SMHI

REPORT OCEANOGRAPHY No. 76, 2024

Oxygen Survey in the Baltic Sea 2023
- Extent of Anoxia and Hypoxia, 1960-2023

Front: Onboard R/V Svea during the International Bottom Trawl Survey (IBTS) in Kattegat organized by SLU-Aqua. During the fishing surveys, before or after each trawl, a CTD-profile and water samples are collected for analysis. Dissolved oxygen is one of the parameters that are collected. Data from the ICES co-ordinated trawl surveys are well suited for concurrent oxygen surveys because of randomized sampling and since surveys are performed by different countries almost simultaneously, a vast sea area can be monitored. Photo by Martin Hansson, August 2023.

ISSN: 0283-1112

REPORT OCEANOGRAPHY No. 76, 2024

Oxygen Survey in the Baltic Sea 2023
- Extent of Anoxia and Hypoxia, 1960-2023

Martin Hansson & Lena Viktorsson

Swedish Meteorological and Hydrological Institute - SMHI
Oceanographic Unit, Göteborg, Sweden

Summary

In 2011 SMHI published the Report Oceanography No 42 with a climatological atlas of the oxygen status in the deep water of the Baltic Sea. Subsequently, annual updates have been released as new data have been reported to the International Council for the Exploration of the Sea (ICES) data centre. This report provides an update for 2022 and presents the preliminary results for 2023. The oxygen data for 2023 were collected from various sources, including ICES coordinated trawl surveys, national monitoring programmes, and research projects involving Poland, Estonia, Latvia, Denmark, Sweden, and Finland.

For the autumn period, each profile in the dataset was analyzed 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 to produce two surfaces that represent the depths at which hypoxic and anoxic conditions are present, respectively. The volume and area of hypoxia and anoxia were then calculated and the results transferred to maps and diagrams to visualize the annual autumn oxygen situation during the analyzed period.

The updated results for 2022 and the preliminary results for 2023 show that the severe oxygen conditions in the Baltic Proper after the regime shift in 1999 continues. Levels of anoxia and hypoxia decreased somewhat 2023 compared to the high results for 2022. The increase in 2022 was mainly due to large areas in the south eastern Baltic Proper are added, areas were data is sparse and results are uncertain. In 2022 anoxia was found at 23% of the bottom areas and 35% suffered from hypoxia including anoxic areas. Preliminary results for 2023 show that anoxia affected 18% of the bottom areas and 32% suffered from hypoxia (including anoxic areas). The concentration of hydrogen sulphide is extremely high in all the basins around Gotland. In the Eastern and Western Gotland Basin hydrogen sulphide in the bottom water has reached levels not recorded before. The inflows that occurred during 2022 - 2023 did only affect the oxygen situation in southern parts of the Baltic Proper. No inflows reached the deep basins around Gotland. In late 2023 a larger inflow occurred followed by a series of small inflows that might improve the oxygen situation in 2024.

Sammanfattning

I SMHI rapporten Oceanography nr 42 publicerades en klimatologisk atlas över syresituationen i Östersjöns djupvatten år 2011. Sedan dess har årliga uppdateringar släppts när nya data har rapporterats till International Council for the Exploration of the Sea (ICES). Denna rapport ger en uppdatering för 2022 och preliminära resultat för 2023. Syredata för 2023 samlades in från olika källor; ICES-koordinerade trålundersökningar, nationella mätprogram och forskningsprojekt med deltagande från Polen, Estland, Lettland, Danmark, Sverige och Finland.

Under höstperioden analyserades varje profil i datamängden för förekomst av hypoxi (syrebrist) och anoxi (total frånvaro av syre). Djupet där hypoxi respektive anoxi först påträffades interpolerades sedan mellan provtagningsstationer för att producera två ytor som representerar djupen där hypoxiska respektive anoxiska förhållanden förekommer. Volymen och ytan för hypoxi och anoxi beräknades sedan och resultaten överfördes till kartor och diagram för att visualisera syresituationen under hösten under den analyserade perioden.

Resultaten för 2022 och 2023 visar att de allvarliga syreförhållandena i Östersjön efter regimskiftet 1999 fortsätter. Nivåerna av anoxi och hypoxi minskade något 2023 jämfört med de höga resultaten för 2022. Ökningen under 2022 berodde främst på att områden i sydöstra Östersjön lagts till, områden där data är knapphändig och resultaten osäkra. År 2022 påträffades anoxi på 23% av bottenområdena och 35% drabbades av hypoxi (inkl. anoxiska omr). Preliminära resultat för 2023 visar att anoxi påverkade 18% av bottenområdena och 32% av hypoxi (inkl. anoxiska omr.). Koncentrationen av svavelväte är extremt hög i alla djupbassänger. I Östra och Västra Gotlandsbassängen har svavelväte i bottenvattnet nått nivåer som inte tidigare registrerats. De inflöden som inträffade under 2022-2023 påverkade endast syresituationen i södra delarna av Östersjön. Inga inflöden nådde de djupare bassängerna runt Gotland. I slutet av 2023 inträffade ett större inflöde följt av en serie mindre inflöden som eventuellt kan förbättra syresituationen i Östersjön under 2024.

Table of contents

1 Background

The central deep regions of the Baltic Proper have a well-established pattern of experiencing low oxygen levels, largely influenced by the sea's geographical features. With its predominantly enclosed and fjord-like shape, the sea naturally retains lower oxygen levels. Additionally, limited water exchange between the Baltic Sea and the North Sea is facilitated by narrow straits and shallow sills in the Belt Sea and Sound.

The vast catchment area surrounding the Baltic Sea generates significant freshwater runoff, typically the positive water balance results in a flow outward through the Sound and Belt Sea into the Kattegat and North Sea. However, occasional shifts in wind, weather, and sea levels can reverse this flow, allowing rare inflows to occur. These inflows, though uncommon, can bring substantial amounts of oxygenated and saline water into the Baltic Sea. Due to the varying densities of brackish and saline waters, a stable stratification develops, hindering the ventilation of deep-water layers. Consequently, the decomposition of organic matter consumes the available oxygen in the deep water, resulting in critical oxygen levels for marine life or even the development of oxygen-depleted zones.

However, large inflow events or series of small inflows, can supply the deep water of the Baltic Proper with dissolved oxygen, as inflowing water usually is well-oxygenated. The inflow either form a layer that follows the sea floor or is interleaved at intermediate depths, depending on its density. Inflows can only reach the deep basins of the central basin in the Baltic Proper if the volume is large enough to move over the sills between the different basins of the Baltic Proper, and the density is high enough to settle the inflow along the bottom. Major Baltic Inflows (MBI) are rare, with the latest large MBI occurring as a series of large inflows during 2014-2016 [Mohrholz et. al. 2015].

The oxygen situation in the Baltic Proper has become increasingly problematic because large inflows don't occur every year and due to large nutrient inputs over time, mainly between the 1950s and the late 1980s, resulting in escalating eutrophication with increasingly severe symptoms to the Baltic Sea's ecosystem [HELCOM, 2018]. The more organic matter that is supplied to the deep water, the more oxygen is consumed, resulting in oxygen deficiency and if the bottom water is not renewed this will escalate to anoxia. 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 an extended period, hydrogen sulphide (H_2S) is formed, which is toxic to all higher marine life. Only bacteria and fungi can survive in a water environment with total absence of oxygen.

The pool of hydrogen sulphide found in the deep parts of the Baltic Proper must be oxidized by oxygen-rich inflowing water or pushed above the permanent stratification where oxygen is available before a new inflow can have any effect on the oxygen concentrations. During anoxic conditions, sediments release nutrients such as phosphate and silicate to the water column, which, due to vertical mixing or upwelling events, can reach the surface layer and the photic zone. High concentrations of nutrients in surface waters favour phytoplankton growth, especially cyanobacteria during summer, which can further enhance oxygen depletion as the bloom sinks to the bottom and consumes oxygen when it is decomposed - a vicious circle has formed [Vahtera et al. 2007].

These natural factors, combined with external human pressures on the Baltic Sea, form the basis for the increasingly problematic low-oxygen conditions and the "dead zones" or oxygen minimum zones (OMZ) found in the Baltic Sea. Total absence of oxygen and oxygen deficiency in the deep water or at intermediate depths throughout the year are mainly found in the central deep basins in the Baltic Proper and the Gulf of Finland. Seasonal lack of oxygen is generally found in the southern parts of the Baltic Proper.

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. Literature studies [Vaquer-Sunyer & Duarte, 2008] shows that the sublethal concentration ranges from 0.06 ml/l to 7.1 ml/l. The mean for all experimental assessments was 1.8 +/- 0.12 ml/l. The same study also suggests that the commonly used threshold for acute hypoxia around 2.0 mg/l (1.4 ml/l) is below the empirical sublethal and lethal oxygen concentrations for half of the species tested.

The dominant demersal fish population in the Baltic Sea, the Baltic cod (*Gadus morhua*), has been shown to avoid oxygen concentrations below 1 ml/l [Schaber et al., 2012]. However, already at 4.3 ml/l the condition and growth of cod starts to be affected [Chabot and Dutil,1999]. It has also been shown that Baltic Sea 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,]. With this background the limit of acute hypoxia, in this report, is set to 2.0 ml/l.

This report presents a time series of the 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 2023. The time series were first published in 2011 and the results have been updated annually as new additional data have become available at International Council for the Exploration of the Sea (ICES) [ICES, 2009]. In the report from 2011 and in newly published article a distinct regime shift in the oxygen situation in the Baltic Proper was found to occur around 1999 [Hansson et al, 2011; Almroth et al., 2021]. 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.

The report includes maps of bottom areas affected by oxygen deficiencies during 2022 and 2023. The complete and updated time series from 1960 can be found as figures in this report and as maps in Appendix 2, which can be used as a climatological atlas describing the historical development and the present oxygen situation in the Baltic Proper.

2 Data

2.1 Oxygen data

The oxygen data used for the analysis of 2023 are based on oxygen data collected during the annual trawl surveys coordinated by the ICES in the Baltic Sea and North Sea; The Baltic International Acoustic Survey (BIAS), International Bottom Trawl Survey (IBTS) and Polish Multiannual Fisheries Data Collection Programme complemented by data from national and regional marine monitoring programmes and mapping projects with contributions from Finland, Estonia, Latvia, Poland, Denmark and Sweden. See all data contributors in the Acknowledgement below.

These data have not been fully quality controlled; only preliminary checks have been performed. The time series and the results presented for 2023 will be updated when additional data are reported to ICES in 2024/2025. In this report the results for 2022 has been updated with all available bottle and low resolution CTD data retrieved from the dataset on ocean hydrography at ICES (http://www.ices.dk, last access: 2024-01-29).

Data from the trawl surveys are well suited for concurrent oxygen surveys because of randomized sampling and since cruises are performed by different countries almost simultaneously. 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 late summer/autumn period, August to 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.

2.2 Inflow data

The inflow through the Belt Sea and the Sound to the Baltic Sea is an important factor influencing the oxygen development in the deep water in the southern and central basins of the Baltic Proper.

SMHI calculates the flow through the Sound based on the sea level difference between two sea level gauges situated in the northern part (Viken) and the southern part (Klagshamn) of the Sound [Håkansson et. al. 1993, Håkansson 2022]. The results, as accumulated inflow, from 1977 to present are presented in Swedish at the SMHI website under the title “Vattenåret”. To improve the yearly summary of inflow/outflow events the calculations has been revised. Inflow/outflow events are added together but small inflows/outflows, < 0.5 days and <1 km^3, that would interrupt and ongoing inflow/outflow, has been added or removed from inflow/outflow events to get at better overview of the size and duration of inflow and outflow events. For the years 2021 and 2022 see Figure 5 and 6 for accumulated inflow and inflow/outflow events [SMHI, 2023].

Another estimate of the flow through the Sound and the Belt Sea has been presented by [Mohrholz, 2018] and is continuously updated. Simplified, the calculations are based on the mean sea level at Landsort and river discharge to the Baltic Sea. In Figure 1, the two estimates of the flow through the Sound are compared. The results from the two calculations are generally similar and in the same range. The results by [Mohrholz, 2018] is usually higher but the SMHI inflows are often divided into several inflow events. Larger inflows seem to correlate better. However, there are some inflows in both time series that do not correlate at all. For example, during late 1980s and 1990s in [Mohrholz, 2018] and in early 1990s in the SMHI timeseries. The difference could be explained by the local [SMHI, 2023] and regional [Mohrholz, 2018] perspectives of the two methods.

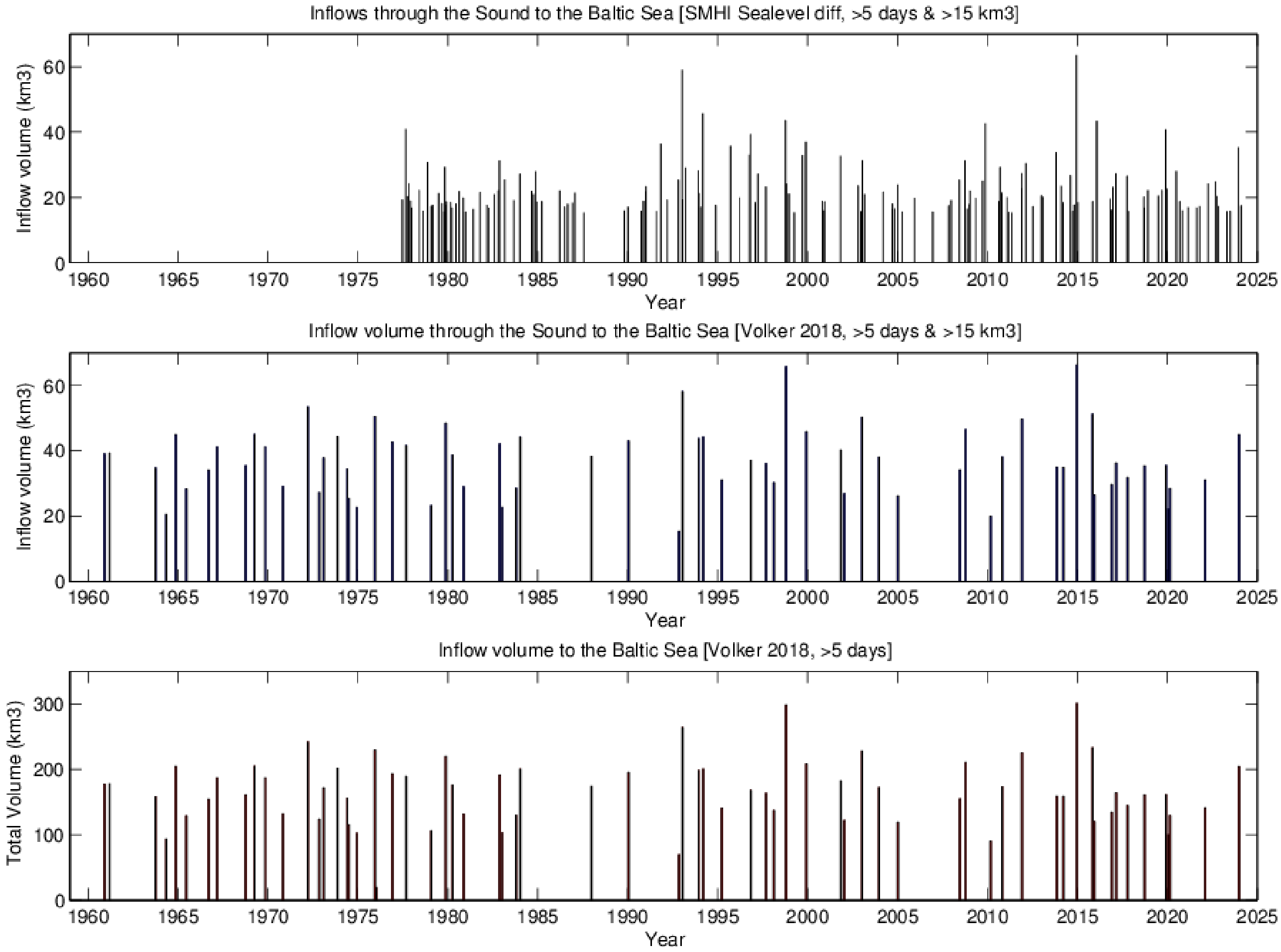


Figure 1. Two different estimations of inflow to the Baltic Sea through the Sound (Öresund). Top: Inflow through the Sound estimated from 1977-2023 by SMHI. [Revised summary of inflow events, SMHI, 2023]. Middle: Inflow through the Sound 1960-2024 estimated by [Mohrholz, 2018]. Bottom: Total volume transport through the Sound and the Danish Straits to the Baltic Sea for inflows, 1960-2024 [Mohrholz 2018, updated 2024-02-26]. Note that and the SMHI results are only available from 1977 to present.

3 Method

For the late summer and 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 profiles had to be filtered out: for example, when data was missing in the deep water, when correct data from a shallow area obviously negatively affects the interpolation results in nearby deep areas 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 was compared with bathymetry data, [Seifert, 2001] see Figure 2, 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 was 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 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. On the other hand, the oxygenated zones below the intermediary layer, does influence the sediment to water nutrient exchange [Hall et al., 2017 and Sommer et al., 2017].

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 2 [Fonselius, 1995].

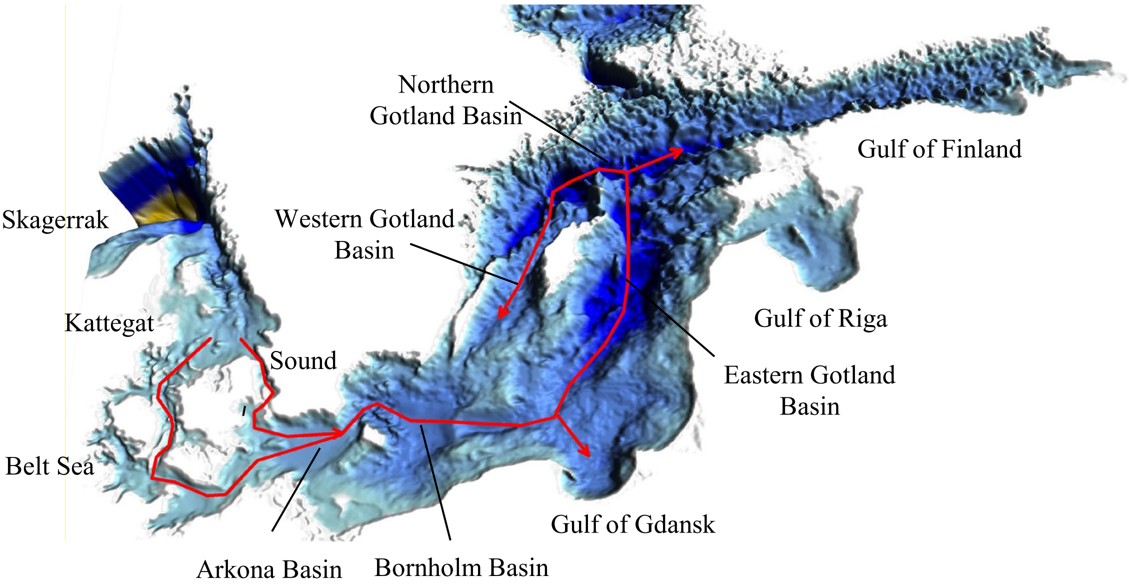


Figure 2. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathways of inflowing deep-water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk, the Gulf of Riga and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

4 Result

Extent and volume affected by hypoxia and anoxia during the period 1960 - 2023 are presented in Figures 3 and 4, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2022 and 2023 can be found in Appendix 2. The mean, max and min areal extent and volume affected by hypoxia and anoxia before and after the regime shift in 1999 [Hansson et. al, 2011]) and the preliminary results for 2023 are presented in Table 1. Note that the hypoxic area and volumes are defined as all area/volume with oxygen concentration below the limit for acute hypoxia, thus it includes both hypoxic and anoxic areas/volumes.

The updated results confirm that 2022 has the highest areal coverage noted during the analysed period. However, the areas that increased both in anoxia and hypoxia, are areas in the southeaster Baltic Proper were data is sparse. Hence, the uncertainty in this area is higher than in other areas were data is available.

The preliminary results for 2023 are all above mean for the period 1999-2022.

Table 1. Mean, max and min 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.

in %	1960 – 1998		1999 – 2022		2023 (Preliminary)	
	Hypoxia	Anoxia	Hypoxia	Anoxia	Hypoxia	Anoxia
Mean Areal extent	22	5	29	17	32	18
Max Areal extent (Year)	27 (1970)	14 (1969)	35 (2022)	24 (2018)	-	-
Min Areal extent (Year)	9 (1993)	1 (1994)	25 (1999)	10 (2000)	-	-
Mean Volume	13	2	19	10	20	12
Max Volume (Year)	19 (1965)	8 (1969)	22 (2019)	15 (2018)	-	-
Min Volume (Year)	5 (1993)	0.1 (1994)	15 (2000)	4 (1999)	-	-

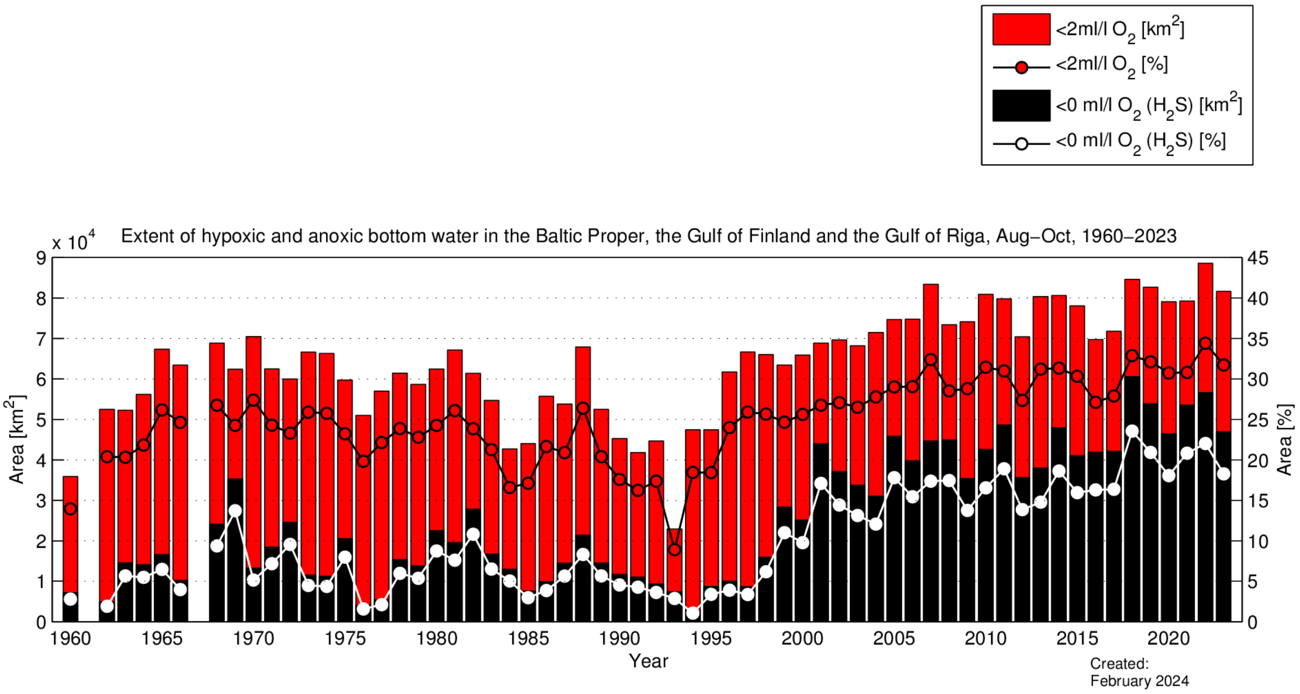


Figure 3. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins. Note that the hypoxic area are defined as all area with oxygen concentration below the limit for acute hypoxia, thus it includes both hypoxic and anoxic areas.

Water volume affected by hypoxia and anoxia

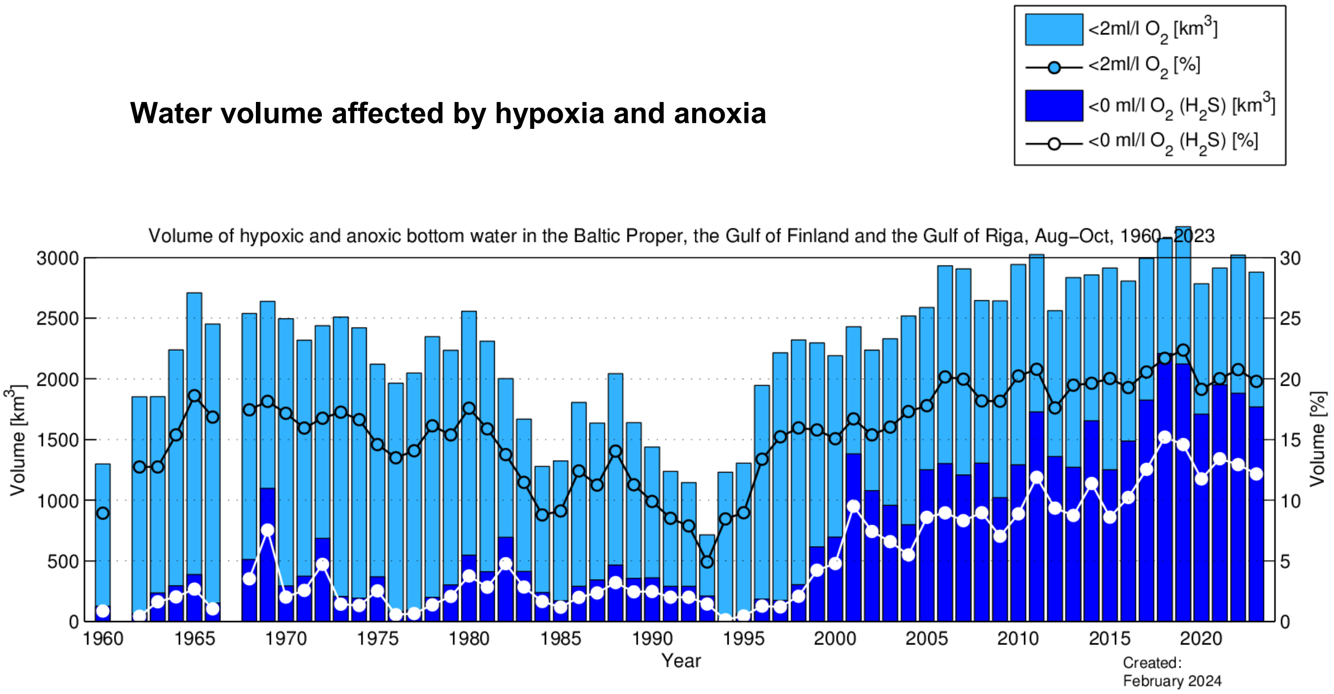


Figure 4. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins. Note that the hypoxic volumes are defined as all volume with oxygen concentration below the limit for acute hypoxia, thus it includes both hypoxic and anoxic volumes.

4.1 Updated results for 2022

The result for 2022 has been updated as additional hydrographic data has been reported to ICES. Overall the update resulted in minor changes to the total areas and volumes of both anoxia and hypoxia. After the update the anoxic and hypoxic area increased in the Gulf of Gdansk.

The proportion of areas affected by anoxia increased from 21% to 23% and the hypoxic areas was increased from 34% to 35%. Small changes were noted on the affected volumes. For anoxia and hypoxia, the proportion of volume affected was unchanged at 13% and 21%, respectively.

The results for 2022 are all above the mean for the period after the regime shift in 1999, see Table 1. The updated results confirm that 2022 has the highest areal coverage noted during the analysed period. The areal extent and volume of anoxia and hypoxia continues to be elevated and the oxygen development in the Baltic Proper that has prevailed since the regime shift in 1999 continues, see Figure 3-4.

In 2022, four inflow events through the Sound, with volume all around 20 km^3 occurred. All to small to make any difference for the oxygen situation in the central deep basins.

The total inflow to the Baltic Sea through the Sound during 2022 was 324 km^3 which is just above the mean for the time period 1977-2021, 318 km^3. The outflow was 603 km^3, which is lower than the mean for the same period as above, 623 km^3. The accumulated inflow through the Sound (Öresund) during 2022, compared to the mean inflow 1977-2023 can be seen in Figure 5.

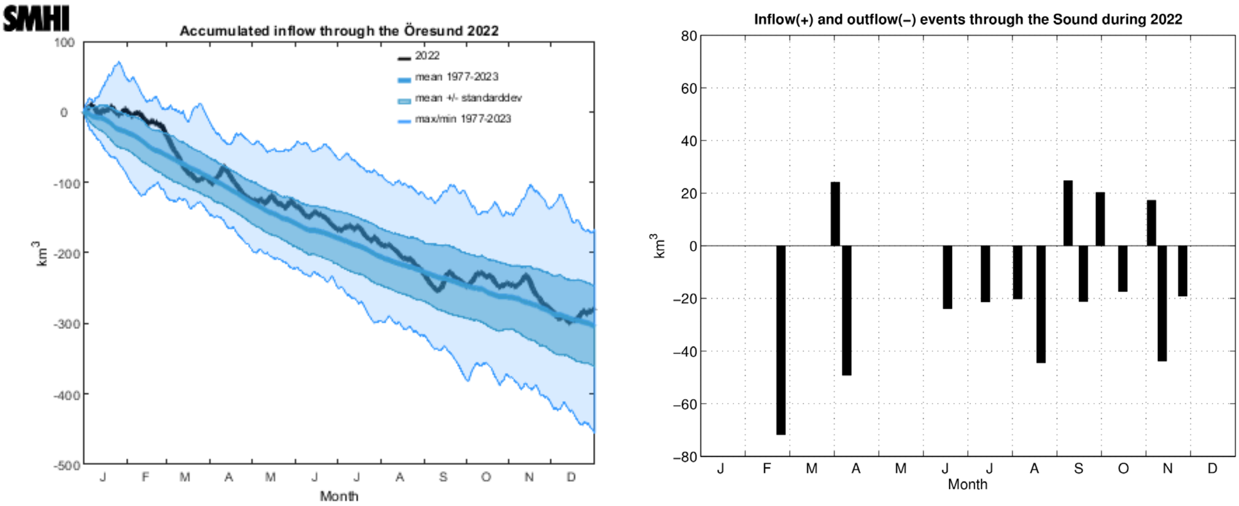


Figure 5. Left: Accumulated inflow (volume transport) through the Sound (Öresund) during 2022 in comparison to mean inflow/outflow 1977-2023. Right: Inflow (+) and outflow (-) events during 2022 that was longer than 5 days and larger than 15 km^3. [Revised summary of inflow events, SMHI, 2024].

4.2 Preliminary results for 2023

The frequency of inflows to the Baltic Sea have been similar during recent years. The latest major inflow to the Baltic Sea occurred in late 2014. After that a series of inflows occurred during the period 2014-2016, but during 2017-2018 only minor inflows was observed. In late 2019, one somewhat larger inflow was noted. During 2020-2022 the frequency of small inflows ranged from 3-4 per year. In 2023, three inflow events were observed through the Sound. The inflows in April and June did not have any impact on the oxygen situation in the deeper parts of the Baltic Proper. The last one, in December, was somewhat larger, just below 40 km^3. This inflow was followed by a series of smaller inflows that might be able to improve the oxygen situation in the southern Baltic during 2024, since it was cold, well oxygenated and relatively high salinity. See Figure 6.

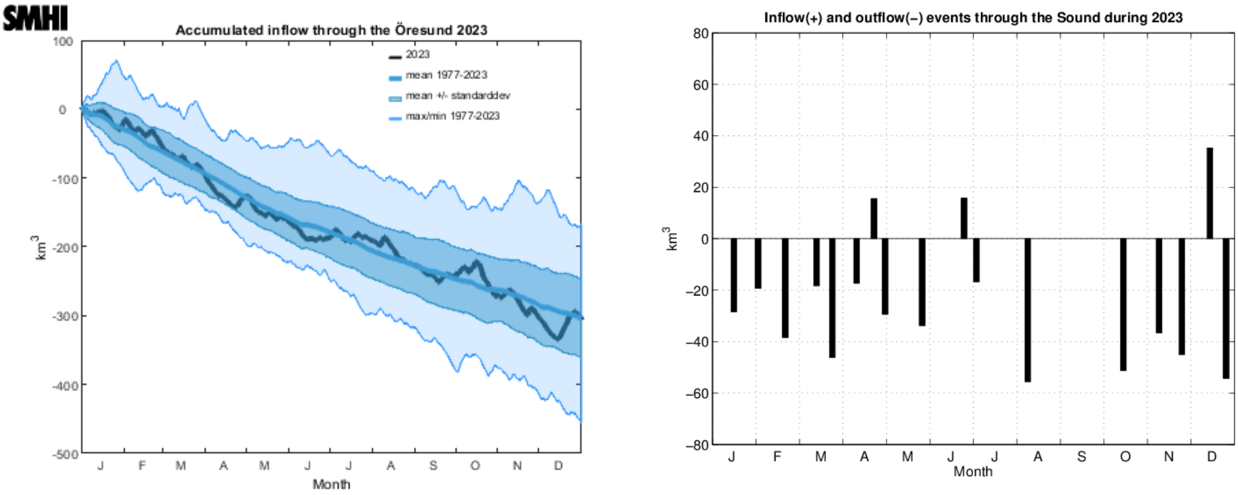


Figure 6. Left: Accumulated inflow (volume transport) through the Sound (Öresund) during 2023 in comparison to mean inflow/outflow 1977-2023. Right: Inflow (+) and outflow (-) events during 2023 that was longer than 5 days and larger than 15 km^3. [Revised summary of inflow events, SMHI, 2024].

In the Arkona Basin the oxygen situation in the deep water normally follows the annual cycle with well oxygenated conditions during winter and spring, followed by decreased oxygen concentrations during summer and recovery during late autumn. In 2023 the oxygen situation followed the same pattern. Low oxygen levels prevailed between July to September. At sampling station BY1 almost oxygen free conditions were measured in September, which is rare at this site in the Arkona basin. However, several small inflows or more likely wind mixing improved the conditions so that good oxygen conditions were found again during the October cruise [SMHI, 2024].

The oxygen situation, in the deep water at Hanö Bight, were hypoxic throughout the year, with the only exception in February when concentrations were just above 2 ml/l. The bottom water was near-anoxic, with oxygen concentrations close to 0 ml/l, from June and throughout the year. In the Bornholm Basin the oxygen conditions throughout the year were similar to those in Hanö Bight.

Further into the southeastern Baltic Proper at station BCSIII-10 the oxygen conditions in the deep water did not change much over the year. Hypoxia, < 2ml/l or near anoxic conditions prevailed throughout the year and anoxic conditions with hydrogen sulphide was detected close to the bottom in January, March, July and August.

In the deep water at Gotland Deep (BY15), in the Eastern Gotland Basin, concentrations of hydrogen sulphide was constantly high during the year. From depths exceeding 225 meters the concentrations of hydrogen sulphide varied between 130 - 213 µmol/l over the year.

The measured concentration of hydrogen sulphide in September, 2023 at 239 meters depth was 213 µmol/l. This is the highest concentration noted in the Eastern Gotland Basin during the analyzed period 1960-2023. See Figure 7, Appendix 1 and SMHI cruise reports from 2023 [SMHI, 2024].

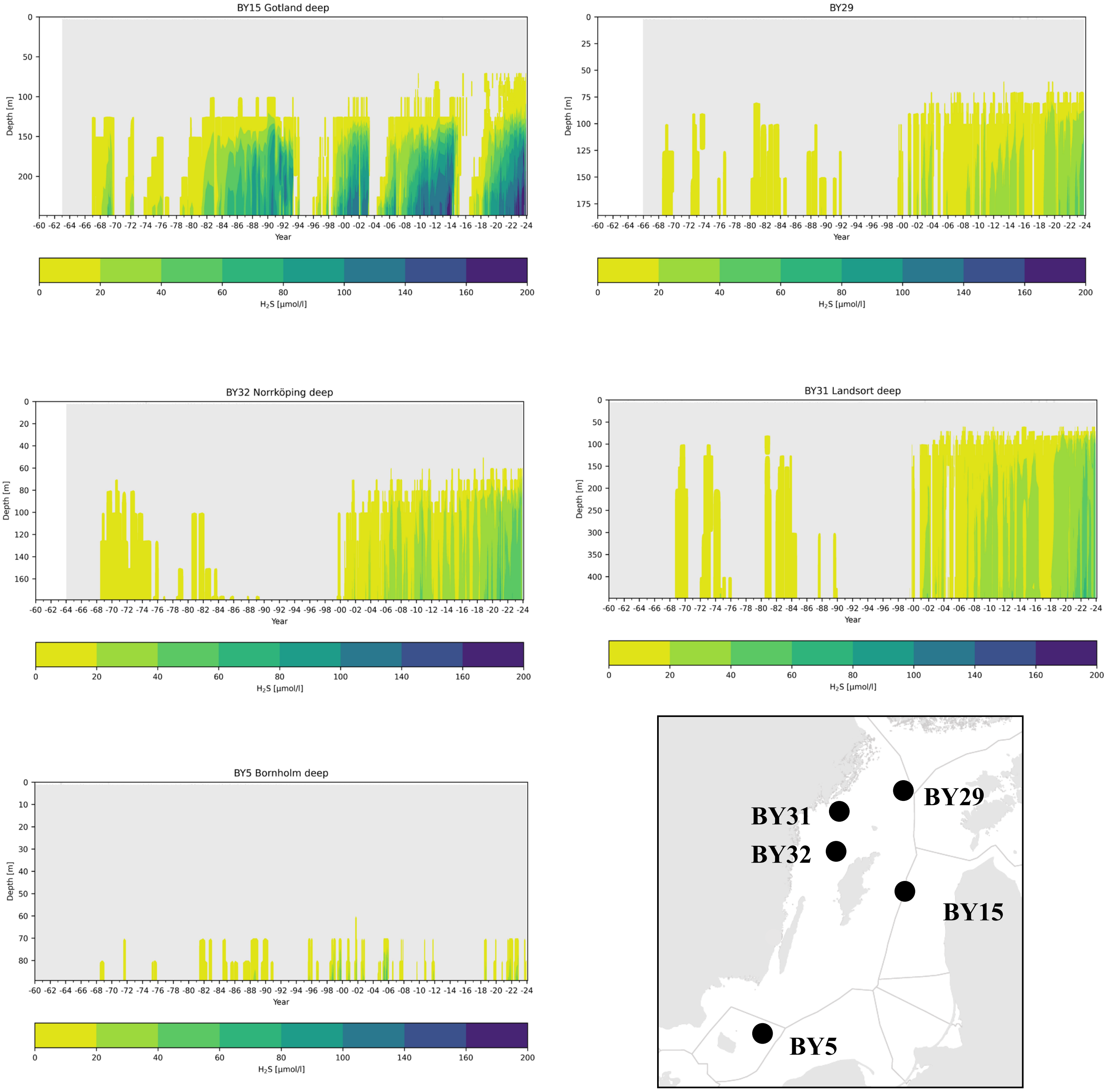


Figure 7. Concentration of hydrogen sulphide (H2S) in the Baltic Proper, 1960-2023. Grey color signifies no hydrogen sulphide present and white indicate that data is missing.
Top left: Gotland Deep (BY15) in Eastern Gotland Basin. Top right: Northern Baltic Proper (BY29).
Middle left: Norrköping Deep (BY32) and middle right: Lamdsort Deep (BY31), in the Western Gotland Basin. Lower left: Bornholm Deep (BY5) in the Bornholm Basin. Lower right: Station map.

