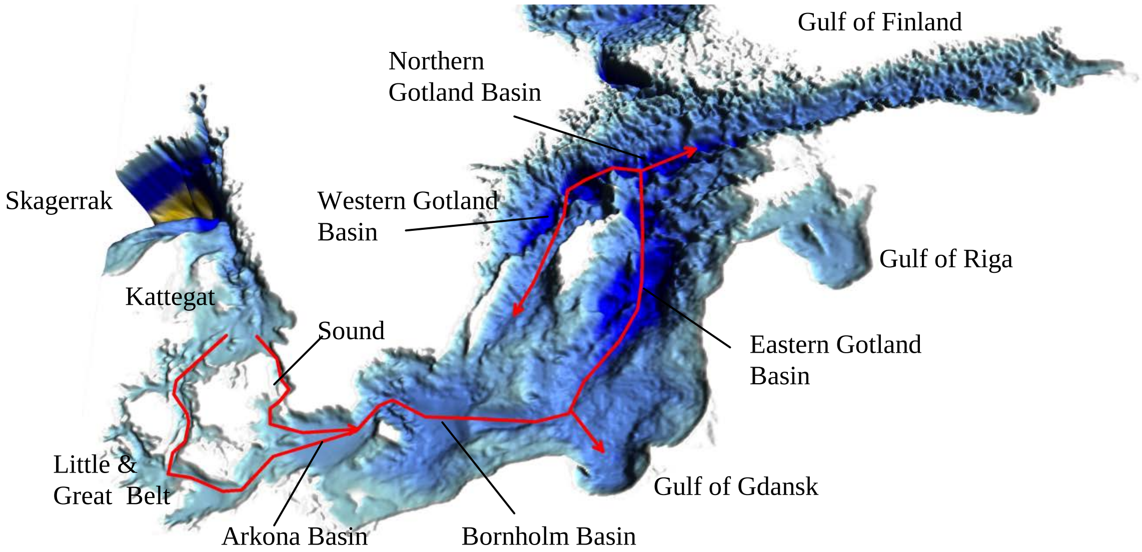
REPORT OCEANOGRAPHY No. 53, 2015

Oxygen Survey in the Baltic Sea 2015

- Extent of Anoxia and Hypoxia, 1960-2015
- The major inflow in December 2014



Front: Bathymetry of the south Baltic Sea and pathways of inflowing deep water during inflows. The major inflow in December 2014 had in December 2015 reached the northern parts of the Eastern Gotland Basin.

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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 2014 have been updated and the preliminary results for 2015 are presented. Oxygen data from 2015 have been collected during the annual Baltic International Acoustic Survey (BIAS) and from national monitoring programmes with contributions from Sweden, Finland, Poland, Estonia 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 2014 and the preliminary results for 2015 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 major inflow to the Baltic Sea in December 2014 approximately 16% of the bottom area was affected by anoxia and 29% by hypoxia during 2015.

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 2014 uppdaterats. De preliminära resultaten för 2015 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, 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 2014 och de preliminära resultaten för 2015 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 det stora inflöde som inträffade i december 2014 beräknas ungefär 16% av bottnarna i Egentliga Östersjön, Finska viken och Rigabukten vara påverkade av anoxiska förhållanden och omkring 29% av hypoxi.

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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 2015. 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 which can be used as a climatological atlas describing the historical development and the present oxygen situation in the Baltic Proper.

2 Data

For 2015 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, Poland, Finland, Germany and Sweden. These data have been subject to initial quality control only (quality assured laboratory procedures, timing and position checks, range checks). The time series and the results presented for 2015 will be updated when additional data are reported to ICES in 2016.

[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 calculations do not account for the existence of oxygenated water below an anoxic layer. 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.

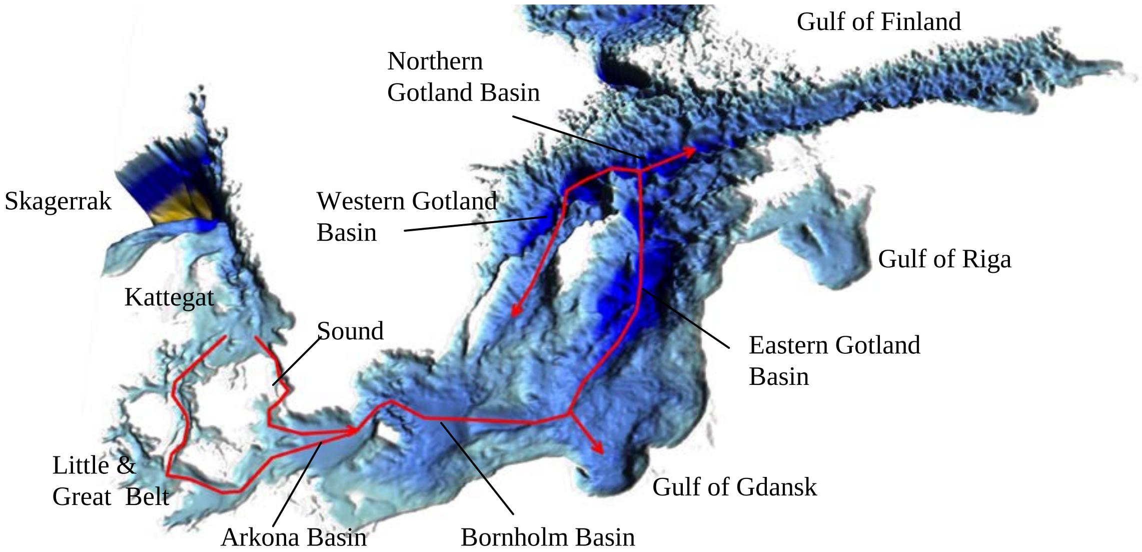


Figure 1. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathways of inflowing deep water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

