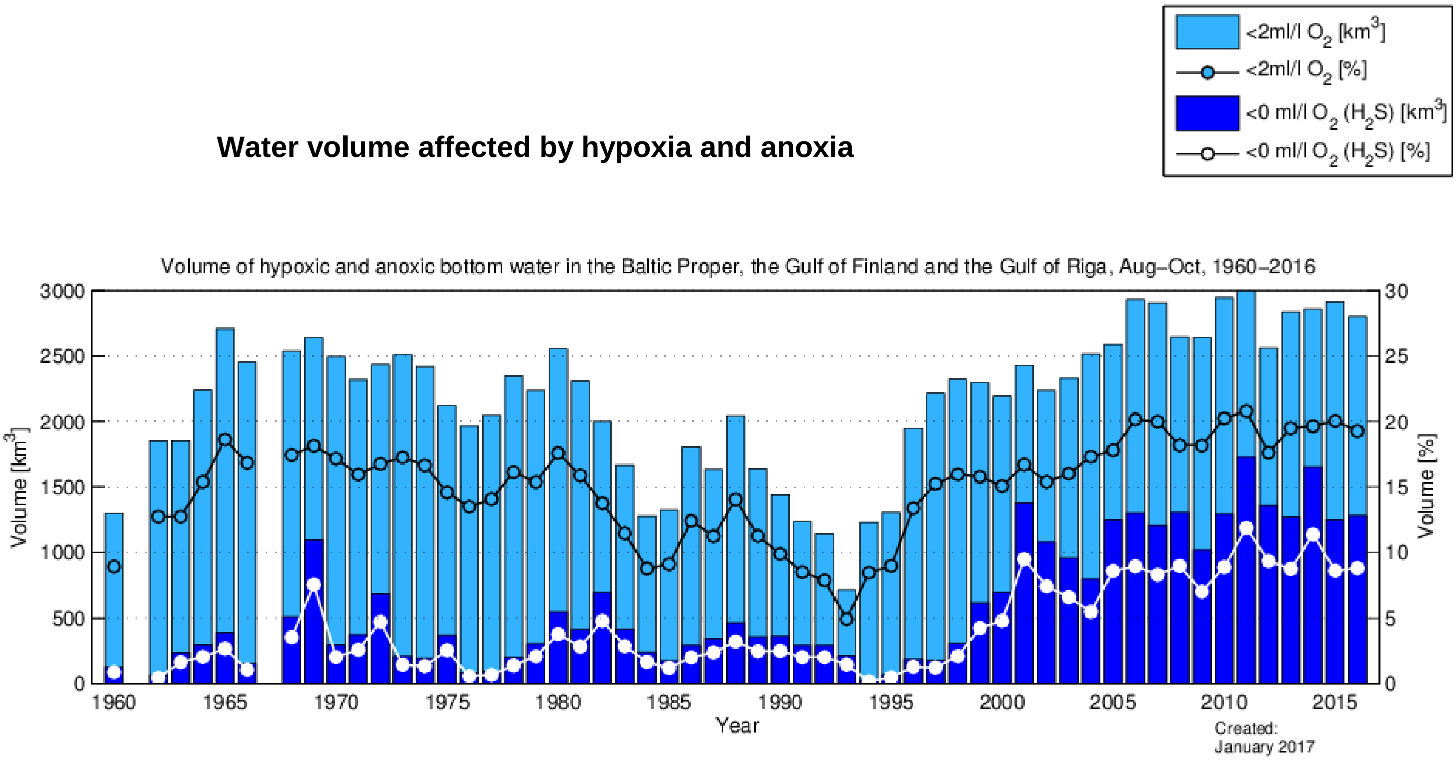

Figure 3. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

Updated results for 2015

Additional anoxic layers were found in the south-eastern parts of the Baltic Proper as the results for 2015 was updated. These anoxic areas are most likely scattered intermediate layers of anoxic water with hypoxic or oxygenated water below due to a series of small to moderate inflows in addition to the major inflow in December 2014. The anoxic areas in the Bornholm Basin that were found with the preliminary data have vanished but the hypoxic areas are now more wide spread.

The proportion of areas affected by anoxia was after the update unchanged at 16%. However, as different areas were affected, the volume did show a small decrease from 9% to 8%.

