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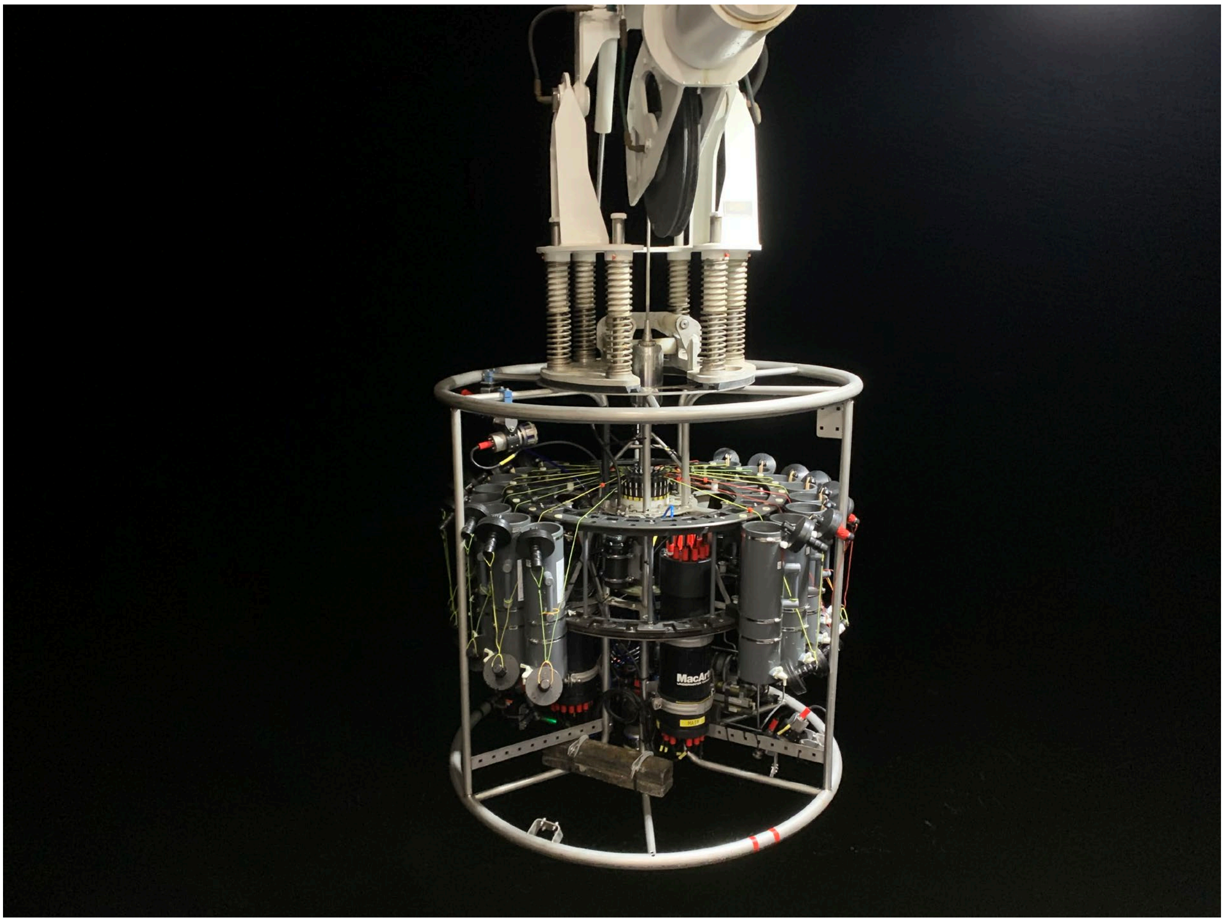
REPORT OCEANOGRAPHY No. 70, 2020

Oxygen Survey in the Baltic Sea 2020

- Extent of Anoxia and Hypoxia, 1960-2020



Front: The photo was taken onboard R/V Svea during SMHI's December cruise in the Gulf of Bothnia and shows the CTD rosette prepared for launching. Photo by M. Hansson.

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Oxygen Survey in the Baltic Sea 2020
- Extent of Anoxia and Hypoxia, 1960-2020

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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 International Council for the Exploration of the Sea (ICES) data centre. In this report the results for 2019 have been updated and the preliminary results for 2020 are presented. Oxygen data from 2020 have been collected from various sources such as international trawl survey, national monitoring programmes and research projects with contributions from Germany, Poland, Estonia, Latvia, 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 2019 and the preliminary results for 2020 show that the severe oxygen conditions in the Baltic Proper after the regime shift in 1999 continues. Levels of anoxia decreased somewhat compared to the record years 2018-2019, while the extent of hypoxia remained largely unchanged. The decreased in anoxia was seen in the southern Baltic Proper and in the Gulf of Finland.

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 during 2020.

Sammanfattning

En klimatologisk atlas över syresituationen i Östersjöns djupvatten publicerades 2011 i SMHI:s Report Oceanography No 42. Sedan 2011 har årliga uppdateringar gjorts då kompletterande data från länder runt Östersjön har rapporerats till ”International Council for the Exploration of the Sea” (ICES) datacenter. I denna rapport har resultaten från 2019 uppdaterats och preliminära resultat för 2020 tagits fram. Resultaten för 2020 baseras på preliminära data insamlade under internationella fiskeriundersökningar, nationell miljöövervakning och forskningsprojekt med bidrag från Tyskland, Danmark, Estland, Lettland, 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 1960-2020.

Resultaten för 2019 och de preliminära resultaten för 2020 visar att den extrema syrebristen som observerats i Egentliga Östersjön, efter regimskiftet 1999, fortsätter. Utbredningen av syrefria områden har minskat något jämfört med rekordåren 2018-2019, medan områden påverkade av syrebrist var ungefär lika stora. Minskningen i utbredning av syrefria bottnar var tydligast i södra delen av Egentliga Östersjön samt i Finska Viken.

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 2020.

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1 Background

Low oxygen conditions in the deep parts of the Baltic Sea are historically a natural phenomenon caused by its topography as an almost completely enclosed sea and "fjordlike" form. The narrow straits and shallow sills in the Belt Sea and the Sound permits only a limited water exchange between the Baltic Sea and the North Sea.

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 and the North Sea. Only during specific wind, weather and sea level conditions the direction of the flow through these straits gets reversed 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 mixed by the wind. The 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 water 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 large nutrient inputs over time, mainly between the 1950s and the late 1980s resulting in escalating eutrophication with symptoms of increased severity to the Baltic Seas ecosystem [HELCOM, 2018].

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 – a vicious circle has formed.

All these natural factors in combination 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) 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. 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 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 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 2020. 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 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 2019 and 2020. 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 2020 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, Germany, 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 2020 will be updated when additional data are reported to ICES in late 2021. In this report the results for 2019 have 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: 2021-01-26).

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]. The results, as accumulated inflow, from 1977 to present are presented at the SMHI website. For the years 2019 and 2020 see Figure 5 and 6. [SMHI, 2021]

Another estimate of the flow through the Sound and the Belt Sea has been presented by [Volker 2018]. 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 [Volker 2018] is usually higher but the SMHI inflows are often divided into several inflow events. However, there are some inflows in both time series that do not correlate at all. For example, during late 1980s and 1990 in [Volker 2018] and in early 1990s in the SMHI timeseries. The difference could be explained by the local [SMHI, 2021] and regional [Volker, 2018] perspectives of the two methods.

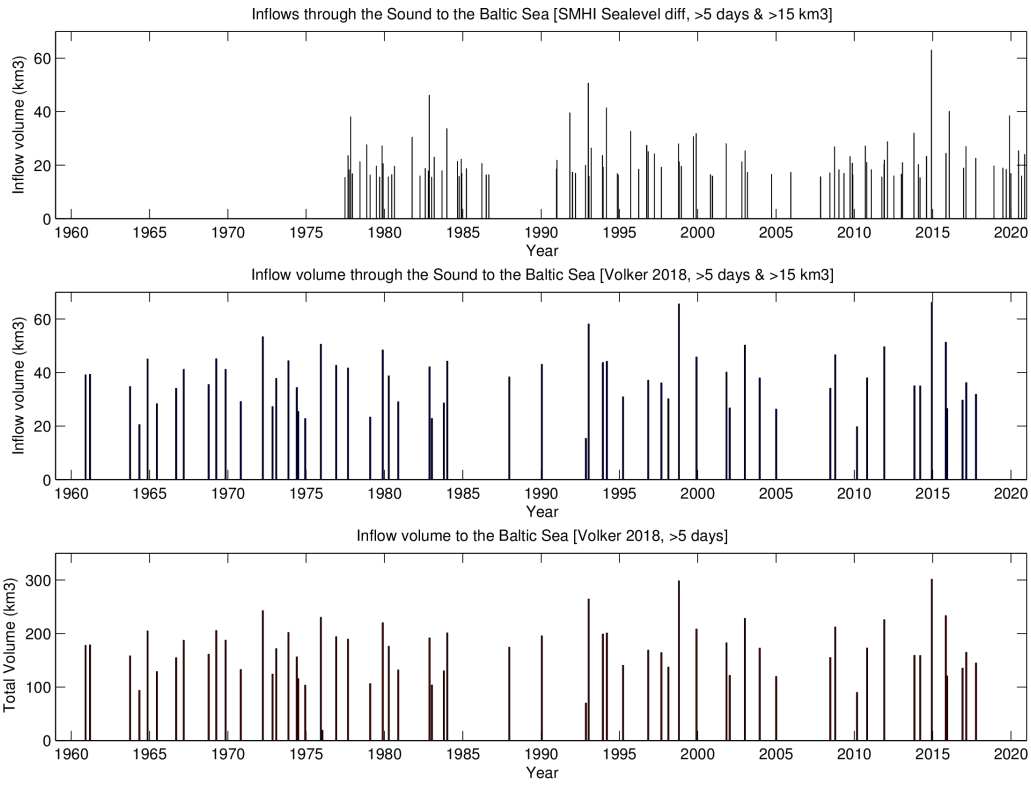


Figure 1. Two different estimations of inflow to the Baltic Sea through the Sound (Öresund). Top: Inflow through the Sound estimated by [SMHI, 2021]. Middle: Inflow through the Sound estimated by [Volker, 2018] 1960-2018. Bottom: Total volume transport through the Sound and the Danish Straits to the Baltic Sea for inflows [Volker 2018]. Note that the time series from [Volker 2018] has not been updated with data after 2018, 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 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].

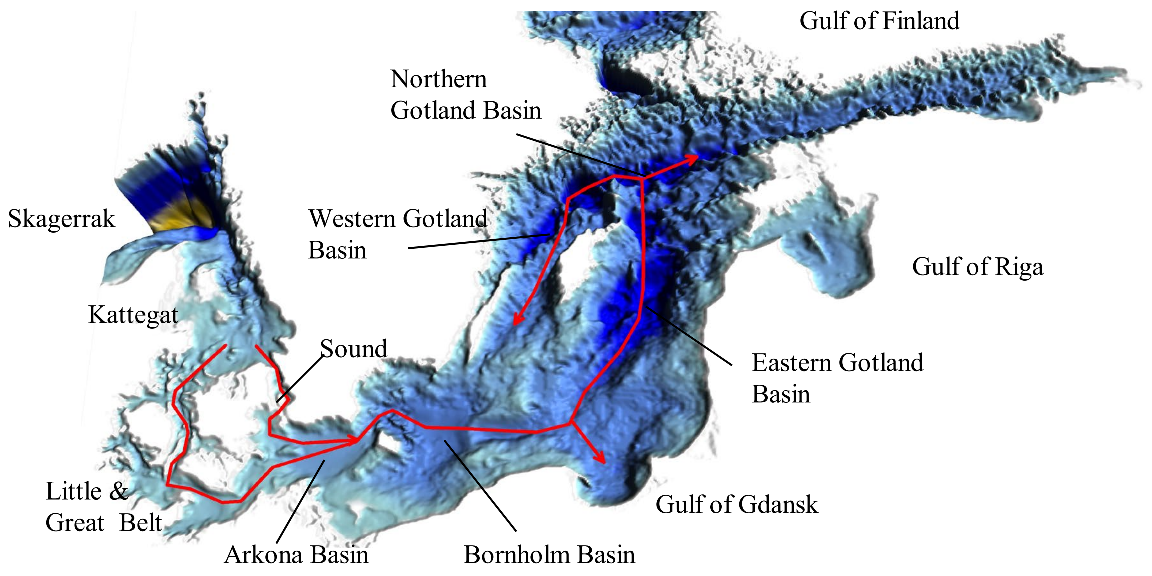


Figure 2. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathways of inflowing deep-water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk, the Gulf of Riga and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

4 Result

Extent and volume affected by hypoxia and anoxia during the period 1960 - 2020 are presented in Figures 3 and 4, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2019 and 2020 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 2020 are presented in Table 1.

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. Note that the results for 2020 are preliminary.

in %	1960 – 1998		1999 – 2019		2020	
	Hypoxia	Anoxia	Hypoxia	Anoxia	Hypoxia	Anoxia
Mean Areal extent	22	5	29	16	31	18
Max Areal extent (Year)	27 (1970)	14 (1969)	33 (2018)	24 (2018)	-	-
Min Areal extent (Year)	9 (1993)	1 (1994)	25 (1999)	10 (2000)	-	-
Mean Volume	13	2	19	9	18	11
Max Volume (Year)	19 (1965)	8 (1969)	22 (2019)	15 (2018)	-	-
Min Volume (Year)	5 (1993)	0.1 (1994)	15 (2000)	4 (1999)	-	-

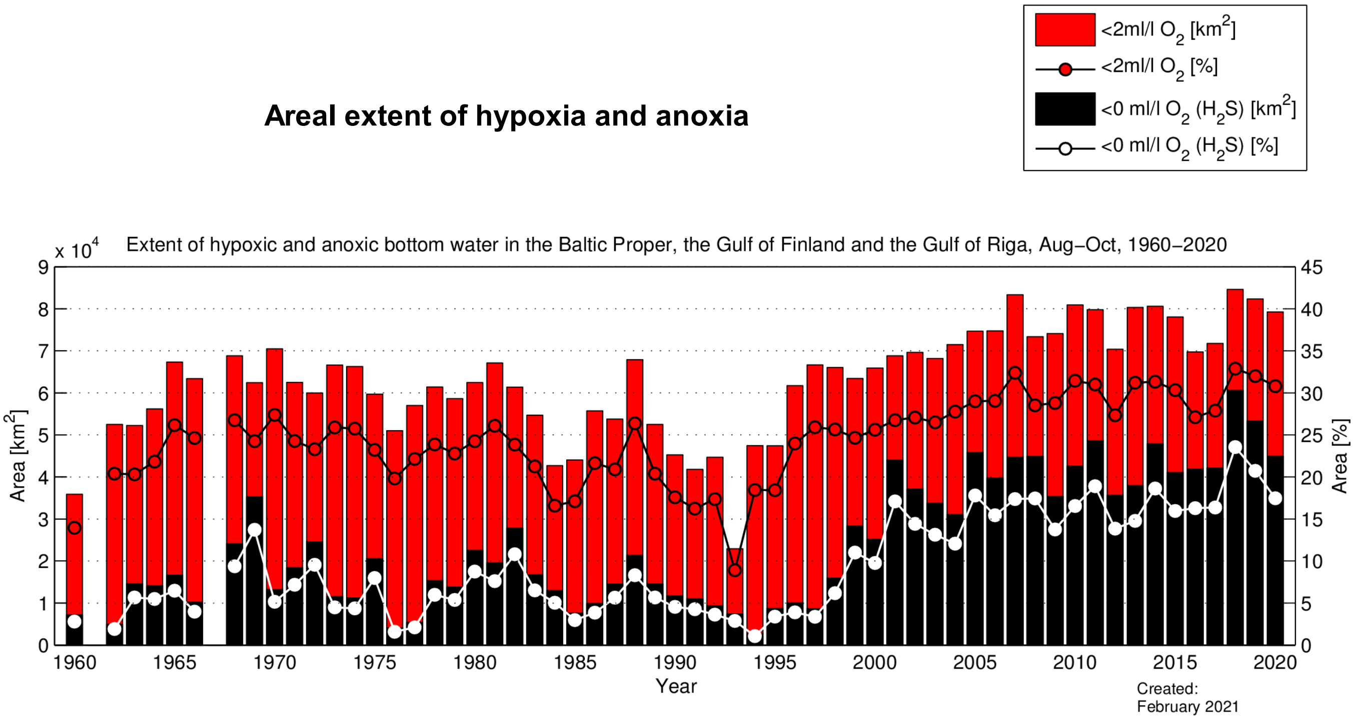


Figure 3. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

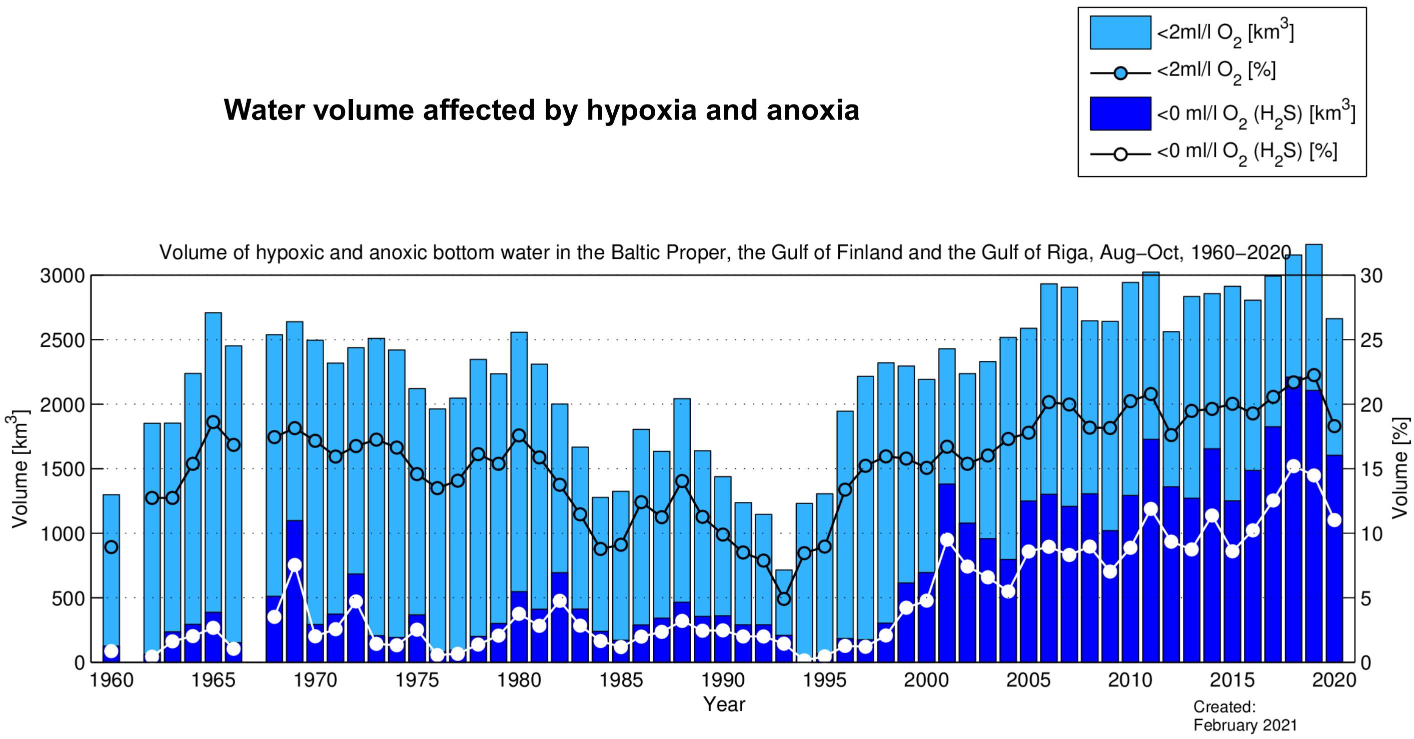


Figure 4. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

4.1 Updated results for 2019

The result for 2019 has been updated as new hydrographic data has been reported to ICES. New anoxic areas were found in the Gulf of Finland and the anoxic areas in the southern Eastern Gotland Basin and outside the Gulf of Gdansk decreased. However, overall the update only resulted in minor changes.

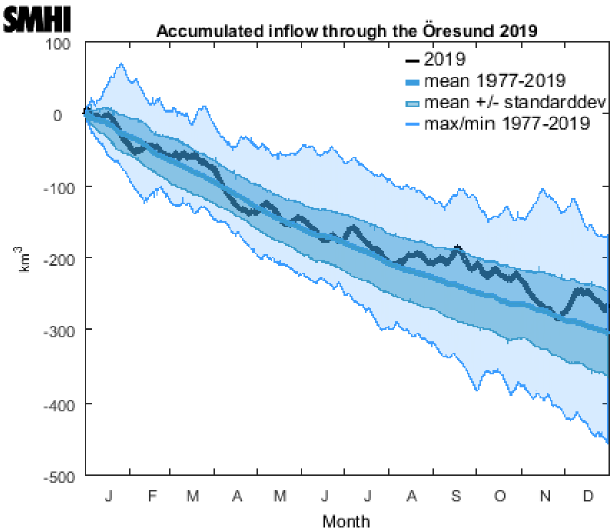
As the results both increased and decreased the final proportion of areas affected by both anoxia and hypoxia was unchanged, 21% and 32% respectively. Similar small changes were found for water volume affected; volume of anoxic water increased from 14% to 15% and the volume of hypoxia water was unchanged at 22%.

As the results for 2019 has been updated its clear that the oxygen development that has prevailed since the regime shift in 1999 continues. The areal extent of anoxia and hypoxia are large and has only decreased slightly compared to the record year 2018 when the area of both anoxic and hypoxic were the largest noted during the analysed period. However, as the different areas have specific bathymetry the result for volume of anoxic and hypoxic water do not fully follow the results for areal extent. Hence, the largest volume of hypoxic water, during the analysed period, was found during 2019; 22%.

Three inflow events (larger than 15 km^3) occurred in 2019. In June/July and September about a week of inflow resulted in two inflows of ~20 km^3 each, registered through the Sound. The inflow 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 when ~40 km^3 water flowed through the Sound (194 km^3 through the Danish Straits [Pers. Comm. M. Naumann, Jan 2020]). See also Figure 5 below.

The total inflow to the Baltic Sea through the Sound during 2019 was 332 km^3 which is higher than normal (compared to the time period 1977-2018 with mean 318 km^3). The outflow was 596 km^3, which is smaller than normal when (mean 623 km^3). The accumulated inflow through the Sound (Öresund) during 2019, compared to the mean inflow 1977-2019 can be seen in Figure 5.



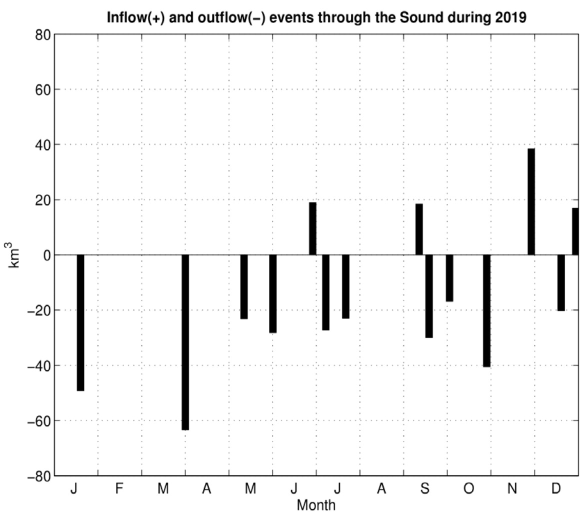


Figure 5. Left: Accumulated inflow (volume transport) through the Sound (Öresund) during 2019 in comparison to mean inflow/outflow 1977-2019. Right: Inflow (+) and outflow (-) events during 2019 with duration longer than 5 days. [SMHI, 2021].

4.2 Preliminary results for 2020

The frequency of inflows to the Baltic Sea have been similar during the last 4-5 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 2019, one medium inflow was noted. During 2020 three inflows, larger than 15 km^3 and longer than 5 days, through the Sound was noted. Inflows in June/July and in November contributed with about 25 km^3 and a smaller inflow of ~16 km^3 occurred in September.