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 - 2015 are presented in Figures 2 and 3, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2014 and 2015 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 2015 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., 2011-2014. Note that the results for 2015 are preliminary.

in %	1960 – 1998		1999 – 2014		2015	
	Hypoxi	Anoxi	Hypoxi	Anoxi	Hypoxi	Anoxi
Mean Areal extent	22	5	29	15	29	16
Max Areal extent (Year)	27 (1968)	14 (1969)	32 (2007)	19 (2011)	-	-
Mean Volume	13	2	18	8	20	9
Max Volume (Year)	19 (1965)	8 (1969)	21 (2011)	12 (2011)	-	-

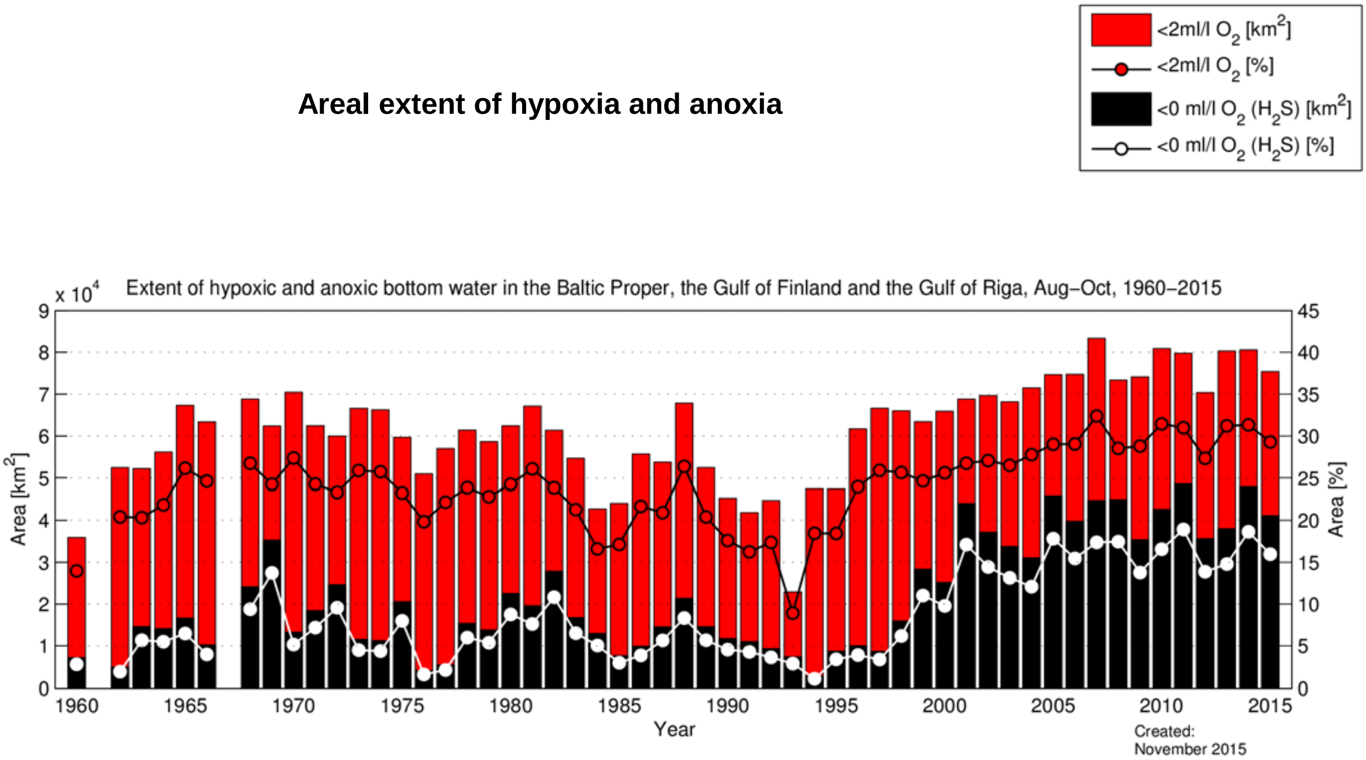
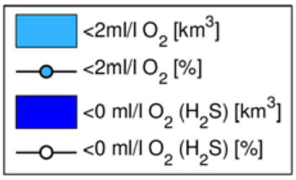