Small changes were also found for the portion of areas suffering from hypoxia, which increased from 29% to 30%. The volume of hypoxic water was unchanged at 20%. The updated results for 2015 follow the oxygen development that has prevailed since the regime shift in 1999.

The inflows to the Baltic Sea through the Sound, during 2015 summed up to 331 km^3 and the summed outflow was 670 km^3. The average for inflows and outflows during the period 1977-2014 is 325 km^3 respectively 641 km^3. Both inflows and outflows during 2015 were thus slightly larger than normal. The large inflow in December 2014 was followed by an inflow of 30 km^3 in January 2015 caused by the storm “Egon”. During the period February to June winds were relatively weak due to high pressure weather and no larger inflows occurred. Two minor inflows in early July and also in late August/early September pushed another 10-20 km^3 through the Sound. From September to December, about ten minor inflows of short duration, with a volume of 10-30 km^3 each, entered through the Sound.

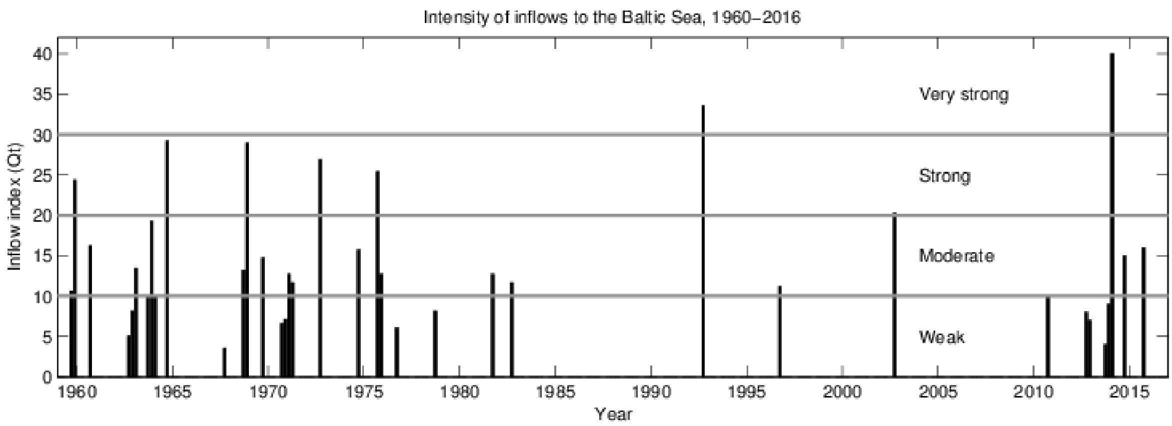

Figure 4. Intensity of inflows to the Baltic Sea, 1960-2016. [Mohrholz et al. 2015, Feistel et al. 2016] Revised and updated.

Preliminary results for 2016

The frequency of inflows to the Baltic Sea has increased since 2014. The intensity and number of inflows are now similar to the conditions that prevailed during the 1960s and 1970s. See figure 4.

Just like the effects of the 2014 inflows could be seen in the 2015 data the moderate inflow in 2015 could be seen in the 2016 data in the Eastern and Northern Gotland Basin. Another moderate inflow during early 2016 further improved the oxygen situation. However, hypoxic and anoxic conditions were still present at intermediate depth in large areas. For a few month,(April – September) the southern parts of Eastern Gotland basin was well oxygenated. Though, bottom water samples taken in December 2016 and in January 2017 showed that the oxygen concentrations have decreased and were found to be below 1 ml/l in the south eastern Baltic Proper. [SMHI 2016]

In the Gotland Deep, BY15, the whole water column was oxygenated from October 2015 to August 2016 when low concentrations of hydrogen sulphide again were present at the bottom. The concentrations of oxygen found during the oxygenated period below 100 meters was generally below 2 ml/l. [SMHI, 2016]

In the Northern Gotland Basin at BY29 and BY31, anoxic conditions were found but the concentrations of hydrogen sulphide had also decreased compared to previous years. Further, in the Western Gotland Basin, at BY32 Norrköping Deep, the stagnation period continues with high concentrations of hydrogen sulphide in the deep water. Hypoxia and anoxia were found at shallow depths, hypoxia from ~60 meters depth and anoxia from ~70-80 meters depth. [SMHI, 2016]

Preliminary results, focusing solely on the extent and volumes of anoxia and hypoxia, suggest that the severe oxygen situation continues at an elevated level. The proportion of areas affected by hypoxia remains at the same level ~28% and the anoxic areas affect ~17%. Nevertheless, the inflows have improved the oxygen situation by reducing the amount of hydrogen sulphide in large parts of the Baltic Proper, see Figure 5. It is likely that the extremely high hydrogen sulphide concentrations found before the 2014 inflows are the reason that the area and volume of anoxic bottoms remains nearly as high as before the inflow.

