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REPORT OCEANOGRAPHY No. 67, 2019

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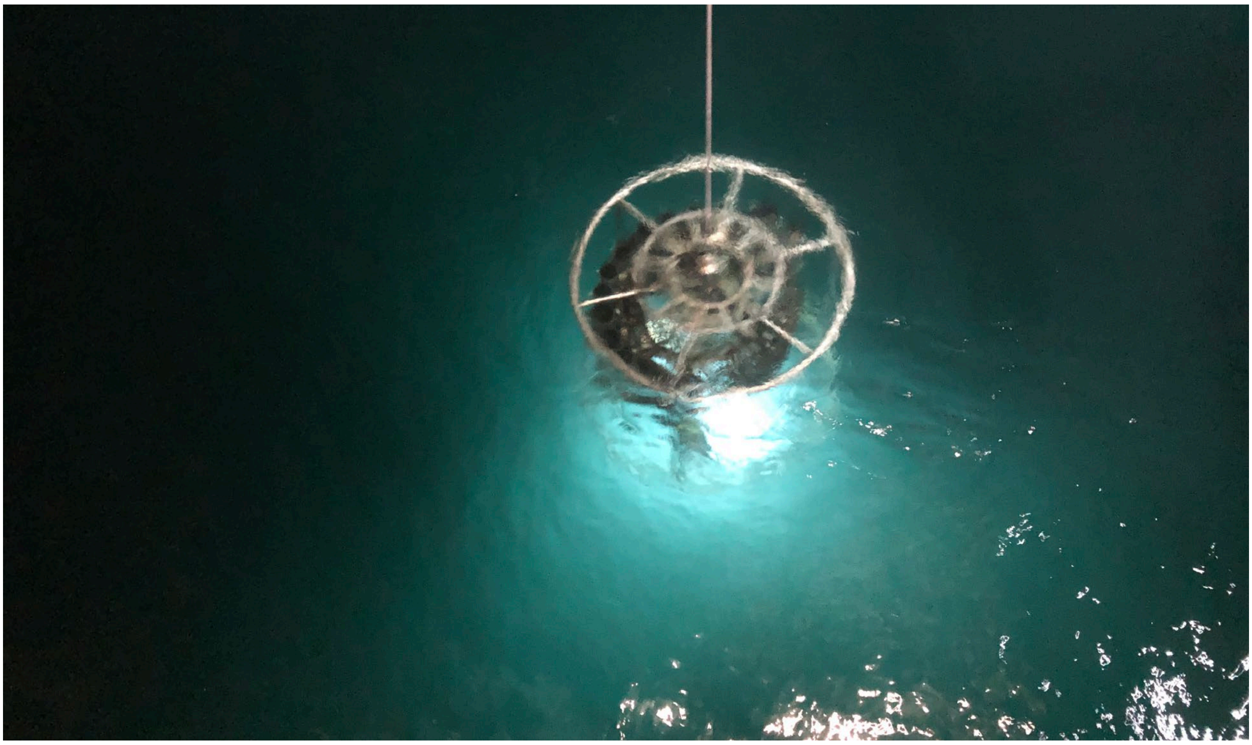
- Extent of Anoxia and Hypoxia, 1960-2019



Front: The photo was taken onboard R/V Svea and shows the CTD rosette on its way up during SMHIs cruise in January 2020 somewhere in the Baltic Proper.
Photo by Daniel Bergman Sjöstrand

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Oxygen Survey in the Baltic Sea 2019
- Extent of Anoxia and Hypoxia, 1960-2019

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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 the ICES data center. In this report the results for 2018 have been updated and the preliminary results for 2019 are presented. Oxygen data from 2019 have been collected from various sources such as international trawl survey, national monitoring programmes and research projects with contributions from Poland, Estonia, Russia, Denmark, Sweden and Finland.

For the autumn period each profile in the dataset was examined for the occurrence of hypoxia (oxygen deficiency) and anoxia (total absence of oxygen). The depths of onset of hypoxia and anoxia were then interpolated between sampling stations producing two surfaces representing the depths at which hypoxic and anoxic conditions respectively are found. 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 analysed period.

The updated results for 2018 and the preliminary results for 2019 show that the severe oxygen conditions in the Baltic Proper after the regime shift in 1999 continue. In 2018 the largest bottom areas and volumes affected by anoxia was recorded during the analysed period starting in 1960. Anoxic conditions affected ~24% of the bottom areas and ~33% suffered from hypoxia in 2018 and similar values just below was noted during 2019. The results from these two years could be the beginning of a new trend as the anoxia has reached another stage and new areas are affected regularly. In the southern basins of the Baltic Proper, such as the Gulf of Gdansk, Hanö Bight and in the Bornholm Basin, hypoxia has previously been found in the deep water but anoxia is now found regularly in the deep water. The hydrogen sulphide that had disappeared from the Eastern and Northern Gotland Basin due to the inflows in 2014-2016 is now steadily increasing in the deep water again. No major inflow has occurred since 2016.

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 datacenter. I denna rapport har resultaten från 2018 uppdaterats och preliminära resultat för 2019 tagits fram. Resultaten för 2019 baseras på data insamlade under internationella fiskeriundersökningar, nationell miljöövervakning och forskningsprojekt med bidrag från Danmark, Estland, Sverige, Finland, Ryssland och Polen.

Förekomsten av hypoxi (syrebrist) och anoxi (helt syrefria förhållanden) under höstperioden, har undersökts i varje mätprofil. Djupet där hypoxi eller anoxi först påträffas i en profil har interpolerats mellan provtagningsstationer och kombinerats med en djupdatabas för beräkning av utbredning och volym av hypoxiska och anoxiska förhållanden. Resultaten har överförts till kartor och diagram för att visualisera syresituationen i Östersjöns djupvatten 1960-2019.

Resultaten för 2018 och de preliminära resultaten för 2019 visar att den extrema syrebristen som observerats i Egentliga Östersjön, efter regimskiftet 1999, fortsätter. Under 2018 noterades den största utbredningen av syrefria bottnar sedan tidsseriens start 1960. Omkring ~24% av bottnarna var syrefria och ~33% var påverkade av syrebrist. Liknande nivåer återfinns 2019. Resultaten från de senaste två åren indikerar en ny fas då utbredningen av syrefria bottnar har nått nya områden. I de södra områdena av Egentliga Östersjön; Hanöbukten, Gdanskbukten och Bornholmsbassängen har syrebrist förekommit i djupvattnet tidigare men nu återfinns syrefria områden regelbundet. Mängden svavelväte, som på grund av inflödena 2014-2016, helt försvann från Östra och Norra Gotlandsbassängerna, ökar åter i dessa bassängers djupvatten. Inget större inflöde till Östersjön har inträffat under perioden 2017-2019.

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1 Background

Bottom areas with low oxygen concentrations are historically a natural phenomenon in the Baltic Sea caused by its formation as an almost completely enclosed sea and “fjordlike” topography. The narrow straits and shallow sills in the Belt Sea and the Sound only permit limited water exchange with the more oceanic sea areas; Kattegat, Skagerrak and North Sea.

High freshwater runoff, from the large catchment area around the Baltic Sea, means that the general direction of the flow through the Sound and Belt Sea is out from the Baltic Sea to the Kattegat. Only during specific wind and weather conditions the direction of the flow through these straits gets reversed for short periods and an inflow occurs. Large inflows can transport vast amounts of oxygenated and high saline water into the Baltic Sea. Due to the different densities of low and high saline waters a stable stratification develops. The low saline surface water is generally well oxygenated since it is permanently well mixed by the wind. The much denser, high saline, water ends up at the bottom of the deep basins and is not affected by surface mixing processes; hence the stratification prevents ventilations of the deep water. Degradation of organic matter consumes the available oxygen in the deep water and oxygen concentrations can drop to critical levels for higher marine life or create completely oxygen free conditions.

However, large inflow events can supply the deep areas of the Baltic Proper with dissolved oxygen as the inflowing water from the North Sea usually is well oxygenated. Due to the high salinity and density of the inflowing water it either forms 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 their volume is large enough to move over the sills between the different basins of the Baltic Proper and the density high enough to settle the inflow along the bottom.

The oxygen situation has become increasingly problematic as large inflows don’t occur every year and due to an escalating eutrophication in the 1980-1990s. As the conditions of oxygen deficiency last longer and more organic matter is supplied the deep water areas affected by low oxygen conditions spreads and a pool of hydrogen sulphide is formed in the central deep basin. This pool of hydrogen sulphide either needs to be oxidised by oxygen rich inflowing water or pushed to above the permanent stratification where oxygen is available before a new inflow can have any effect on the oxygen concentrations. The oxygen problem escalates further by on-going eutrophication, algal blooms and internal processes. During oxygen free condition sediments release nutrients, such as phosphate and silicate, to the water column, which, due to vertical mixing, 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 the oxygen depletion as the bloom sinks to the bottom and consume oxygen when it is decomposed.

All these natural factors in combination with external pressures on the Baltic Sea form the basis for the increasingly problematic low-oxygen conditions and the “dead zones” that are 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.

Anoxia is the condition when all oxygen has been consumed by microbial processes and no oxygen is left in the water. If the water stays anoxic for a longer period of time hydrogen sulphide (H_2S) is formed, which is toxic for all higher marine life. Only bacteria and fungi can survive in a water environment with total absence of oxygen.

Oxygen depletion or hypoxia occurs when dissolved oxygen falls below the level needed to sustain most animal life. The concentration at which animals are affected varies broadly and literature studies [Vaquer-Sunyer & Duarte, 2008] show that the threshold for hypoxia range from 0.2 ml/l to 2.8 ml/l. However, the sublethal concentration ranges from 0.06 ml/l to 7.1 ml/l. The mean and median for all experimental assessments was 1.8 +/- 0.12 ml/l and 1.6 +/- 0.15 ml/l respectively. The same study also suggests that the commonly used threshold for 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. Baltic cod has been shown to avoid oxygen concentrations below 1 ml/l [Schaber et al. 2012]. However, already at 4 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 hypoxia, in this report, is set to 2.0 ml/l.

This report presents a time series of the bottom areal extent and water volume of anoxic and hypoxic autumn conditions of the Baltic Proper, including the Gulf of Finland and the Gulf of Riga, for the period 1960 to 2019. The time series were first published in 2011 and the results have been updated annually as new additional data have become available at ICES [ICES,2009]. In the report from 2011 a distinct regime shift in the oxygen situation in the Baltic Proper was found to occur around 1999. During the first regime, 1960-1999, hypoxia affected large areas while anoxic conditions were found only in minor deep areas. After the regime shift in 1999, both areal extent and volume of anoxia have been constantly elevated to levels that only occasionally have been observed before 1999. [Hansson et. al, 2011]

The report includes maps of bottom areas affected by oxygen deficiencies during 2018 and 2019. The complete and updated time series from 1960 can be found as figures and maps at; http://www.smhi.se, which can be used as a climatological atlas describing the historical development and the present oxygen situation in the Baltic Proper.

2 Data

2.1 Oxygen data

The results for 2019 are preliminary and based on oxygen data collected during the annual trawl surveys in the Baltic 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, Russia, Poland, Denmark and Sweden.

These data have not been fully quality controlled; only preliminary checks have been performed. The time series and the results presented for 2019 will be updated when additional data are reported to ICES in late 2020. In this report the results for 2018 have been updated with all available data collected at ICES.

Data from the ICES 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]. The results, as accumulated inflow, from 1977 to present are presented at the SMHI web. For the years 2018 and 2019 see also Figure 5 and 6. [SMHI, 2020]

A continues time series of major inflow events to the Baltic Sea from 1887 to present was reconstructed using long term data series from the Belt Sea and the Sound by [Fischer & Matthäus, 1996]. This time series of major inflows has frequently been used for comparing the recent development with the past. Several updates have also been done since the first publication (Figure 1). However, a recent publication comparing this time series with new calculations using sea level, river discharge and salinity from the Belt Sea and the Sound suggests that there is a significant difference due to lack of appropriate data between 1976 and 1991 and the change in observations afterwards, which cause a bias in the inflow statistics, missing weak and moderate inflows. [Volker 2018]

The newly published time series for inflows to the Baltic Sea presents the amount of salt transported and flow into the Baltic Sea. The two time series can be compared in Figure 1. Note that the figure has not been updated with data from 2019 since it is not yet available. However, no major inflows were recorded through the Danish straits during 2019 [Pers. Comm. M. Naumann, IOW, 2020-01-29)

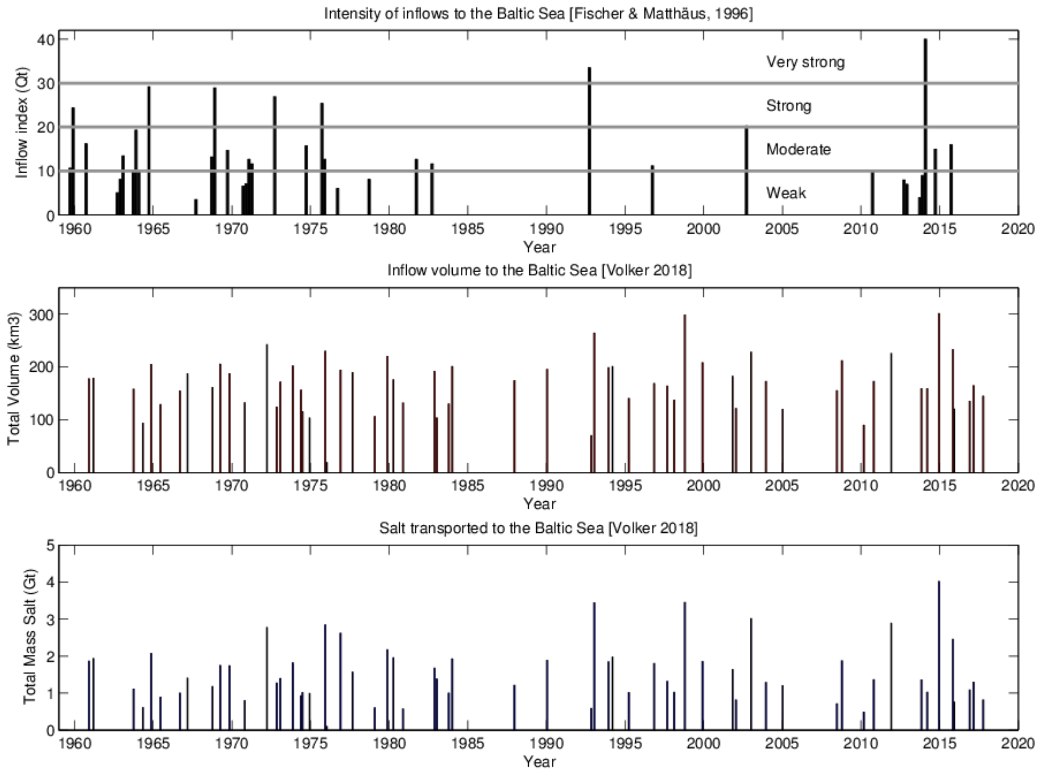

Figure 1. Two different estimations of major inflow to the Baltic Sea. Top: Intensity of inflows to the Baltic Sea, 1960-2018. [Fischer & Matthäus, 1996, Mohrholz et al. 2015, Feistel et al. 2016] Revised and updated. Middle and Lower: Total volume and salt transport to the Baltic Sea for inflows that last more than 5 days [Volker 2018].

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 station profiles had to be filtered out: for example when data was missing in the deep water or when questionable data were found.

The depths of the onset of hypoxia and anoxia were gridded with linear interpolation (Delaunay triangulation) between sampling stations, producing a surface representing the depth at which hypoxic and anoxic conditions are found. The surface has then been compared with bathymetry data, [Seifert, 2001] see Figure 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 have been calculated for each year.

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

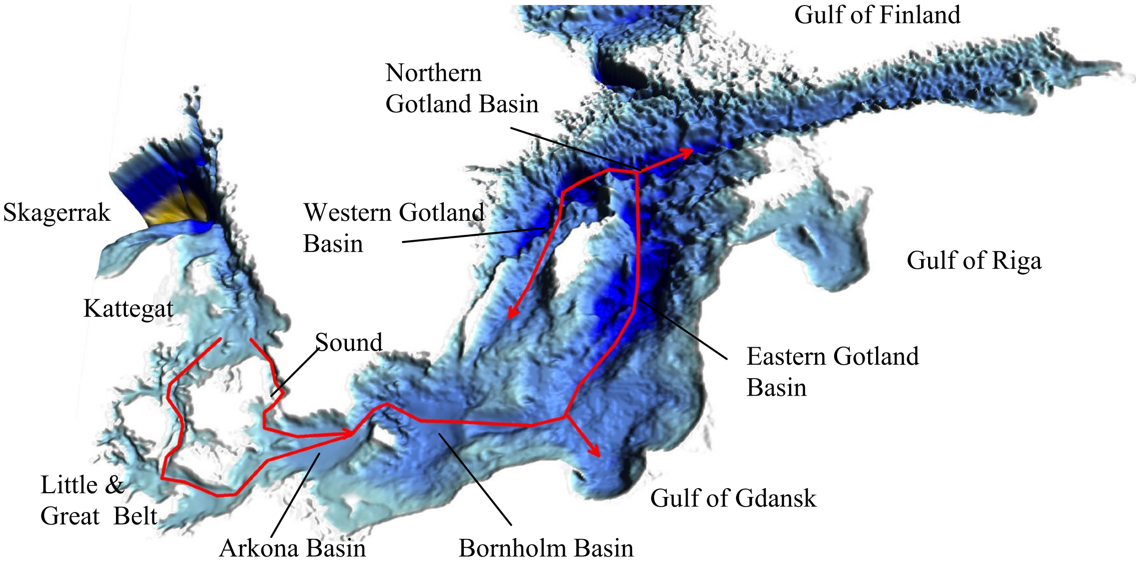

Figure 2. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathways of inflowing deep water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk, the Gulf of Riga and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

4 Result

Extent and volume affected by hypoxia and anoxia during the period 1960 - 2019 are presented in Figures 3 and 4, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2018 and 2019 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 2019 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. Note that the results for 2019 are preliminary.

in %	1960 – 1998		1999 – 2018		2019	
	Hypoxia	Anoxia	Hypoxia	Anoxia	Hypoxia	Anoxia
Mean Areal extent	22	5	29	16	32	22
Max Areal extent (Year)	27 (1970)	14 (1969)	33 (2018)	24 (2018)	-	-
Mean Volume	13	2	19	9	22	14
Max Volume (Year)	19 (1965)	8 (1969)	22 (2018)	15 (2018)	-	-

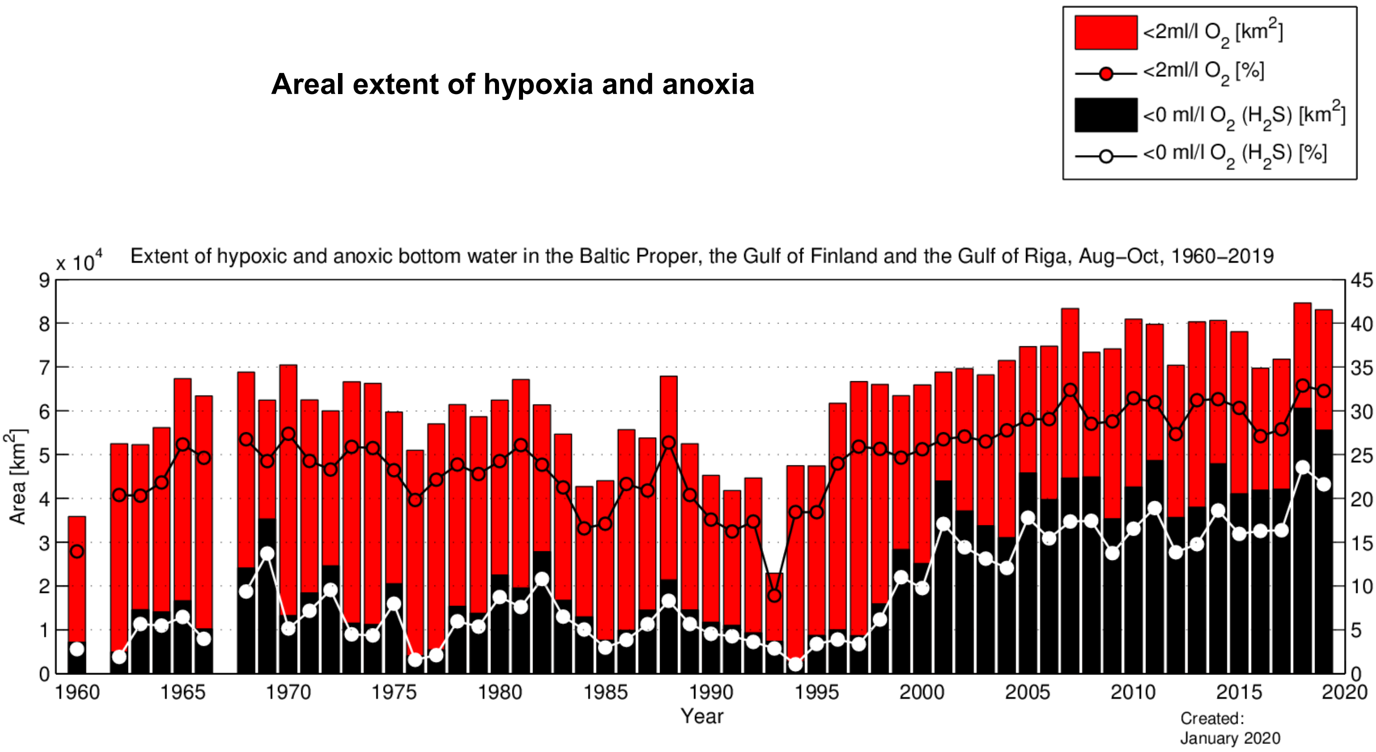

Figure 3. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

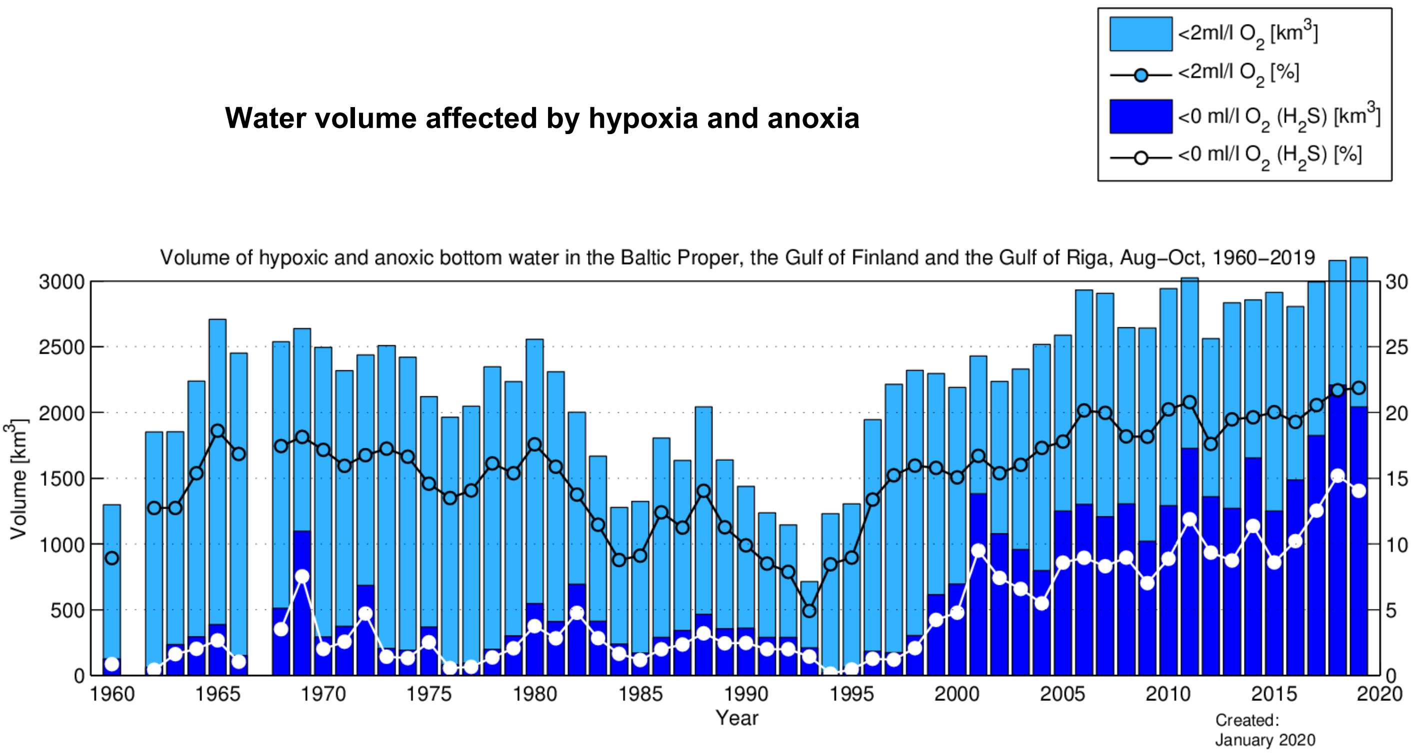

Figure 4. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

4.1 Updated results for 2018

As additional data has been reported to ICES the results for 2018 was updated. The anoxic areas in the Gulf of Finland and Gulf of Gdansk increased and new areas were found in the northern parts of the Baltic Proper. Hypoxic areas showed similar small changes.

The proportion of areas affected by anoxia increased after the update (22% to 24%). However, as different areas were affected, the volume did not show any changes and remained on 15%.

The 2018 updated results confirm the preliminary results that the areas and volumes of anoxia was the largest that has been recorded during the investigated period 1960-2018. The proportion of areas suffering from hypoxia did also increase after the update, from 32 to 33%, and the volume from 20-22%. The updated results for 2018 follow the oxygen development that has prevailed since the regime shift in 1999. New areas affected have been found in the southern Baltic Proper; in the Hanö Bight, the Bornholm Basin and Gulf of Gdansk. The reason for the large area and volume of anoxia, in the Baltic Proper and in these new areas, during 2018 is still not clear but the extremely warm and calm weather during the spring and summer might have favoured extremely high biological production [Rehder G, 2018], resulting in a larger proportion of organic material to be degraded in the deep water during the late summer and autumn.

The total outflow from the Baltic Sea through the Sound during 2018 was 645 km^3, which is somewhat larger than normal when compared to the time period 1977-2017 (623 km^3). During 2018 there were a few inflows that were large enough to improve the oxygen situation temporarily in the southern Baltic Proper. A small inflow through the Sound was noted in mid-June (~20 km^3) and later in mid-September a larger inflow (~40 km^3) occurred. Another inflow through the Sound (~30 km^3) was recorded in the beginning of December.

The inflow through the Sound during 2018, compared to the mean inflow 1977-2019, gives that outflow from the Baltic Sea prevailed. See Figure 5 that show the accumulated inflow volume through the Sound (Öresund), where the inflow curve of 2018 runs below the mean of the reference period 1977-2019 during the whole year.

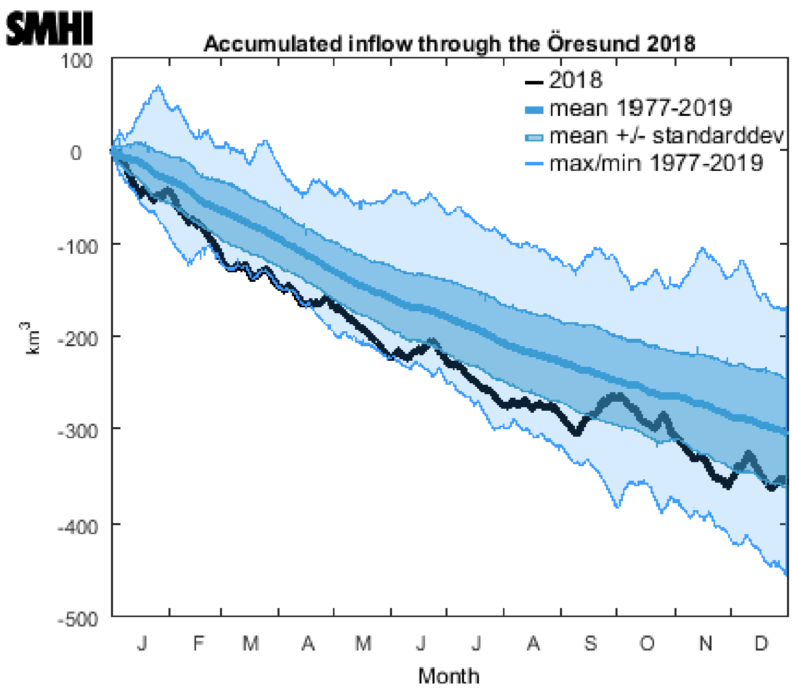

Figure 5. Accumulated inflow (volume transport) through the Sound (Öresund) during 2018 in comparison to mean inflow/outflow 1977-2019 [SMHI, 2020].

4.2 Preliminary results for 2019

The frequency of inflows to the Baltic Sea increased during the period 2014-2016, but during 2017-2018 only minor inflows was observed. Similarly in 2019, no large inflows were noted.

Only a few inflow events occurred in 2019. Three events in July, August and September of ~20 km^3 each was registered through the Sound. The event in beginning of July was also noted through the Danish Straits and had a total volume of 156 km^3 but the salinity was low and only minor high saline water was pushed into the Baltic Proper. [Pers. Comm. M. Naumann, Jan 2020].

The largest inflow in 2019 occurred from the end of November to mid-December. About 40 km^3 water flowed through the Sound (194 km^3 through the Danish Straits [Pers. Comm. M. Naumann, Jan 2020]). See also Figure 6 below.

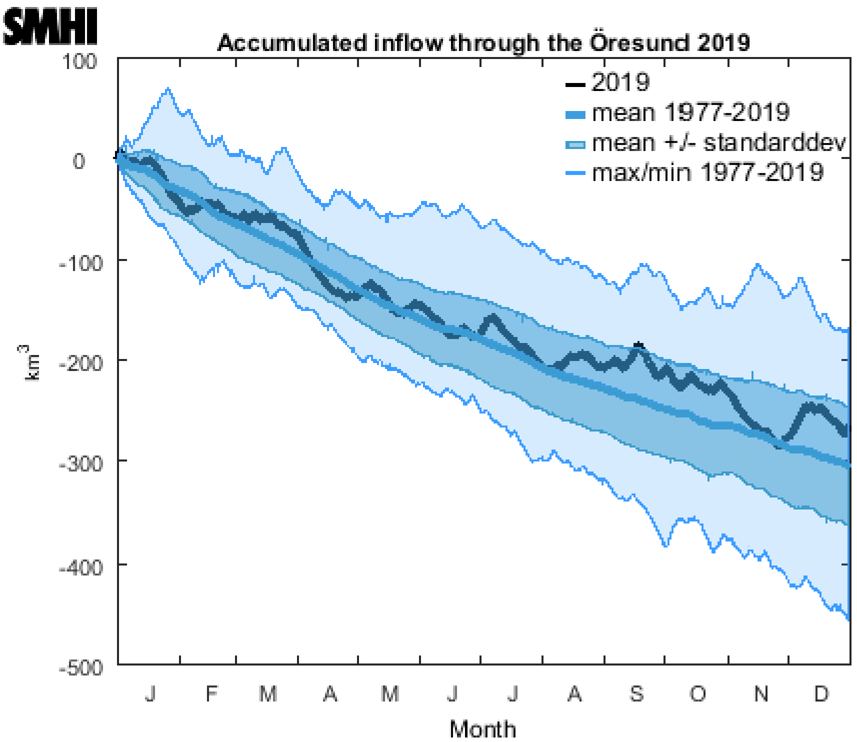

Figure 6. Accumulated inflow (volume transport) through the Sound (Öresund) during 2019 in comparison to mean inflow/outflow 1977-2019. [SMHI, 2020]

In comparison with 2018, the year with the most widespread anoxic and hypoxic conditions since the 1960s, the oxygen situation in the deep water was similar but with somewhat smaller areas affected in 2019.

In the Arkona Basin the oxygen situation in the deep water followed the annual cycle with well oxygenated conditions during winter and spring, followed by decreased oxygen concentrations during summer and reaching the minimum oxygen concentrations and hypoxia (< 2ml/l) in August to October. In December the oxygen concentrations improved, due to inflow events. During late spring and summer the oxygen concentrations in the bottom water was higher than normal, probably due to summer inflow events. [SMHI, 2019 and Figure 6]

The oxygen conditions in the bottom water at Hanö Bight were near anoxic with oxygen concentrations close to 0 ml/l throughout the year. Anoxic conditions, with hydrogen sulphide present, were found during late summer and in December. Hypoxia was generally found from depth exceeding 60 meters, which is about 10 meter higher up in the water column than normal.

In the Bornholm Basin hypoxia was found from depth exceeding 60-70 meters and anoxia or close to 0 ml/l from about 80 meters depth throughout the year. Signs of improvement in the bottom were only observed in January at BY4 as the bottom oxygen concentration increase to about 4 ml/l. However, already in February the conditions were below 2 ml/l again.

At the station BCSIII-10, further into the southern Baltic Proper, anoxic condition or oxygen concentrations close to 0 ml/l were found from 80 meter depth throughout the year. Hydrogen sulphide that was observed from June to October in 2018 was now observed only in August. In September an inflow improved the conditions from anoxic to about 2 ml/l but the following month the conditions deteriorated back to almost anoxic. Historically, anoxic conditions at BCSIII-10 are rare and the oxygen conditions in the bottom water were lower than normal throughout most parts of the year; i.e. from January to August.

