

Oxygen Survey in the Baltic Sea 2017 - Extent of Anoxia and Hypoxia, 1960-2017



Front: The photo was taken on-board M/S Meri during SMHIs September cruise in 2017 somewhere east of Gotland.

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Oxygen Survey in the Baltic Sea 2017
- Extent of Anoxia and Hypoxia, 1960-2017

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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 2016 have been updated and the preliminary results for 2017 are presented. Oxygen data from 2017 have been collected during the annual Baltic International Acoustic Survey (BIAS) and from national monitoring programmes with contributions from Sweden, Finland and Poland.

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 and anoxic conditions respectively 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 2016 and the preliminary results for 2017 show that the severe 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 during the period 2014-2016 approximately 18% of the bottom area was affected by anoxia and 28% by hypoxia during 2017. The hydrogen sulphide has, due to the inflows, disappeared from the Eastern and Northern Gotland Basin. However, the oxygen concentrations in the deep water are still near zero and signs of increasing hydrogen sulphide close to the bottom have been observed during 2017.

Sammanfattning

En klimatologisk atlas över syresituationen i Östersjöns djupvatten publicerades 2011 i SMHI:s Report Oceanography No 42. Sedan 2011 har årliga uppdateringar gjorts då kompletterande data från länder runt Östersjön har rapporterats till ICES. I denna rapport har resultaten från 2016 uppdaterats. De preliminära resultaten för 2017 baseras på data insamlade under Baltic International Acoustic Survey (BIAS) och nationell miljöövervakning med bidrag från Sverige, Finland 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 2016 och de preliminära resultaten för 2017 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 under perioden 2014-2016 beräknas ungefär 18% av bottenarna i Egentliga Östersjön, Finska viken och Rigabukten vara påverkade av anoxiska förhållanden och omkring 28% av hypoxi under 2017. Inflödena 2014-2016 har minskat poolen av svavelväte så att den nästan helt försvunnit i Östra och Norra Gotlandsbassängen. Dock är syrgashalterna fortsatt noll eller mycket nära noll i djupvattnet och tecken på ökade halter av svavelväte har noterats under 2017.

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1 Background

Vast bottom areas in the Baltic Sea are suffering from oxygen deficiency. Total absence of oxygen and lack of oxygen in the deep water are mainly found in the central deep basins in the Baltic Proper, Gulf of Finland and Gulf of Riga. Limited inflows of high saline and oxygen rich water from the North Sea through the Belt Sea and the Sound together with the high freshwater input from land and precipitation 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 low-oxygen conditions that are found in the Baltic Sea.

Anoxia is the condition when all oxygen has been consumed by microbial processes and no oxygen is left in the water. If the water stays anoxic for a longer period of time hydrogen sulphide (H₂S) 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 in surface waters 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 when it is decomposed.

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 2017. The time series were first published in 2011 and the results have been updated annually as new additional data have become available at ICES¹. 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 2016 and 2017. The complete and updated time series from 1960 can be found 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 2017 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 Finland, 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 2017 will be updated when additional data are reported to ICES in late 2018. In this report the results for 2016 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 providing a synoptic view of the oxygen situation. 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].