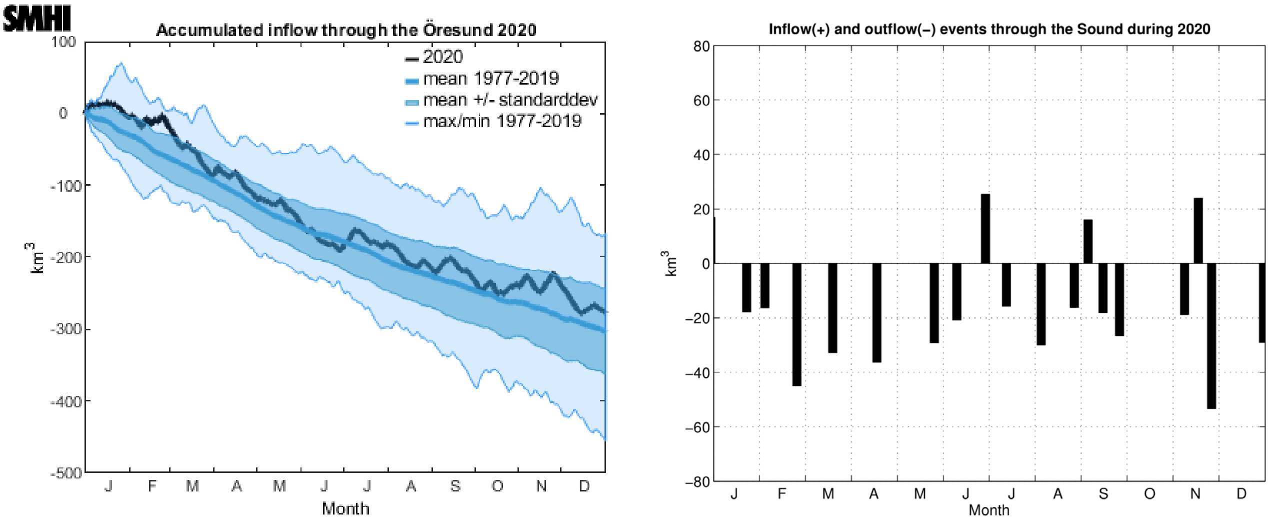


Figure 6. Left: Accumulated inflow (volume transport) through the Sound (Öresund) during 2020 in comparison to mean inflow/outflow 1977-2019. Right: Inflow (+) and outflow (-) events during 2020 with duration longer than 5 days. [SMHI, 2021].

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. The minimum oxygen concentrations and hypoxia (< 2ml/l) was recorded in July-August at station BY1 and later in the east at station BY2, September-October. In October-November the oxygen concentrations improved, due to inflow events. [SMHI, 2020]

The oxygen conditions in the bottom water at Hanö Bight were near anoxic with oxygen concentrations close to 0 ml/l throughout most parts of the year, from May to November. Oxygen concentrations just above 2 ml/l were only found during the February and March cruise. Hypoxia was generally found from depth exceeding 60-70 meters.

In the Bornholm Basin hypoxia was found from depth exceeding 60-70 meters and anoxia or close to 0 ml/l from about 70-80 meters depth from June to December. Signs of improvement in the bottom were only observed in January-February at BY4 and BY5 as the bottom oxygen concentration increased to about 3-4 ml/l. However, already in March the conditions were around 2 ml/l again and in June close to 0 ml/l.

At the station BCSIII-10, further into the southern Baltic Proper inflowing water improved the near bottom oxygen situation during the beginning of the year. However, oxygen concentration at the bottom was just above 2 ml/l during January to March. From April to October the concentrations varied between 1 to 2 ml/l. Anoxic conditions were found in November and December. Hypoxia was found from 60-70 meters depth.

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 60-70 meters depth during the first month of the year but deeper from May, at 70-80 meters depth. Around 0 ml/l were found between 80-125 meters depth and below 125-150 meters hydrogen sulphide was present throughout the year. The pool of hydrogen sulphide are increasing and the concentrations in the deep water are higher than normal. See Figure 7, Appendix 1 and SMHI cruise reports from 2020. [SMHI, 2020]

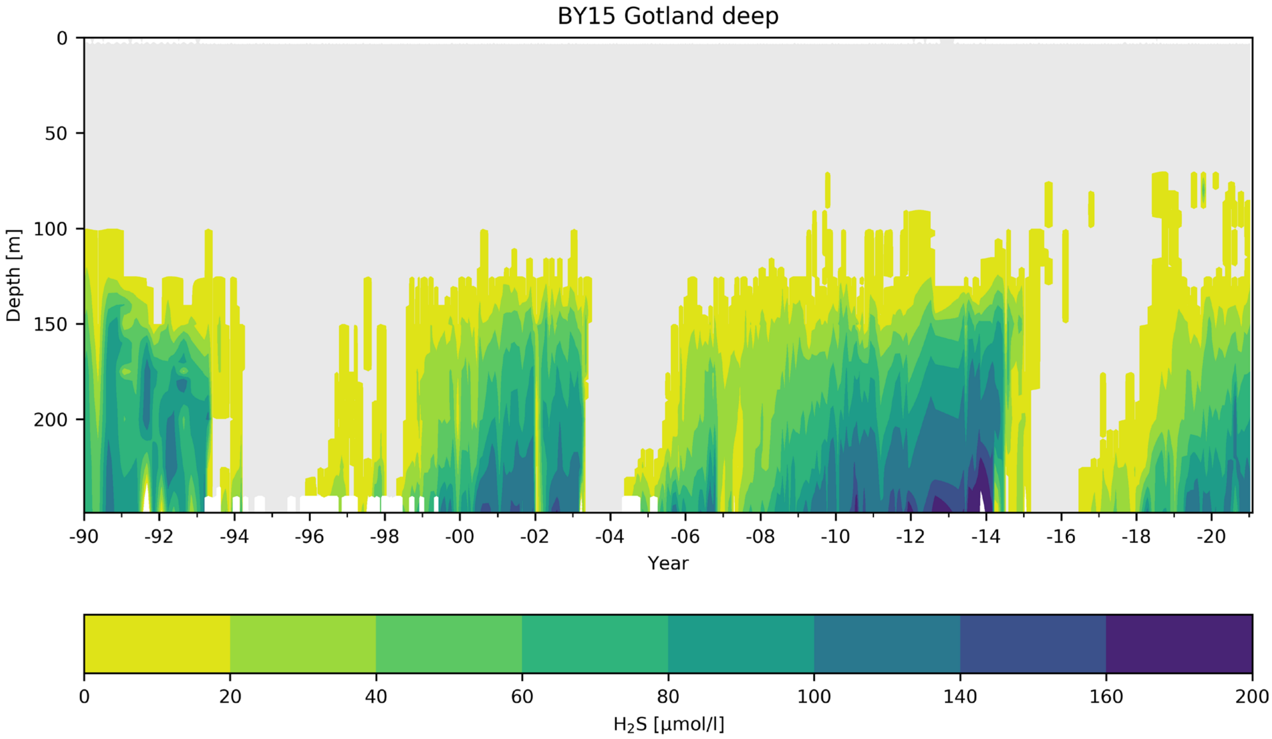


Figure 7. Concentration of hydrogen sulphide (H_2S) at Gotland Deep (BY15) in Eastern Gotland Basin from 1990-2021. Grey signifies no hydrogen sulphide present.

The Northern Gotland Basin and the Eastern Gotland Basin show similar development in the deep water. 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. In February anoxic conditions were found from 60 meters depth and hypoxia from 50 meters depth. However, from March hypoxia was found from 70 meters depth and anoxia at 80 meters with only small variations during the rest of the year. [SMHI, 2020]

The preliminary results for 2020 shows that the severe oxygen situation that has prevailed since 1999 continues. When comparing 2018/2019, the two years with the most widespread anoxic and hypoxic conditions since the 1960s, with the results for 2020, the levels are now back at the same levels that as was noted during the period 2000-2017.

The main difference to 2019 is that the anoxic and hypoxic areas are less widespread in the southern parts of Baltic Proper, such as the Bornholm Basin, Gulf of Gdansk and Gulf of Finland. The extent in the central deep basins around Gotland are more similar between years and the interannual differences are be seen in the more dynamic areas in the areas mentioned above.

The small improvements seen during 2020 in the southern parts of the Baltic Proper could be connected to the inflow that occurred in November/December 2019 and several smaller inflows before and after this medium inflow. The positive development in the Gulf of Finland is not connected to inflows, since no inflows has reached this area during 2020. The positive changes here are more likely coupled to changes in stratification and mixing, since no inflows has reached this area.

It should be noted that the 2020 results are preliminary; however, the results are based on several extensive data sets with essential data contributions from almost all countries around the Baltic region. Please see the Acknowledgement for all helpful data contributors.

5 Conclusions

- Anoxic conditions affected 21% of the bottom areas and 32% suffered from hypoxia in 2019. In 2020 anoxia affected 18% of the bottom areas and 31% suffered from hypoxia.
- Preliminary results for 2020 shows that anoxic and hypoxic conditions have decreased compared to the record years 2018-2019. However, the decrease in hypoxia is small.
- 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.
- The decreas in anoxia noted during 2020 in the southern Baltic Proper can be connected to the inflow that occurred during 2019. The positive development in the Gulf of Finland is most likely due to changes in stratification and mixing since no inflows has reached this area.
- The pool of hydrogen sulphide is increasing in the Eastern Gotland Basin. No major inflows reached the deep water in this basin during 2020.
- 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

Many thanks to Tycjan Wodzinowski, National Marine Fisheries Research Institute in Poland, for sending data from two surveys: Polish Multiannual Fisheries Data Collection Programme (September), Relations between recruitment of selected fish species and driving forces as hydro-meteorological factors and food availability (August).

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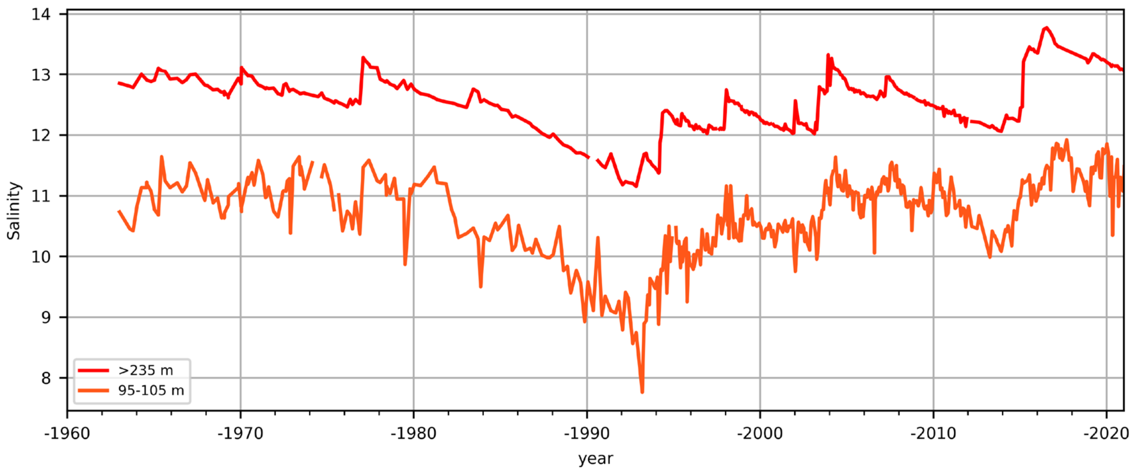
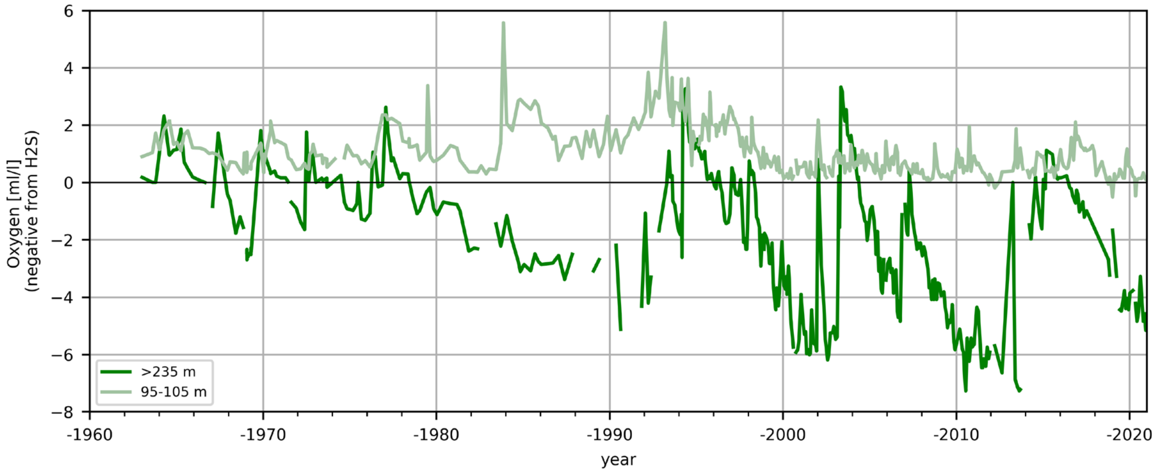
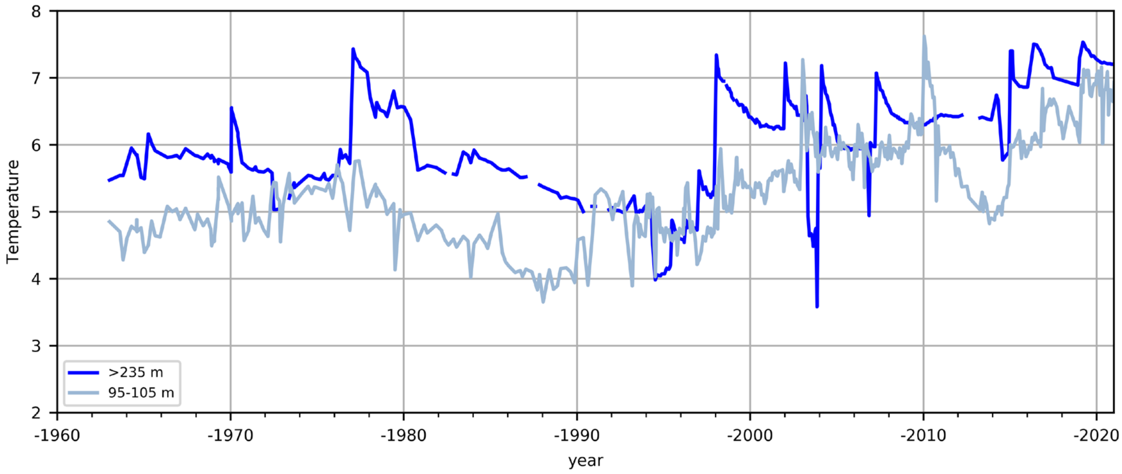
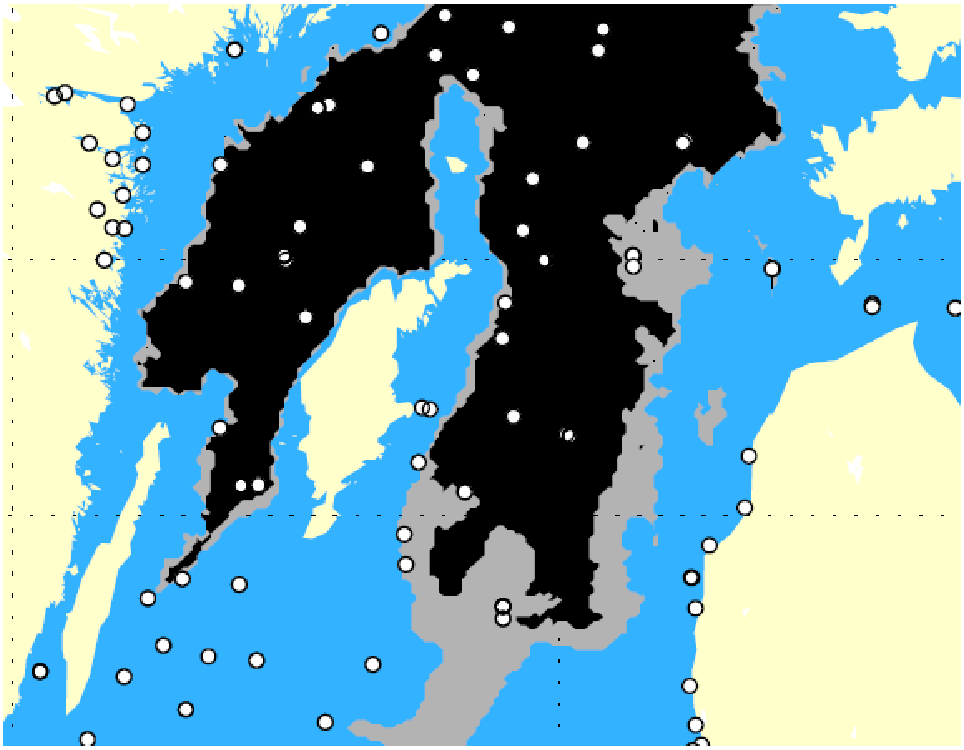
Appendix 1 – Temperature, salinity and oxygen in Eastern Gotland Basin at station BY15, 1960-2019



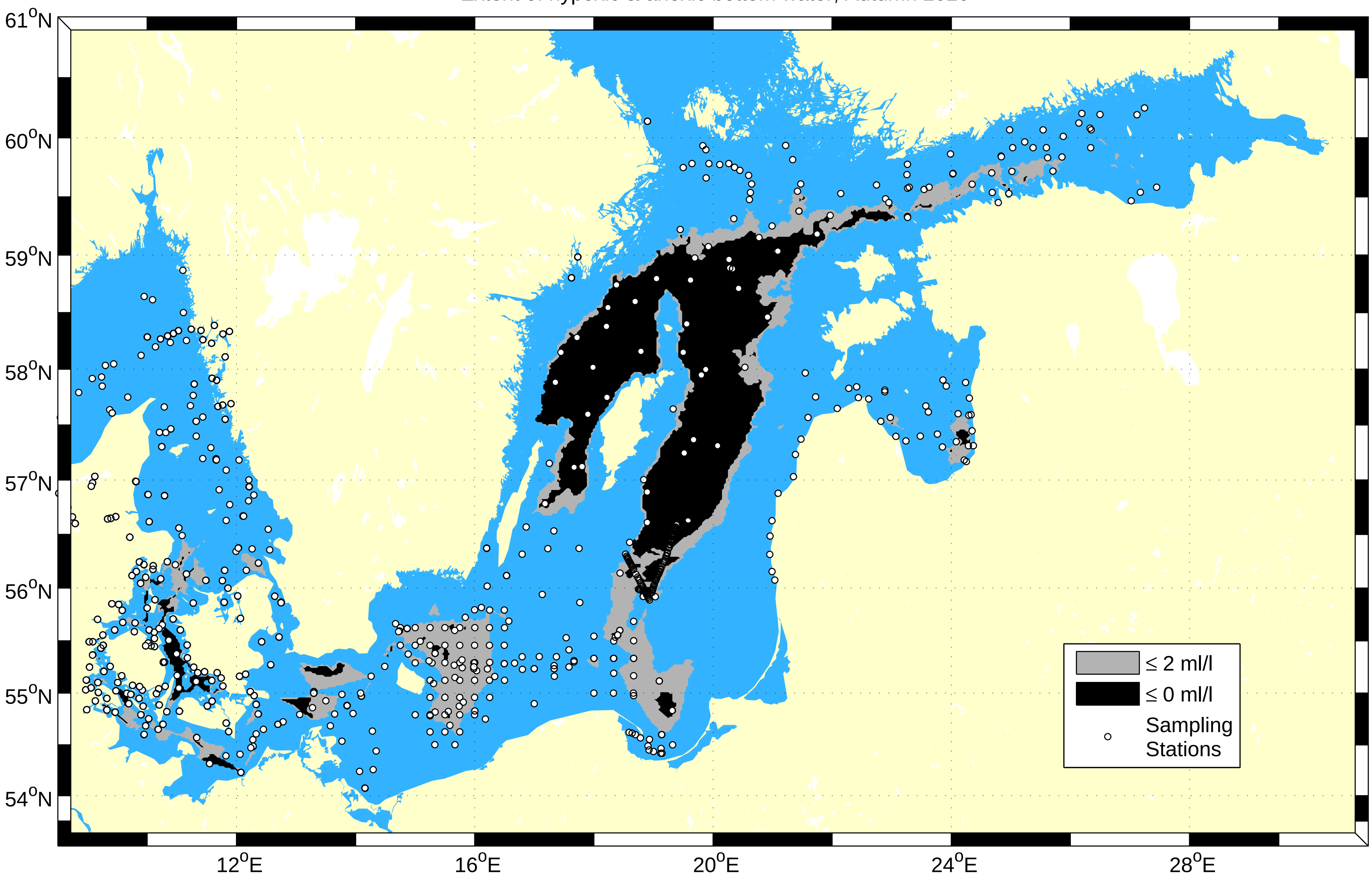




Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea
- updated maps 1960-2020



Extent of hypoxic & anoxic bottom water, Autumn 2020



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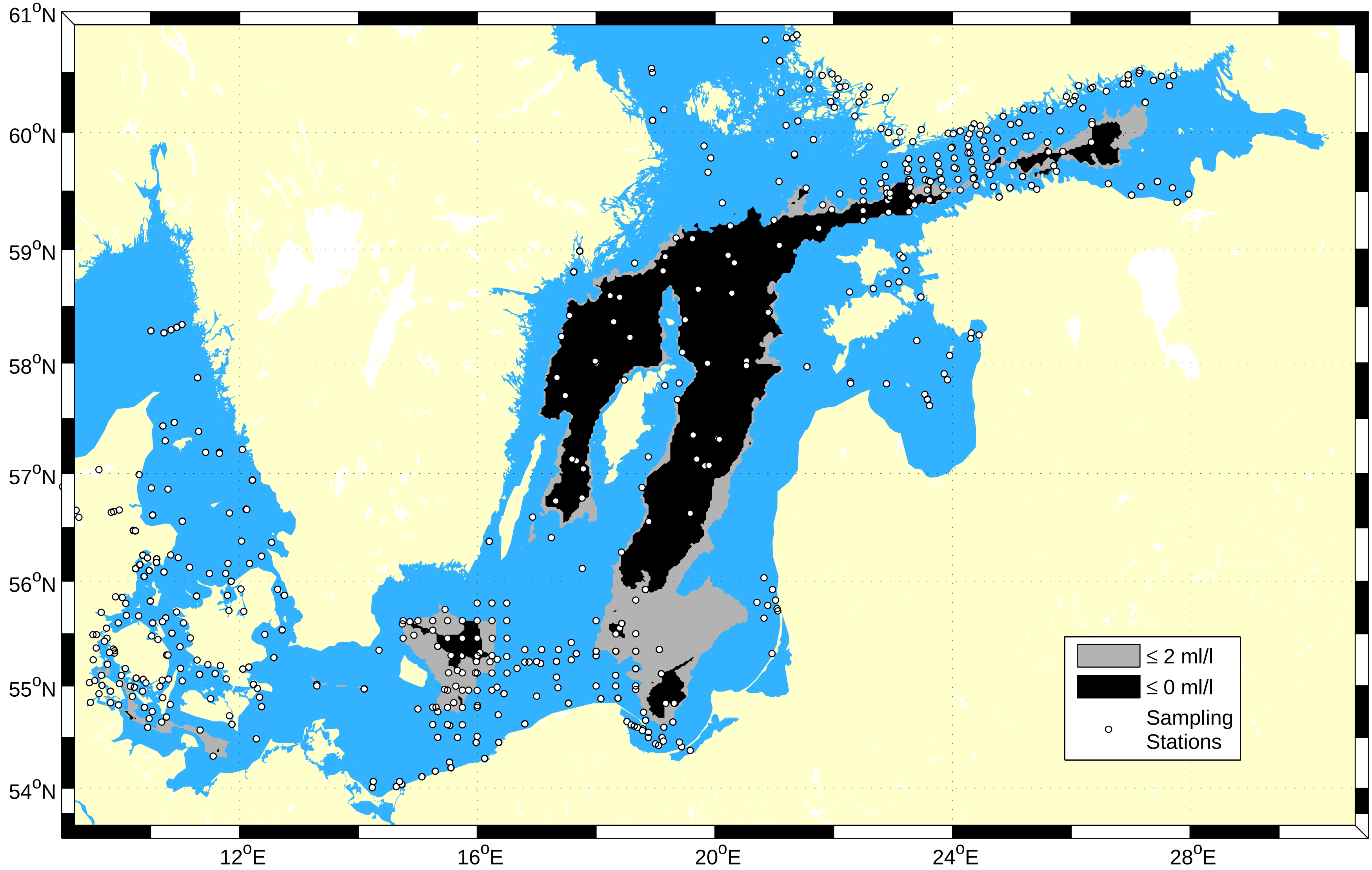
February 2021