Figure 2. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

Water volume affected by hypoxia and anoxia



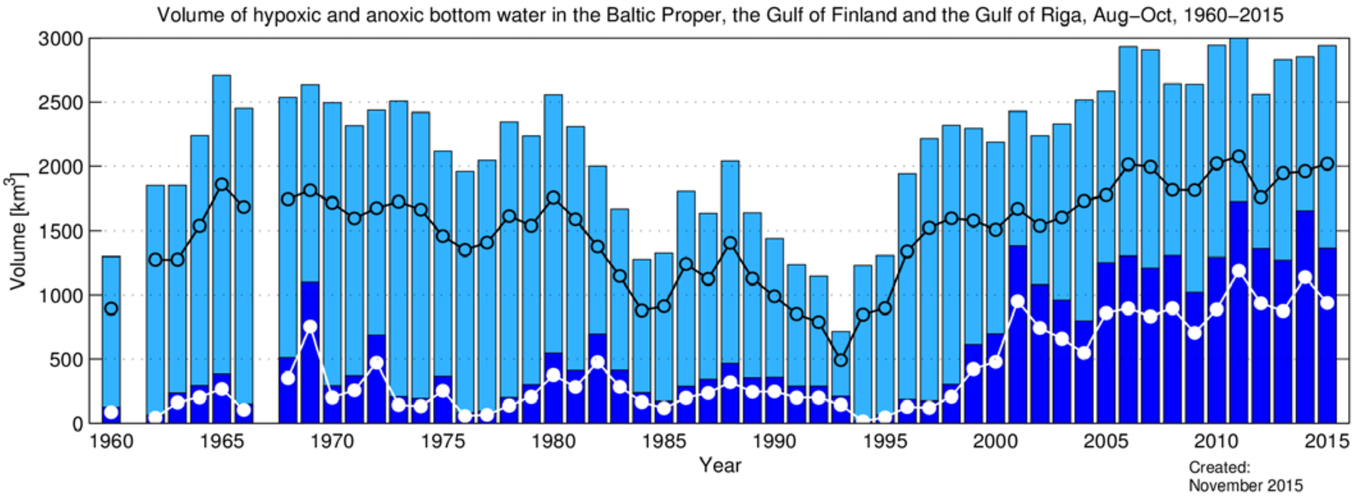


Figure 3. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

5 The oxygen situation after the major inflow in December 2014

In December 2014 a major Baltic inflow took place, the first major inflow since 2003. During the period from the 2nd to the 24th about 70 km^3 saline water entered through the Sound. About a week after the onset of this inflow water started to enter also via the Danish Belts. The total amount of water entering the Baltic during this period is estimated to about 198 km^3 [Mohrholz et.al. 2015]. During the first part of January 2015 an additional inflow of 30 km^3 entered through the Sound. The major inflow in December was preceded by a number of smaller inflows in 2014. During February and March 30 and 20 km^3, respectively, entered through the Sound, in August 30 km^3 and in October 25 km^3.

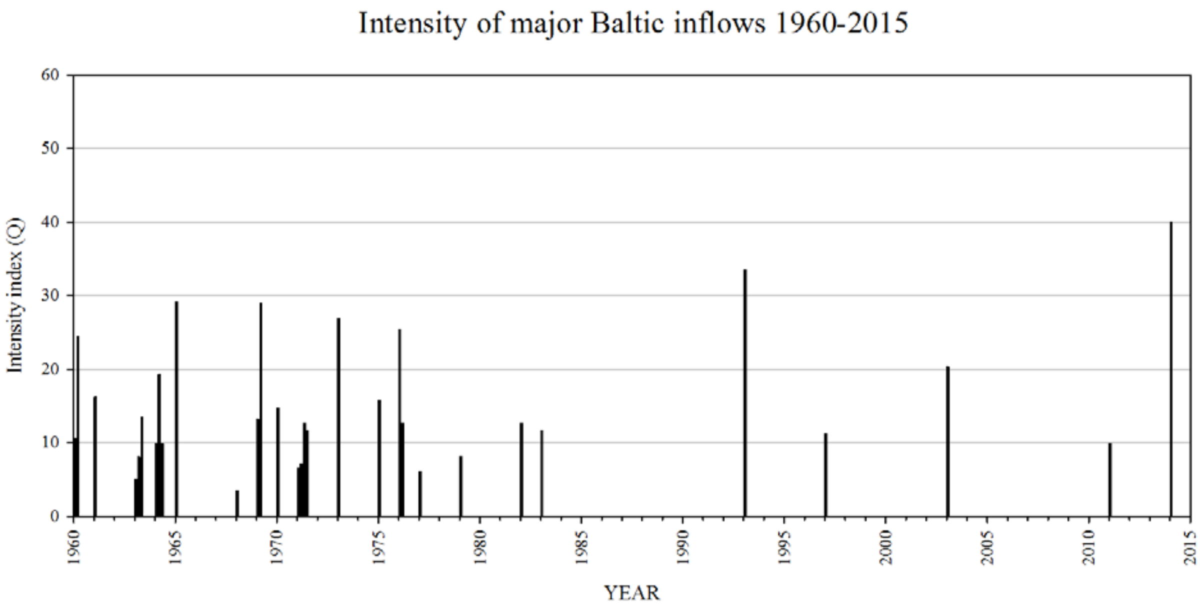


Figure 4. Index of inflows to the Baltic Sea, 1960-2015. [Mohrholz et al. 2015] Revised and updated.

Already during December the effects of the inflow were visible in the Arkona Basin, where the observed oxygen concentrations, were between 6 and 7 ml/l. In January the inflowing water had reached the Bornholm Basin as well as the Hanö Bight. In February the Bornholm Basin was filled up to sill depth with water having a salinity of 18 psu and an oxygen content of 5.5 ml/l. In the Stolpe Furrow water with a salinity of 16 psu and an oxygen concentration of 4 ml/l was found. At the station BCSIII-10 in the southeast the corresponding figures were 12 psu and 2.8 ml/l, also the Bay of Gdansk was well oxygenated at depths exceeding 90 metres. In the southern part of the Eastern Gotland Basin water with an oxygen content of about 2 ml/l were found close to the bottom, even though hydrogen sulphide was present in the water column above. The effects in the latter areas, however, probably stems from the earlier inflow during the autumn 2014.