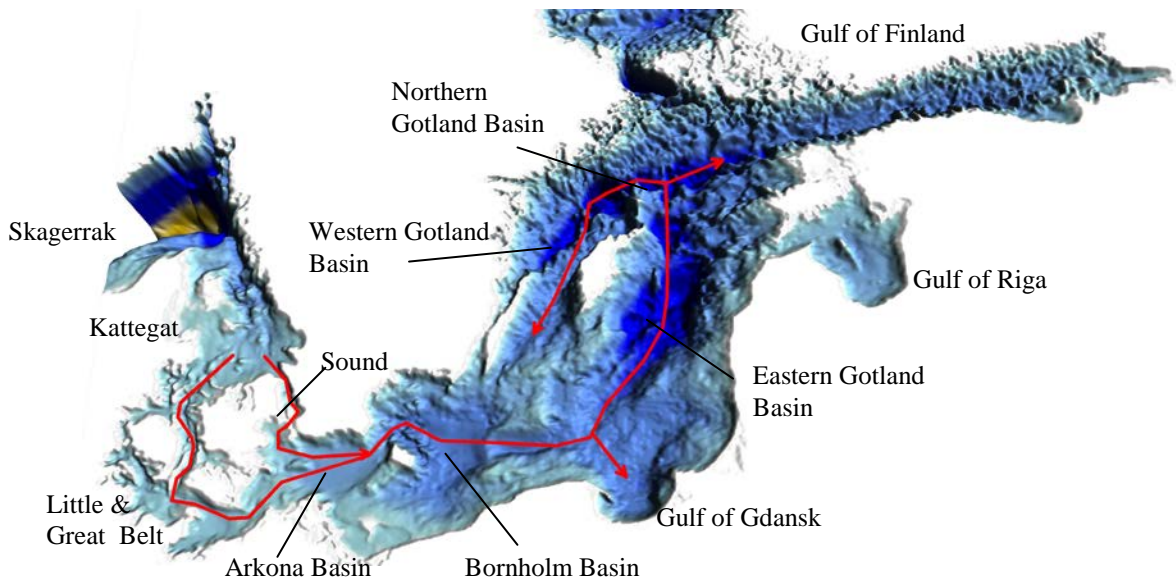


Figure 1. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathways of inflowing deep water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

4 Result

Extent and volume affected by hypoxia and anoxia during the period 1960 - 2017 are presented in Figures 2 and 3, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2016 and 2017 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 2017 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., 2011-2016. Note that the results for 2017 are preliminary.

in %	1960 – 1998		1999 – 2016		2017	
	Hypoxia	Anoxia	Hypoxia	Anoxia	Hypoxia	Anoxia
Mean Areal extent	22	5	29	15	28	18
Max Areal extent (Year)	27 (1968)	14 (1969)	32 (2007)	19 (2011)	-	-
Mean Volume	13	2	18	8	22	12
Max Volume (Year)	19 (1965)	8 (1969)	21 (2011)	12 (2011)	-	-