The oxygen situation further up in the water column just below the permanent halocline remained stable over the year. Acute hypoxic conditions, below 2 ml/l, was found at approximately 70 meters depth. From 80-125 meters depth near anoxic conditions prevailed with oxygen concentrations near zero or low concentrations of hydrogen sulphide.

The oxygen situation in the deep water in the Northern Gotland Basin shows similar development as in the Eastern Gotland Basin. The concentration of hydrogen sulphide in the bottom water also show values elevated above what is normal throughout the year, but concentrations are lower than in the Eastern Gotland Basin. At depths exceeding 150 meters the concentration ranged from 37-53 µmol/l. See Figure 7.

Also, in the Western Gotland Basin the severe stagnation continues. The concentrations of hydrogen sulphide is higher than normal and are at a record high levels for this basin, never measured before, see appendix 1. At station Landsort Deep (BY31) the hydrogen sulphide concentration in the deep water exceeding 400 meters depth ranged from 35-49 µmol/l. Similar values was found in the deep water at station Norrköpings Deep (BY32) further south in the Western Gotland Basin. Acute hypoxia was found from 60-80 meters depth and anoxic conditions from 60-90 meters depth. [SMHI, 2024]

In late 2023 a medium inflow occurred, that was followed by a series of small inflows, cold and relatively high saline and well oxygenated, that could possibly improve the oxygen situation in the southern Baltic Proper.

Note that the 2023 results are preliminary and that there are uncertain results in the south eastern Baltic Proper that affects the overall results; however, the results are based on extensive data sets with essential data contributions from almost all countries around the Baltic Proper.

The updated results for 2022 and the preliminary results for 2023 show that the severe oxygen conditions in the Baltic Proper after the regime shift in 1999 continues. The areal extent of anoxia and hypoxia is more or less similar to previous years only with small differences. The situation in the Eastern Gotland Basin continues to deteriorate as the concentration of hydrogen sulphide continues to increase with new record high concentrations. This means that no small or medium inflows will have any affect in this area. Only a major inflow can have a positive impact on the oxygen situation in this area.

5 Conclusions

- The severe oxygen conditions in the Baltic Proper continues. The areal extent and volume of anoxia are still elevated and follow the development that have prevailed since the regime shift in 1999.

- In 2022 anoxia was found at ~23% of the bottom areas and ~35% suffered from hypoxia during the autumn period. The results for 2022 are record high. But they might be overestimated since areas in the south eastern Baltic Proper were added, areas where data is sparse, hence the uncertainty high.

- Preliminary results for 2023 shows similar results as 2022. About ~18% of the bottom areas suffer from anoxia and approximate ~32% suffered from hypoxia.

- The concentration of hydrogen sulphide is above normal in all the basins around Gotland. In the Eastern and Western Gotland Basin hydrogen sulphide in the bottom water has reached extremely high levels, never recorded before.

- The inflows that occurred during 2022 - 2023 did only affect the oxygen situation in southern parts of the Baltic Proper. No inflows reached the deeper basins around Gotland. In late 2023 a larger inflow occurred, how this will affect the oxygen situation will be investigated in the next annual oxygen reports.

6 Acknowledgement

We extend our sincere gratitude to Tycjan Wodzinowski from the National Marine Fisheries Research Institute in Poland, for generously providing data from two surveys as part of the project "Polish Multiannual Fisheries Data Collection Programme." Data collected under the EU Data Collection Framework (DCF).

Additionally, we express our appreciation to David Rytter at the Institute for Bioscience, Aarhus Universitet, Denmark, for sharing the extensive "Iltsvind" dataset from 2023.

Special thanks are also due to Māris Skudra, a researcher at the Latvian Institute of Aquatic Ecology, for sharing CTD-data from the Gulf of Riga and Eastern Baltic Proper.

We are thankful to Taavi Liblik, from Tallinn University of Technology, Department of Marine Systems, Estonia, for contributing data from the Estonian National Monitoring Programme.

Our gratitude also extends to Jakob Walve and Svante Nyberg at Stockholm University, DEEP Marine Pelagic Ecology Laboratory, for sharing data from the coastal and offshore stations along the Swedish east coast as part of the Swedish National Marine Monitoring Programme.

We would also like to thank Heini Jalli at the Finnish Meteorological Institute (FMI) for generously sharing CTD-data collected during Combine-3 (SYKE cruise), Vedenvaihto 2023 FMI:s research cruise and LUKE:s ICES-BIAS 2023.

Many thanks to the SMHI crew onboard R/V Svea for their dedicated efforts in collecting data for the Swedish National Marine Monitoring Programme, as well as during the Swedish BIAS and IBTS cruise arranged by SLU-Aqua.

Finally, we express our gratitude to the Swedish Agency for Marine and Water Management (HaV) for their support of SMHI and the Swedish National Marine Monitoring Programme.

7 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.

Almroth-Rosell E, Wåhlström I, Hansson M, Väli G, Eilola K, Andersson P, Viktorsson L, Hieronymus M and Arneborg L (2021) A Regime Shift Toward a More Anoxic Environment in a Eutrophic Sea in Northern Europe. Front. Mar. Sci. 8:799936. doi10.3389/fmars.2021.799936

Chabot D., & Dutil J.-D., 1999, Reduced growth of Atlantic cod in non-lethal hypoxic conditions. J. Fish Biol., 55, 472-491.

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.

Feistel S., Feistel R., Nehring D., Matthäus W., Nausch G. & Naumann M., 2016: Hypoxic and anoxic regions in the Baltic Sea 1969-2015, Meereswissenschaftliche Berichte, Marine Science Reports, No 100.

Fischer H. and Matthäus W., 1996: The importance of the Drogden Sill in the Sound for major Baltic inflows. J. Mar. Syst. 9, 137–157.

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

Hall P.O.J., Almroth Rosell E., Bonaglia S., Dale A.W., Hylén A., Kononets M., Nilsson M., Sommer S., Van de Velde S. & Viktorsson L., 2017: Influence of Natural Oxygenation of Baltic Proper Deep Water on Benthic Recycling and Removal of Phosphorus, Nitrogen, Silicon and Carbon, Front. Mar. Sci. 4:27.

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.

HELCOM (2018): State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155. ISSN 0357-2994

Håkansson B., Broman B. & Dahlin H., 1993: The flow of water and salt in the Sound during the Baltic major inflow event in January 1993. ICES Statutory Meeting 1993, C.M. 1993/C:57 SESS.V.

Håkansson B., 2022: On barotropic net water exchange applied to the Sound strait in the Baltic Sea. Geophysica, 57 (1), 3–22.

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

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

Mohrholz, V. (2018). Baltic saline barotropic inflows (SBI) 1887 - 2024. Leibniz Institute for Baltic Sea Research (IOW), http://doi.io-warnemuende.de/10.12754/data-2018-0004 . last access: 2024-06-26.

Naumann M., Umlauf L., Mohrholz V., Kuss J., Siegel H., Waniek J.J., Schulz-Bull, D.E.: Hydrographic-hydrochemical assessment of the Baltic Sea 2017. Meereswiss. Ber., Warnemünde, 107 (2018), doi:10.12754/msr-2018- 0107.

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.

Rehder G., Müller J. D., Bittig H.C., Johansson J., Kaitala S., Karlson B., Kaspar F., Rutgersson A., Schneider B., Siegel H., Siiriä S.-M., Tuomi L., and Wasmund N, 2019: Response of net community production to extreme meteorological conditions in spring/summer 2018, Geophysical Research Abstracts, Vol. 21, EGU2019-10714-4.

Schaber M., Hinrichsen H.-H., & Gröger J., 2012, Seasonal changes in vertical distribution patterns of cod (Gadus morhua) in the Bornholm Basin, Central Baltic Sea, Fish. Oceanogr. 21, 33-43.

SMHI, 2022: Cruise report archive: http://www.smhi.se/en/theme/marine-environment-2-885, last access: 2024-02-26.

SMHI, 2022: Accumulated inflow through the Öresund. URL: http://www.smhi.se/hfa_coord/BOOS/Oresund.html, last access: 2024-02-26.

Sommer S., Clemens D., Yücel M., Pfannkuche O., Hall P.O.J., Almroth-Rosell E., Schulz-Vogt H.N. and Dale A.W., 2017: Major Bottom Water Ventilation Events Do Not Significantly Reduce Basin-Wide Benthic N and P Release in the Eastern Gotland Basin (Baltic Sea). Front. Mar. Sci. 4:18.

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

Seifert T., Tauber F., Kayser B.: 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.

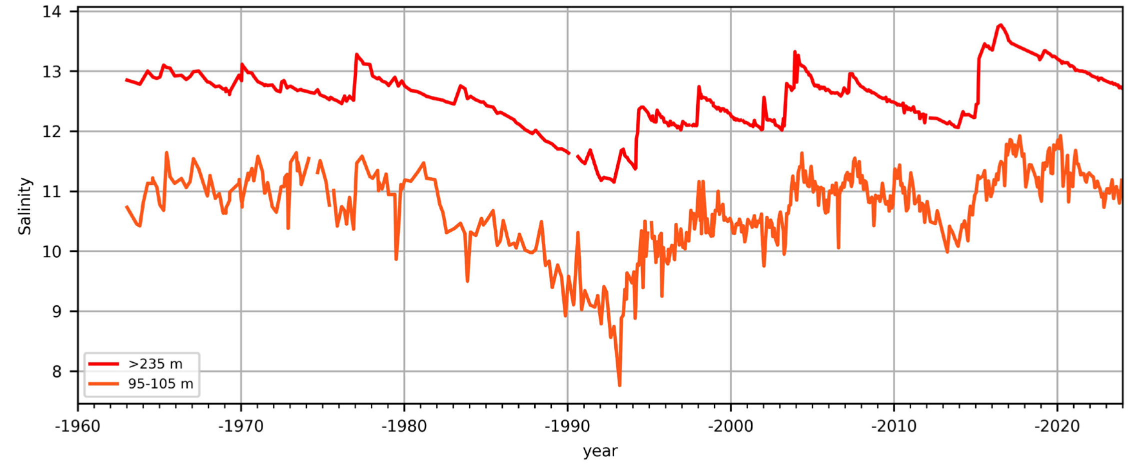
U.S. EPA, 2000: Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras, U.S. Environmental Protection Agency, EPA-822-R-00-012.

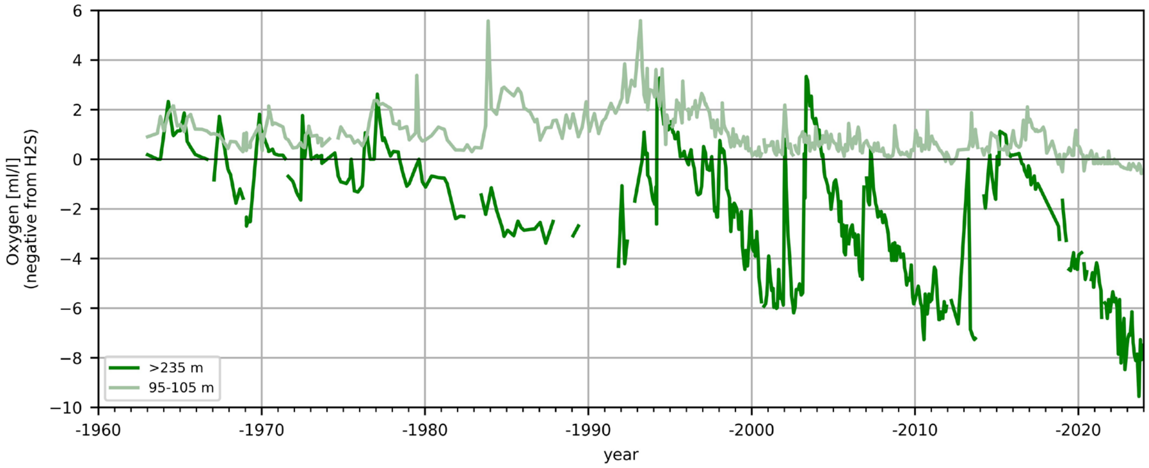
Vahtera E., Conley D. J., Gustafsson B. G., Kuosa H., Pitkänen H., Savchuk O. P., Tamminen T., Viitasalo M., Voss M., Wasmund N. and Wulff F., 2007: Internal Ecosystem Feedbacks Enhance Nitrogen-fixing Cyanobacteria Blooms and Complicate Management in the Baltic Sea. AMBIO: A J. of the Human Environment, 36(2):186-19.

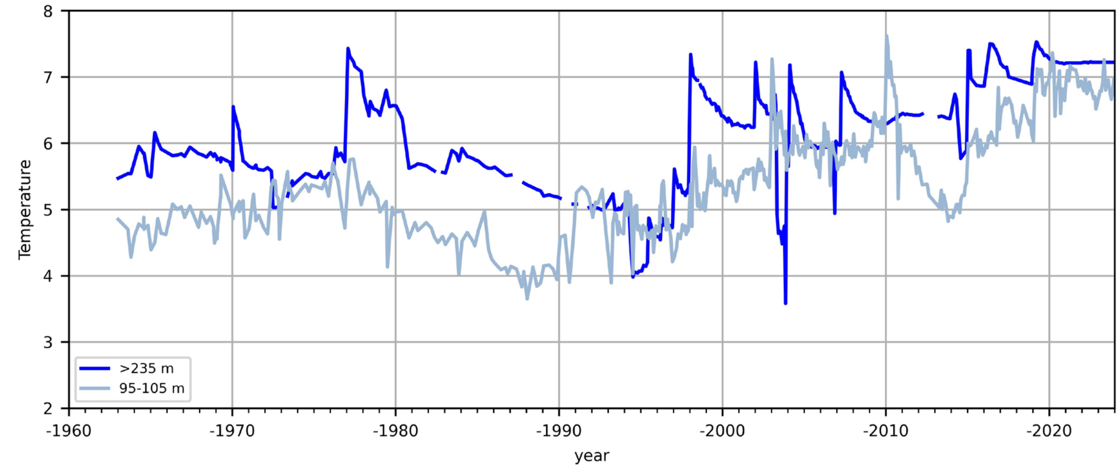
Vaquer R. & Duarte C. M., 2008: Thresholds of hypoxia for marine biodiversity, PNAS, vol. 105, no 40.

Appendix 1

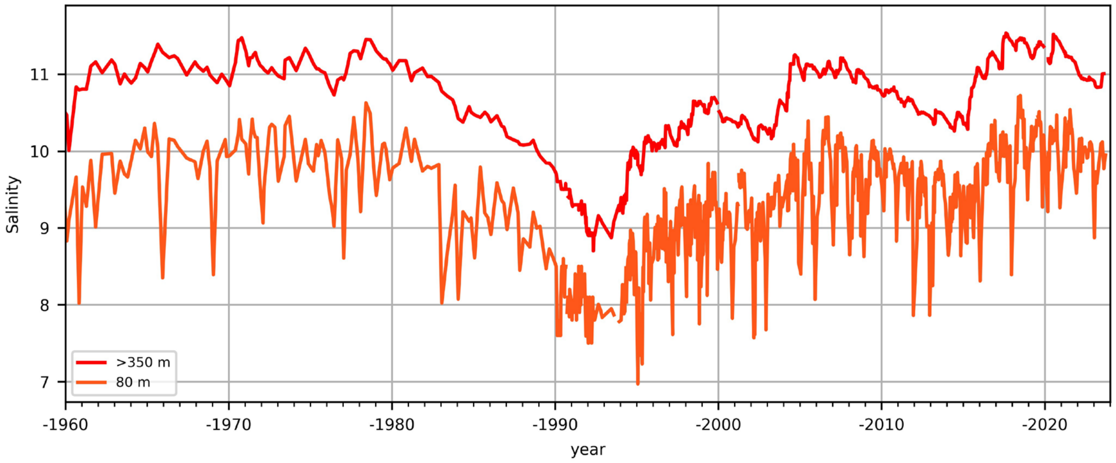
Temperature, salinity and oxygen in the Eastern Gotland Basin at station BY15, 1960-2023

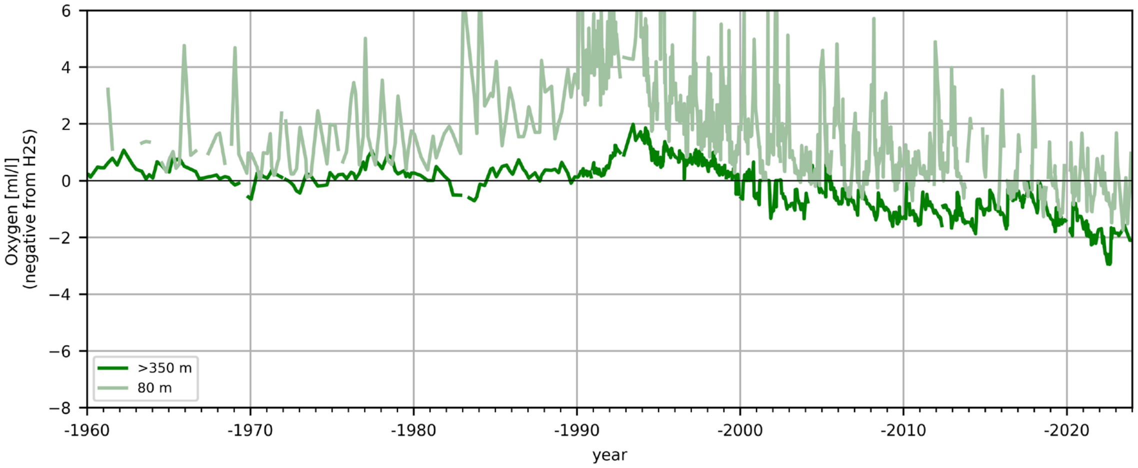


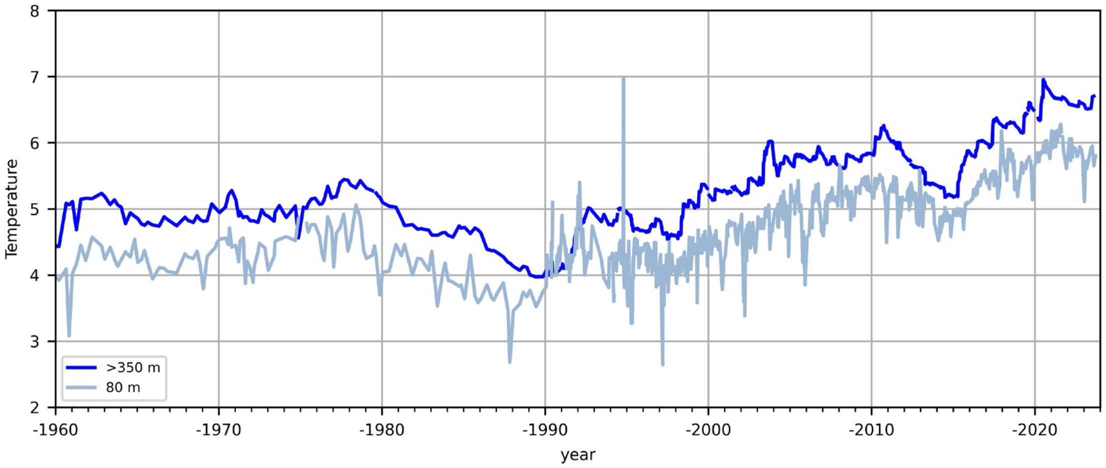




Temperature, salinity and oxygen in the Western Gotland Basin at station BY31, 1960-2023