During the SMHI cruise in March, effects were clearly seen in the Eastern Gotland Basin. At the station BY15 (the Gotland Deep), hydrogen sulphide was now present at intermediate depths between 120 and 190 metres, while the bottom water had an oxygen content of about 1 ml/l. Salinity in the bottom water had also increased from 12.4 psu in February to 13.2 psu.

In April, even more water had entered the central parts of the Eastern Gotland Basin and hydrogen sulphide was present at depths between 125 and 150 metres, while the onset of hypoxia started at 70 metres. Below these layers, the bottom water was oxygenated and the concentrations had increased from 1 to 3 ml/l since March, also salinity had increased with about 0.5 psu. However, no effects were seen in the northern part of the Eastern Gotland Basin, where hydrogen sulphide was present at depths exceeding 90 metres. There were no lack of oxygen in the Arkona- or Bornholm Basins or in the Hanö Bight, however, oxygen concentrations had decreased by 0.5- 1 ml/l since the cruise in March.

Some effects of the inflow were seen, in the northern part of the Eastern Gotland Basin, during the June cruise. At the station Fårö Deep (BY20), some effects were seen in the halocline and there were also decreasing levels of hydrogen sulphide at depths exceeding 110 meters. Hydrogen sulphide was only present in a thin layer at a depth of 115 metres in the Gotland Deep, but the oxygen concentrations in the bottom water had decreased since the last measurement in April, from 2.61 to 1.63 ml/l. Also the salinity had decreased in the bottom water while it had increased in intermediate layers around 100-150 metres. In the southernmost parts of the Eastern Gotland Basin acute hypoxia was present at depths exceeding 75 metres, and the oxygen concentration in the bottom water had decreased from 2.2 ml/l to 0.4 ml/l. There was also a continuous decrease in oxygen content in the bottom water in the southern parts of the Baltic Proper.

In July weak signs of the inflow were found at the Fårö Deep (BY20). The inflow was more clearly seen between the Fårö Deep and the Gotland Deep (BY15) as a thin bottom layer, where the maximum oxygen concentration had increased from about 0.9 ml/l to 1.4 ml/l. At the Gotland Deep, in the Eastern Gotland Basin, acute hypoxia was found at depths exceeding 70 metres and hydrogen sulphide was found at intermediate depths in a narrow layer at about 110-120 metres. Below the oxygen free layer, the deep water was still oxygenated, but the concentrations had declined to below 2 ml/l.

The oxygen content in the bottom water in the Arkona Basin and the Hanö Bight had declined further compared to the measurements in June, and also here acute hypoxia was observed.

No noticeable signs of the inflow were to be seen during the September cruise north of BY20 but just as during the previous visit, weak signs of the inflow were found intermediary at BY20. In the Gotland Deep, acute hypoxia was found at depths exceeding 70 metres. Hydrogen sulphide was now found at two intermediate thin layers; 80-95 metres and around 125 metres. Below the oxygen free layer, the deep water was still oxygenated, but the concentrations had declined even more since the expedition in July.

In the Northern and Eastern Gotland Basins and in the western Gulf of Finland hypoxia was found from 70-80 metres depth. The oxygen content in the bottom water in the Bornholm Basin and the Hanö Bight had declined further and also here acute hypoxia was observed. The oxygen concentration in the Arkona Basin had increased since the last visit to above 2 ml/l.

The conditions remained almost the same till the end of the year. The inflow did not reach further north, and the oxygen concentrations continued to decrease in the Eastern Gotland Basin and south thereof.

6 Discussion

Results for 2014

As the results for 2014 were updated additional anoxic areas were found in the south-eastern parts of the Baltic Proper while some anoxic areas in the Eastern Gotland Basin where found to be oxygenated. The final result showed that the proportion of areas affected by anoxia increased somewhat, from 17% to 19%.

The proportion of areas suffering from hypoxia also increased from 27% to 31%. New areas were found in the Baltic Proper, Gulf of Finland and the Gulf of Riga. The updated results for 2014 follow the oxygen development that has prevailed since the regime shift in 1999.

In January and February there were two smaller inflows of 30 km^3 and 20 km^3 through the Sound. After the summer another two small inflows occurred. The major inflow in December, described above, had no effect on the 2014 results of anoxic and hypoxic areas since the calculations are based on data from August to October. The summed up inflow to the Baltic Sea in 2014 was 323 km^3 and the summed up outflow was 625 km^3. The average for inflows and outflows during the period 1977-2014 is 309 km^3 and 610 km^3 respectively. Both inward and outward flows to the Baltic Sea in 2014 were thus slightly larger than normal.

Preliminary results for 2015

Despite the major inflow in December 2014 the preliminary results for 2015 show that the serious oxygen situation in the Baltic Proper continues. The results are similar to the mean conditions for the period 1999-2014 i.e. after the regime shift. However, in comparison with 2014, the area affected by anoxia in the Eastern Gotland Basin has decreased due to the major inflow in 2014.