Areal extent of hypoxia and anoxia

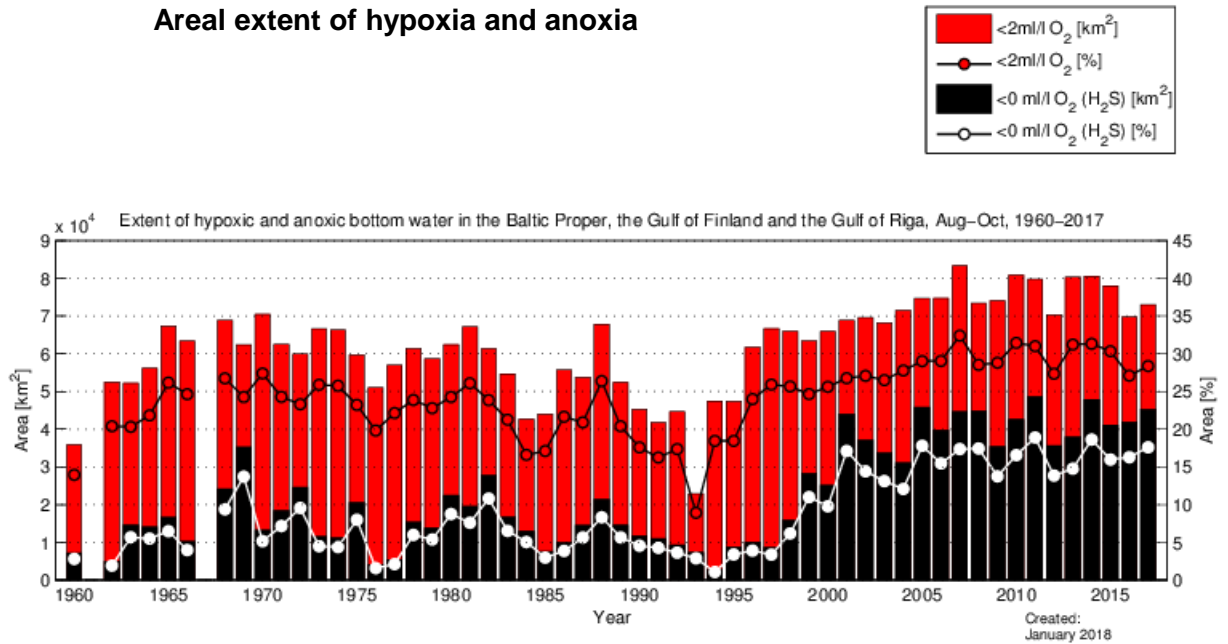


Figure 2. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

Water volume affected by hypoxia and anoxia

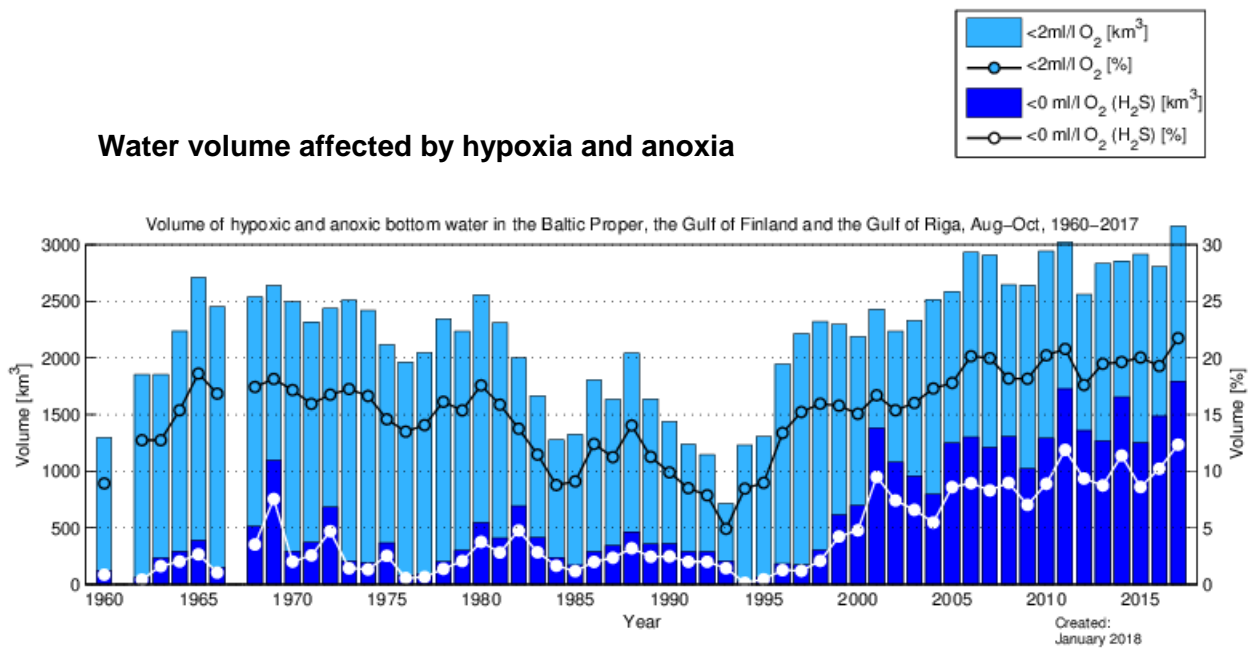


Figure 3. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

Updated results for 2016

After updating the results for 2016 with new data reported to ICES the area affected by anoxia and hypoxia only showed minor changes. The anoxic areas in the Bornholm Basin almost vanished and in the Gulf of Finland the areas affected decreased slightly, only affecting the deepest areas of the basins. The hypoxic areas showed similar small changes with the exception of the southern parts of the Eastern Gotland Basin where the area increased after additional data was added.

The proportion of areas affected by anoxia was after the update more or less unchanged (17 % to 16%). However, as different areas were affected, the volume did show a small increase from 9% to 10%. Small changes were also found for the portion of areas suffering from hypoxia, which decreased from 28% to 27%. The volume of hypoxic water was unchanged at 19%. The updated results for 2016 follow the oxygen development that has prevailed since the regime shift in 1999.

The inflows to the Baltic Sea through the Sound, during 2016 summed up to 294 km³ and the summed outflow was 654 km³. The average for inflows and outflows during the period 1977-2015 is 316 km³ respectively 624 km³. Hence, the inflows were lower than normal and the outflows during 2016 were slightly larger than normal.

During the first quarter of 2016 two periods of inflows were recorded through the Sound, of which the greater, January-February was approximately ~40 km³. This inflow was classified by Leibniz Institute for Baltic Sea Research, Warnemünde (IOW) to be a Major Baltic Inflow (Q_{FM96}) of moderate intensity [Feistel et al. 2016]. The inflow came after a period of low water levels in the Baltic Sea in January and brought enough and heavy water to be traced in the deep water of the Baltic Proper.