At the Gotland Deep (BY15) in the Eastern Gotland Basin hypoxic followed by anoxic conditions or close to zero oxygen started to appear from approximately 70-80 meters depth. Below 150 meters hydrogen sulphide was present throughout the year and the concentrations of hydrogen sulphide was higher than normal. From 90 to 150 meters depth small increases in oxygen could be seen during some months due to inflows at intermediate depths. In February a small increase in oxygen was observed at 110 meters depth. In June a larger increase was noted between 100-150 meters depth with oxygen concentrations up to 1.5 ml/l oxygen. The following month this oxygenated layer became smaller and with lower oxygen concentration. In December oxygen concentrations around 0.5 ml/l was found at depth ranging from 90-125 meters. See Figure 7, Appendix 1 and SMHI cruise reports from 2019. [SMHI, 2019]

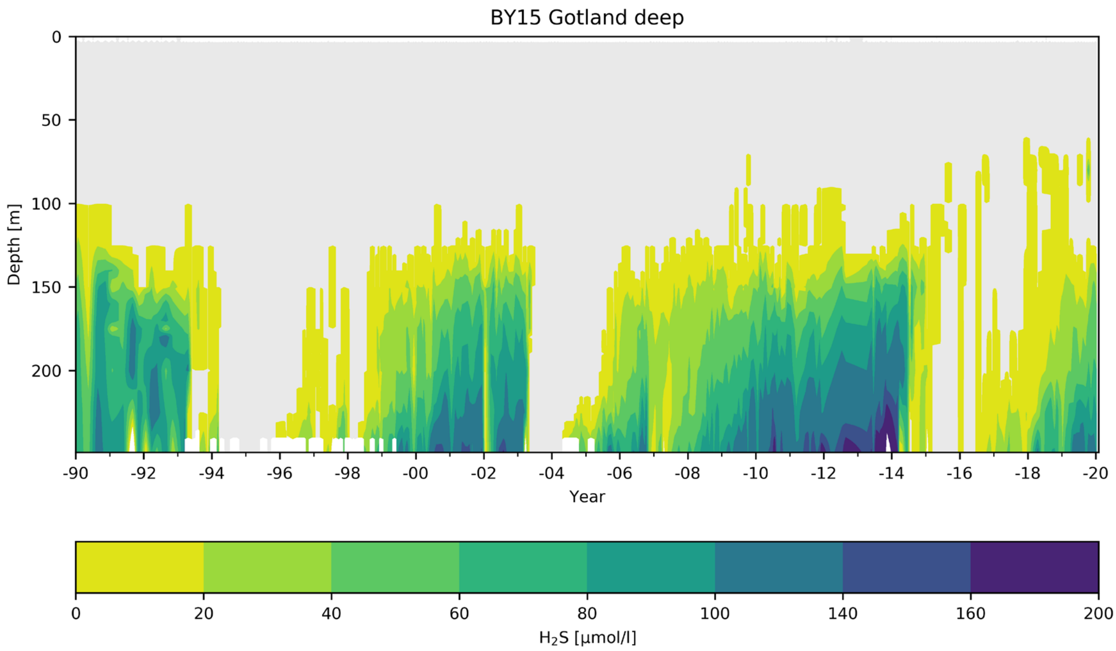

Figure 7. Concentration of hydrogen sulphide (H_2S) at Gotland Deep (BY15) in Eastern Gotland Basin from 1990-2020. Grey signifies no hydrogen sulphide present.

The Northern Gotland Basin and the Eastern Gotland Basin show similar development in the deep water. However, the signs of the inflows at intermediate depths are faint. The concentration of hydrogen sulphide in the deep water also show values elevated above what is normal throughout the year.

The severe stagnation in the Western Gotland Basin continues with high concentrations of hydrogen sulphide. Anoxic conditions were found from 70-80 meters depth and hypoxia from 60-70 meters depth throughout the year. [SMHI 2019]

The preliminary results for 2019 suggest that the severe oxygen situation that has prevailed since 1999 continues. A new trend seems to be that the area and volume affected of hypoxia and anoxia has reached another elevated level, starting with the record year 2018 followed by 2019 that show results in the same range. The increase can be found both in hypoxia and anoxia but it's the areas and volume affected by anoxic conditions that has increased the most. In the southern basins of the Baltic Proper, such as the Gulf of Gdansk, Hanö Bight and in the Bornholm Basin, hypoxia has been dominating but anoxia is now found regularly in the deep water. The smaller increase in hypoxia is strongly connected to the position of the permanent stratification in the Baltic Proper that separates oxygenated and hypoxic water. Hence, hypoxia cannot increase over this natural limit, while anoxic conditions can increase in the water column up to the permanent stratification.

It should be noted that the 2019 results are preliminary; however the results are based on an extensive data set with essential data contributions from most countries around the Baltic region. Please see the Acknowledgement for all helpful data contributors.

5 Conclusions

- Similar to previous year, the severe oxygen conditions in the Baltic Proper continued during 2019. The areal extent and the volume of anoxia and hypoxia have since the regime shift in 1999 been constantly elevated.

- The anoxic and hypoxic areas in 2018 were the largest noted during the analysed period starting 1960. Anoxic conditions affected ~24% of the bottom areas and about 33% suffered from hypoxia.

- The increase of area and volume in 2018 are mainly due to new areas being affected, such as the Gulf of Gdansk, Hanö Bight and the Bornholm Basin. In these basins hypoxia has been found previously but anoxia is now regularly found in the deep water.

- The reason for the large area affected by anoxia/hypoxia during 2018 is still not clear but the extremely warm and calm weather during the spring and summer and the resulting large biological production might have enhanced the oxygen consumption in the deep water as organic material is degraded.

- Preliminary results for 2019 shows that anoxic conditions are in the same range as the record year 2018 with similar areas affected. Anoxic conditions affected ~22% of the bottom areas and about 32% suffered from hypoxia. The results from 2018-2019 could be the beginning of a new trend as the areal extent of anoxia has reached another stage and new areas are affected regularly.

- The latest series of inflows to the Baltic Sea occurred between 2014 - 2016. These inflows reduced the large pool of hydrogen sulphide that was present in the Eastern and Northern Gotland Basin. However, the pool of hydrogen sulphide is now increasing again.

- New major inflows are needed in combination with continuous efforts to reduce eutrophication to prevent further deterioration of the oxygen situation, with the formation of even higher hydrogen sulphide concentrations as a result.

6 Acknowledgement

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The ICES Dataset on Ocean Hydrography was used for updating the result for 2018. The data was collected at the excellent web service at the International Council for the Exploration of the Sea (ICES). Many thanks to the Else Juul Green at ICES for always professional and fast support.

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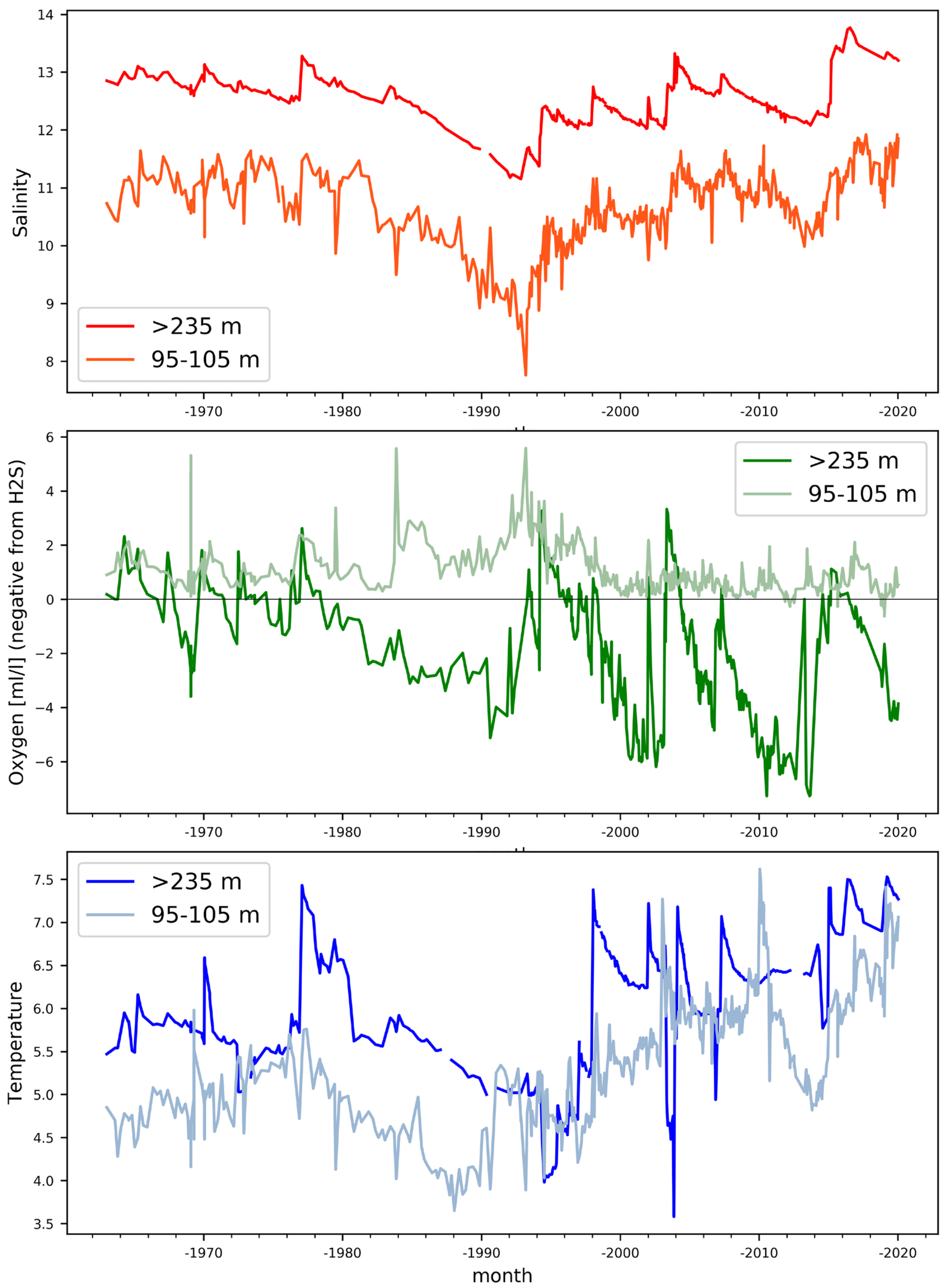
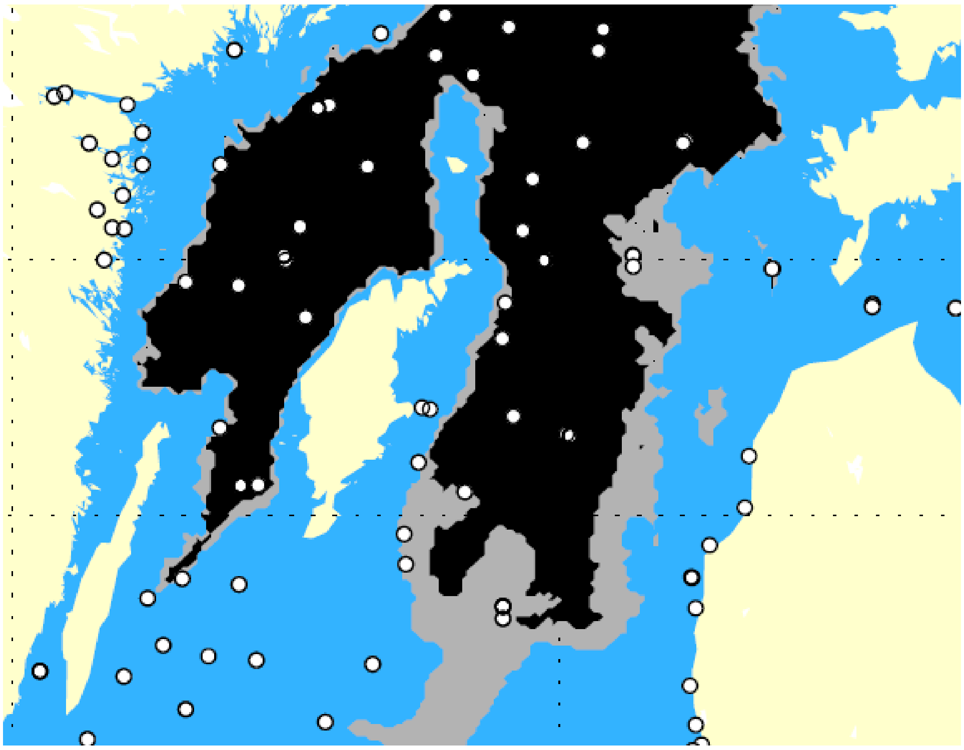
Appendix 1 – Temperature, salinity and oxygen in Eastern Gotland Basin at station BY15, 1960-2018

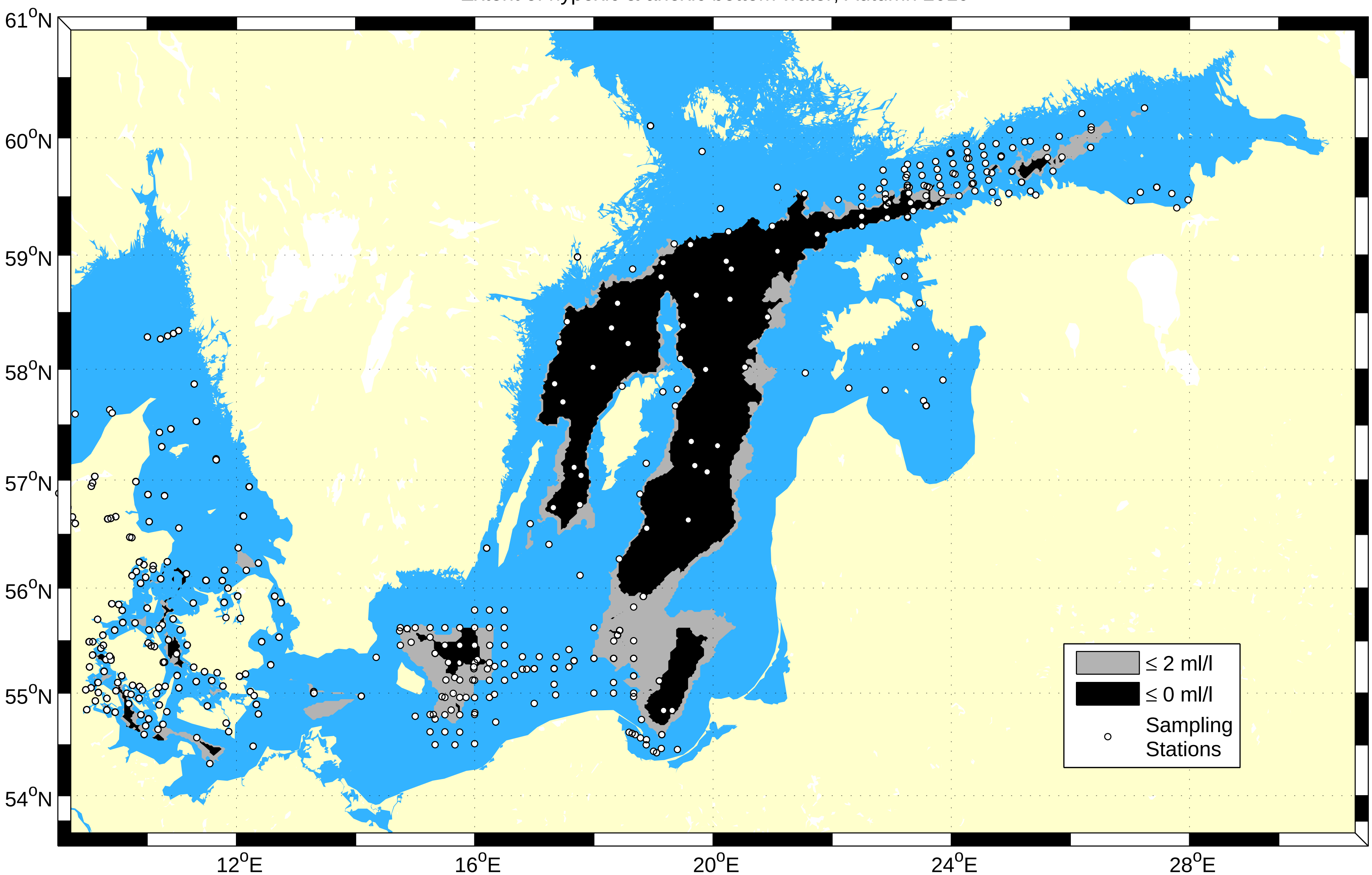


Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea

- updated maps 1960-2019



Extent of hypoxic & anoxic bottom water, Autumn 2019



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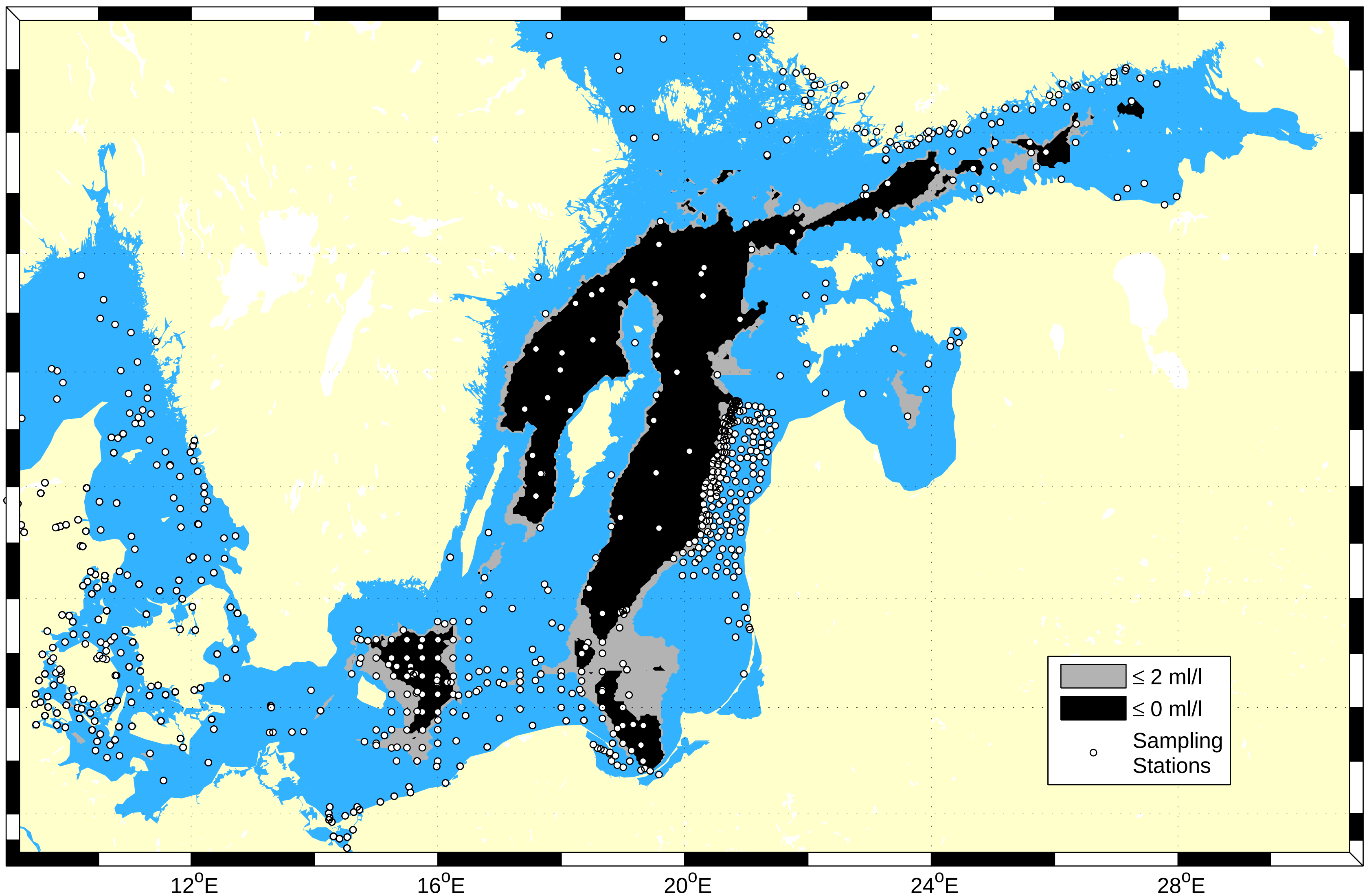
Extent of hypoxic & anoxic bottom water, Autumn 2018



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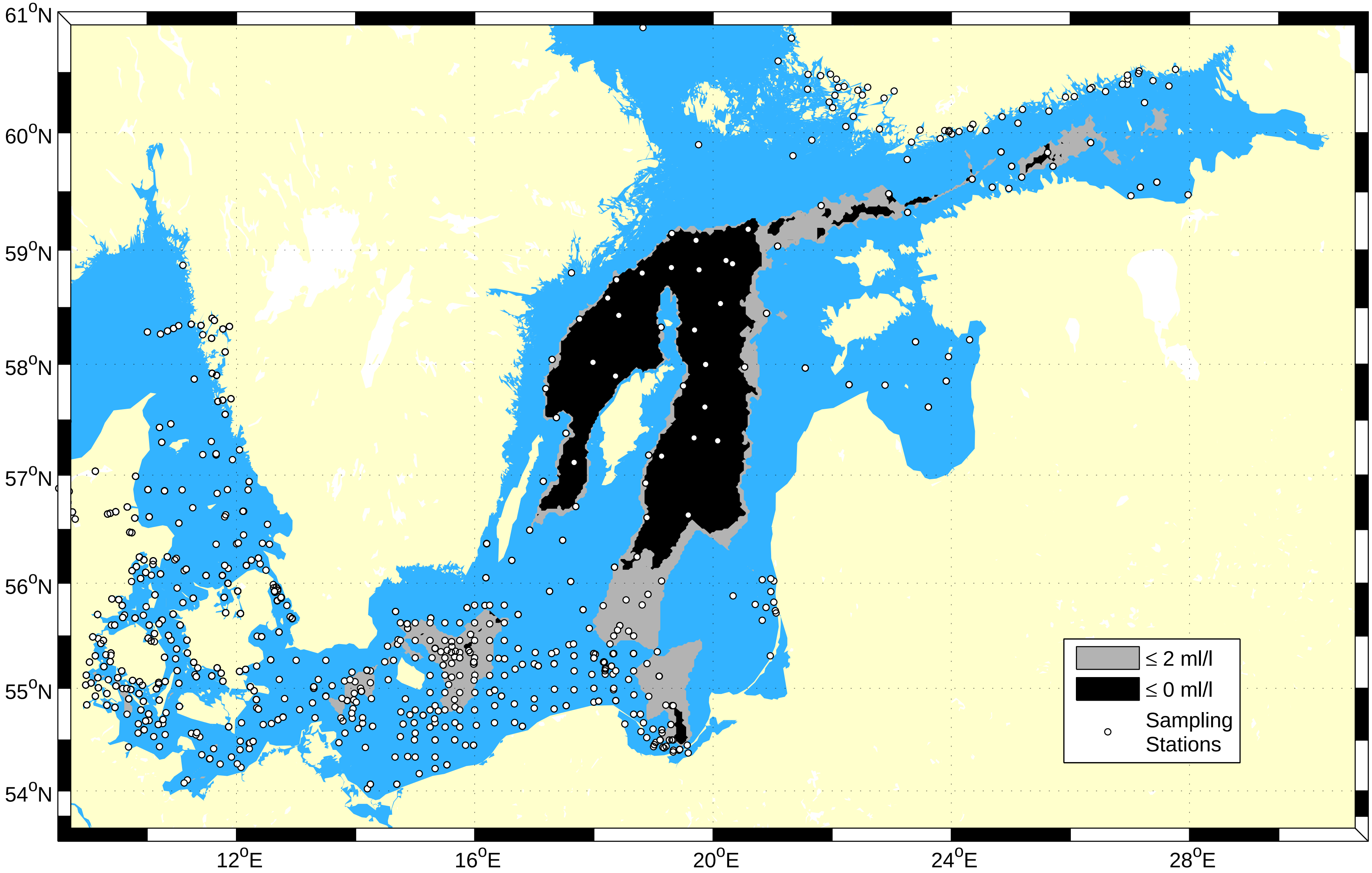
Extent of hypoxic & anoxic bottom water, Autumn 2017



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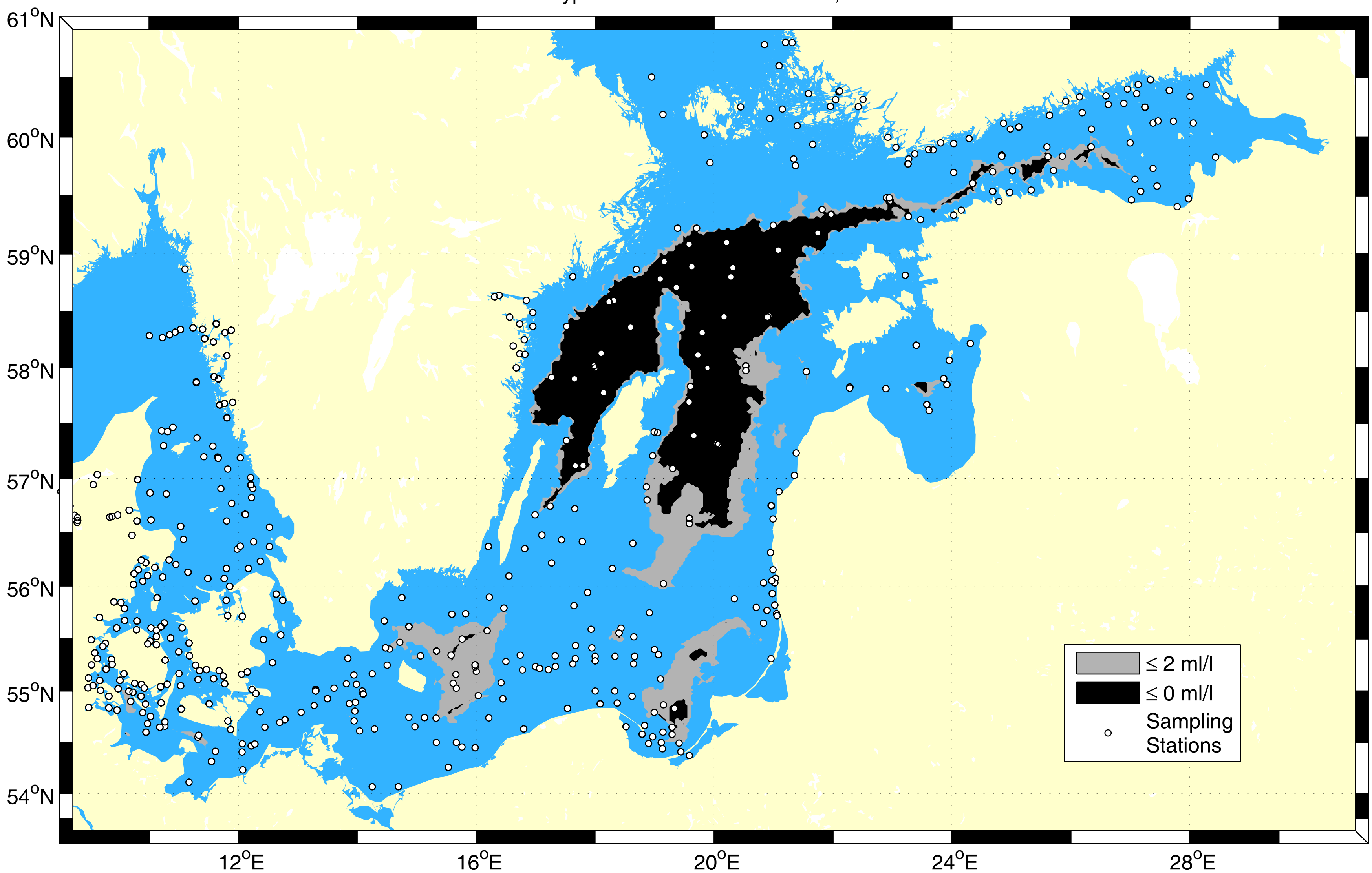
Extent of hypoxic & anoxic bottom water, Autumn 2016



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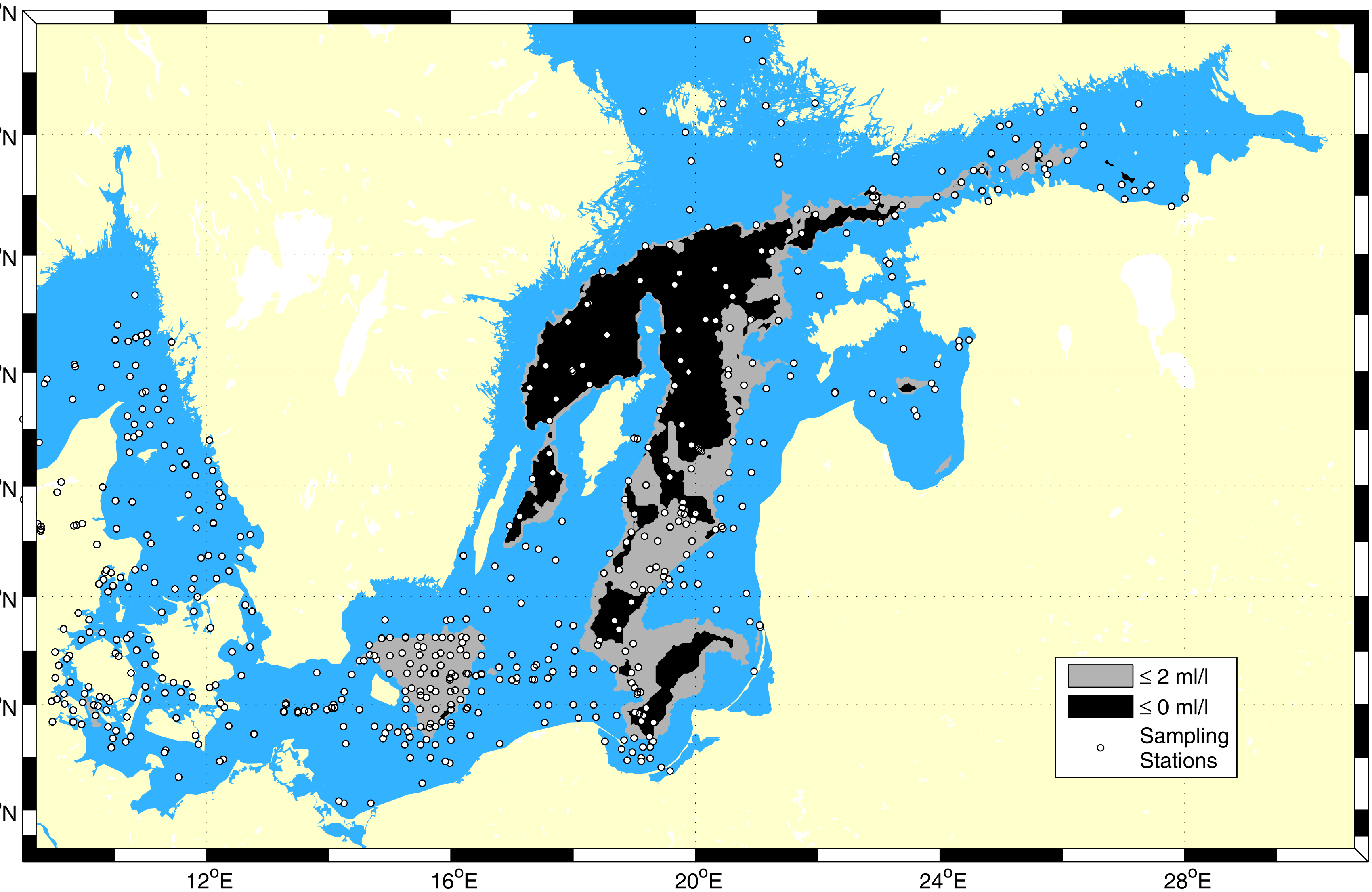
Extent of hypoxic & anoxic bottom water, Autumn 2015



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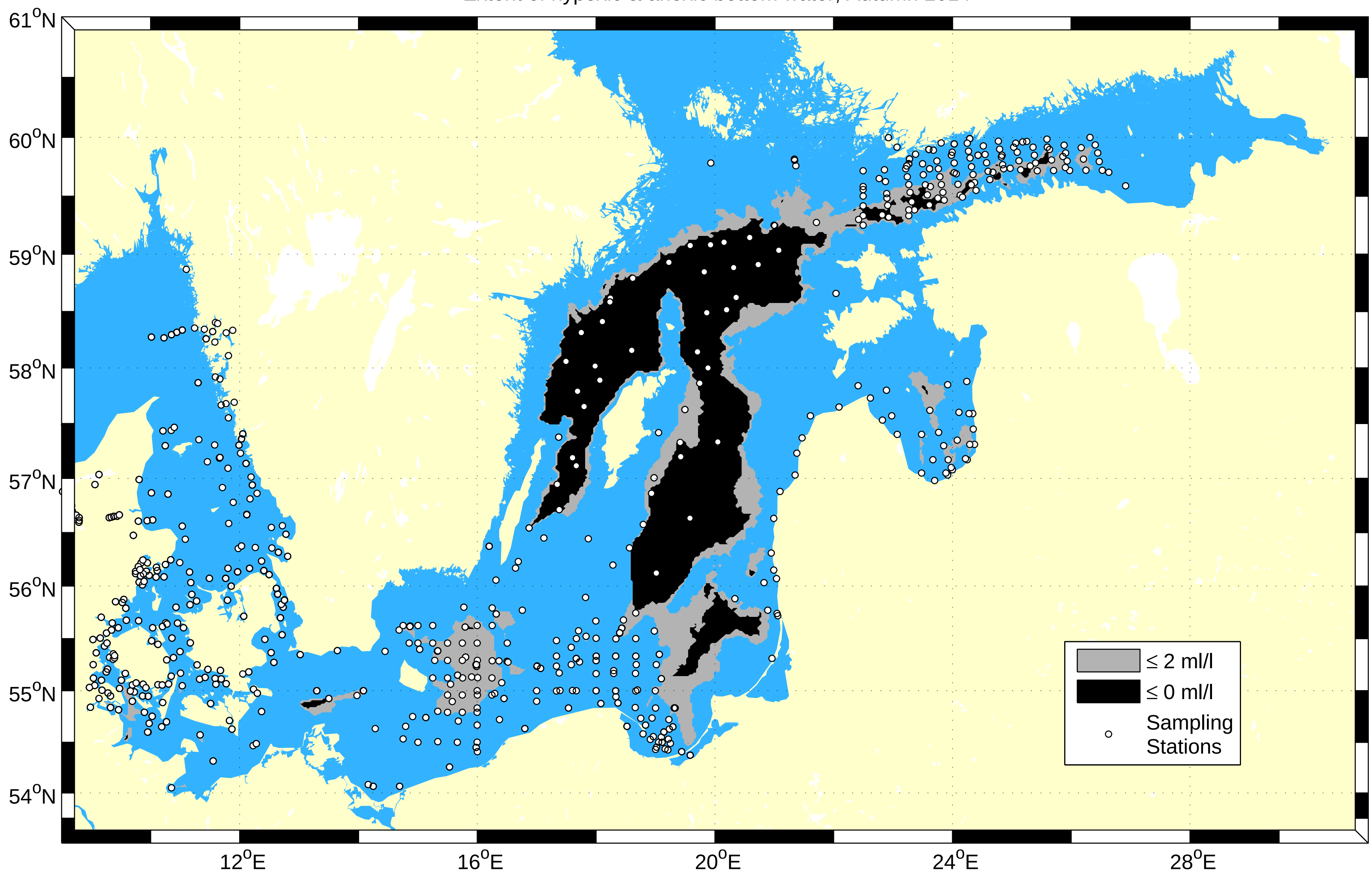
January
2017