But, the effects of the major inflow are not that obvious in the results as would be expected in the Eastern Gotland Basin. Both hypoxia and anoxia have been present during the late summer and autumn at intermediate depth in the Eastern Gotland Basin and the used calculations do not account for the existence of oxygenated water below an anoxic layer. Hence, the oxygen concentration in the bottom water at BY15 Gotland Deep varied in September from 0.3-1.4 ml/l but anoxic conditions were found between 80 and 125 meters depth.

So far (January 2016), the inflow has not been strong enough to reach the Western Gotland Basin, the Northern Baltic Proper or the Gulf of Finland. All these areas are still suffering from serious stagnation. In southern Western Gotland Basin, hypoxia and anoxia are found at shallow depths. Hypoxia from ~50 meters depth and anoxia from ~70 meters depth. [SMHI, 2016]

There are several possible explanations to the relative minor positive effects of the major inflow in December 2014. The whole water column in Kattegat and the surface layer down to 100 metres in Skagerrak showed exceptional high temperatures one month before the December inflow. This explains the high temperature of the inflowing water. Compared with the 1993 inflow, the inflowing water during the 2014 event had higher temperatures and contained less oxygen. Water with high temperature contains less oxygen and high temperature in the bottom water can stimulate decomposition rates.

The stagnation period before 1993 was characterized by a weakened stratification in the Baltic and the deep water in the Gotland Deep had a markedly lower salinity. Before the December 2014 inflow the stagnation was extreme with very high concentrations of hydrogen sulphide in the deep water of the Baltic Proper and the areal extent of anoxic conditions were also larger than before.

To sustain the positive effects, of this last major inflow, in the Eastern Gotland Basin and to improve the oxygen situation in the Western Gotland Basin and the Northern Baltic Proper, new major inflows to the Baltic Sea are needed. Otherwise the oxygen situation will deteriorate and the anoxic and hypoxic areas will increase again.

7 Conclusions

- Despite the major inflow to the Baltic in December 2014 the extreme oxygen conditions in the Baltic Proper continued during 2015. The areal extent and the volume of anoxia have since the regime shift in 1999 been constantly elevated and there are no signs that the inflow in December 2014 will reach and oxygenate the northern Baltic Proper or the Western Gotland Basin which still suffers from hypoxia and anoxia.

- The major inflow in December 2014 has improved the oxygen situation in the Eastern Gotland Basin, but a year after the event the progress of the inflow has halted. During the major inflow in 1993 it took about 1 year for the inflowing water to reach the Western Gotland Basin.

- Preliminary results for 2015 shows that anoxic conditions affect around 16% of the bottom areas in the Baltic Proper, including the Gulf of Finland and the Gulf of Riga and approximately 29% suffer from hypoxia.

8 Acknowledgement

Data for updating the 2014 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. Many thanks also to the Finnish Environment Institute (SYKE) and Susanne Feistel, The Leibniz Institute for Baltic Sea Research, Warnemünde for sending data from their national monitoring programme.

9 References

Aertebjerg, G., Carstensen, J., Axe, P., Druon, J-N. & Stips, A., 2003: The oxygen Depletion Event in the Kattegat, Belt Sea and Western Baltic. Baltic Sea Environment Proceedings No. 90. Helsinki Commission Baltic Marine Environment Protection Commission. ISSN 0357-2994.

Diaz, R. J. & Rosenberg, R., 1995: Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna, Oceangr. Mar. Bio. Ann. Rev., 33, 245-303.

Fonselius, S., 1995: Västerhavets och Östersjöns Oceanografi. ISBN 91-87996-07-3.

Hansson, M., Andersson, L. & Axe, P., 2011: Areal Extent and Volume of Anoxia and Hypoxia in the Baltic Sea, 1960-2011, Report Oceanography no 42, ISSN: 0283-1112.

Hansson, M., Andersson, L. Szaron J. & Axe, P., 2013: Oxygen Survey in the Baltic Sea 2012 - Extent of Anoxia and Hypoxia, 1960 -2012, Report Oceanography no 46, ISSN: 0283-1112.

Hansson, M. & Andersson, L., 2013: Oxygen Survey in the Baltic Sea 2013 - Extent of Anoxia and Hypoxia 1960-2013, Report Oceanography no 49, ISSN: 0283-1112.

MacKenzie, B., Hinrichsen, H.H., Plikshs, M., Wieland, K., Zezera, A.S., 2000: Quantifying environmental heterogeneity : habitat size necessary for successful development of cod Gadus morhua eggs in the Baltic Sea. Marine Ecology - Progress Series, vol: 193, pages: 143-156.

Mohrholz, V., M. Naumann, G. Nausch, S. Krüger, U. Gräwe, 2015: Fresh oxygen for the Baltic Sea — An exceptional saline inflow after a decade of stagnation. Journal of Marine Systems 148, 152–166.

Nausch, G., Feistel, R., Umlauf, L., Mohrholz, V., Nagel, K., Siegel, H., 2012: Hydrographisch-chemische Zustandseinschätzung der Ostsee 2011, Meereswissenschaftliche Berichte MARINE SCIENCE REPORTS No. 86. Leibniz- Institut für Ostseeforschung Warnemünde.

Nissling, A., 1994: Survival of eggs and yolk sac larvae of Baltic cod (Gadus morhua) at low oxygen levels in different salinities. ICES Marine Science Symposium 198:626-631.