After a period of continuous outflow of water, three inflows occurred of about 20 km³ individually at the end of October, mid-November and the end of December.

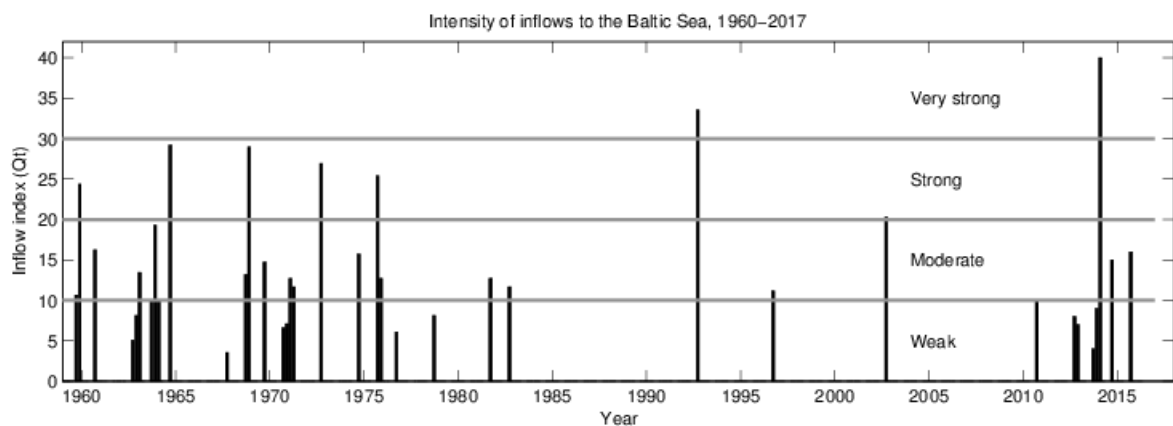


Figure 4. Intensity of inflows to the Baltic Sea, 1960-2017. [Mohrholz et al. 2015, Feistel et al. 2016] Revised and updated.

Preliminary results for 2017

The frequency of inflows to the Baltic Sea increased during the period 2014-2016. However, during 2017 no major inflow to the Baltic Sea was noted. During the first quarter of 2017, in mid-February an inflow of ~30 km³ was recorded through the Sound. Outflow prevailed during the second and third quarter. In the beginning of October two inflows could be seen of totally ~30 km³. The salinity was too low and stratified conditions were mostly measured at the Darss Sill and only thin inflow layer at the bottom occurred [Pers. Com. M. Neumann, IOW].

In the Arkona Basin the oxygen conditions near bottom followed the annual cycle with well oxygenated conditions during winter and spring and thereafter decreasing concentrations from early summer, resulting in oxygen minima and hypoxia in September. The small inflows in October improved the conditions by raising the oxygen concentration in Arkona but did not affect the deep areas further into the Baltic Proper.

The oxygen conditions in the bottom water at Hanö Bight were hypoxic throughout the year. No anoxic conditions were found although the oxygen concentration was close to zero during most sampling occasions. Hypoxia was generally found from depth exceeding 70 meters but in December already from about 50 meters depth. Signs of the inflows that occurred during the year could be seen at intermediate depths.

In the Bornholm Basin hypoxia was found at 70 and 80 meters depth throughout the year. However, high oxygen concentrations were observed at the Christiansö (BY4) bottom water in January which indicates inflowing water. The positive effect lasted until March when the oxygen levels dropped below 2 ml/l and hypoxic conditions close to zero oxygen prevailed.

In the southern parts of the Eastern Gotland Basin the whole water column was oxygenated throughout the year even though concentrations close to zero was observed both at intermediate depth below the permanent stratification and in the deep water. Pulses of oxygenated water to the deep water were recorded during the period March to April. In May the oxygen concentrations from depth exceeding 100 meters down to near bottom was just above 2 ml/l. The conditions deteriorated after these pulses and hypoxia or near anoxic conditions prevailed during the rest of the year.

In the central parts of the Eastern Gotland Basin, hypoxia was present from 70-80 meters and in late summer already from ~60 meters depth. The water below the stratification was hypoxic with oxygen concentrations close to zero. Anoxic conditions were found near bottom, > 200 meters, at Gotland Deep (BY15) during all year and concentrations of hydrogen sulphide increased, see Appendix 1. Further north at Fårö Deep (BY20) anoxia was found near bottom from July and onwards.