Extent of hypoxic & anoxic bottom water, Autumn 2014



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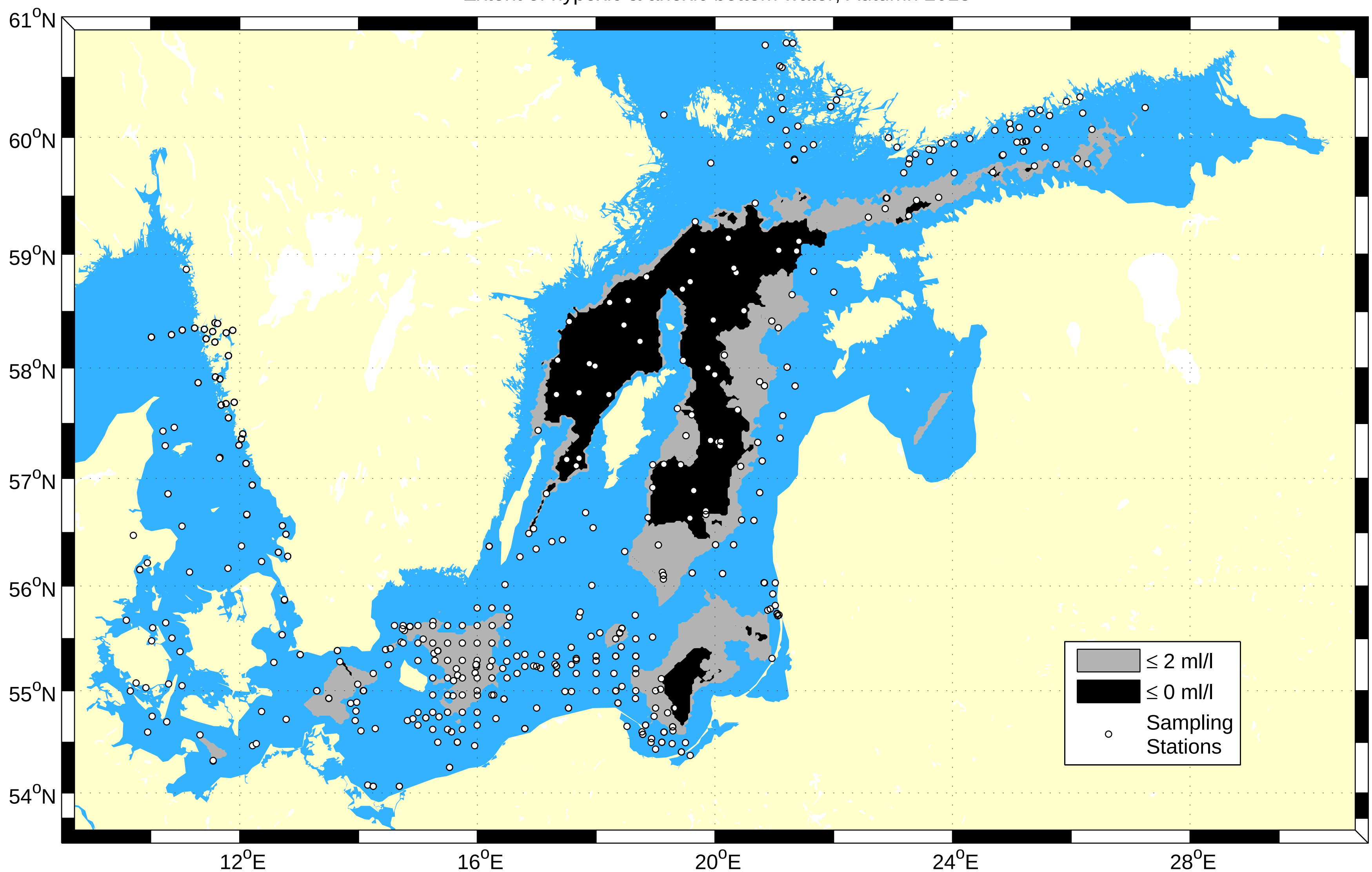
Extent of hypoxic & anoxic bottom water, Autumn 2013



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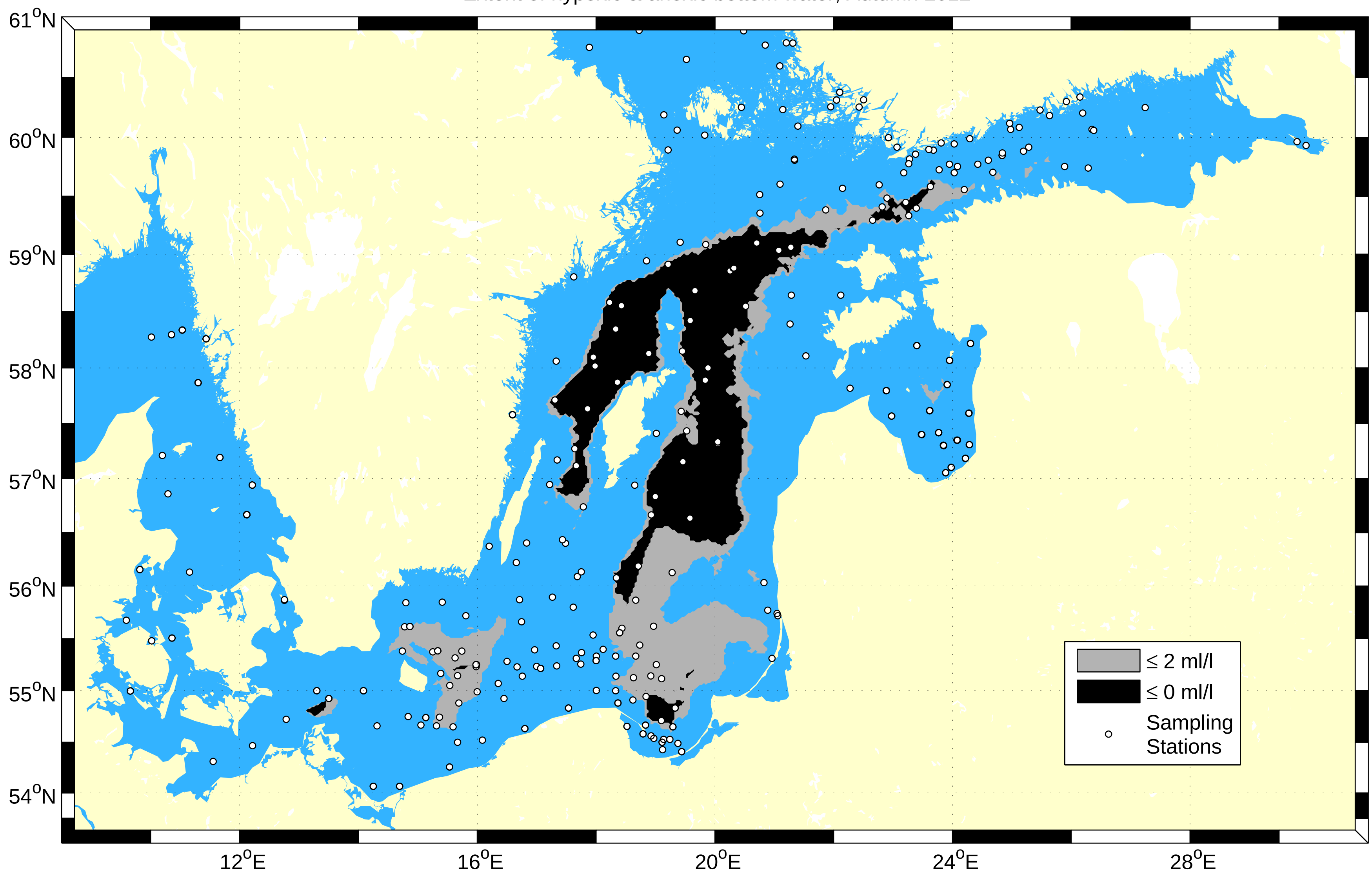
Extent of hypoxic & anoxic bottom water, Autumn 2012



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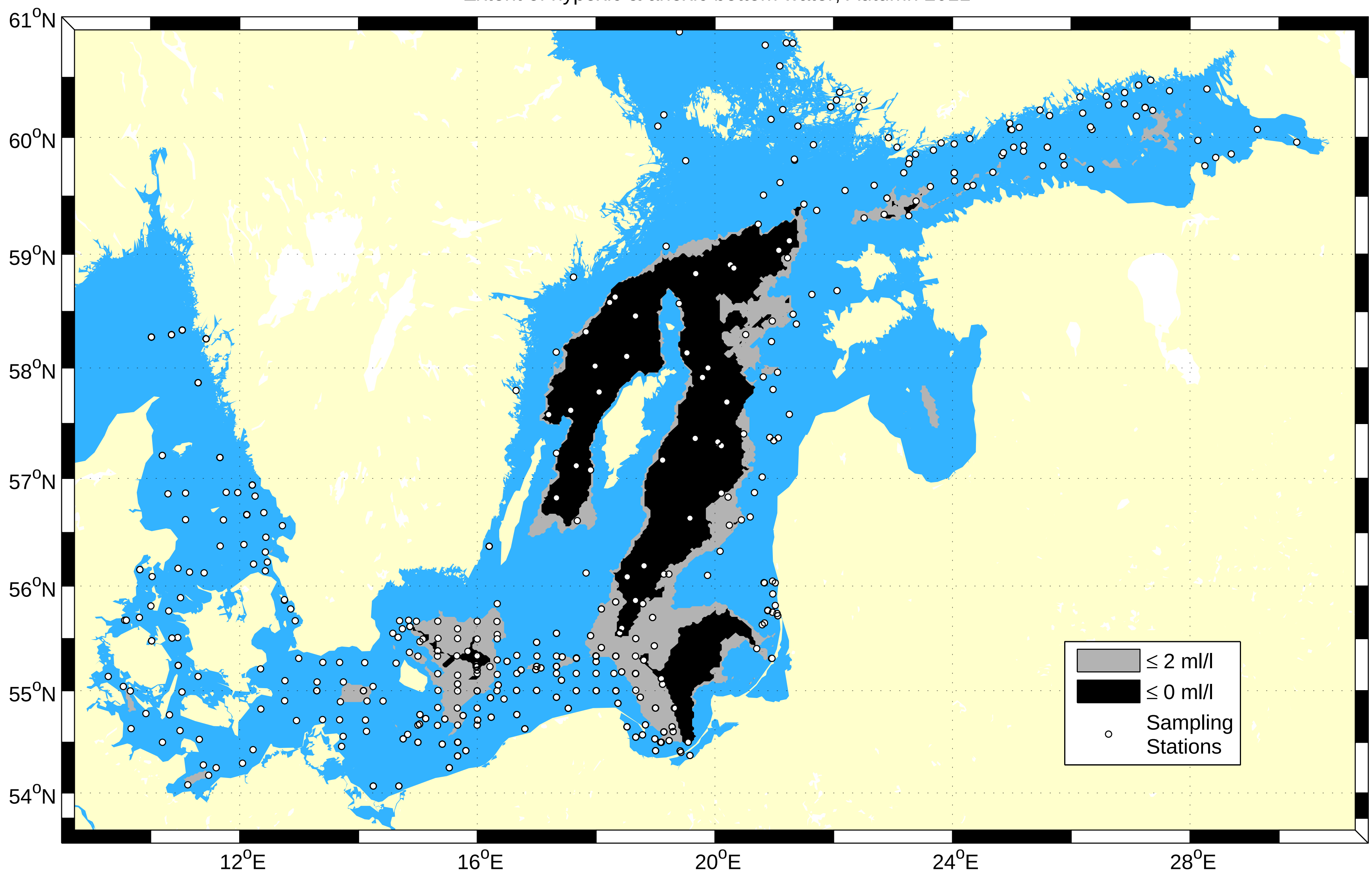

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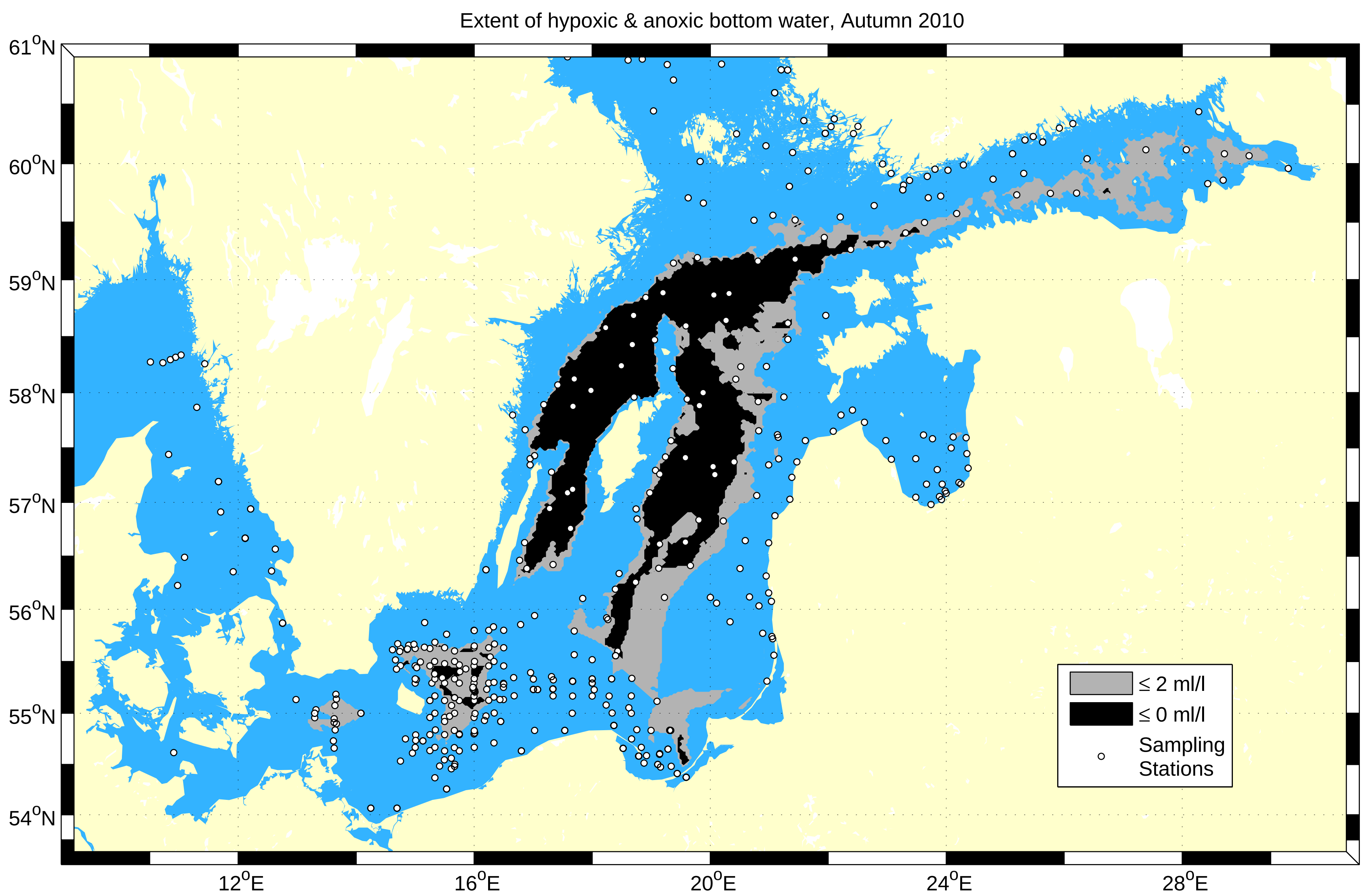

Extent of hypoxic & anoxic bottom water, Autumn 2010
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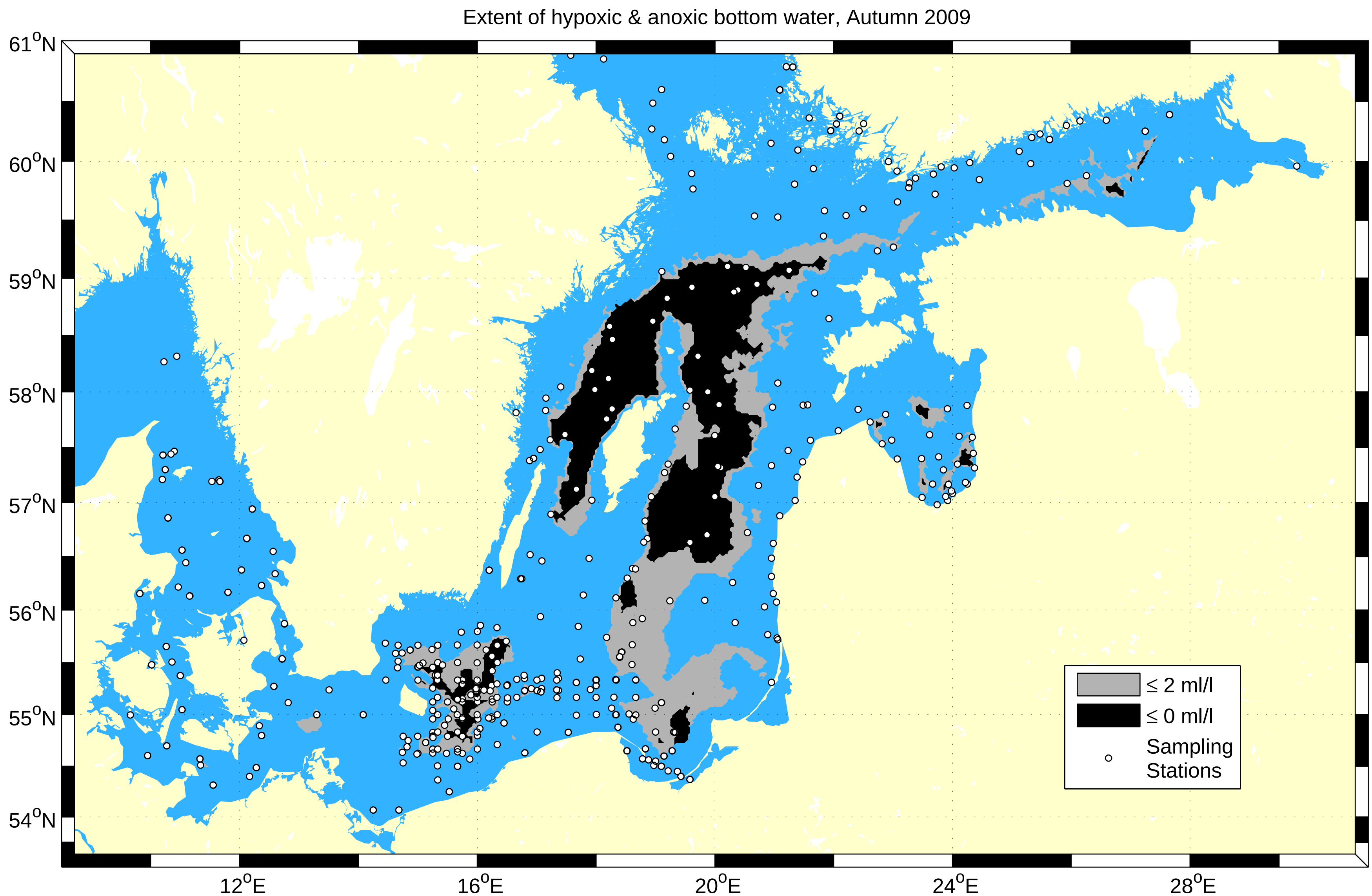
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations



Extent of hypoxic & anoxic bottom water, Autumn 2009
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60°N
59°N
58°N
57°N
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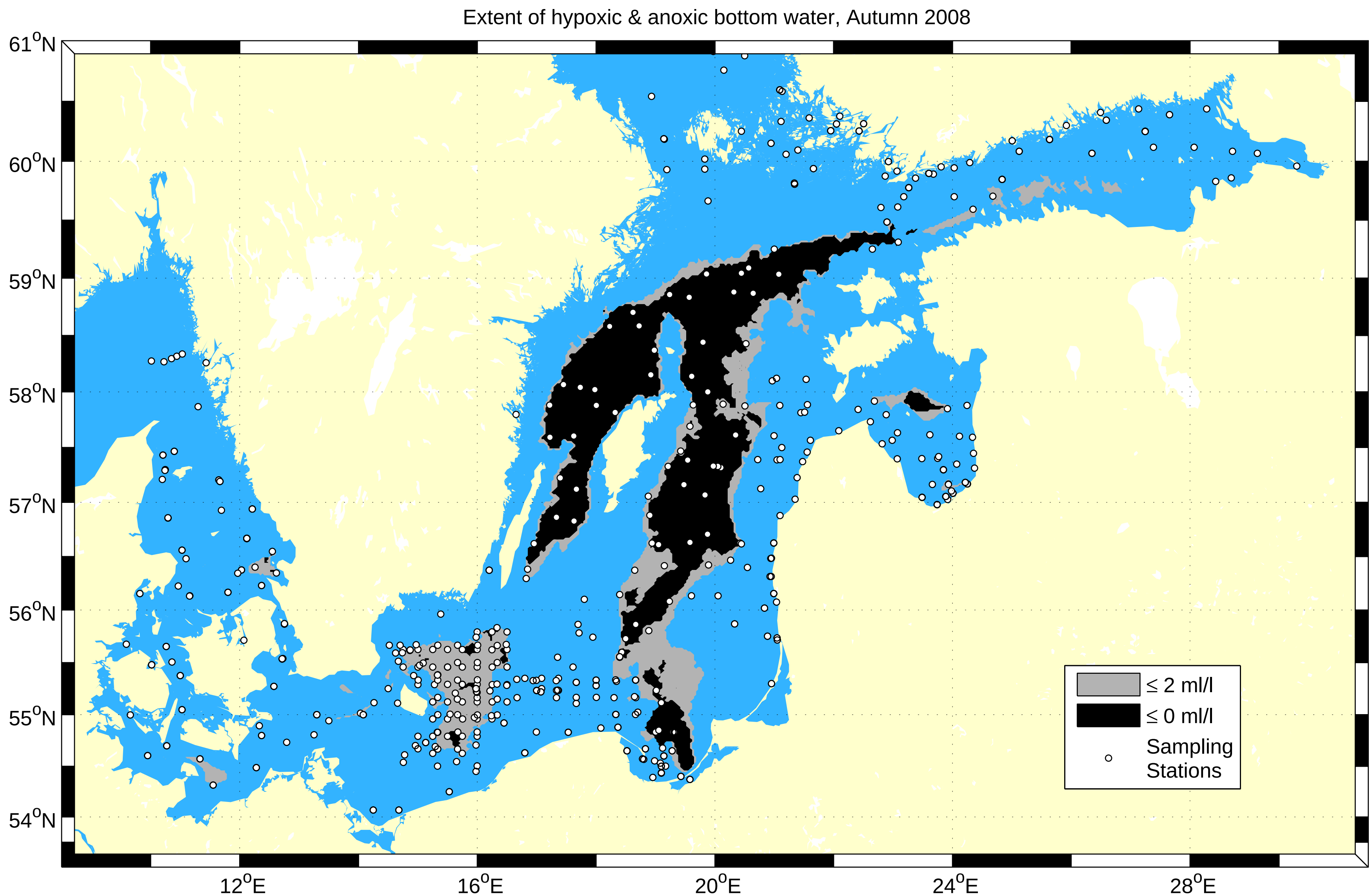
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations


Extent of hypoxic & anoxic bottom water, Autumn 2008
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57°N
56°N
55°N
54°N
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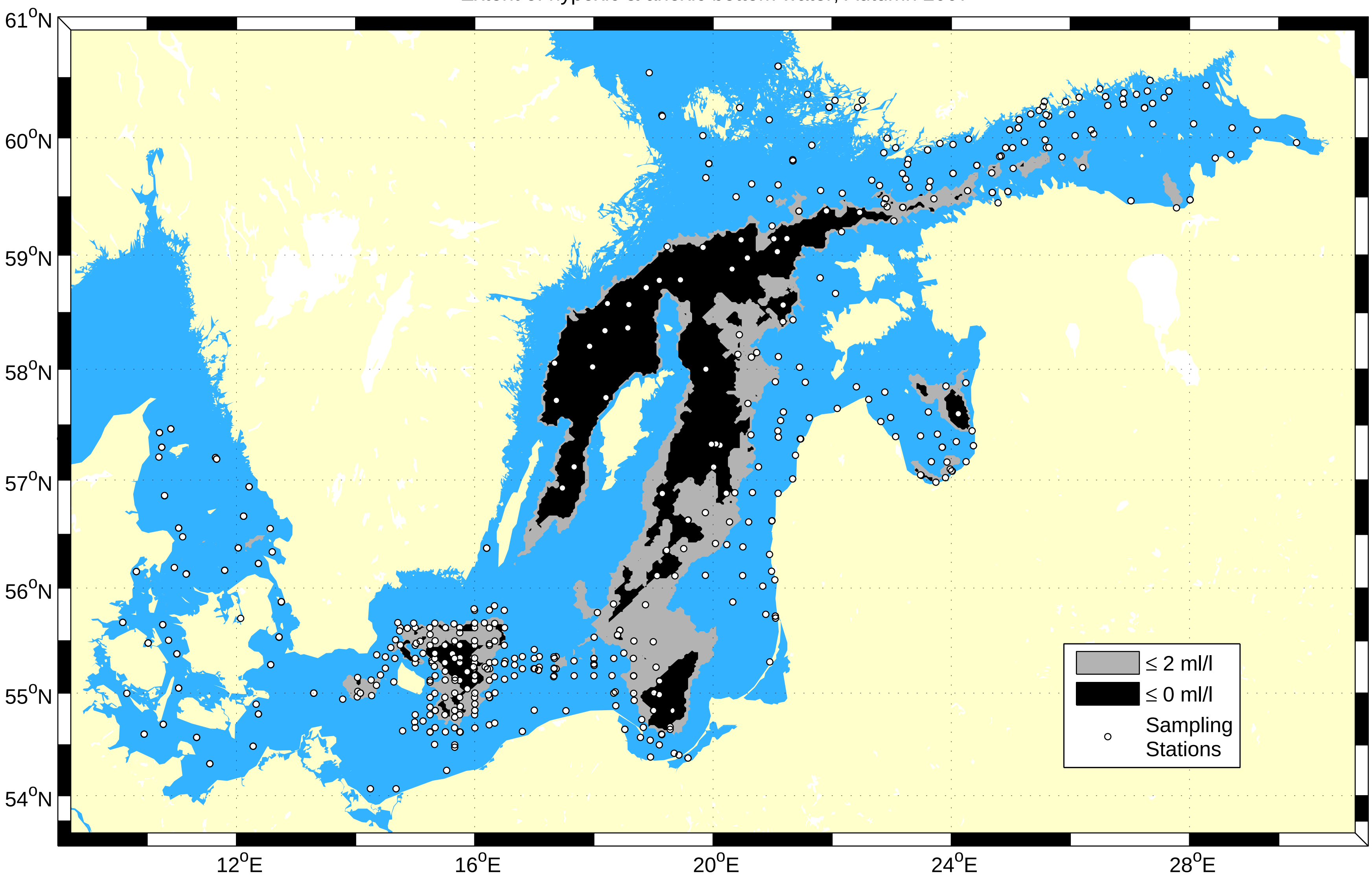
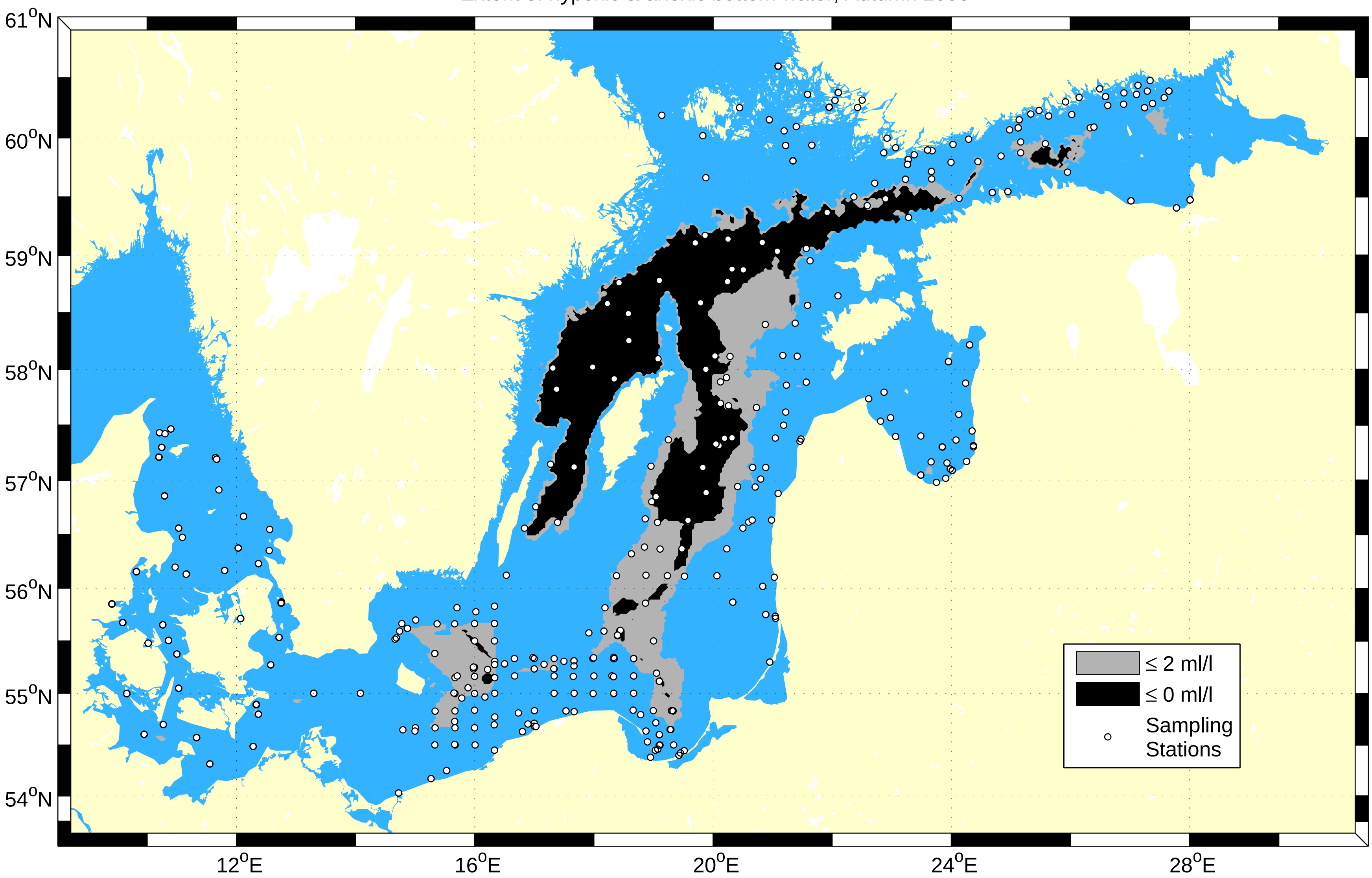
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