Plikshs, M., Kalejs, M. & Grauman, G., 1993: The influence of environmental conditions and spawning stock size on the year-class strength of the Eastern Baltic cod. ICES CM 1993/J:22.

Rabalais, N. N. & Eugene, R., Turner (Editors), 2001: Coastal and Estuarine Studies, Coastal Hypoxia, Consequences for living resources and ecosystems. American Geophysical Union. ISBN 0-87590-272-3.

SMHI, 2014: Cruise report archive: http://www.smhi.se/en/theme/marine-environment-2-885. Updated: December, 2014.

SMHI, 2016: Cruise report archive: http://www.smhi.se/en/theme/marine-environment-2-885. Updated: January, 2016.

SMHI, 2014: Accumulated inflow through the Öresund. URL: http://www.smhi.se/hfa_coord/BOOS/Oresund.html

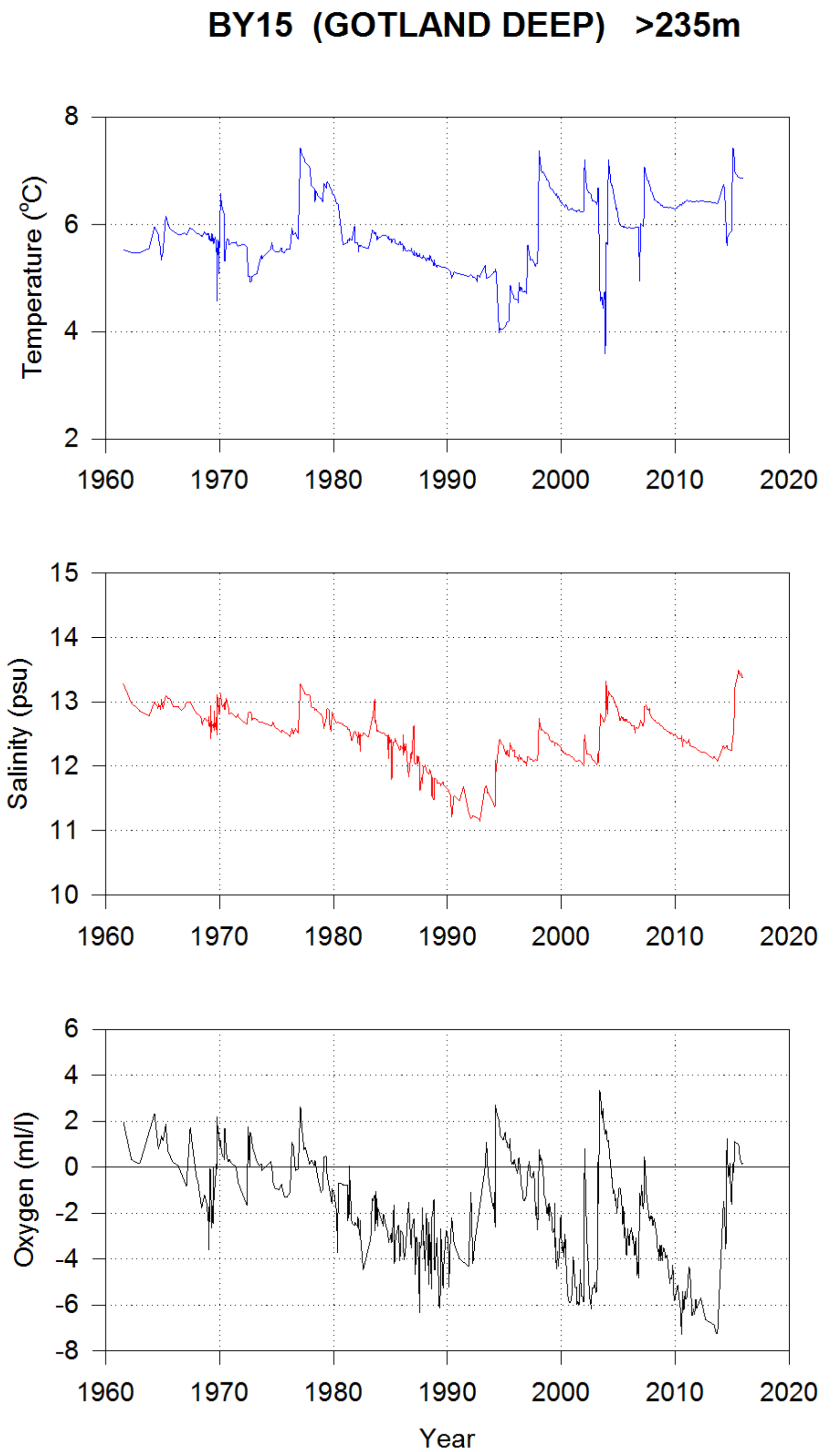
Swedish EPA, 2007: Bedömningsgrunder för kustvatten och vatten i övergångszonen, Bilaga B till handboken 2007:4, Naturvårdsverket, ISBN 978-91-620-0149-0.

T. Seifert, F. Tauber, B. Kayser: 2001: A high resolution spherical grid topography of the Baltic Sea – 2nd edition, Baltic Sea Science Congress, Stockholm 25-29. November 2001, Poster #147.

U.S. EPA, 2003: Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries, U.S. Environmental Protection Agency.