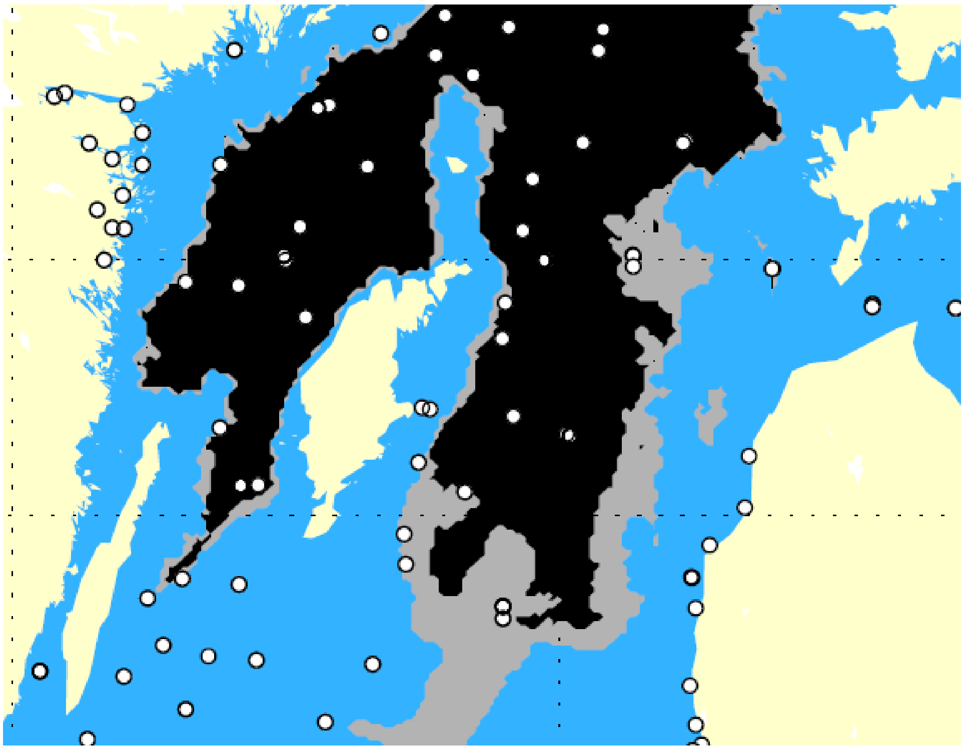




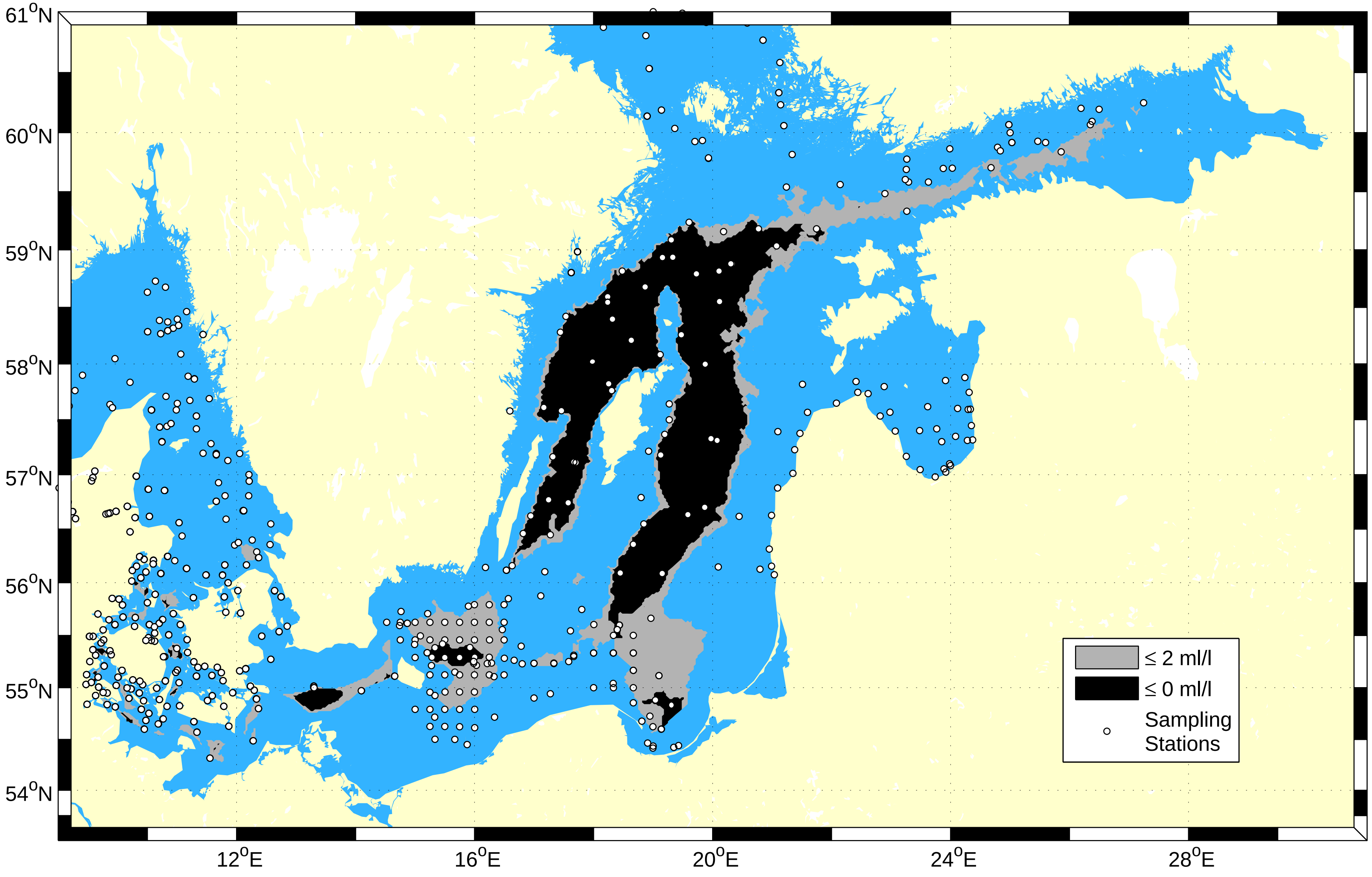


Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea

- updated maps 1960-2023

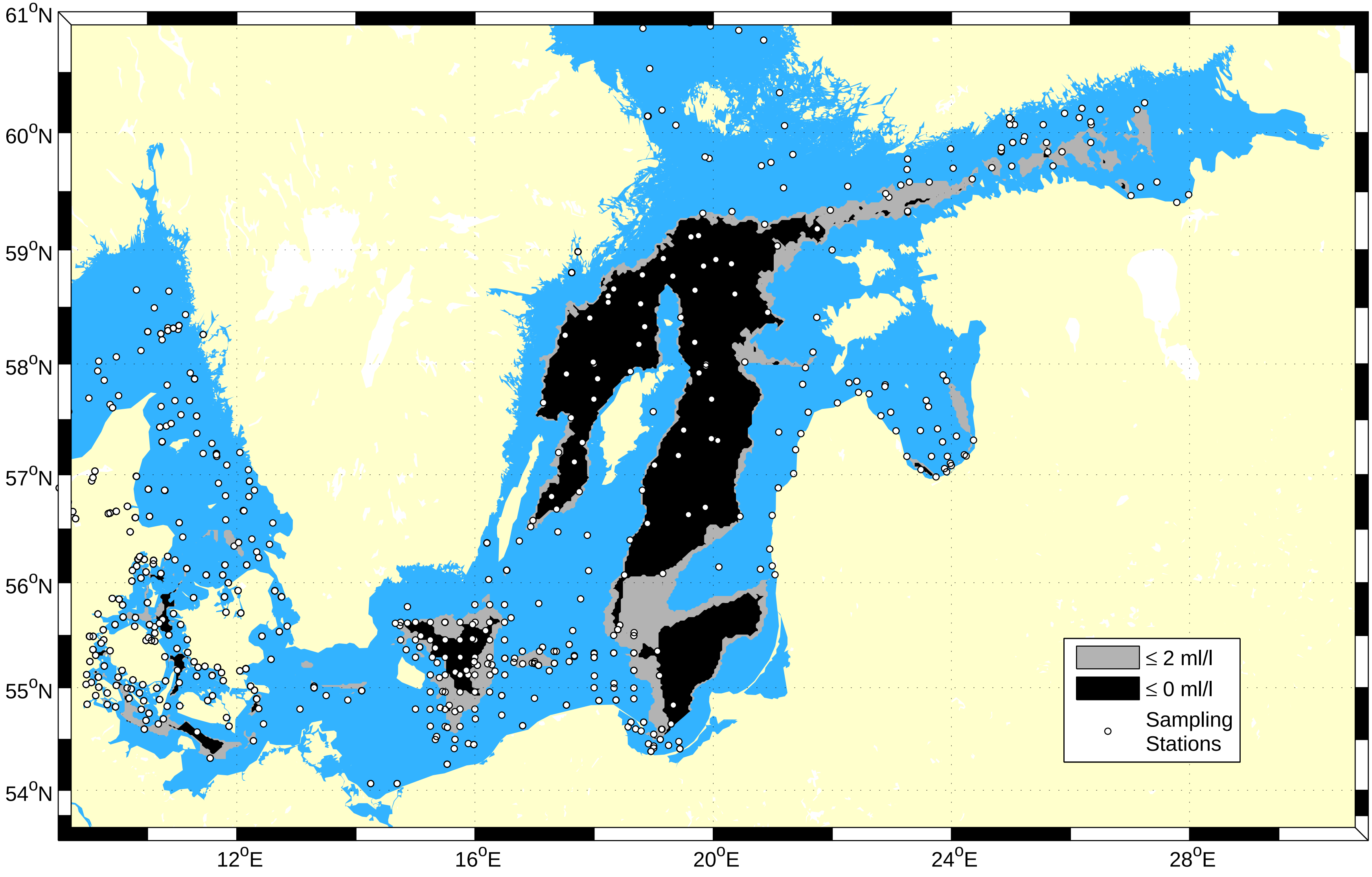


Extent of hypoxic & anoxic bottom water, Autumn 2023



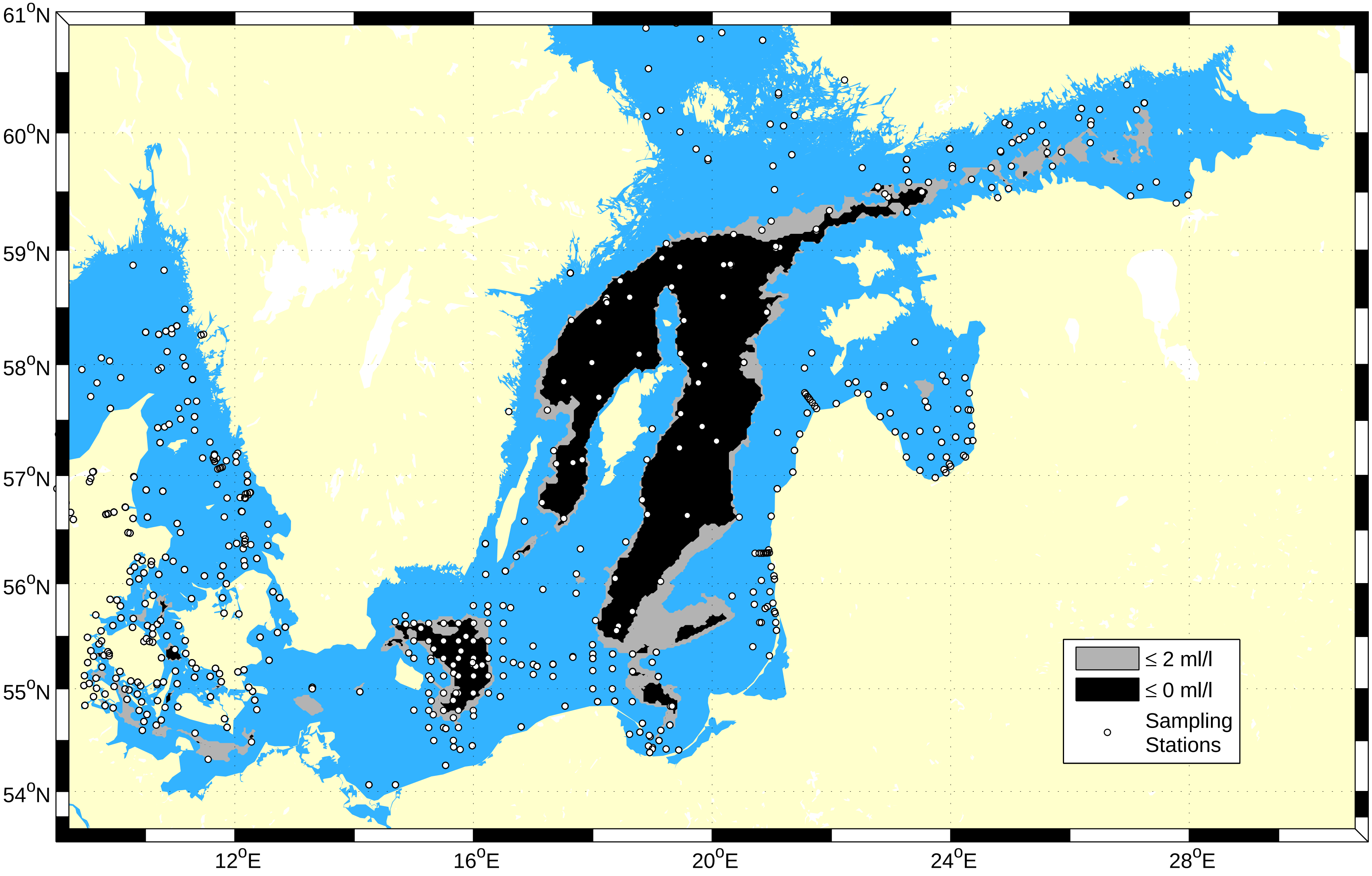
Created:
February 2024

Extent of hypoxic & anoxic bottom water, Autumn 2022

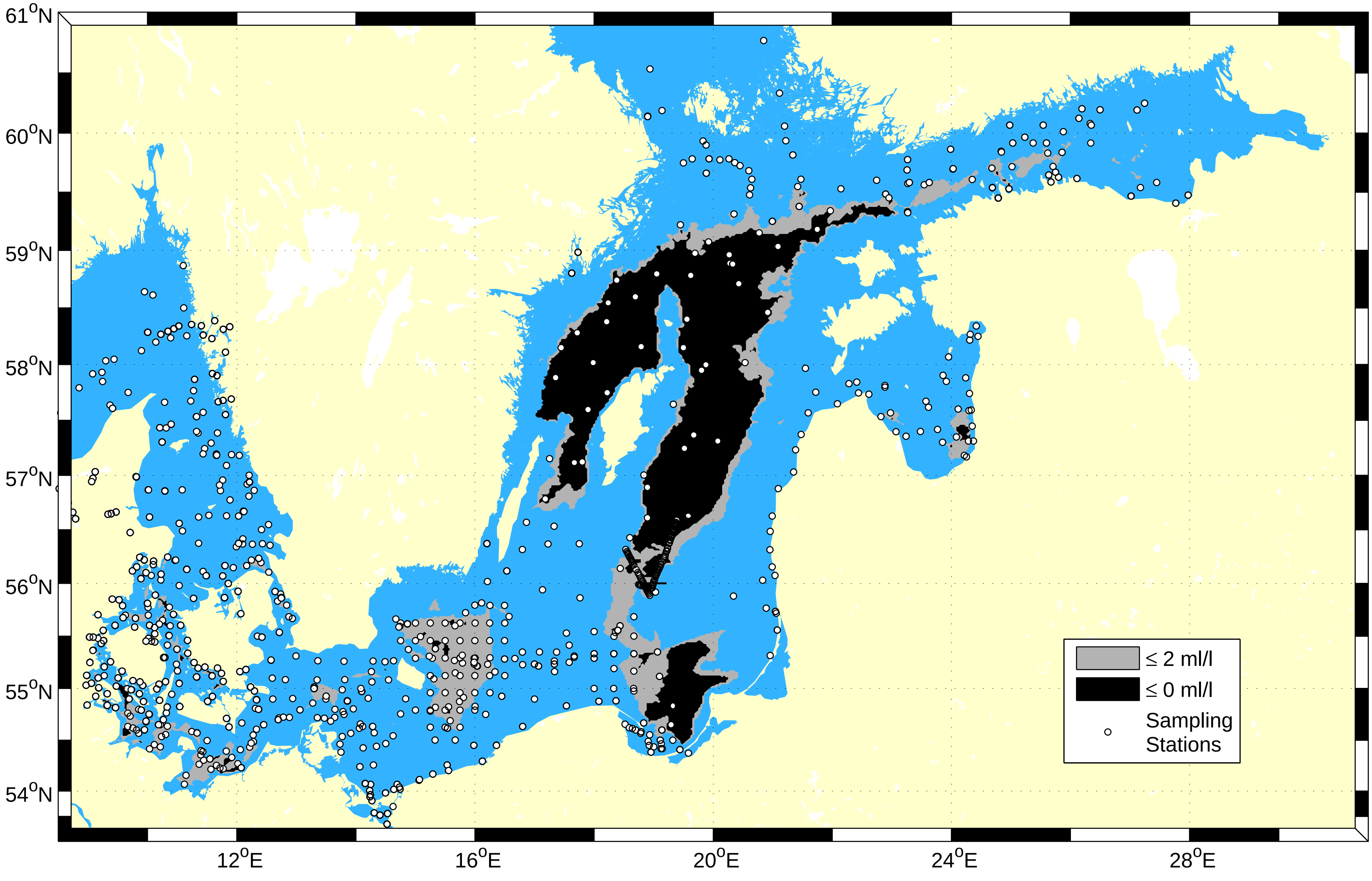


Created:
February 2024

Extent of hypoxic & anoxic bottom water, Autumn 2021



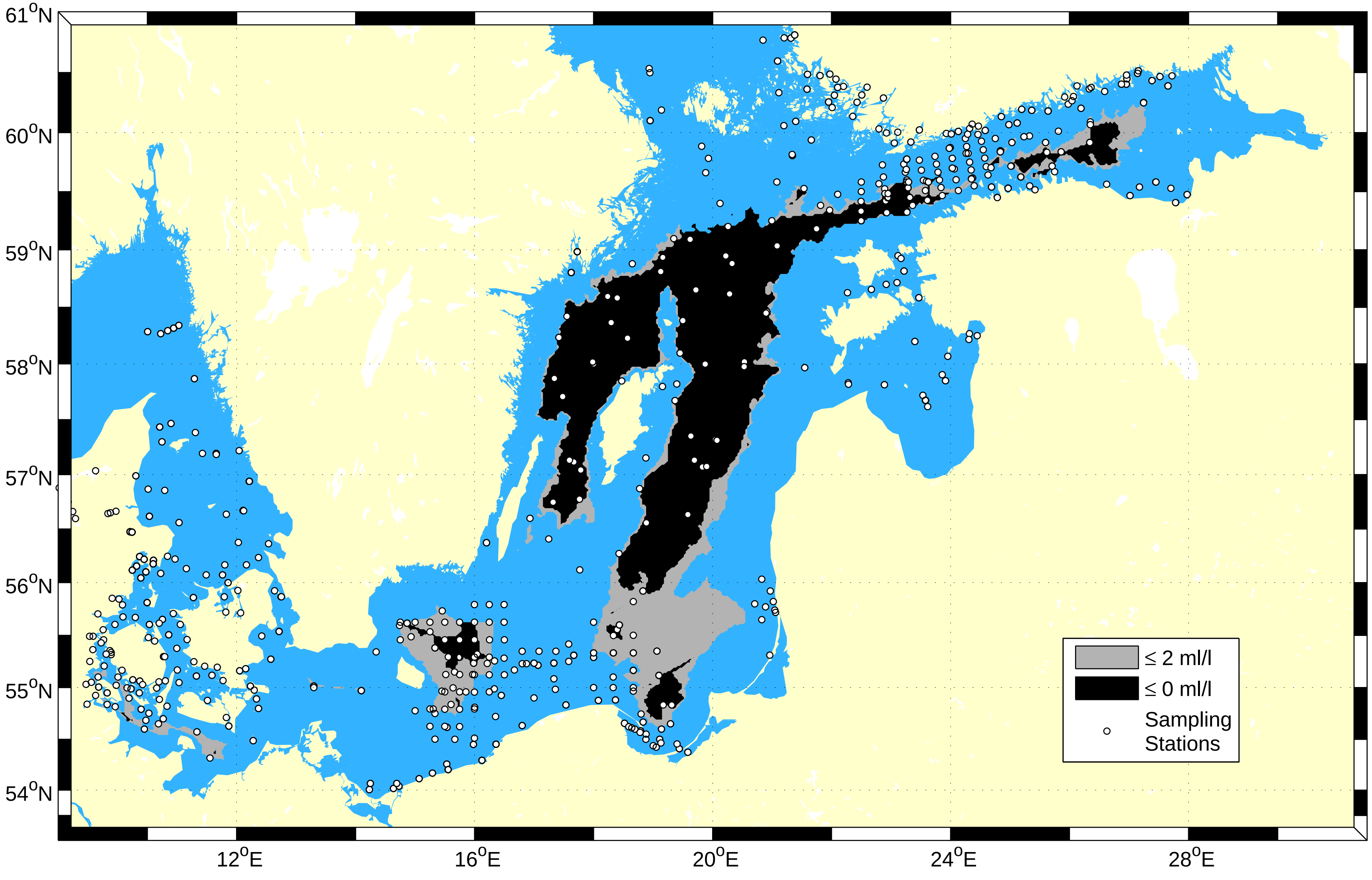
Created:
April 2023



Extent of hypoxic & anoxic bottom water, Autumn 2020

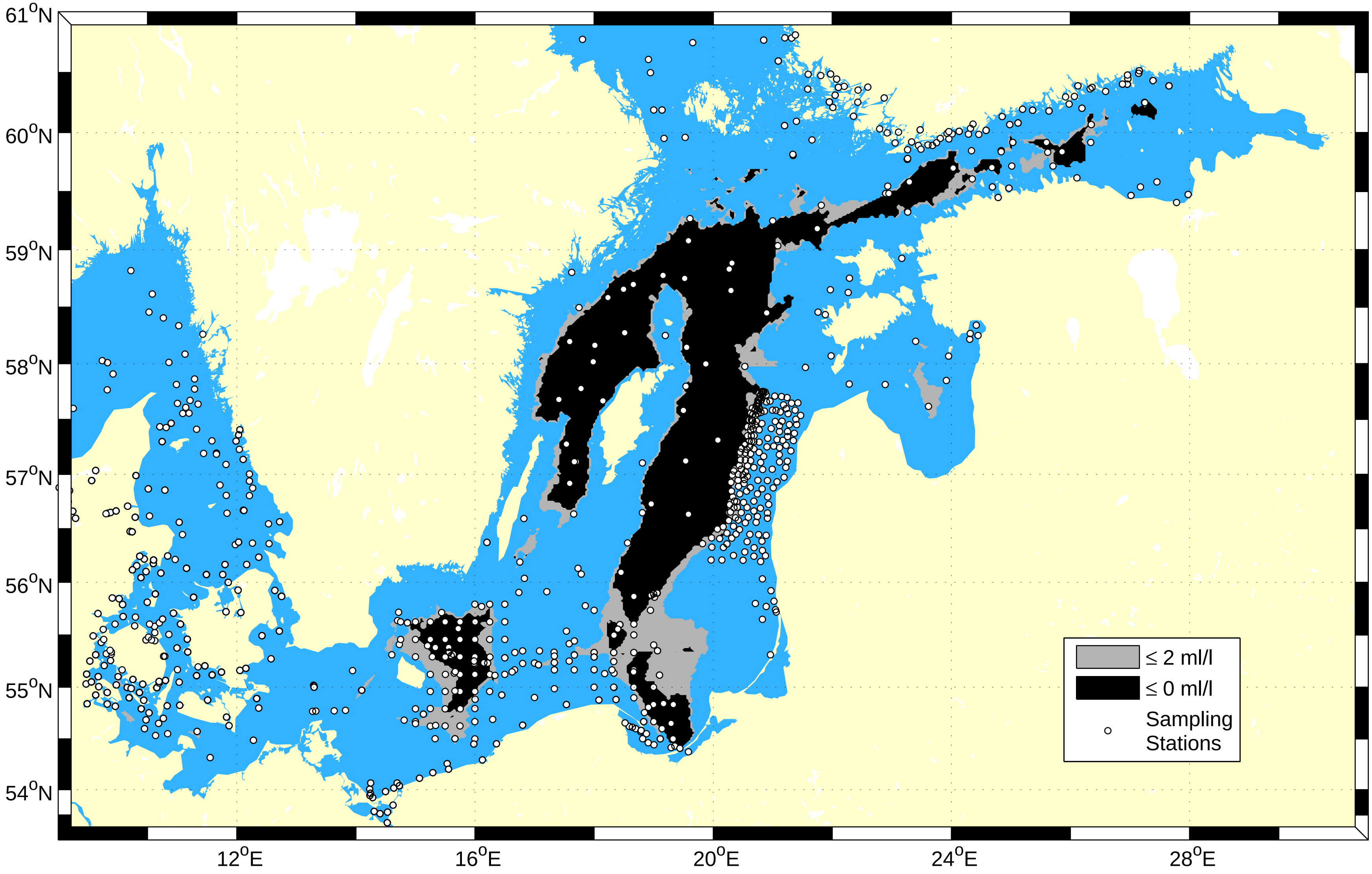
Created:
March 2022

Extent of hypoxic & anoxic bottom water, Autumn 2019



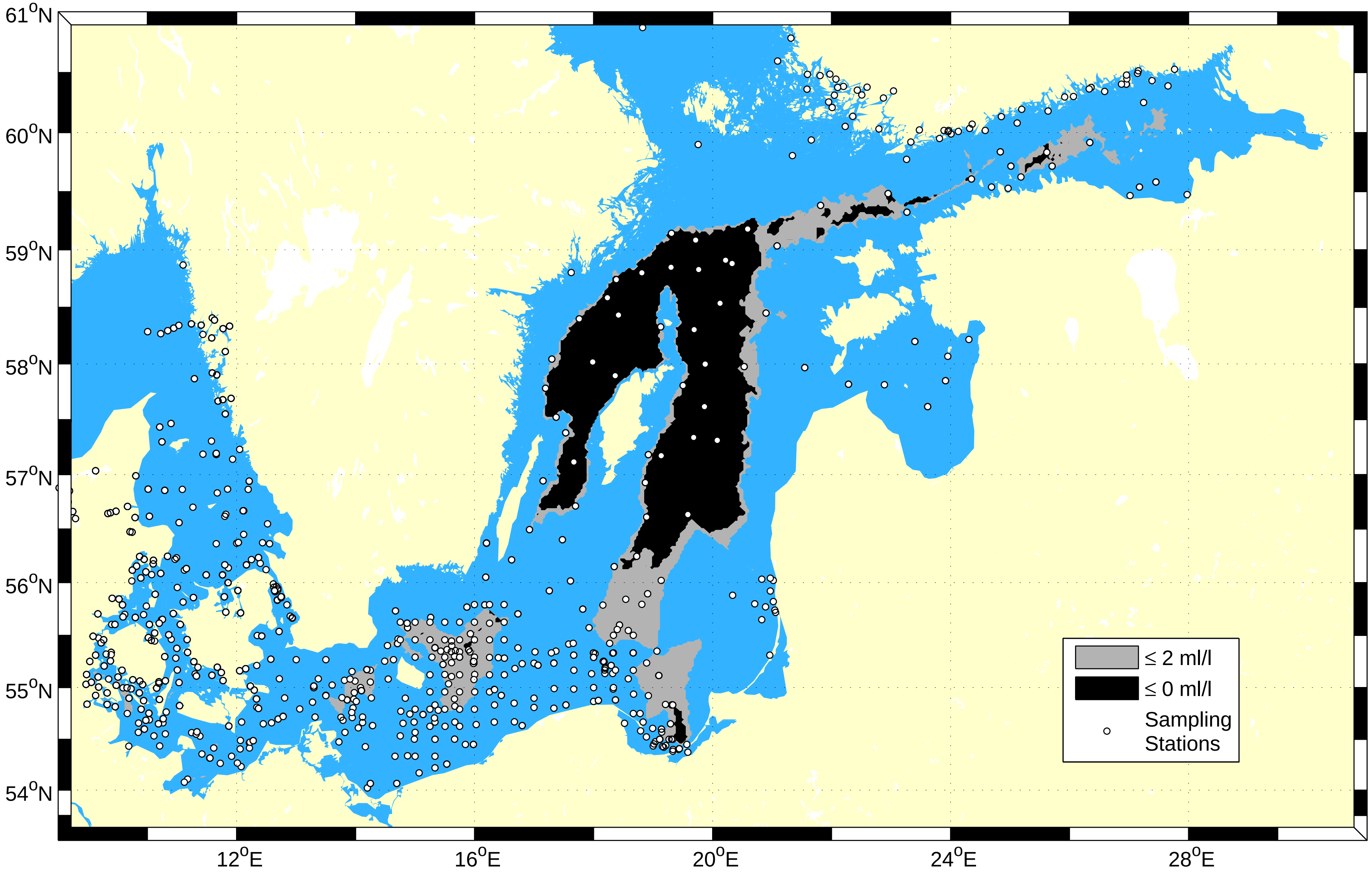
Created:
February 2021

Extent of hypoxic & anoxic bottom water, Autumn 2018

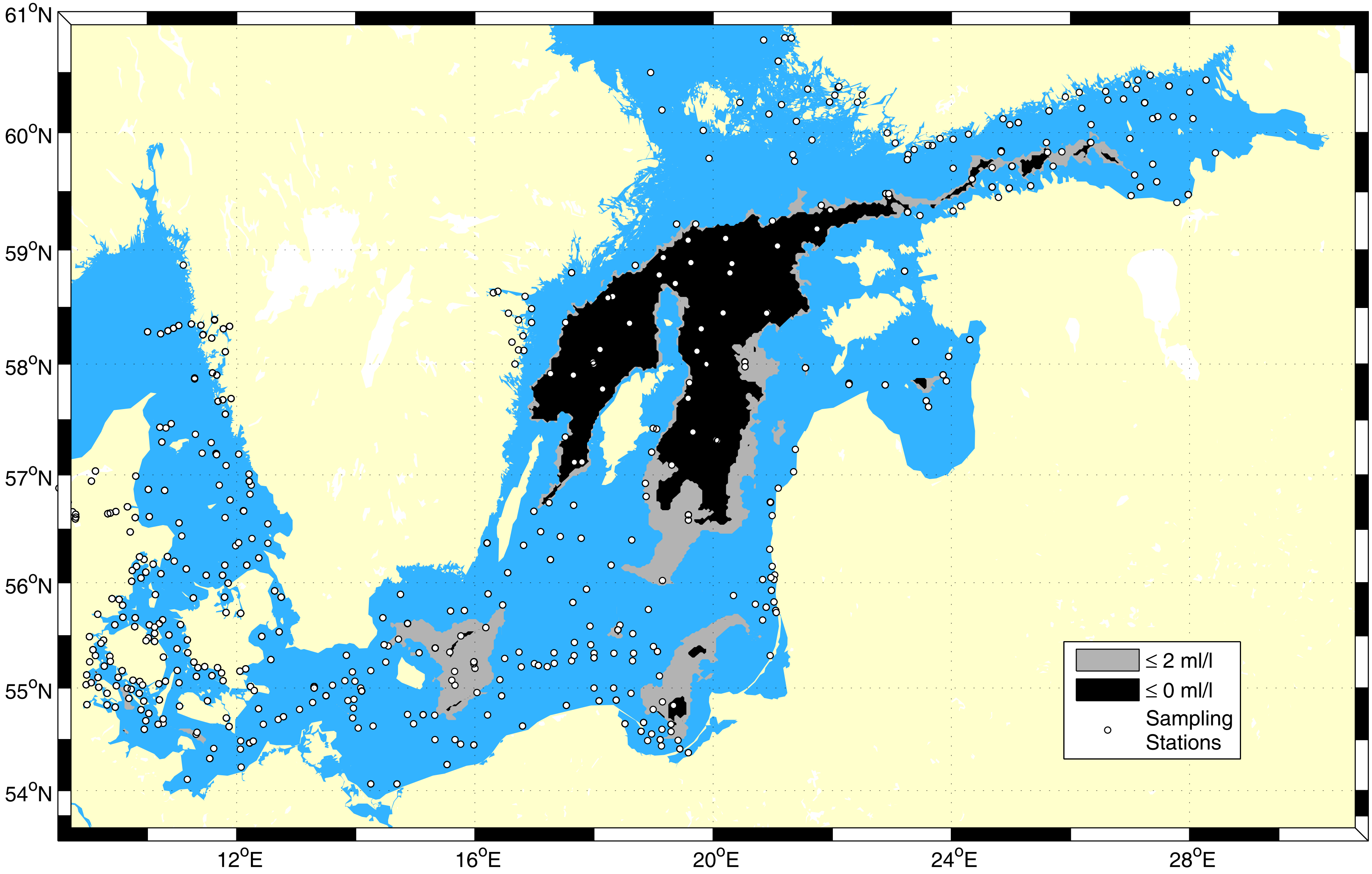


Created:
January 2020

Extent of hypoxic & anoxic bottom water, Autumn 2017

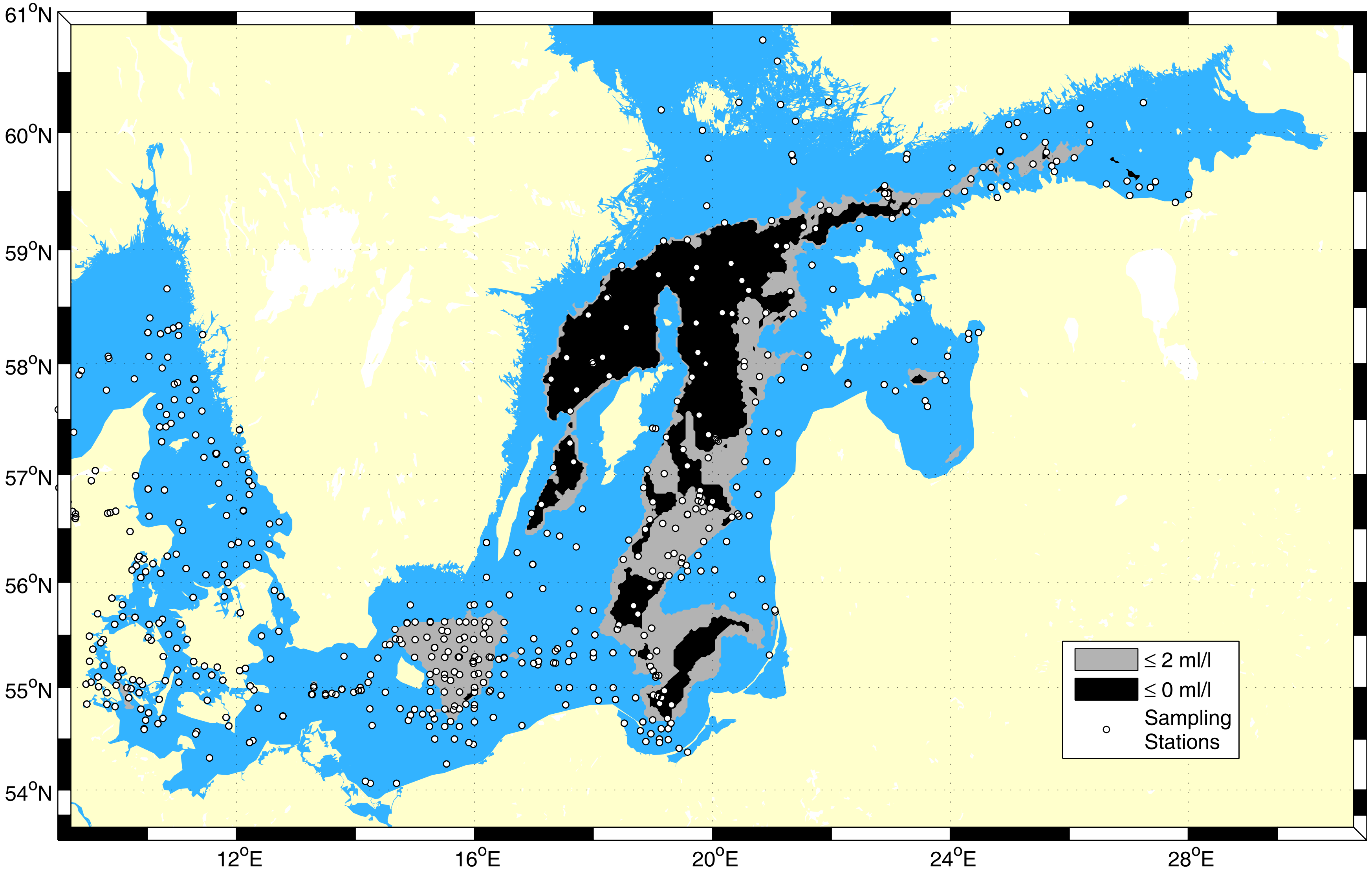


Created:
January 2019



Extent of hypoxic & anoxic bottom water, Autumn 2016

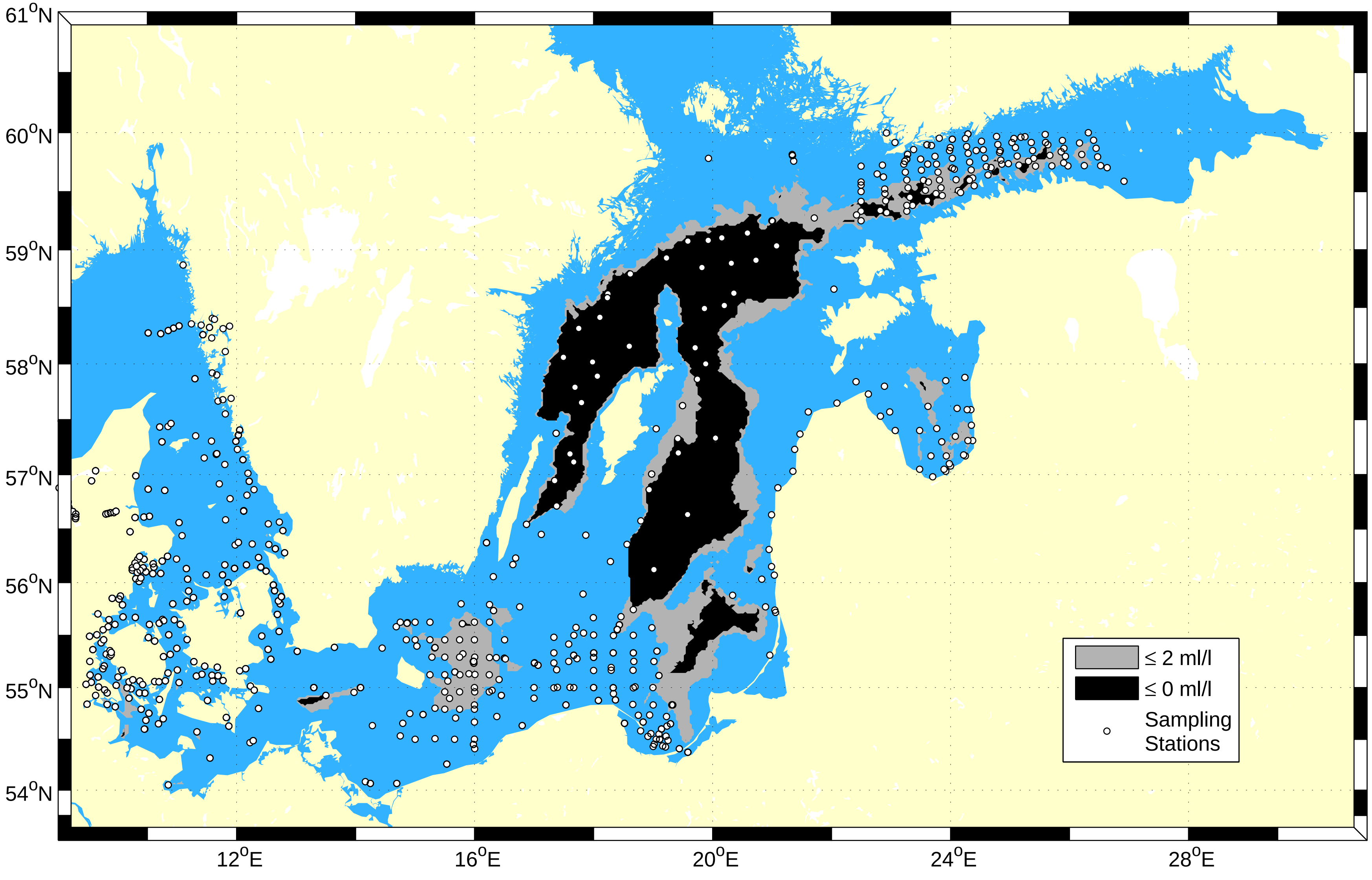
Created:
January
2018



Extent of hypoxic & anoxic bottom water, Autumn 2015

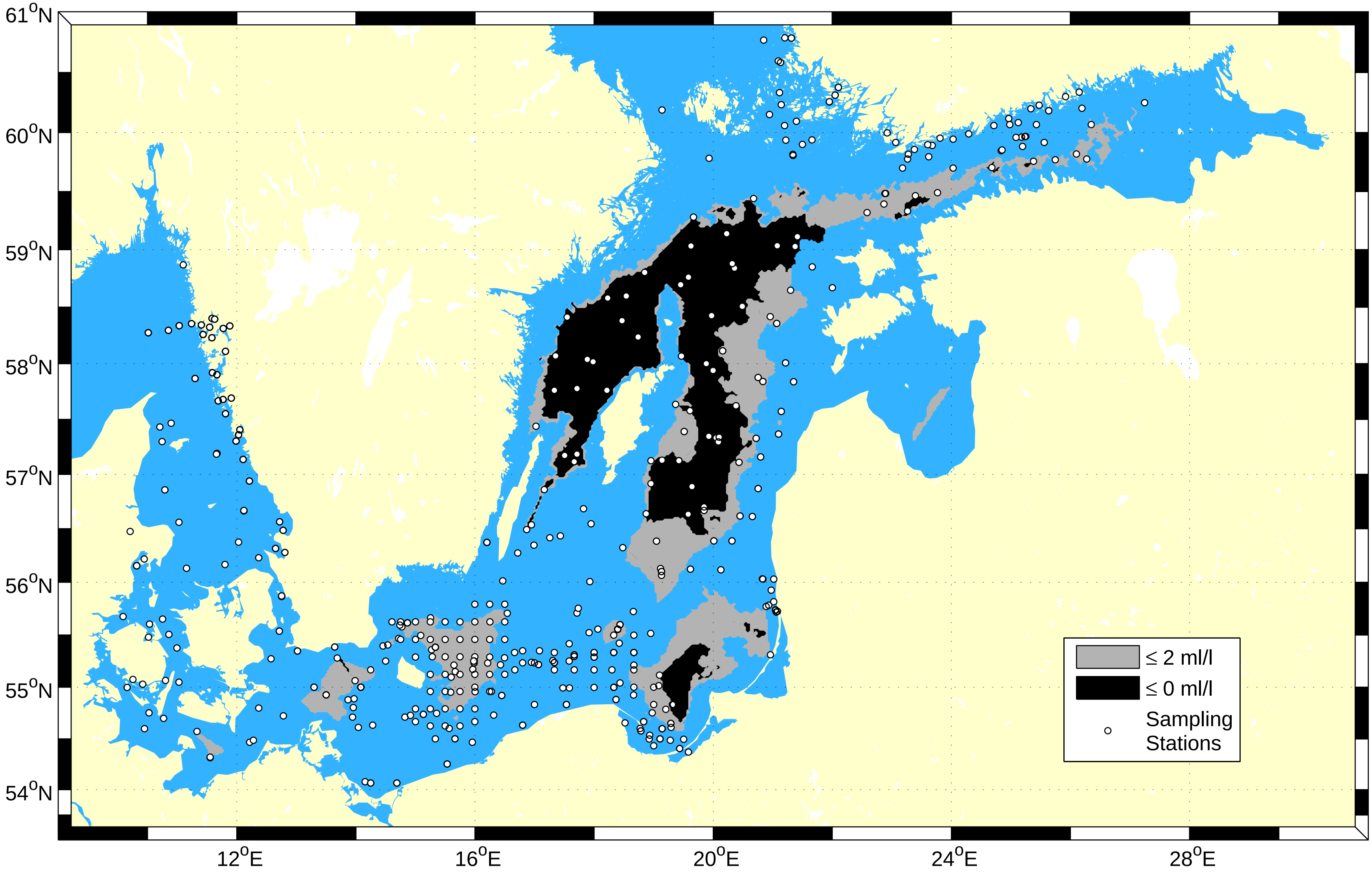
Created:
January
2017

Extent of hypoxic & anoxic bottom water, Autumn 2014



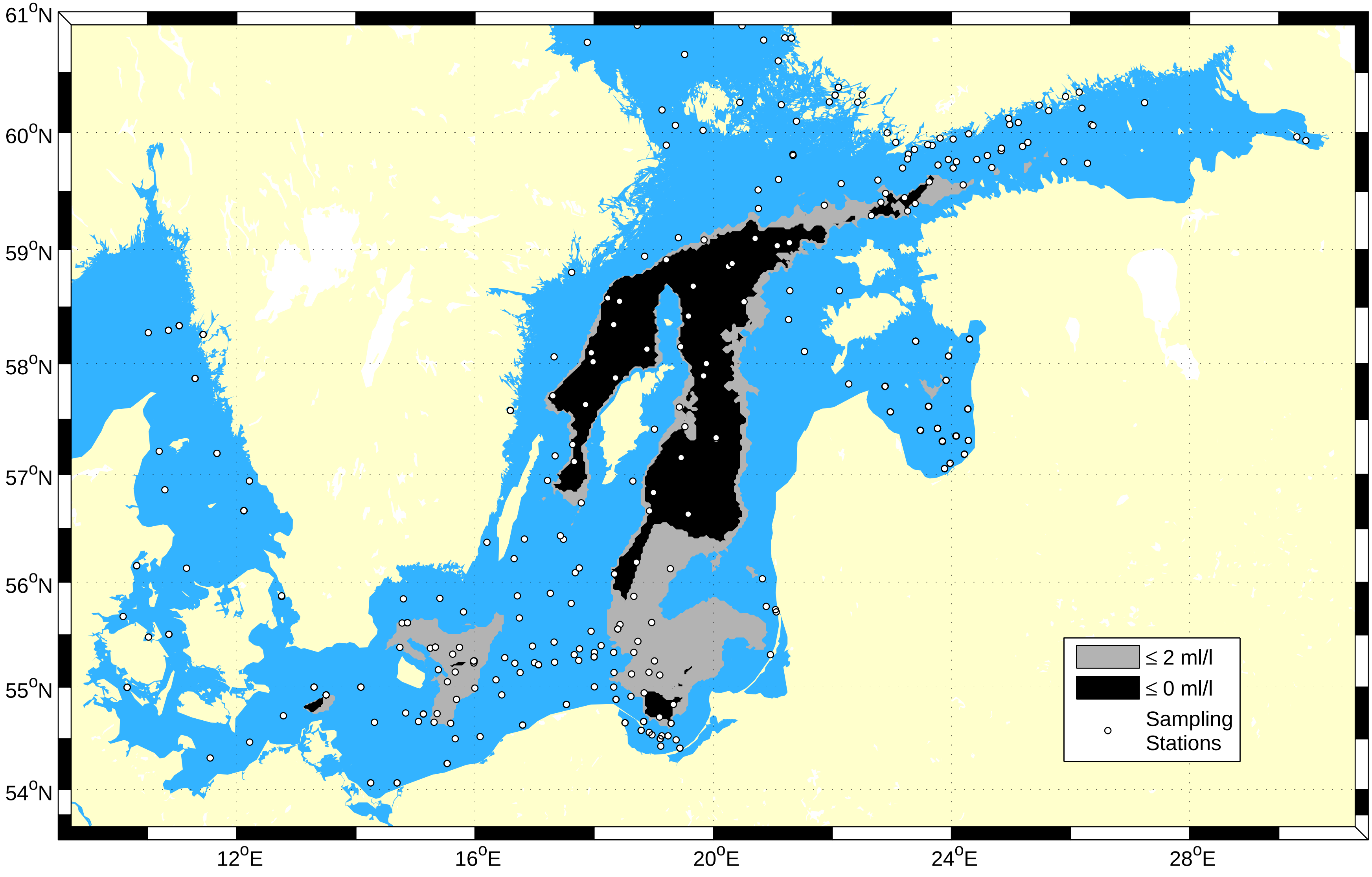
Created:
November
2015

Extent of hypoxic & anoxic bottom water, Autumn 2013



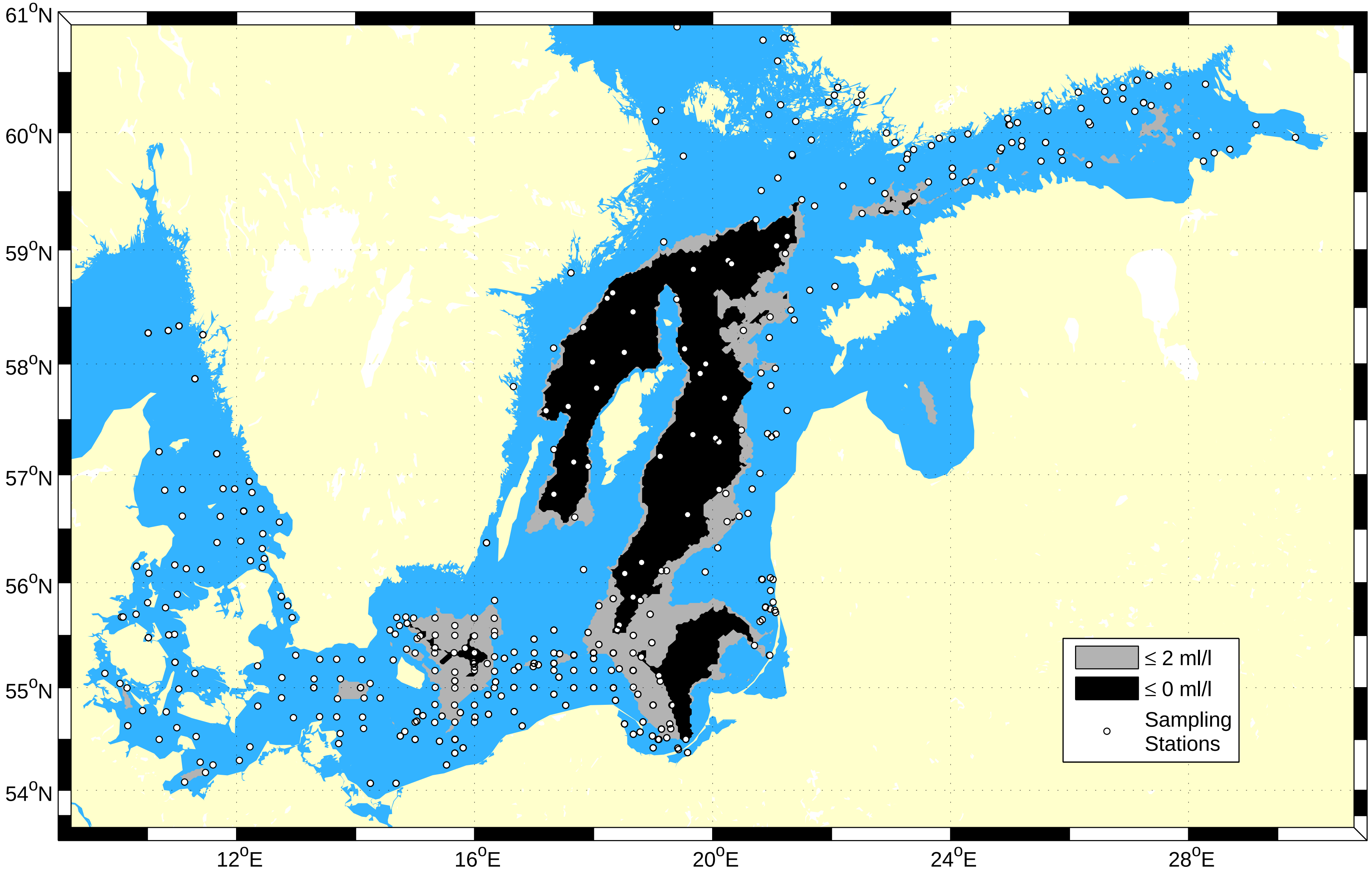
Created:
December 2014

Extent of hypoxic & anoxic bottom water, Autumn 2012

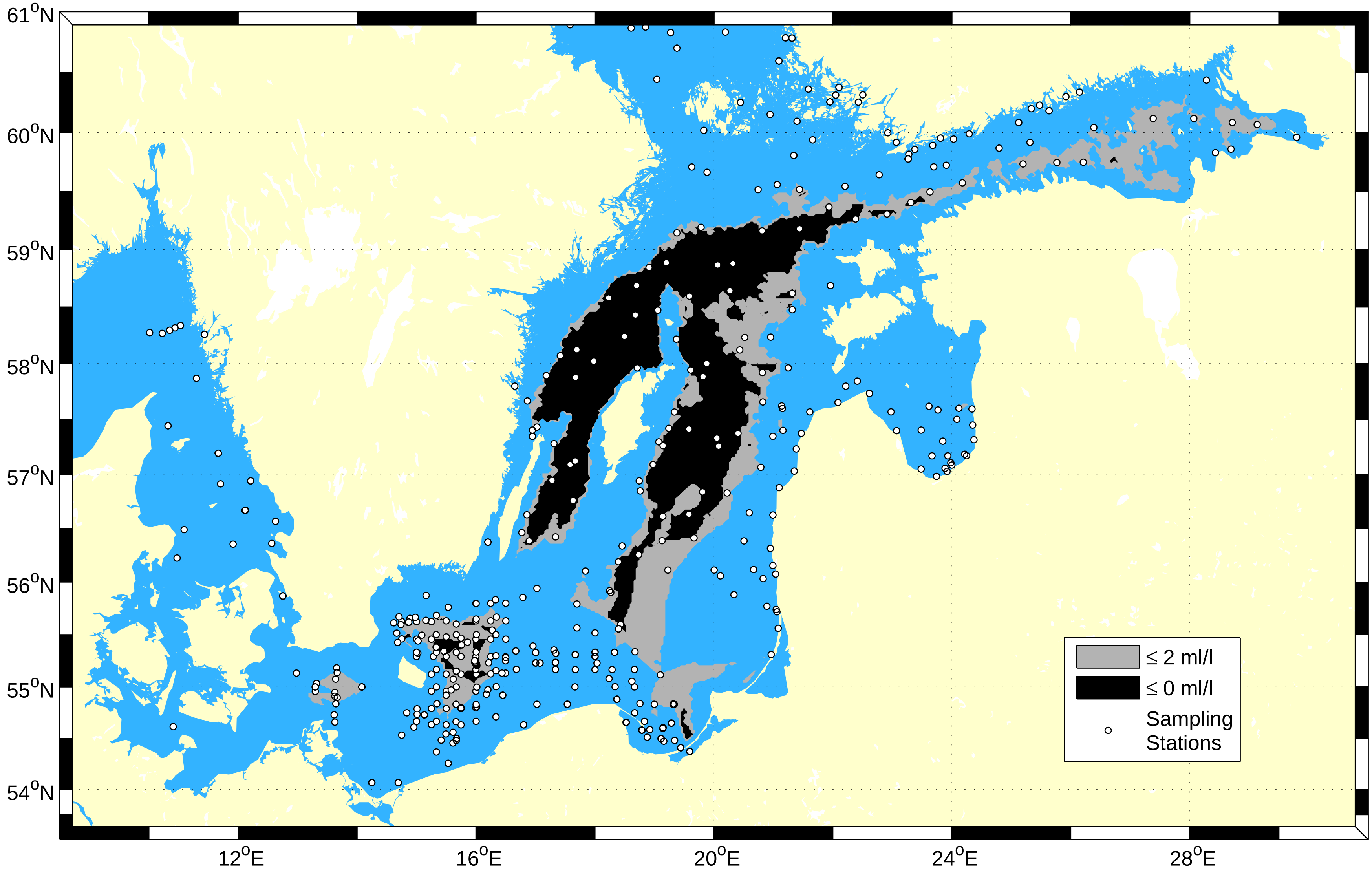


Created:
December 2013

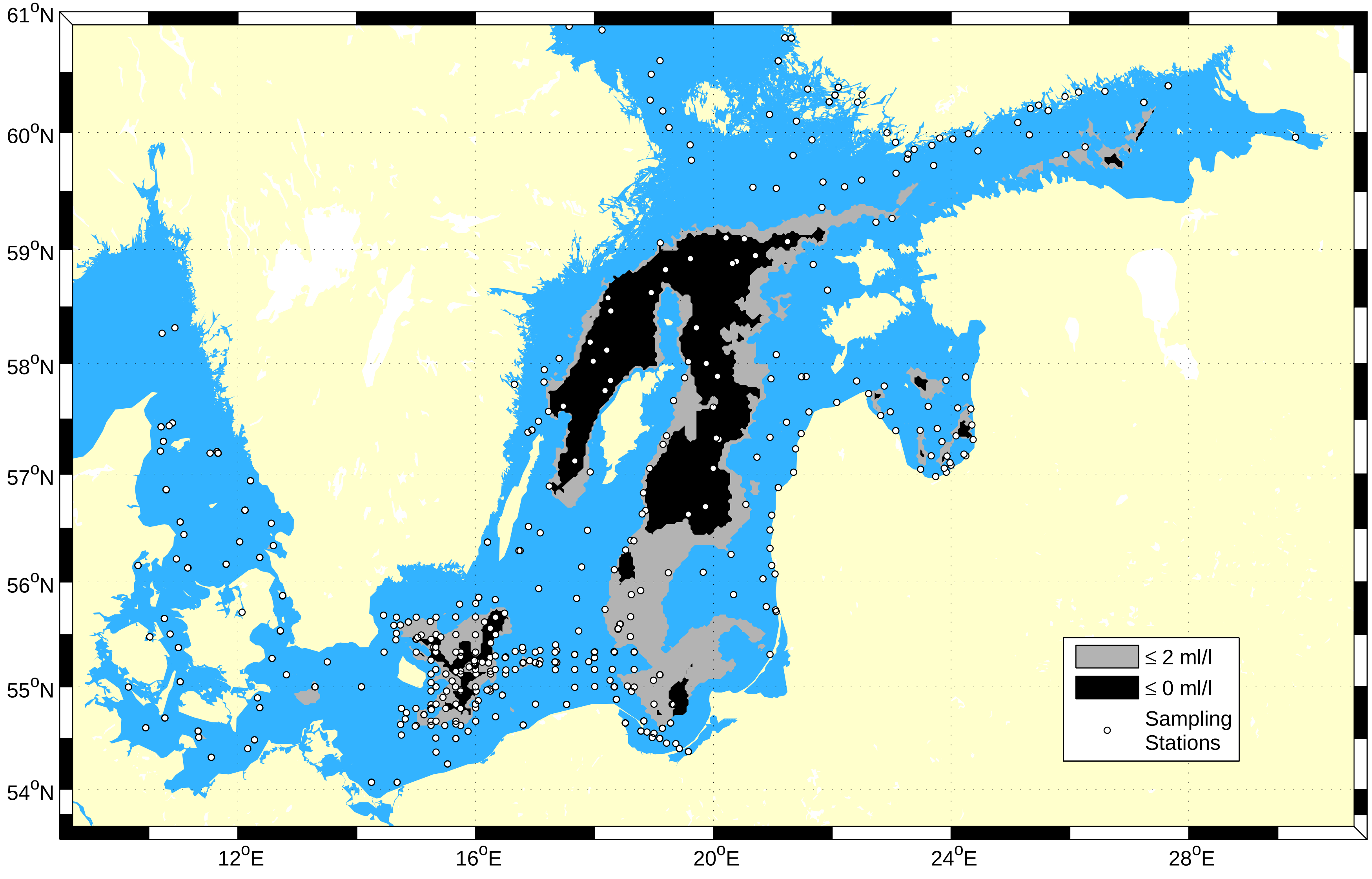
Extent of hypoxic & anoxic bottom water, Autumn 2011