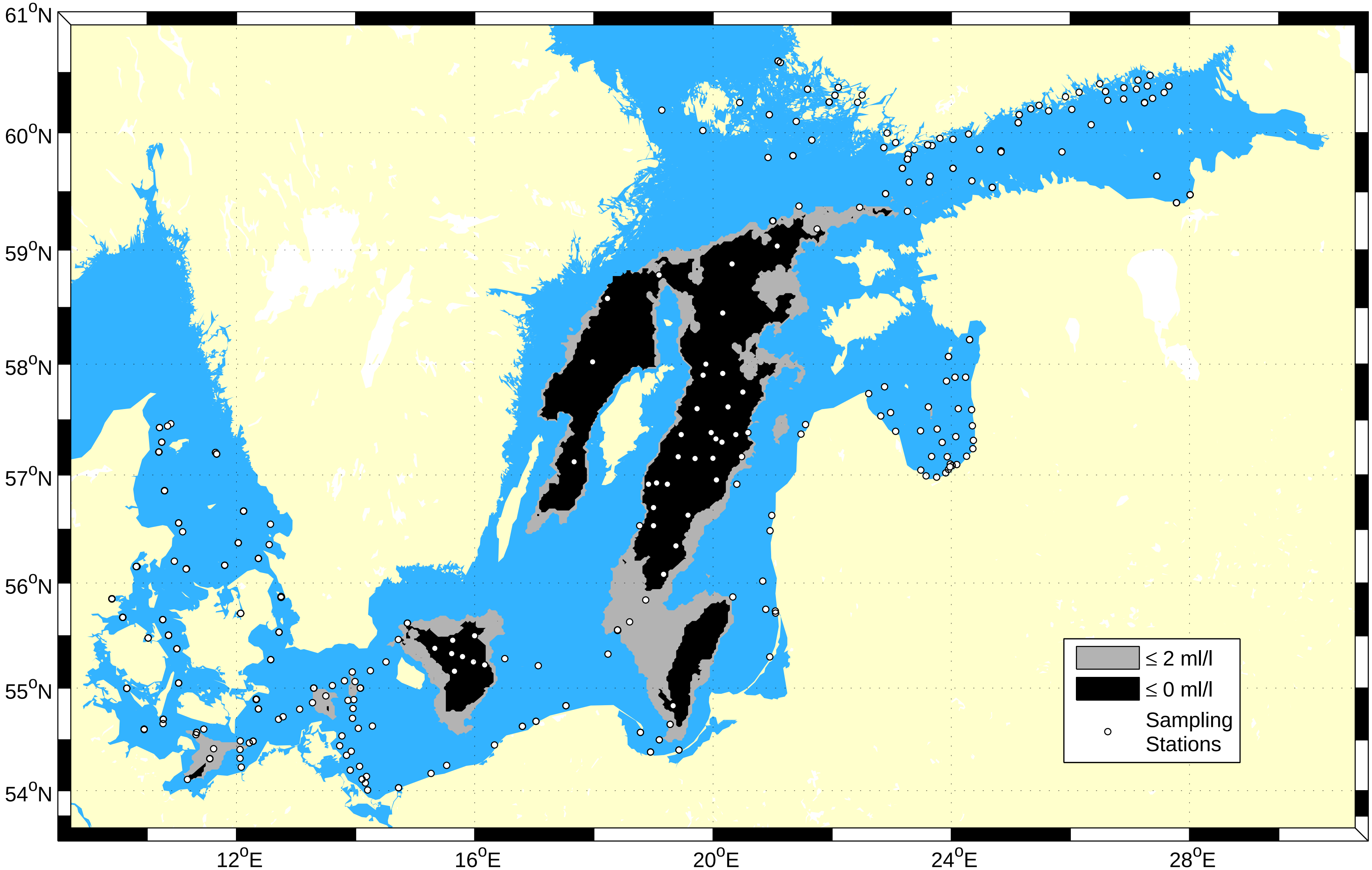
Extent of hypoxic & anoxic bottom water, Autumn 2007

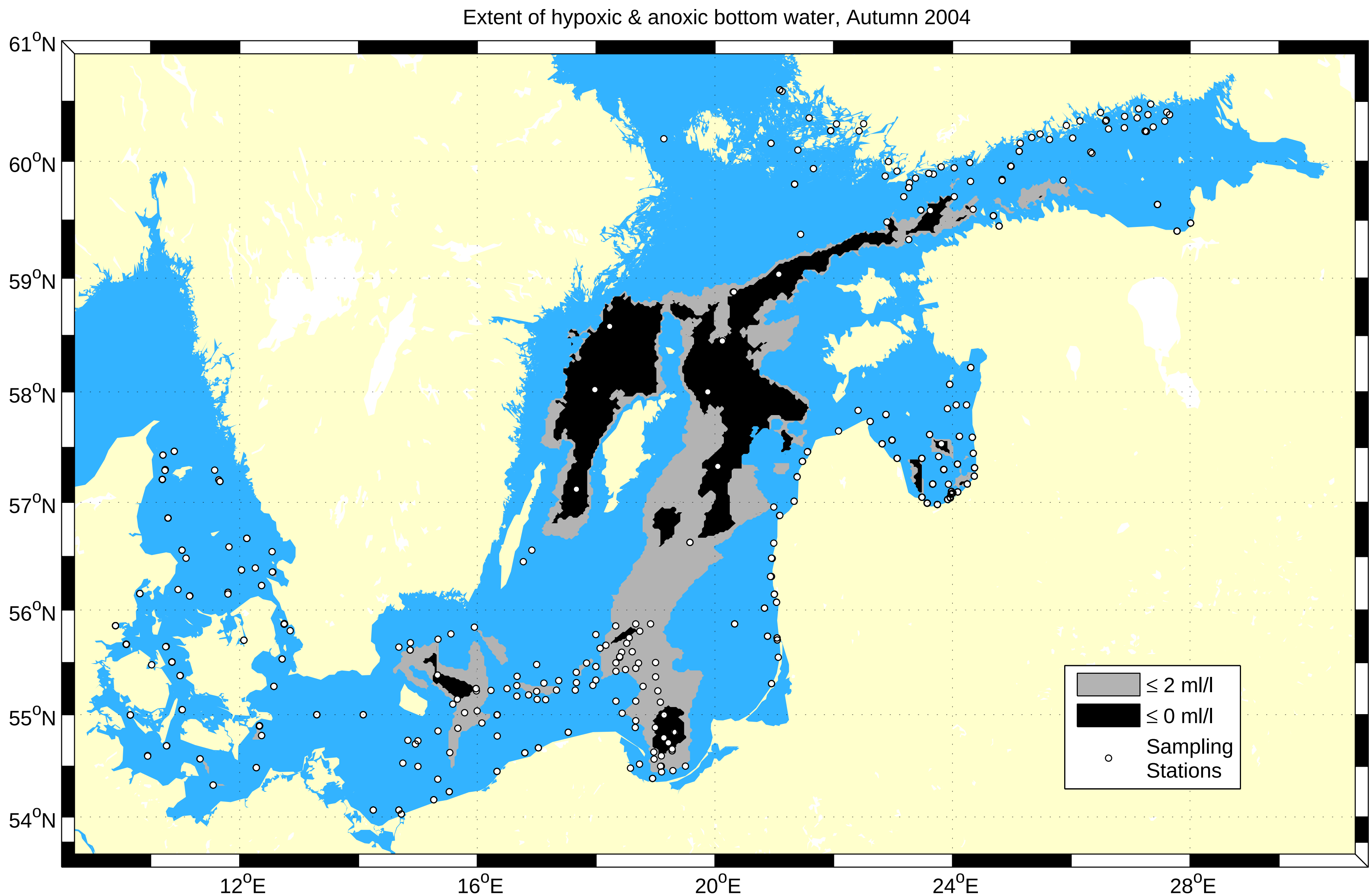


Extent of hypoxic & anoxic bottom water, Autumn 2006



Extent of hypoxic & anoxic bottom water, Autumn 2005




Extent of hypoxic & anoxic bottom water, Autumn 2004
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59°N
58°N
57°N
56°N
55°N
54°N
12°E
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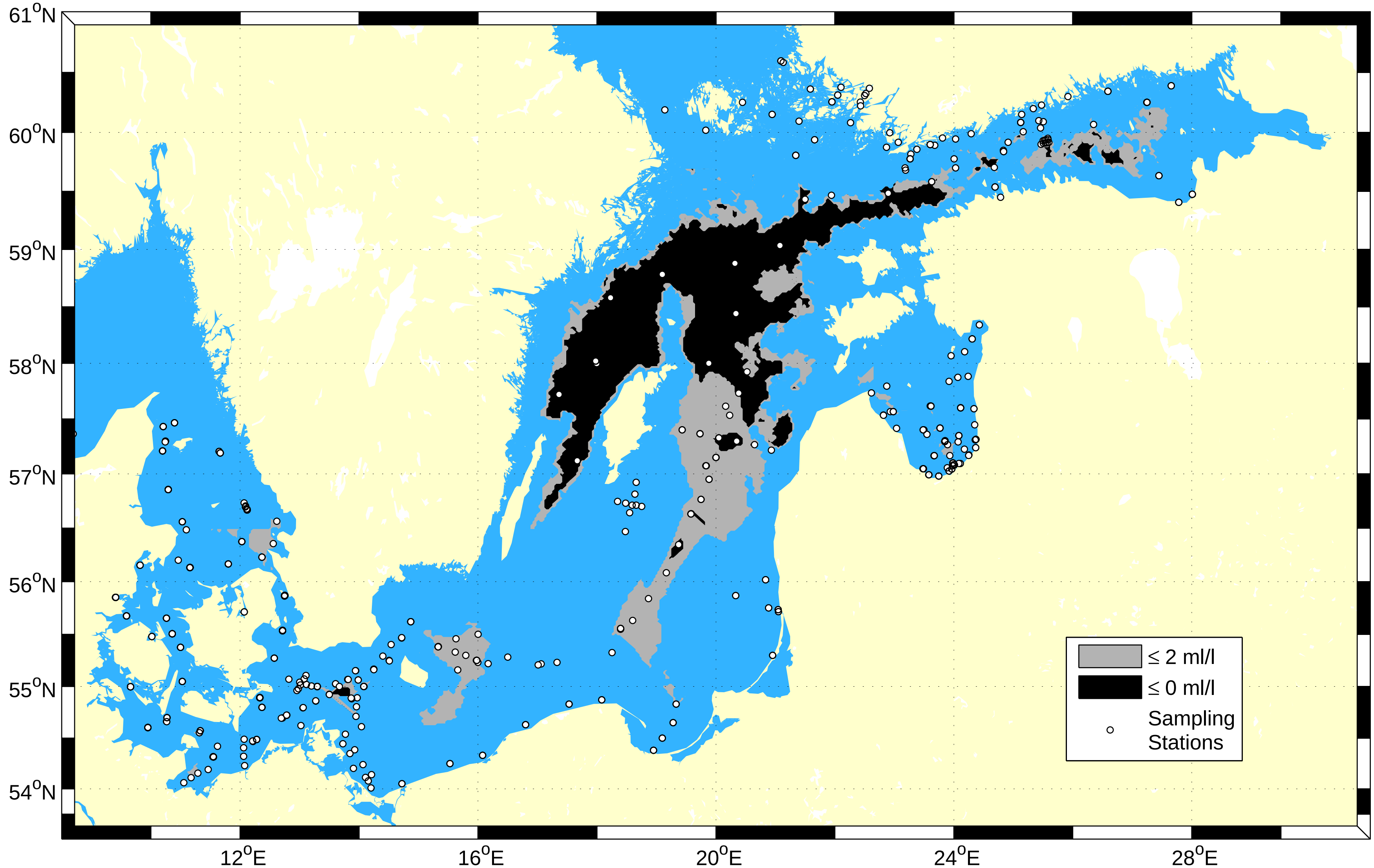
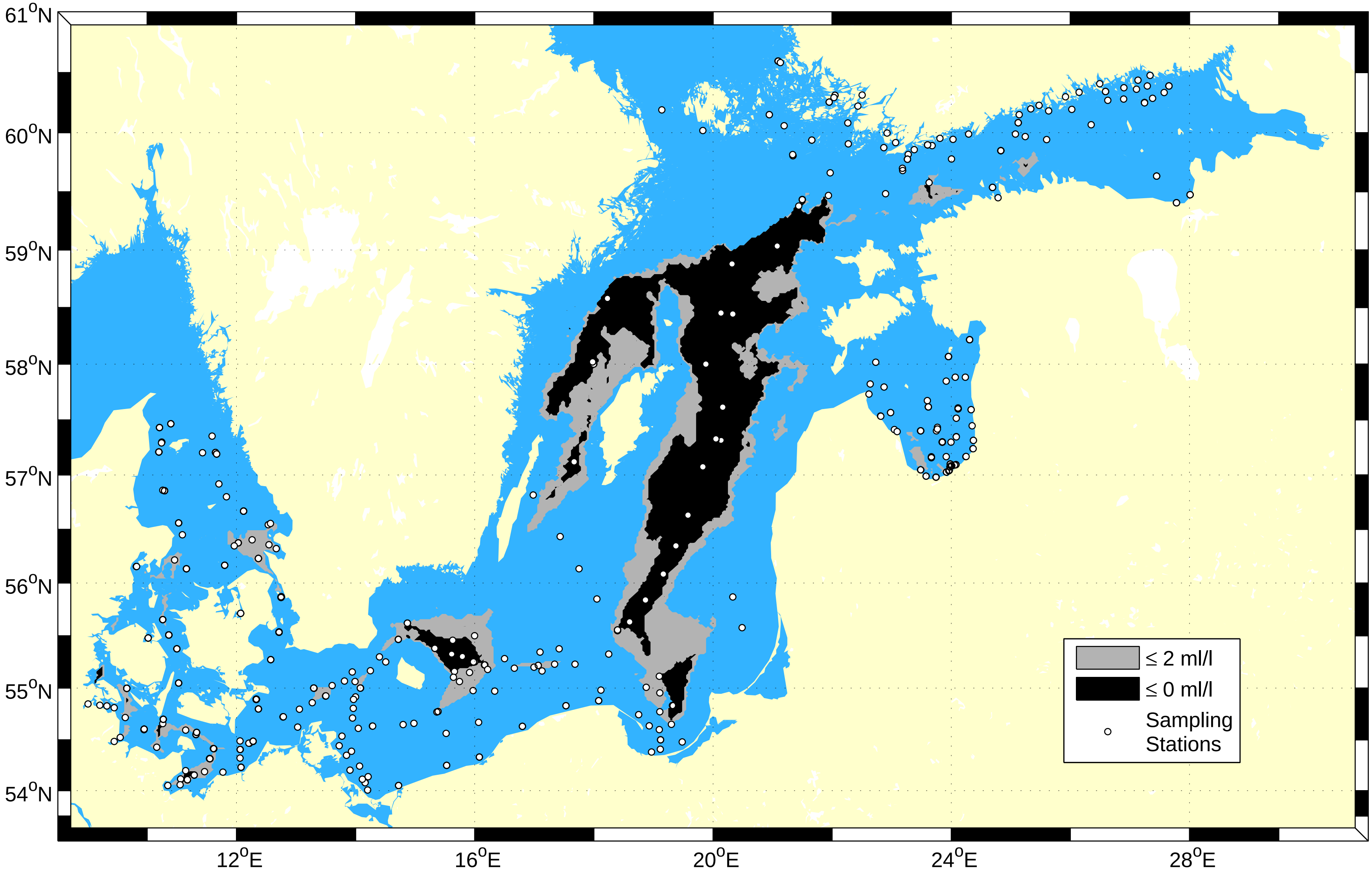
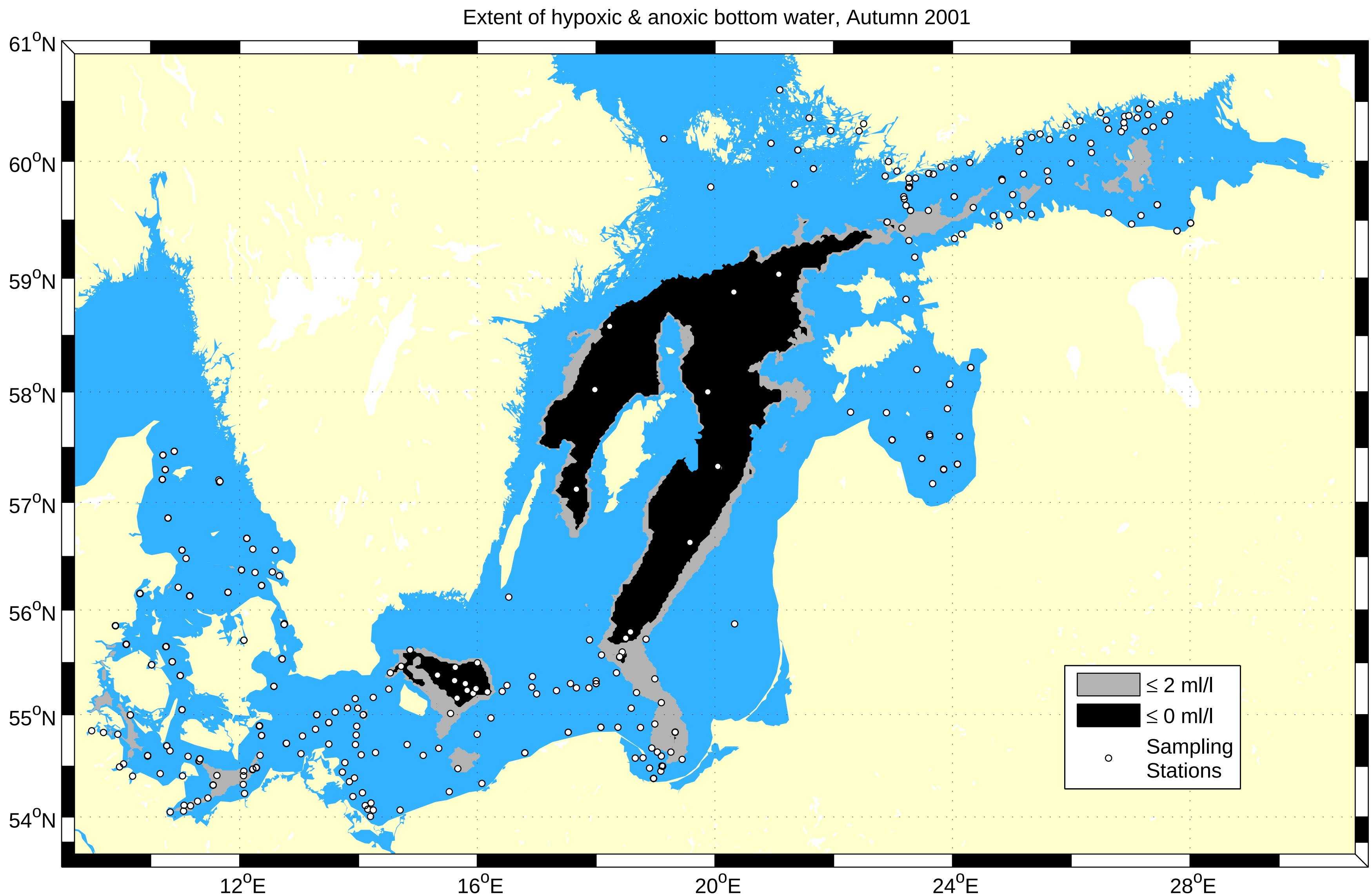
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 2003



Extent of hypoxic & anoxic bottom water, Autumn 2002





Extent of hypoxic & anoxic bottom water, Autumn 2001
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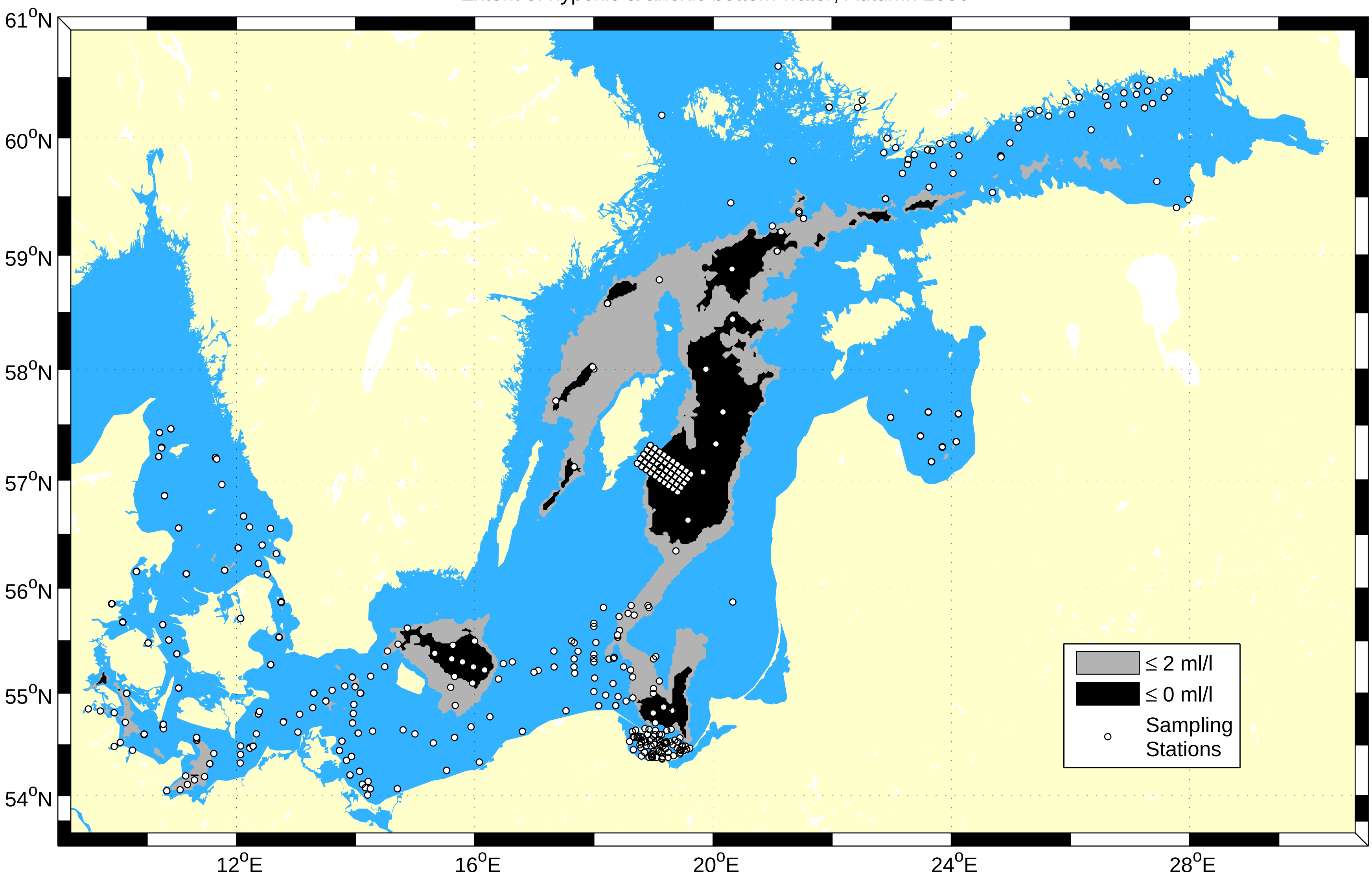
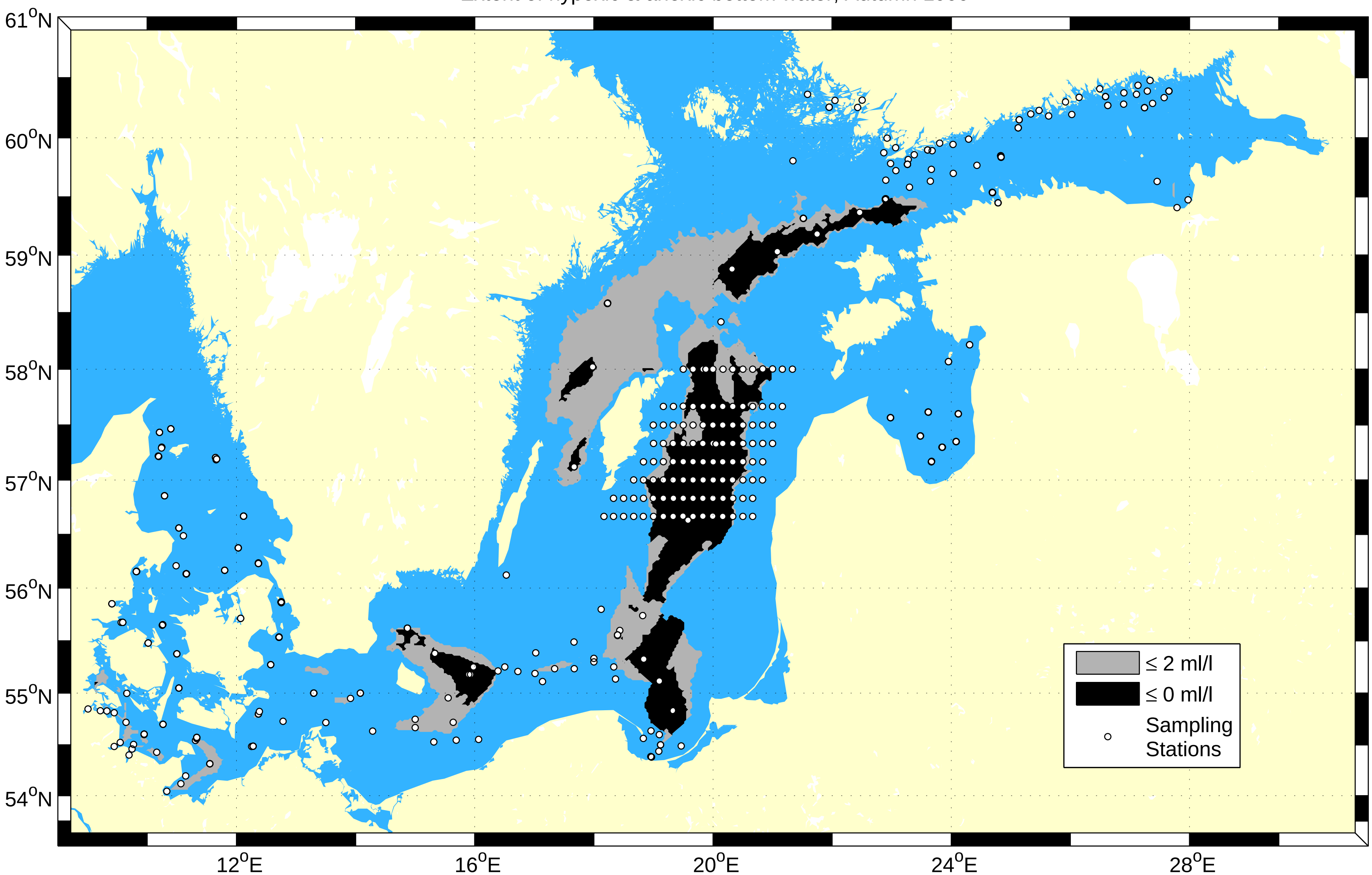
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

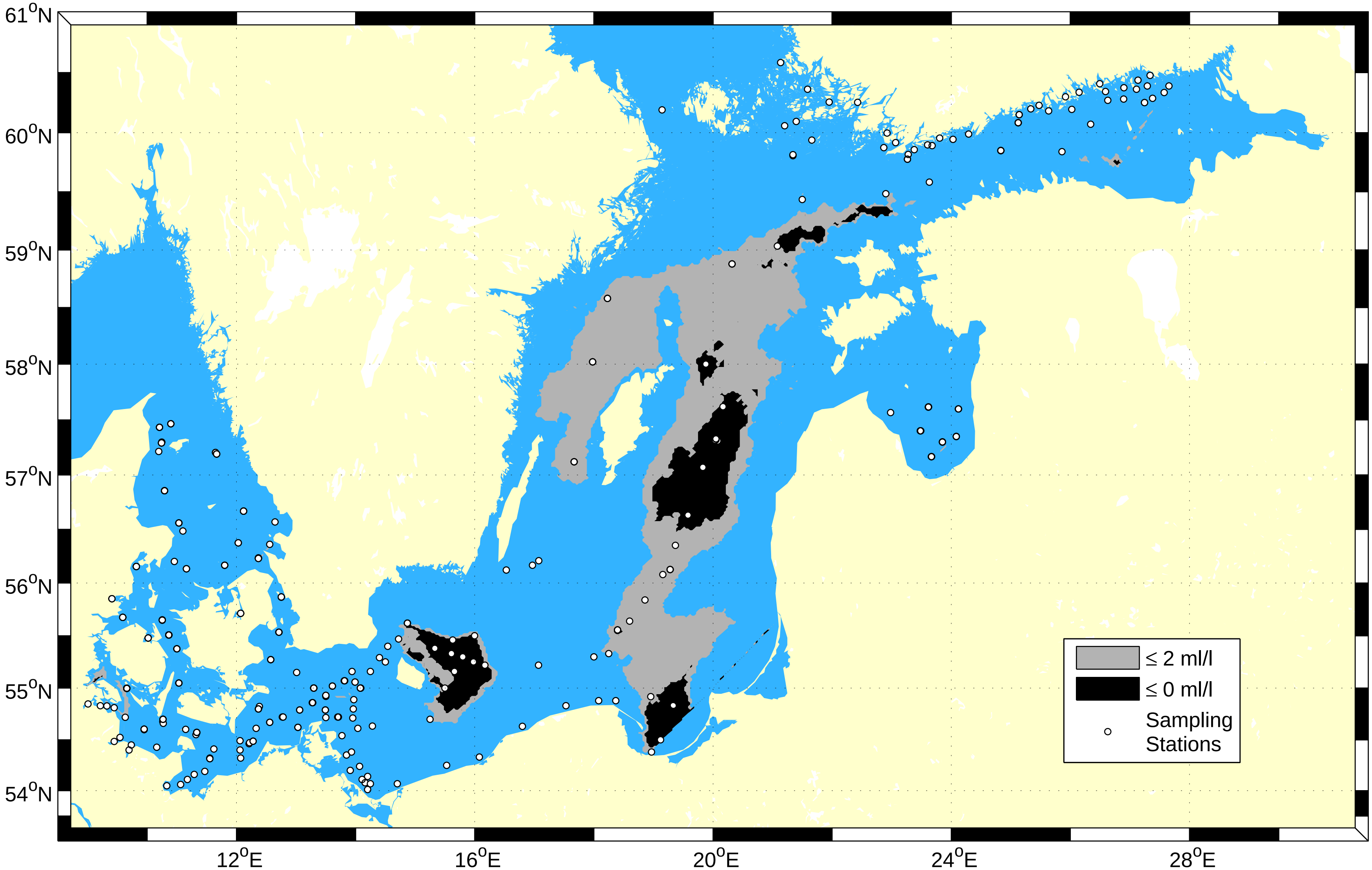
Extent of hypoxic & anoxic bottom water, Autumn 2000



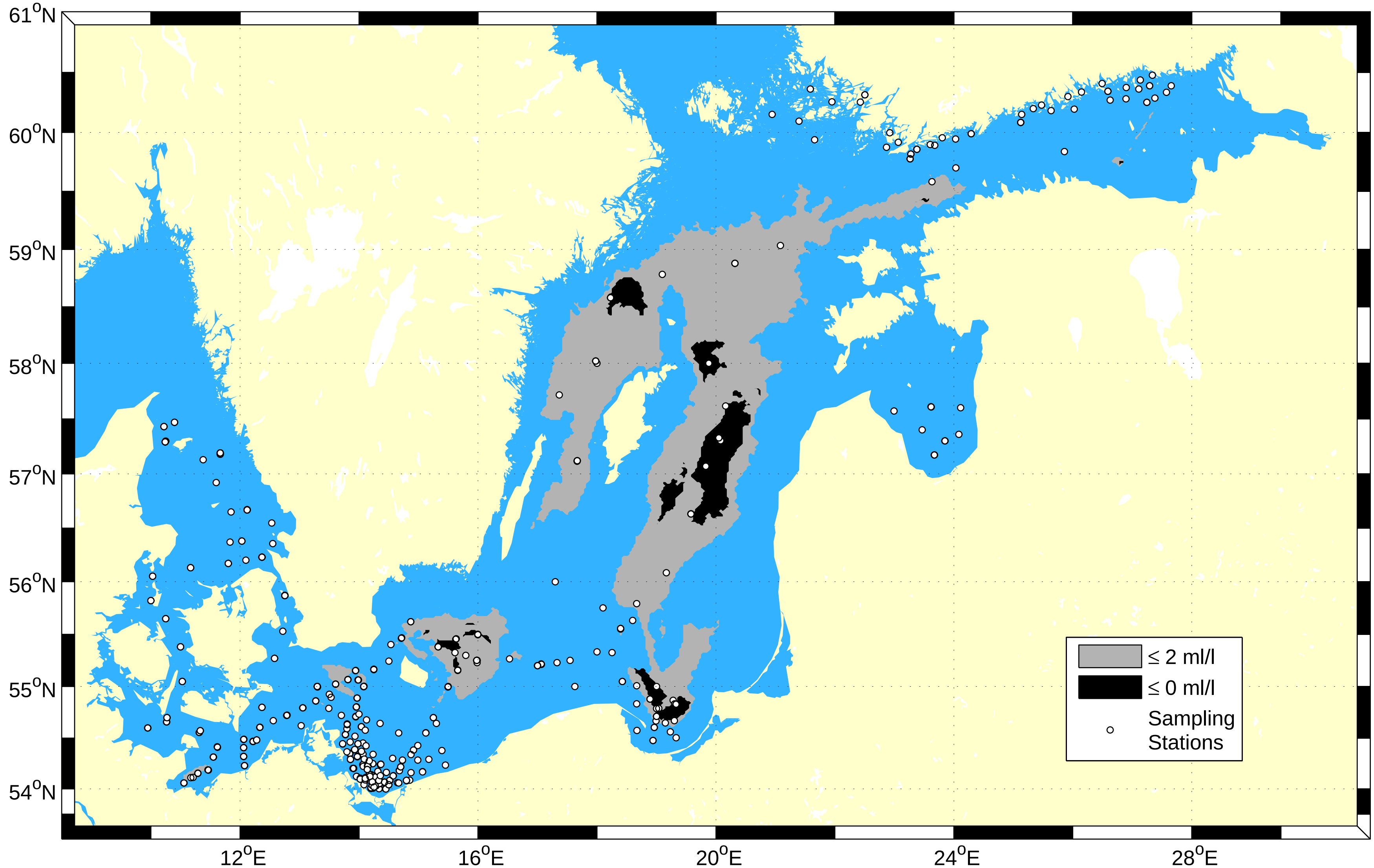
Extent of hypoxic & anoxic bottom water, Autumn 1999