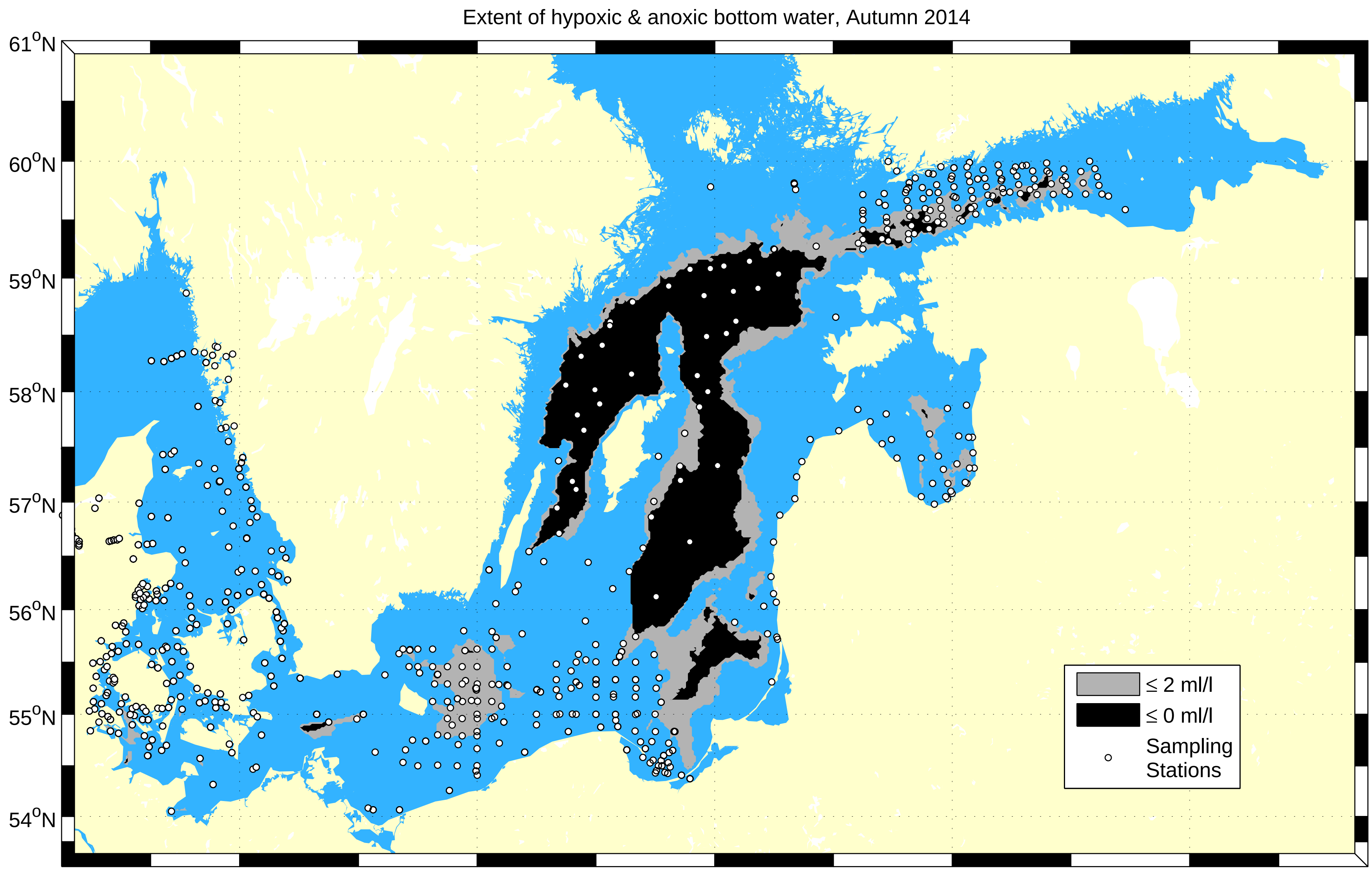
U.S. EPA, 2000: Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras, U.S. Environmental Protection Agency, EPA-822-R-00-012.

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



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)