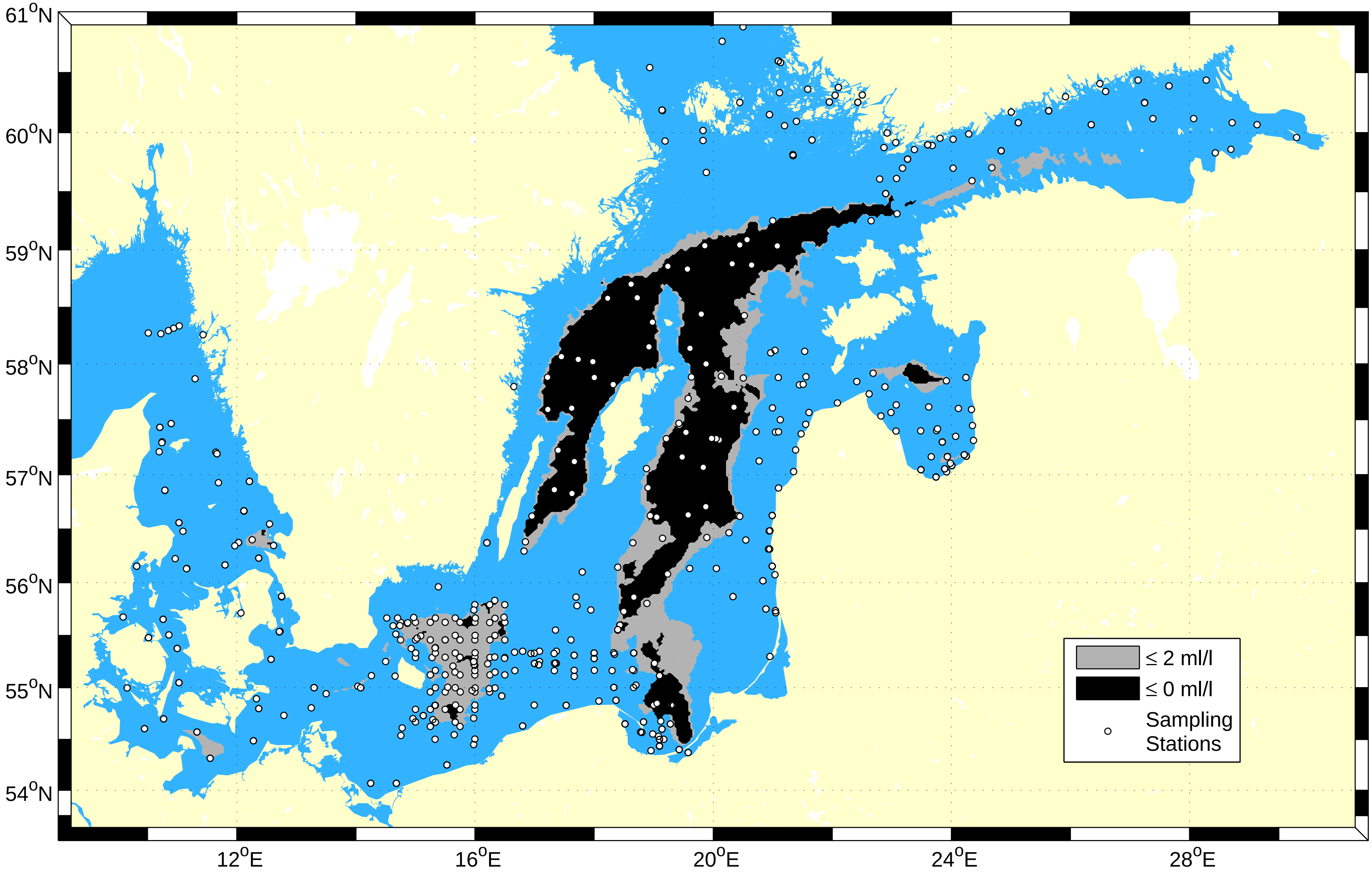
Created: January 2013

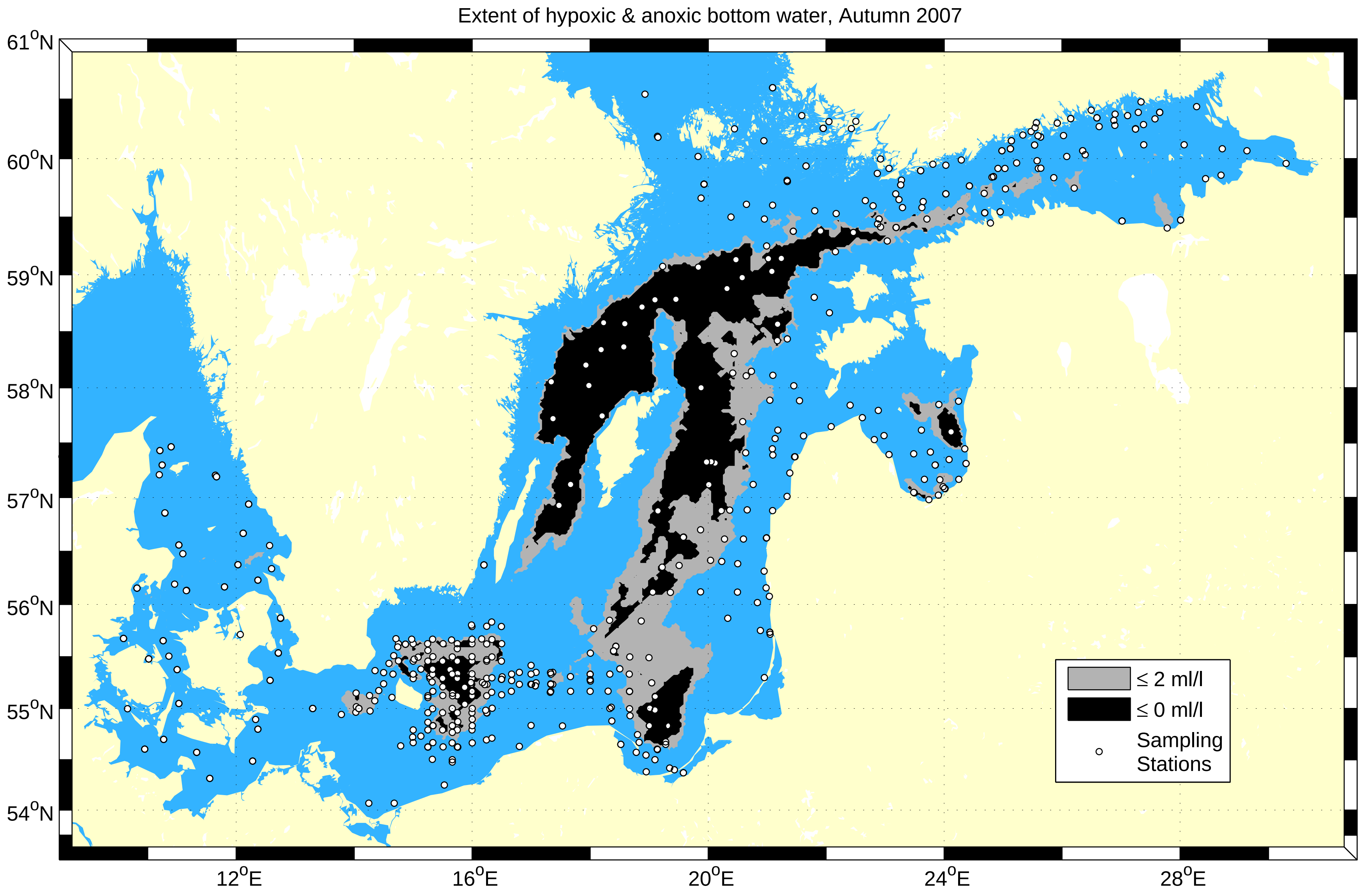

Extent of hypoxic & anoxic bottom water, Autumn 2010

Extent of hypoxic & anoxic bottom water, Autumn 2009

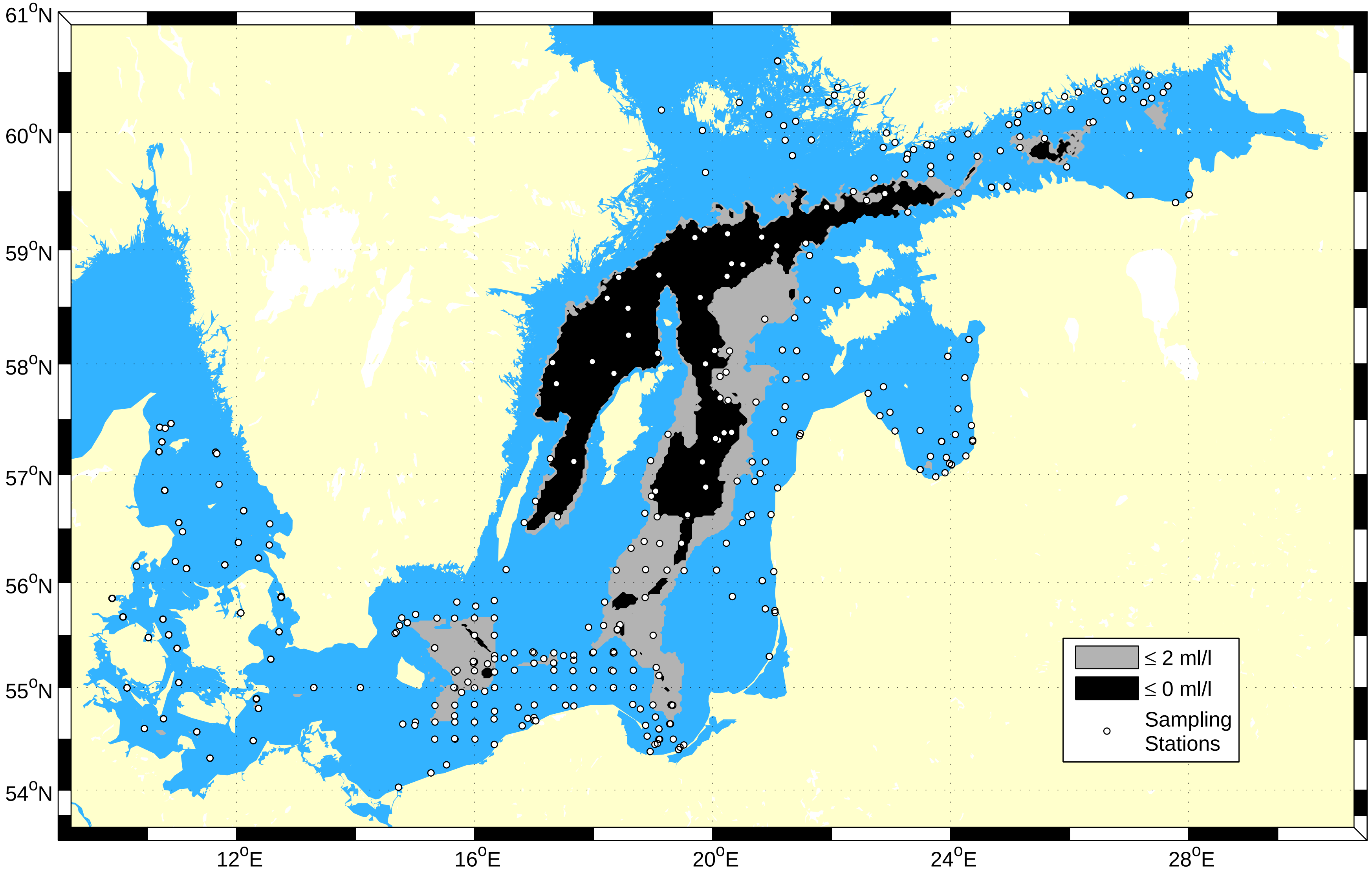


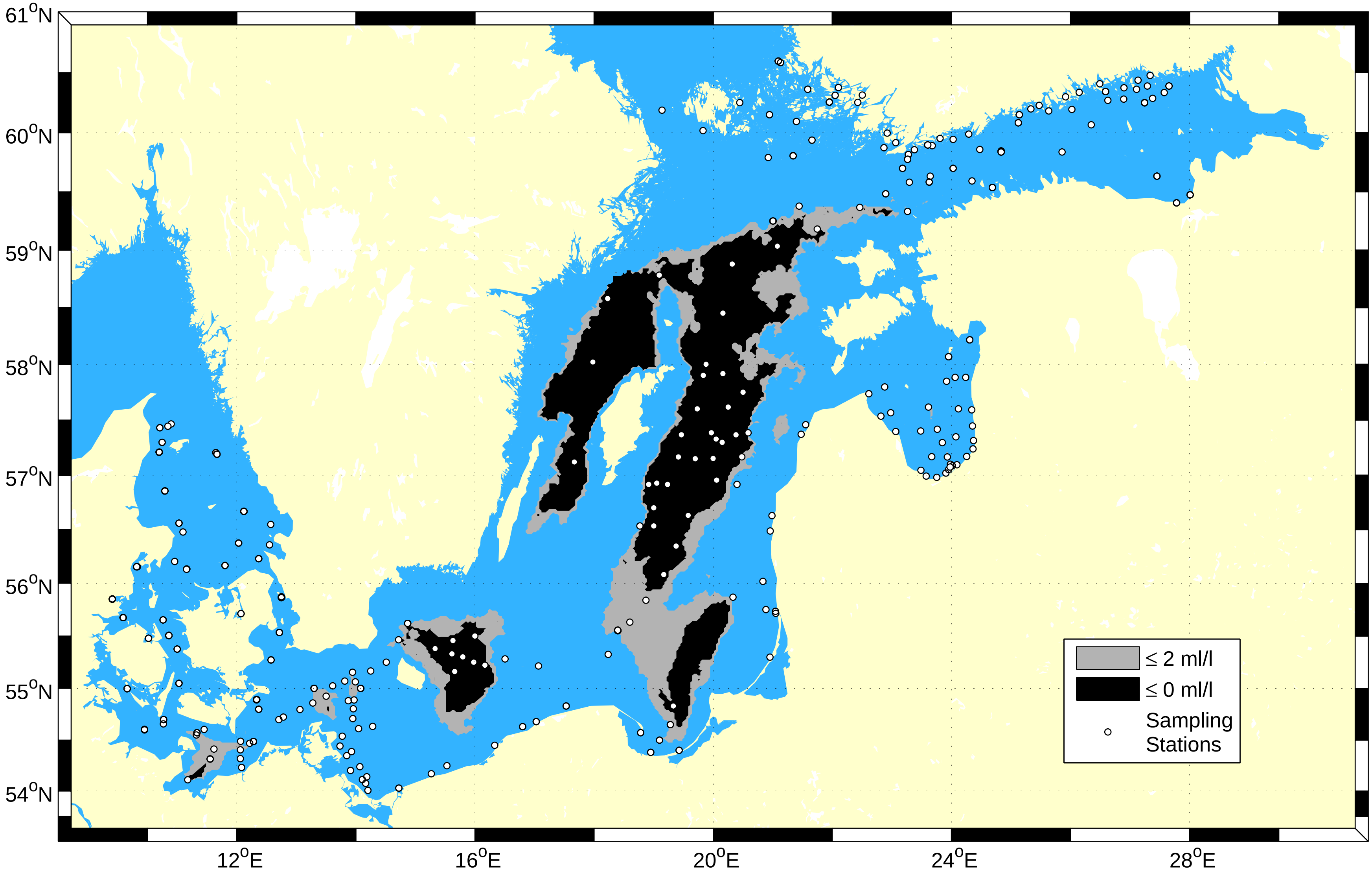
Extent of hypoxic & anoxic bottom water, Autumn 2008




Extent of hypoxic & anoxic bottom water, Autumn 2007
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

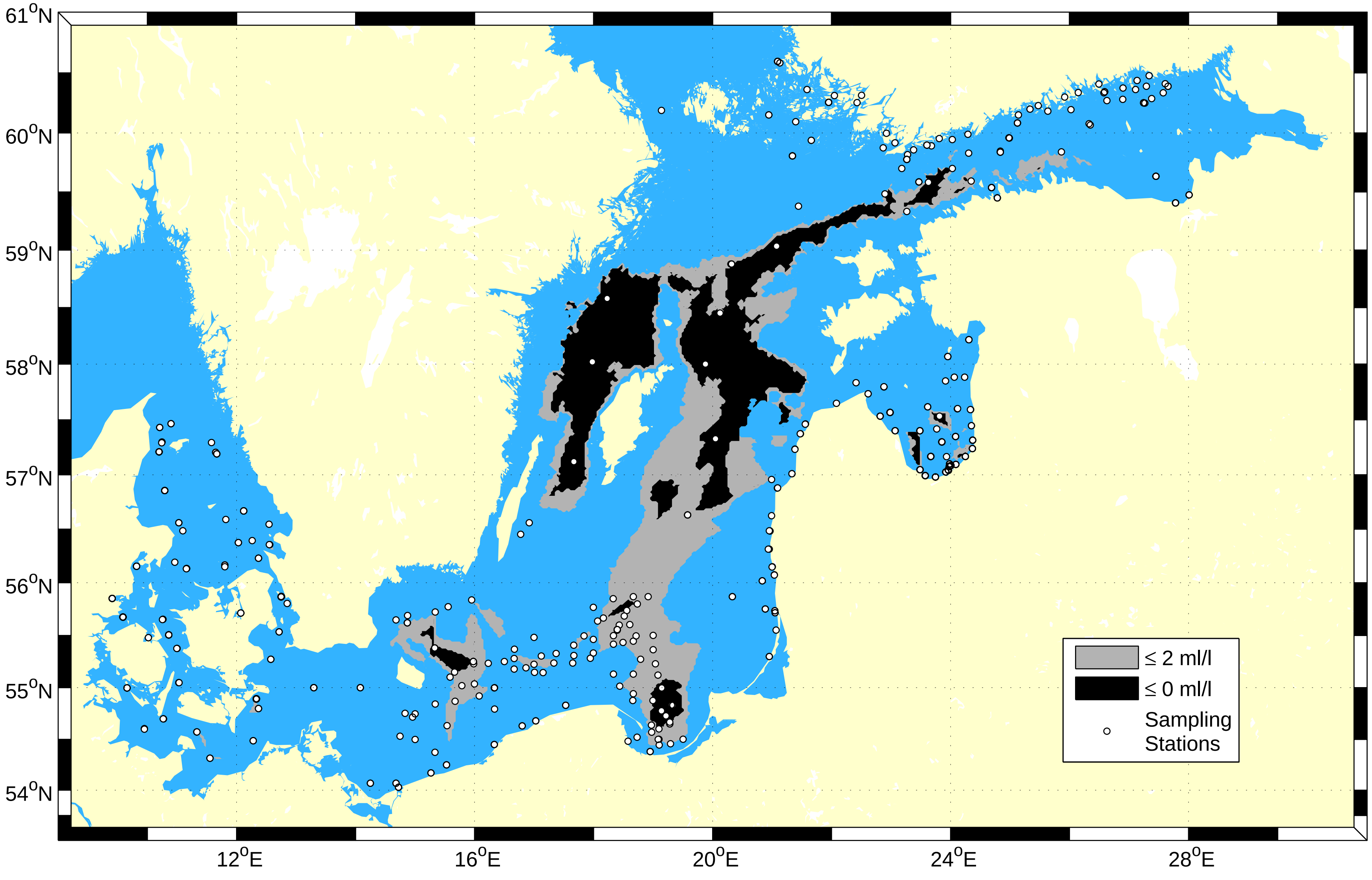
Extent of hypoxic & anoxic bottom water, Autumn 2006

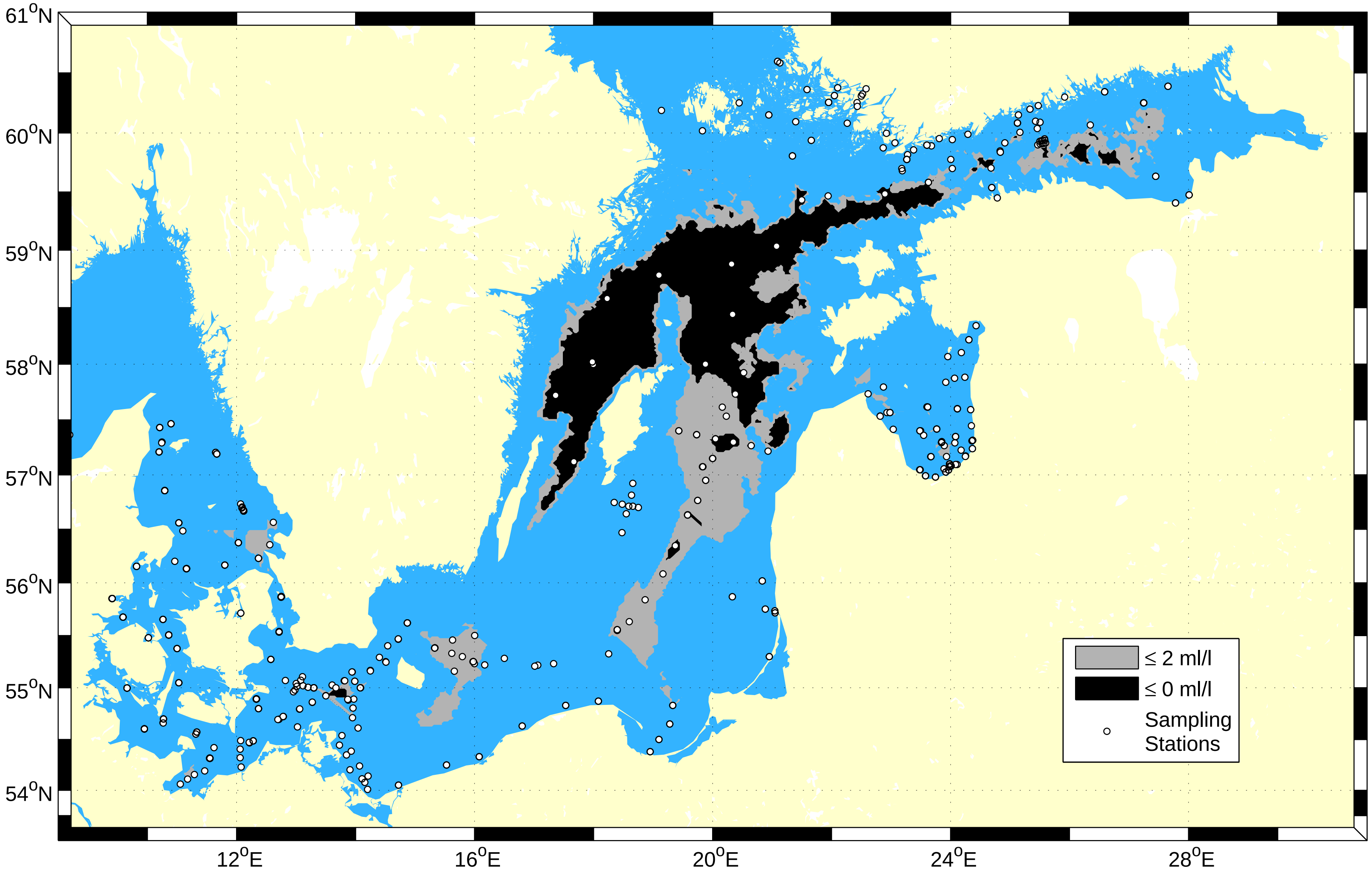




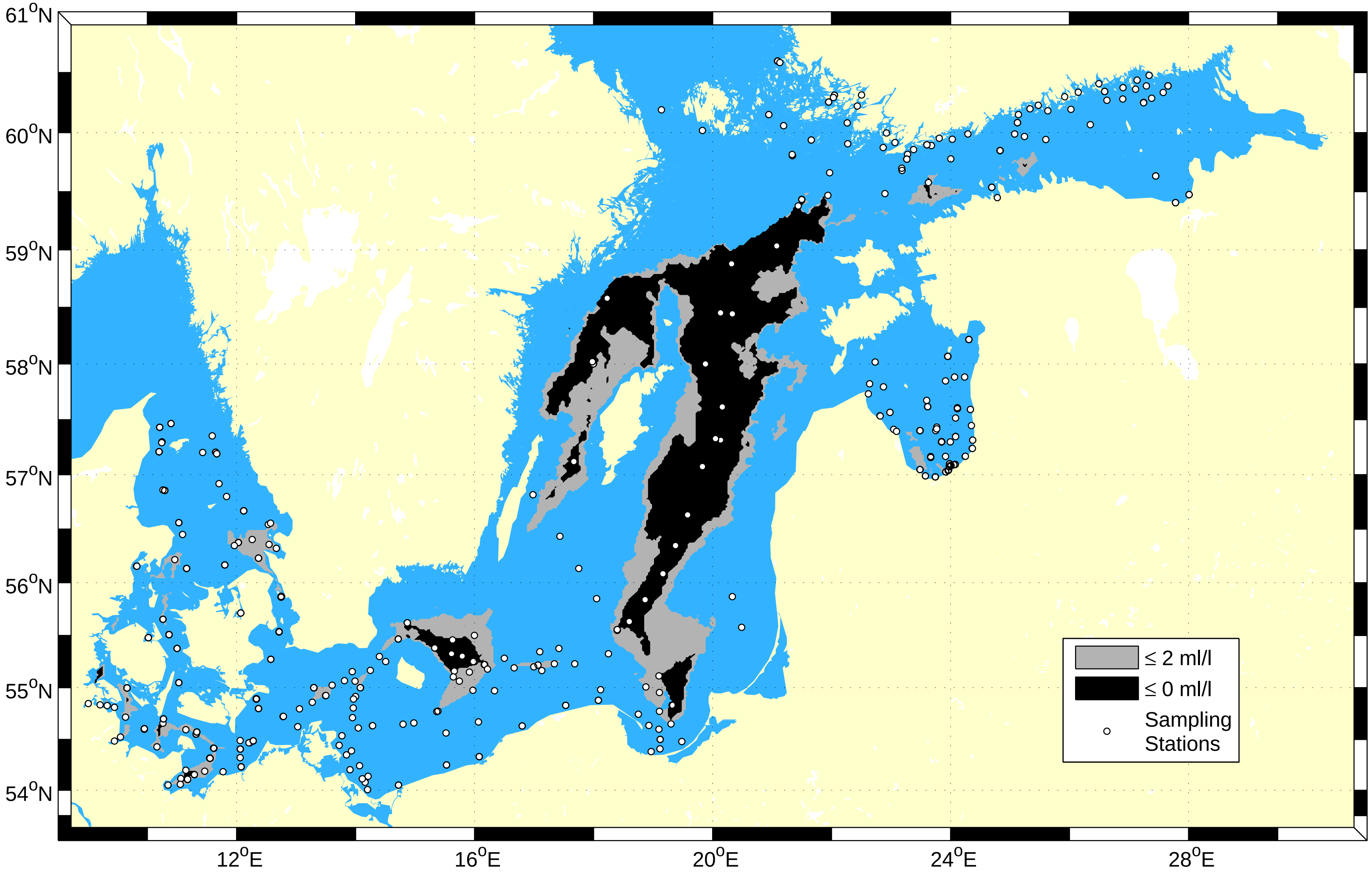
Extent of hypoxic & anoxic bottom water, Autumn 2005

Extent of hypoxic & anoxic bottom water, Autumn 2004



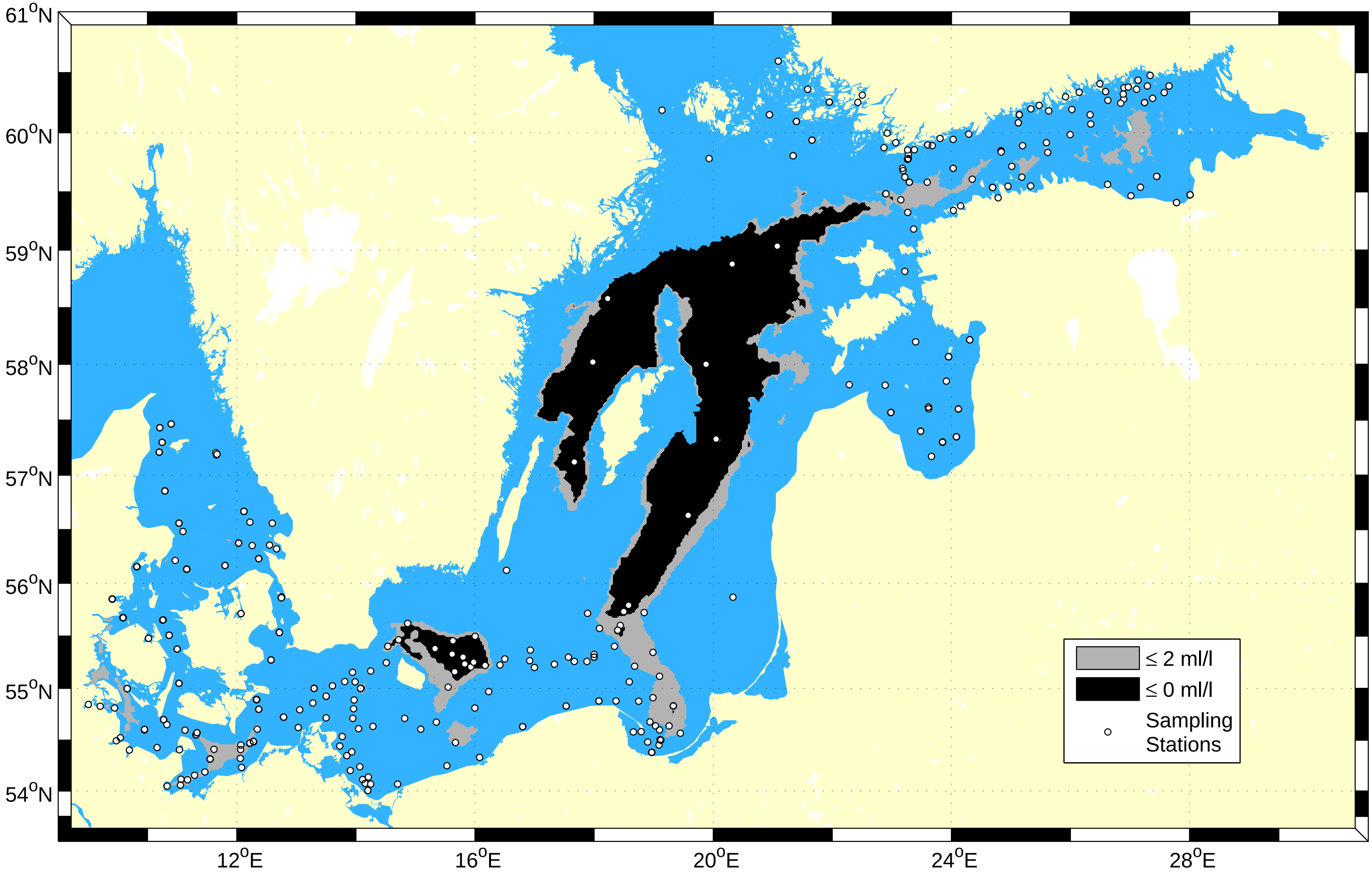


Extent of hypoxic & anoxic bottom water, Autumn 2003

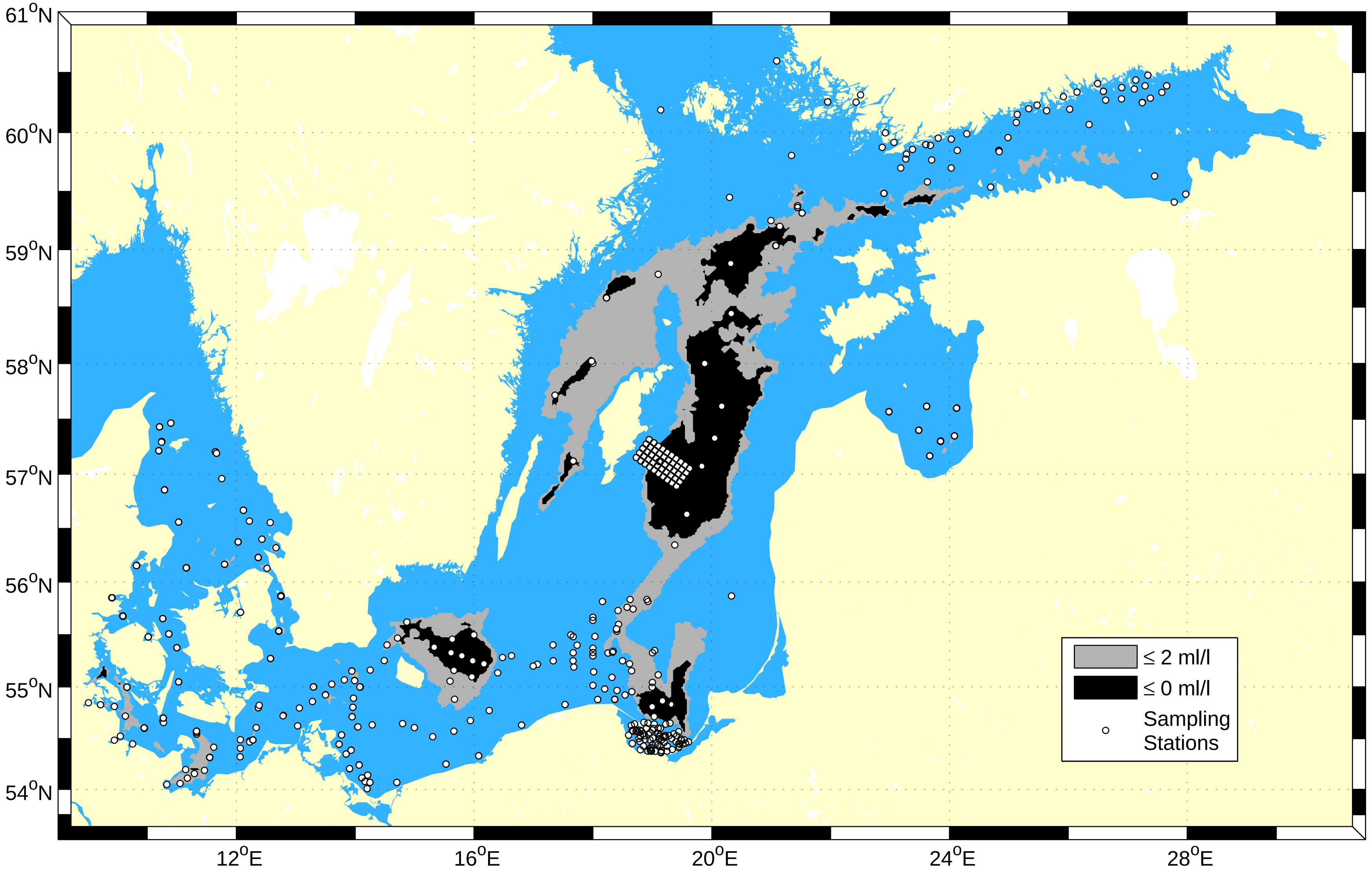


Extent of hypoxic & anoxic bottom water, Autumn 2002

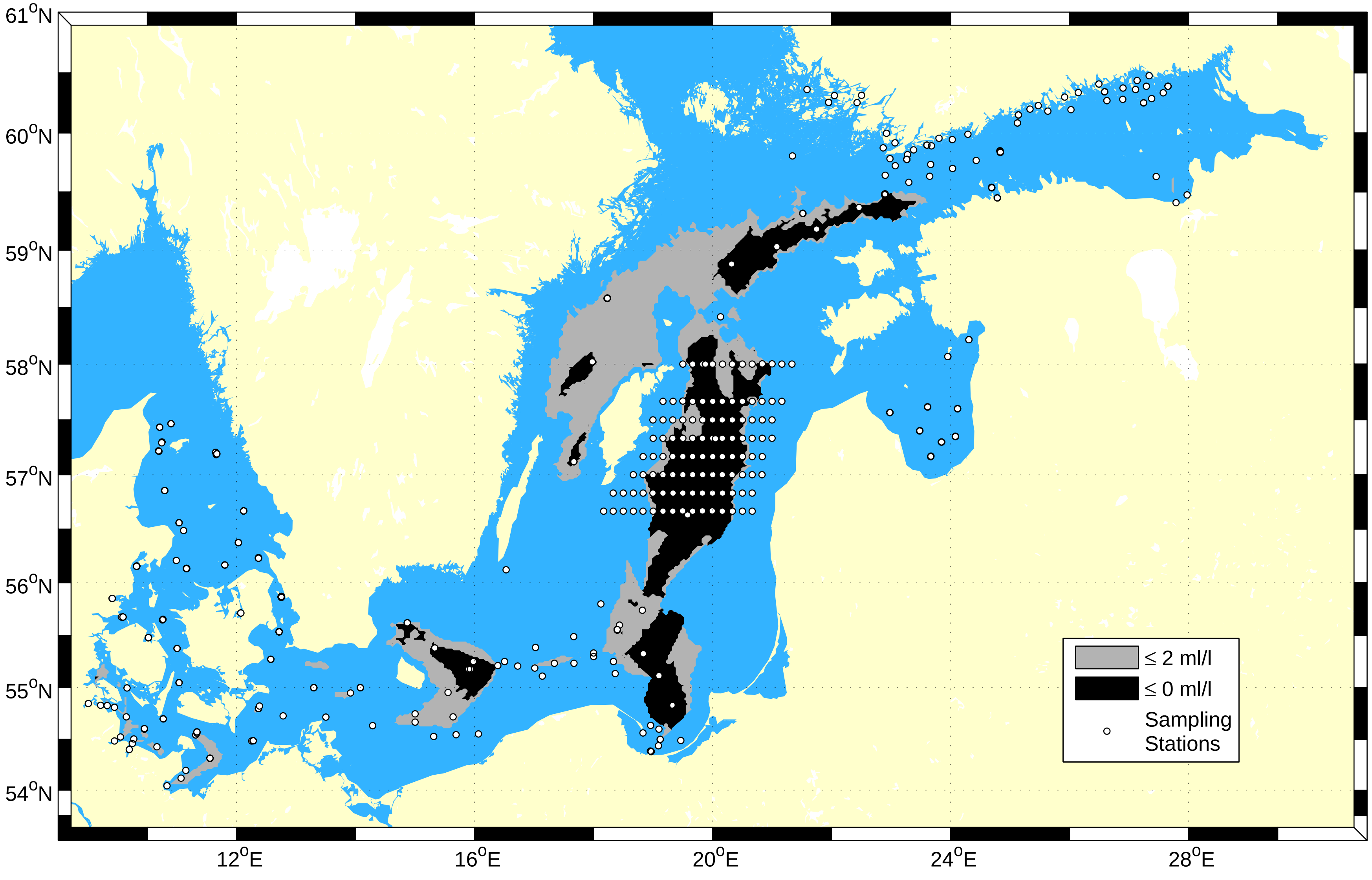
Extent of hypoxic & anoxic bottom water, Autumn 2001