Extent of hypoxic & anoxic bottom water, Autumn 2019



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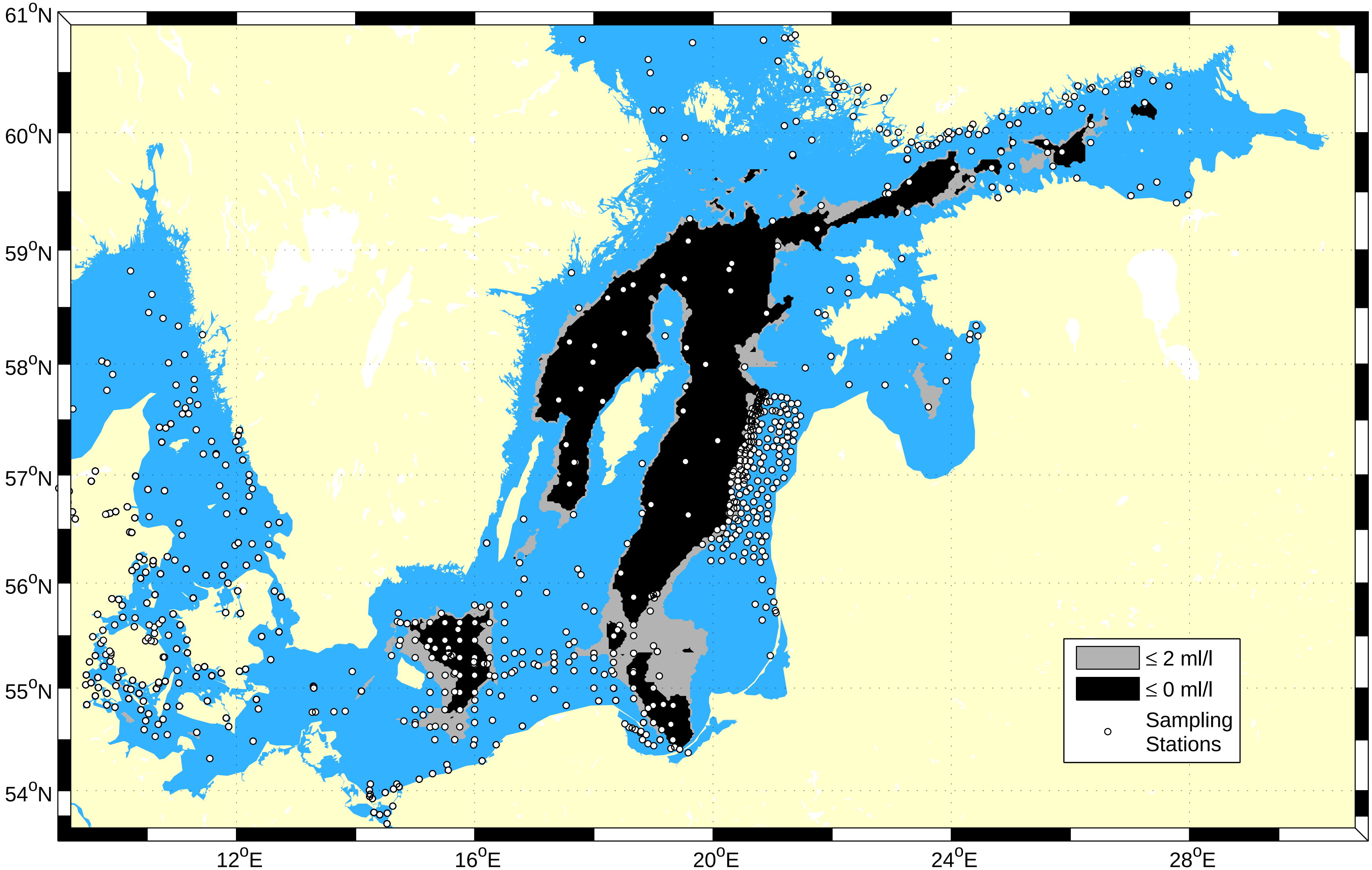
Extent of hypoxic & anoxic bottom water, Autumn 2018



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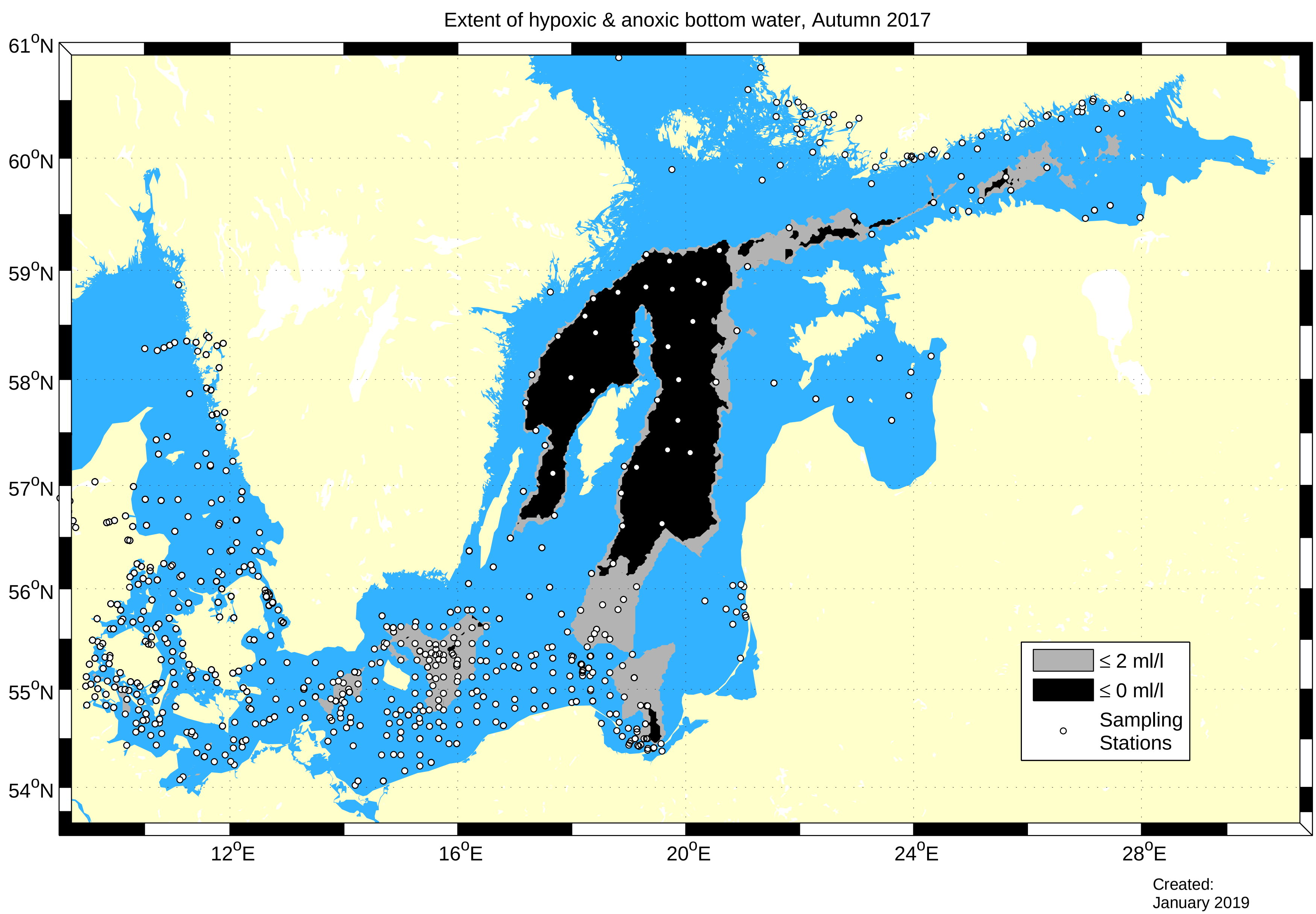
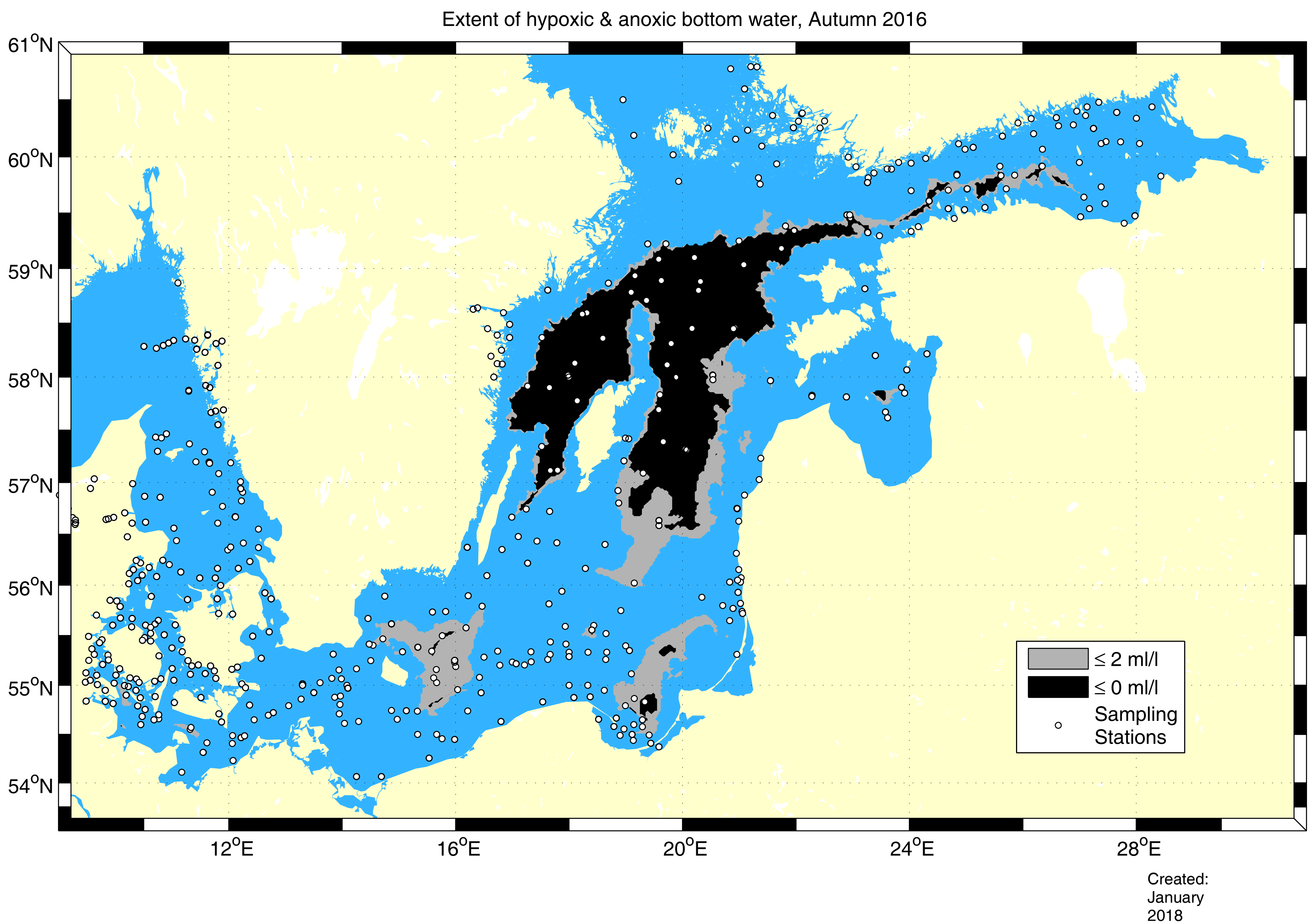
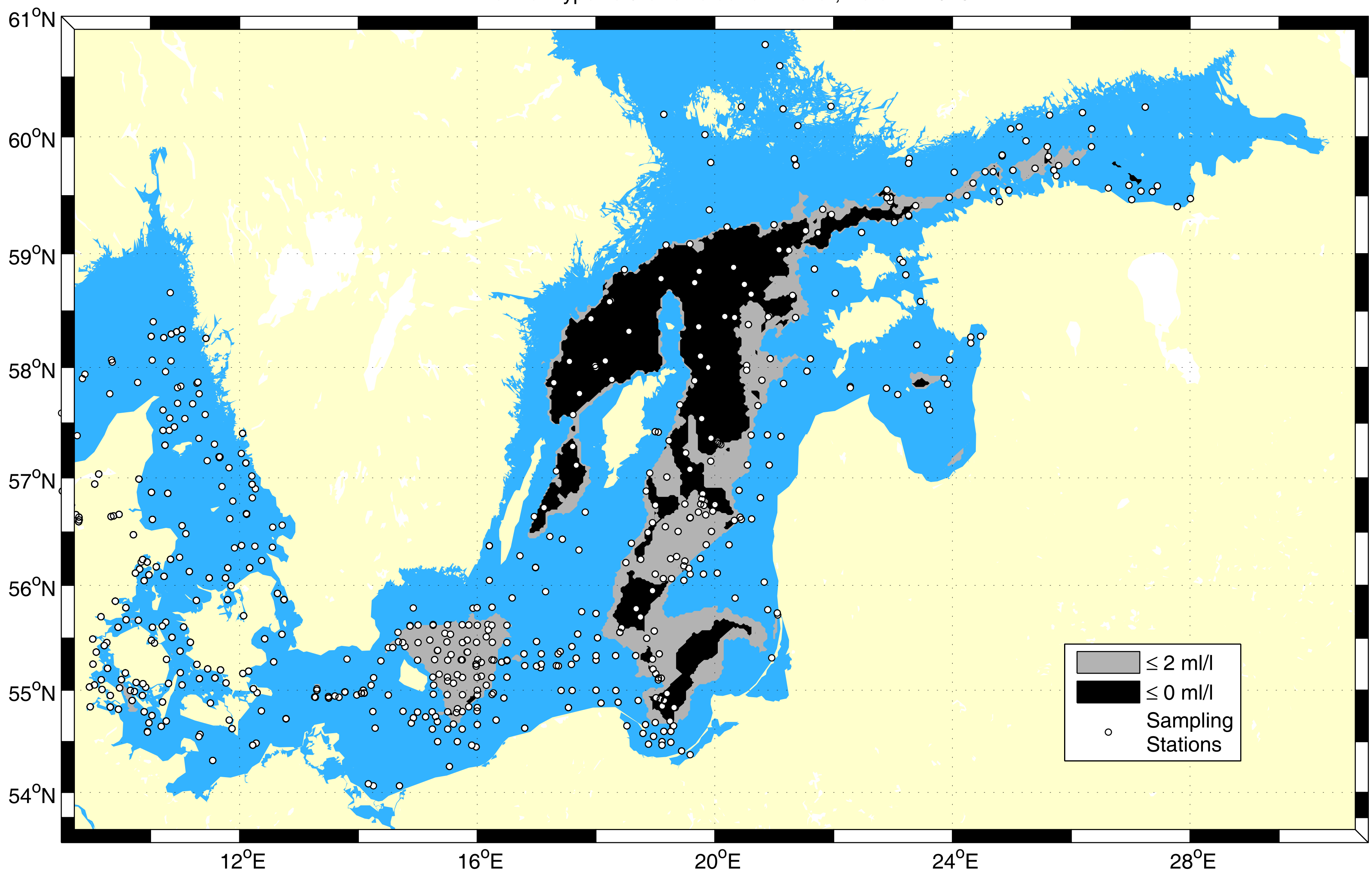
January 2020



Extent of hypoxic & anoxic bottom water, Autumn 2017
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
Created:
January 2019

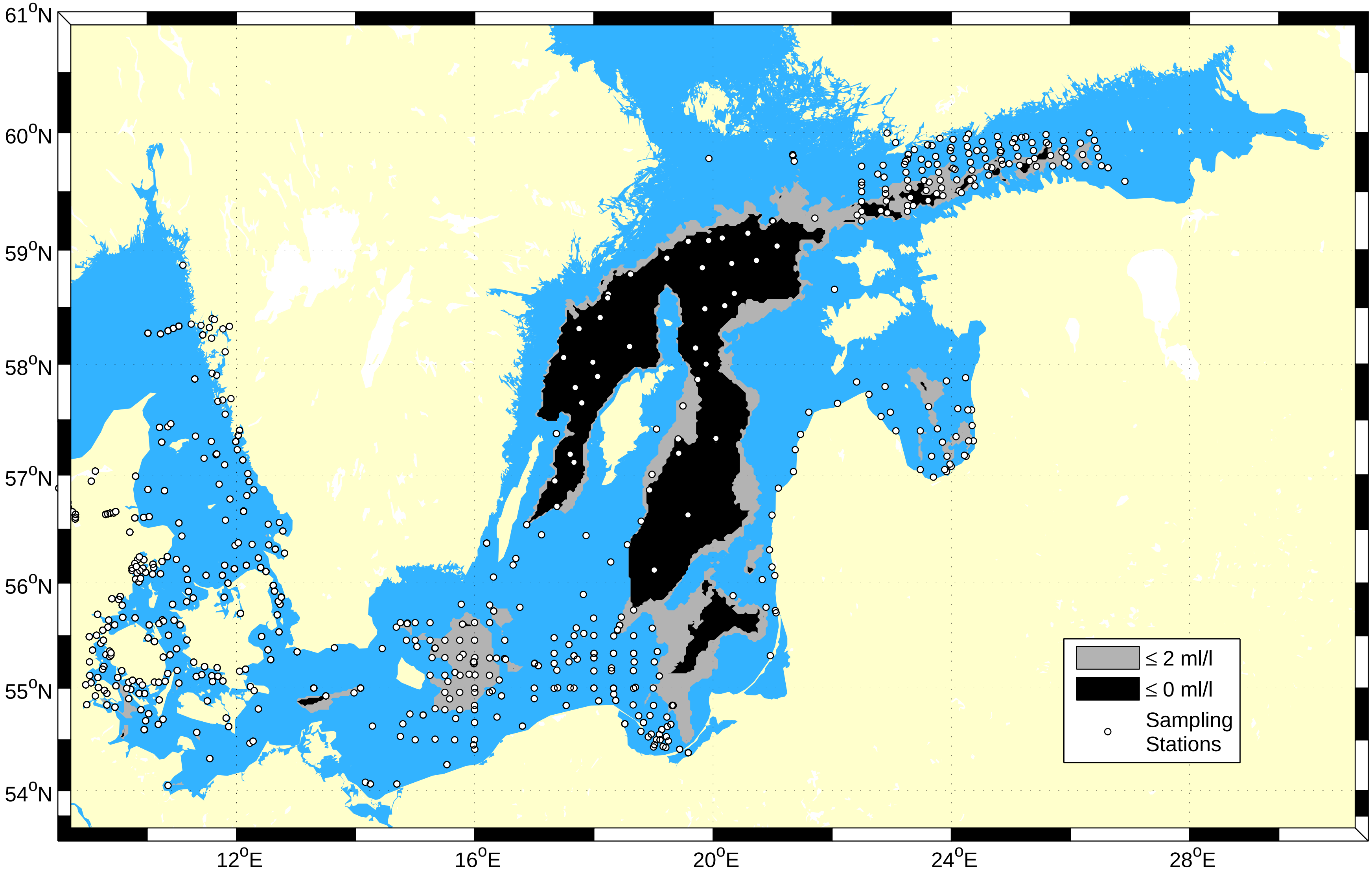

Extent of hypoxic & anoxic bottom water, Autumn 2016
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations
Created: January 2018

Extent of hypoxic & anoxic bottom water, Autumn 2015



Created:
January
2017

Extent of hypoxic & anoxic bottom water, Autumn 2014



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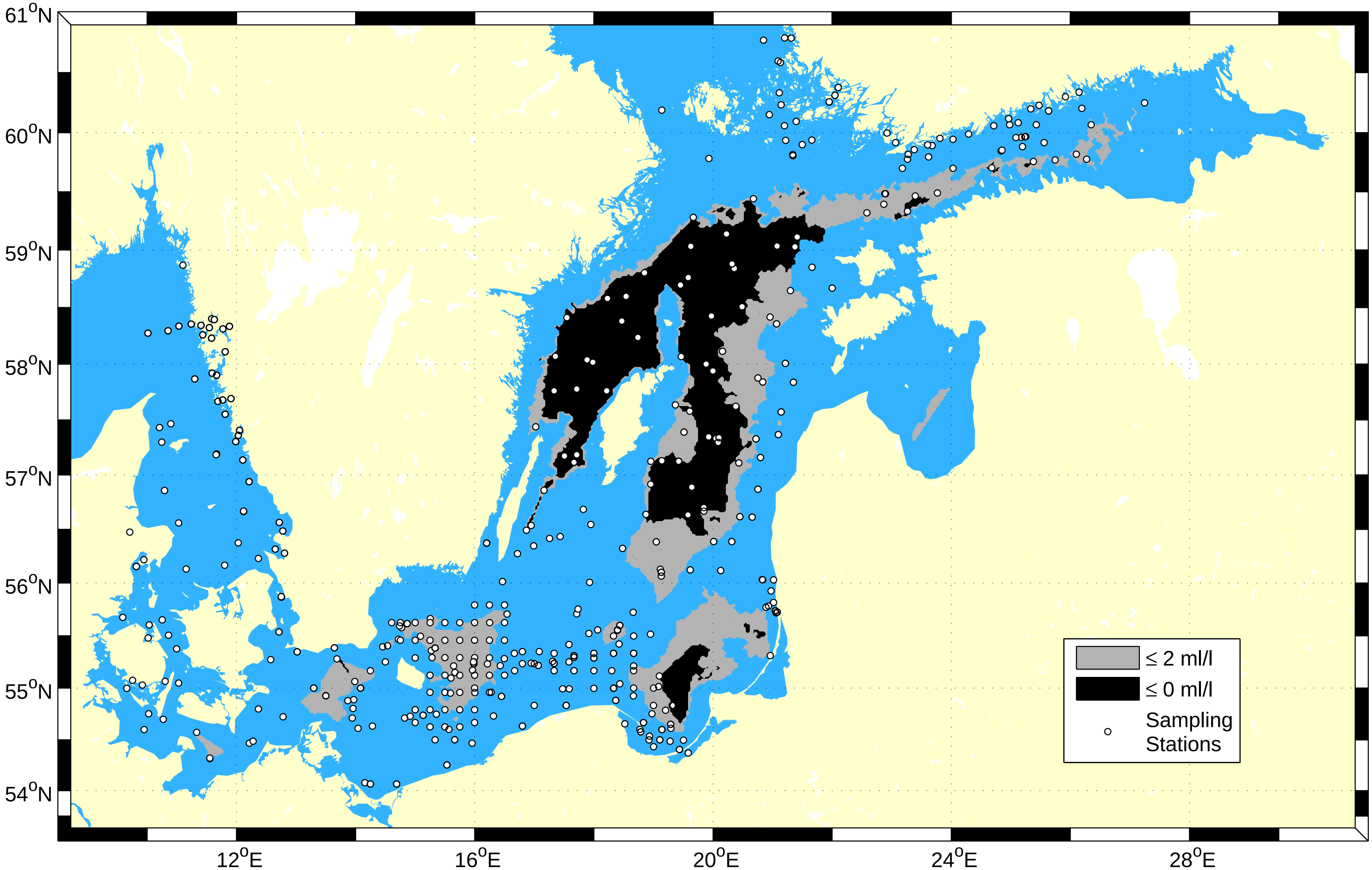
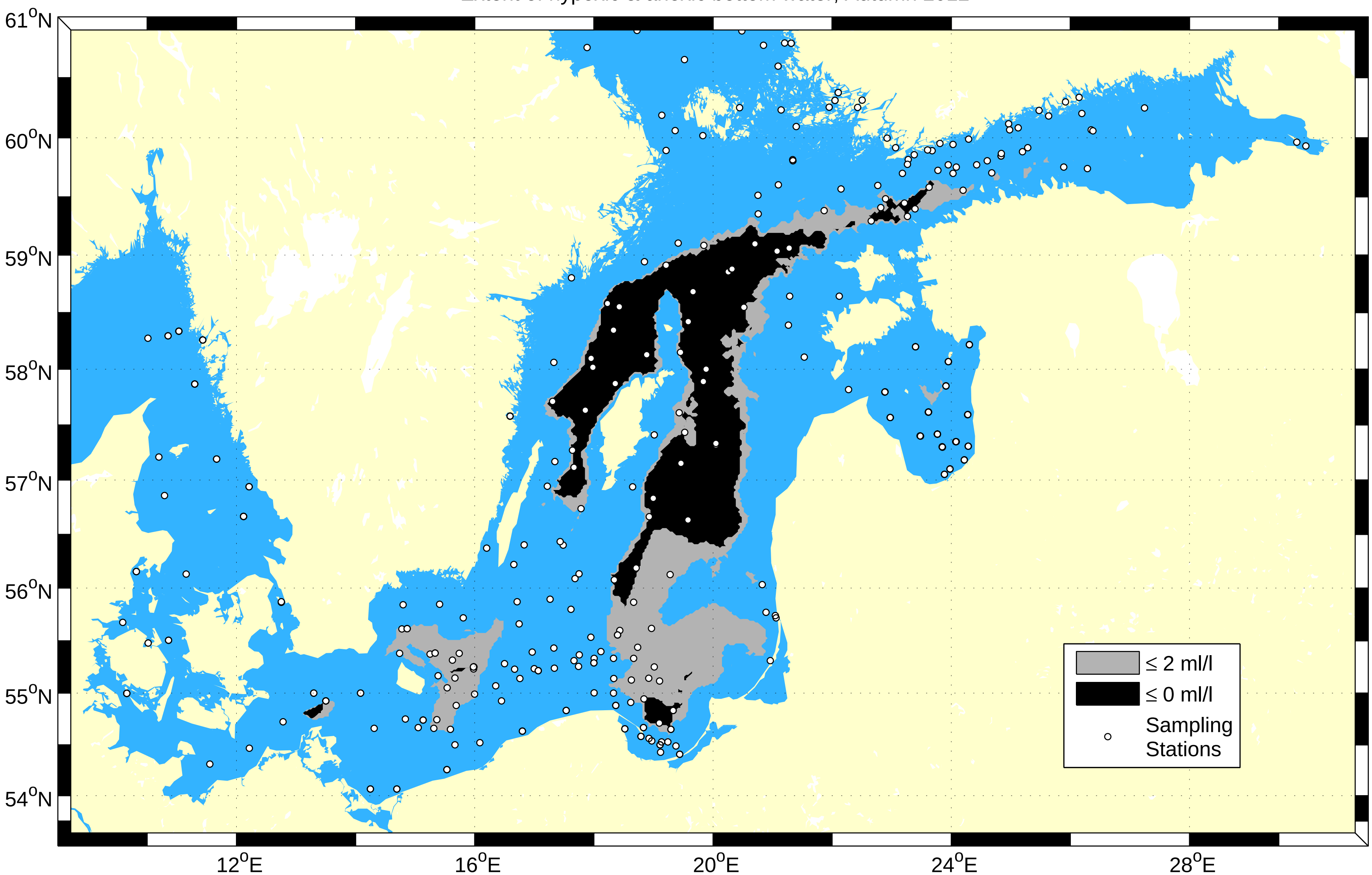
Extent of hypoxic & anoxic bottom water, Autumn 2013