The concentrations of hydrogen sulphide (H₂S) in the Northern and Eastern Gotland Basin continue to be low compared to the years before the large inflow 2014 reached these basins (Figure 5). This means that although the inflow reached these areas, small effects are seen when looking only at the oxygen concentrations, since they are still close to zero in large parts of the deep water.

The severe stagnation in the Western Gotland Basin continues with high concentrations of hydrogen sulphide. Anoxic conditions prevailed from 70-90 meters depth and hypoxia from ~60 meters depth. None or only minor effects of the major inflow that occurred during the period 2014-2016 has been seen in this basin. [SMHI 2017]

The preliminary results for 2017, 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 anoxia remains at the same level ~18% and the hypoxia areas affect ~28%. The series of major inflows that occurred between 2014 and 2016 have improved the situation by reducing the amount of hydrogen sulphide in large parts of the Baltic Proper, see Figure 5.

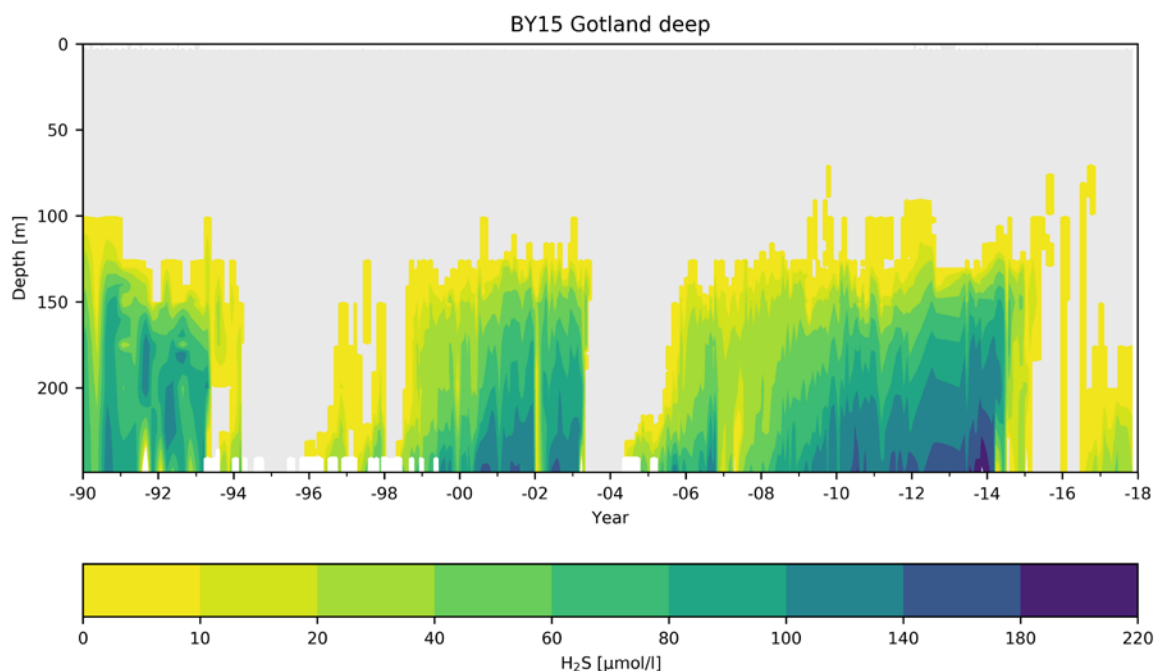


Figure 5. Concentration of hydrogen sulphide (H_2S) at Gotland Deep (BY15) in Eastern Gotland Basin from 1990-2018. Grey signifies no hydrogen sulphide present.

However, no major inflows have occurred since the beginning of 2016 and signs of increasing amounts of hydrogen sulphide can be seen in the Eastern Gotland Basin close to the bottom. New major inflows are needed to prevent further deterioration of the oxygen situation and if a new series of inflow occur similar to the frequent inflow period between 2014 and 2016 the oxygen situation could improve remarkably since the large pool of hydrogen sulphide in the Eastern and Northern Baltic Proper has vanished.