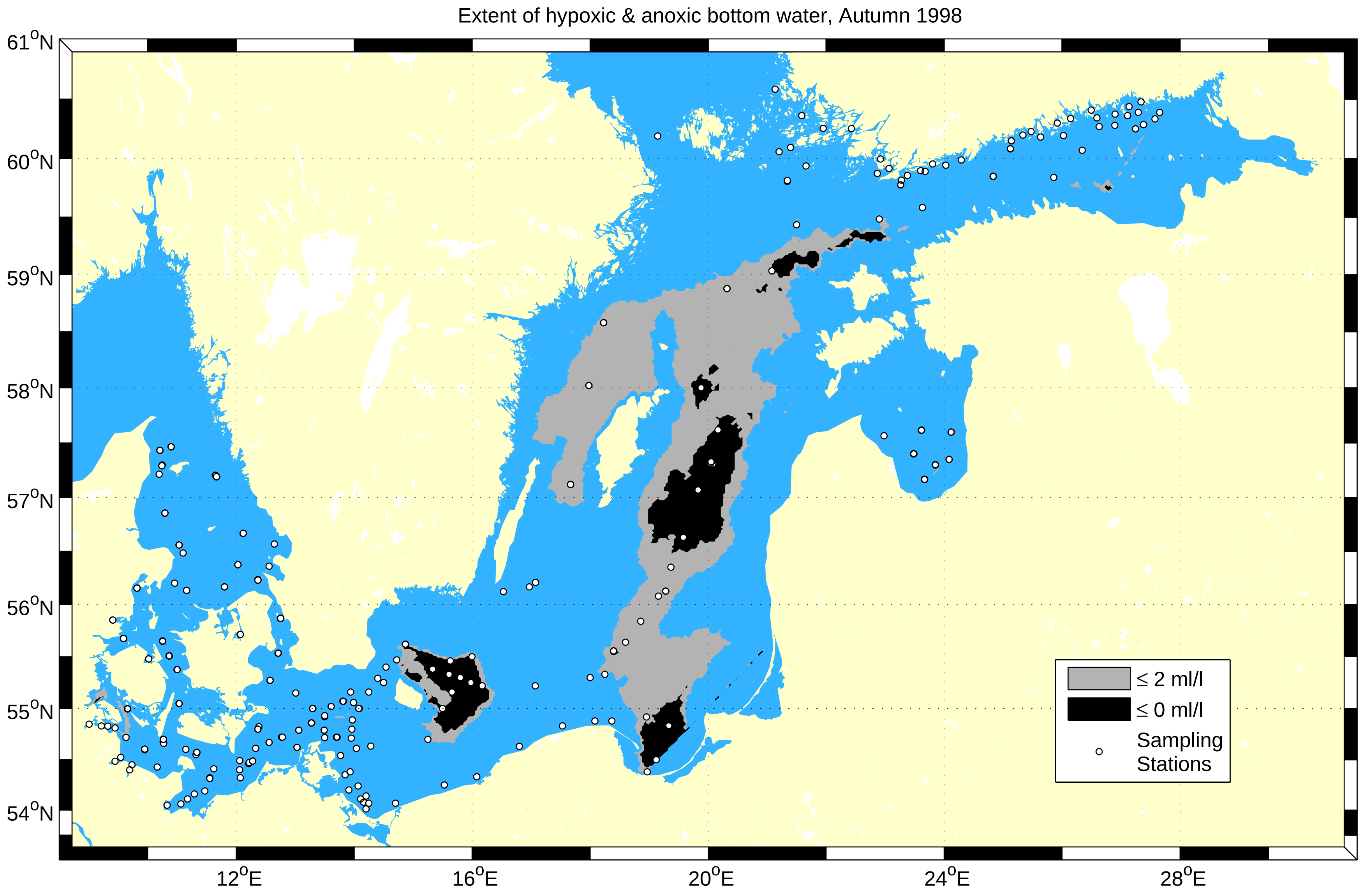


Extent of hypoxic & anoxic bottom water, Autumn 2000

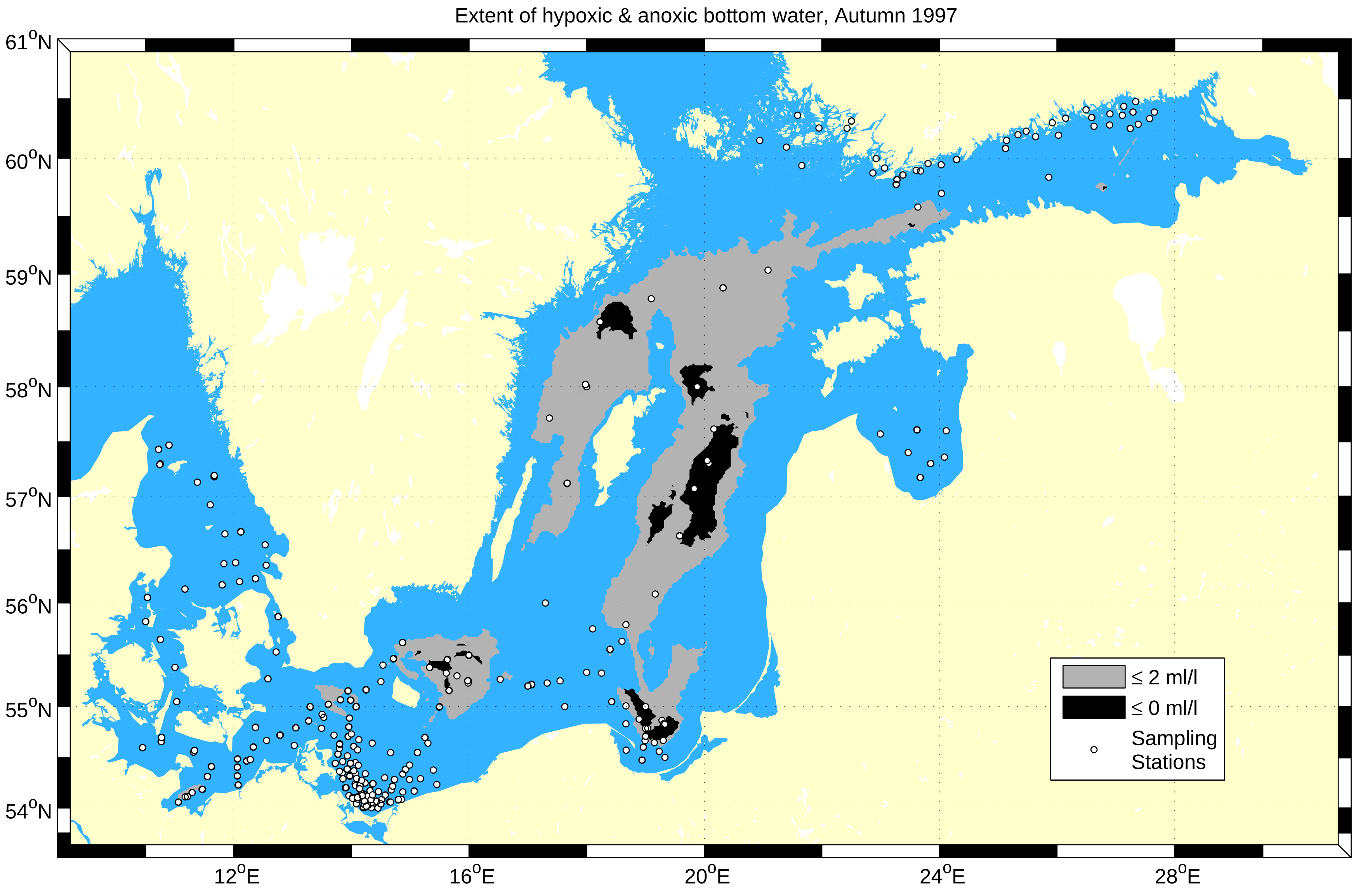


Extent of hypoxic & anoxic bottom water, Autumn 1999

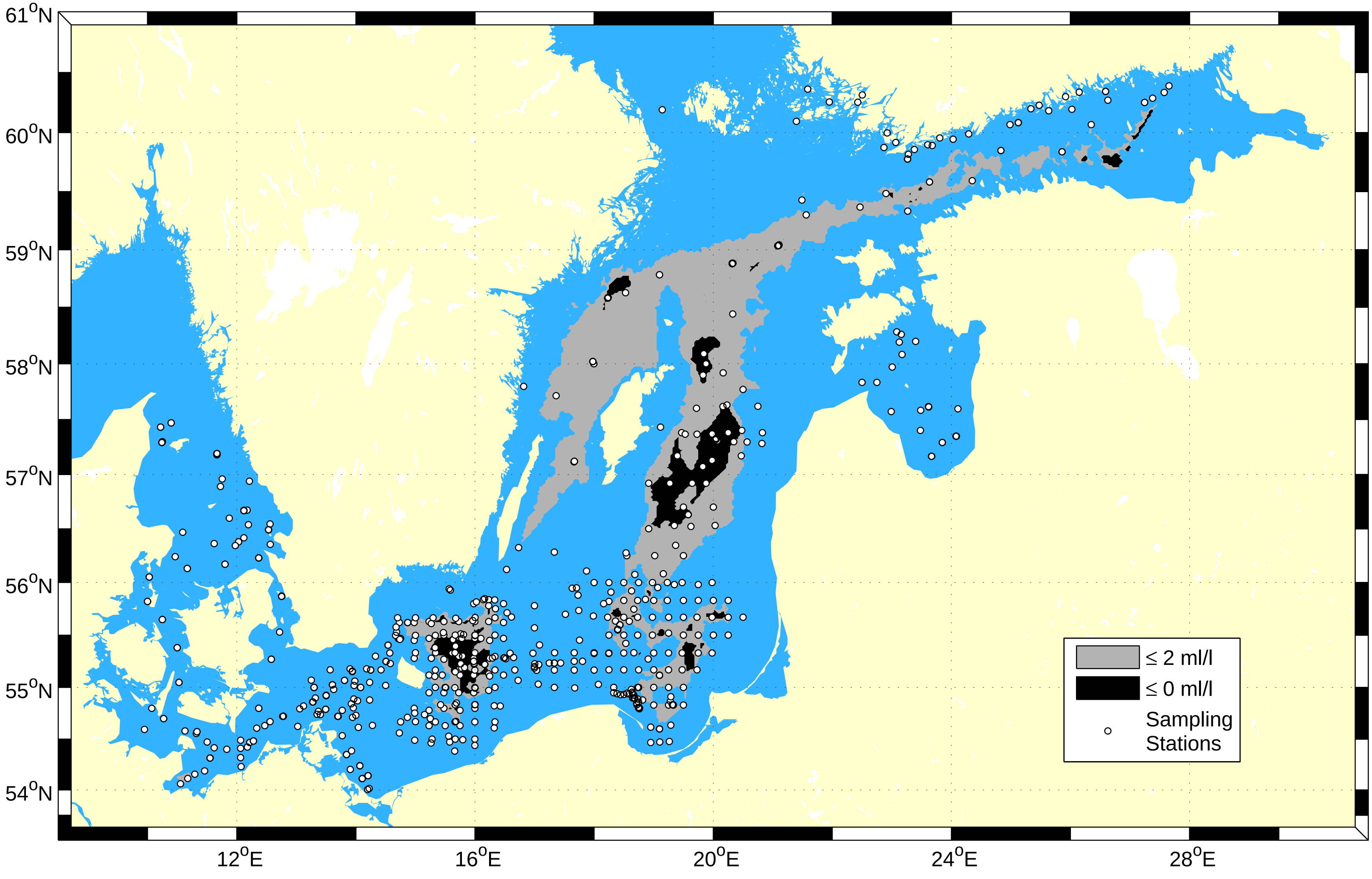




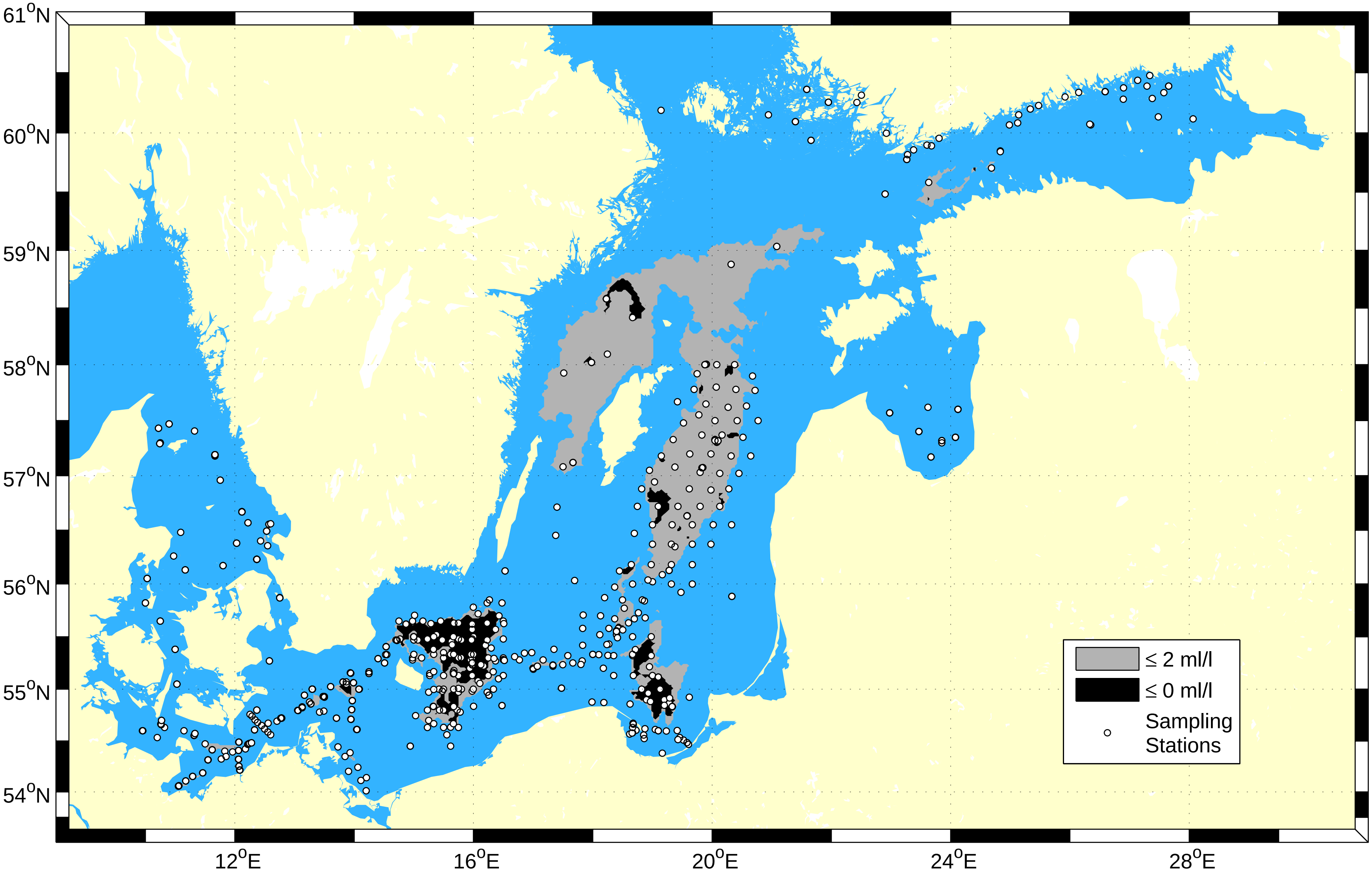
Extent of hypoxic & anoxic bottom water, Autumn 1998



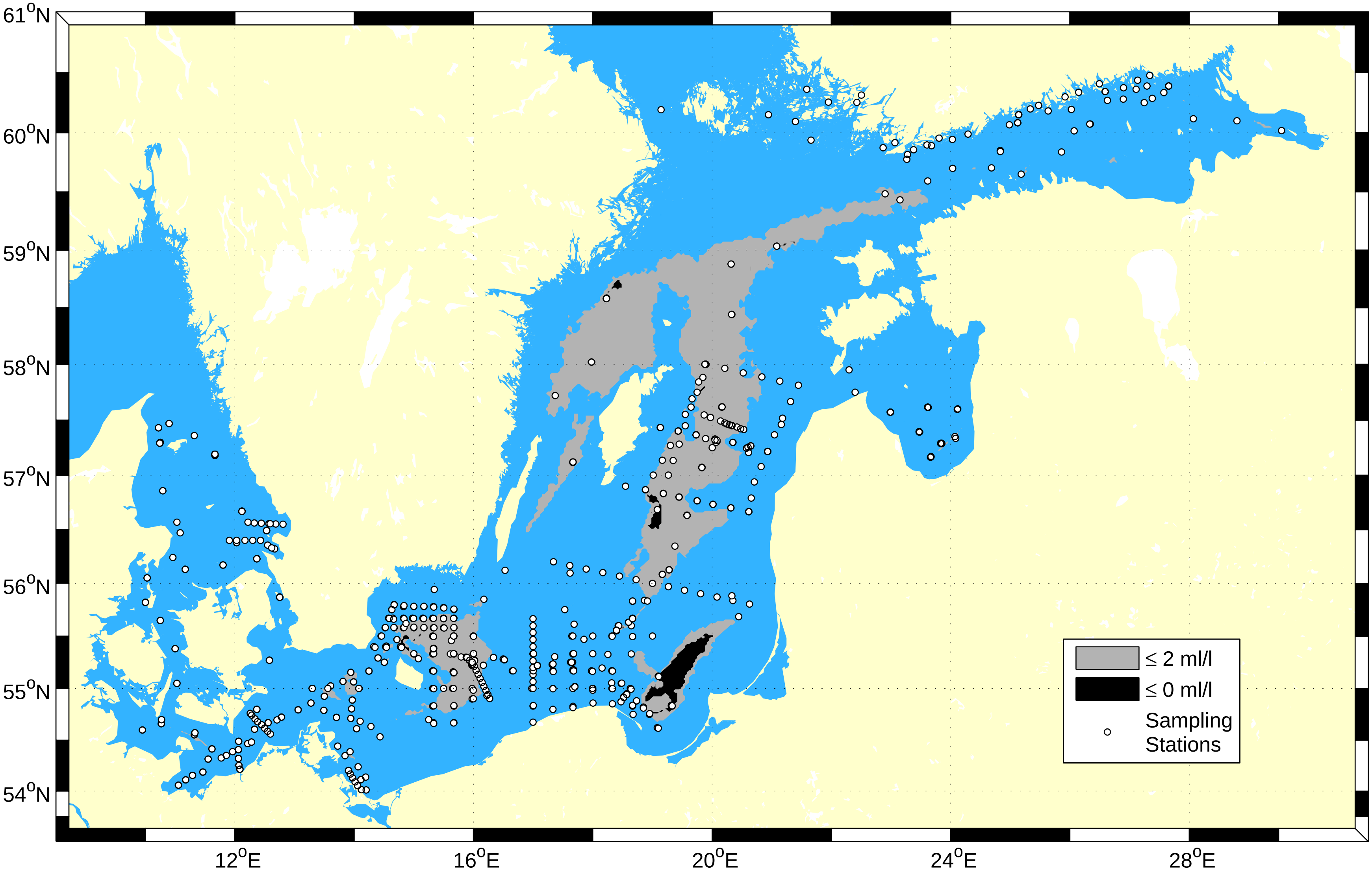
Extent of hypoxic & anoxic bottom water, Autumn 1997



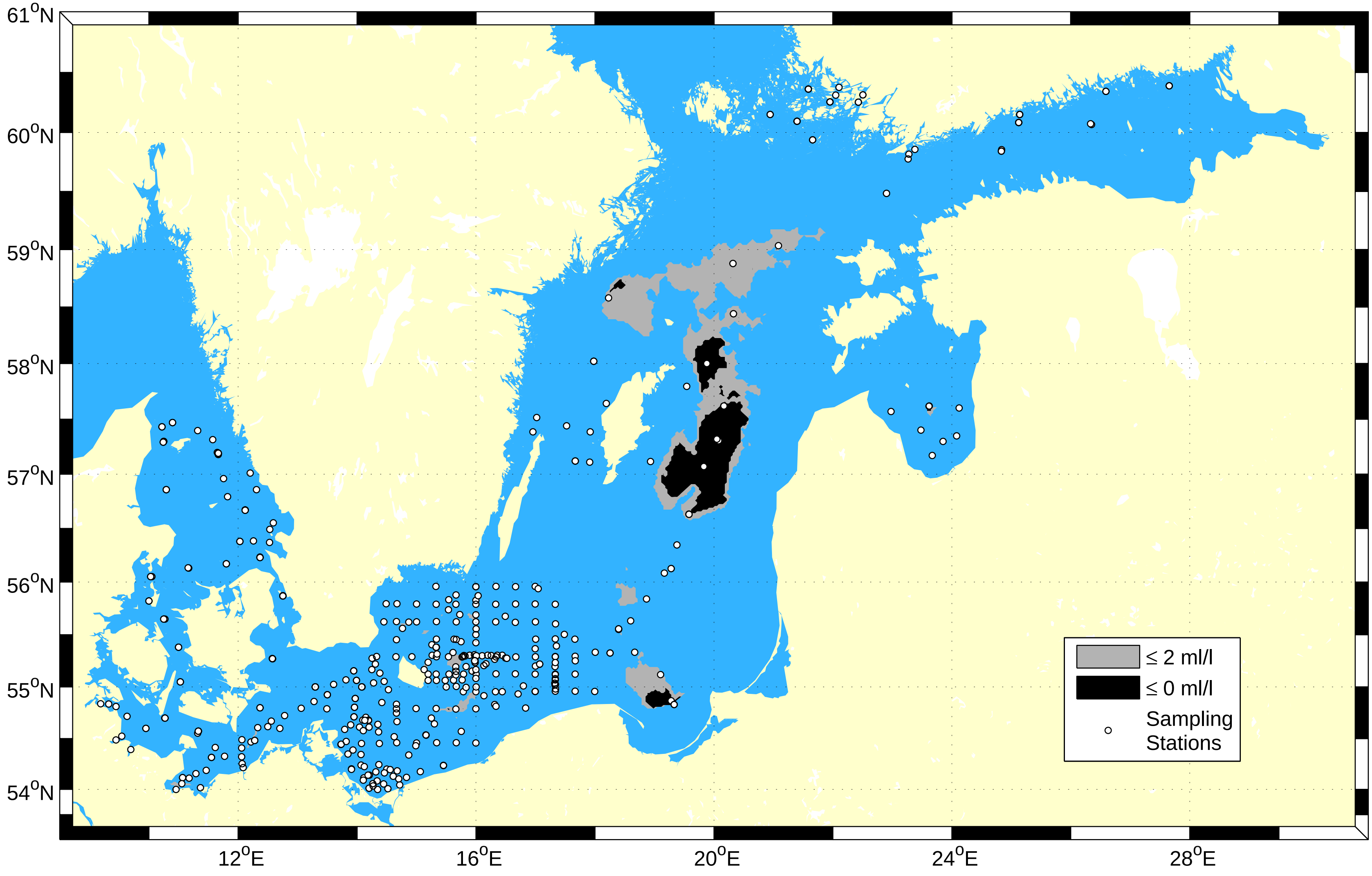
Extent of hypoxic & anoxic bottom water, Autumn 1996

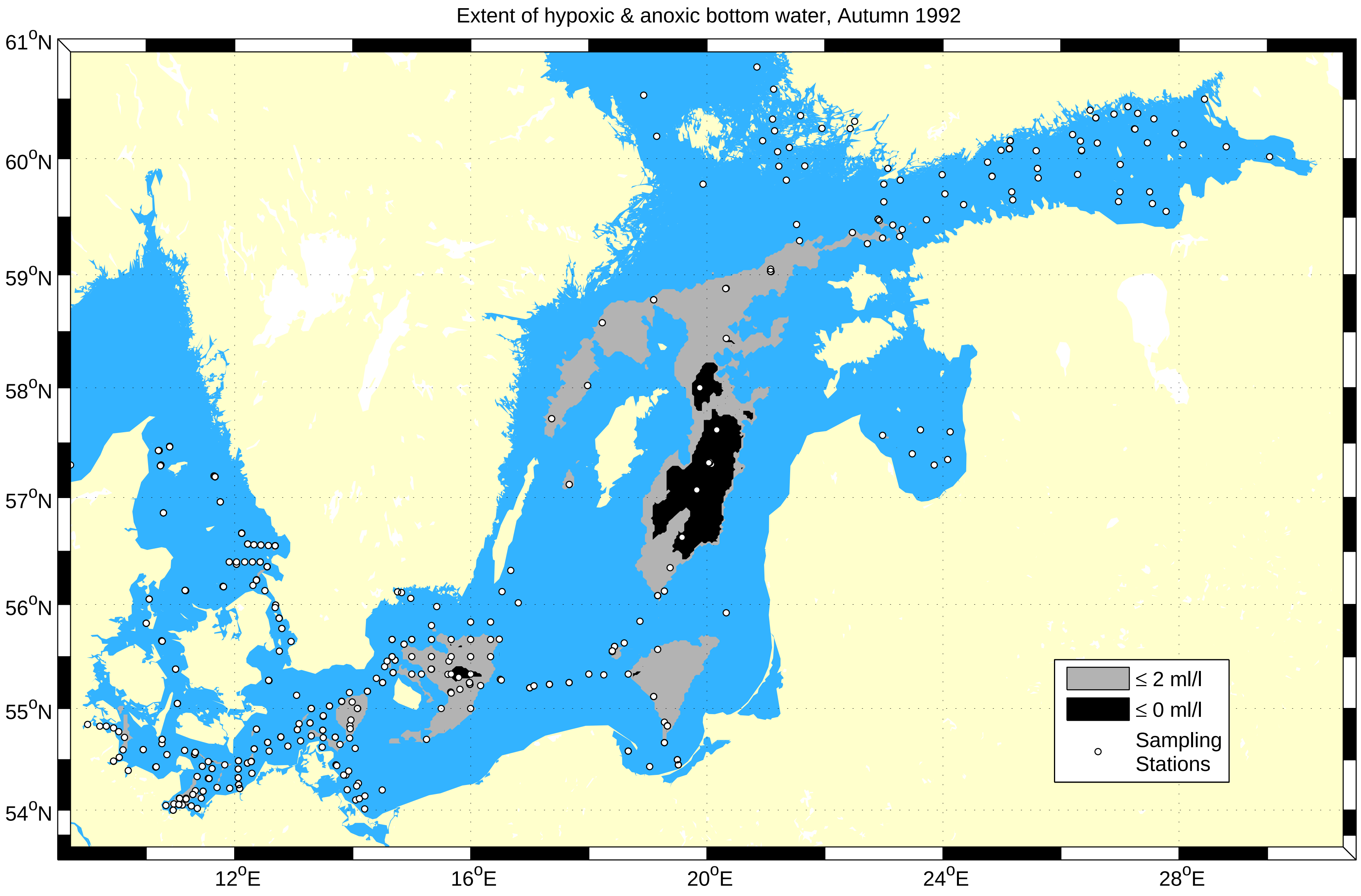


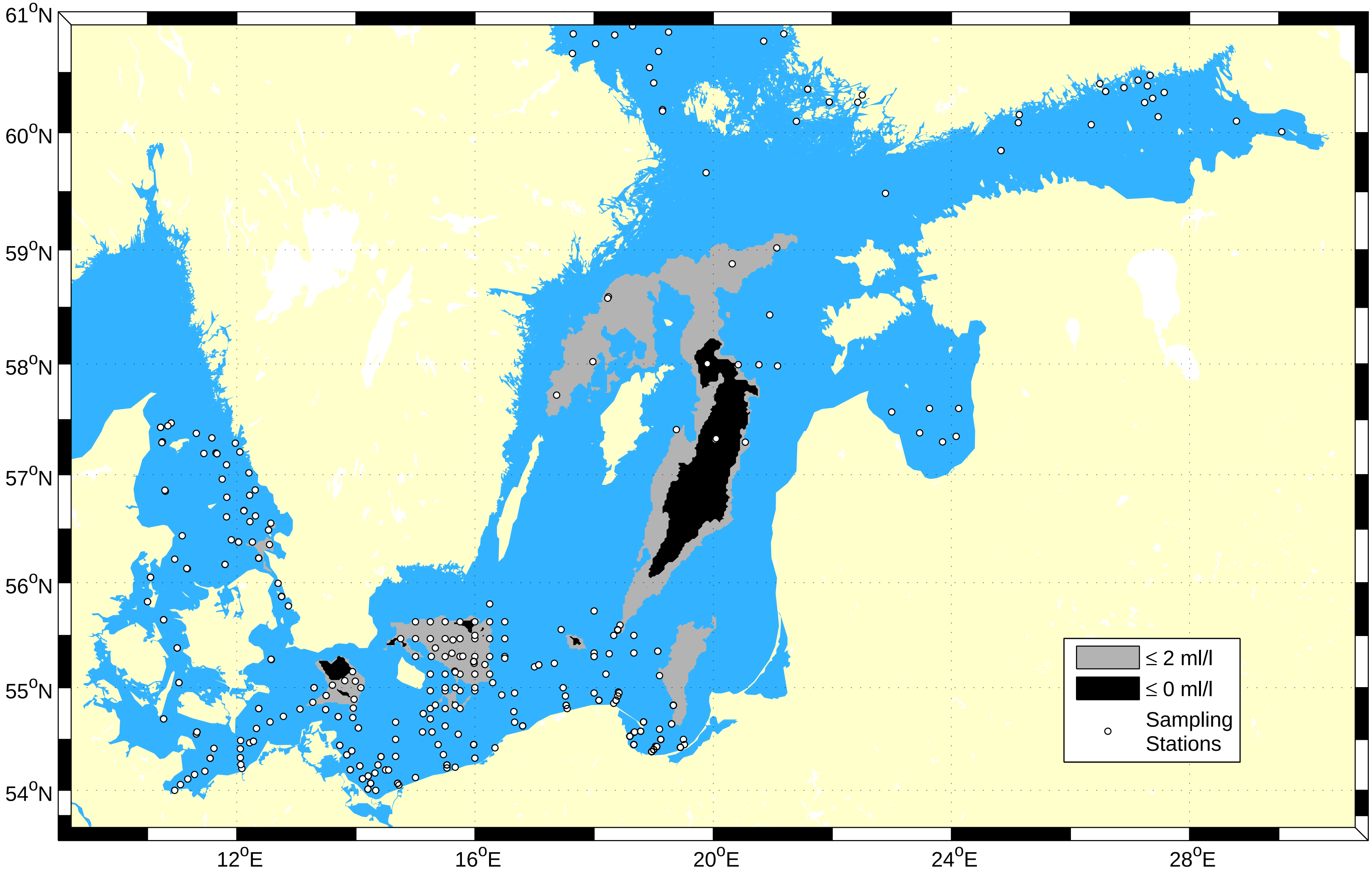
Extent of hypoxic & anoxic bottom water, Autumn 1995


Extent of hypoxic & anoxic bottom water, Autumn 1994

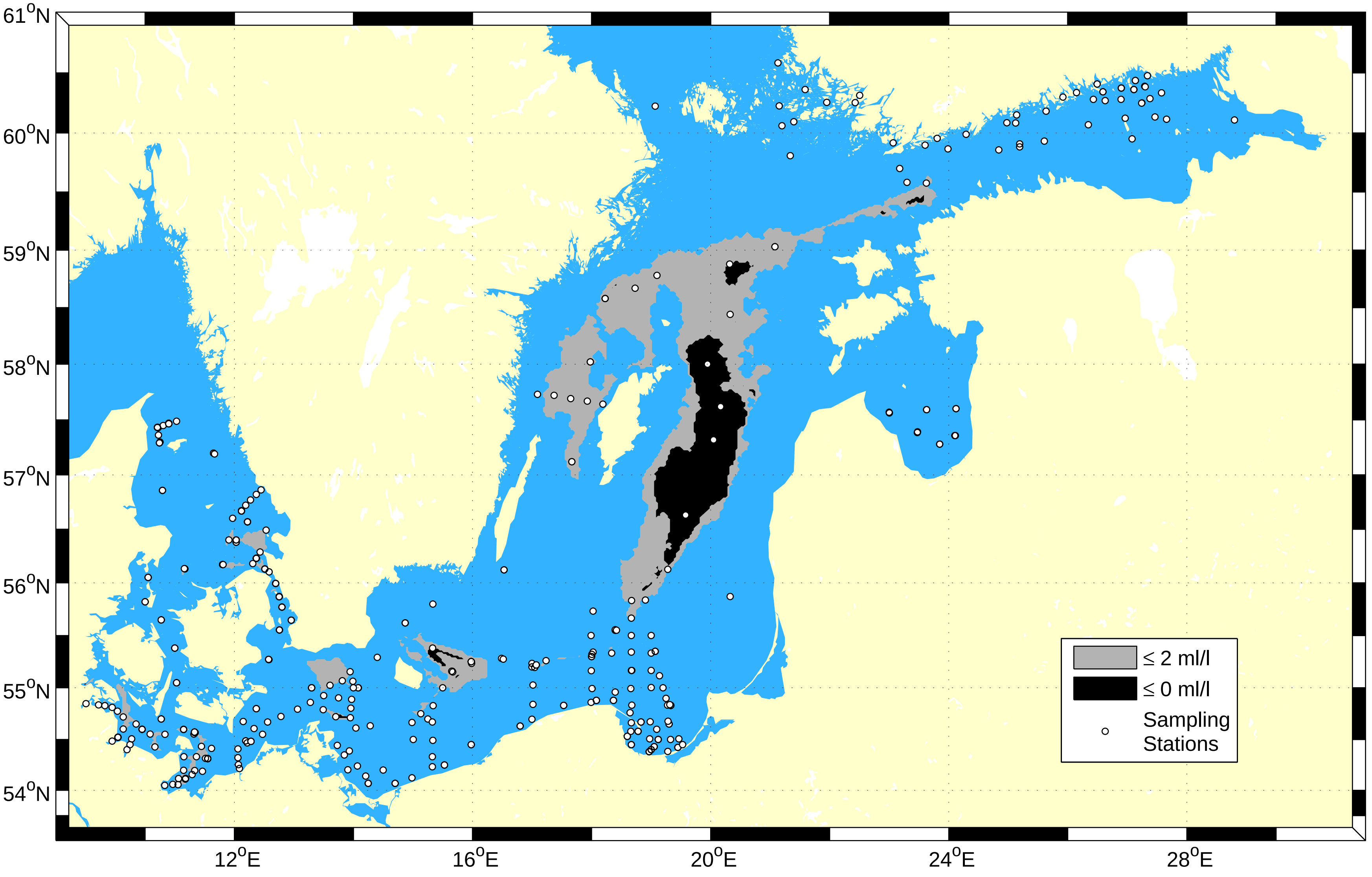
Extent of hypoxic & anoxic bottom water, Autumn 1993



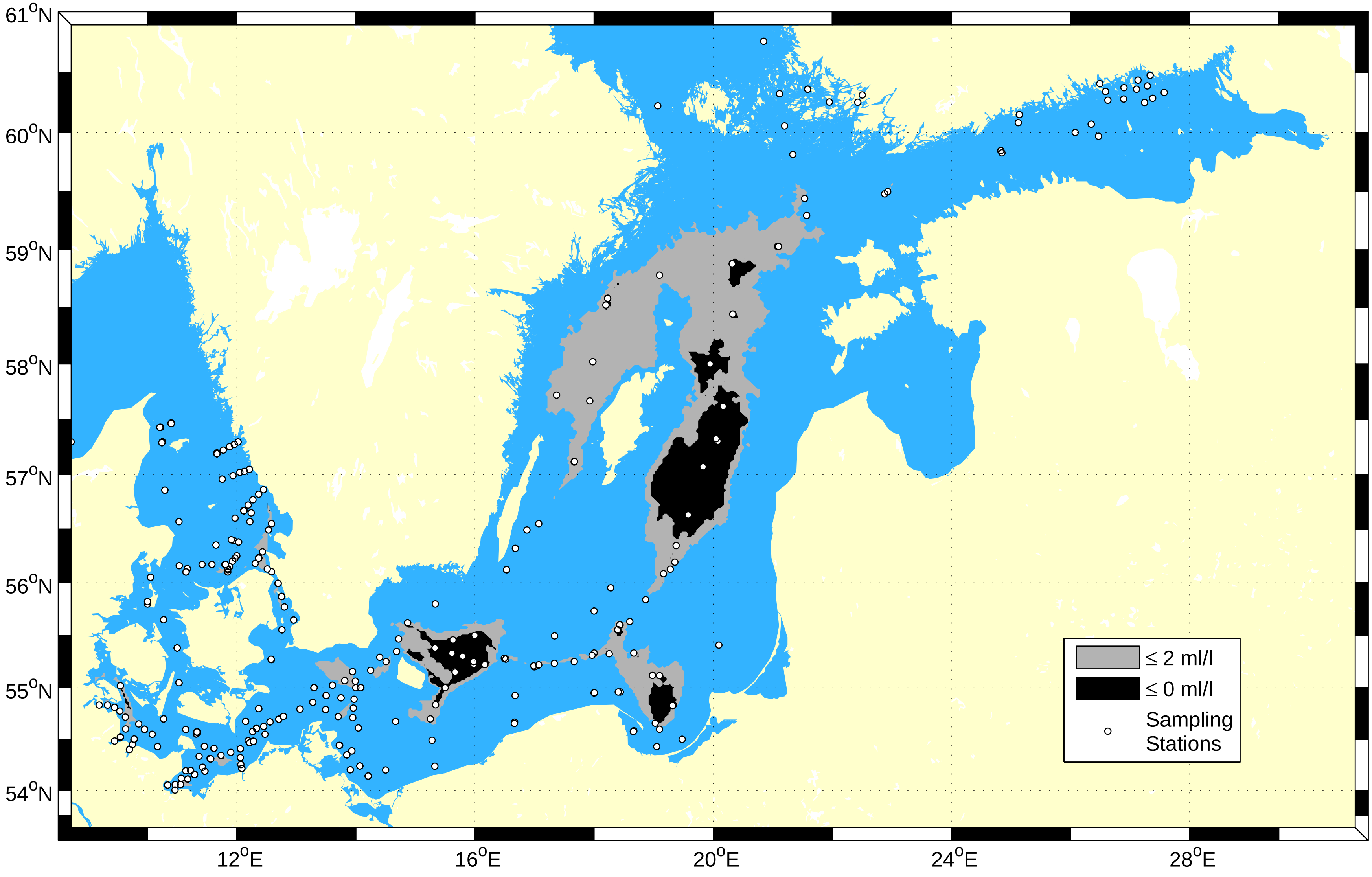

Extent of hypoxic & anoxic bottom water, Autumn 1992
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