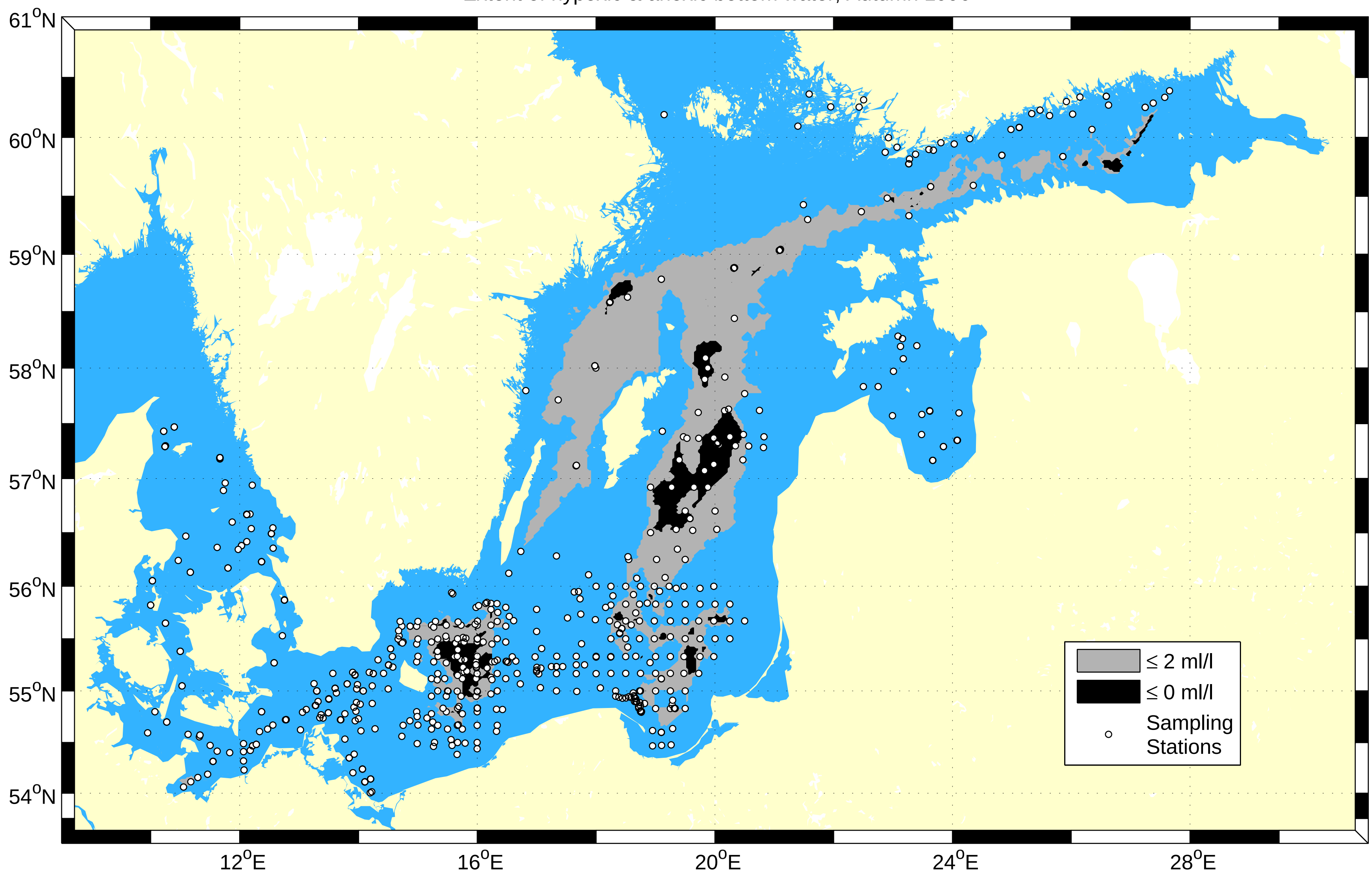
Extent of hypoxic & anoxic bottom water, Autumn 1998

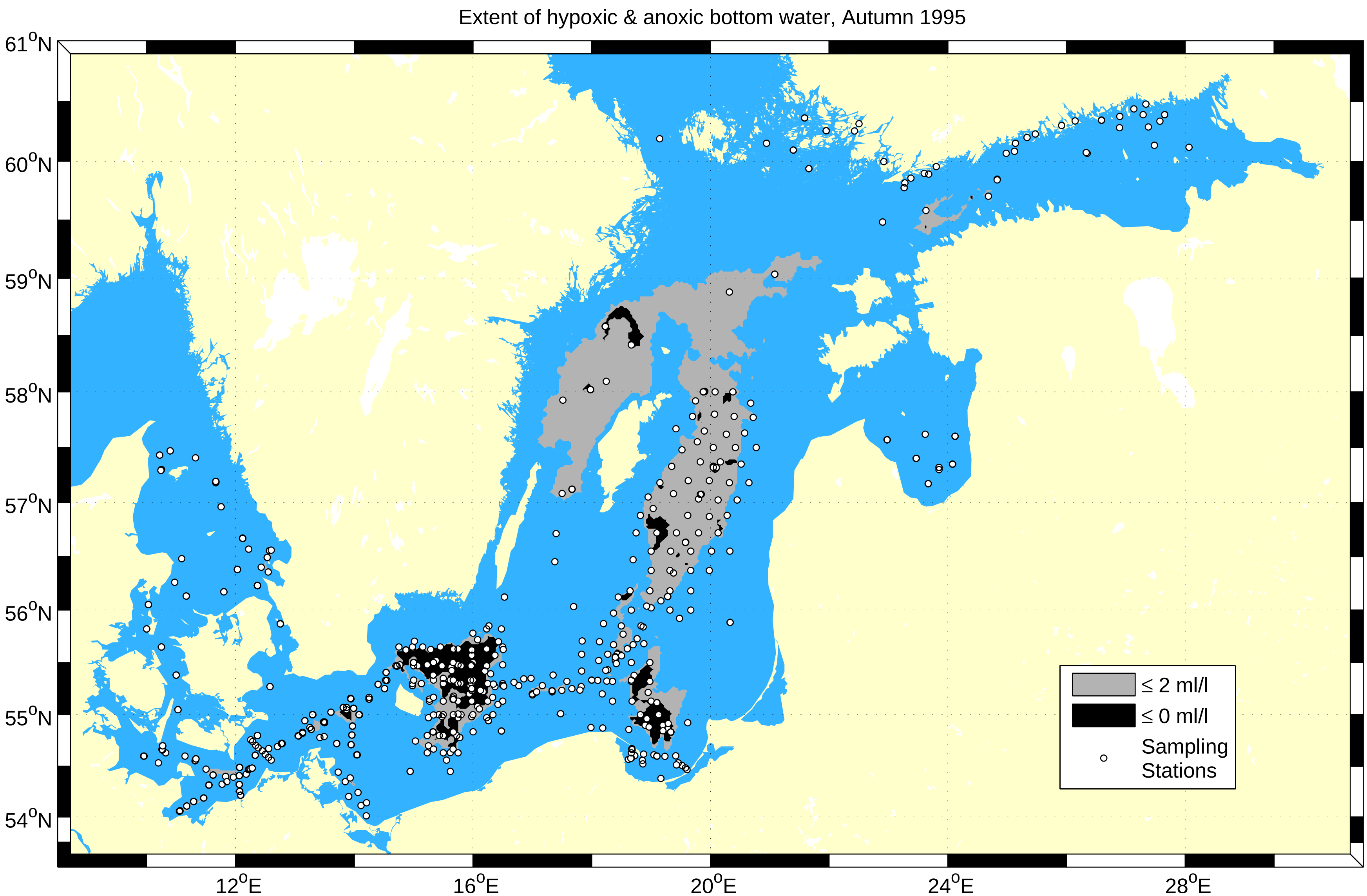


Extent of hypoxic & anoxic bottom water, Autumn 1997



Extent of hypoxic & anoxic bottom water, Autumn 1996





Extent of hypoxic & anoxic bottom water, Autumn 1995
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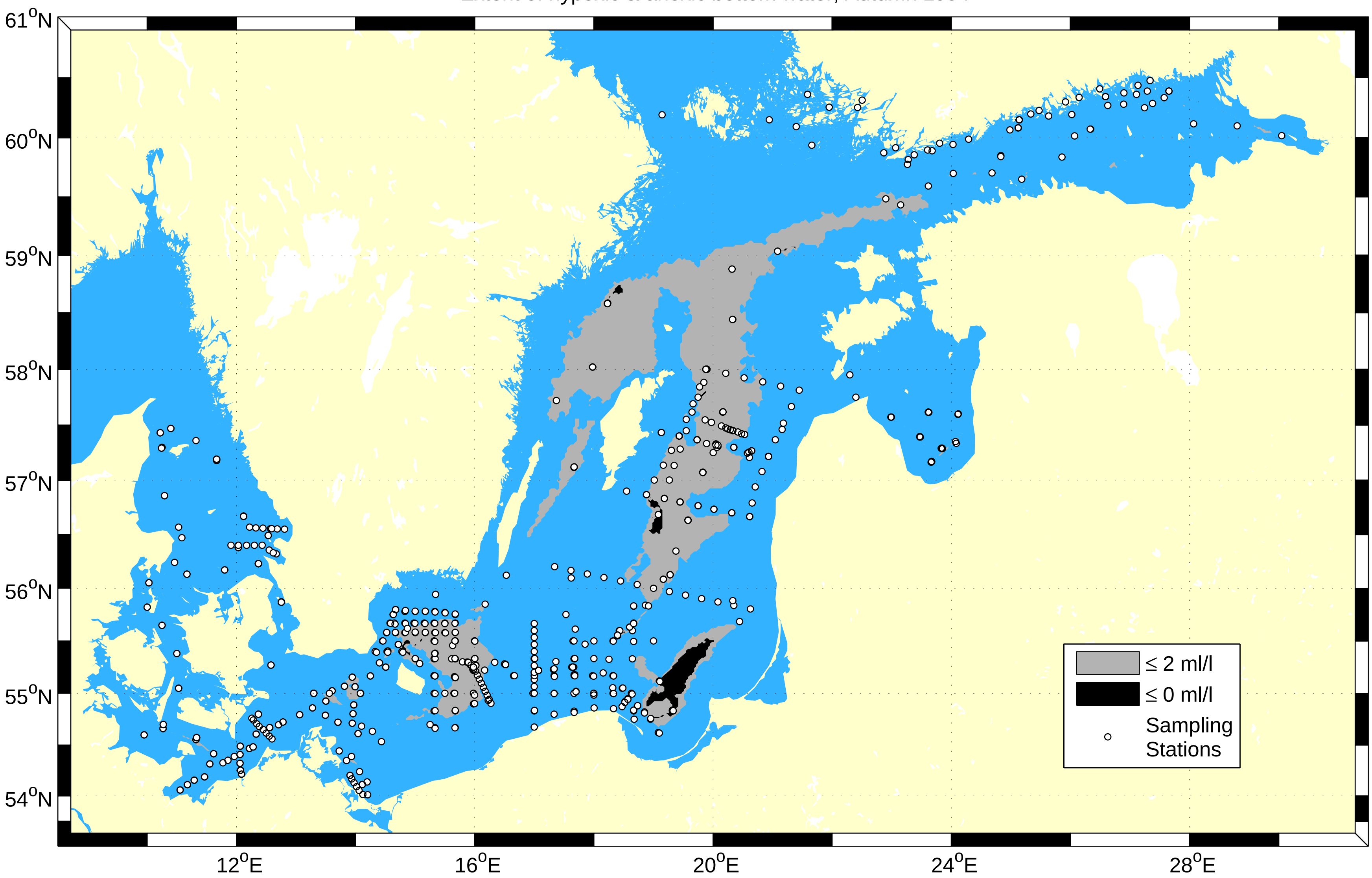
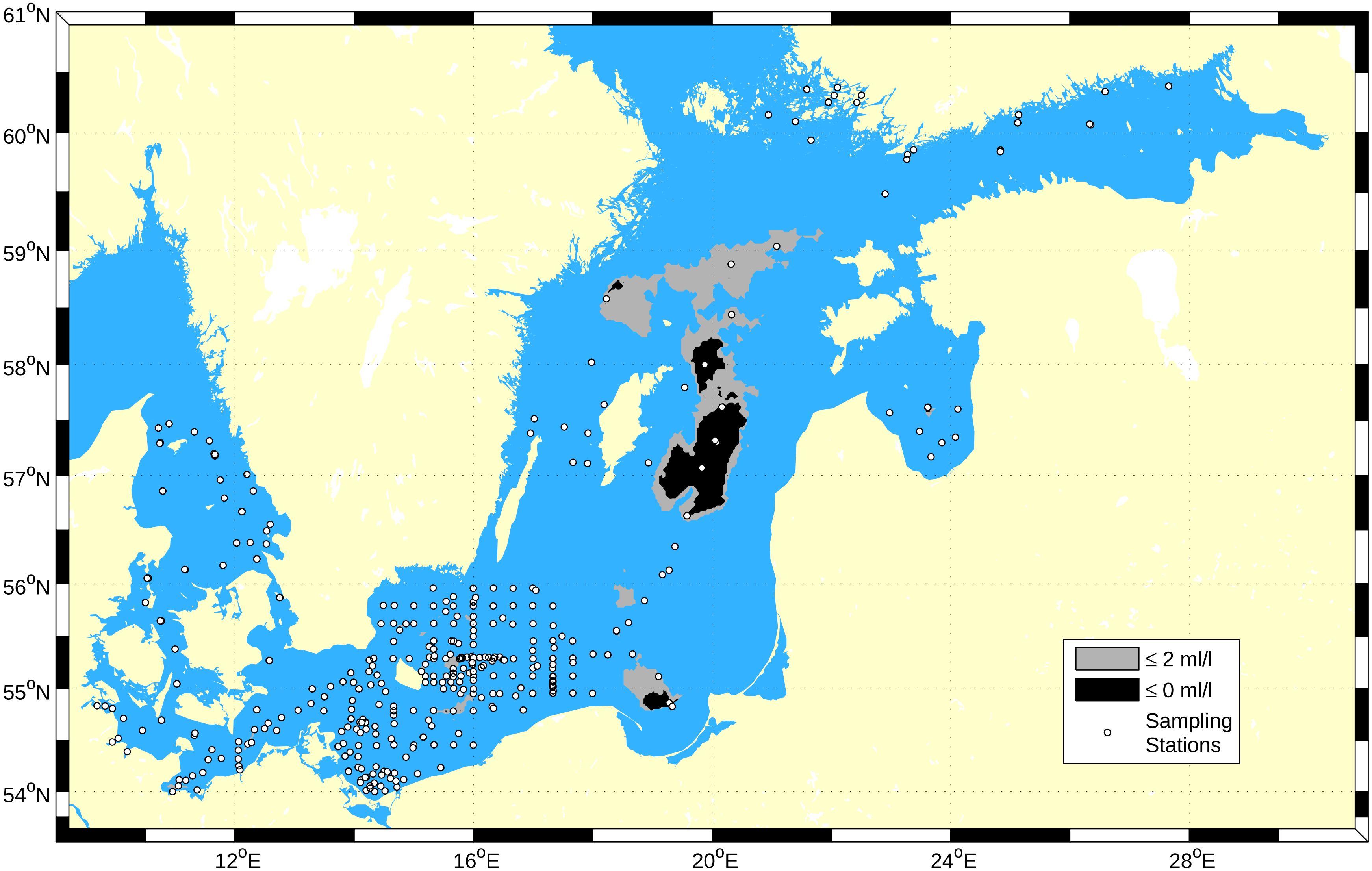
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling
Stations

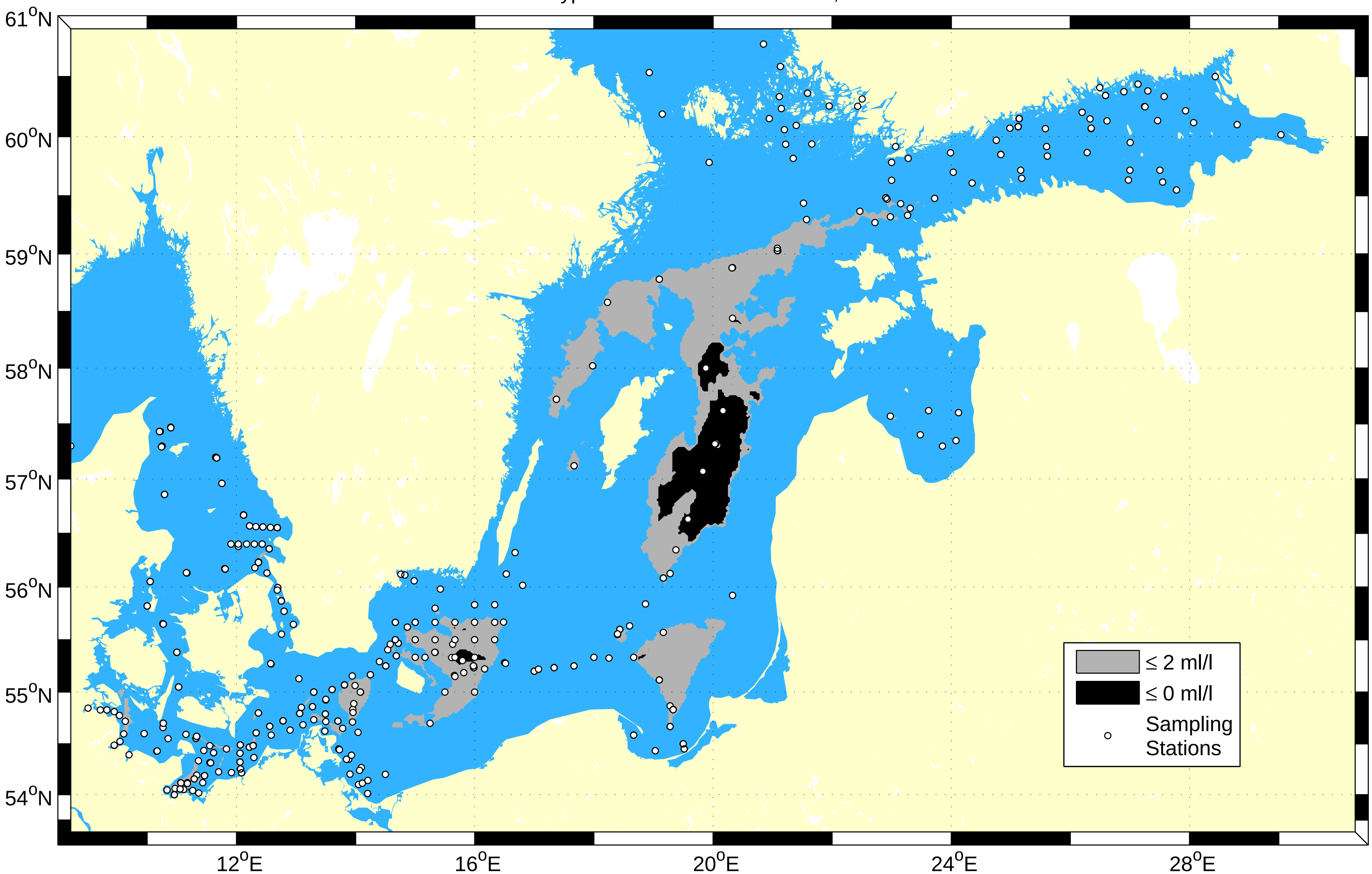
Extent of hypoxic & anoxic bottom water, Autumn 1994



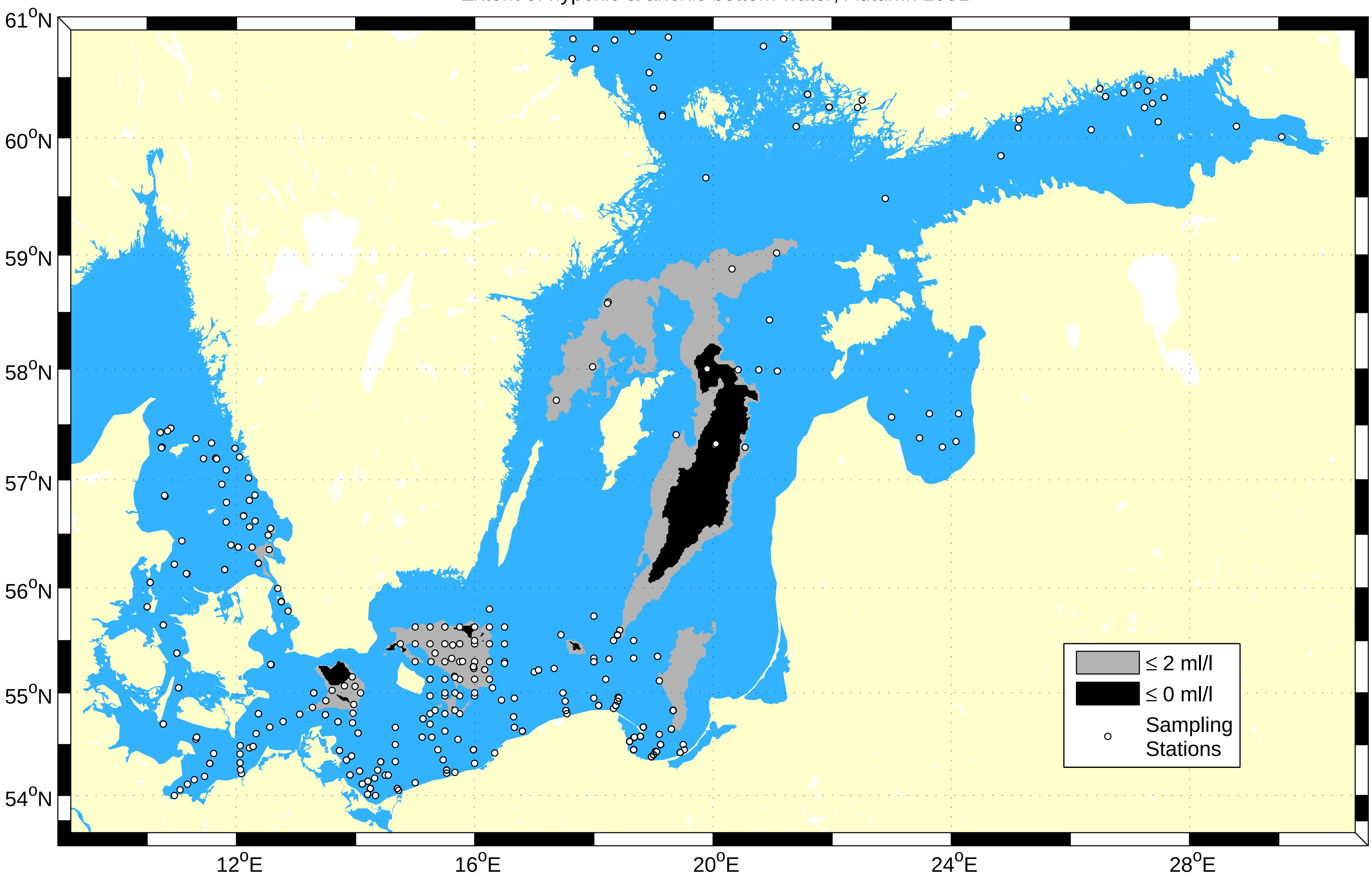
Extent of hypoxic & anoxic bottom water, Autumn 1993



Extent of hypoxic & anoxic bottom water, Autumn 1992



Extent of hypoxic & anoxic bottom water, Autumn 1991



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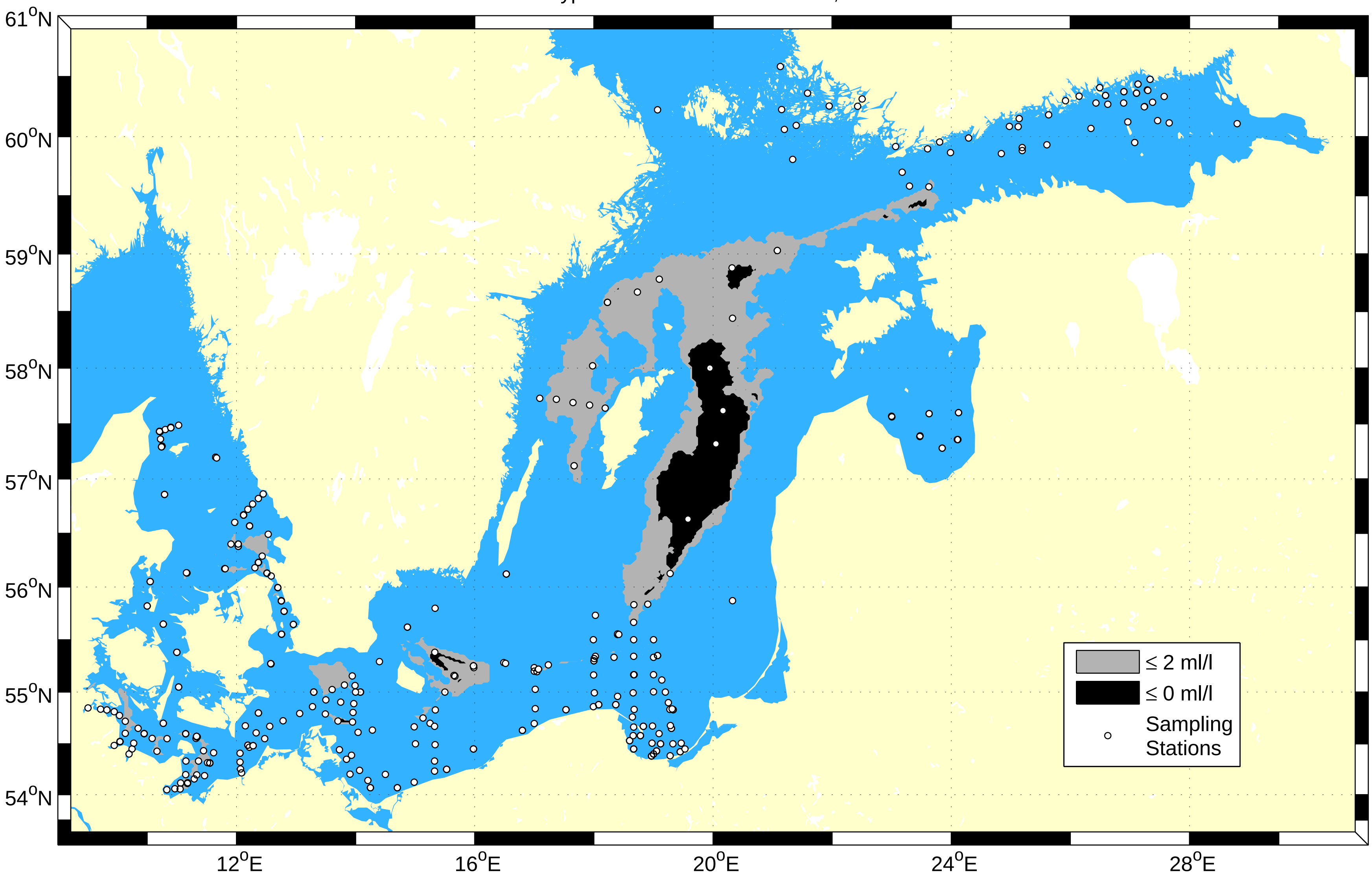
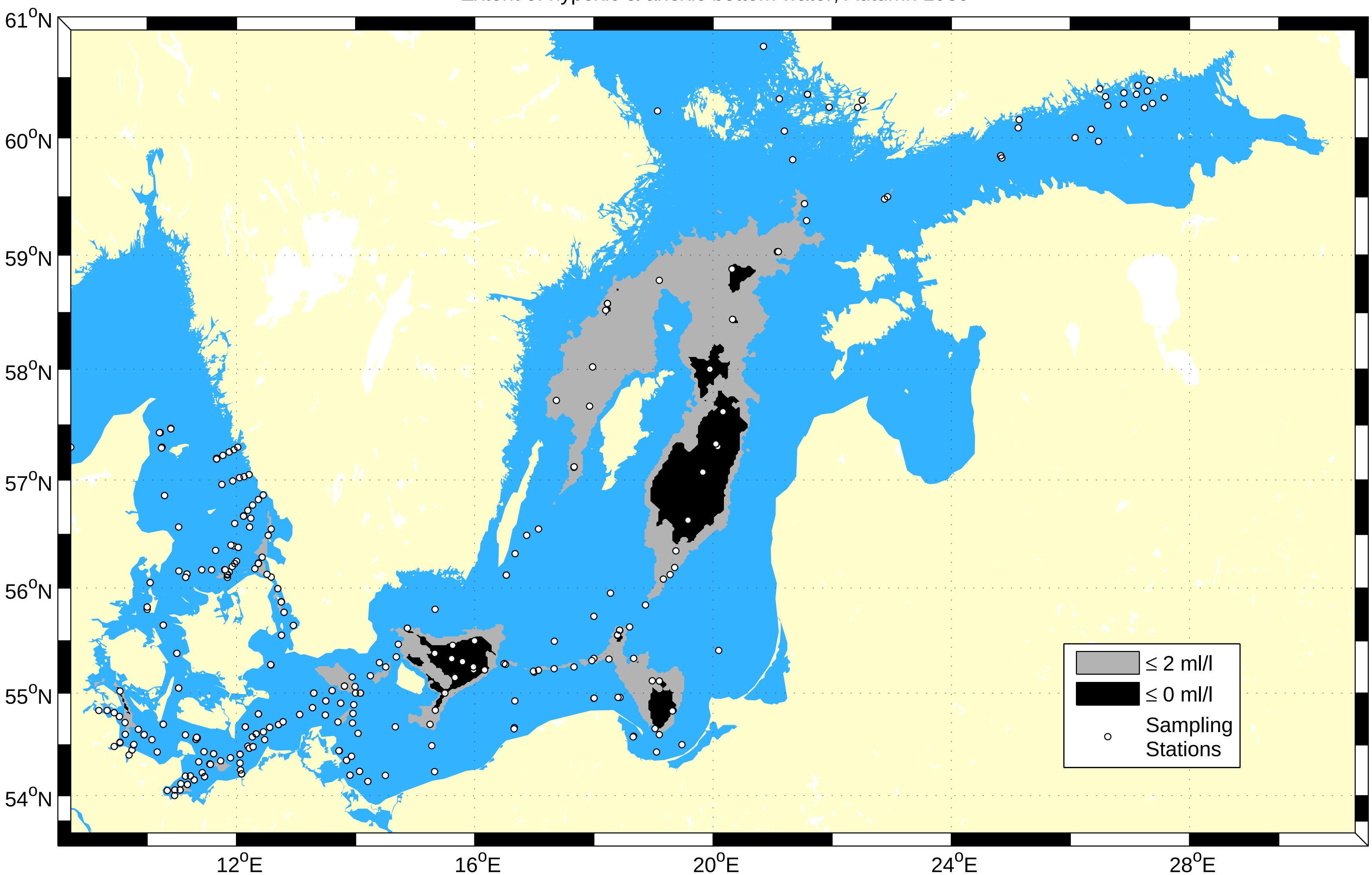
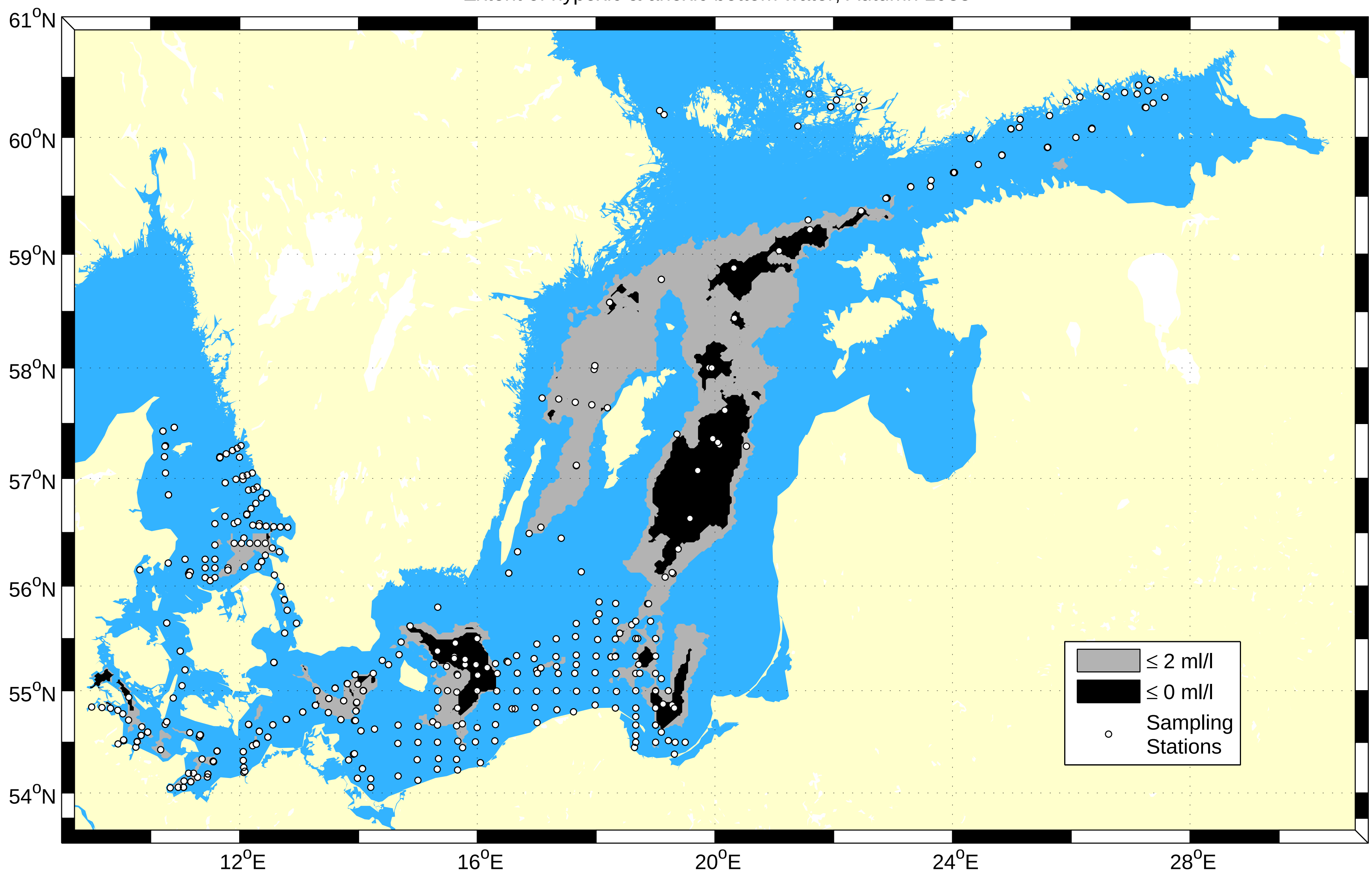