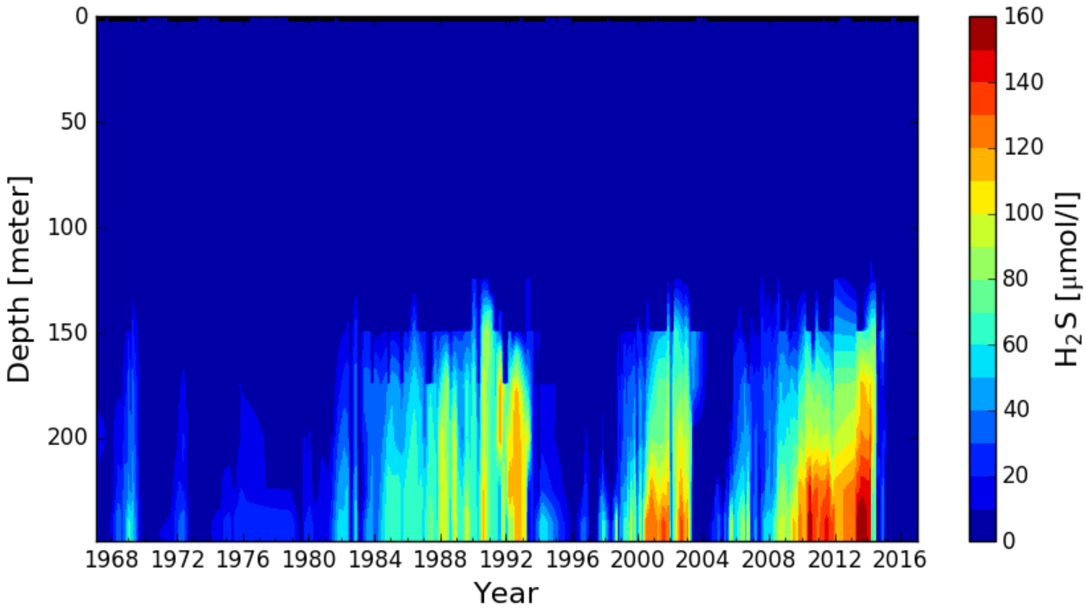

Figure 5. Concentration of hydrogen sulphide (H_2S) at Gotland Deep (BY15) in Eastern Gotland Basin from 1966-2016. Note that there are no H2S data at this station prior to august 1966. The figure shows extremely high H2S concentrations prior to the 2014 inflow, it does however not resolve the intermediary H2S layers after the inflow, concentrations between 0-10 µmol/l is shown in dark blue.

The frequent inflows that have occurred since 2014 are a new positive development that can improve the severe oxygen situation that has prevailed since the regime shift in 2000. However, to sustain the positive effects and to further reduce the vast anoxic and hypoxic areas, even more inflows are needed. Otherwise the oxygen situation will deteriorate and the anoxic and hypoxic areas will increase again.

5 Conclusions

- Similar to previous year, the severe oxygen conditions in the Baltic Proper continued during 2016. The areal extent and the volume of anoxia and hypoxia have since the regime shift in 1999 been constantly elevated.

- Preliminary results for 2016 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 28% suffer from hypoxia.

- The frequency of inflows to the Baltic Sea has increased since 2014. The intensity and number of inflows are now similar to the conditions that prevailed during the 1960s and 1970s. The recent inflows have oxygenated the deep water in the Eastern Gotland Basin but hypoxia and anoxia has still been present at intermediate depths and was also found at the bottom at the end of 2016.

- Due to the frequent inflows the amount of hydrogen sulphide has decreased both in the Eastern and Northern Gotland Basin. However, it is likely that the extremely high hydrogen sulphide concentrations before the major inflow in 2014 are the reason that the area and volume of anoxic bottoms remains nearly as high as before the inflow.