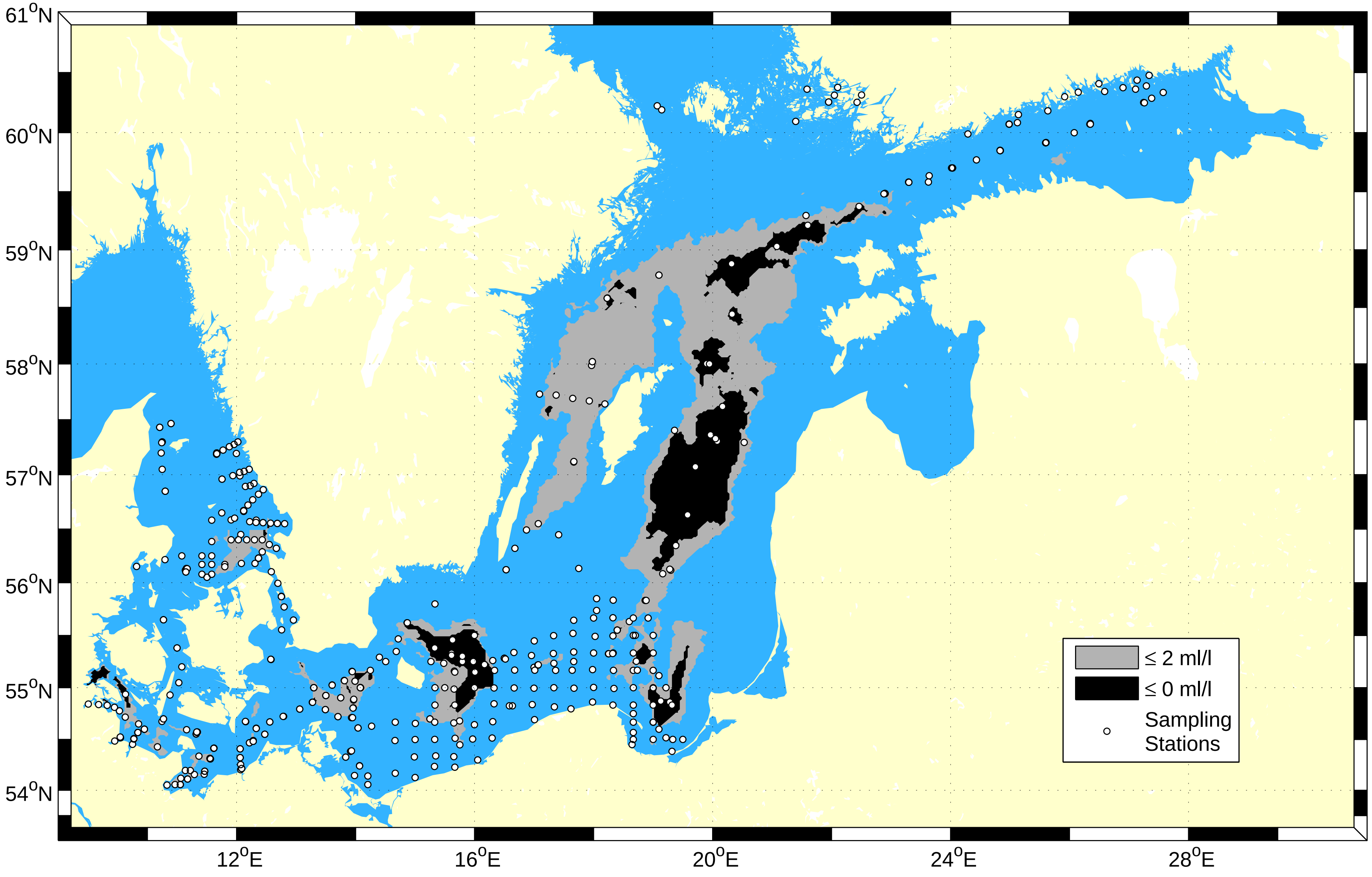


Extent of hypoxic & anoxic bottom water, Autumn 1991



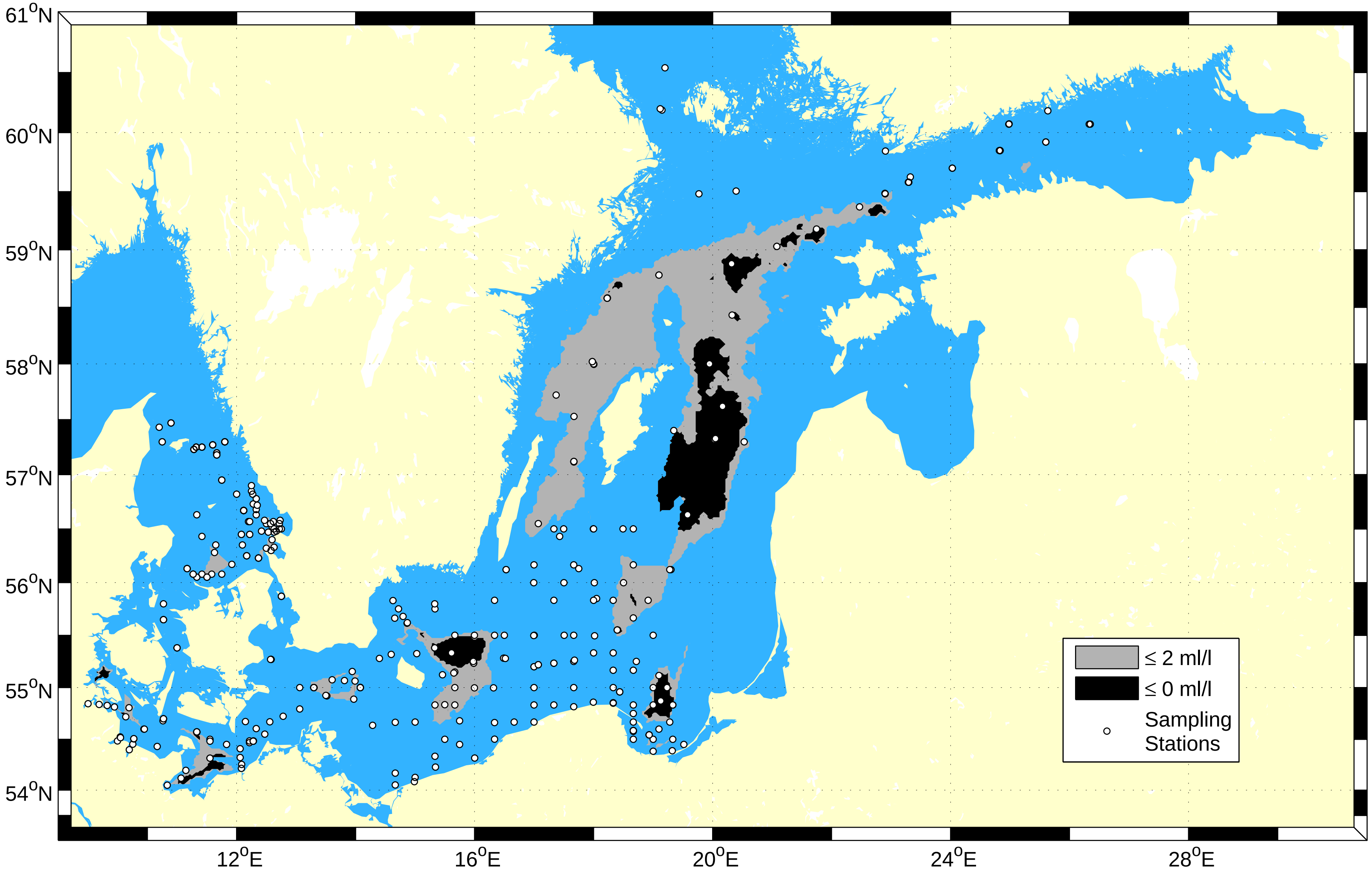
Extent of hypoxic & anoxic bottom water, Autumn 1990


Extent of hypoxic & anoxic bottom water, Autumn 1989

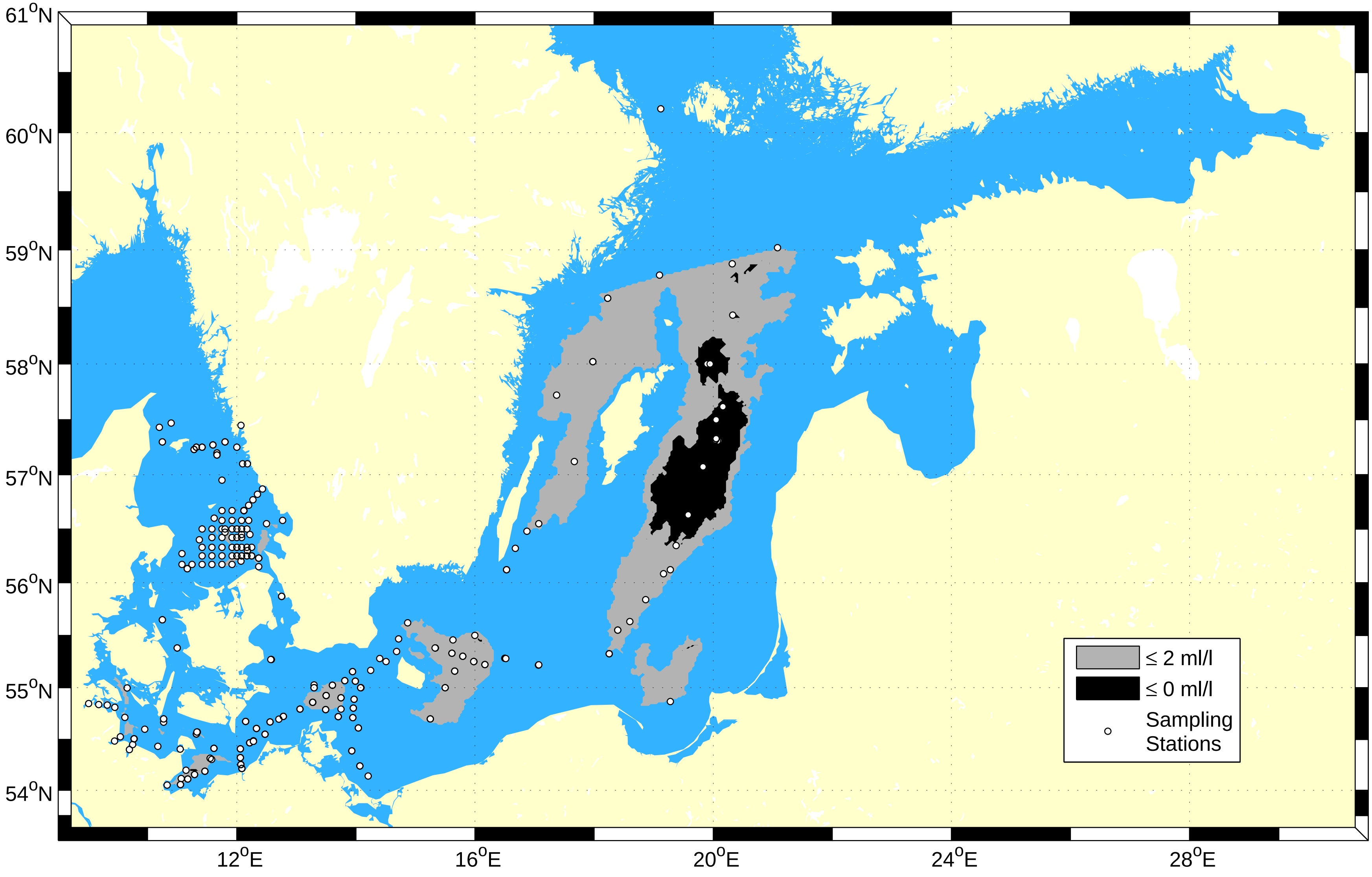


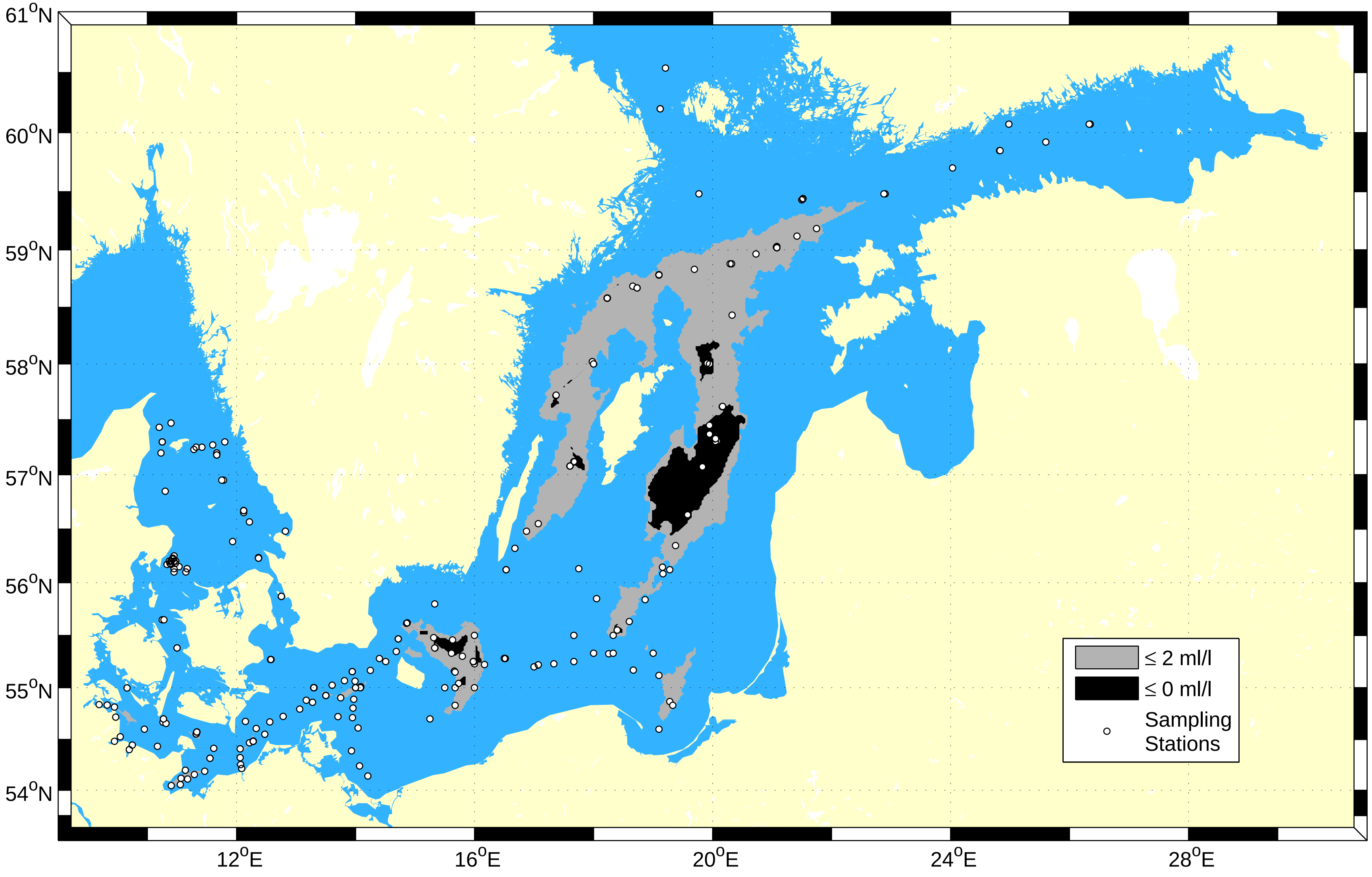
Extent of hypoxic & anoxic bottom water, Autumn 1988

Extent of hypoxic & anoxic bottom water, Autumn 1987

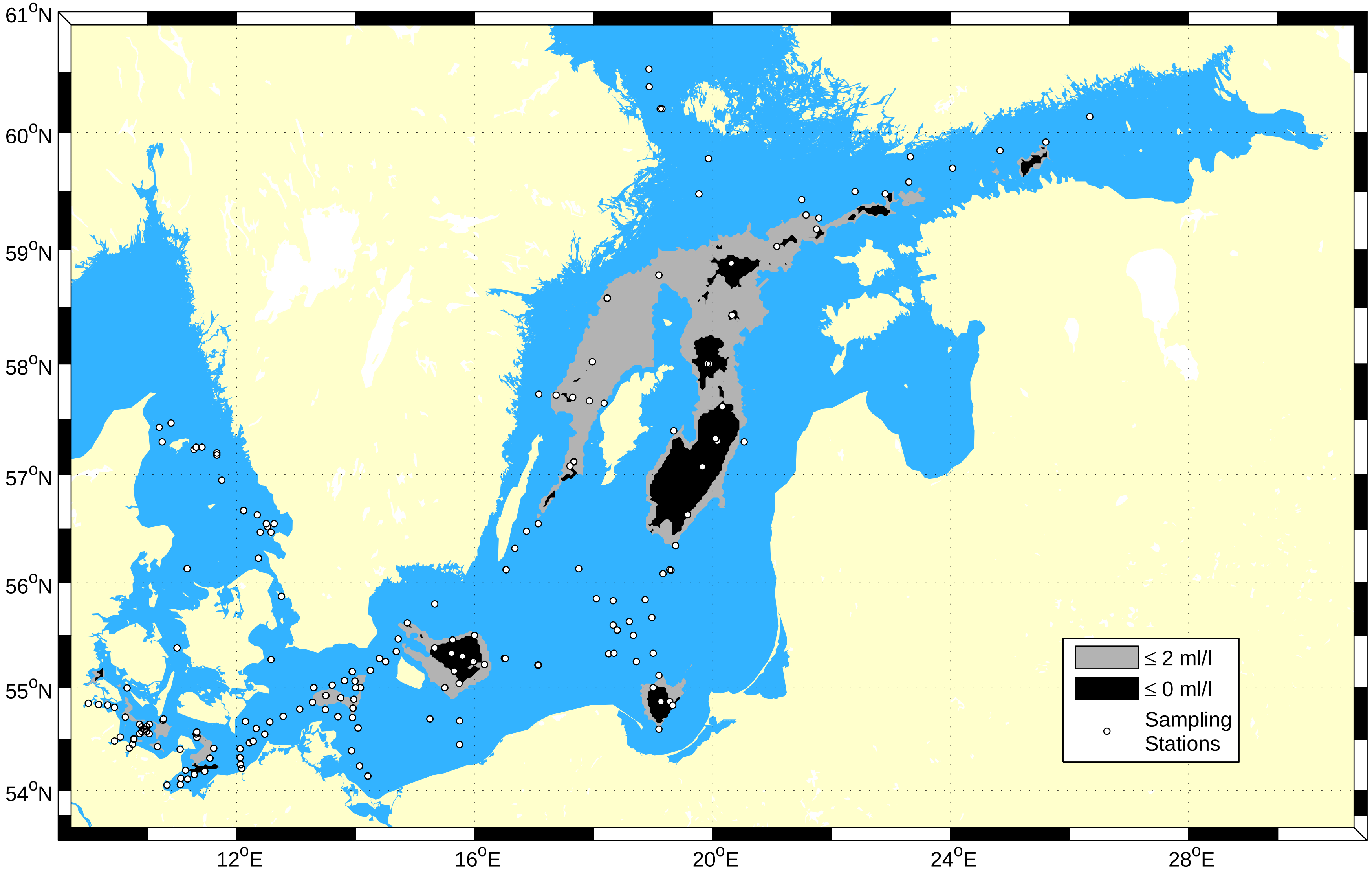


Extent of hypoxic & anoxic bottom water, Autumn 1986

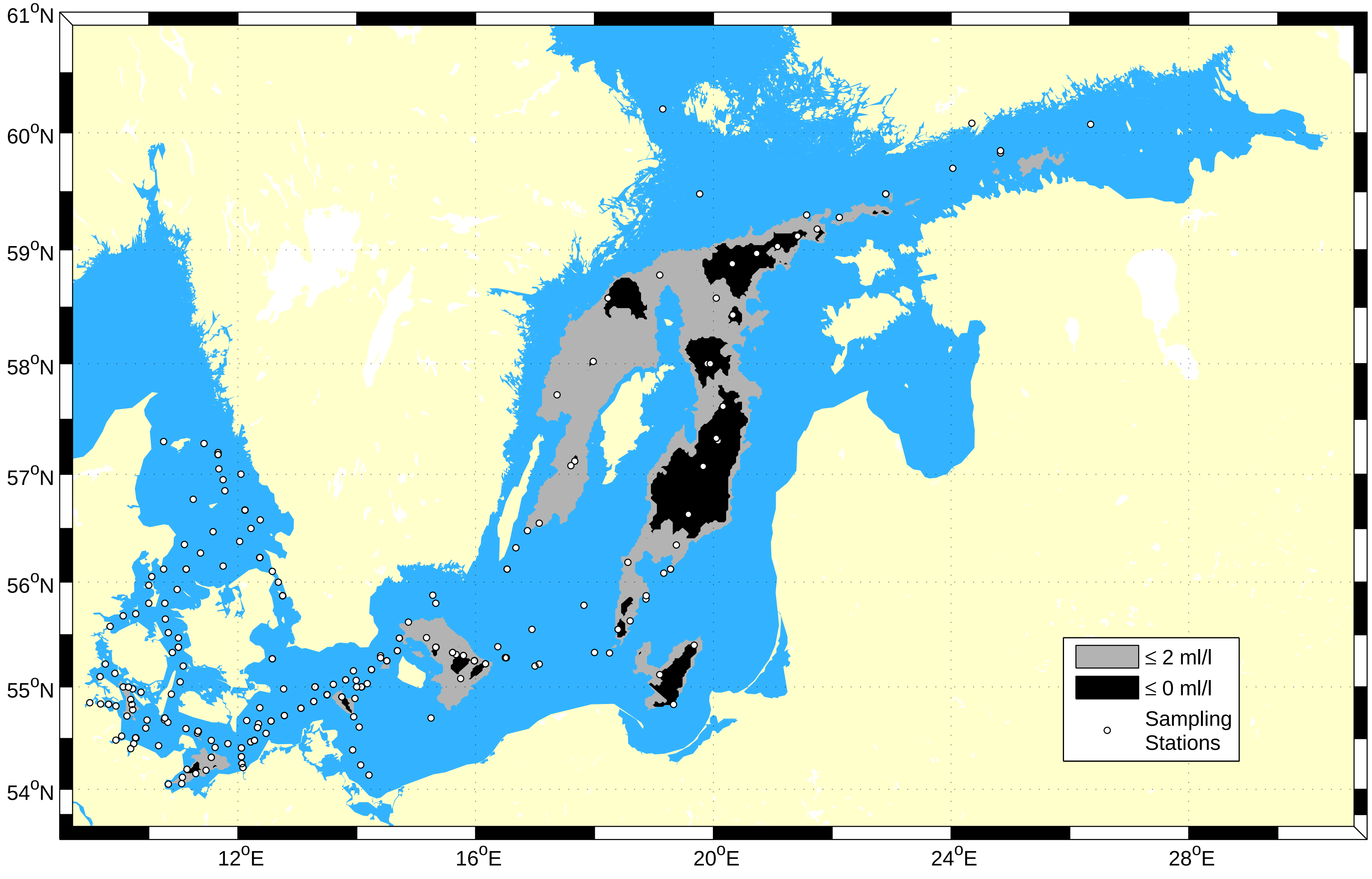




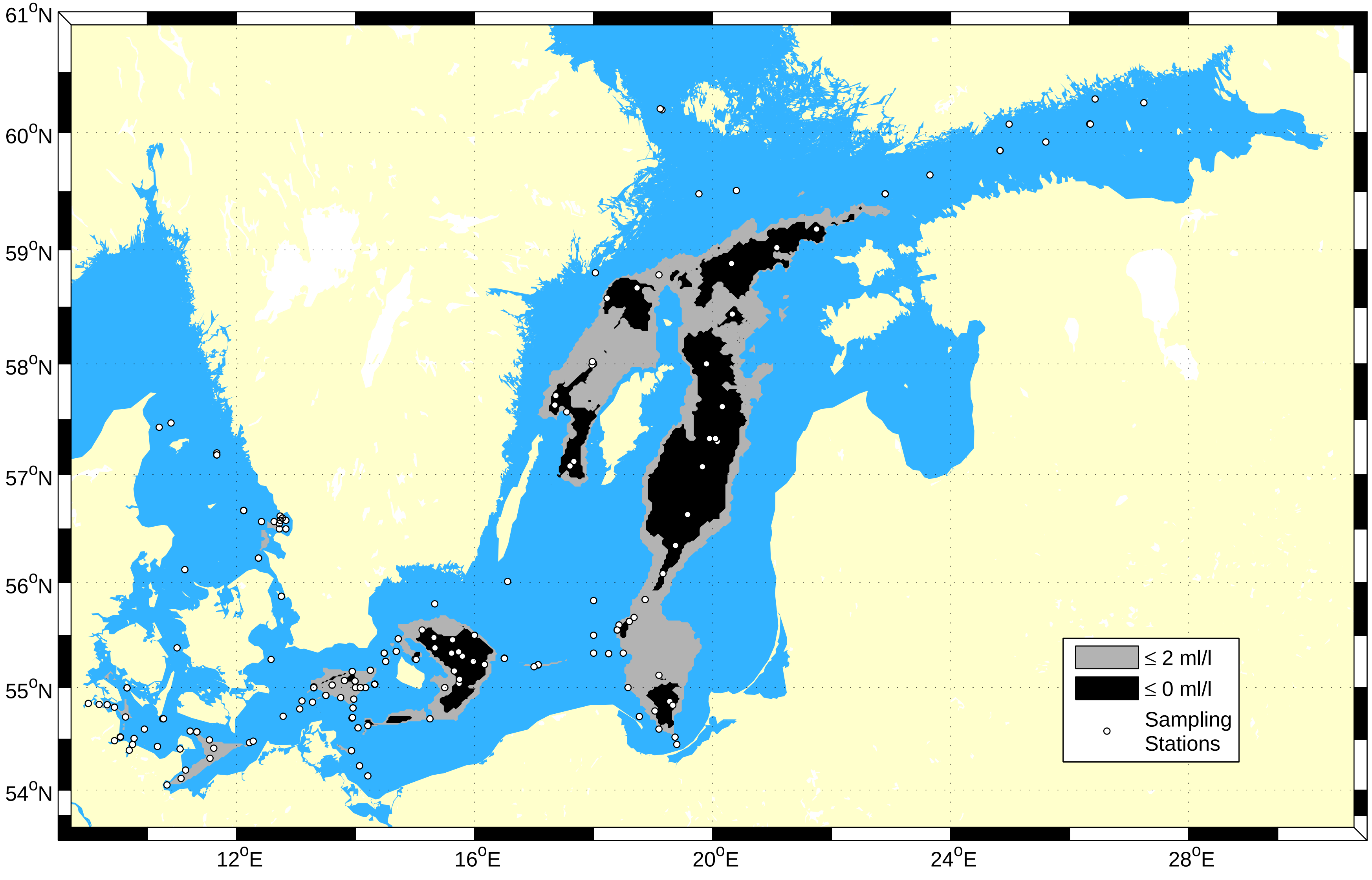
Extent of hypoxic & anoxic bottom water, Autumn 1985



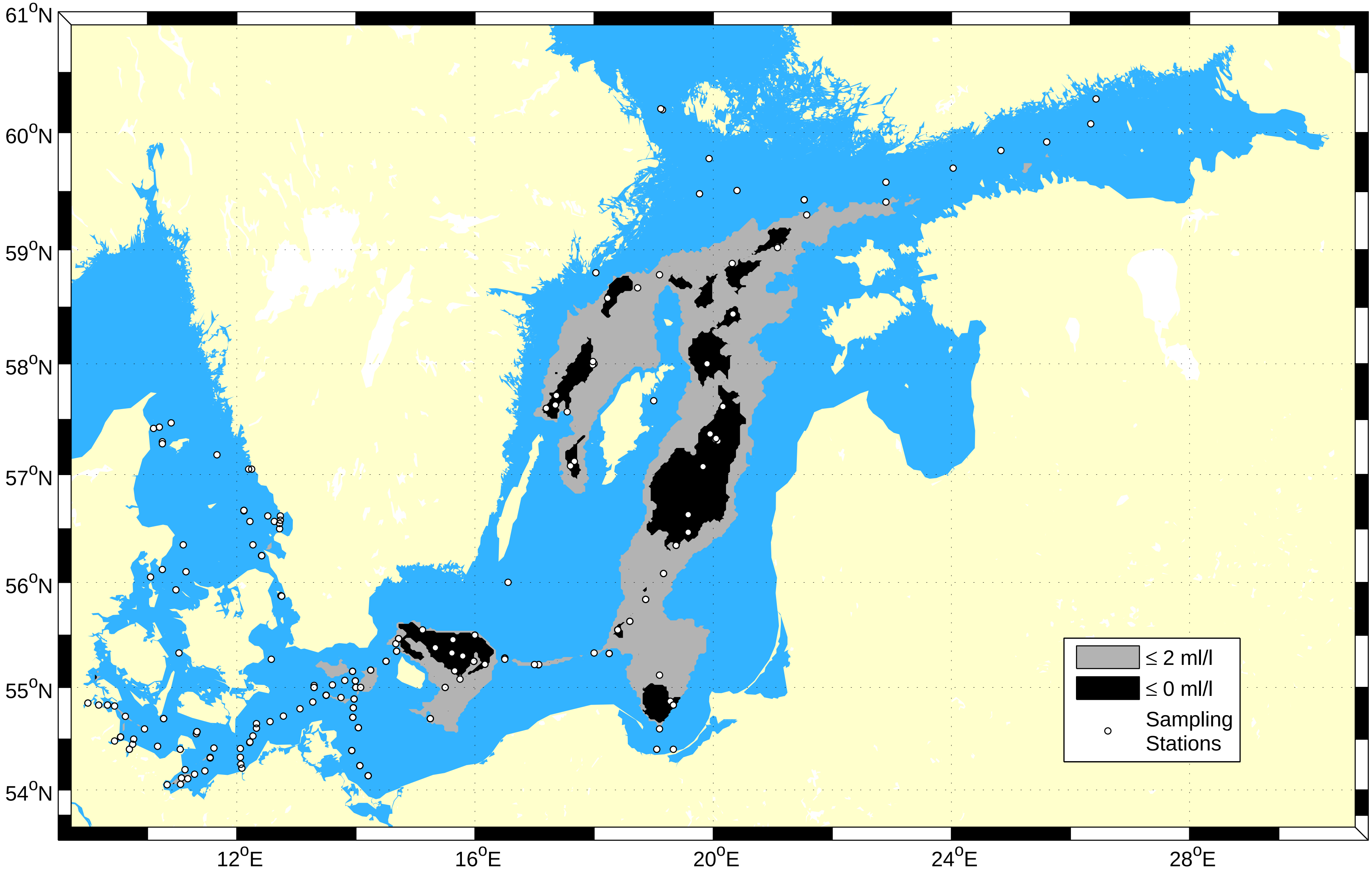
Extent of hypoxic & anoxic bottom water, Autumn 1984



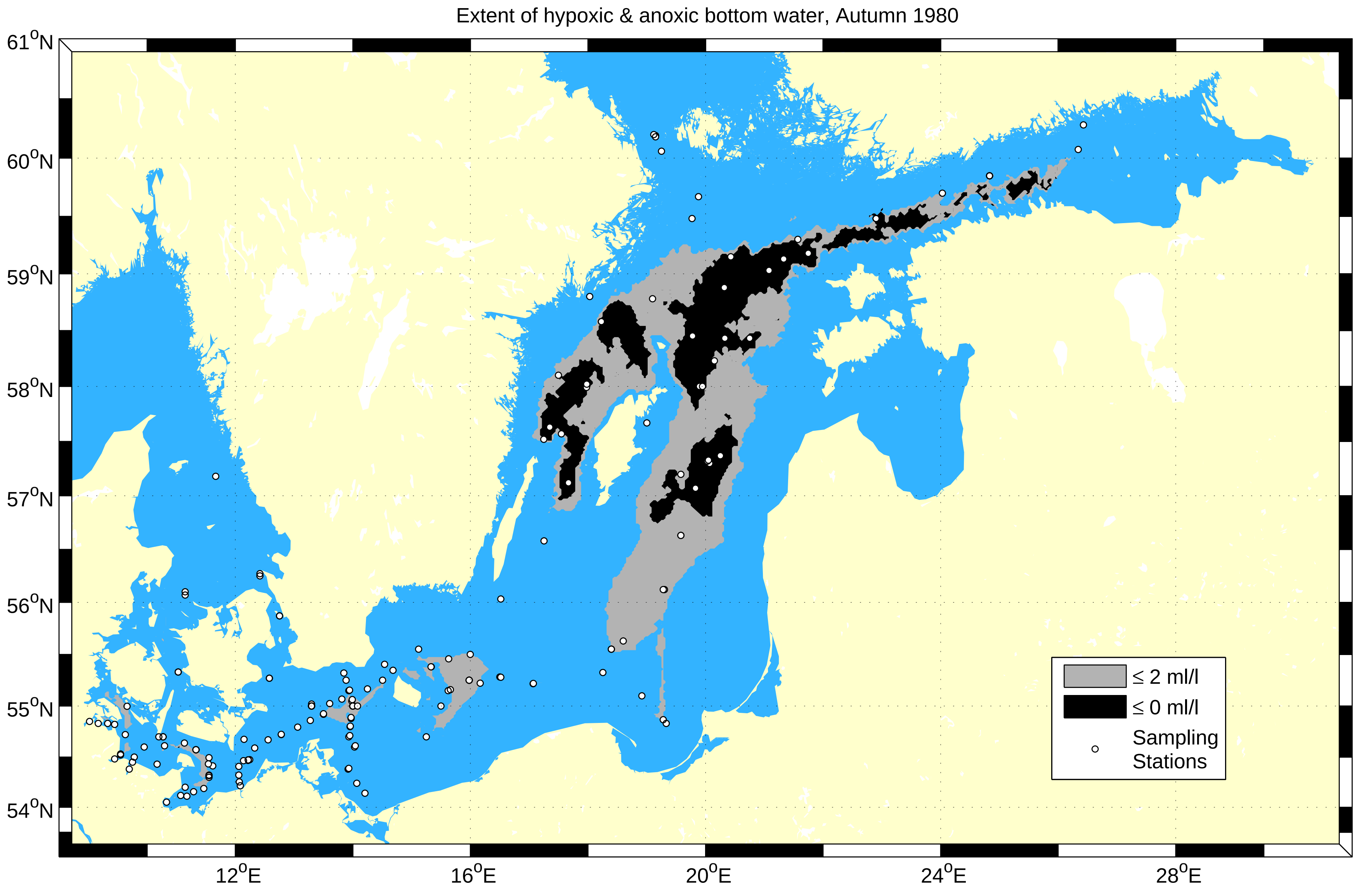
Extent of hypoxic & anoxic bottom water, Autumn 1983



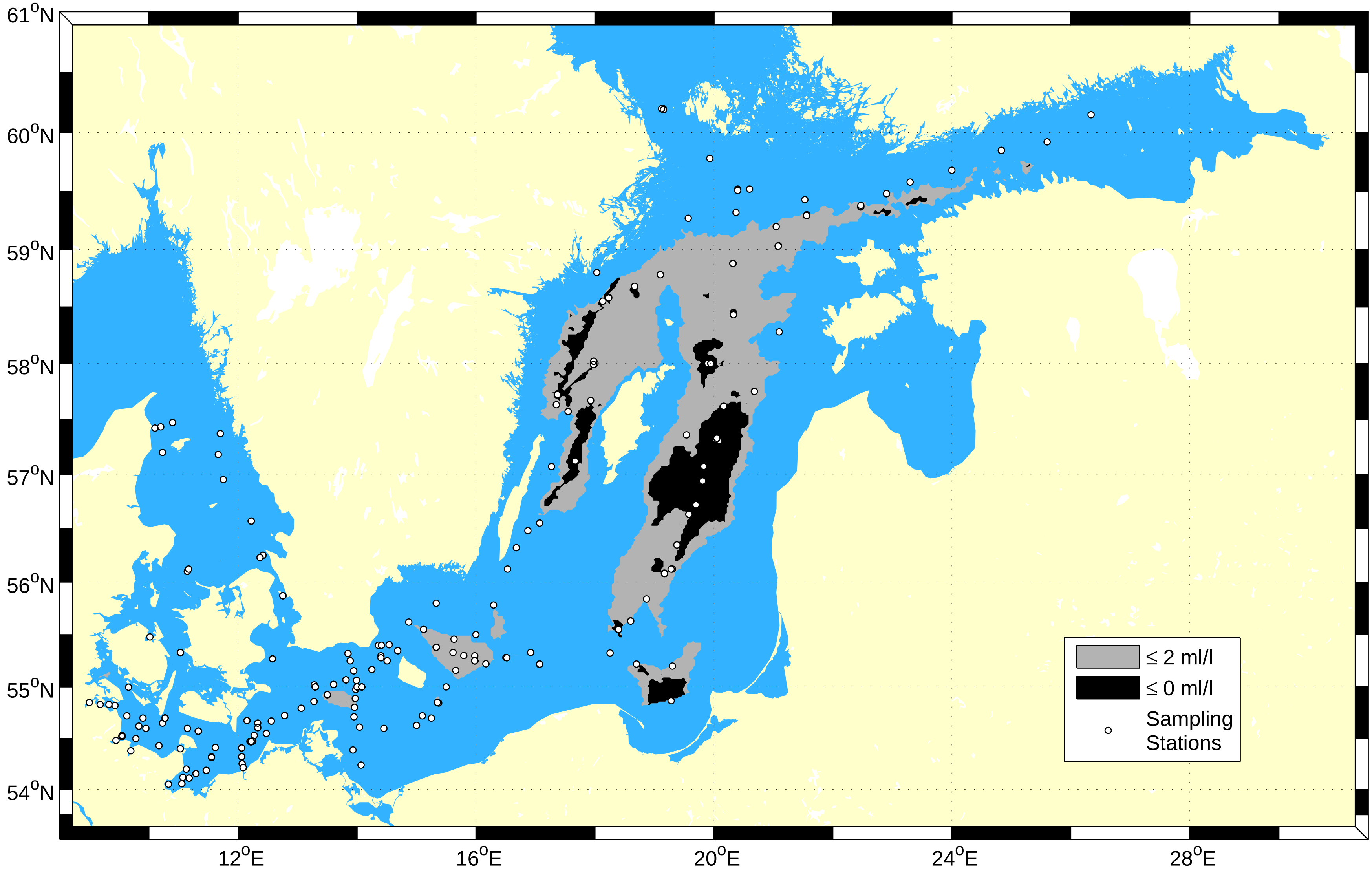
Extent of hypoxic & anoxic bottom water, Autumn 1982