Created:
December 2014

Extent of hypoxic & anoxic bottom water, Autumn 2012



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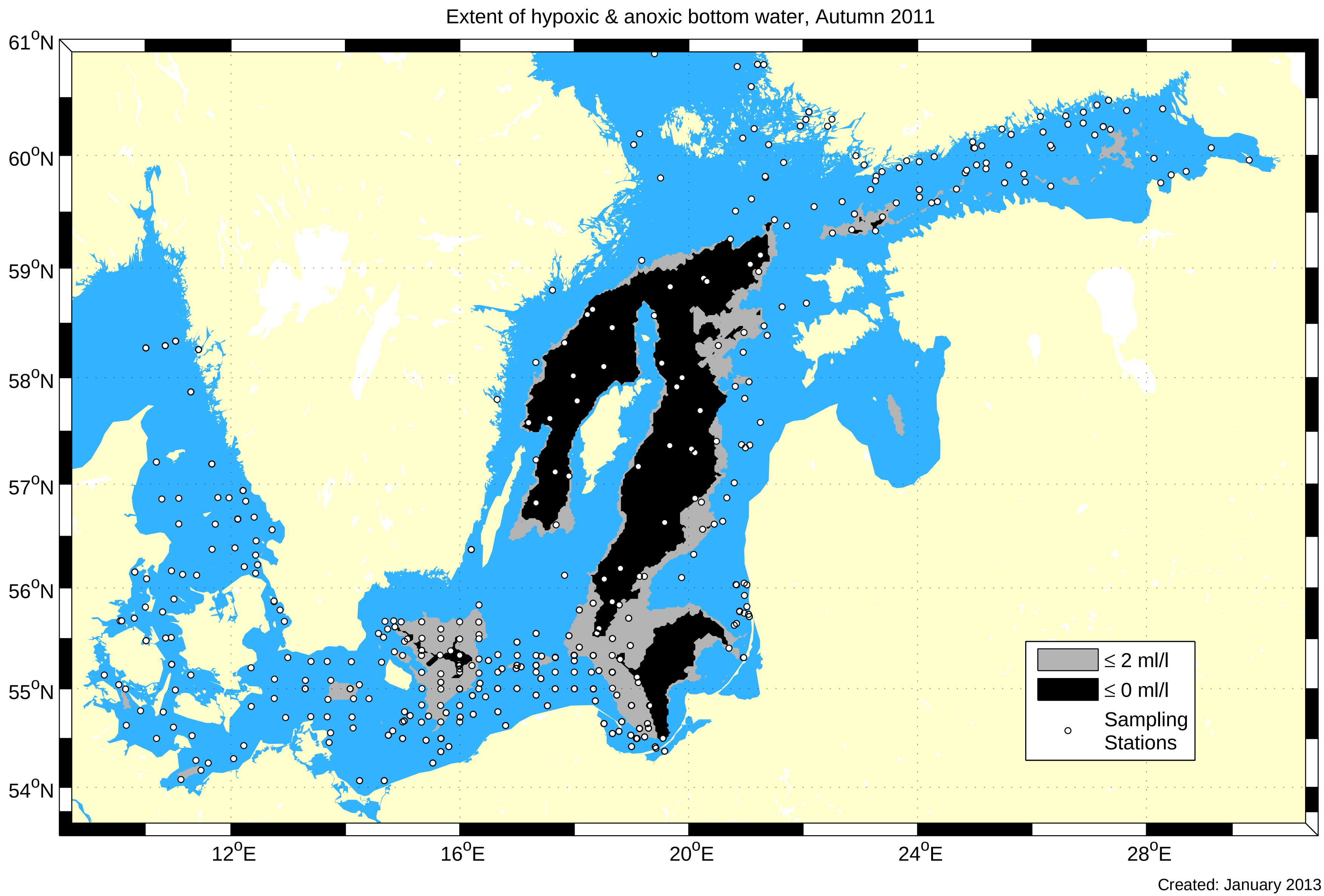
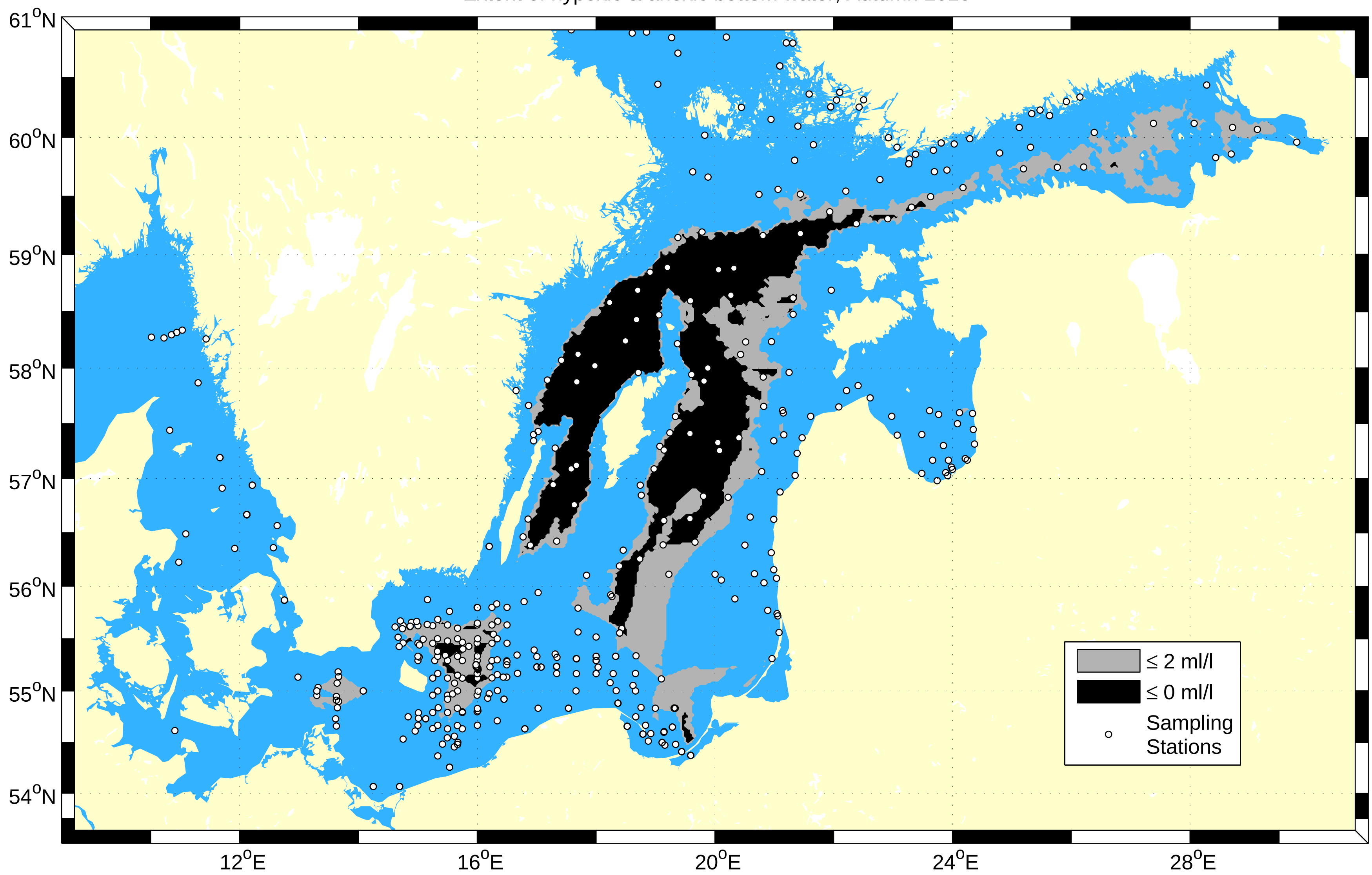
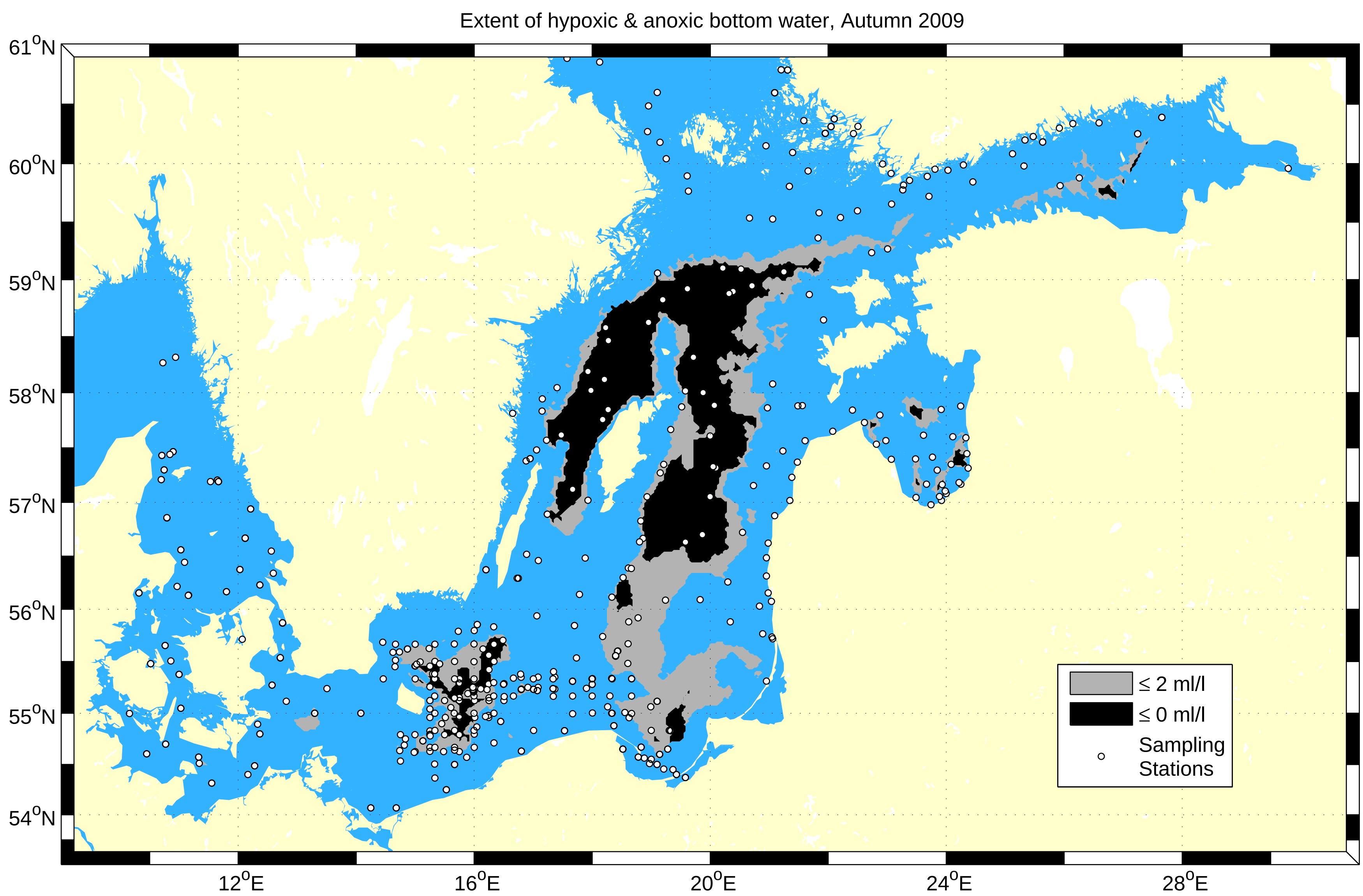
December 2013


Extent of hypoxic & anoxic bottom water, Autumn 2011
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
Created: January 2013

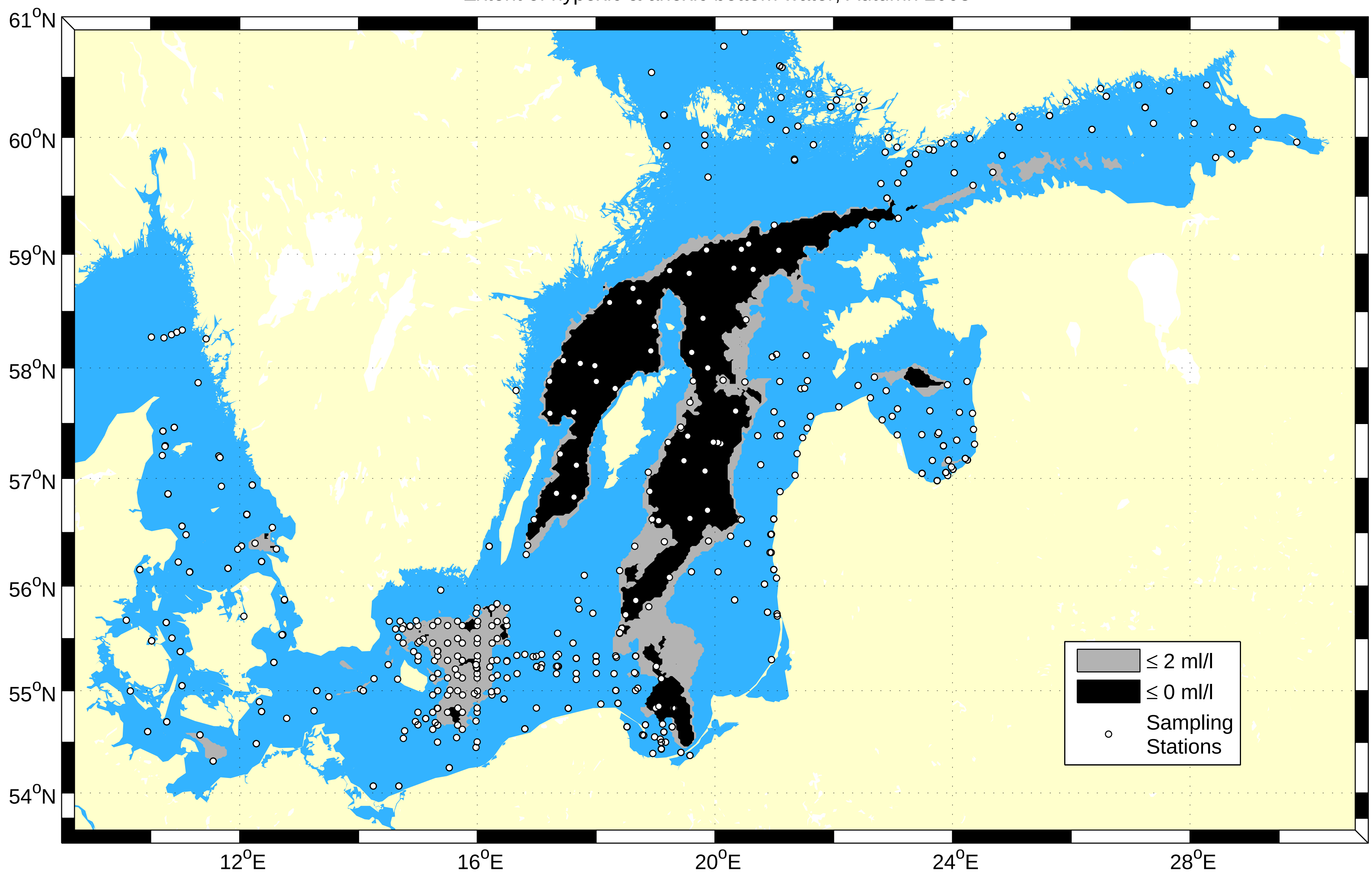
Extent of hypoxic & anoxic bottom water, Autumn 2010



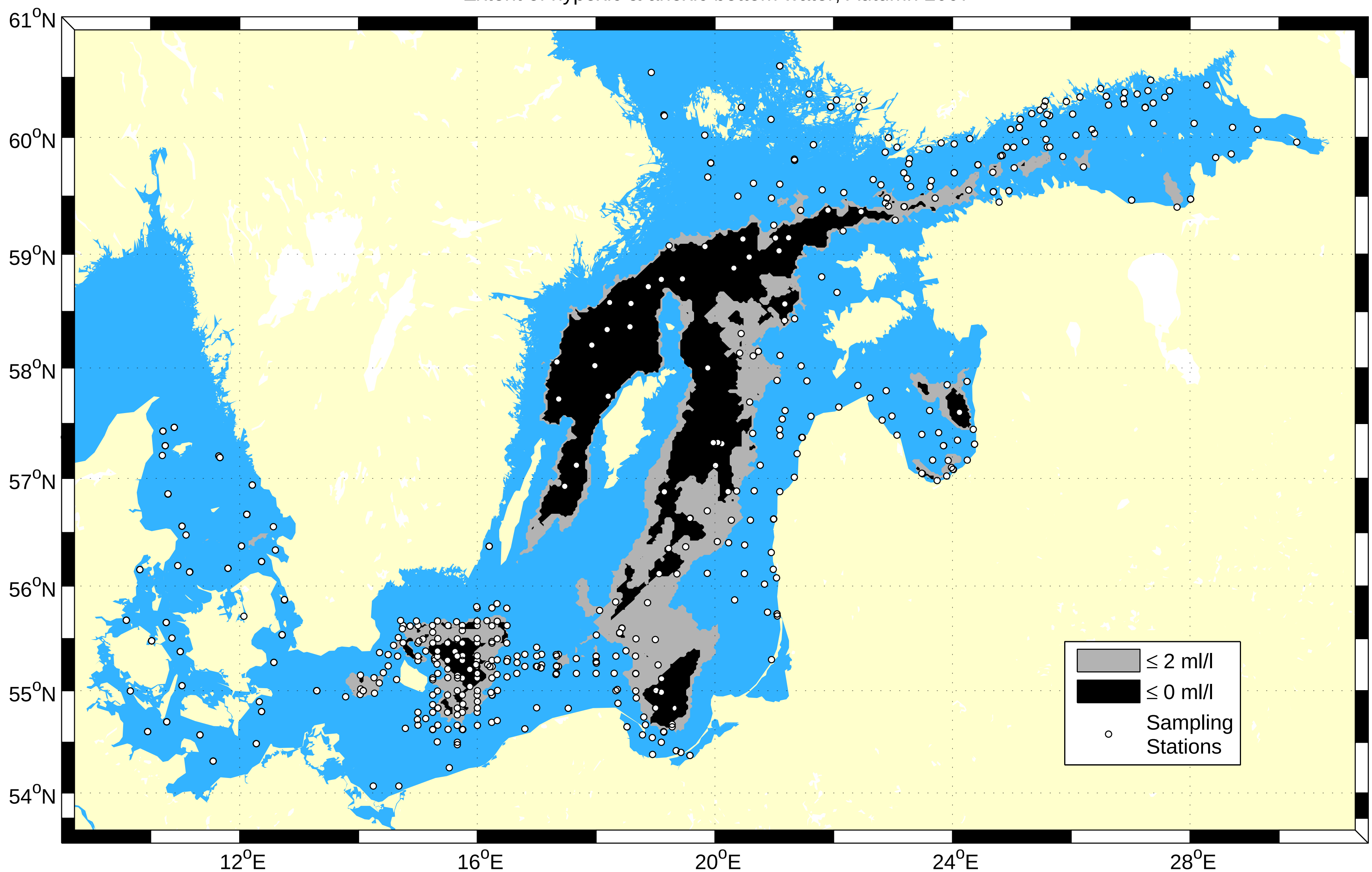


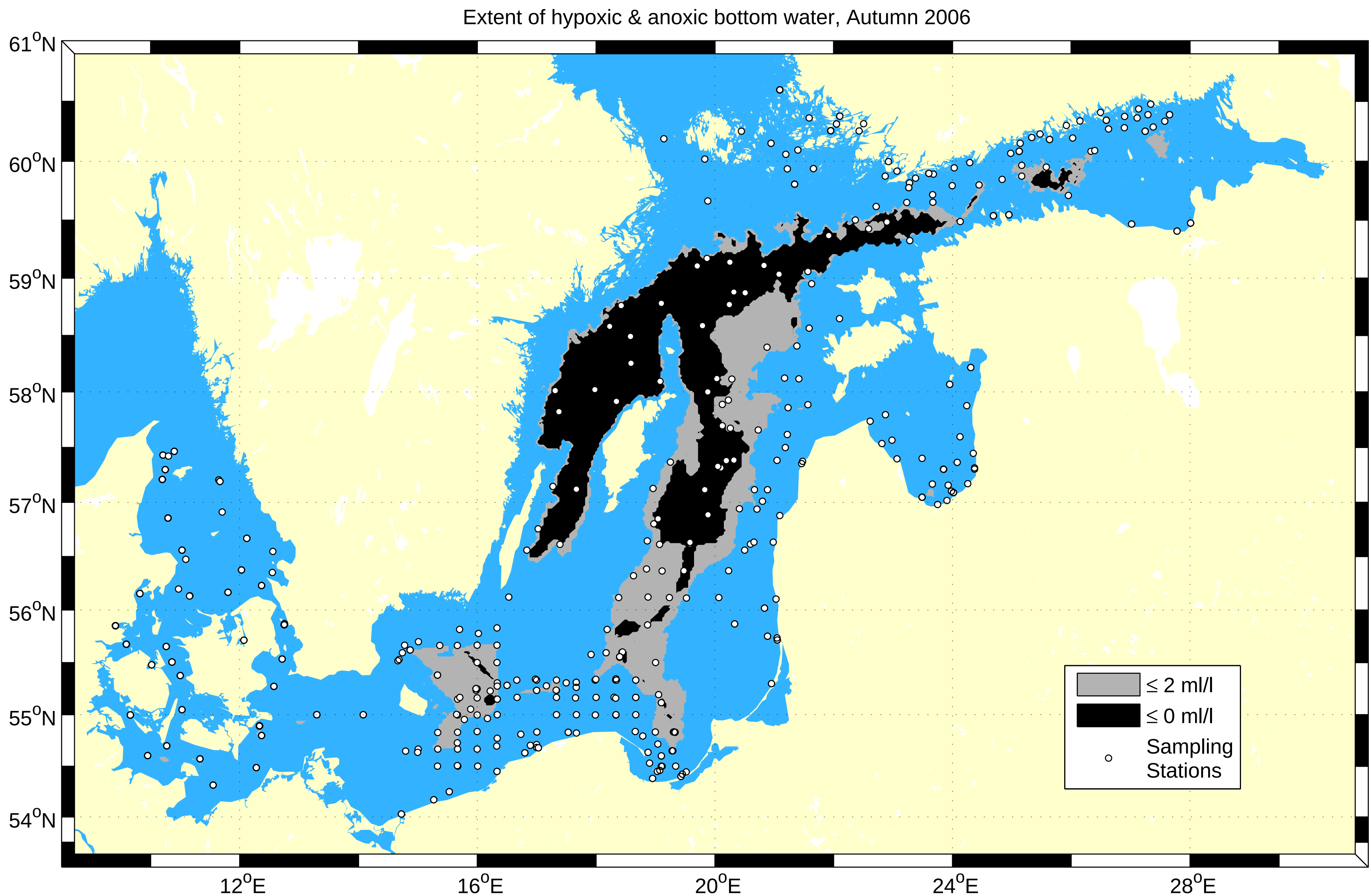
Extent of hypoxic & anoxic bottom water, Autumn 2009
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 2008