6 Acknowledgement

Data for updating the 2015 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 Taavi Liblik, Marine Systems Institute at Tallinn University of Technology, for delivering Estonian national monitoring data and to Tycjan Wodzinowski, National Marine Fisheries Research Institute, for sending data from Polish Multiannual Fisheries Data Collection Programme (under the EU Data Collection Framework).

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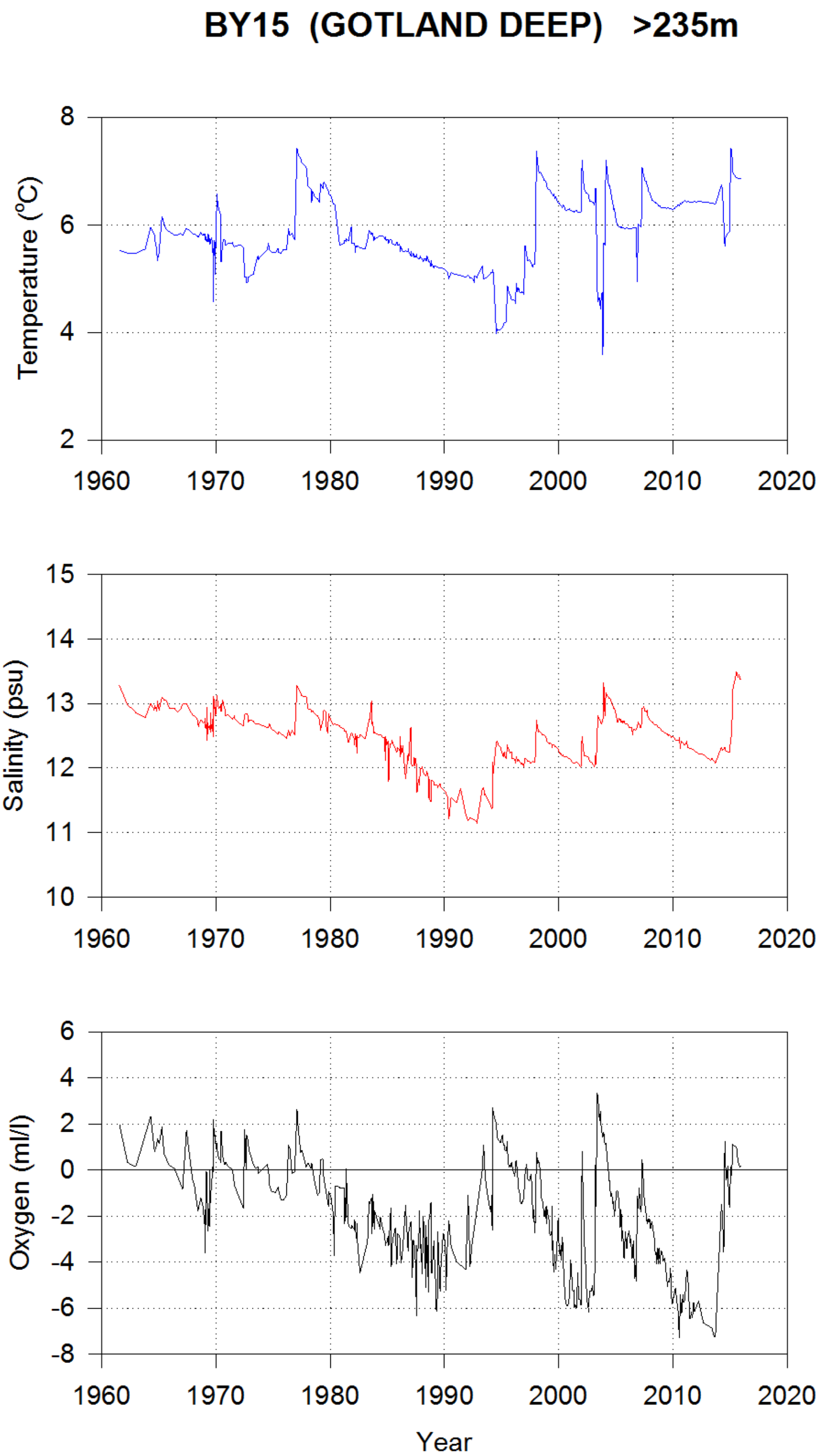
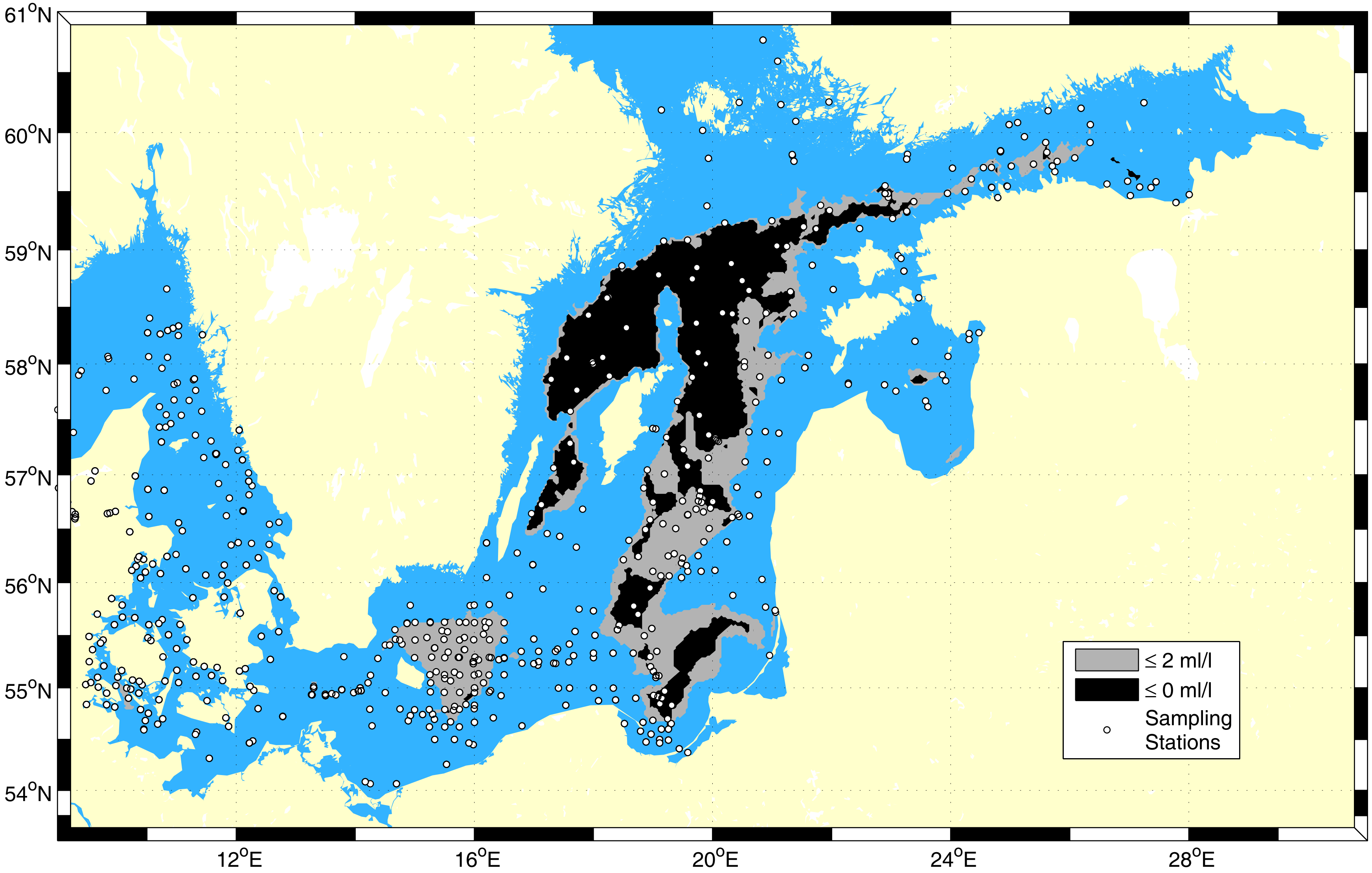
Appendix 1 – Temperature, salinity and oxygen at BY15, Eastern Gotland Basin, 1960-2015



Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea, 2015-2016

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

Extent of hypoxic & anoxic bottom water, Autumn 2015



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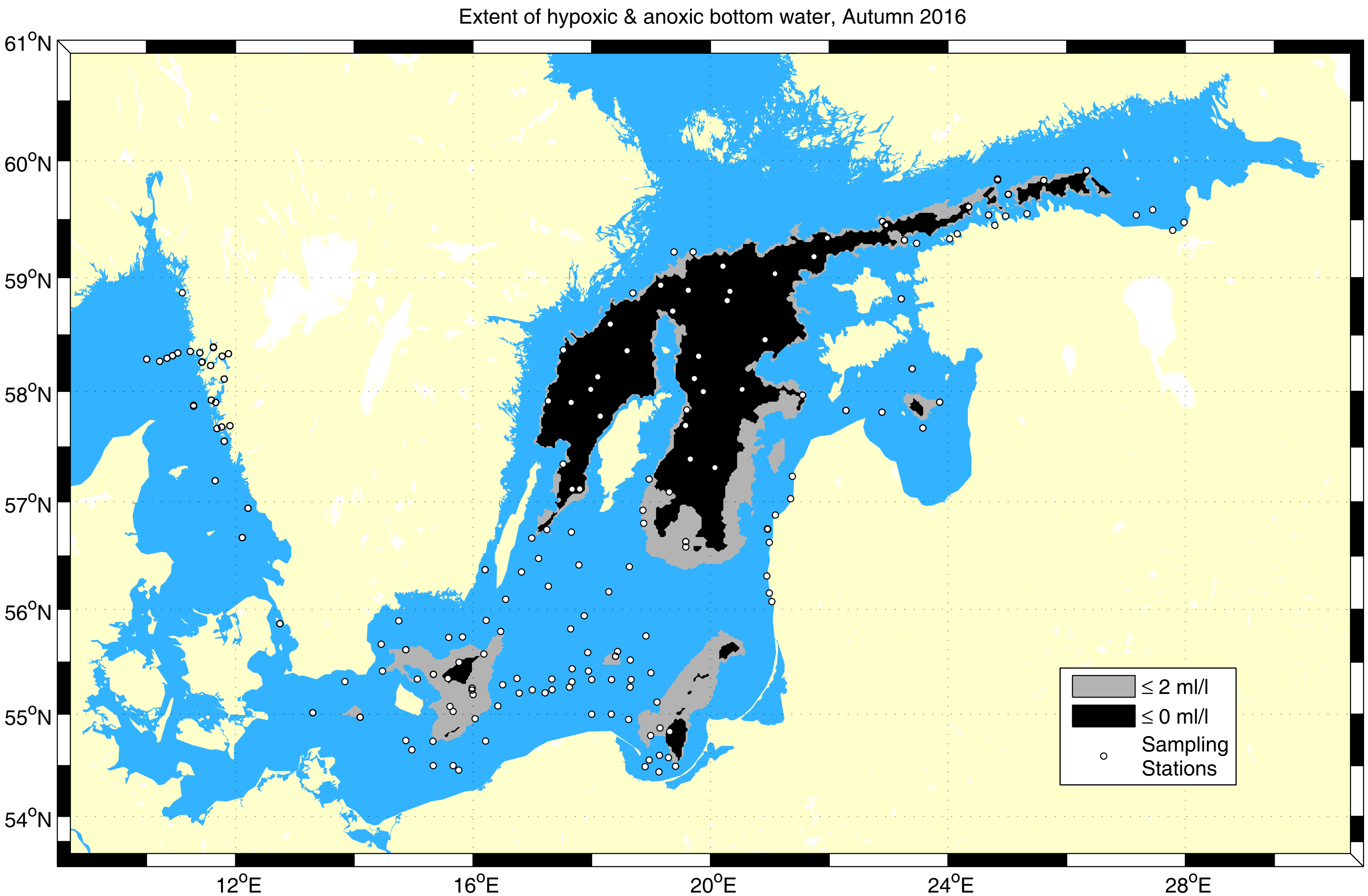

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8 SMHI Publications

SMHI publish seven report series. Three of these, the R-series, are intended for international readers and are in most cases written in English. For the others the Swedish language is used.

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2 Thomas Thompson (1986)
Ymer-80, satellites, arctic sea ice and weather

3 Stig Carlberg et al (1986)
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