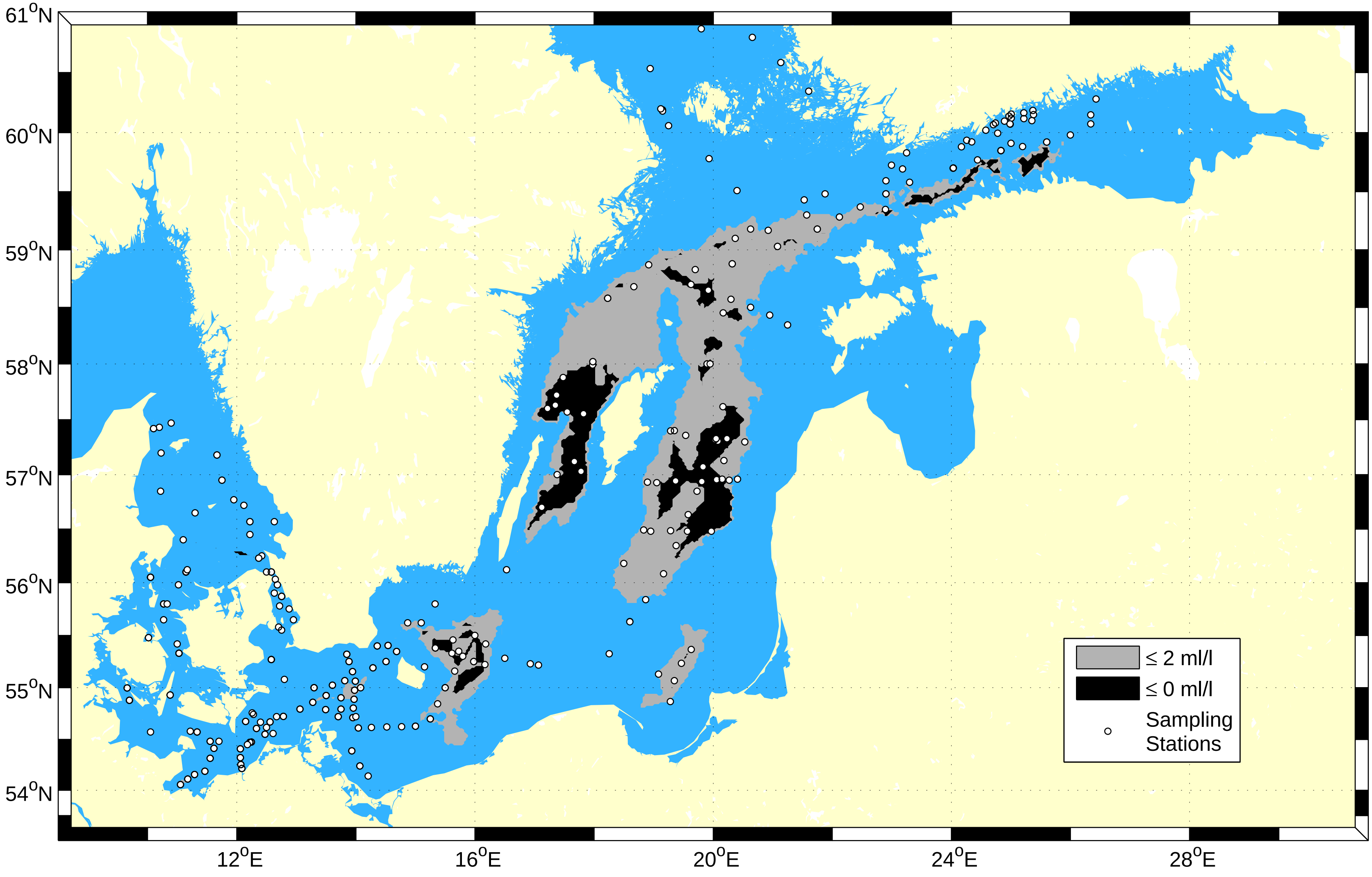
Extent of hypoxic & anoxic bottom water, Autumn 1981

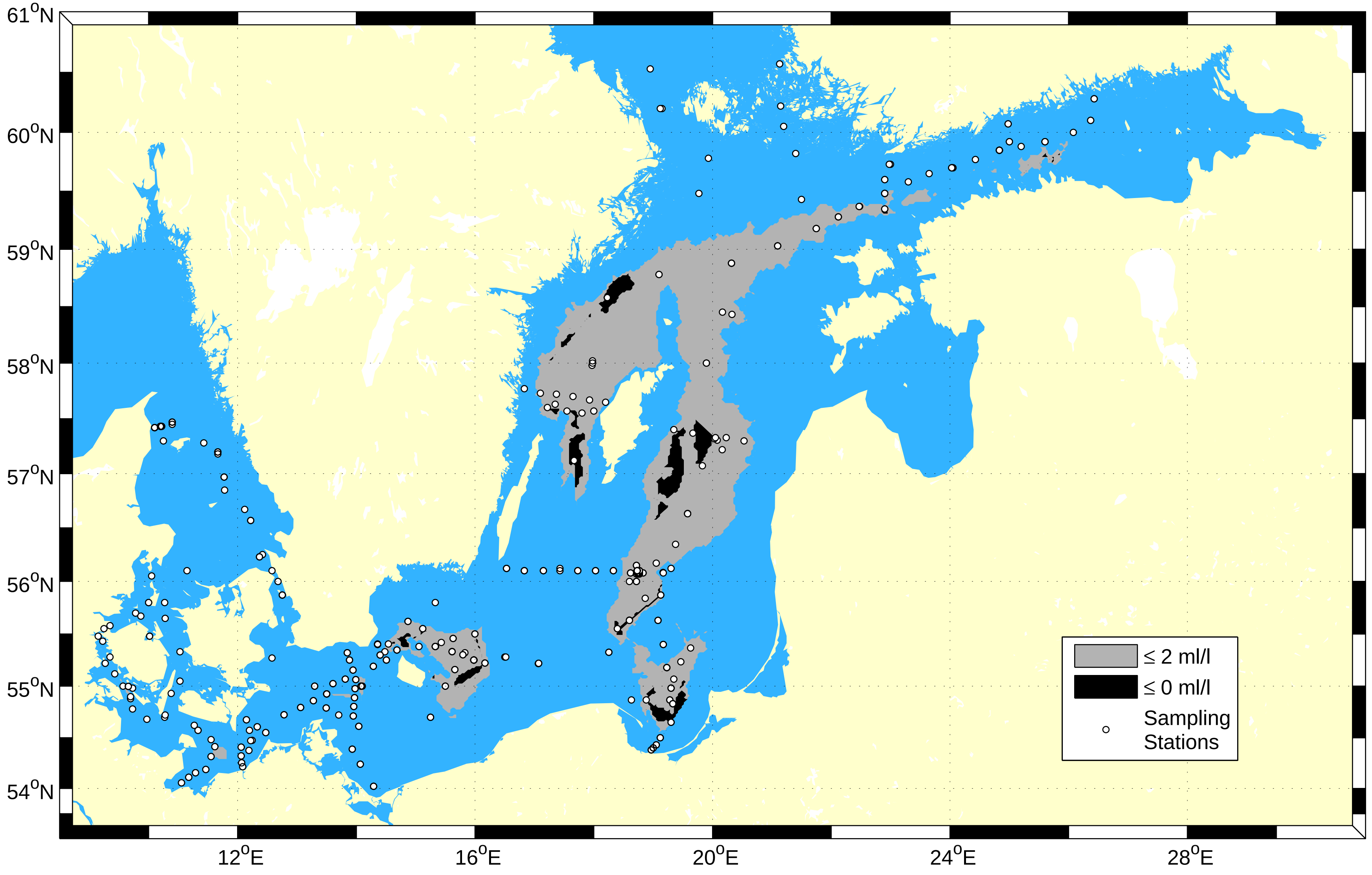

Extent of hypoxic & anoxic bottom water, Autumn 1980

Extent of hypoxic & anoxic bottom water, Autumn 1979

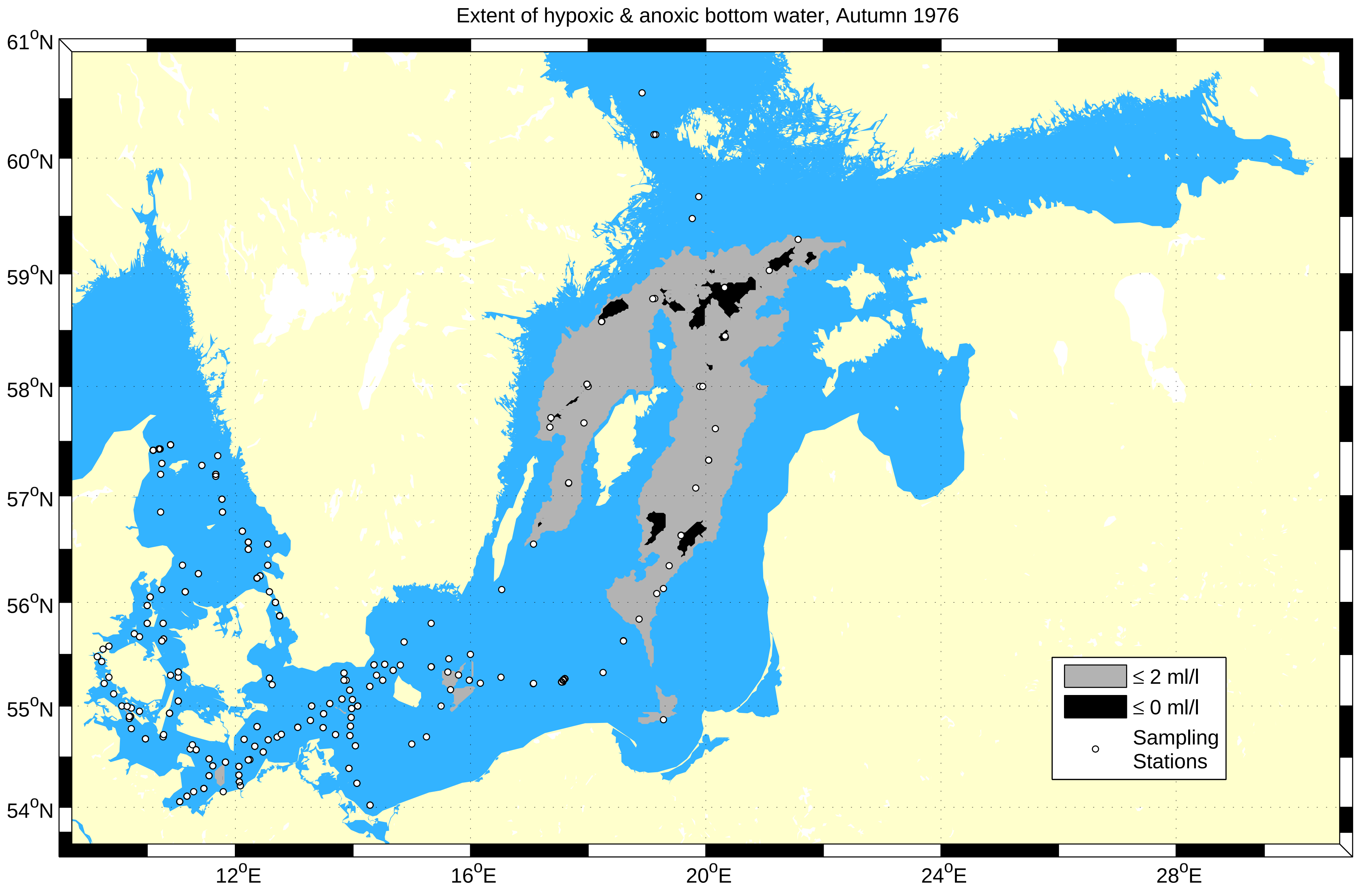


Extent of hypoxic & anoxic bottom water, Autumn 1978

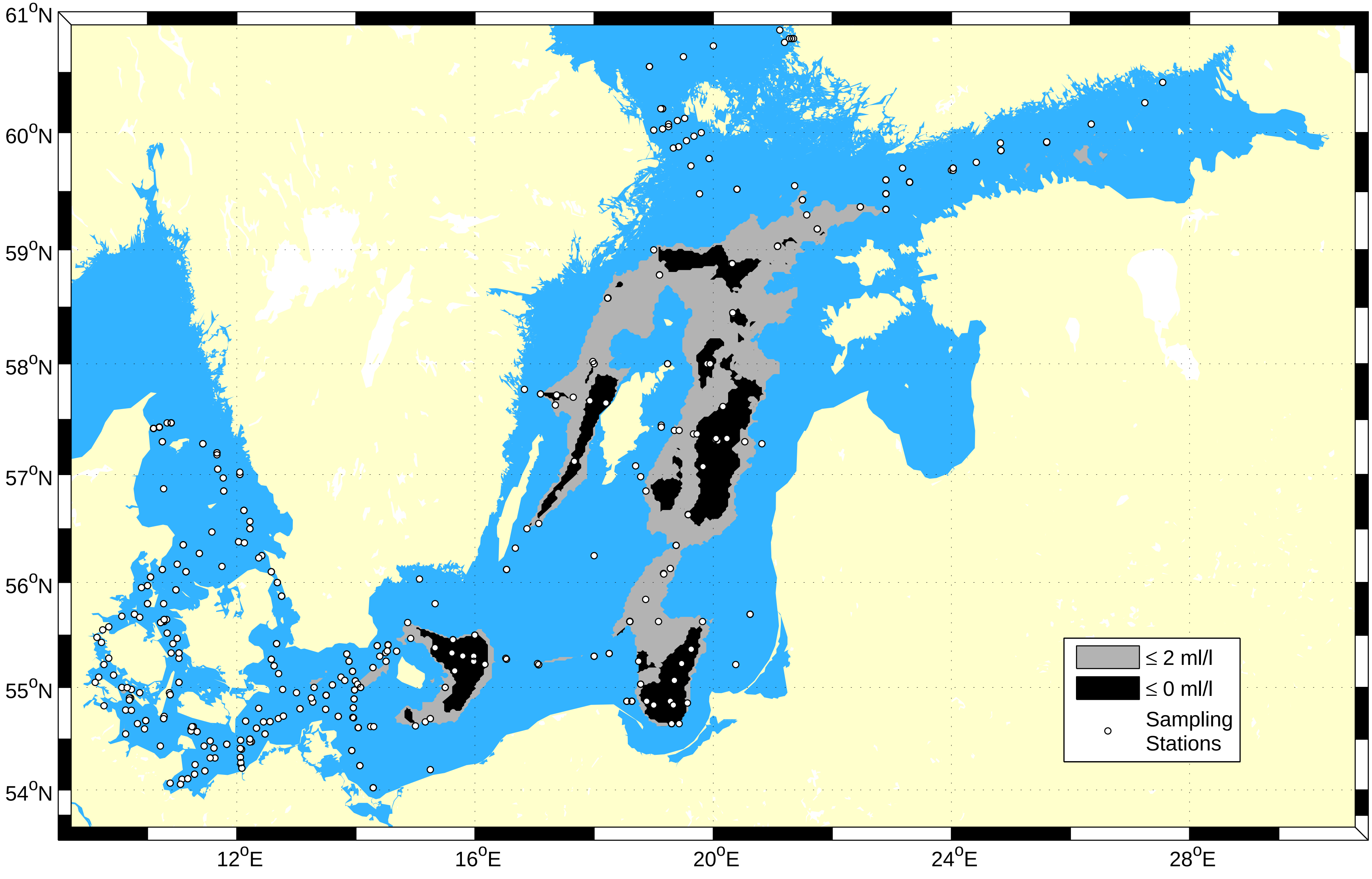


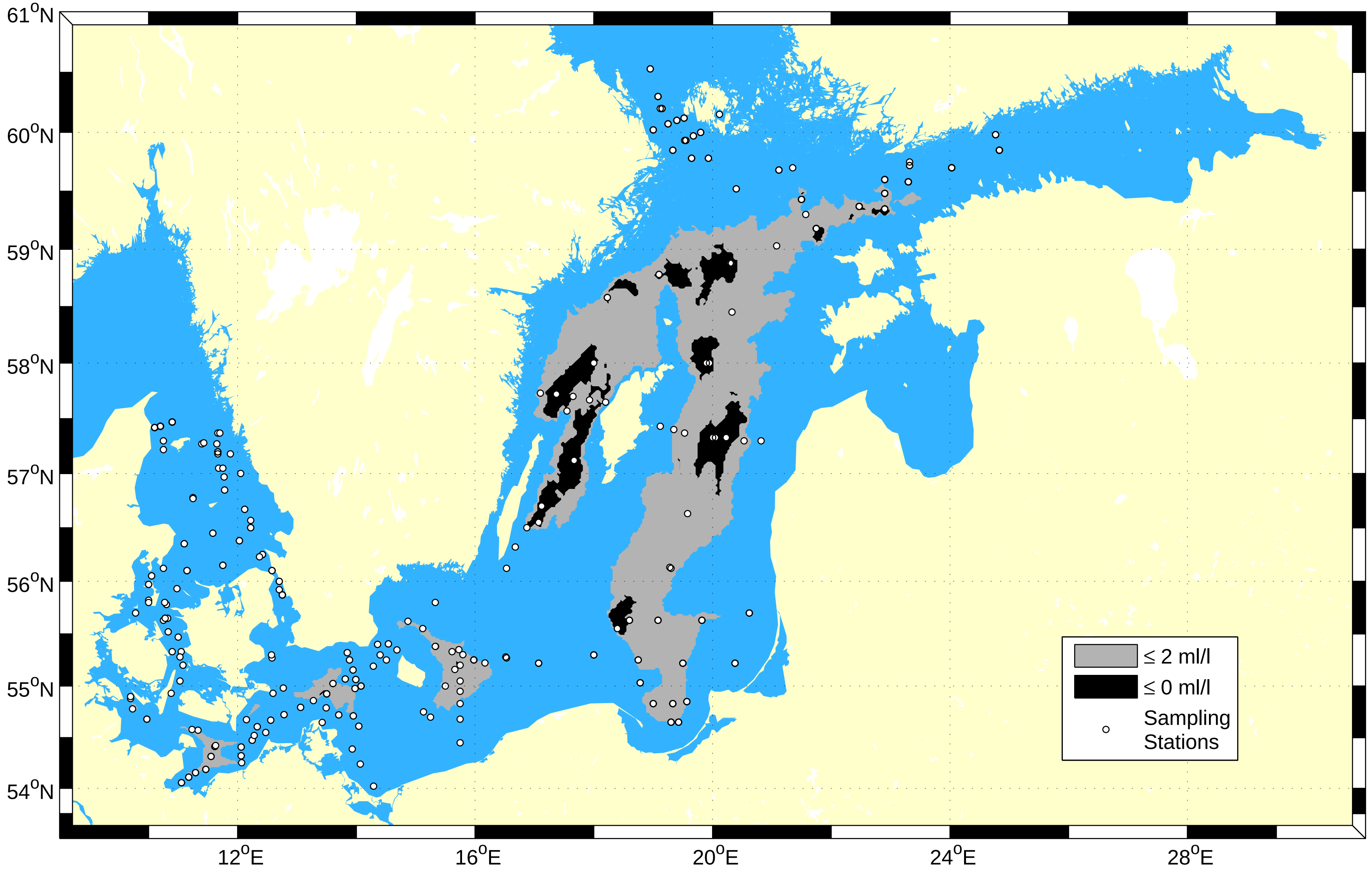


Extent of hypoxic & anoxic bottom water, Autumn 1977

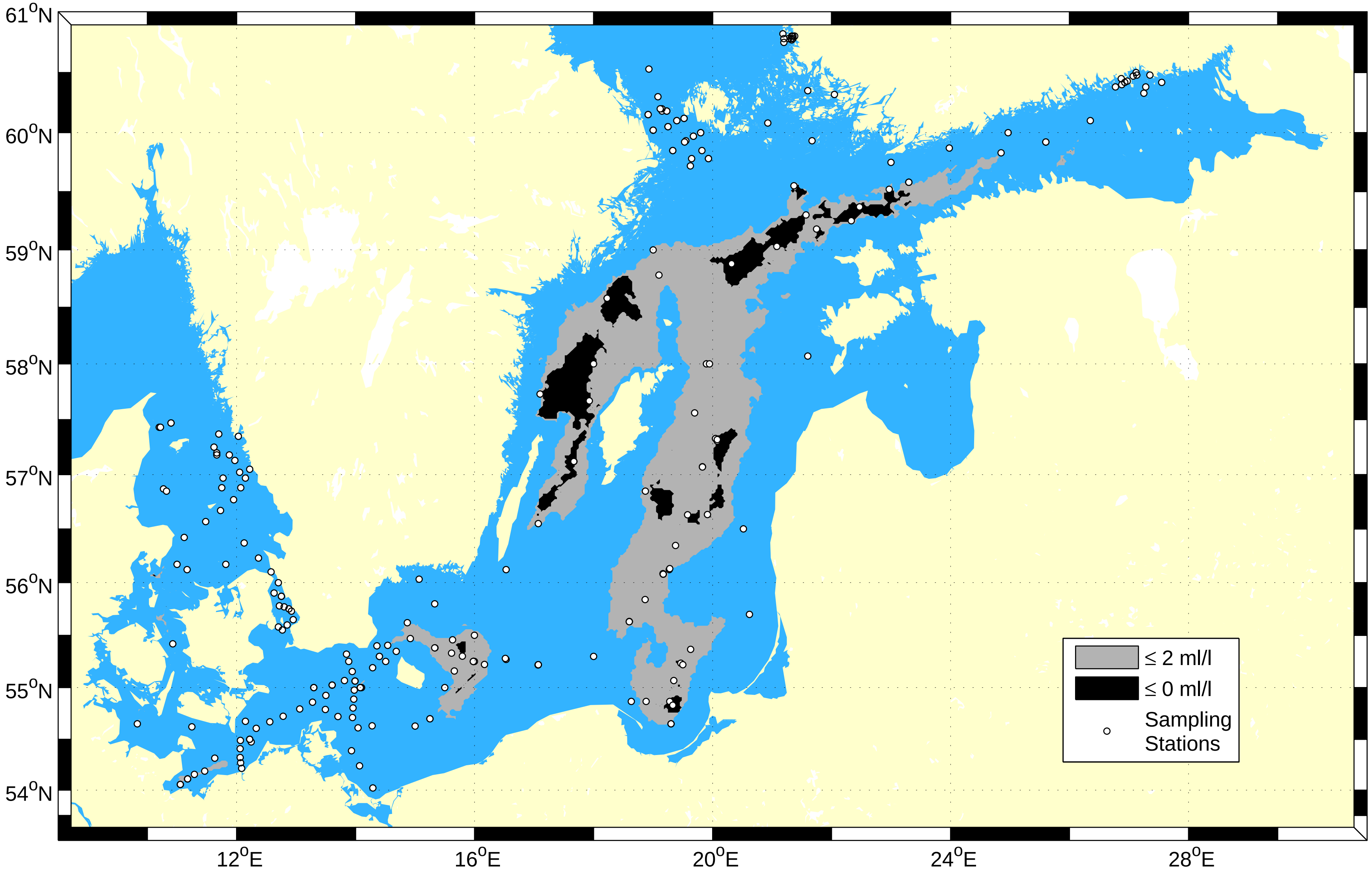

Extent of hypoxic & anoxic bottom water, Autumn 1976
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
▨ ≤ 2 ml/l
■ ≤ 0 ml/l
○ Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 1975

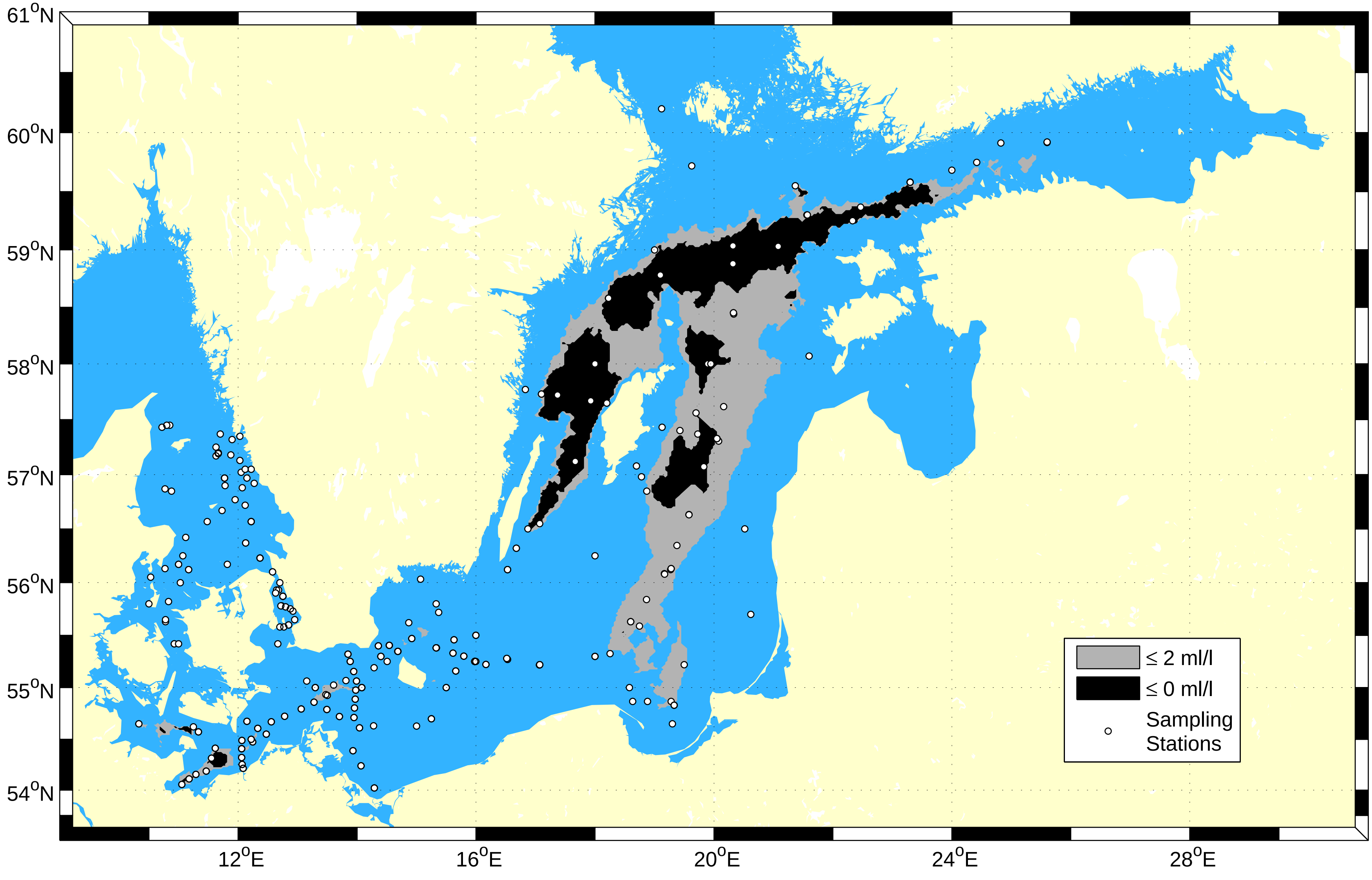


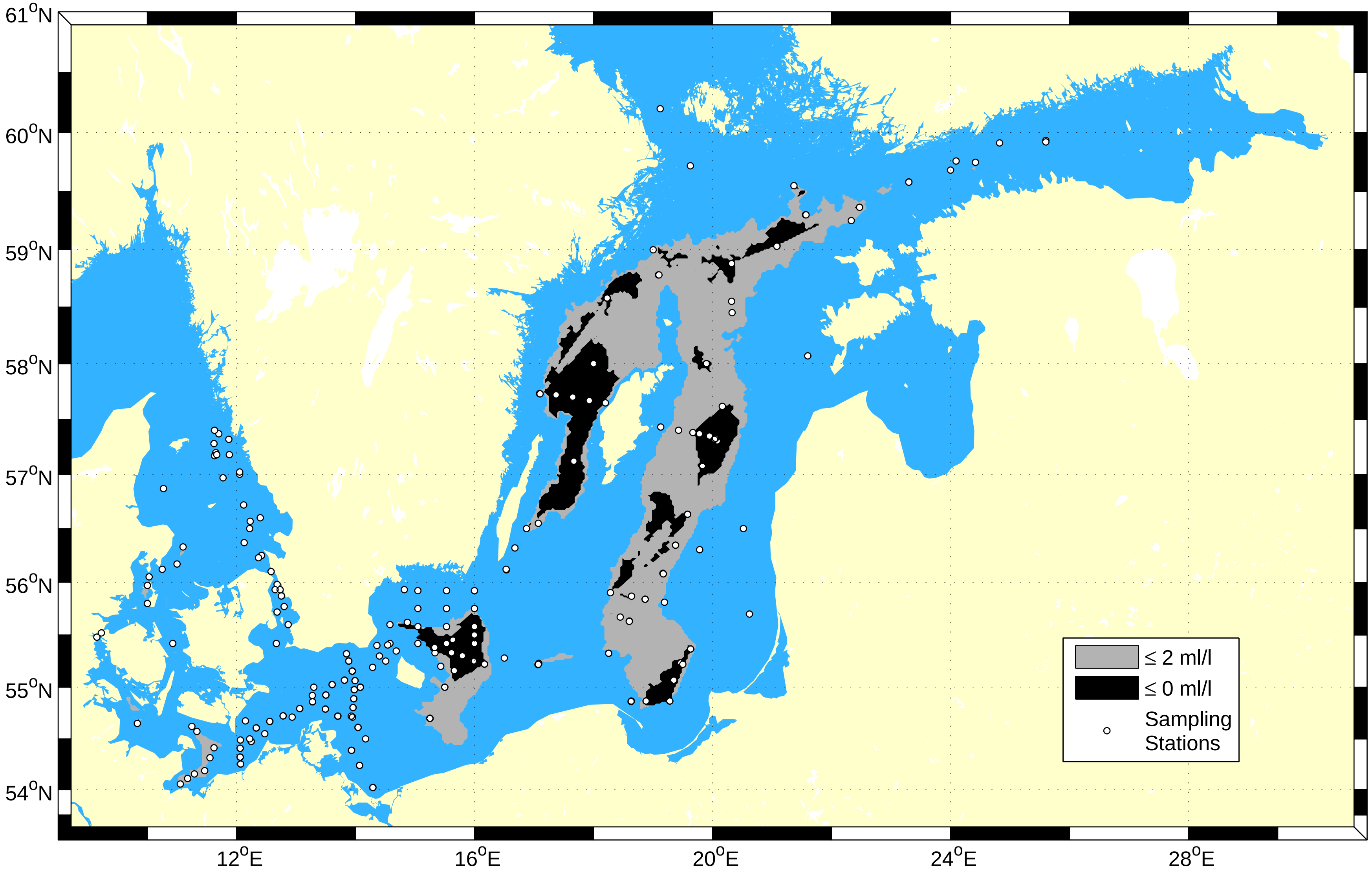


Extent of hypoxic & anoxic bottom water, Autumn 1974


Extent of hypoxic & anoxic bottom water, Autumn 1973

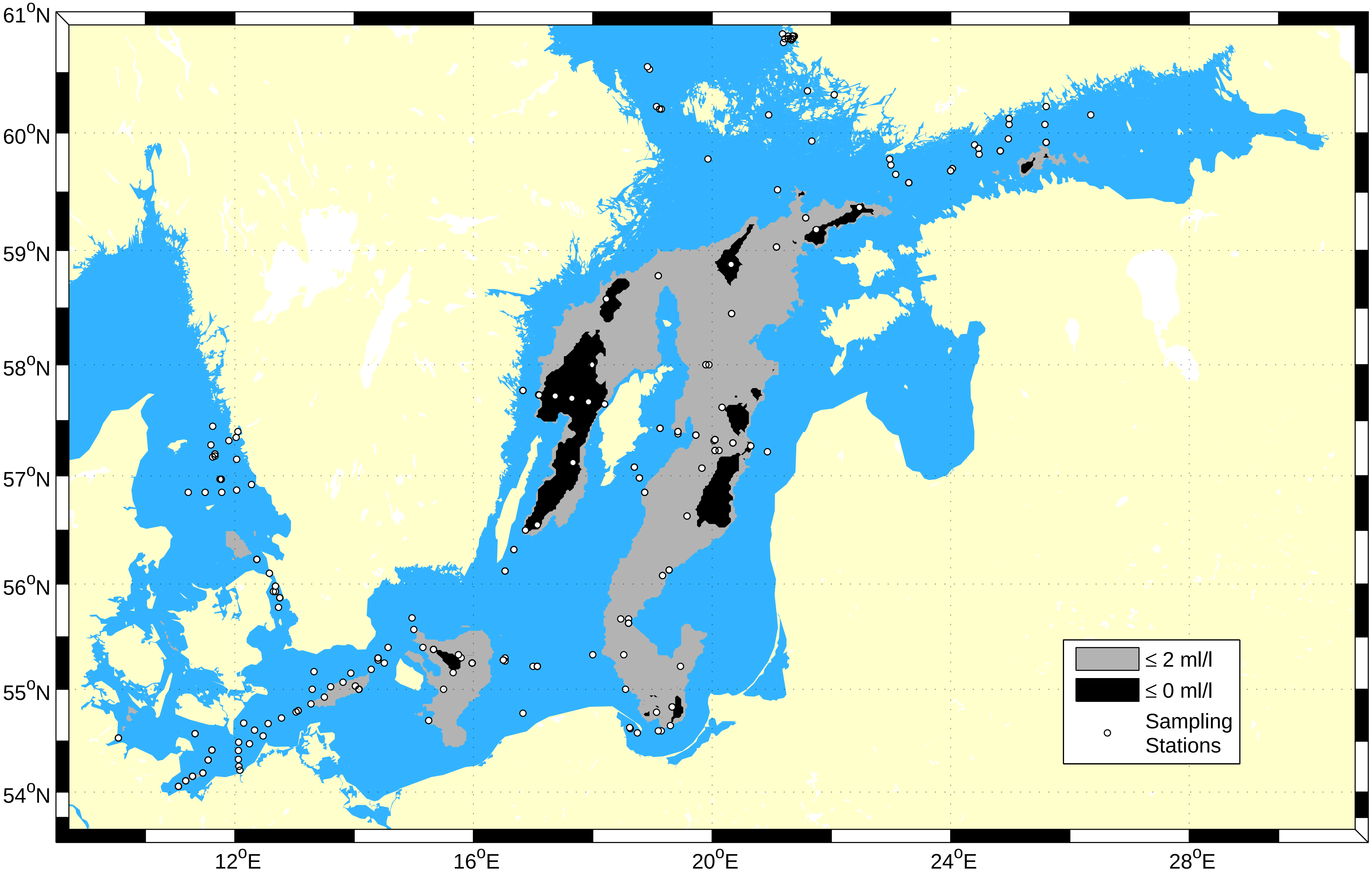
Extent of hypoxic & anoxic bottom water, Autumn 1972