Extent of hypoxic & anoxic bottom water, Autumn 2007




Extent of hypoxic & anoxic bottom water, Autumn 2006
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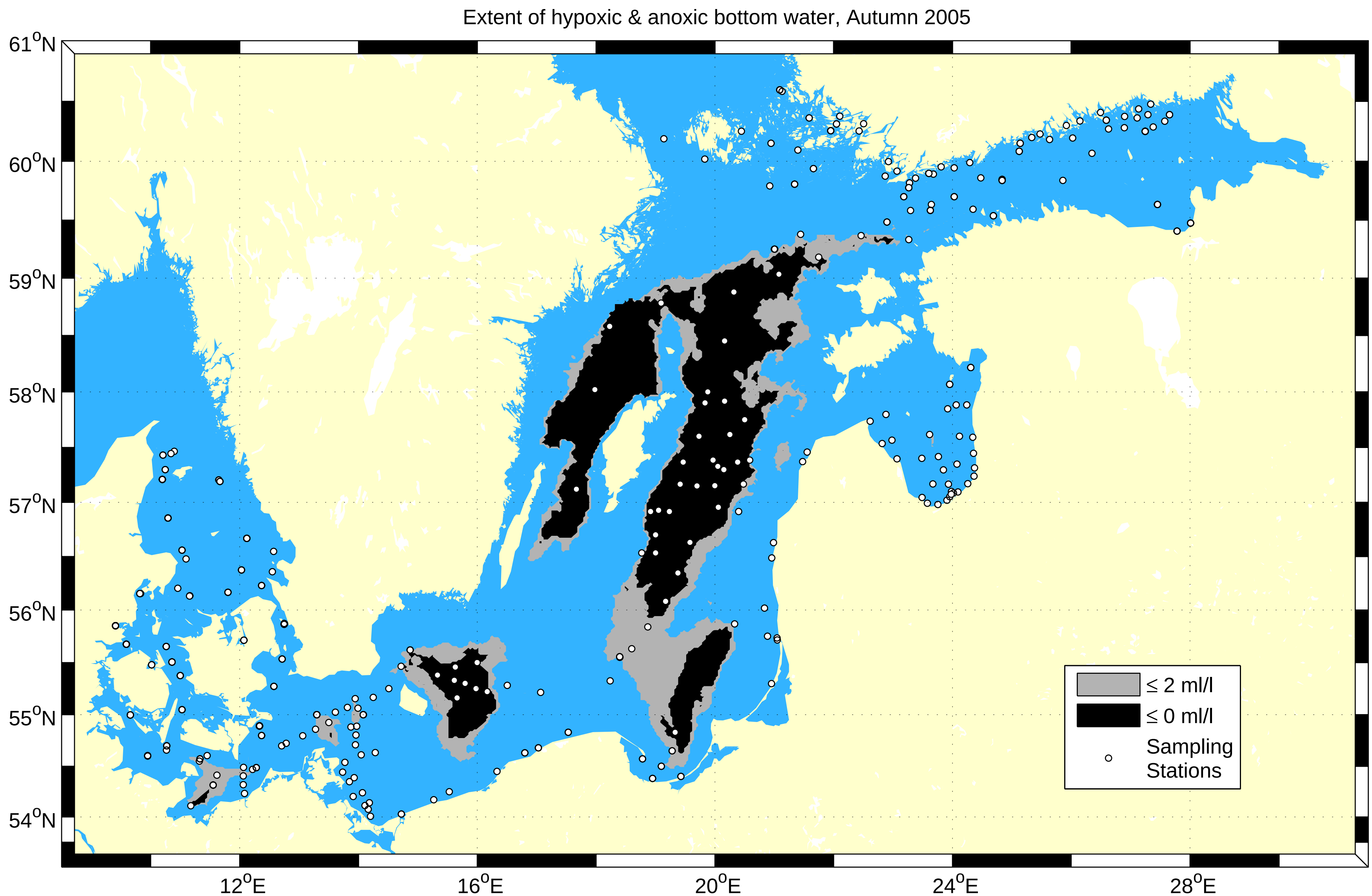
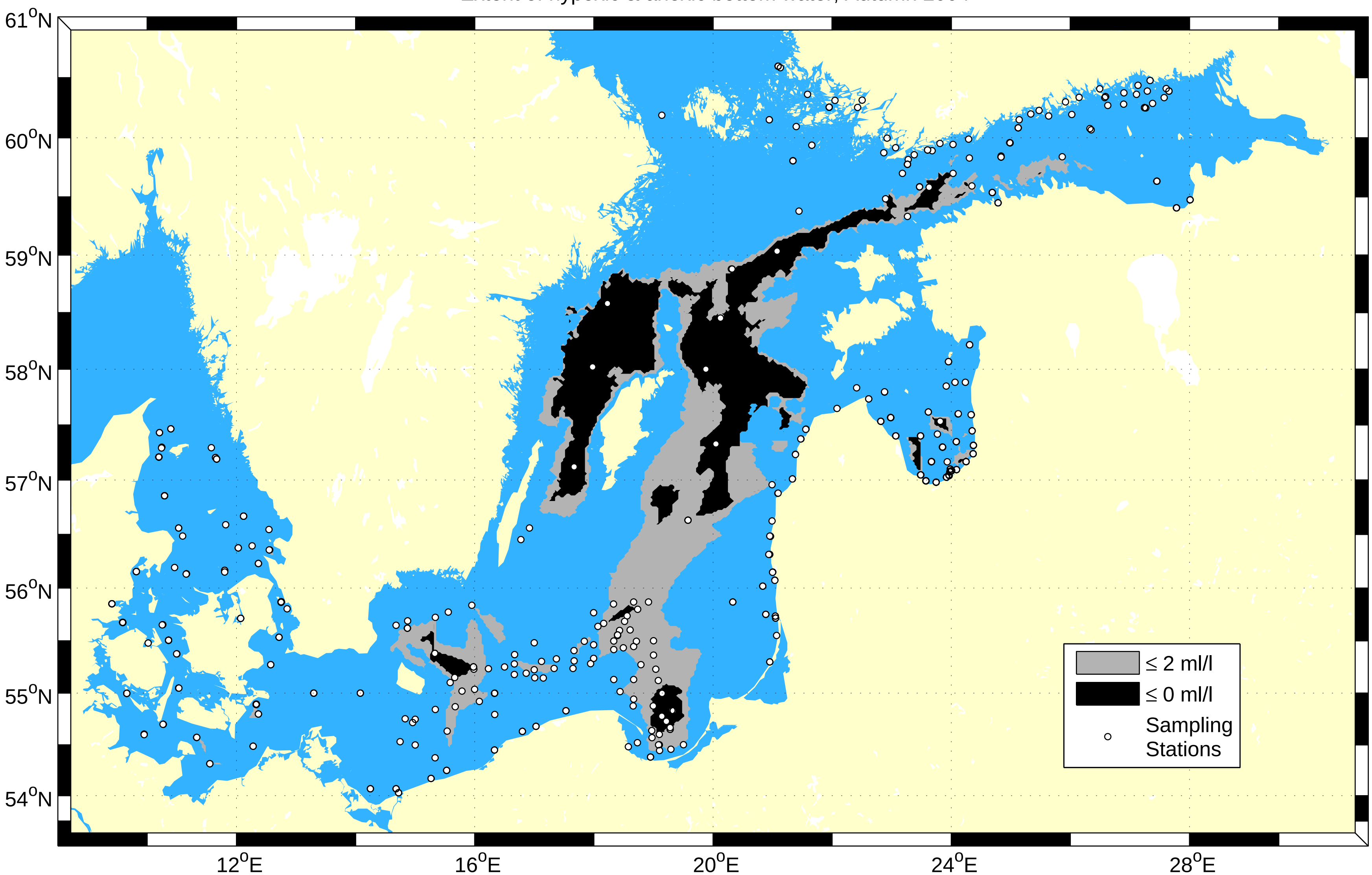
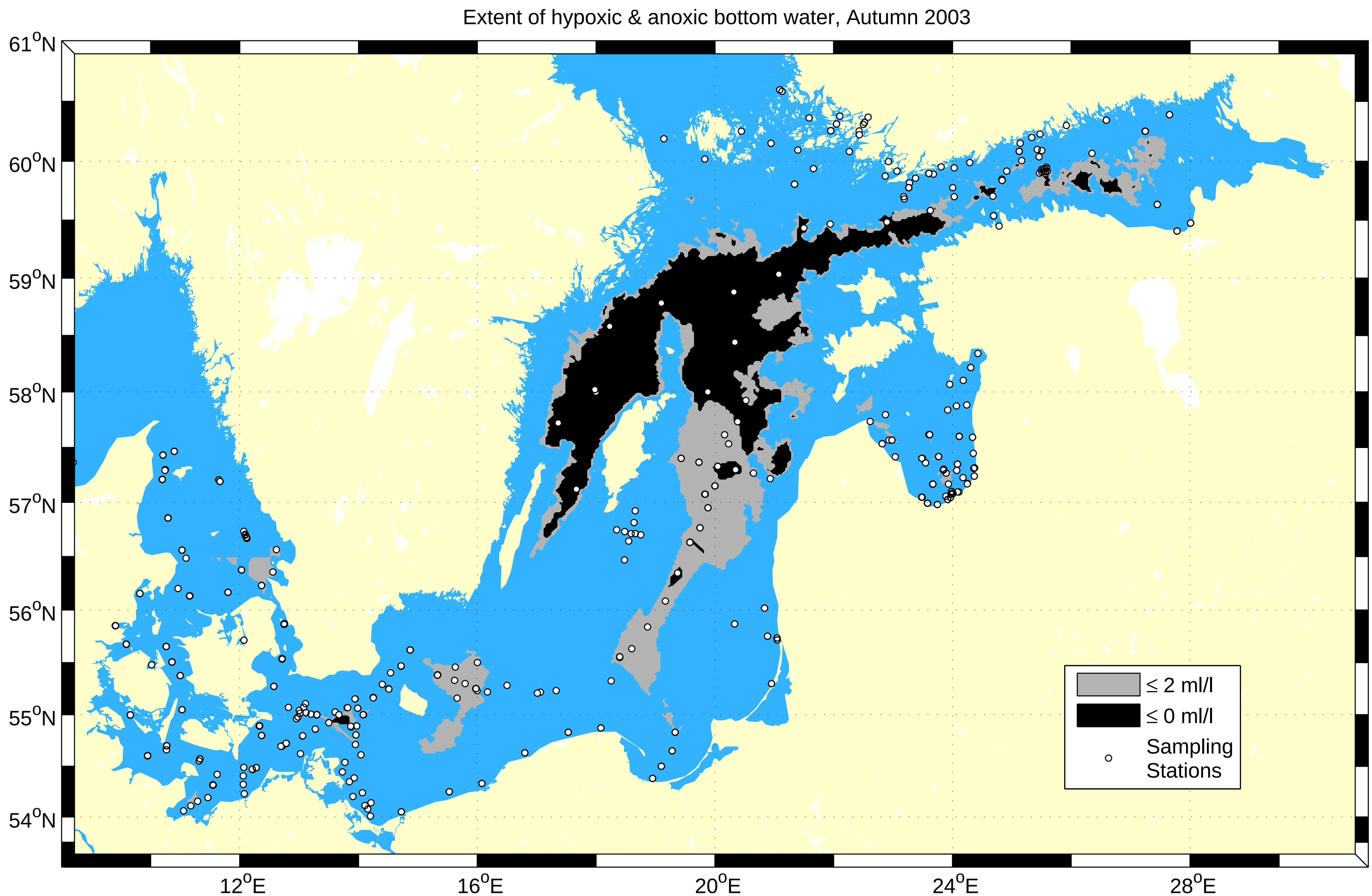
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling
Stations



Extent of hypoxic & anoxic bottom water, Autumn 2005
61⁰N
60⁰N
59⁰N
58⁰N
57⁰N
56⁰N
55⁰N
54⁰N
12⁰E
16⁰E
20⁰E
24⁰E
28⁰E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 2004




Extent of hypoxic & anoxic bottom water, Autumn 2003
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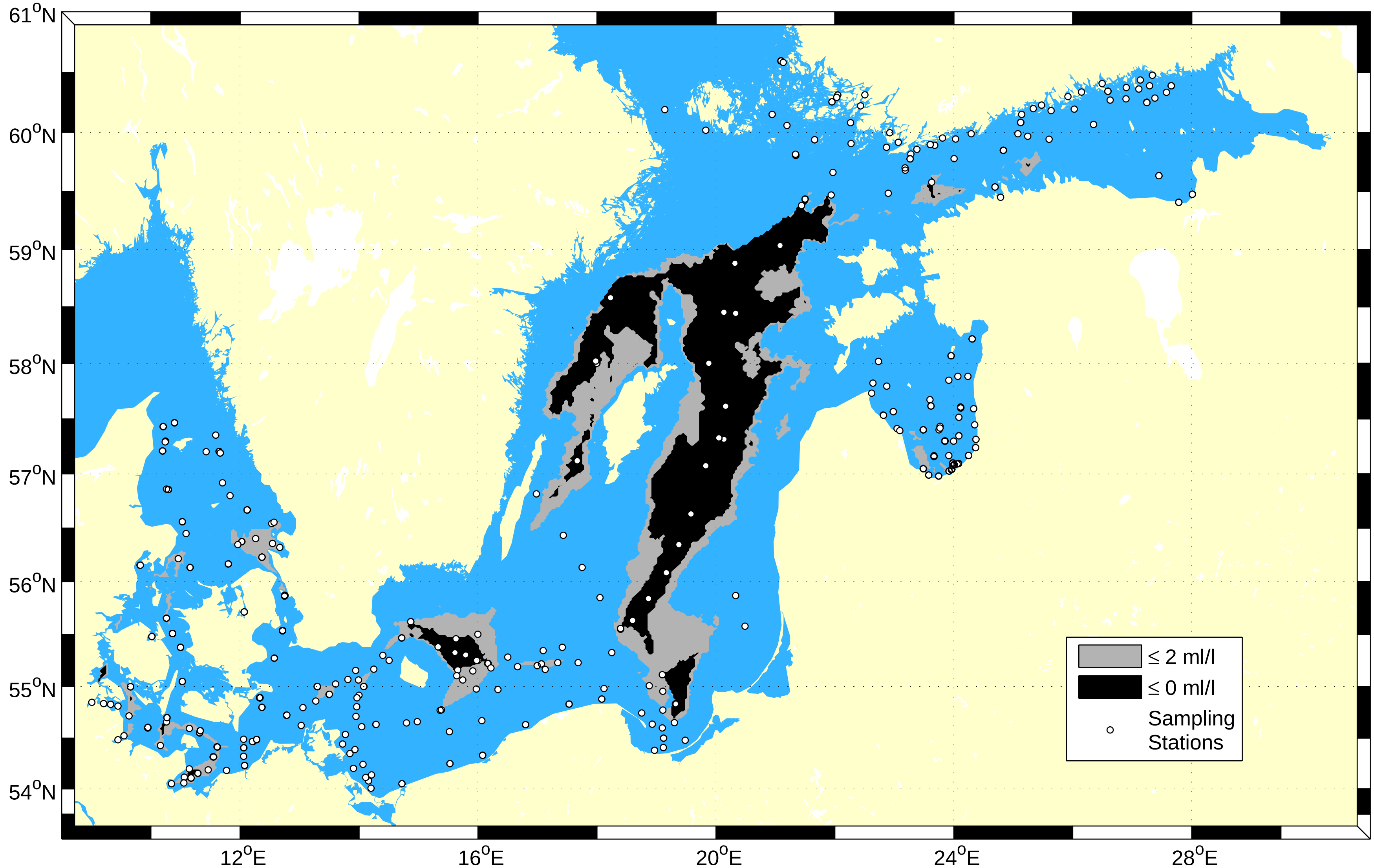
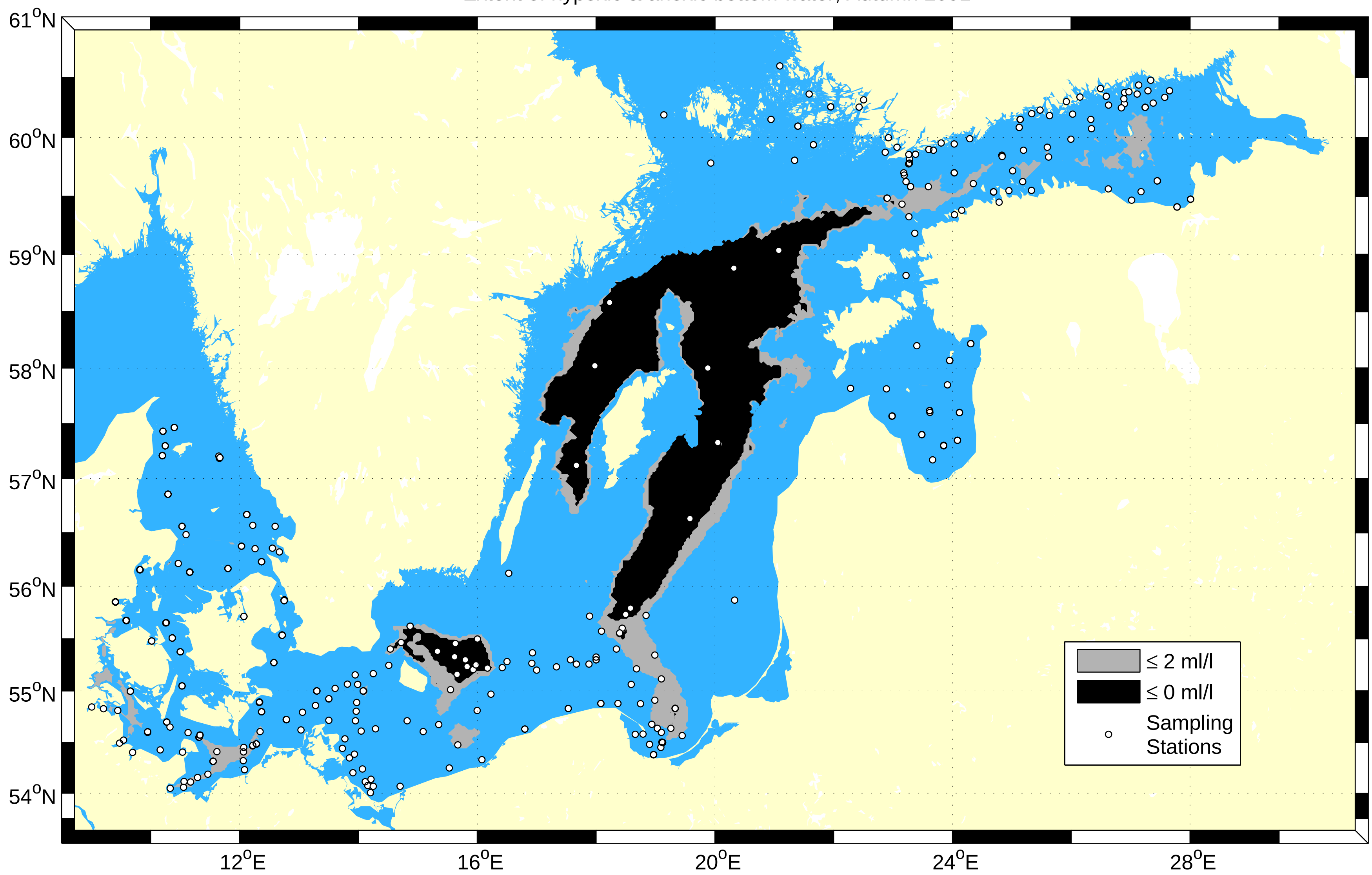
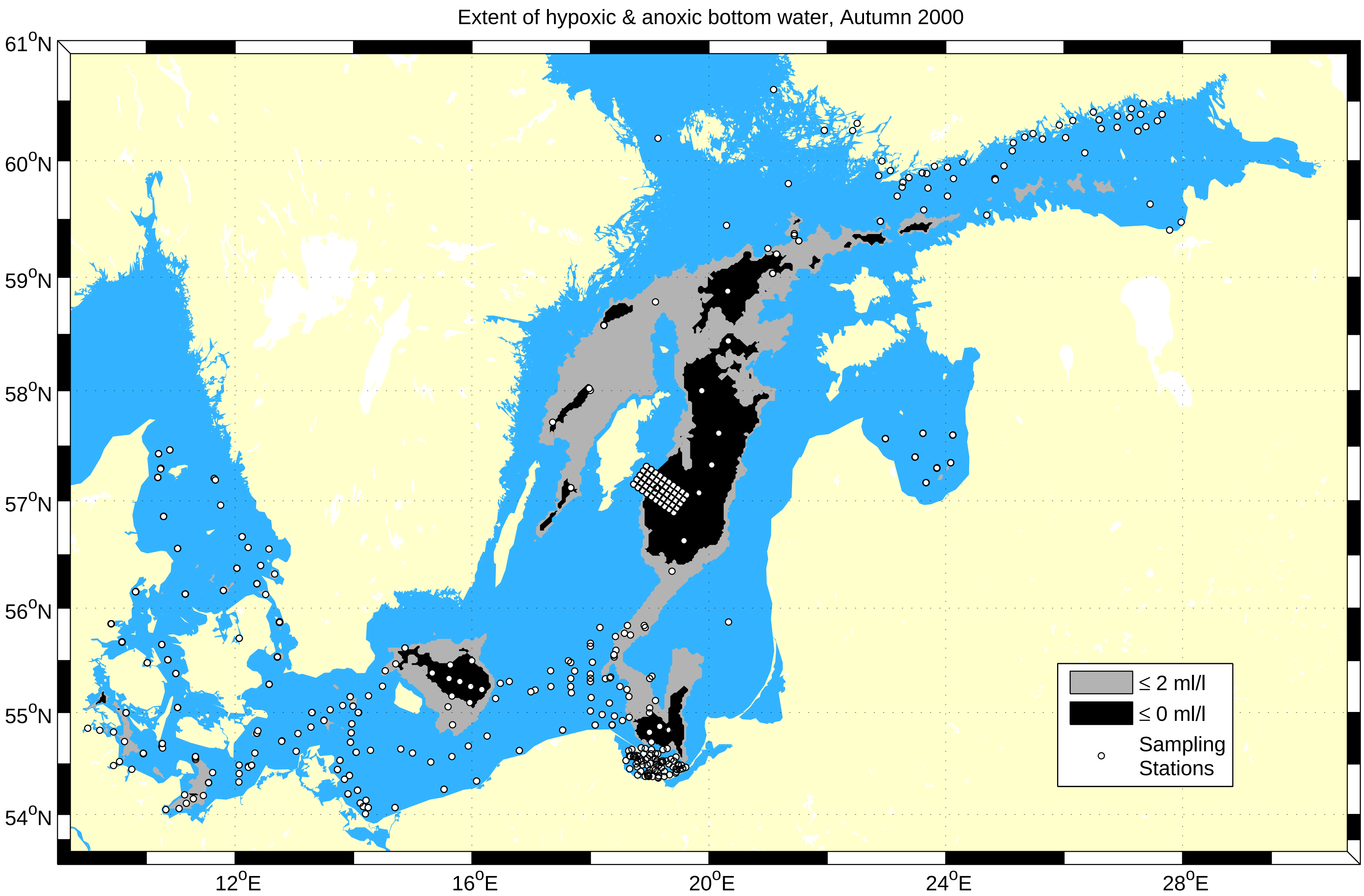
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