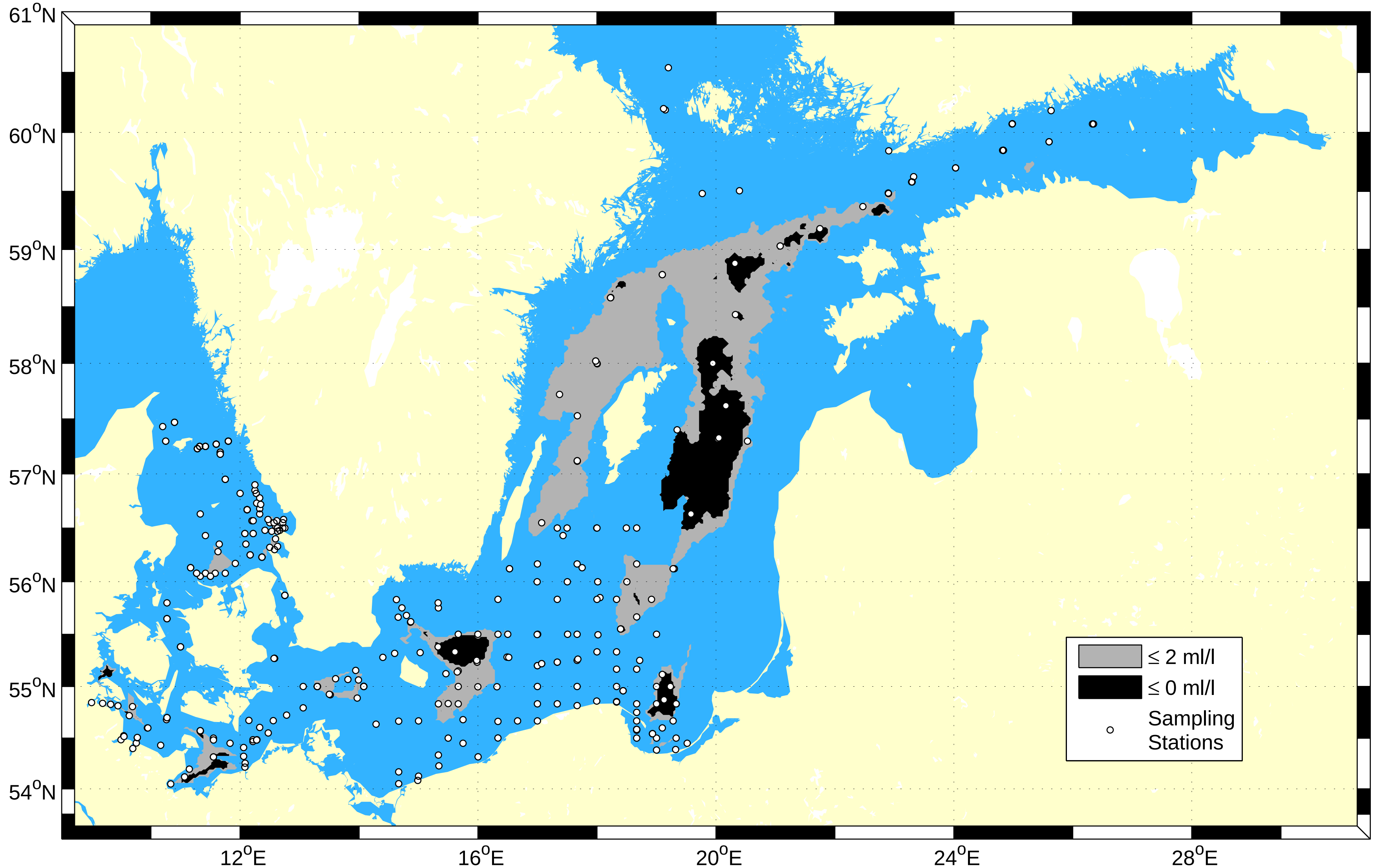
Extent of hypoxic & anoxic bottom water, Autumn 1989



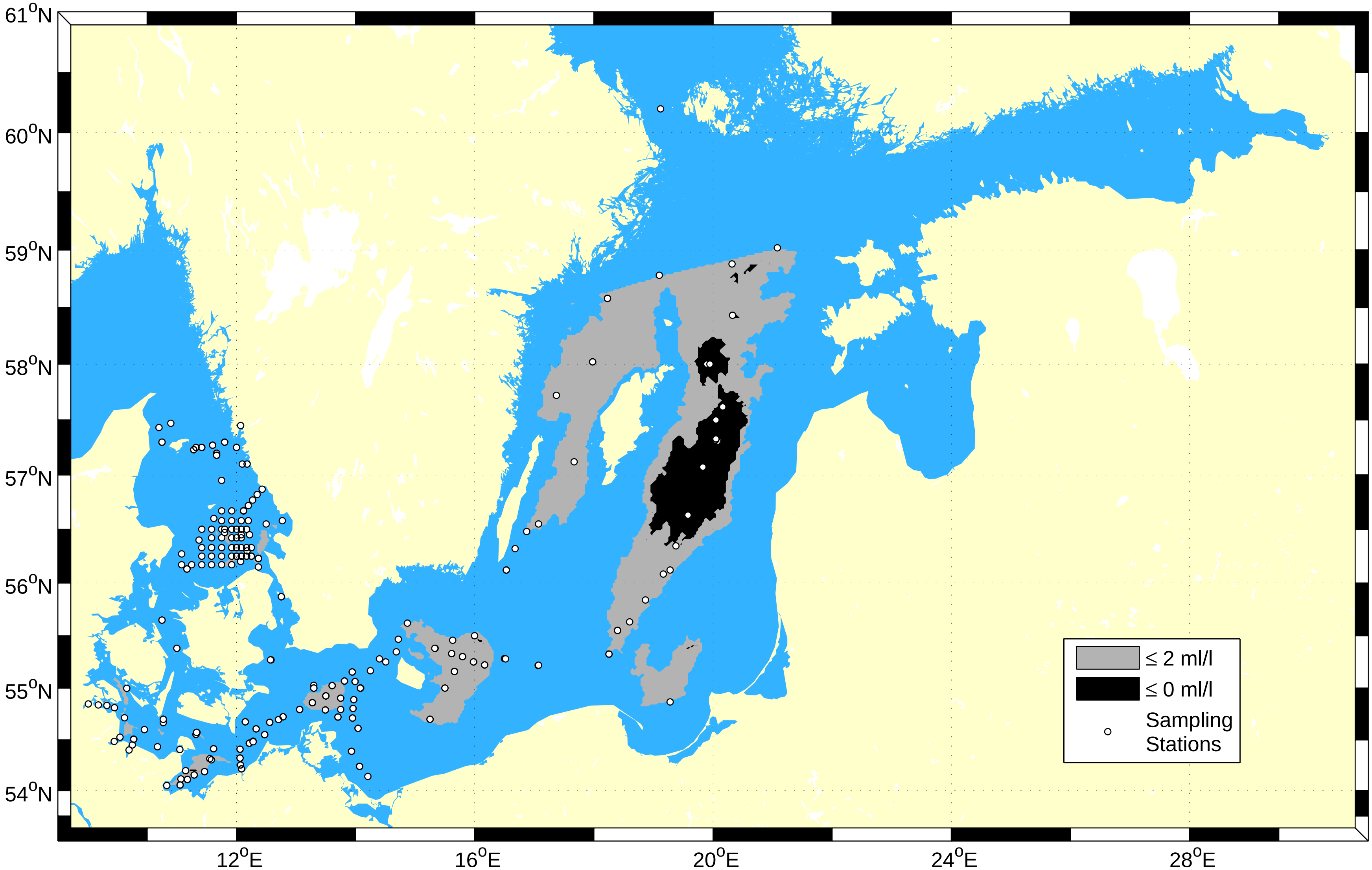
Extent of hypoxic & anoxic bottom water, Autumn 1988



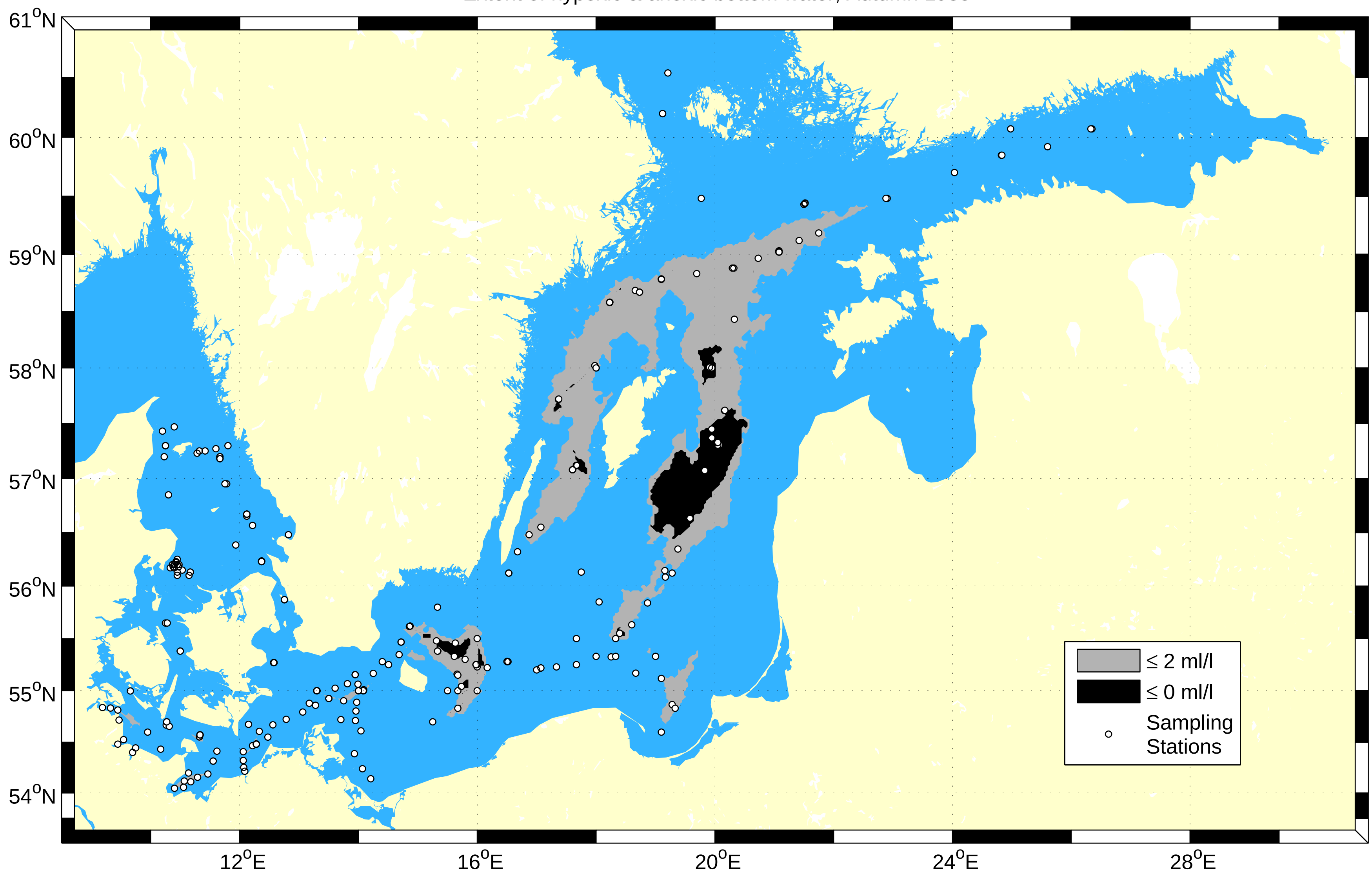
Extent of hypoxic & anoxic bottom water, Autumn 1987



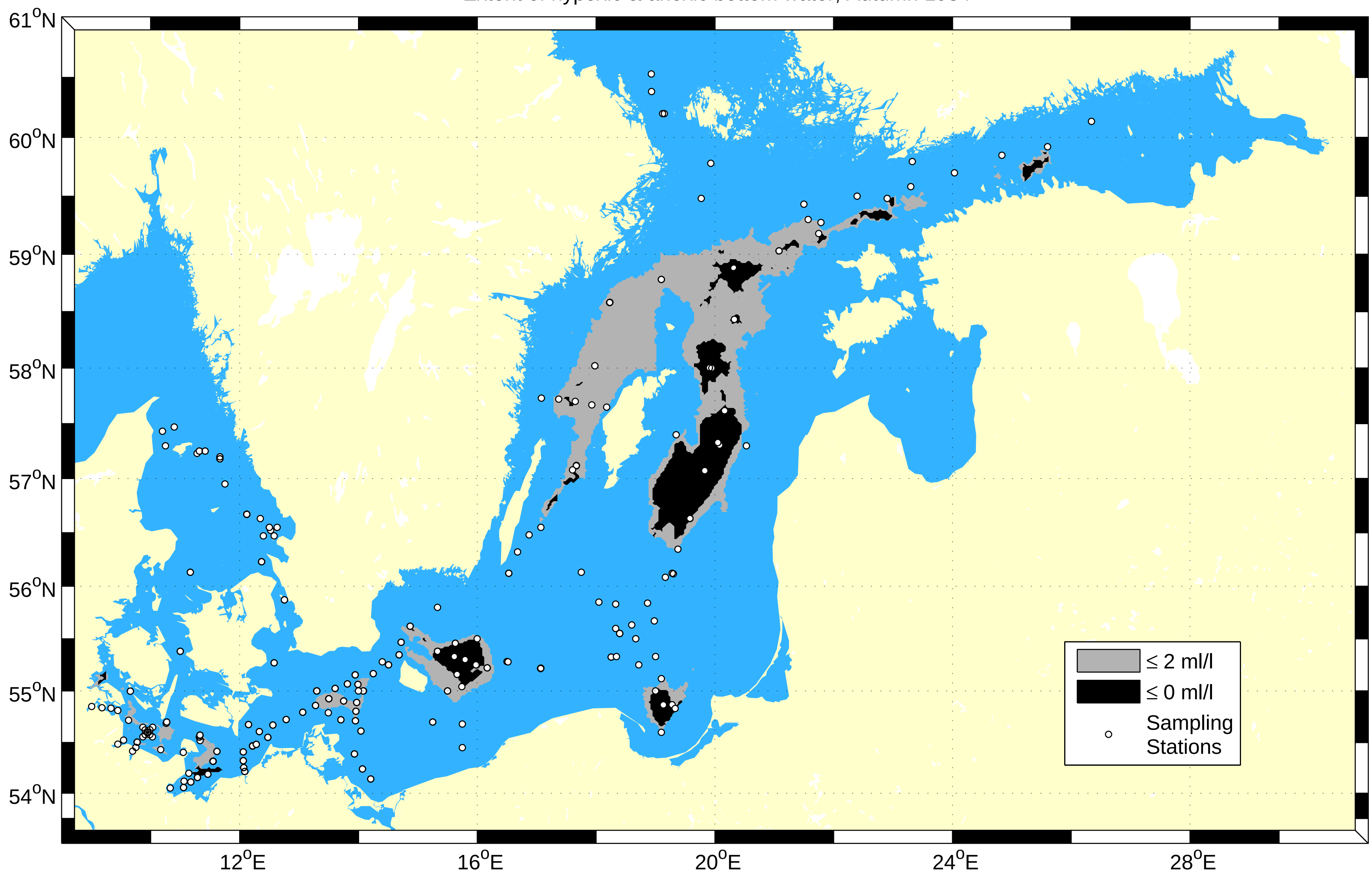
Extent of hypoxic & anoxic bottom water, Autumn 1986



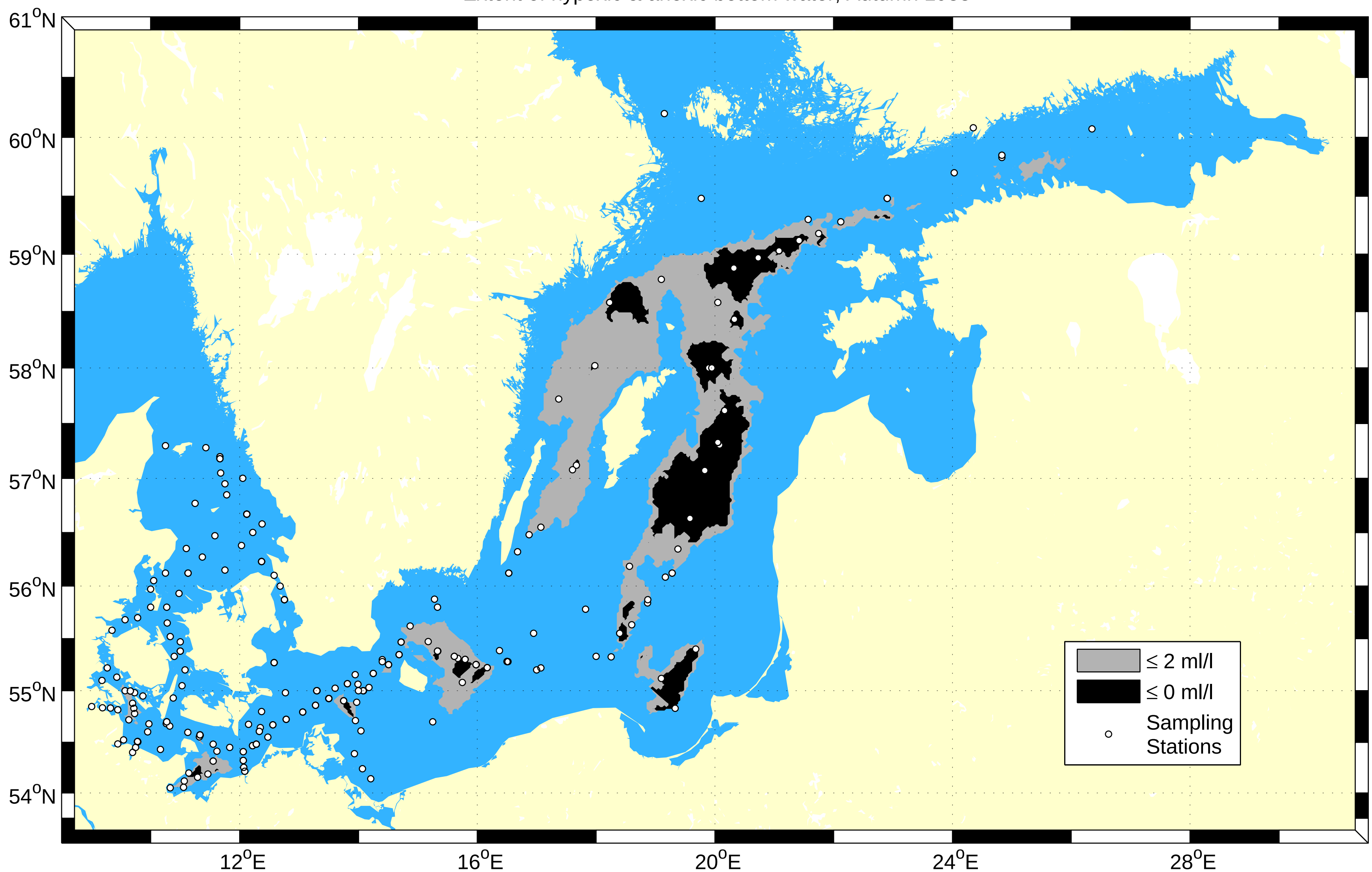
Extent of hypoxic & anoxic bottom water, Autumn 1985

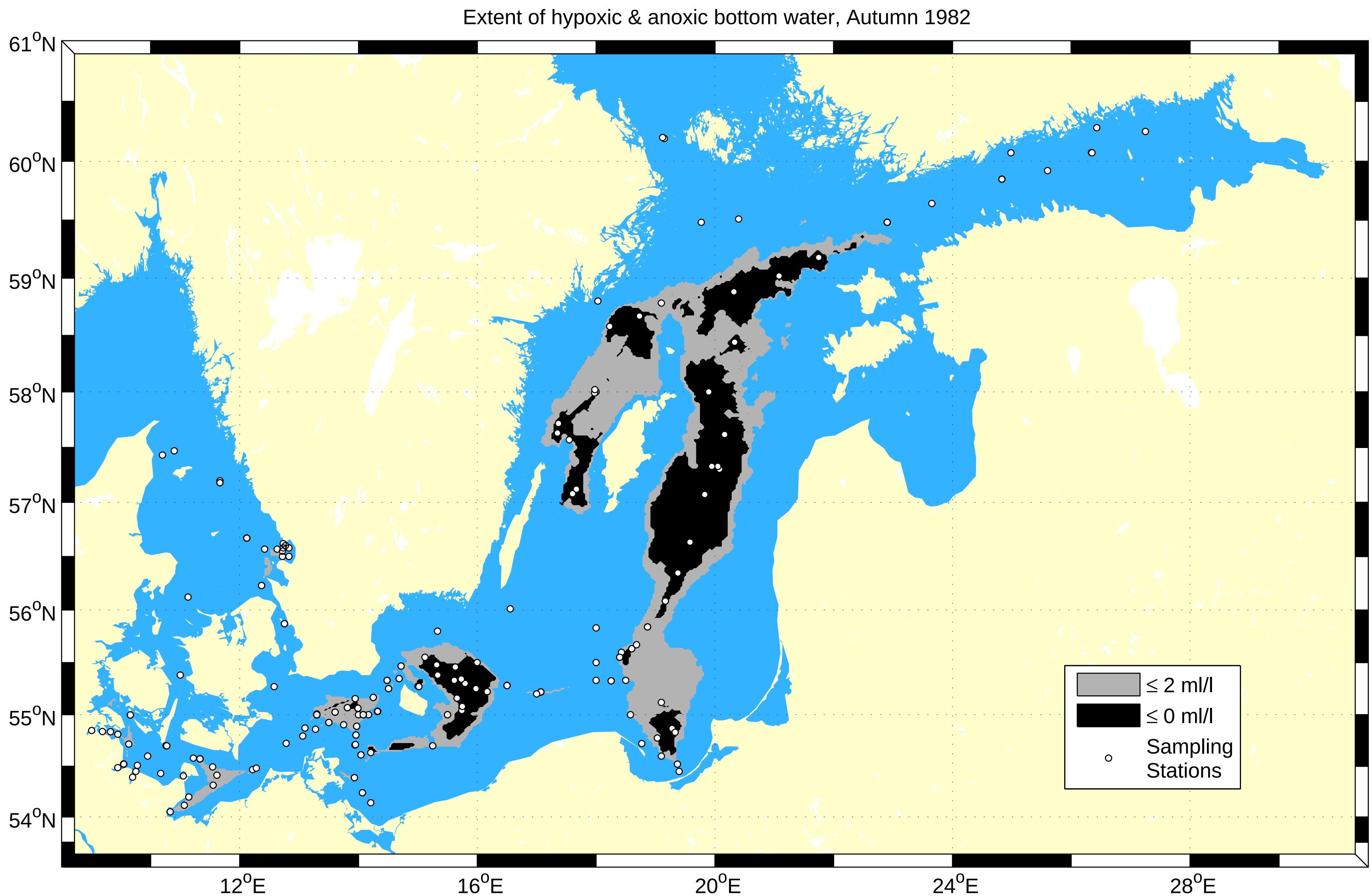


Extent of hypoxic & anoxic bottom water, Autumn 1984



Extent of hypoxic & anoxic bottom water, Autumn 1983





Extent of hypoxic & anoxic bottom water, Autumn 1982
61°N
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58°N
57°N
56°N
55°N
54°N
12°E
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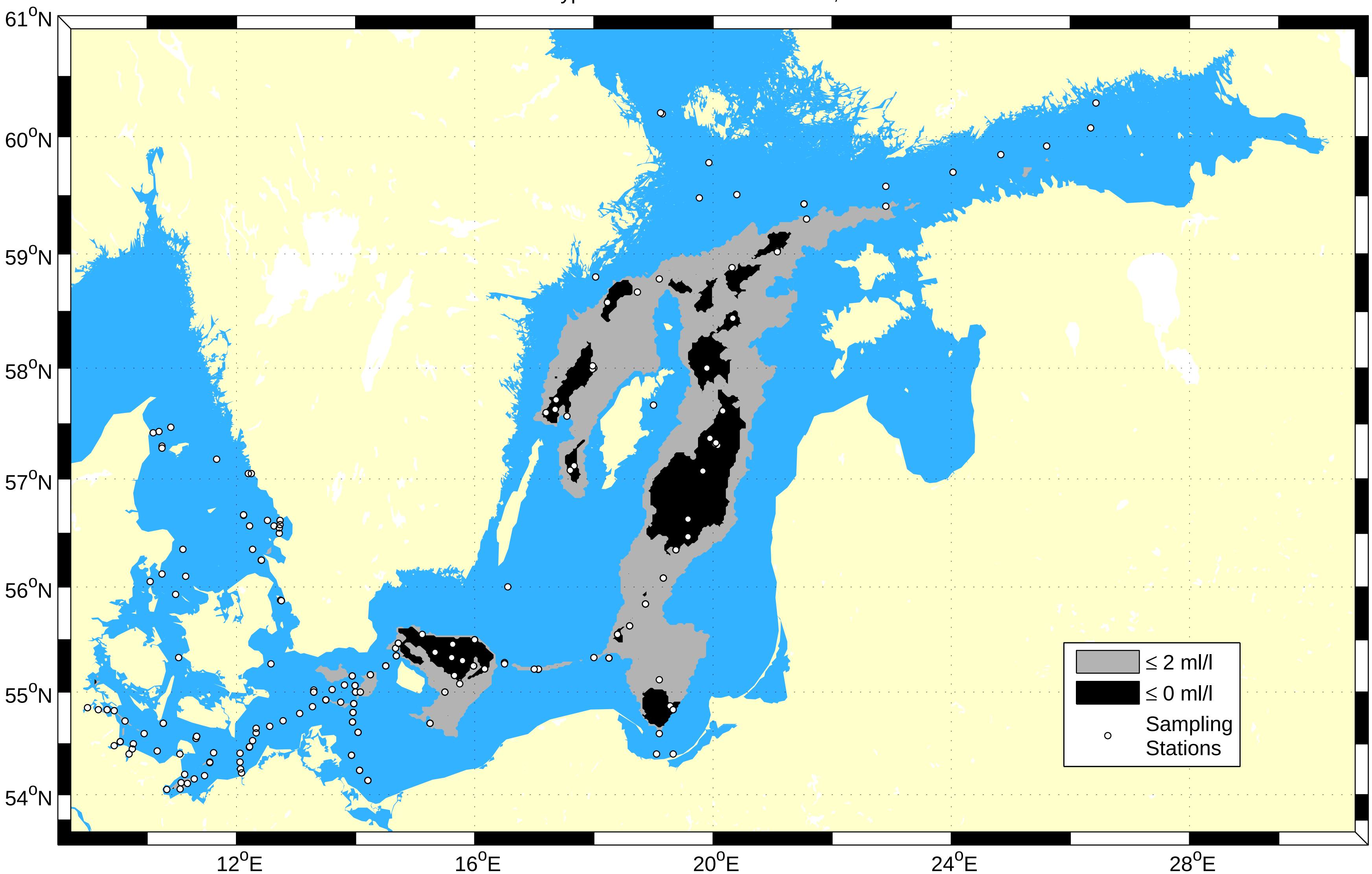
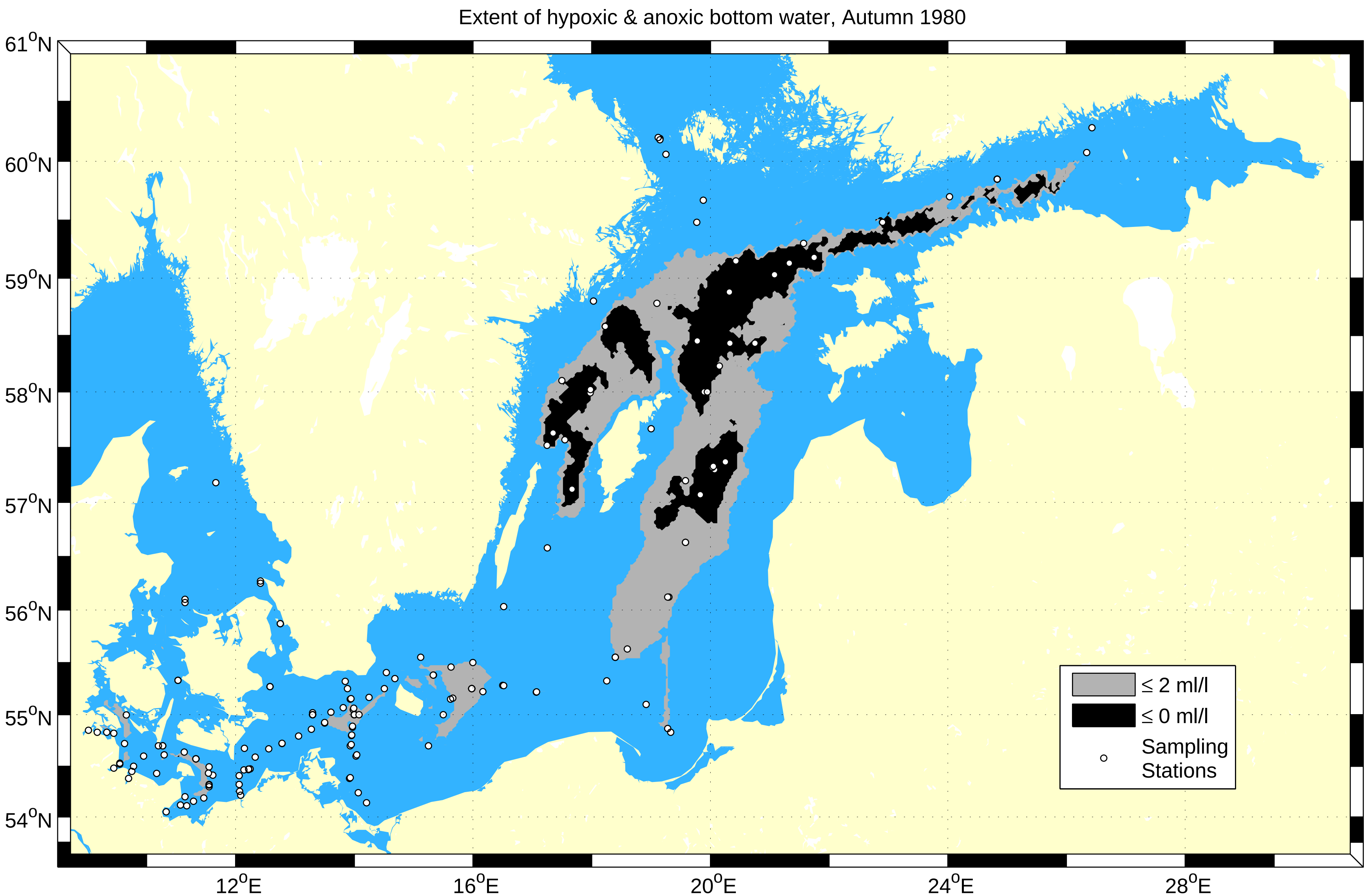
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 1981