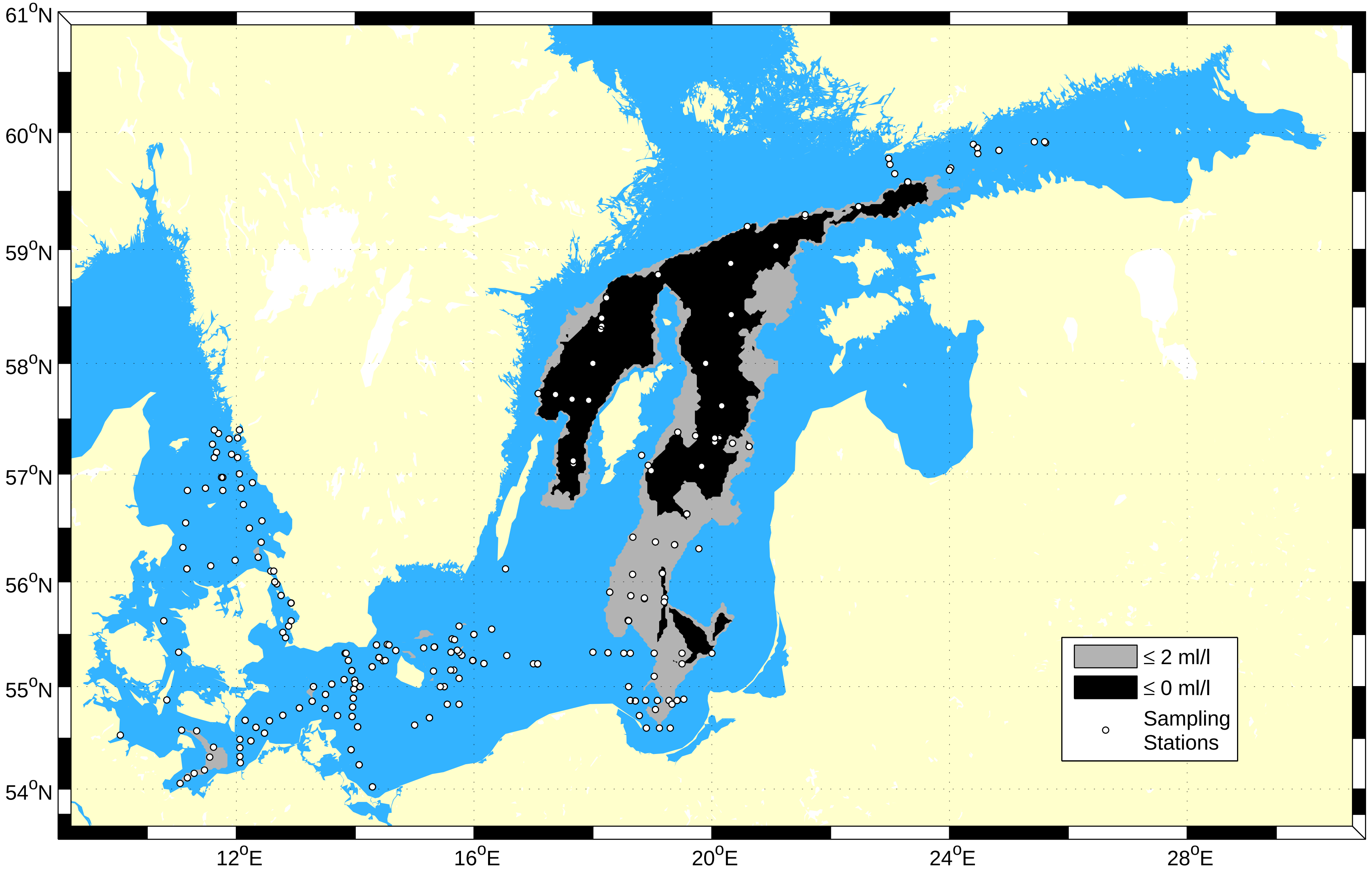




Extent of hypoxic & anoxic bottom water, Autumn 1971

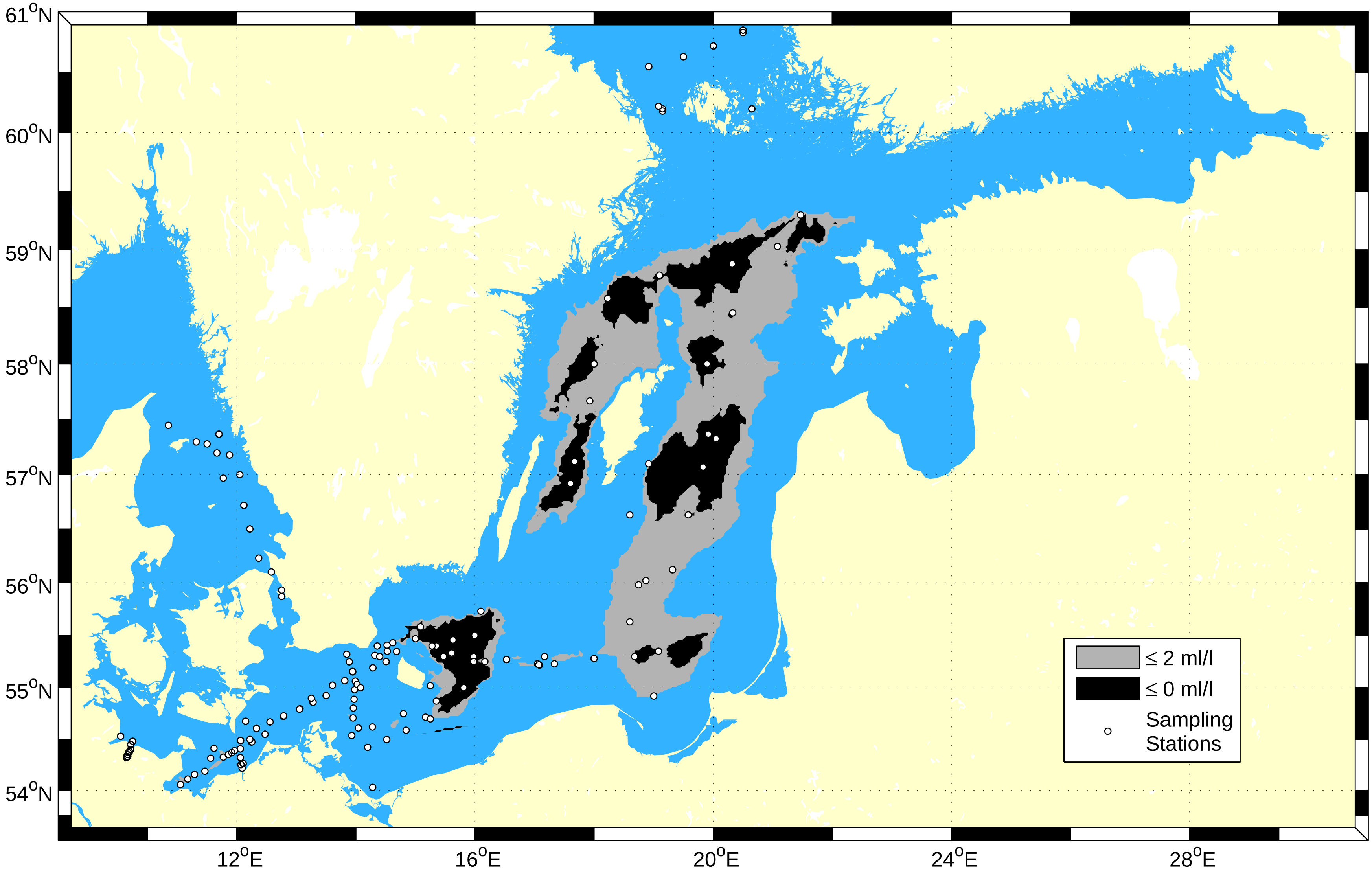
Extent of hypoxic & anoxic bottom water, Autumn 1970

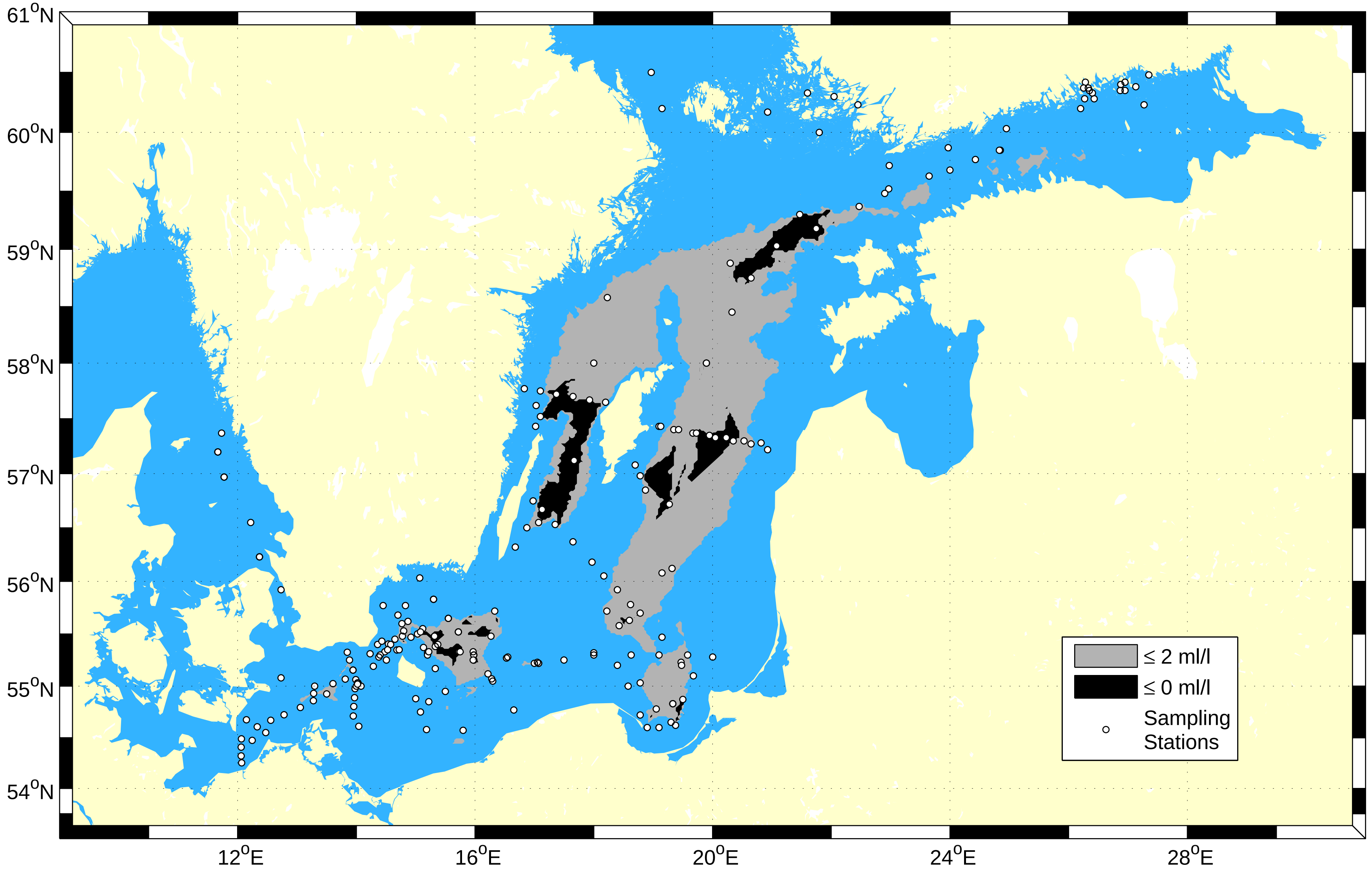




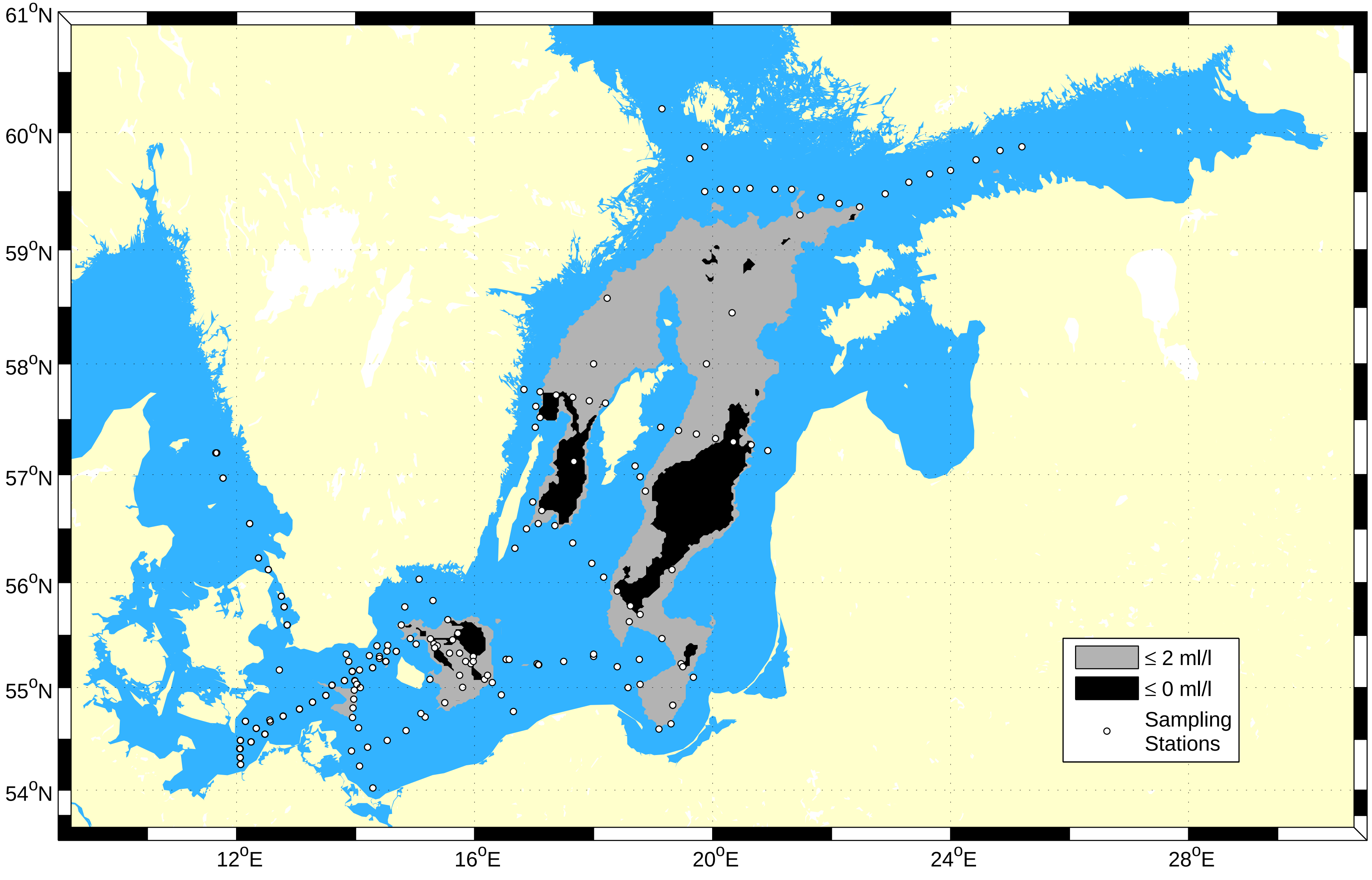
Extent of hypoxic & anoxic bottom water, Autumn 1969

Extent of hypoxic & anoxic bottom water, Autumn 1968

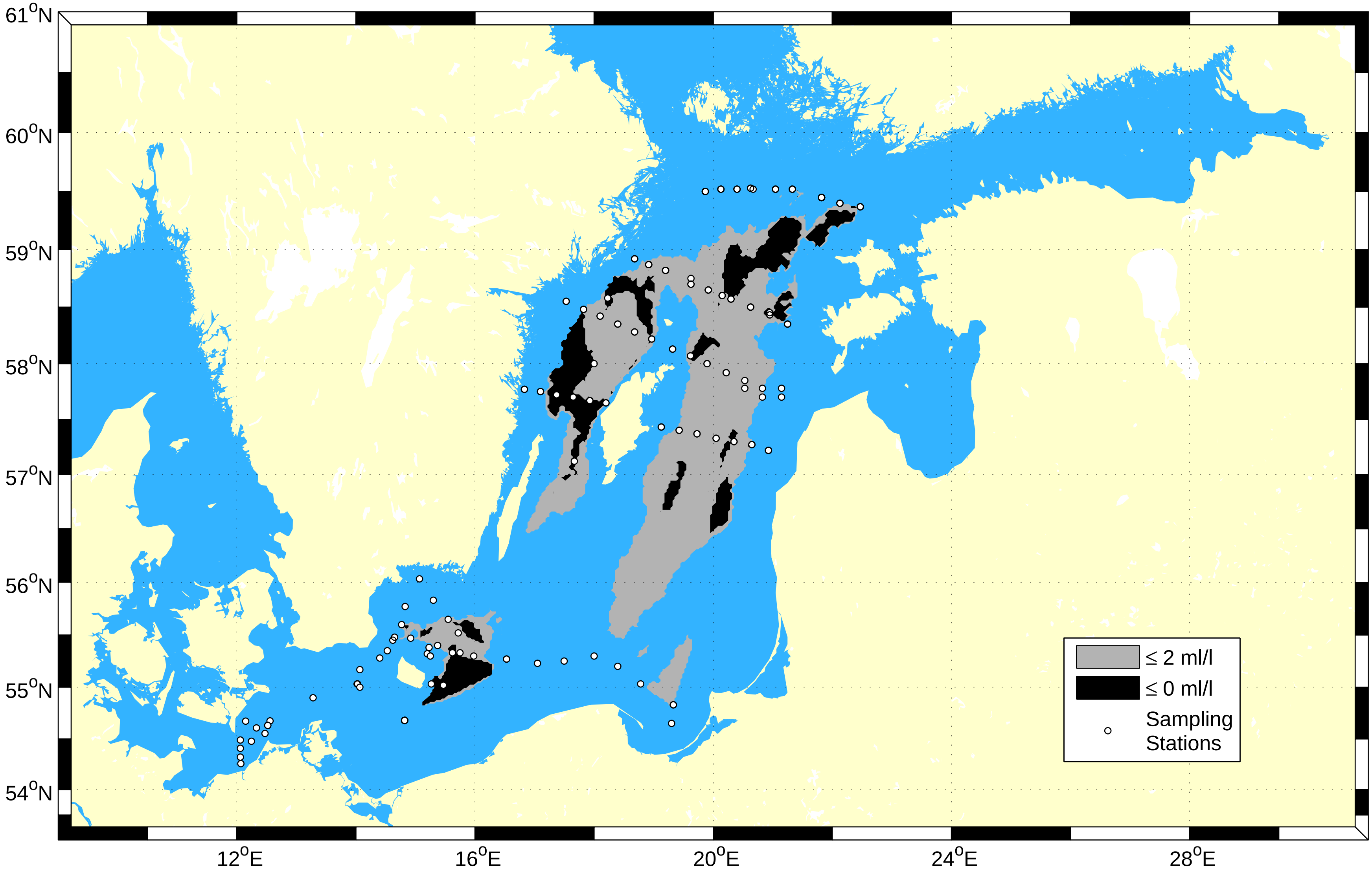


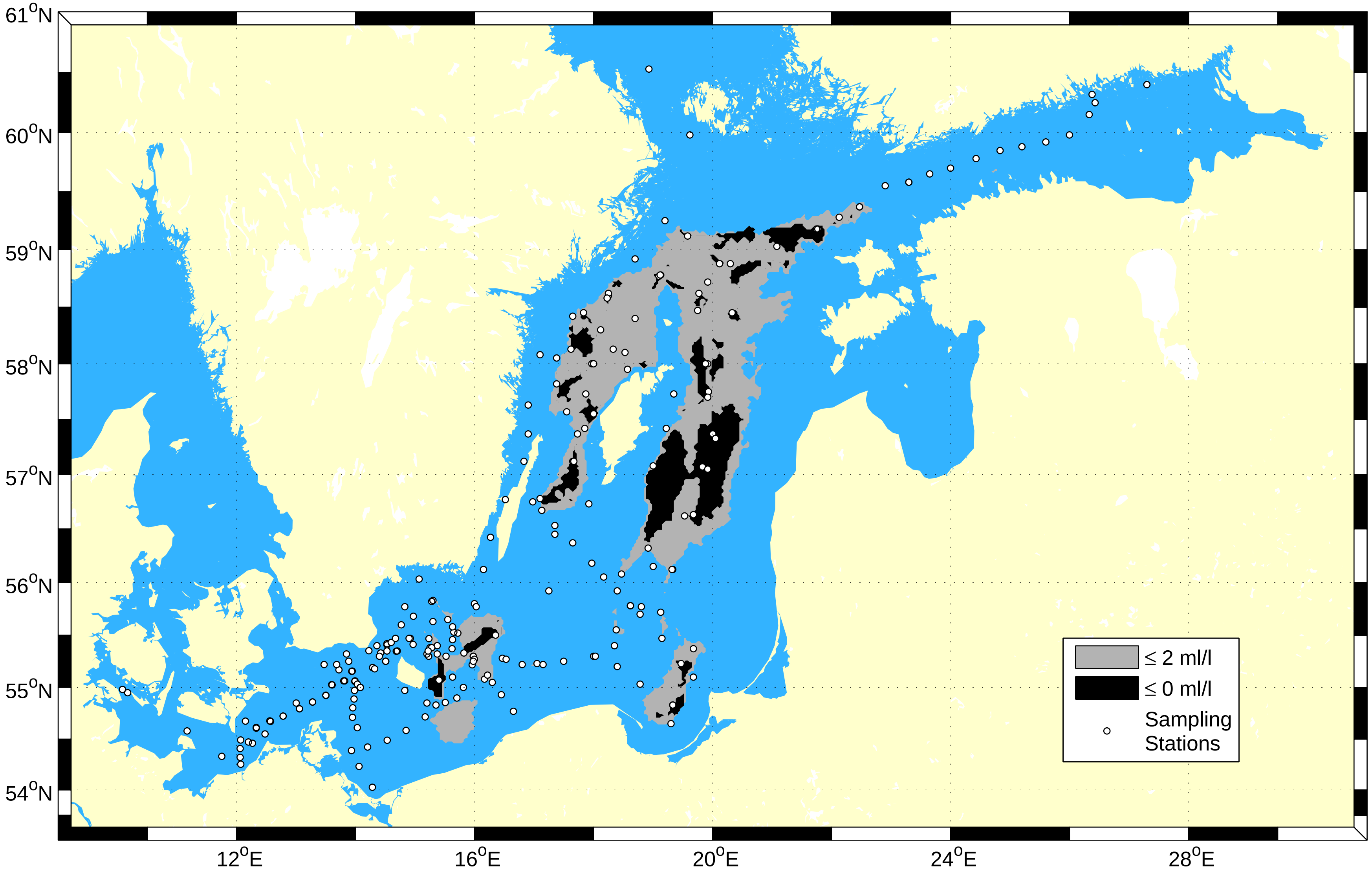


Extent of hypoxic & anoxic bottom water, Autumn 1966



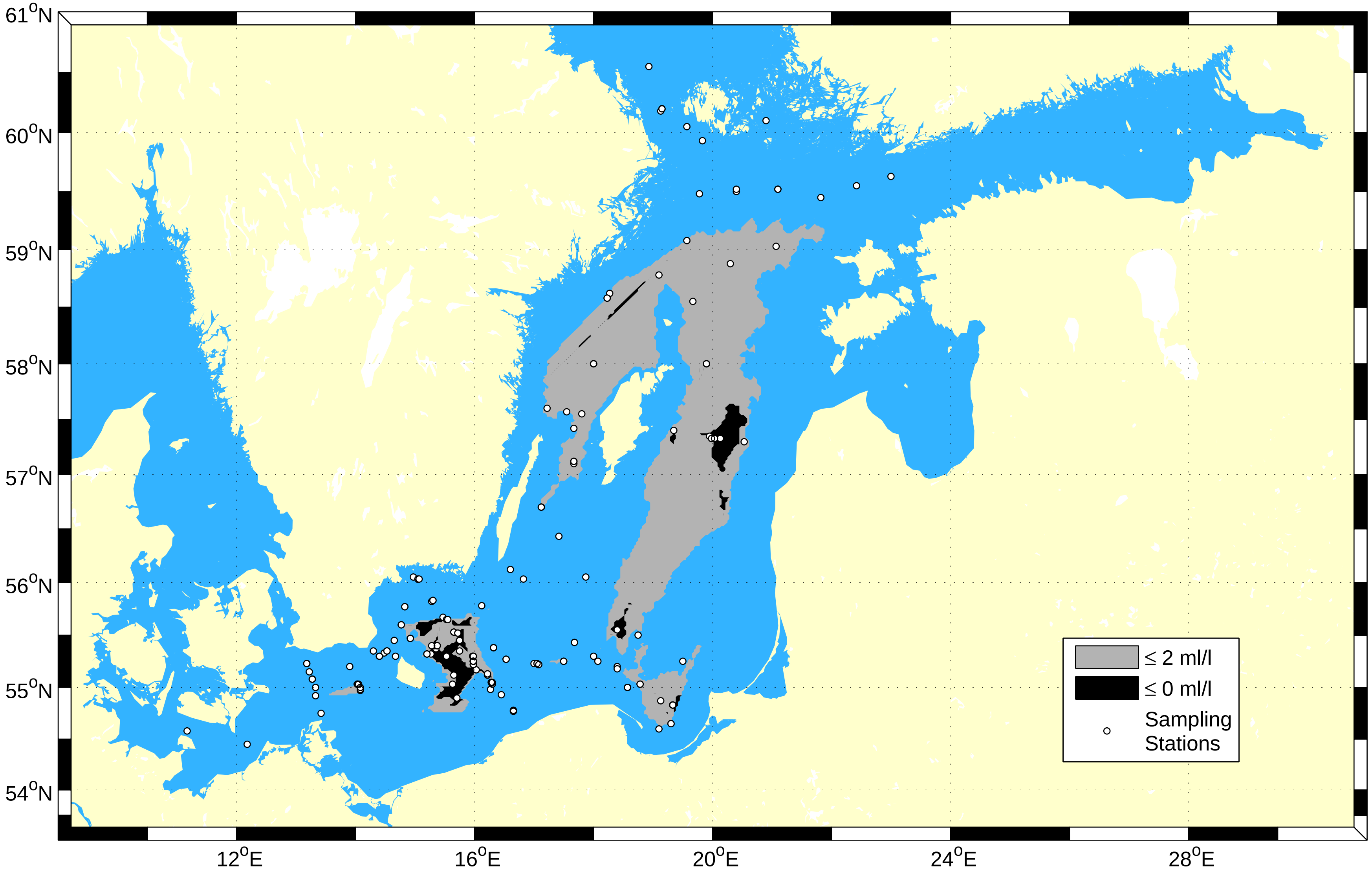
Extent of hypoxic & anoxic bottom water, Autumn 1965

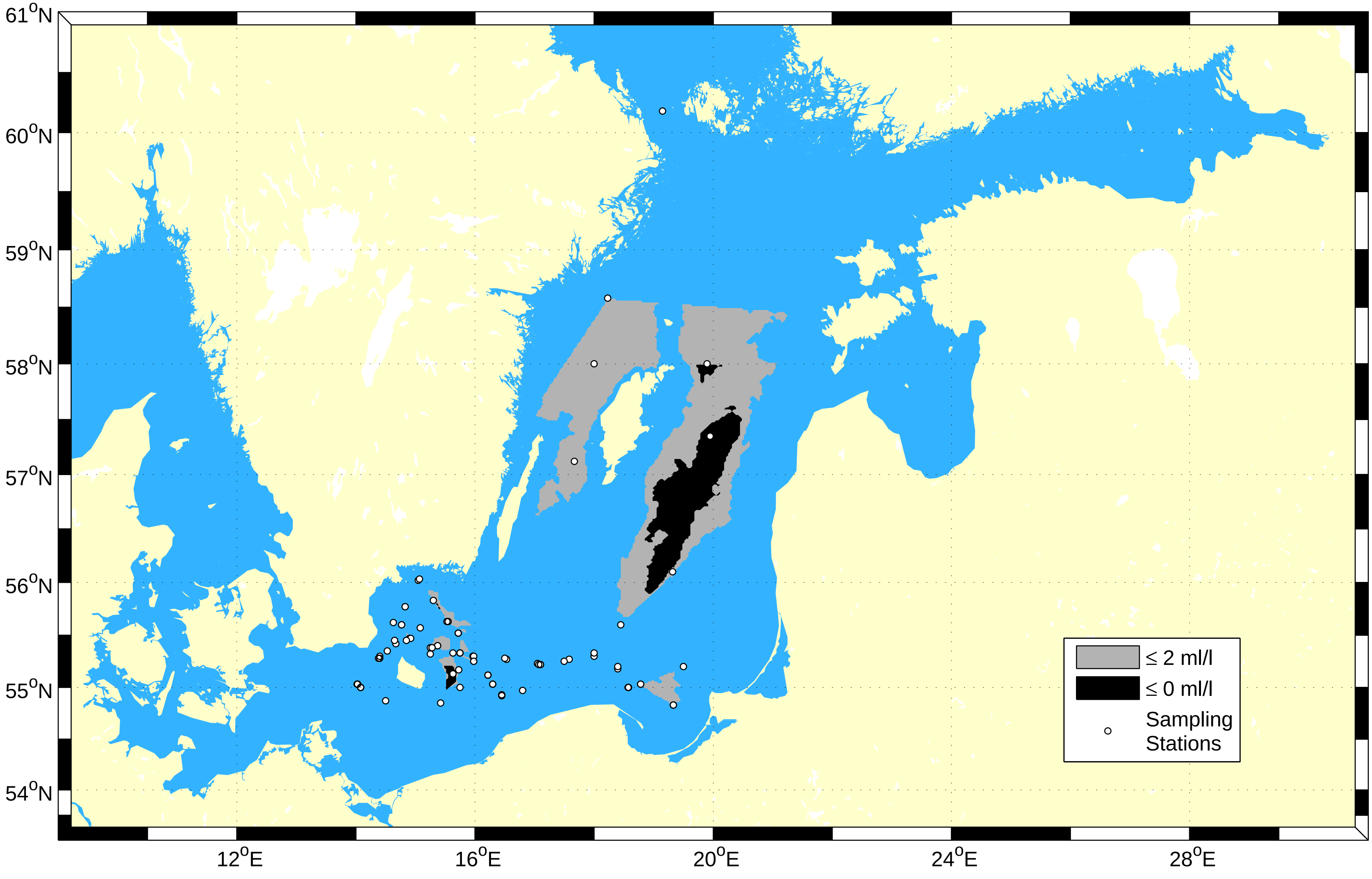

Extent of hypoxic & anoxic bottom water, Autumn 1964



Extent of hypoxic & anoxic bottom water, Autumn 1963

Extent of hypoxic & anoxic bottom water, Autumn 1962




Extent of hypoxic & anoxic bottom water, Autumn 1960

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

13 Lars Andersson, Stig Carlberg, Elisabet Fogelqvist, Stig Fonselius, Håkan Palmén, Eva-Gun Thelén, Lotta Fyrberg, Bengt Yhlén och Danuta Zagradkin (1991) Program för miljökvalitetsövervakning – PMK. Utsjöprogram under 1989.

14 Lars Andersson, Stig Carlberg, Lars Edler, Elisabet Fogelqvist, Stig Fonselius, Lotta Fyrberg, Marie Larsson, Håkan Palmén, Björn Sjöberg, Danuta Zagradkin, och Bengt Yhlén (1992)
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.)

15 Ray Murthy, Bertil Håkansson and Pekka Alenius (ed.) (1993)
The Gulf of Bothnia Year-1991 - Physical transport experiments

16 Lars Andersson, Lars Edler and Björn Sjöberg (1993)
The conditions of the seas around Sweden Report from activities in 1992

17 Anders Omstedt, Leif Nyberg and Matti Leppäranta (1994)
A coupled ice-ocean model supporting winter navigation in the Baltic Sea
Part 1 Ice dynamics and water levels.

18 Lennart Funkquist (1993)
An operational Baltic Sea circulation model Part 1. Barotropic version

19 Eleonor Marmefelt (1994)
Currents in the Gulf of Bothnia during the Field Year of 1991

20 Lars Andersson, Björn Sjöberg and Mikael Krysell (1994)
The conditions of the seas around Sweden
Report from the activities in 1993

21 Anders Omstedt and Leif Nyberg (1995) A coupled ice-ocean model supporting winter navigation in the Baltic Sea Part 2 Thermodynamics and meteorological coupling

22 Lennart Funkquist and Eckhard Kleine (1995) Application of the BSH model to Kattegat and Skagerrak.

23 Tarmo Köuts and Bertil Håkansson (1995) Observations of water exchange, currents, sea levels and nutrients in the Gulf of Riga.

24 Urban Svensson (1998)
PROBE An Instruction Manual.

25 Maria Lundin (1999)
Time Series Analysis of SAR Sea Ice - Backscatter Variability and its Dependence on Weather Conditions

26 Markus Meier[1], Ralf Döscher[1], Andrew, C. Coward[2], Jonas Nycander[3] and Kristofer Döös[3] (1999) RCO – Rossby Centre regional Ocean climate model: model description (version 1.0) and first results from the hindcast period 1992/93

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

27 H. E. Markus Meier (1999)
First results of multi-year simulations using a 3D Baltic Sea model

28 H. E. Markus Meier (2000)
The use of the $k-\varepsilon$ turbulence model within the Rossby Centre regional ocean climate model: parameterization development and results.

29 Eleonor Marmefelt, Bertil Håkansson, Anders Christian Erichsen and Ian Sehested Hansen (2000)
Development of an Ecological Model System for the Kattegat and the Southern Baltic. Final Report to the Nordic Councils of Ministers.

30 H.E Markus Meier and Frank Kauker (2002).Simulating Baltic Sea climate for the period 1902-1998 with the Rossby Centre coupled ice-ocean model.

31 Bertil Håkansson (2003)
Swedish National Report on Eutrophication Status in the Kattegat and the Skagerrak OSPAR ASSESSMENT 2002

32 Bengt Karlson & Lars Andersson (2003)
The Chattonella-bloom in year 2001 and effects of high freshwater input from river Göta Älv to the Kattegat-Skagerrak area

33 Philip Axe and Helma Lindow (2005)
Hydrographic Conditions around Offshore Banks

34 Pia M Andersson, Lars S Andersson (2006)
Long term trends in the seas surrounding Sweden. Part one - Nutrients

35 Bengt Karlson, Ann-Sofi Rehnstam-Holm & Lars-Ove Loo (2007)
Temporal and spatial distribution of diarrhetic shellfish toxins in blue mussels, Mytilus edulis (L.), at the Swedish West Coast, NE Atlantic, years 1988-2005

36 Bertil Håkansson
Co-authors: Odd Lindahl, Rutger Rosenberg, Pilip Axe, Kari Eilola, Bengt Karlson (2007)
Swedish National Report on Eutrophication Status in the Kattegat and the Skagerrak OSPAR ASSESSMENT 2007

37 Lennart Funkquist and Eckhard Kleine (2007) An introduction to HIROMB, an operational baroclinic model for the Baltic Sea

38 Philip Axe (2008)
Temporal and spatial monitoring of eutrophication variables in CEMP

39 Bengt Karlson, Philip Axe, Lennart Funkquist, Seppo Kaitala, Kai Sørensen (2009)
Infrastructure for marine monitoring and operational oceanography

40 Marie Johansen, Pia Andersson (2010) Long term trends in the seas surrounding Sweden
Part two – Pelagic biology

41 Philip Axe, (2012)
Oceanographic Applications of Coastal Radar

42 Martin Hansson, Lars Andersson, Philip Axe (2011) Areal Extent and Volume of Anoxia and Hypoxia in the Baltic Sea, 1960-2011

43 Philip Axe, Karin Wesslander, Johan Kronsell (2012) Confidence rating for OSPAR COMP

44 Germo Väli, H.E. Markus Meier, Jüri Elken (2012) Simulated variations of the Baltic Sea halocline during 1961-2007

45 Lars Axell (2013)
BSRA-15: A Baltic Sea Reanalysis 1990-2004

46 Martin Hansson, Lars Andersson, Philip Axe, Jan Szaron (2013) Oxygen Survey in the Baltic Sea 2012 - Extent of Anoxia and Hypoxia, 1960 -2012

47 C. Dieterich, S. Schimanke, S. Wang,
G. Väli, Y. Liu, R. Hordoir, L. Axell,
A. Höglund, H.E.M. Meier (2013)
Evaluation of the SMHI coupled atmosphere-ice-ocean model RCA4-NEMO

48 R. Hordoir, B. W. An, J. Haapala, C. Dieterich, S. Schimanke, A. Höglund and H.E.M. Meier (2013)
BaltiX V 1.1 : A 3D Ocean Modelling Configuration for Baltic & North Sea Exchange Analysis

49 Martin Hansson & Lars Andersson (2013) Oxygen Survey in the Baltic Sea 2013 - Extent of Anoxia and Hypoxia 1960-2013

50 Martin Hansson & Lars Andersson (2014) Oxygen Survey in the Baltic Sea 2014 - Extent of Anoxia and Hypoxia 1960-2014

51 Karin Wesslander (2015)
Coastal eutrophication status assessment using HEAT 1.0 (WFD methodology) versus HEAT 3.0 (MSFD methodology) and Development of an oxygen consumption indicator

52. Örjan Bäck & Magnus Wenzer (2015) Mapping winter nutrient concentrations in the OSPAR maritime area using Diva

53 Martin Hansson & Lars Andersson (2015) Oxygen Survey in the Baltic Sea 2015 - Extent of Anoxia and Hypoxia 1960-2015 & The major inflow in December 2014

54 Karin Wesslander (2016)
Swedish National Report on Eutrophication Status in the Skagerrak, Kattegat and the Sound OSPAR ASSESSMENT 2016

55 Iréne Wåhlström, Kari Eilola, Moa Edman, Elin Almroth-Rosell (2016) Evaluation of open sea boundary conditions for the coastal zone. A model study in the northern part of the Baltic Proper.

56 Christian Dieterich, Magnus Hieronymus, Helén Andersson (2016)
Extreme Sea Levels in the Baltic Sea, Kattegat and Skagerrak under Climate Change Scenarios

57 Del A: Jens Fölster (SLU), Stina Drakare (SLU), Lars Sonesten (SLU) Del B: Karin Wesslander (SMHI), Lena Viktorsson (SMHI), Örjan Bäck (SMHI), Martin Hansson (SMHI), Ann-Turi Skjevik (SMHI) (2017)
Förslag till plan för revidering av fysikalisk-kemiska bedömningsgrunder för ekologisk status i sjöar, vattendrag och kust.

58 Martin Hansson, Lars Andersson (2016) Oxygen Survey in the Baltic Sea 2016 - Extent of Anoxia and Hypoxia 1960-2016

59 Andersson Pia, Hansson Martin, Bjurström Joel, Simonsson Daniel (2017) Naturtypsbestämning av miljöövervakningsstationer SMHI pelagial miljöövervakning

60 Karin Wesslander, Lena Viktorsson (2017) Summary of the Swedish National Marine Monitoring 2016. Hydrography, nutrients and phytoplankton

61 Eilola Kari, Lindqvist Stina, Almroth-Rosell Elin, Edman Moa, Wåhlström Iréne, Bartoli Marco, Burska Dorota, Carstensen Jacob, Helleman dana, Hietanen Susanna, Hulth Stefan, Janas Urzula, Kendzierska Halina, Pryputniewiez-Flis, Voss Maren, och Zilius Mindaugas (2017).
Linking process rates with modelling data and ecosystem characteristics

62 Lena Viktorsson, Karin Wesslander (2017) Revidering av fysikaliska och kemiska bedömningsgrunder i kustvatten
Underlag inför uppdatering av HVMFS 2013:19

63 Martin Hansson, Lena Viktorsson, Lars Andersson (2017)
Oxygen Survey in the Baltic Sea 2017 - Extent of Anoxia and Hypoxia 1960-2017

64 Karin Wesslander, Lena Viktorsson och Ann-Turi Skjevik (2018)
The Swedish National Marine Monitoring Programme 2017. Hydrography, nutrients and phytoplankton

65 Martin Hansson, Lena Viktorsson & Lars Andersson (2018)
Oxygen Survey in the Baltic Sea 2018 - Extent of Anoxia and Hypoxia 1960-2018

66 Lena Viktorsson (2019) The Swedish National Marine Monitoring Programme 2018

67 Martin Hansson, Lena Viktorsson (2019) Oxygen Survey in the Baltic Sea 2019 - Extent of Anoxia and Hypoxia 1960-2019

68 Iréne Wåhlström[1], Jonas Pålsson[2], Oscar Törnqvist[4], Per Jonsson[3], Matthias Gröger[1], Elin Almroth-Rosell[1] (2020) [1]Swedish Meteorological and Hydrological Institute, Sweden. [2]Swedish Agency for Marine and Water Management. [3]University of Gothenburg. [4]Geological Survey of Sweden
Symphony – a cumulative assessment tool developed for Swedish Marine Spatial Planning

69 Karin Wesslander, Lena Viktorsson, Peter Thor, Madeleine Nilsson and Ann-Turi Skjevik Swedish Meteorological and Hydrological Institute. The Swedish National Marine Monitoring Programme 2019.

70 Martin Hansson, Lena Viktorsson (2020) Oxygen Survey in the Baltic Sea 2020 - Extent of Anoxia and Hypoxia 1960-2020

71 Ann-Turi Skjevik, Karin Wesslander, Lena Viktorsson (2021) The Swedish National Marine Monitoring Programme 2020

72 Martin Hansson, Lena Viktorsson (2021) Oxygen Survey in the Baltic Sea 2021 - Extent of Anoxia and Hypoxia 1960-2021

73 Ann-Turi Skjevik, Karin Wesslander, Lena Viktorsson, Madeleine Nilsson (2022) The Swedish National Marine Monitoring Programme 2021

74 Martin Hansson, Lena Viktorsson (2023) Oxygen Survey in the Baltic Sea 2022 - Extent of Anoxia and Hypoxia 1960-2022

75 Ann-Turi Skjevik, Karin Wesslander, Lena Viktorsson, Madeleine Nilsson (2023) The Swedish National Marine Monitoring Programme 2022

SMHI

Swedish Meteorological and Hydrological Institute
SE 601 76 NORRKÖPING
Phone +46 11-495 80 00 Telefax +46 11-495 80 01

ISSN 0283-1112