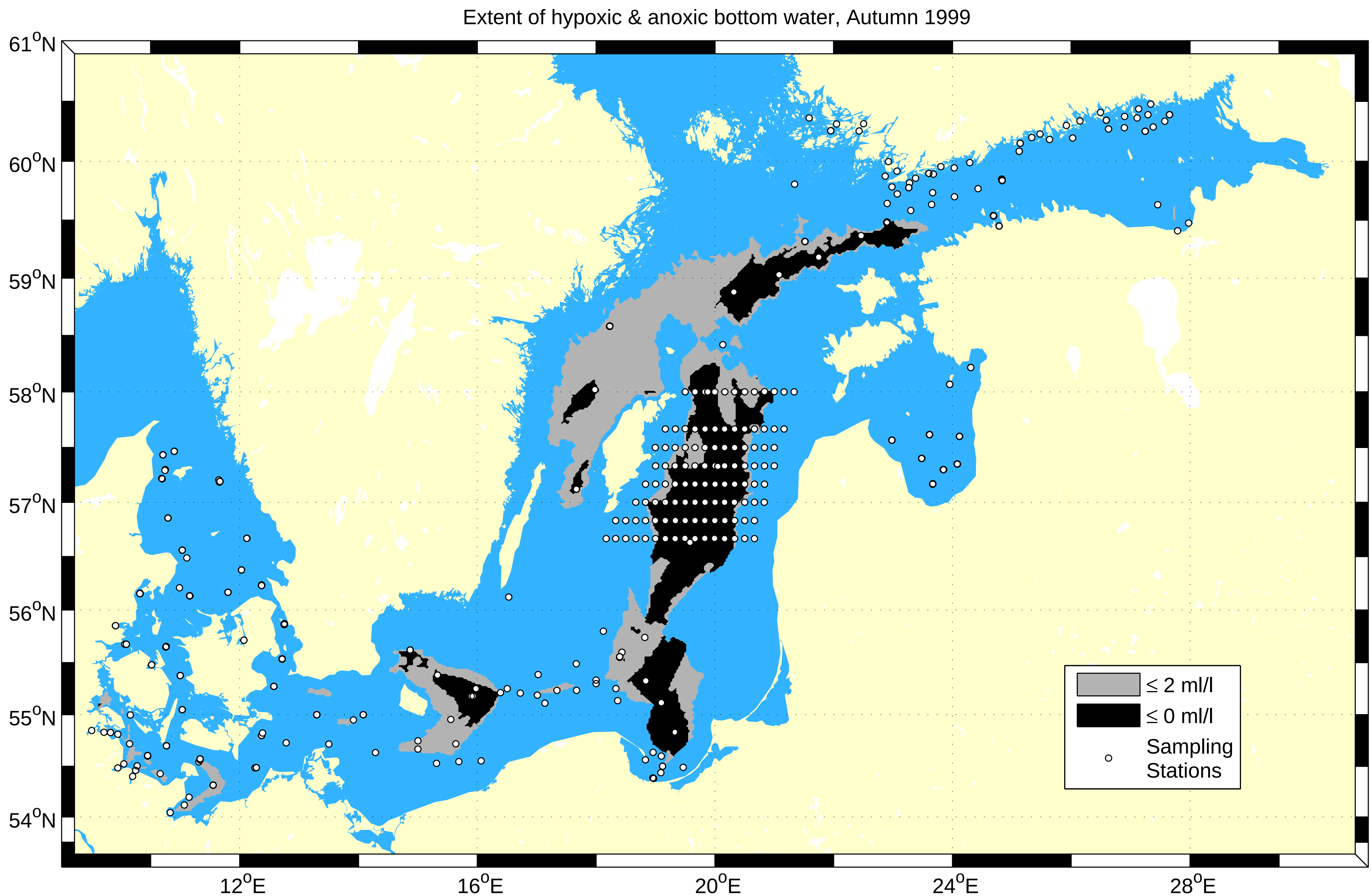
Extent of hypoxic & anoxic bottom water, Autumn 2002



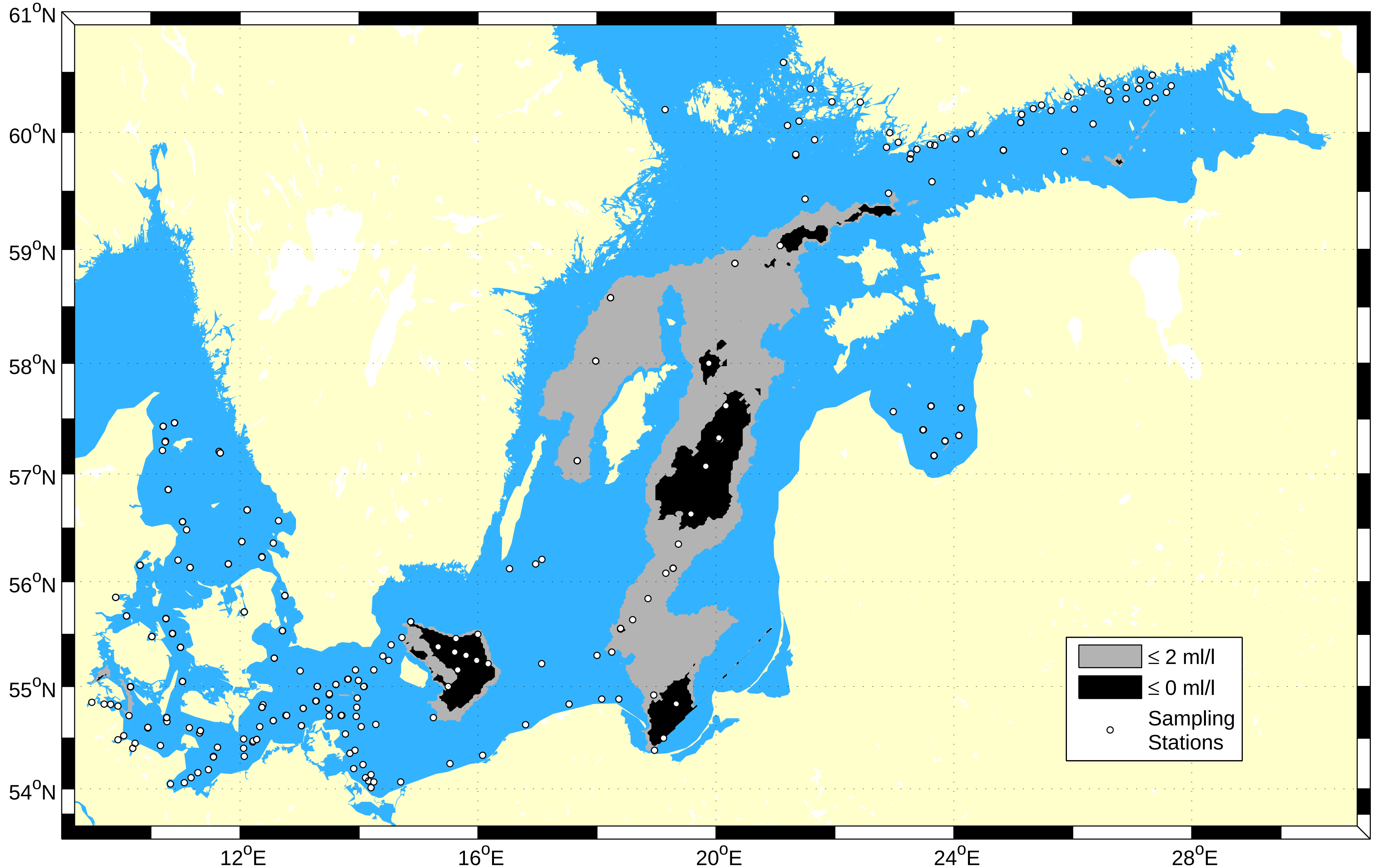
Extent of hypoxic & anoxic bottom water, Autumn 2001



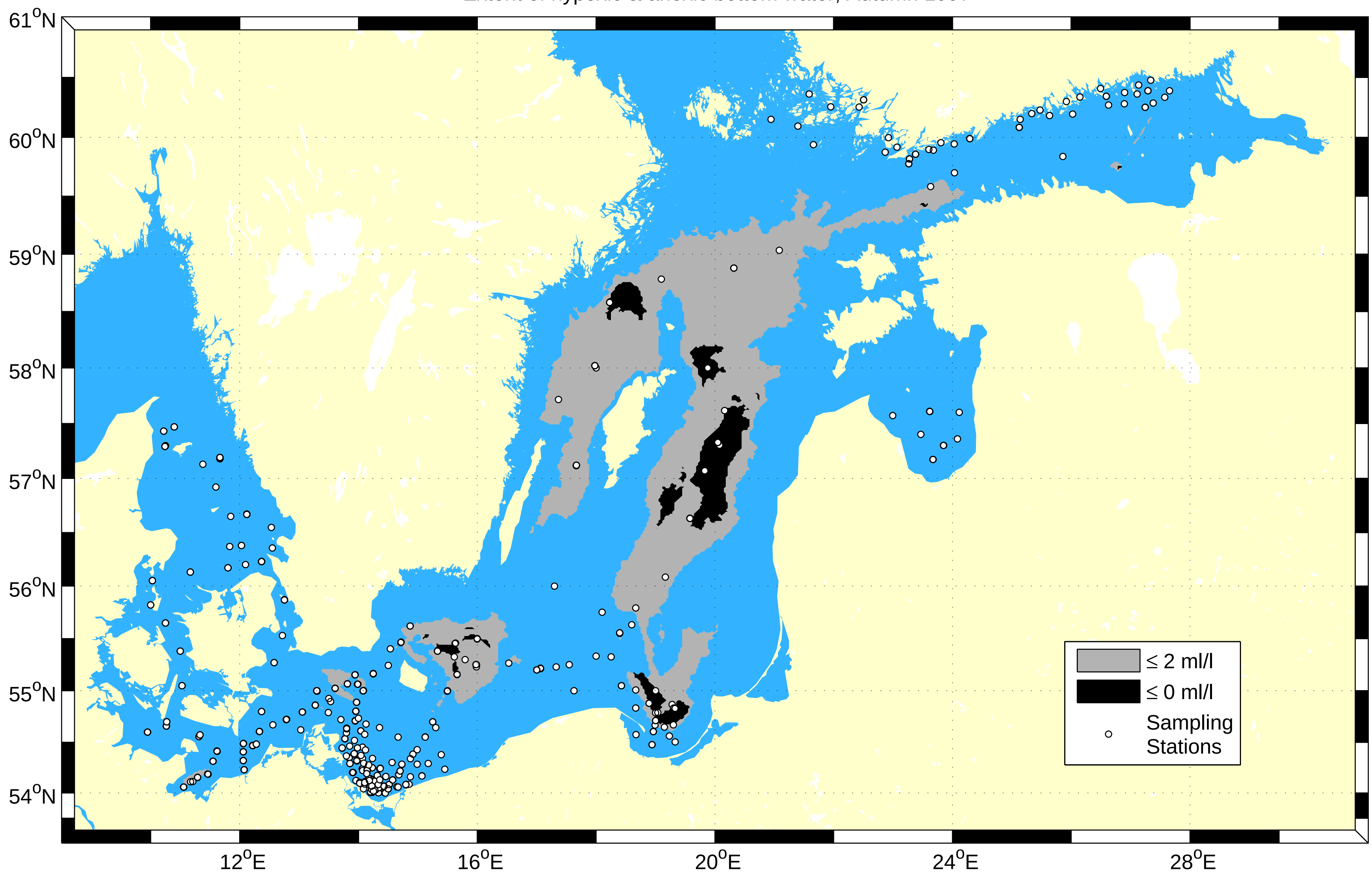

Extent of hypoxic & anoxic bottom water, Autumn 2000
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations


Extent of hypoxic & anoxic bottom water, Autumn 1999
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

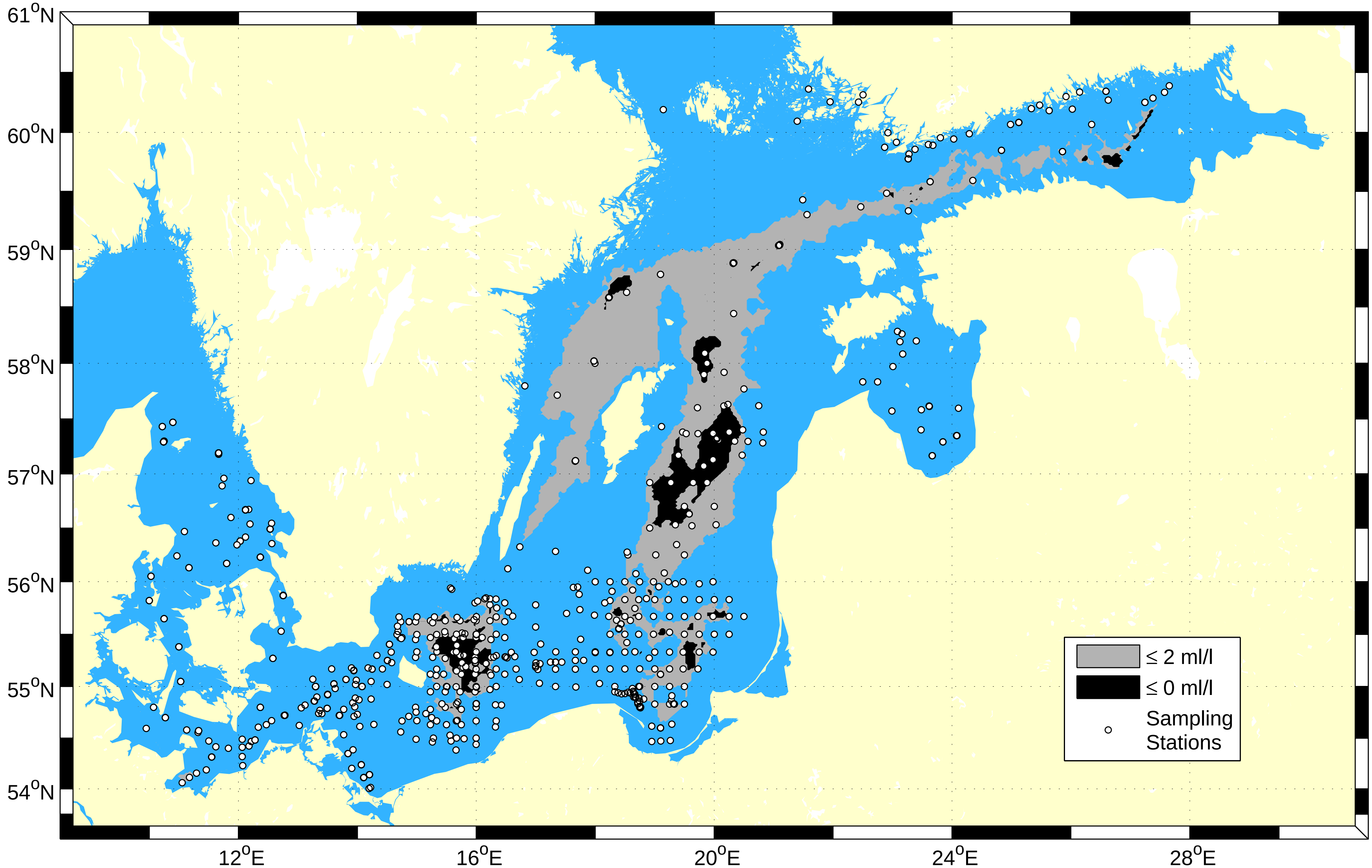
Extent of hypoxic & anoxic bottom water, Autumn 1998



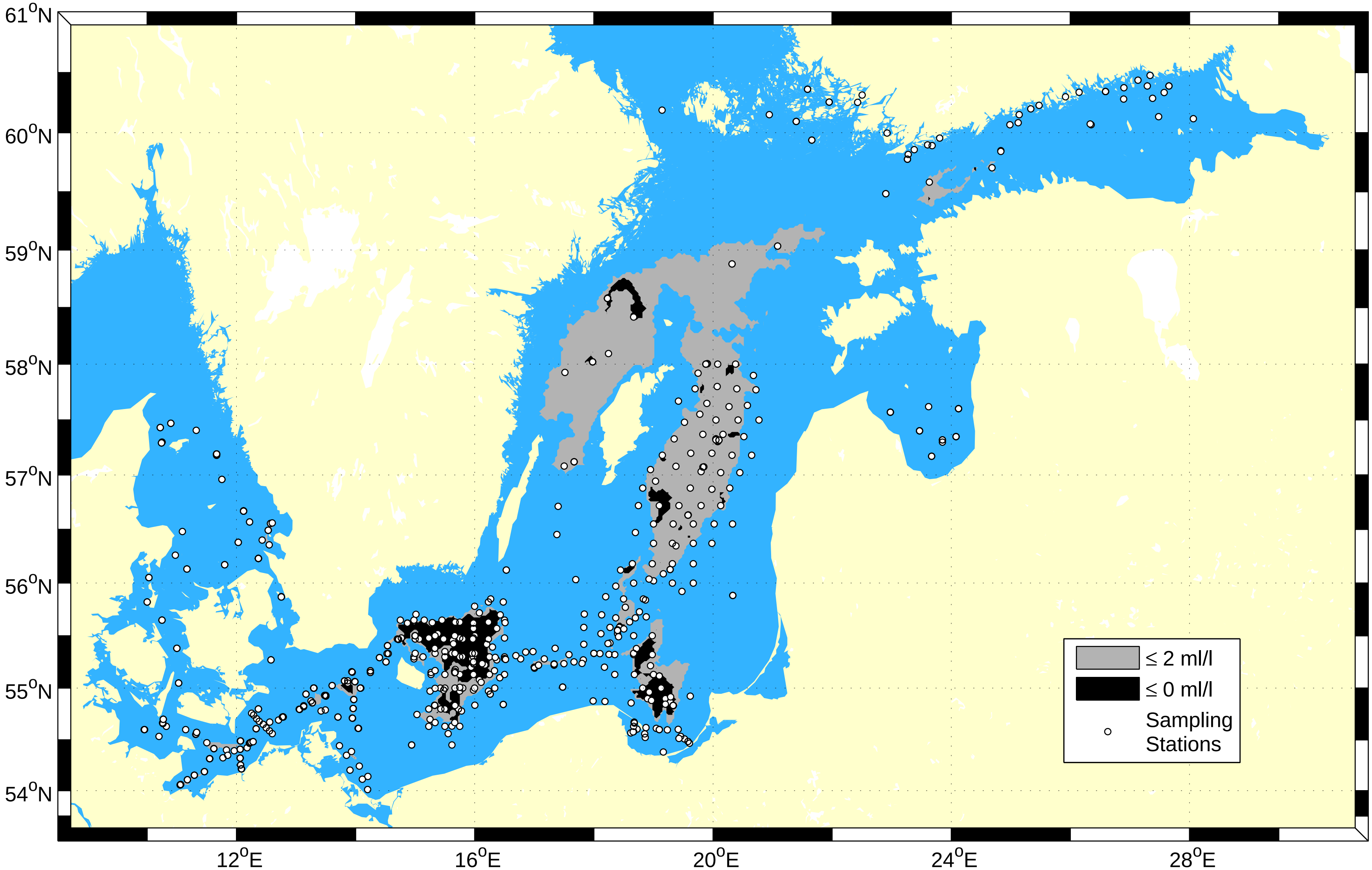
Extent of hypoxic & anoxic bottom water, Autumn 1997



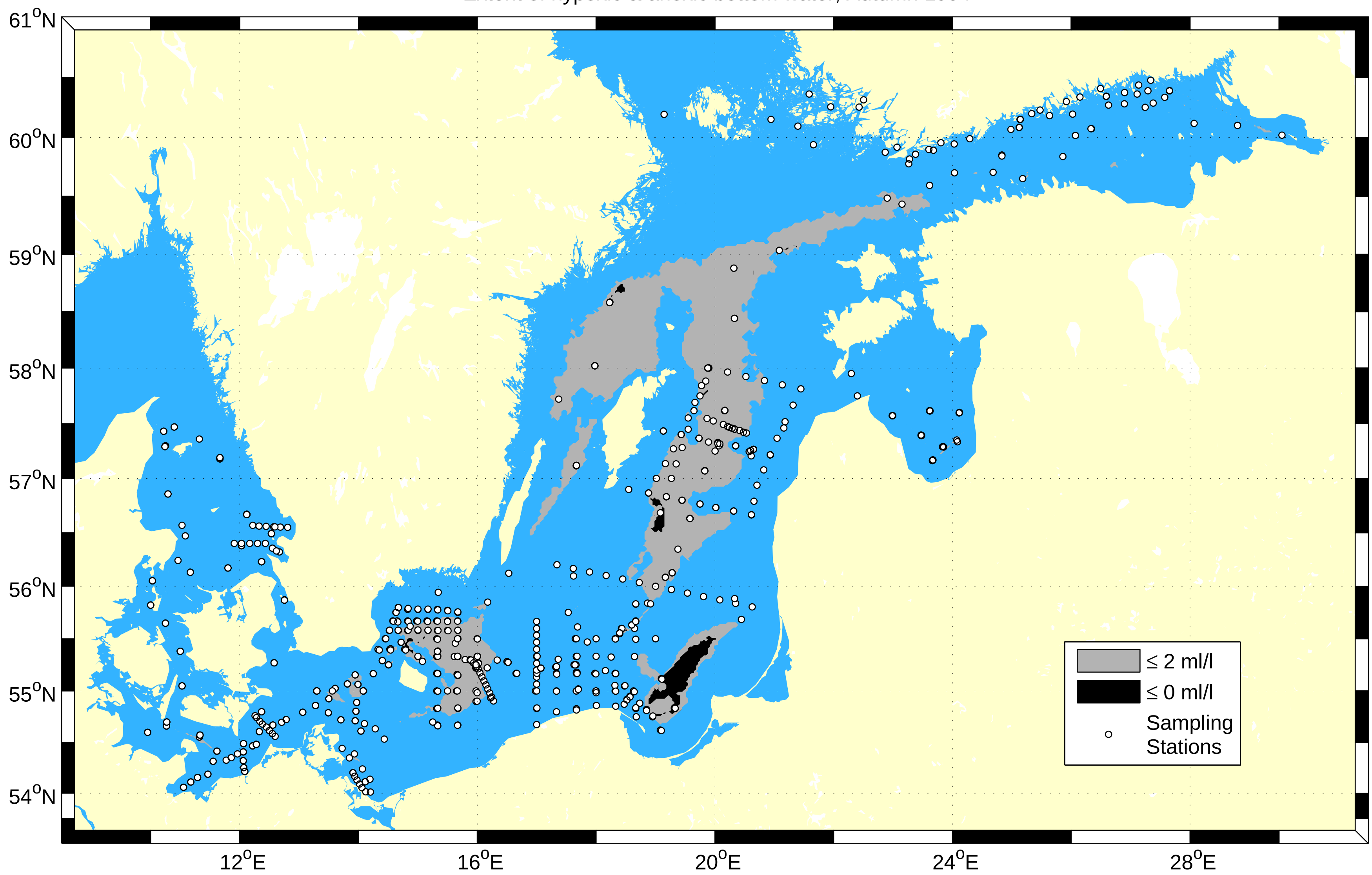
Extent of hypoxic & anoxic bottom water, Autumn 1996