5 Conclusions

- Similar to previous year, the severe oxygen conditions in the Baltic Proper continued during 2017. The areal extent and the volume of anoxia and hypoxia have since the regime shift in 1999 been constantly elevated.
- Preliminary results for 2017 shows that anoxic conditions affect ~18% of the bottom areas in the Baltic Proper, including the Gulf of Finland and the Gulf of Riga and approximately 28% suffer from hypoxia.
- A series of major inflows to the Baltic Sea occurred between 2014 and 2016. The recent inflows have reduced the large pool of hydrogen sulphide that was present in the Eastern and Northern Gotland Basin. However, oxygen concentrations in the deep water are near zero below the permanent stratification and conditions near bottom has become increasingly anoxic during 2017.
- Signs of increasing amounts of hydrogen sulphide can be seen in the Eastern and Northern Gotland Basins close to the bottom. New major inflows are needed to prevent further deterioration of the oxygen situation, with the formation of higher hydrogen sulphide concentrations as a result.
- If a new series of inflow occur similar to what occurred between 2014 and 2016 the oxygen situation could improve remarkably since the large pool of hydrogen sulphide in the Eastern and Northern Gotland Basin has vanished.

6 Acknowledgement

Data for updating the 2016 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 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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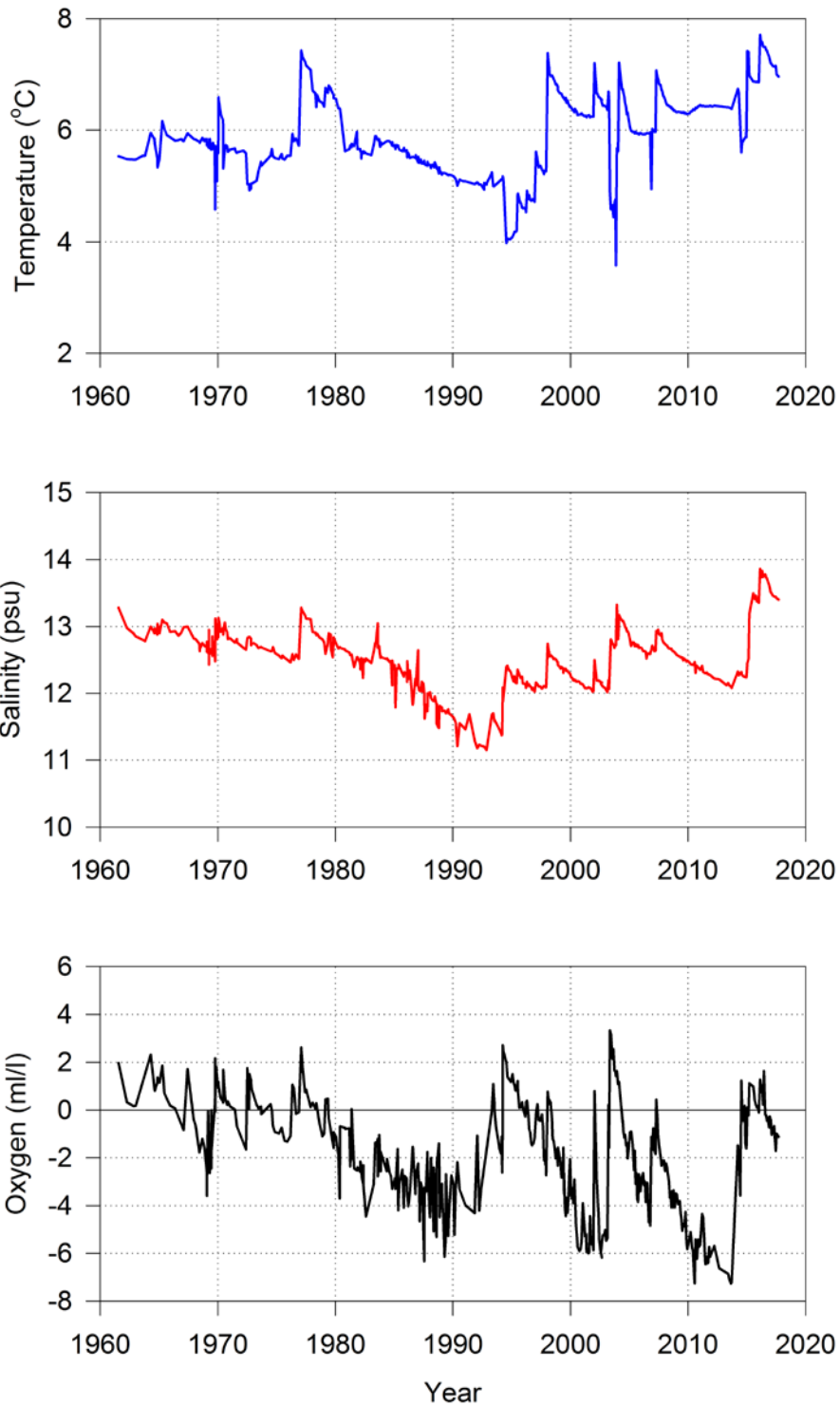
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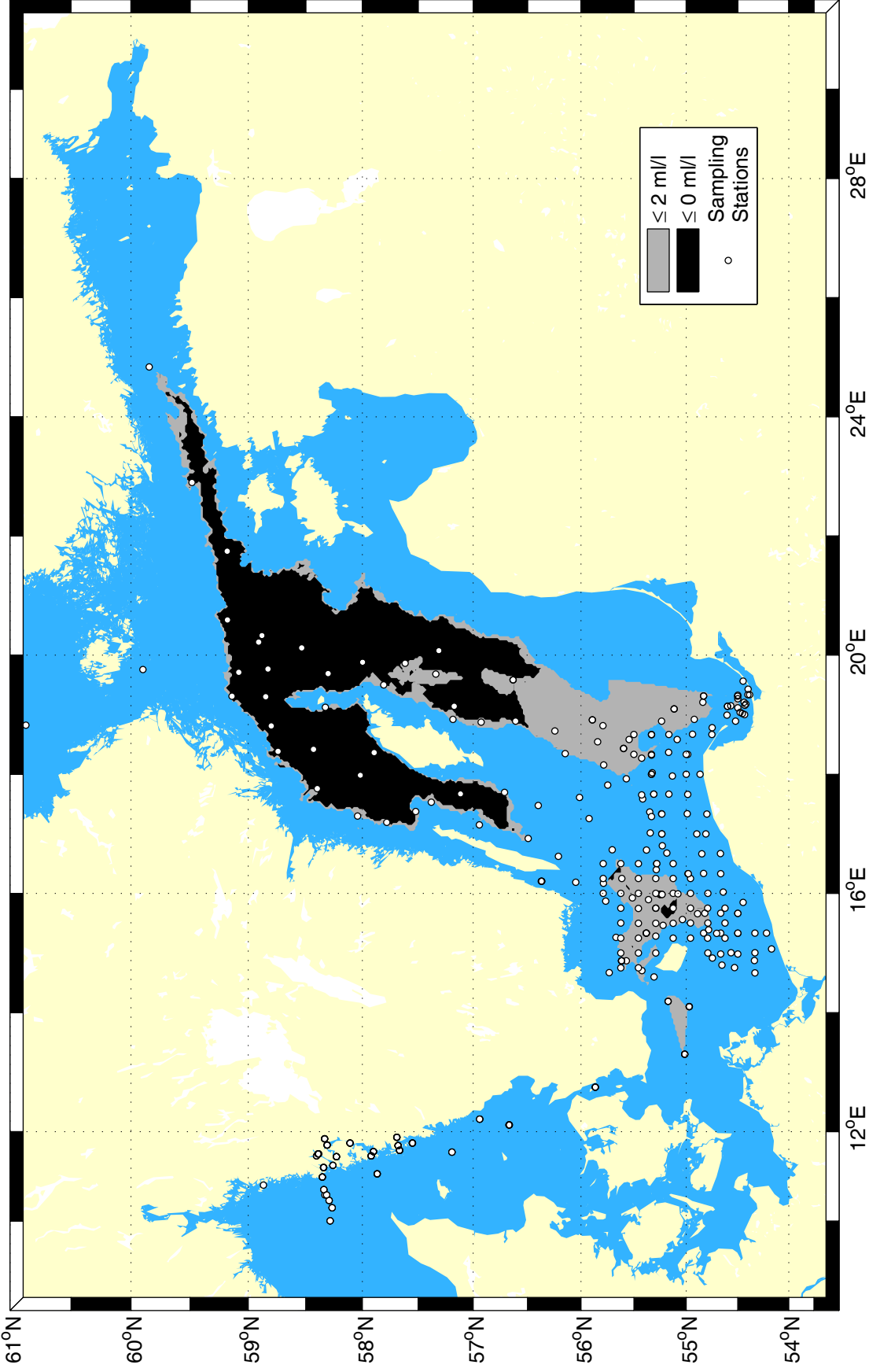
Appendix 1 – Temperature, salinity and oxygen in Eastern Gotland Basin at station BY15, 1960-2017