Extent of hypoxic & anoxic bottom water, Autumn 1980
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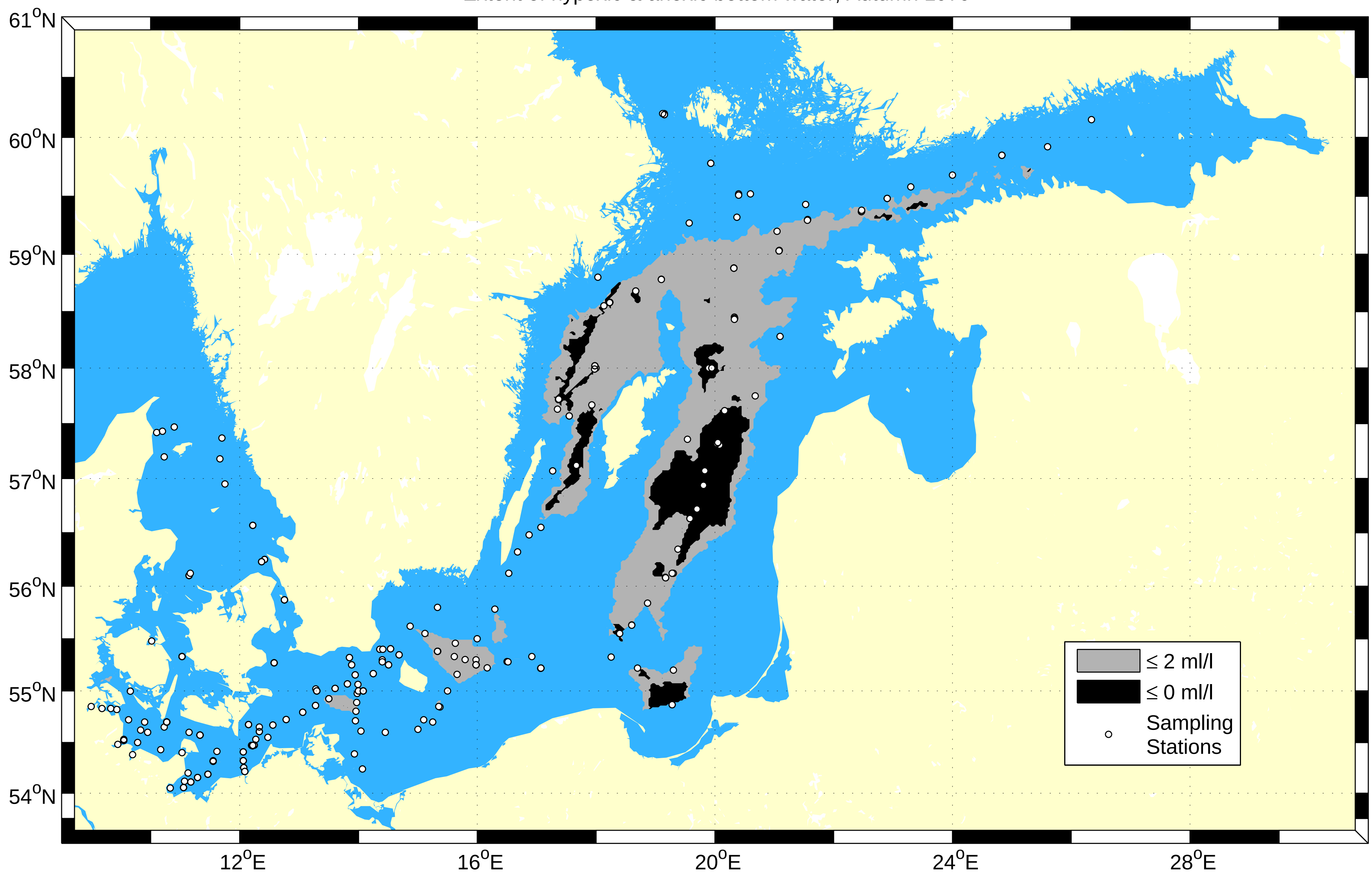
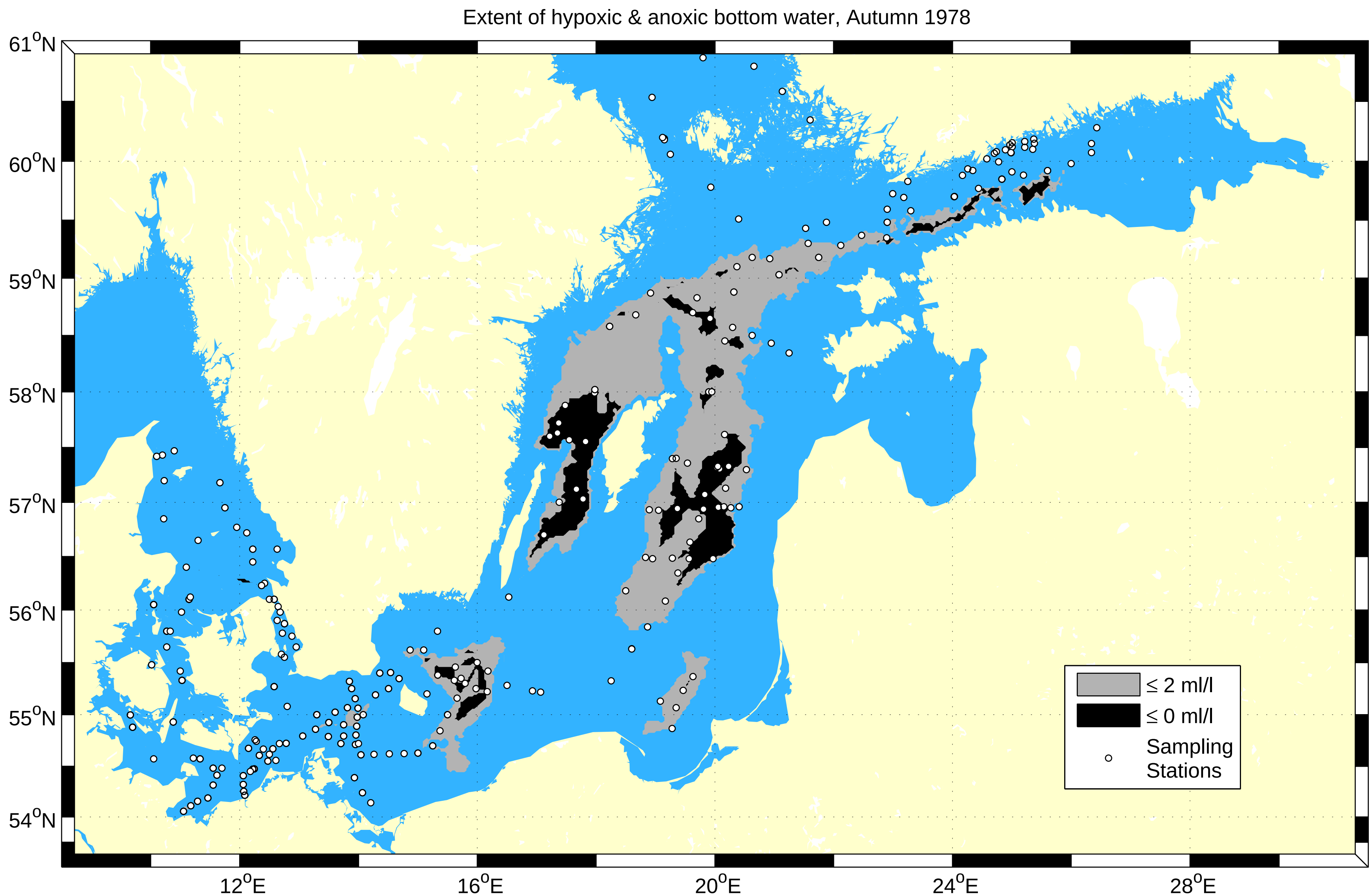
59^{0}N
58^{0}N
57^{0}N
56^{0}N
55^{0}N
54^{0}N
12^{0}E
16^{0}E
20^{0}E
24^{0}E
28^{0}E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 1979




Extent of hypoxic & anoxic bottom water, Autumn 1978
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57°N
56°N
55°N
54°N
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20°E
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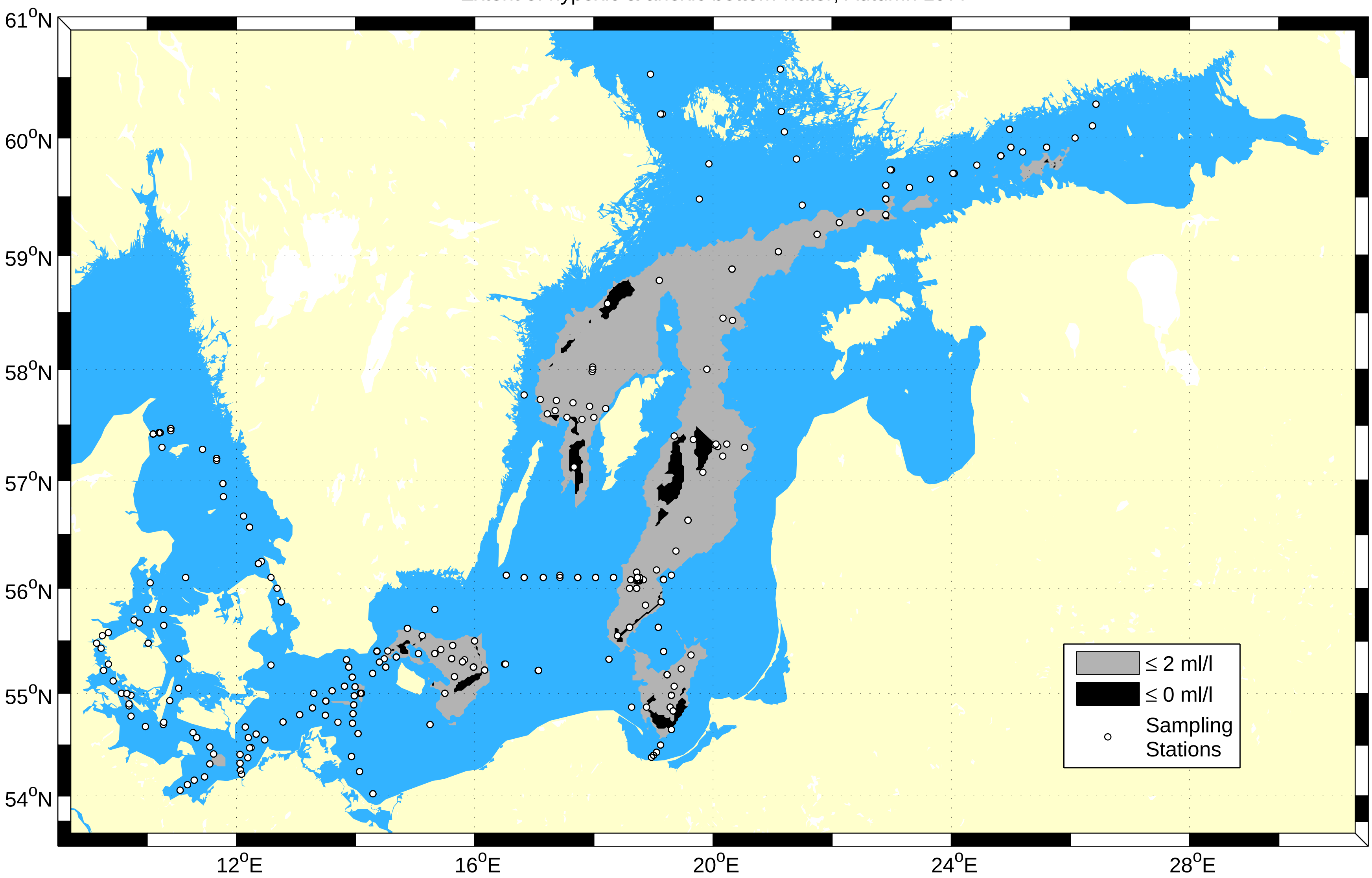
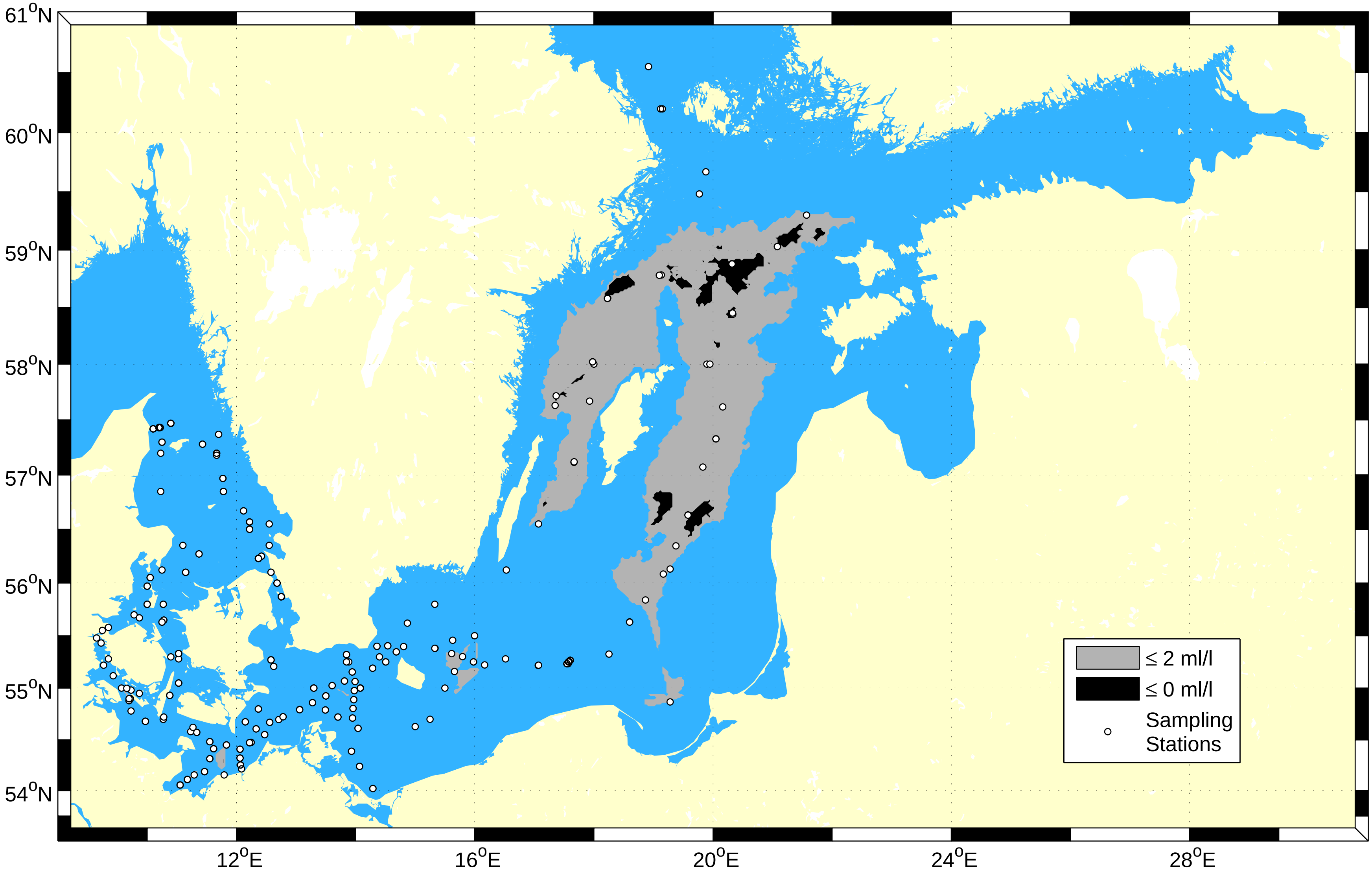
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

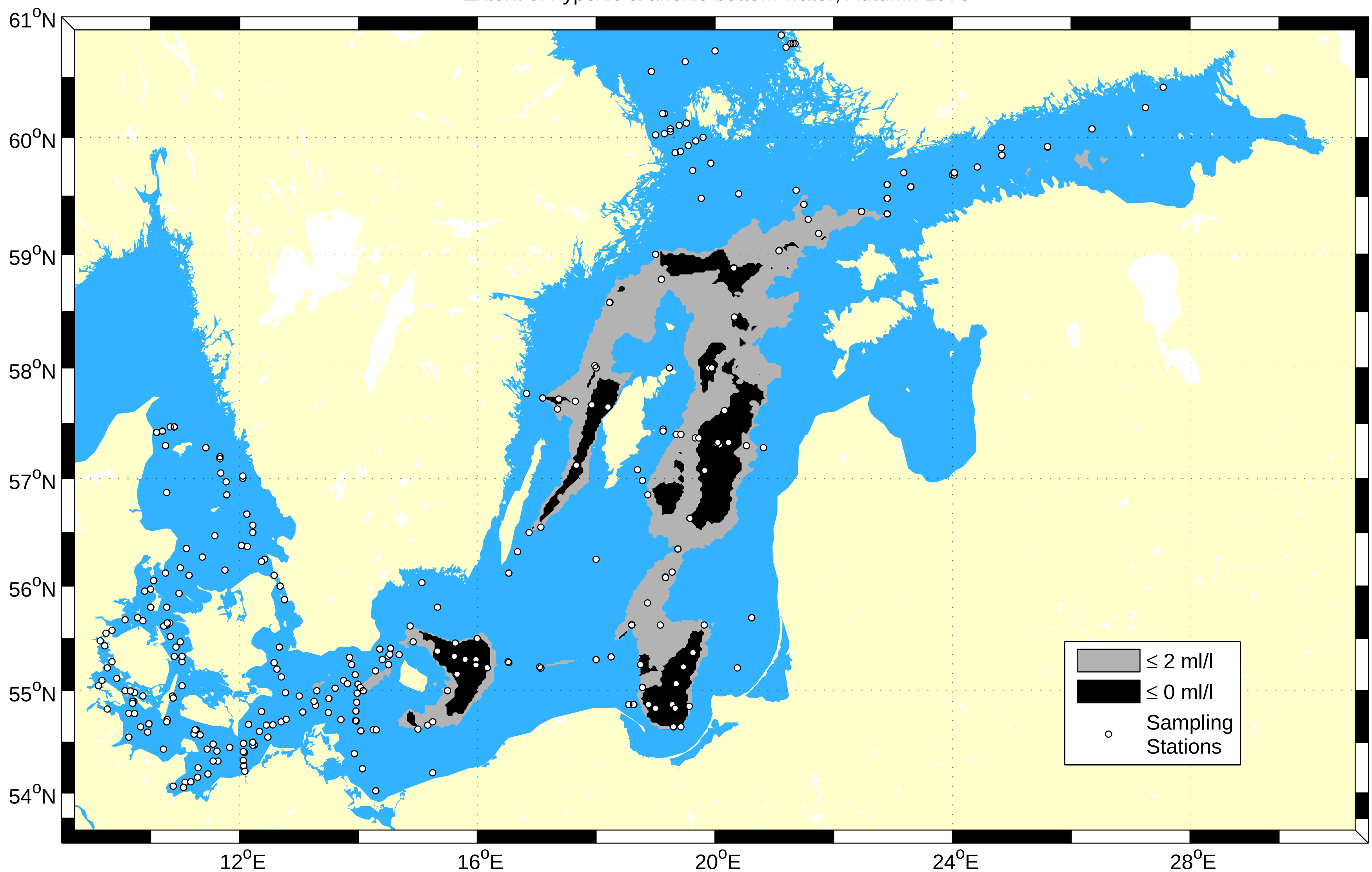
Extent of hypoxic & anoxic bottom water, Autumn 1977



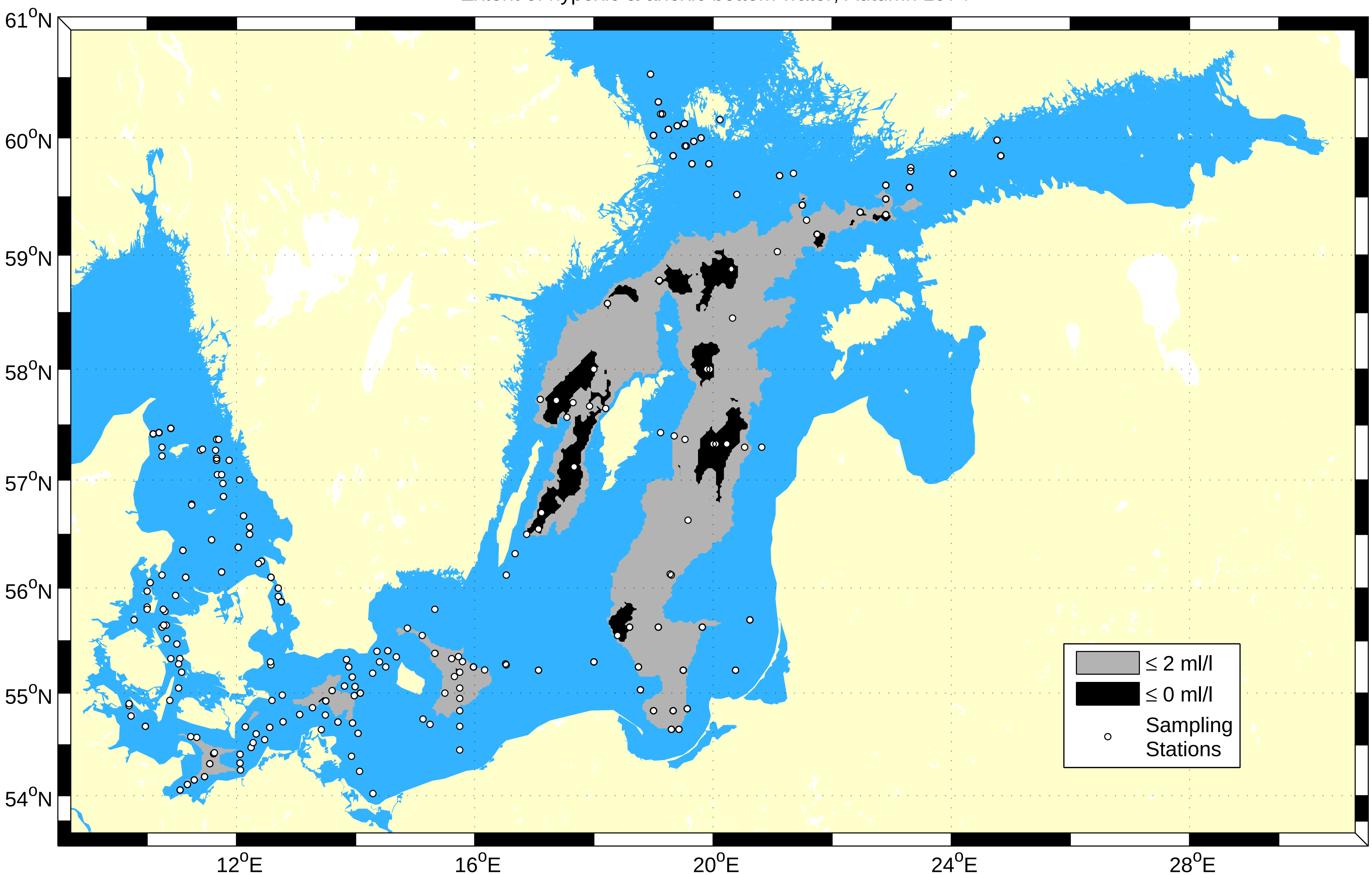
Extent of hypoxic & anoxic bottom water, Autumn 1976



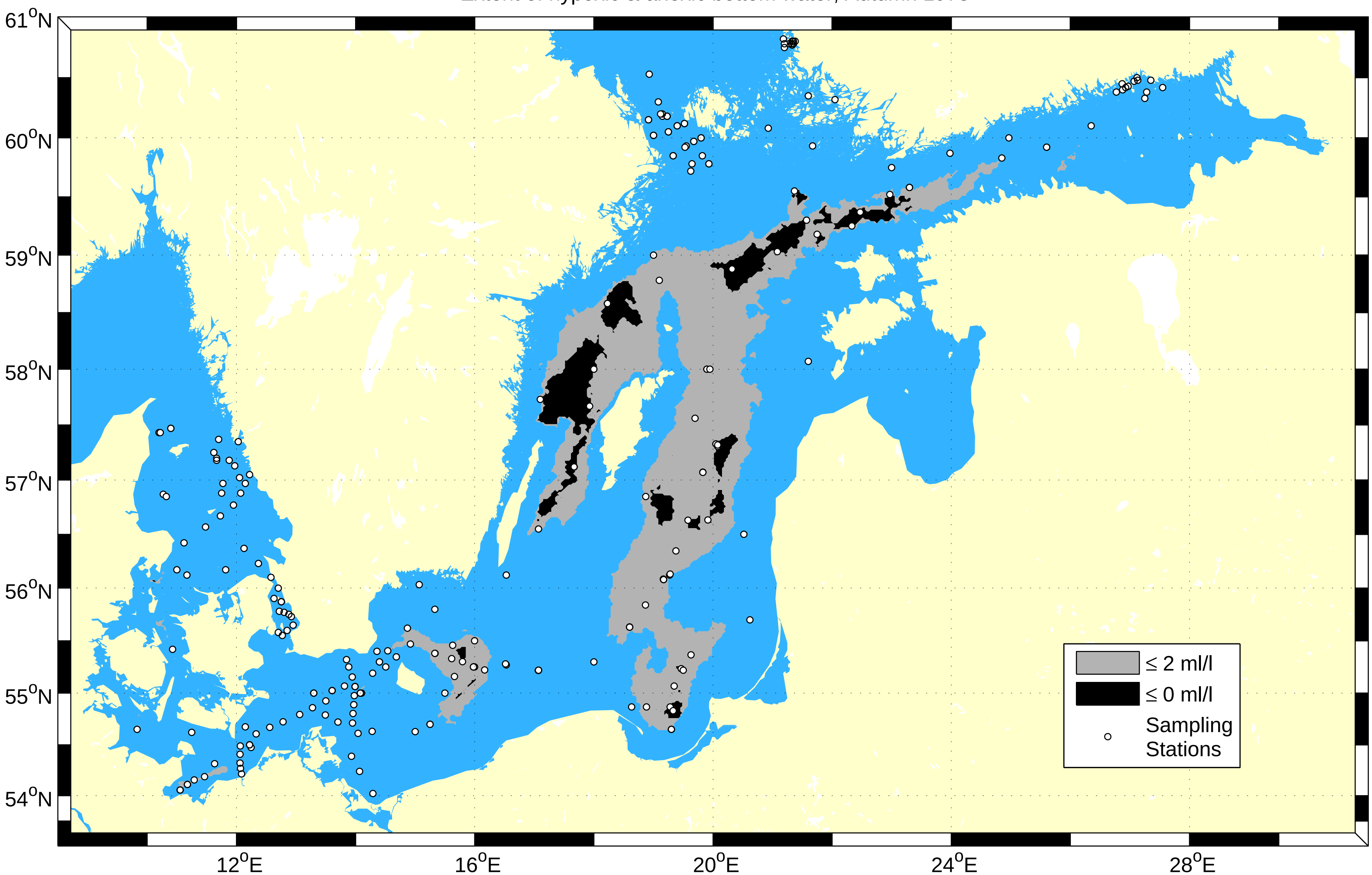
Extent of hypoxic & anoxic bottom water, Autumn 1975

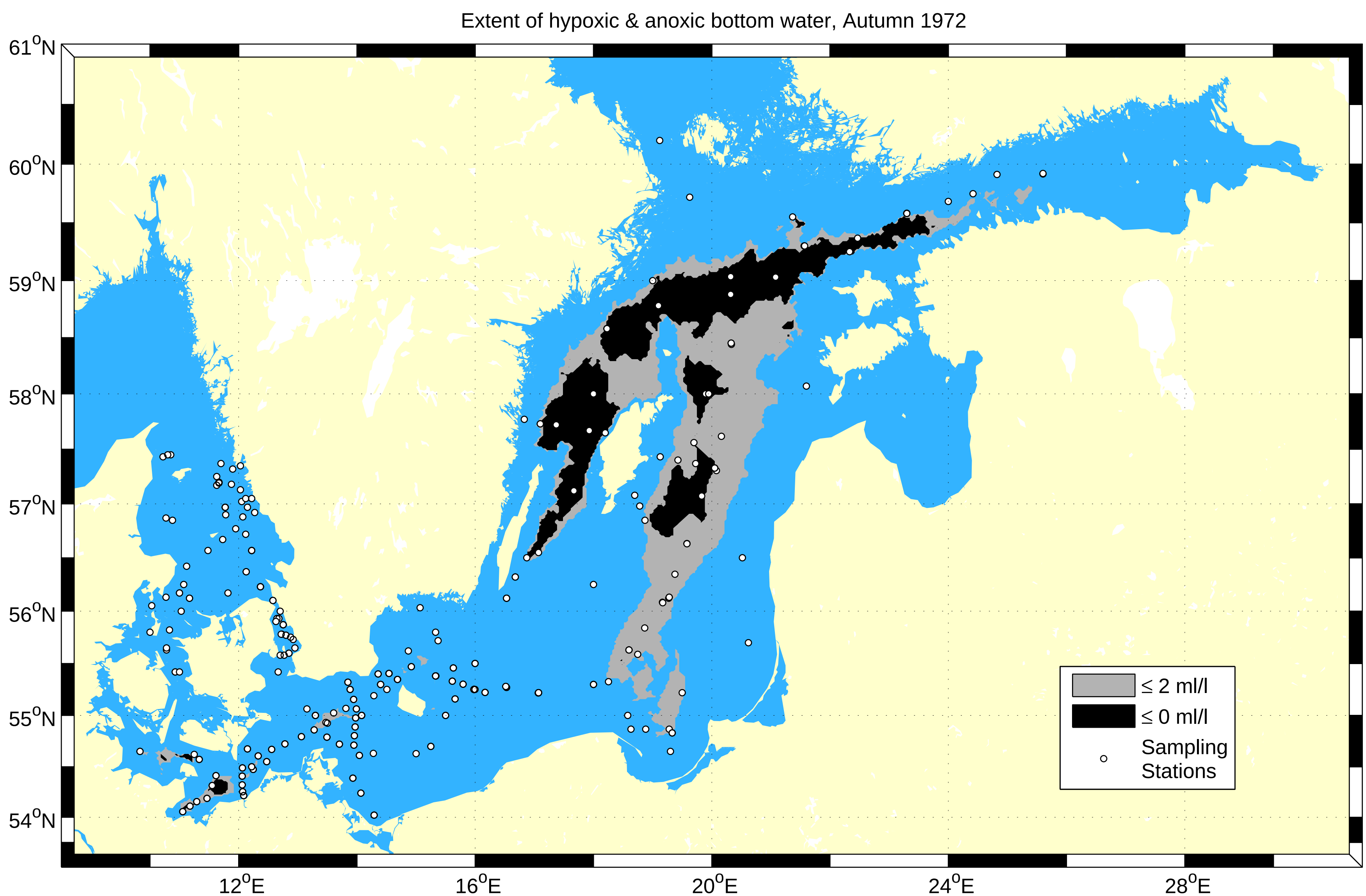


Extent of hypoxic & anoxic bottom water, Autumn 1974



Extent of hypoxic & anoxic bottom water, Autumn 1973




Extent of hypoxic & anoxic bottom water, Autumn 1972
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57°N
56°N
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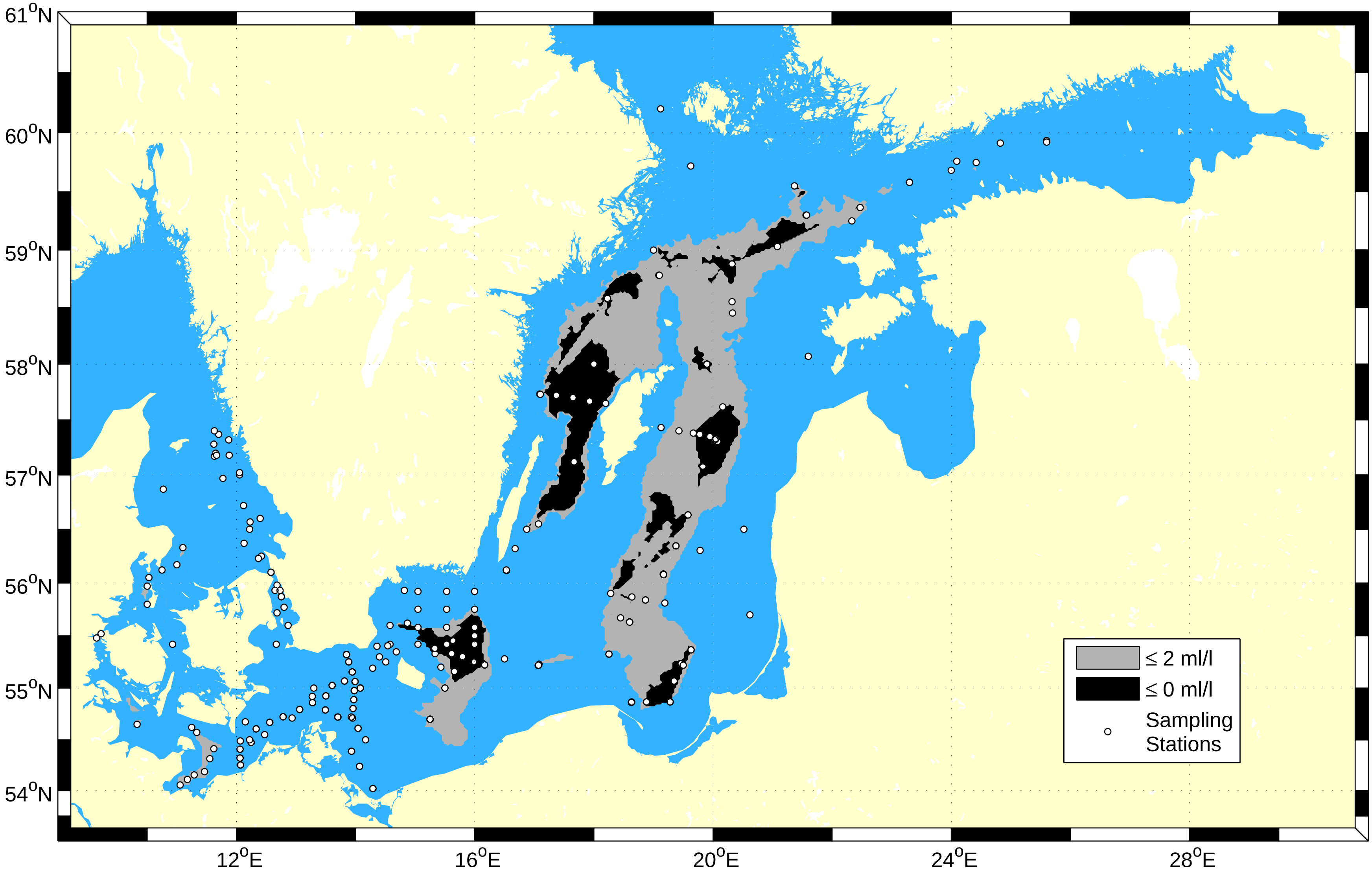
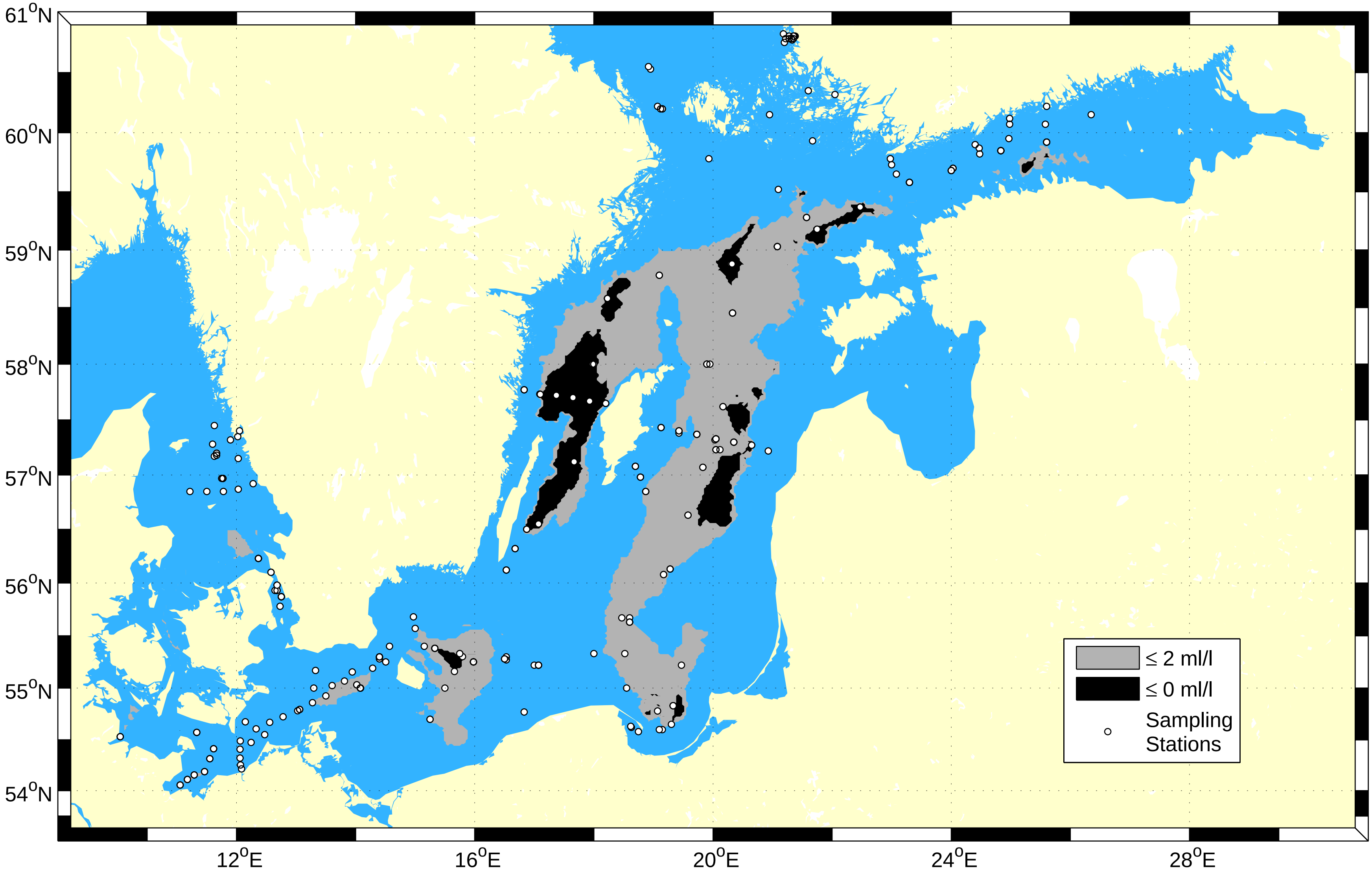
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