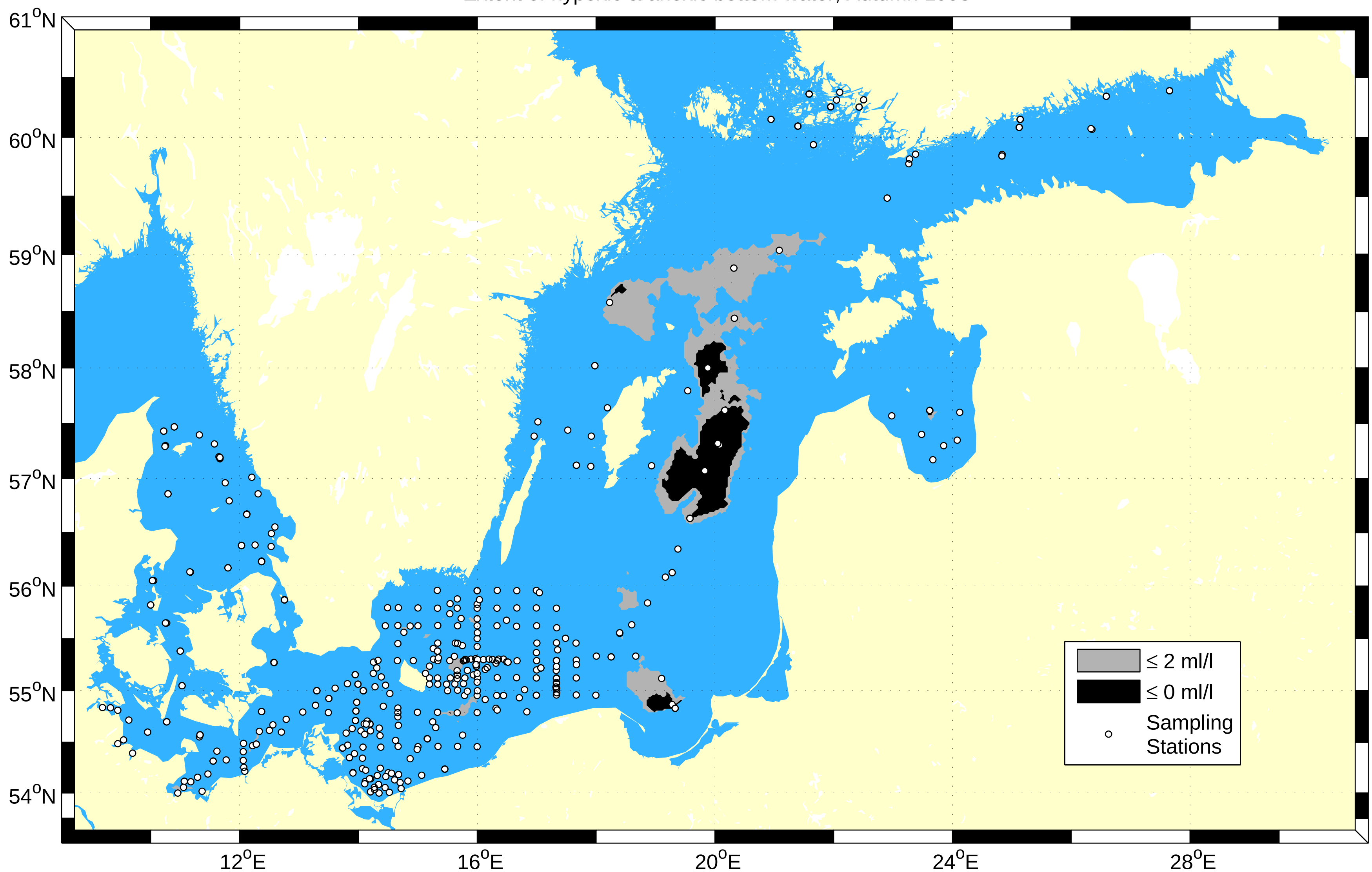
Extent of hypoxic & anoxic bottom water, Autumn 1995



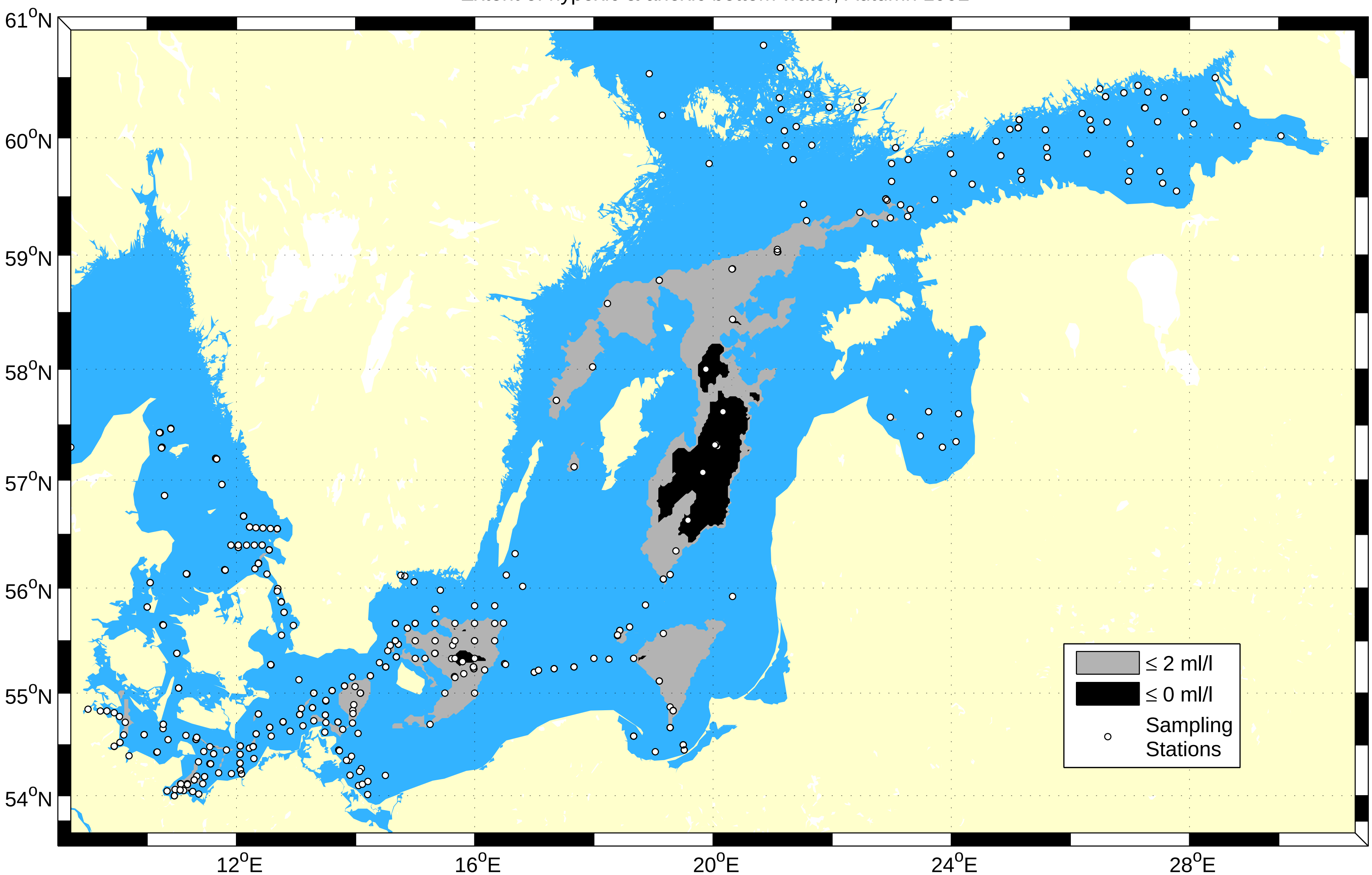
Extent of hypoxic & anoxic bottom water, Autumn 1994



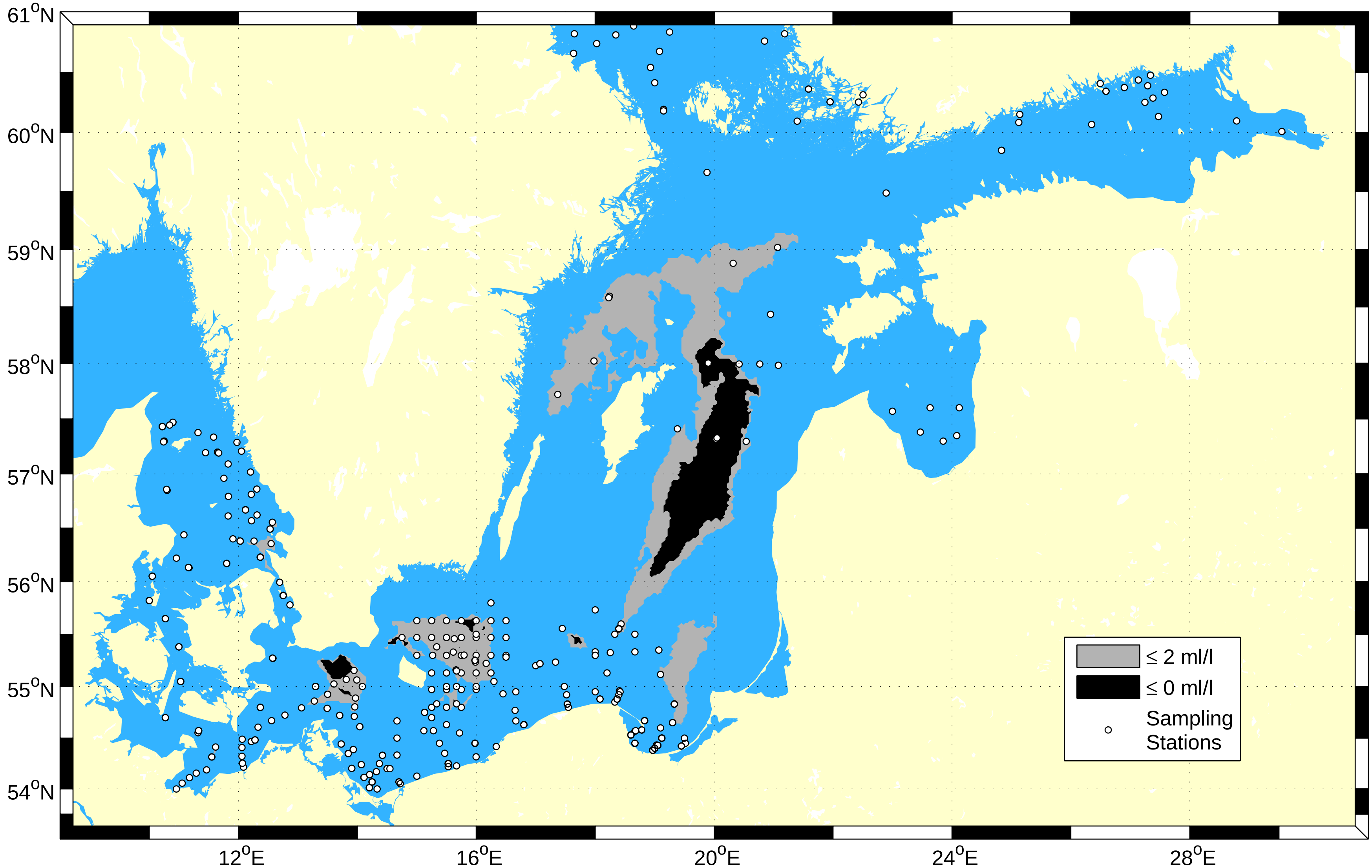
Extent of hypoxic & anoxic bottom water, Autumn 1993



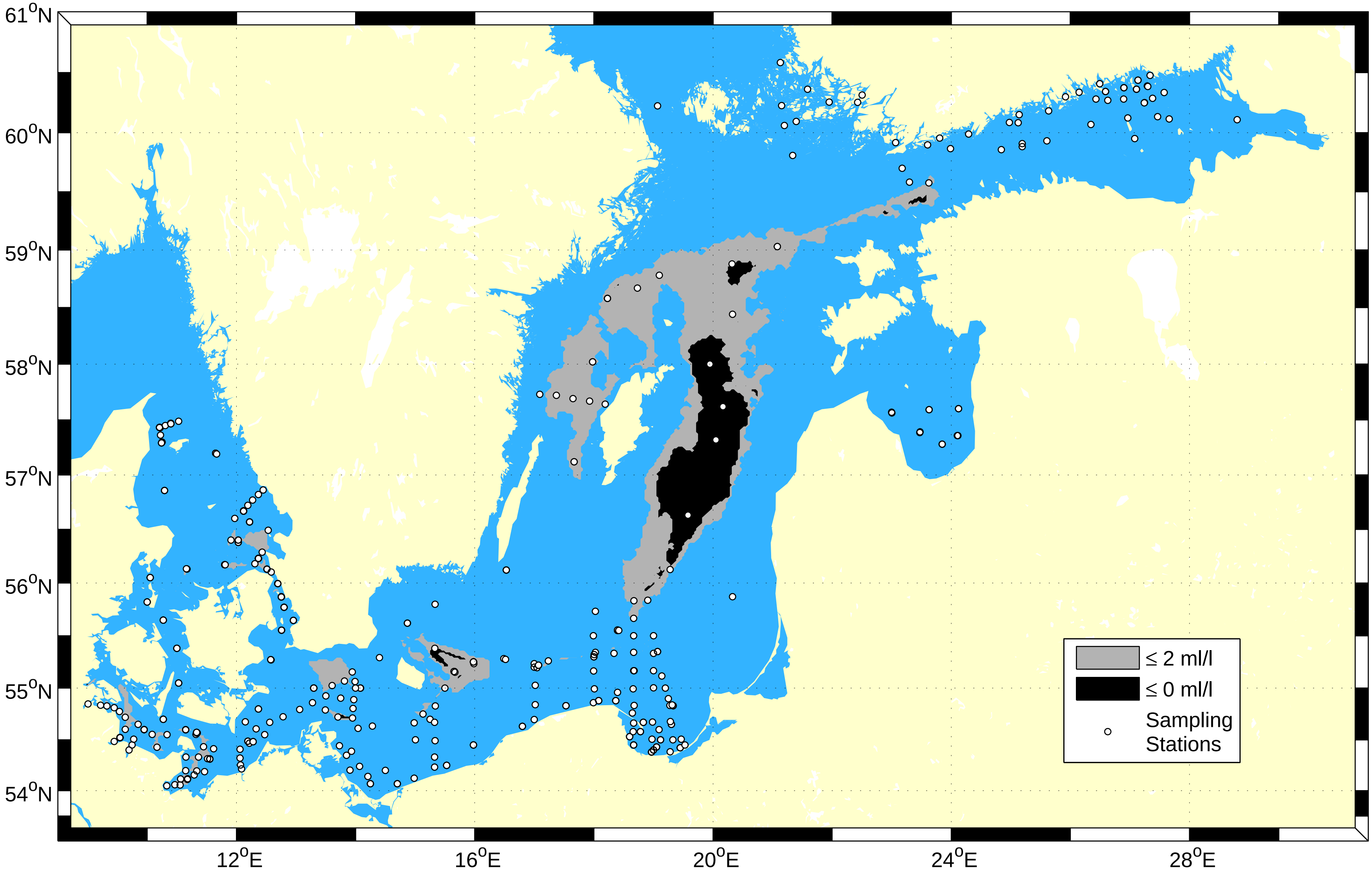
Extent of hypoxic & anoxic bottom water, Autumn 1992



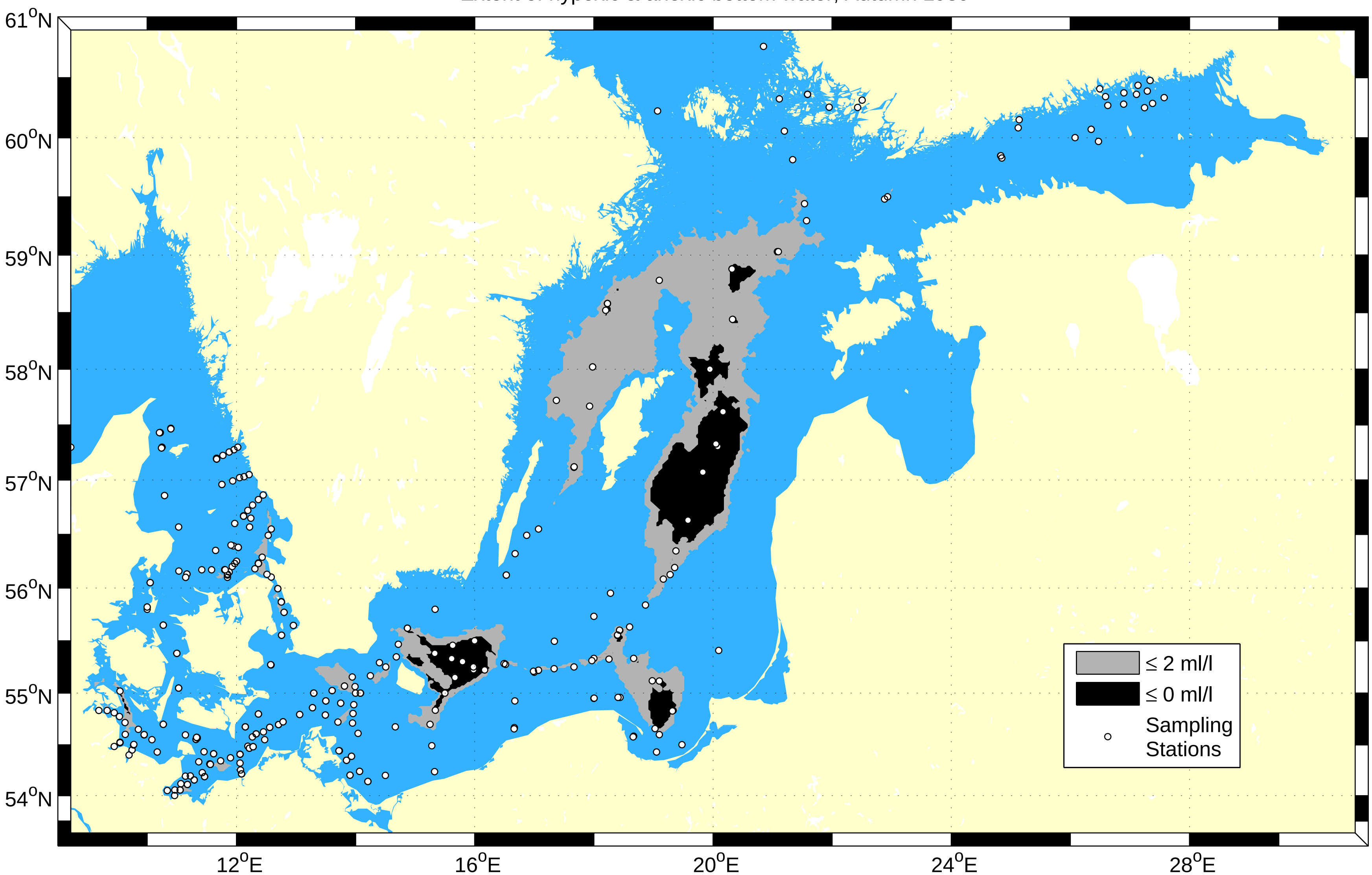
Extent of hypoxic & anoxic bottom water, Autumn 1991



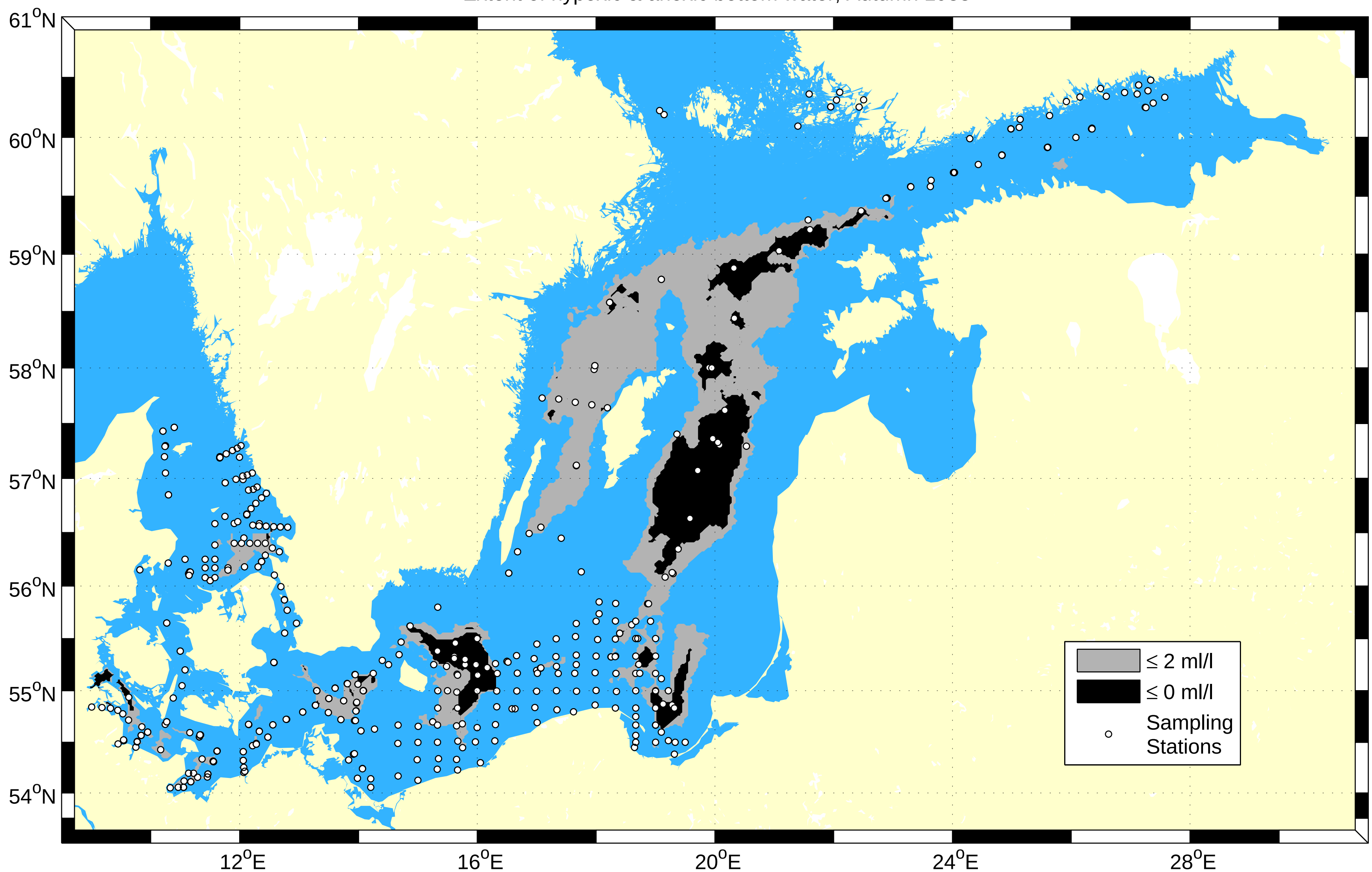
Extent of hypoxic & anoxic bottom water, Autumn 1990