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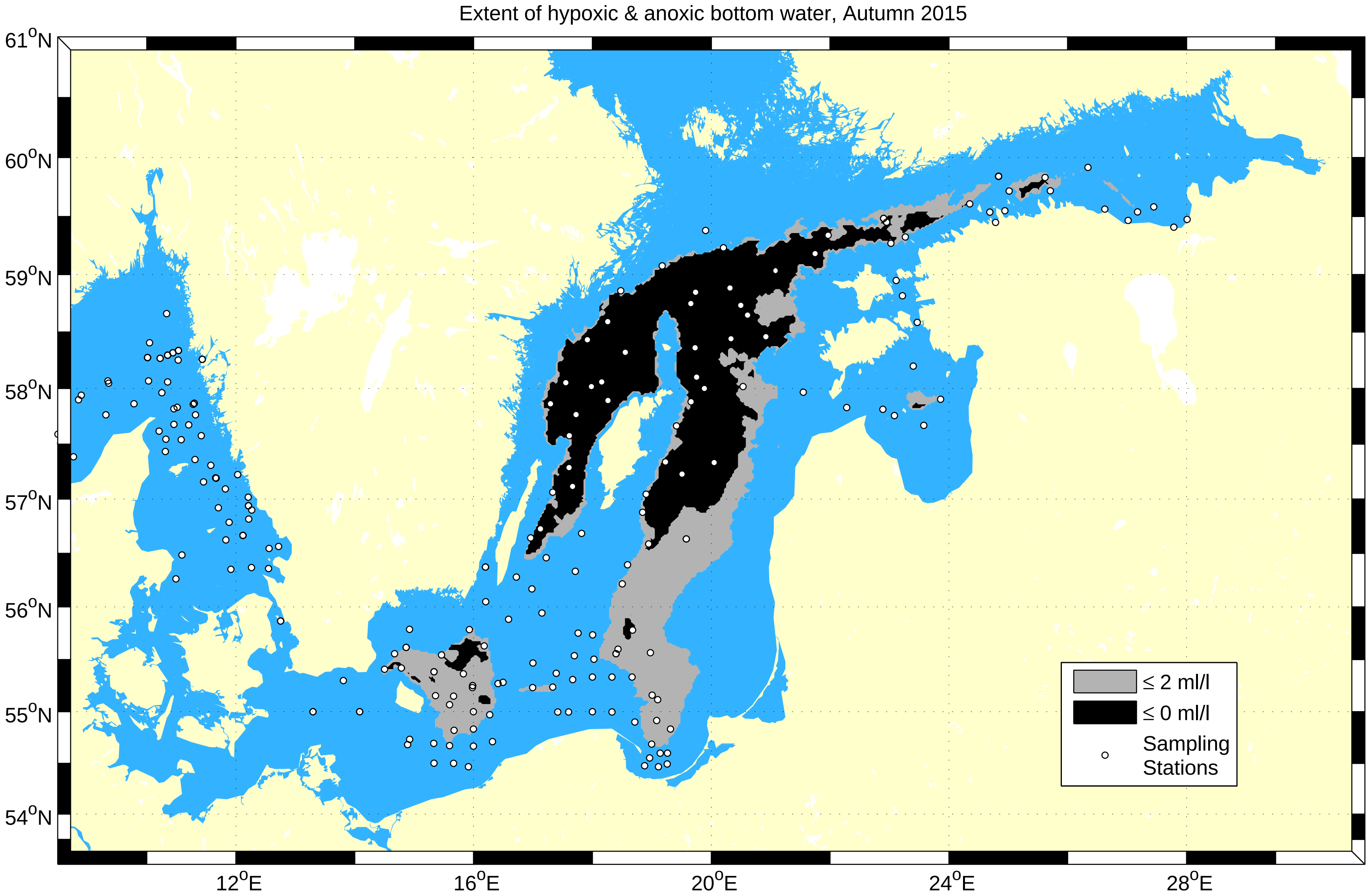

Created: November 2015

10 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.

Name of the series	Published since
RMK (Report Meteorology and Climatology)	1974
RH (Report Hydrology)	1990
RO (Report Oceanography)	1986
METEOROLOGI	1985
HYDROLOGI	1985
OCEANOGRAFI	1985
KLIMATOLOGI	2009

Earlier issues published in RO

1 Lars Gidhagen, Lennart Funkquist and Ray Murthy (1986)
Calculations of horizontal exchange coefficients using Eulerian time series current meter data from the Baltic Sea.

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

3 Stig Carlberg et al (1986)
Program för miljökvalitetsövervakning - PMK.

4 Jan-Erik Lundqvist och Anders Omstedt (1987)
Isförhållandena i Sveriges södra och västra farvatten.

5 Stig Carlberg, Sven Engström, Stig Fonselius, Håkan Palmén, Eva-Gun Thelén, Lotta Fyrberg och Bengt Yhlen (1987)
Program för miljökvalitetsövervakning - PMK. Utsjöprogram under 1986

6 Jorge C. Valderama (1987)
Results of a five year survey of the distribution of UREA in the Baltic Sea.

7 Stig Carlberg, Sven Engström, Stig Fonselius, Håkan Palmén, Eva-Gun Thelén, Lotta Fyrberg, Bengt Yhlén och Danuta Zagradkin (1988).
Program för miljökvalitetsövervakning - PMK. Utsjöprogram under 1987

8 Bertil Håkansson (1988)
Ice reconnaissance and forecasts in Storfjorden, Svalbard.

9 Stig Carlberg, Sven Engström, Stig Fonselius, Håkan Palmén, Eva-Gun Thelén, Lotta Fyrberg, Bengt Yhlén, Danuta Zagradkin, Bo Juhlin och Jan Szaron (1989)
Program för miljökvalitetsövervakning - PMK. Utsjöprogram under 1988.

10 L. Fransson, B. Håkansson, A. Omstedt och L. Stehn (1989)
Sea ice properties studied from the ice-breaker Tor during BEPERS-88.

11 Stig Carlberg, Sven Engström, Stig Fonselius, Håkan Palmén, Lotta Fyrberg, Bengt Yhlen, Bo Juhlin och Jan Szaron (1990)
Program för miljökvalitetsövervakning - PMK. Utsjöprogram under 1989

12 Anders Omstedt (1990)
Real-time modelling and forecasting of temperatures in the Baltic Sea

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Haven runt Sverige 1991. Rapport från SMHI, Oceanografiska Laboratoriet, inklusive PMK - utsjöprogrammet. (The conditions of the seas around Sweden. Report from the activities in 1991, including PMK - The National Swedish Programme for Monitoring of Environmental Quality Open Sea Programme.)

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

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