BY15 (GOTLAND DEEP) >235m



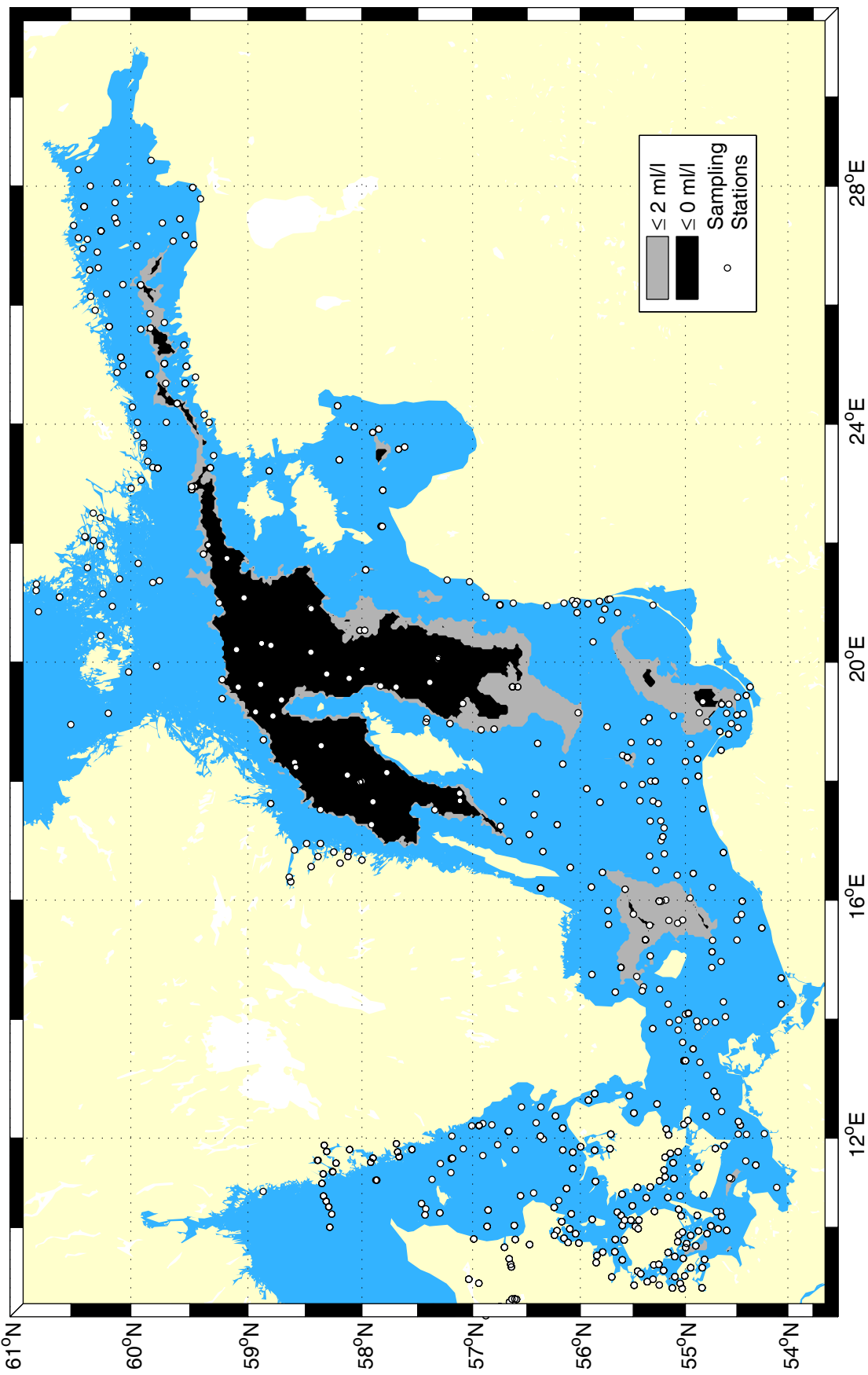
Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea, 2016-2017
(The complete and updated time series can be found in on <http://www.smhi.se>)

Extent of hypoxic & anoxic bottom water, Autumn 2017



Created:
January
2018

Extent of hypoxic & anoxic bottom water, Autumn 2016



Created:
January
2018

8 SMHI Publications

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