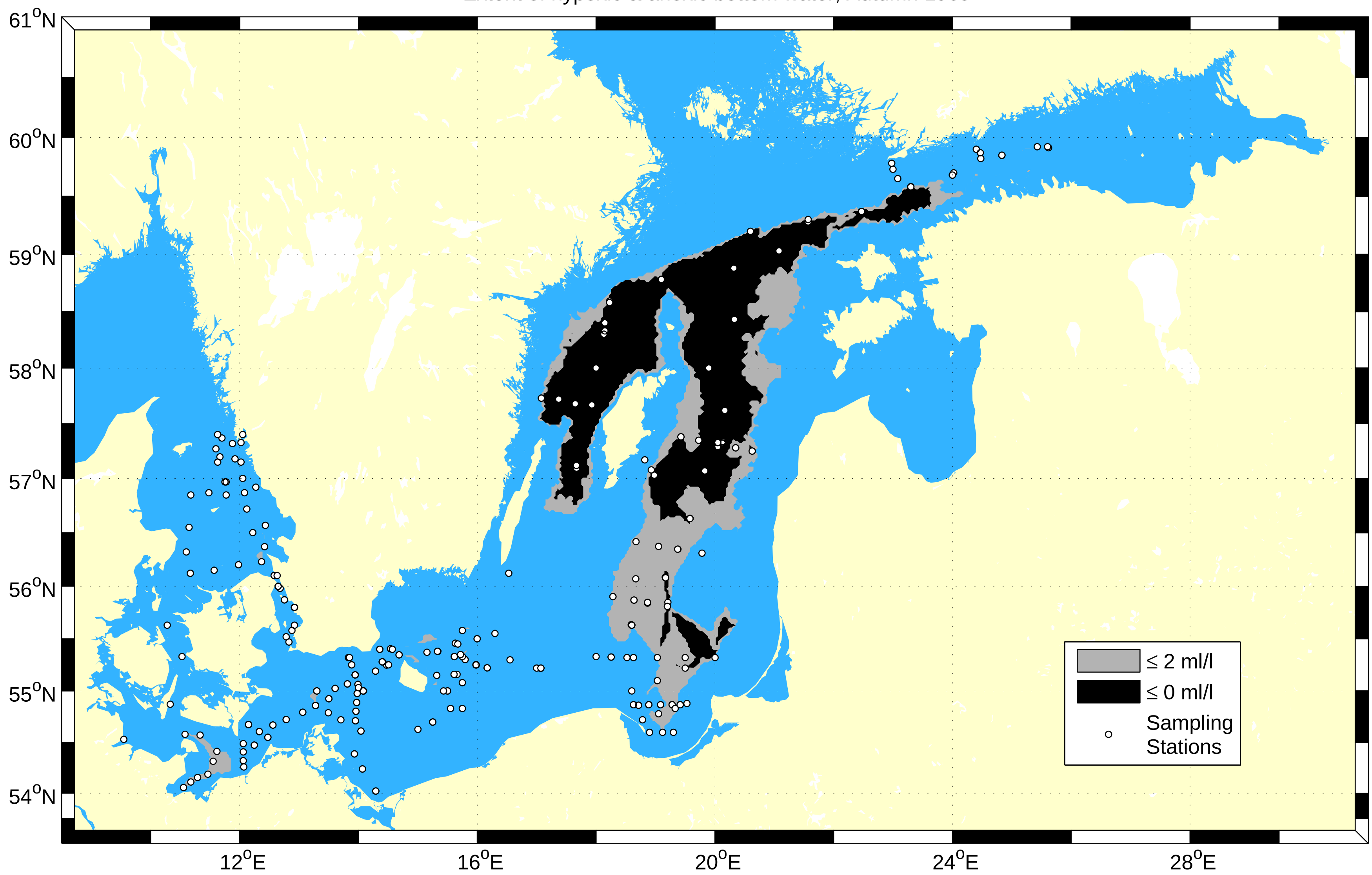
Extent of hypoxic & anoxic bottom water, Autumn 1971



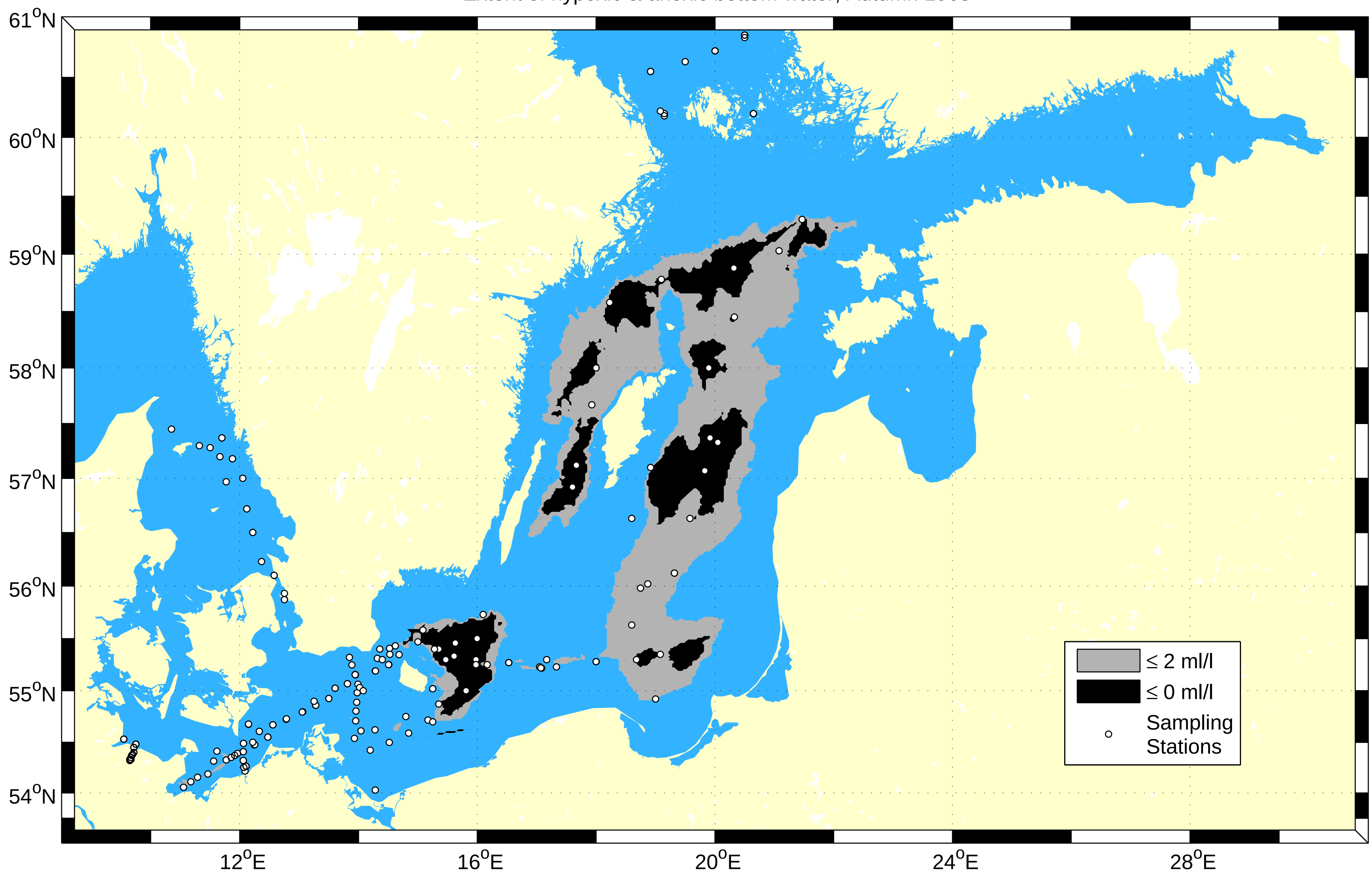
Extent of hypoxic & anoxic bottom water, Autumn 1970



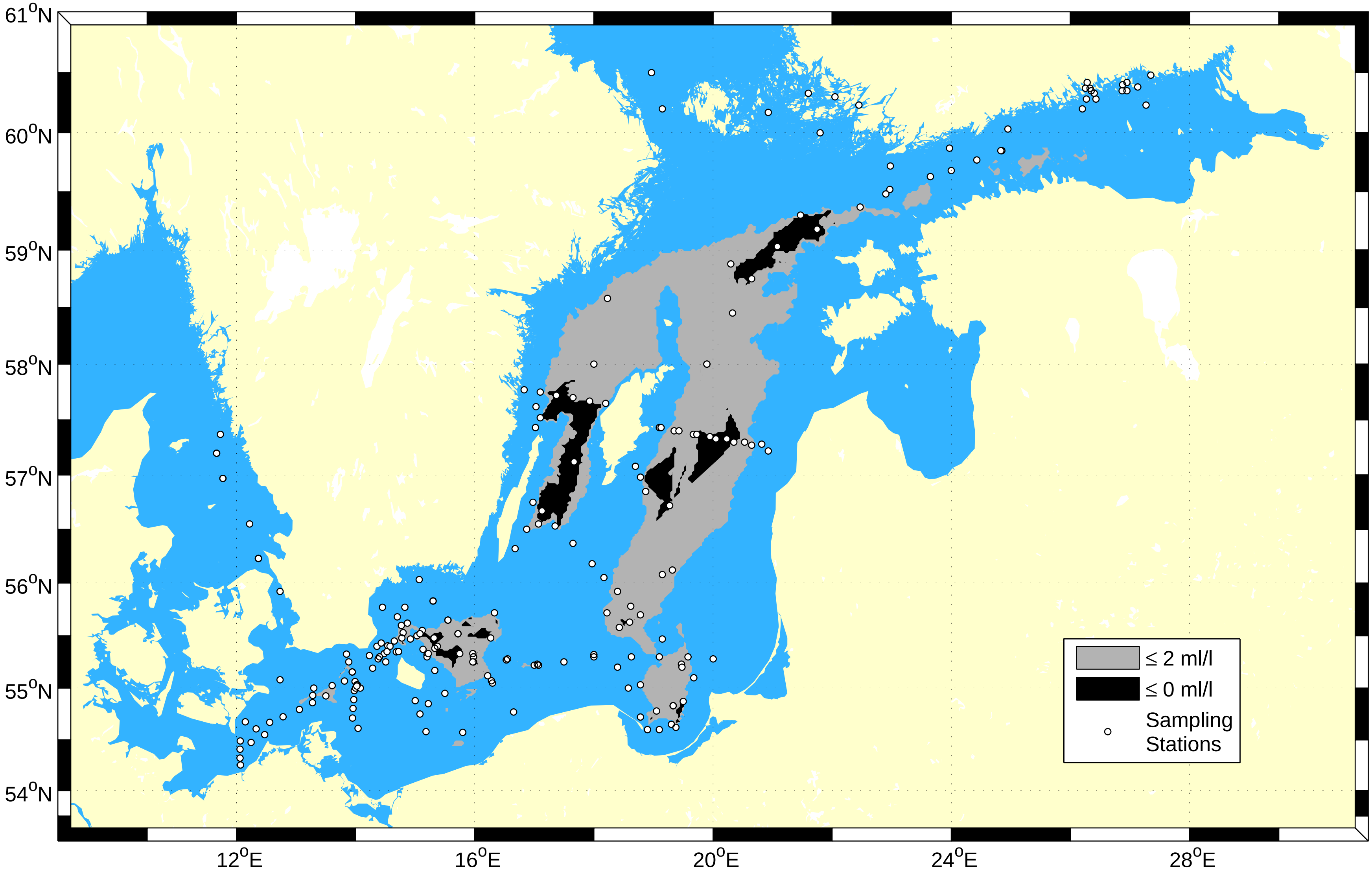
Extent of hypoxic & anoxic bottom water, Autumn 1969



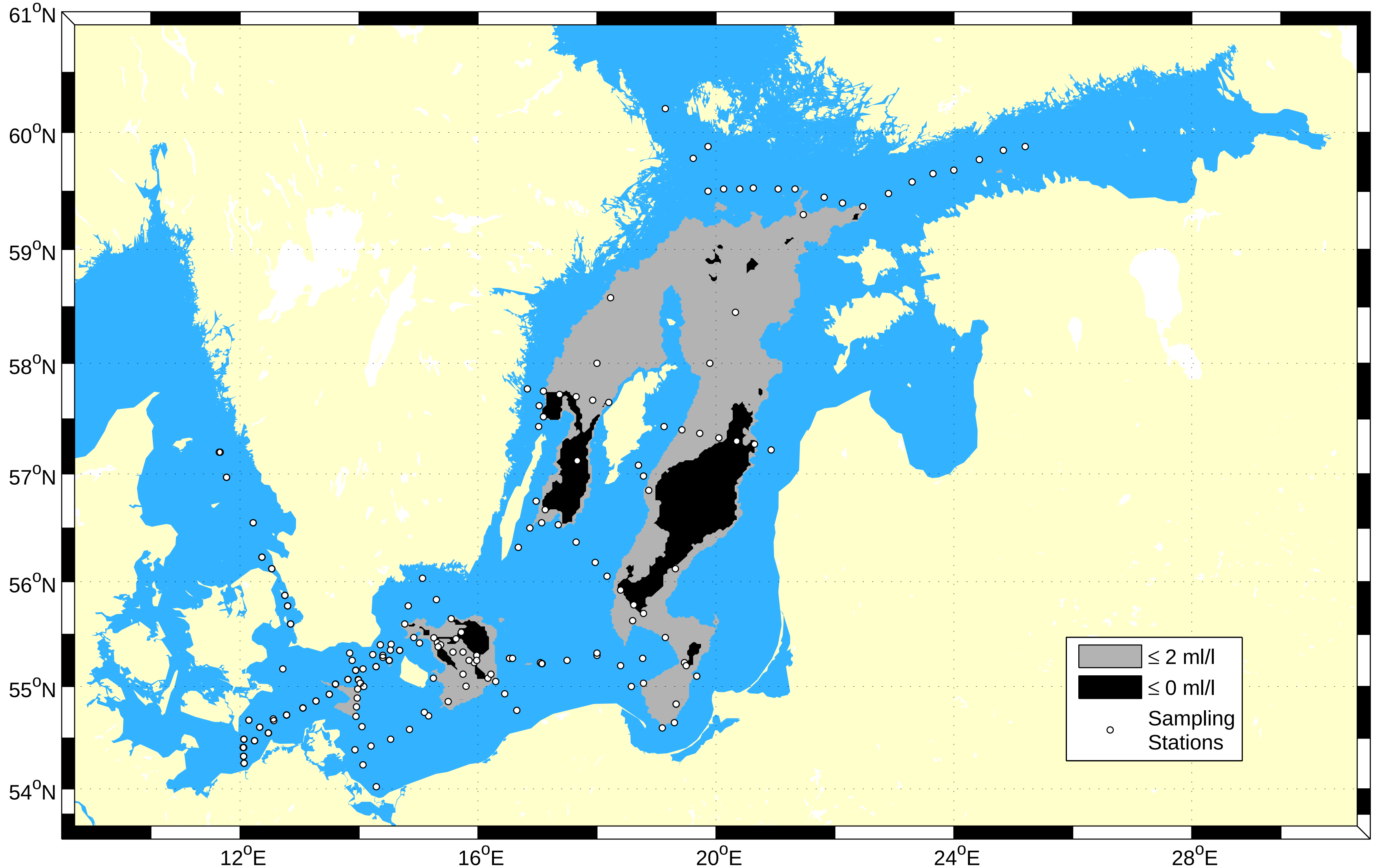
Extent of hypoxic & anoxic bottom water, Autumn 1968



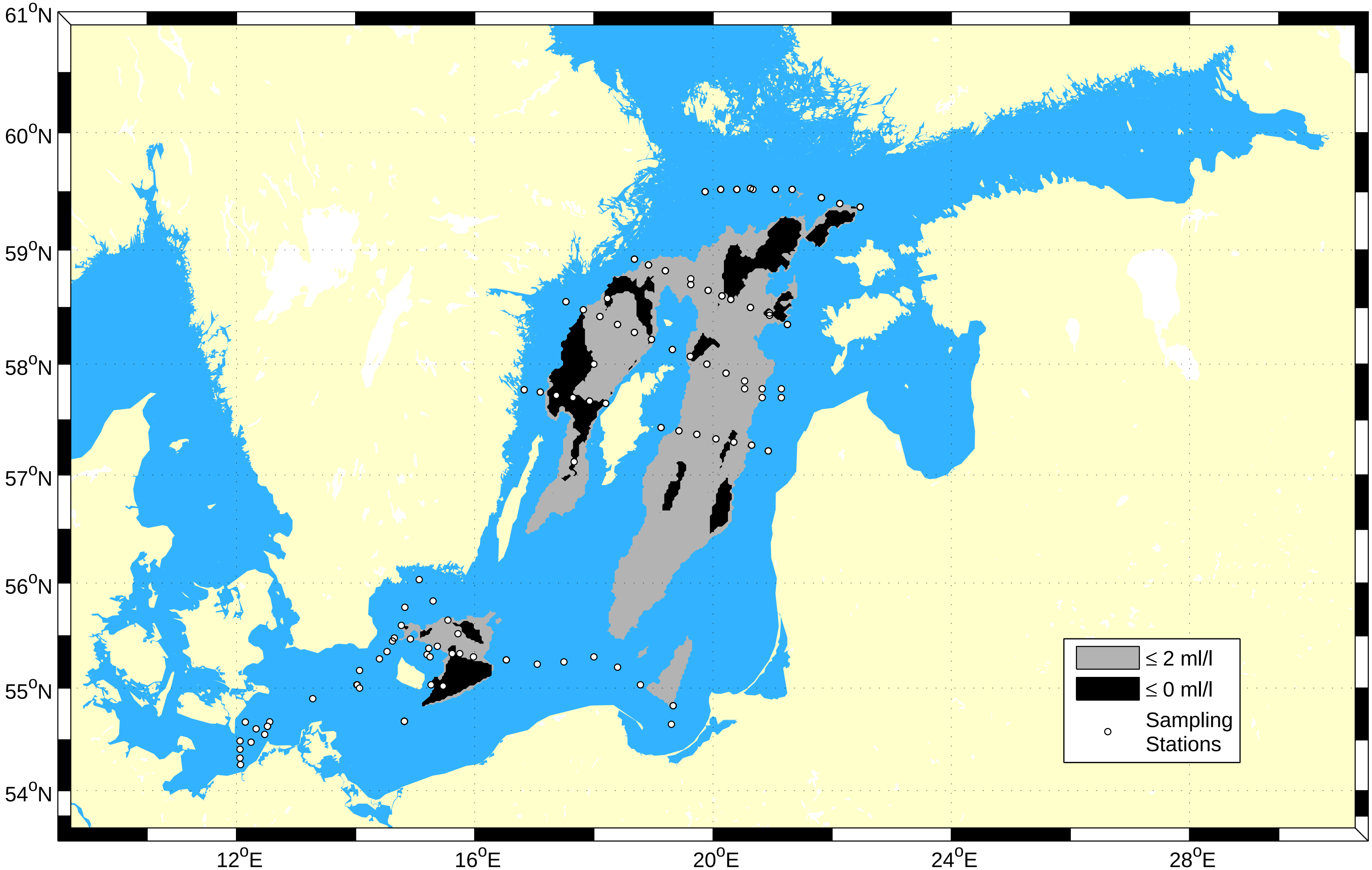
Extent of hypoxic & anoxic bottom water, Autumn 1966



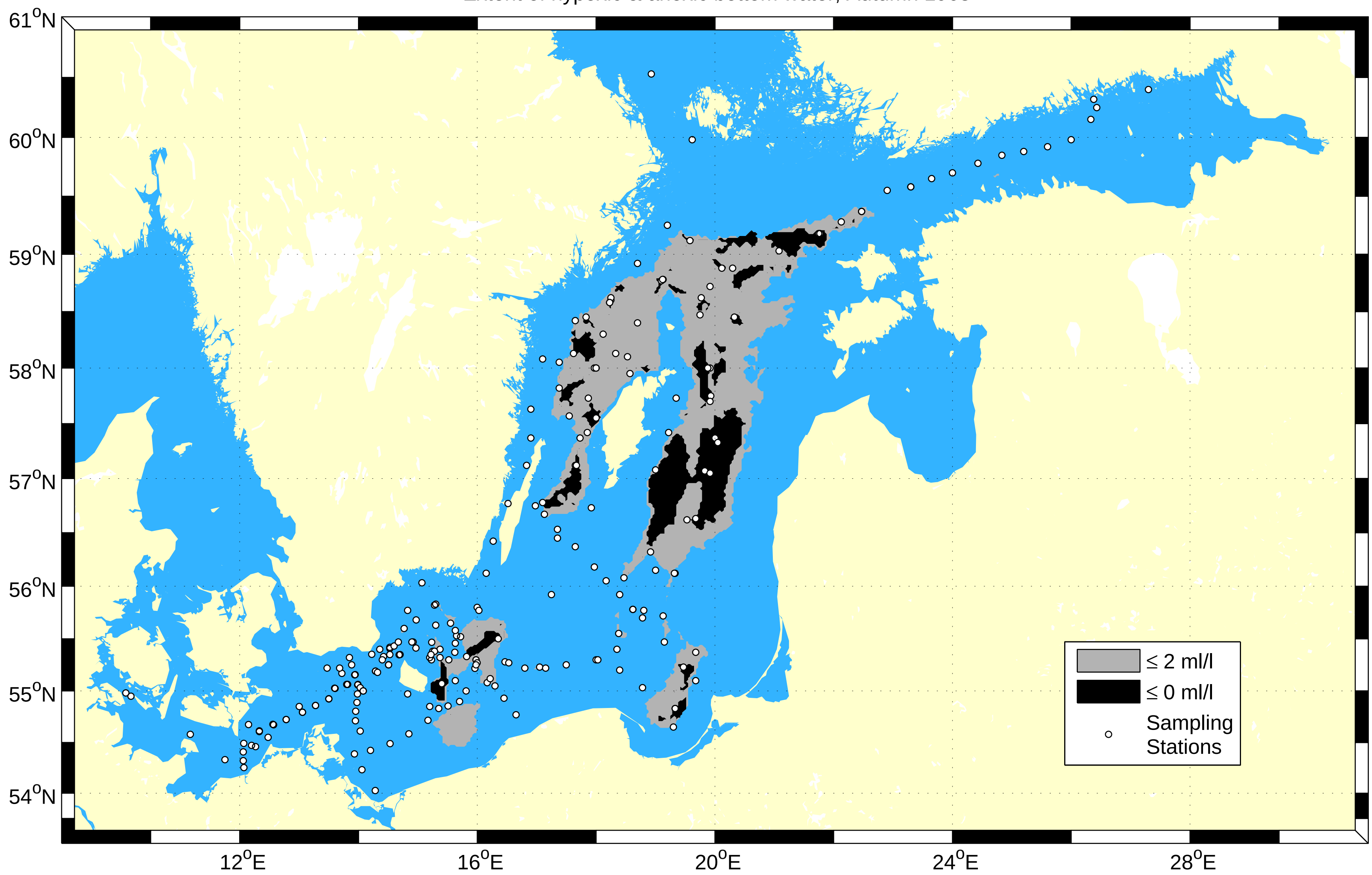
Extent of hypoxic & anoxic bottom water, Autumn 1965



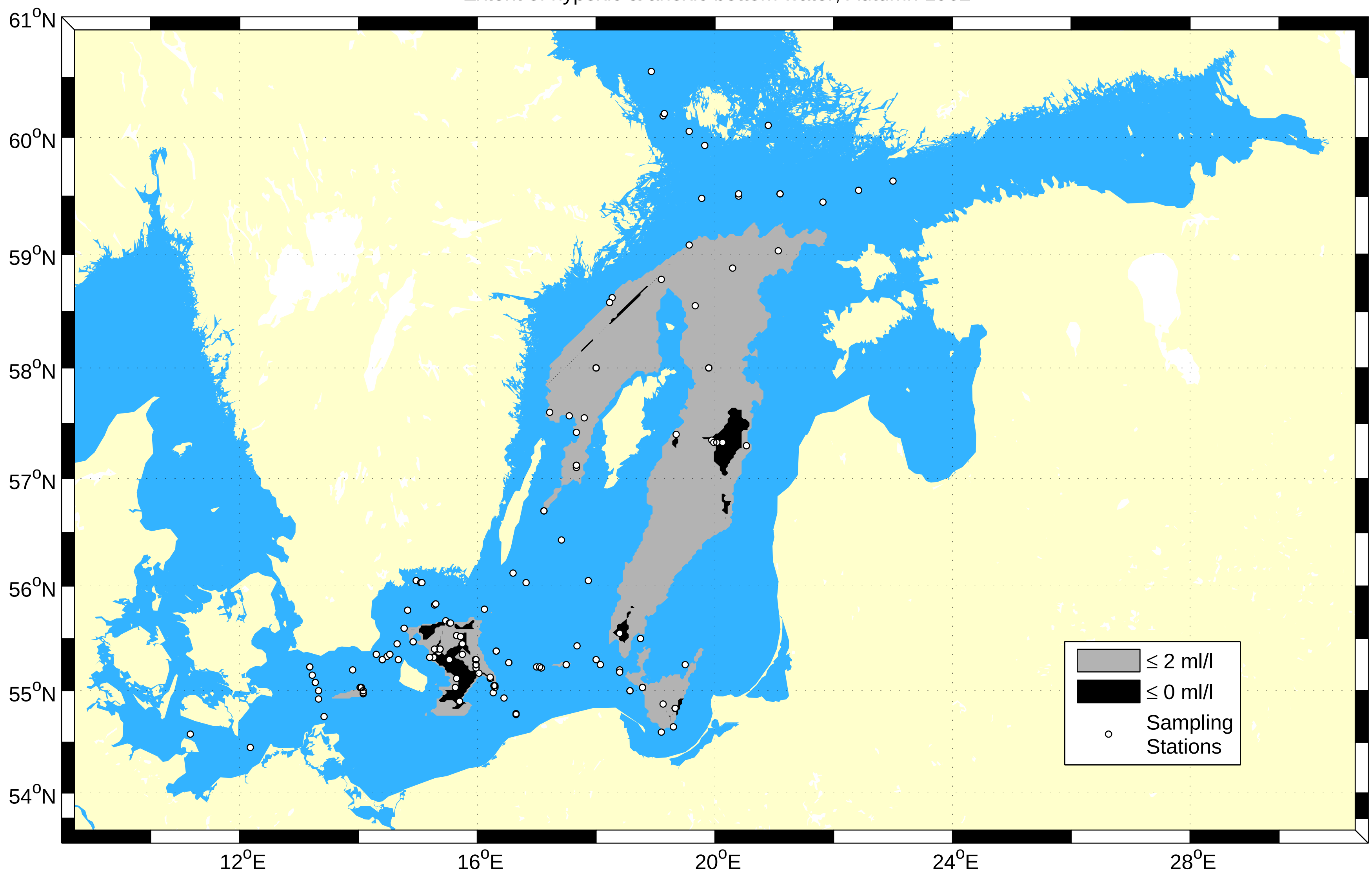
Extent of hypoxic & anoxic bottom water, Autumn 1964

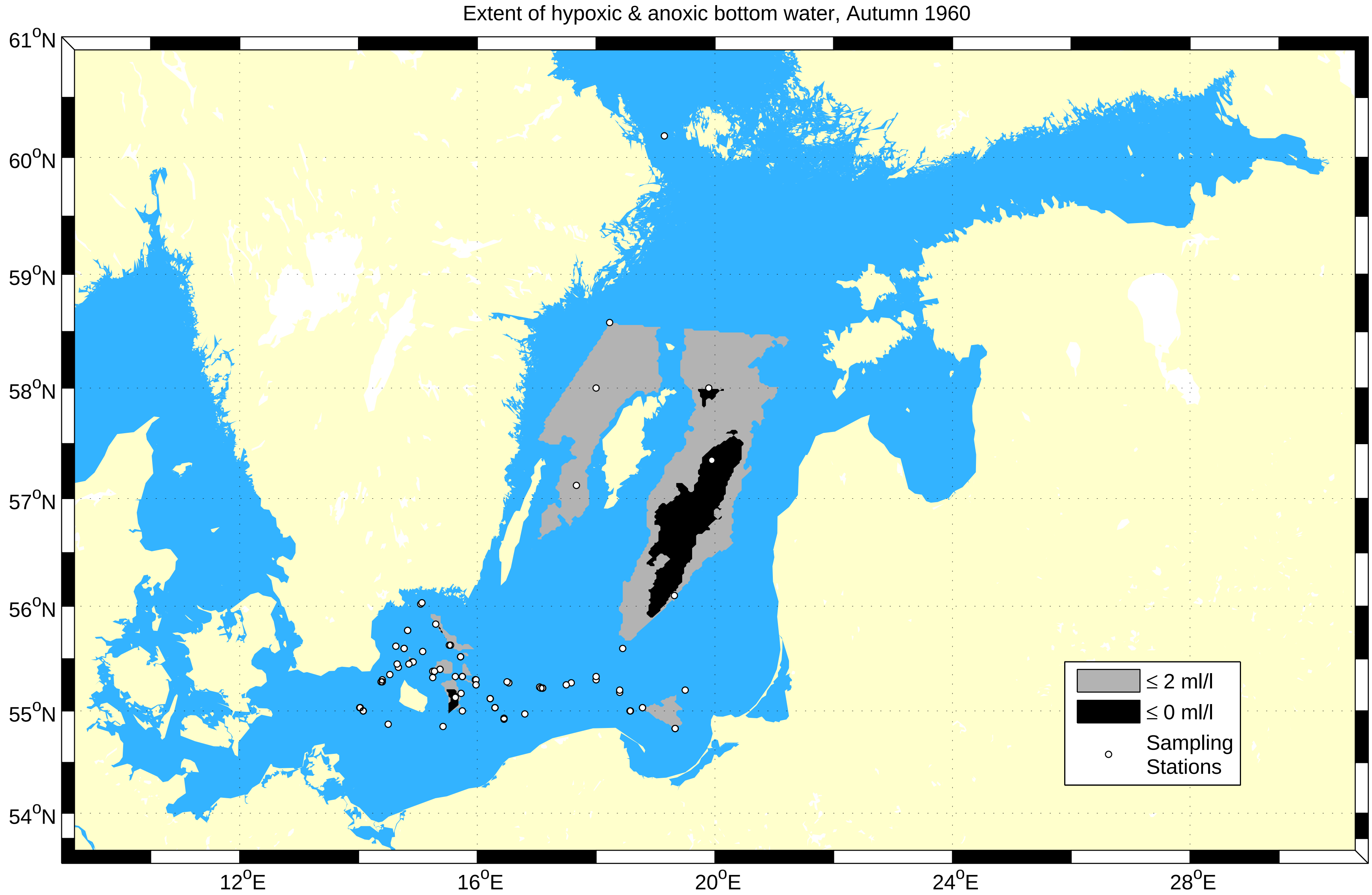


Extent of hypoxic & anoxic bottom water, Autumn 1963



Extent of hypoxic & anoxic bottom water, Autumn 1962





Extent of hypoxic & anoxic bottom water, Autumn 1960
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

8 SMHI Publications

SMHI pub§lish 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
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