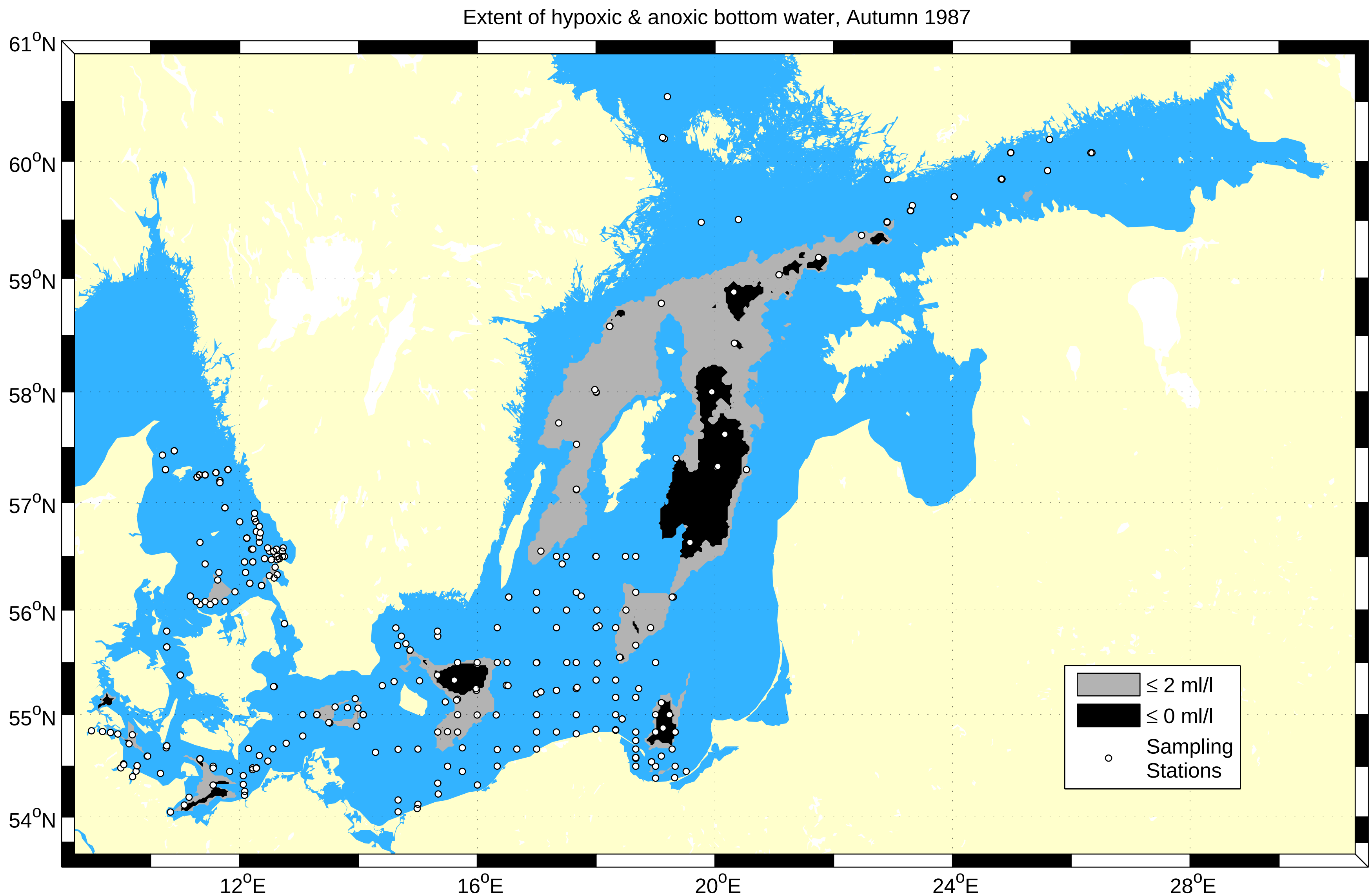


Extent of hypoxic & anoxic bottom water, Autumn 1989



Extent of hypoxic & anoxic bottom water, Autumn 1988




Extent of hypoxic & anoxic bottom water, Autumn 1987
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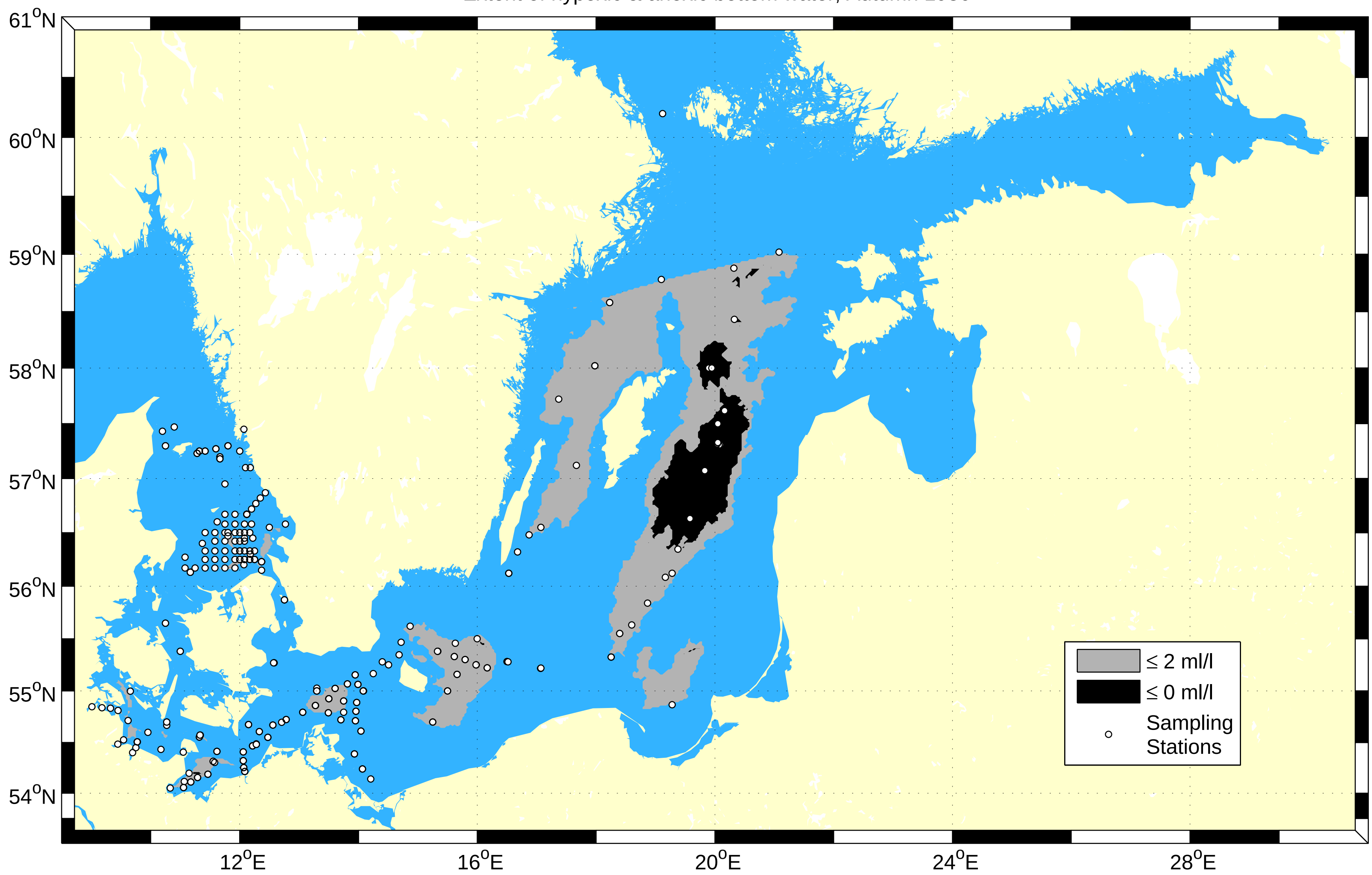
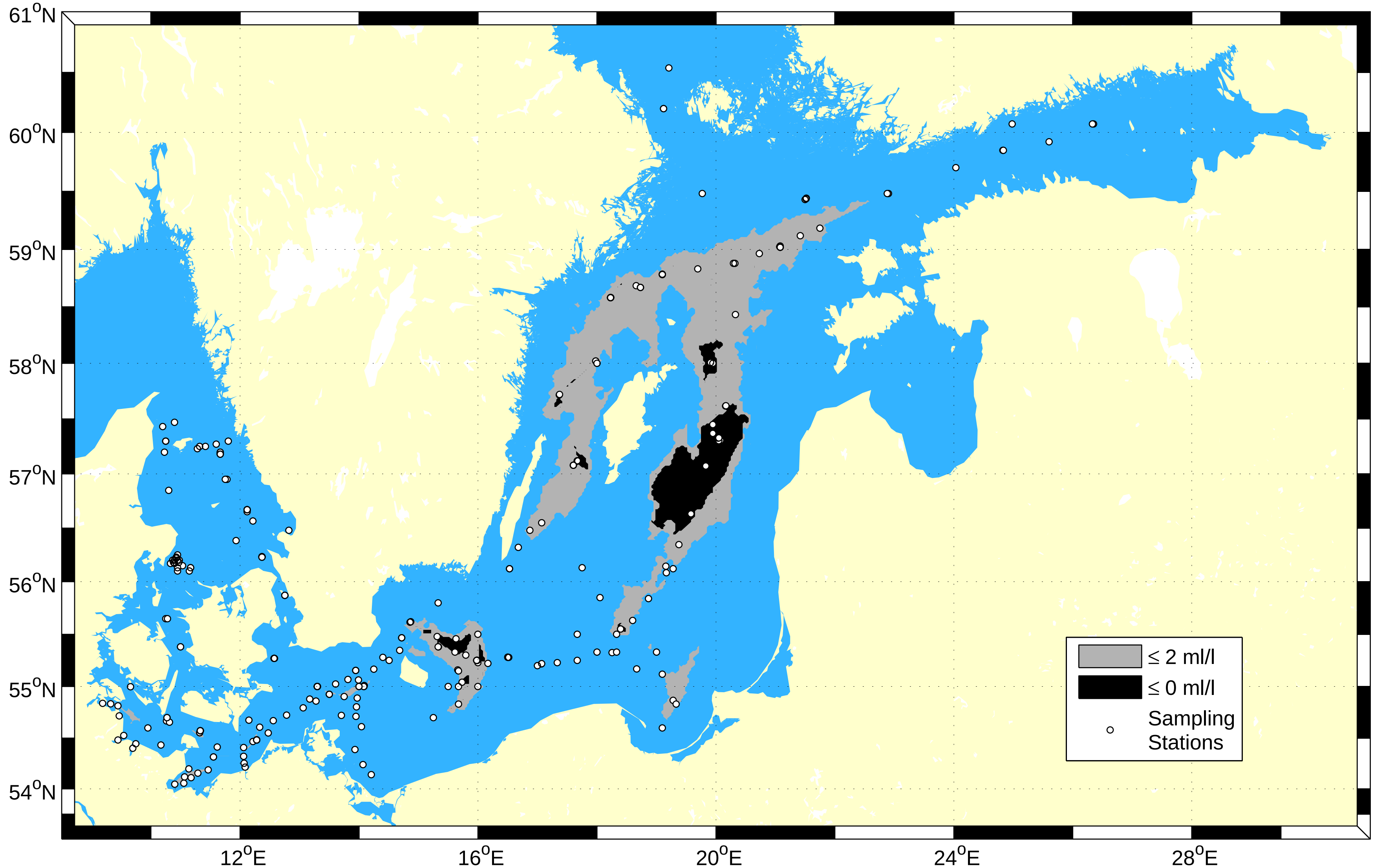
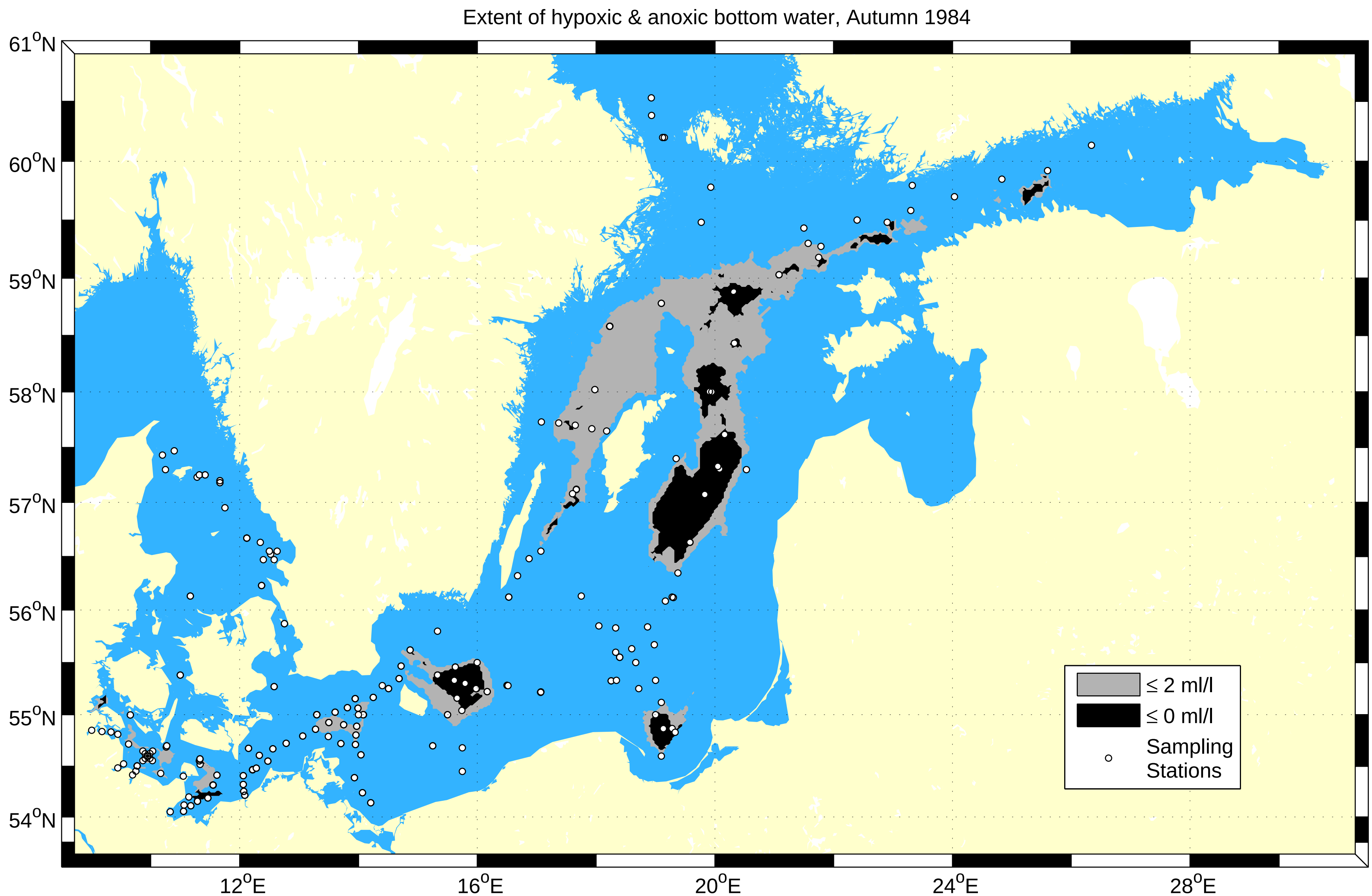
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 1986

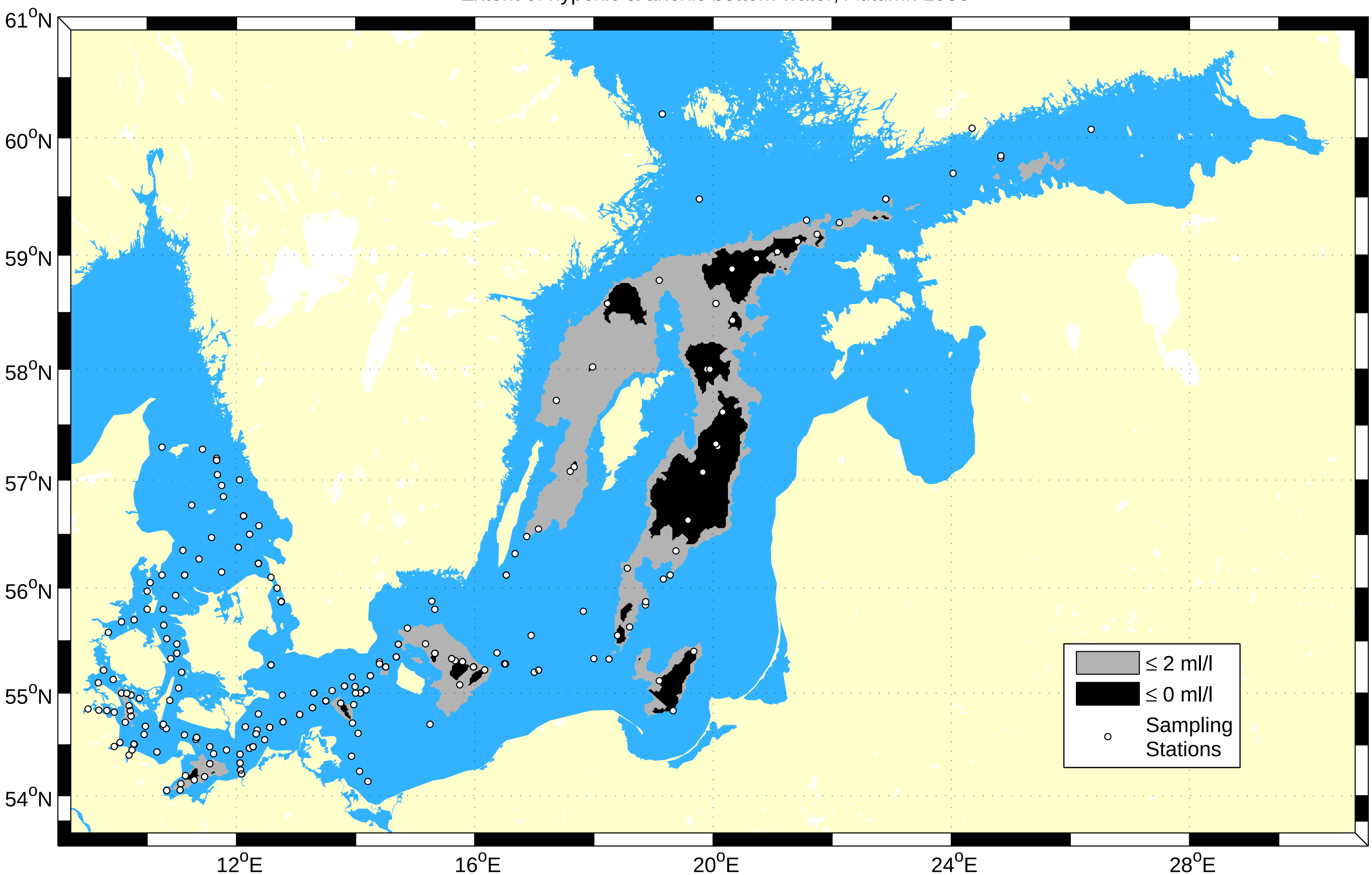


Extent of hypoxic & anoxic bottom water, Autumn 1985

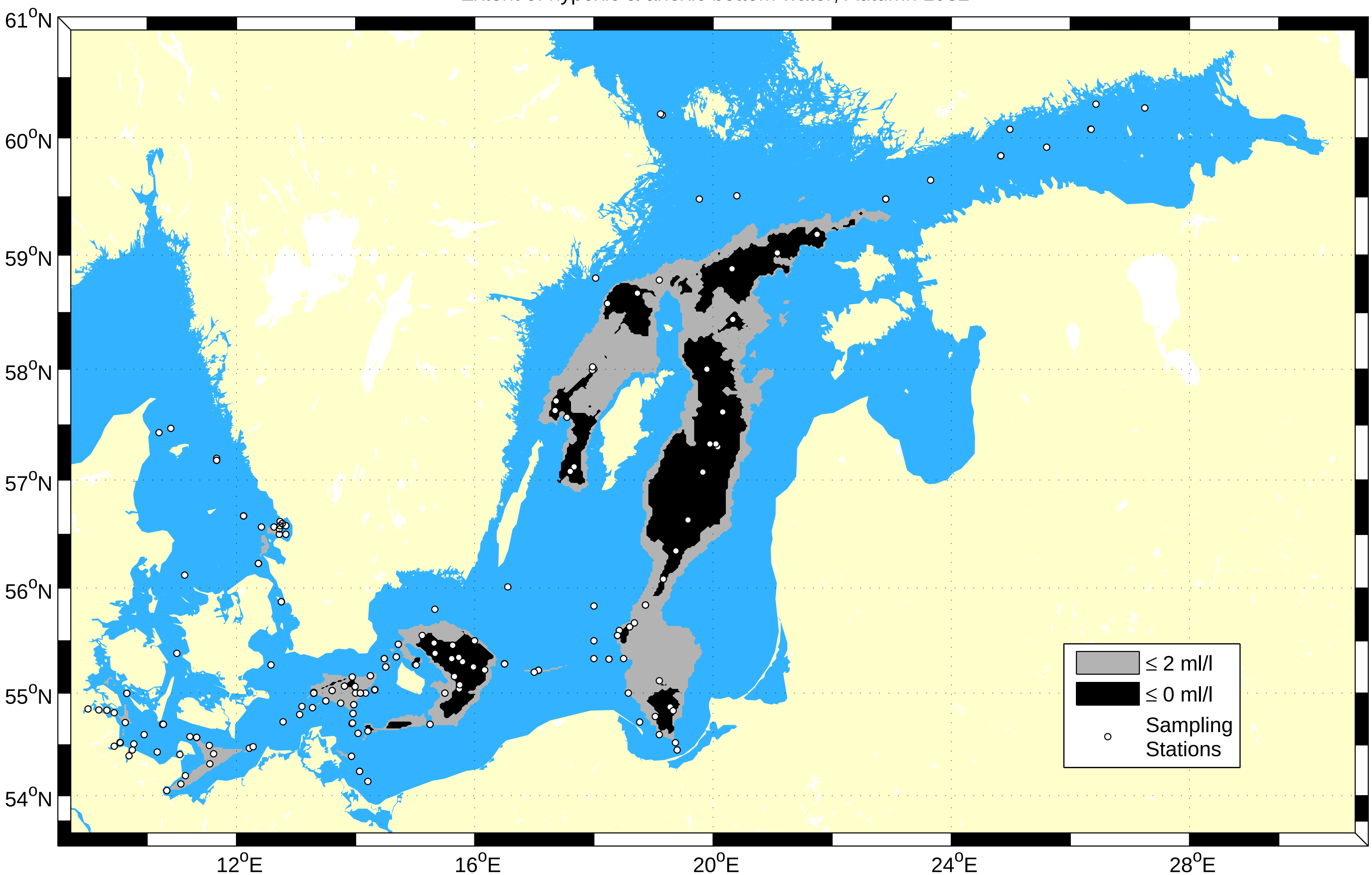


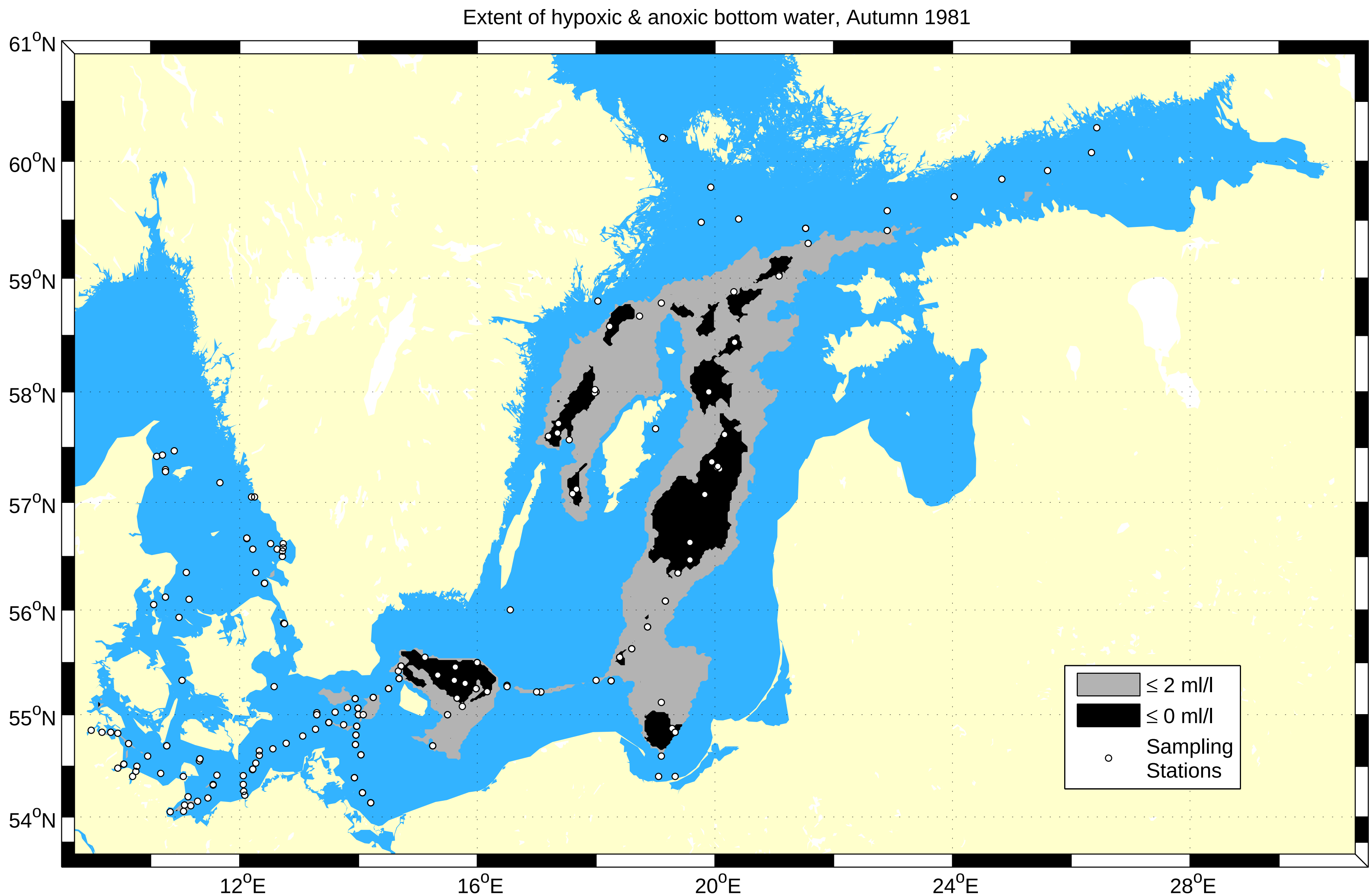

Extent of hypoxic & anoxic bottom water, Autumn 1984
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 1983

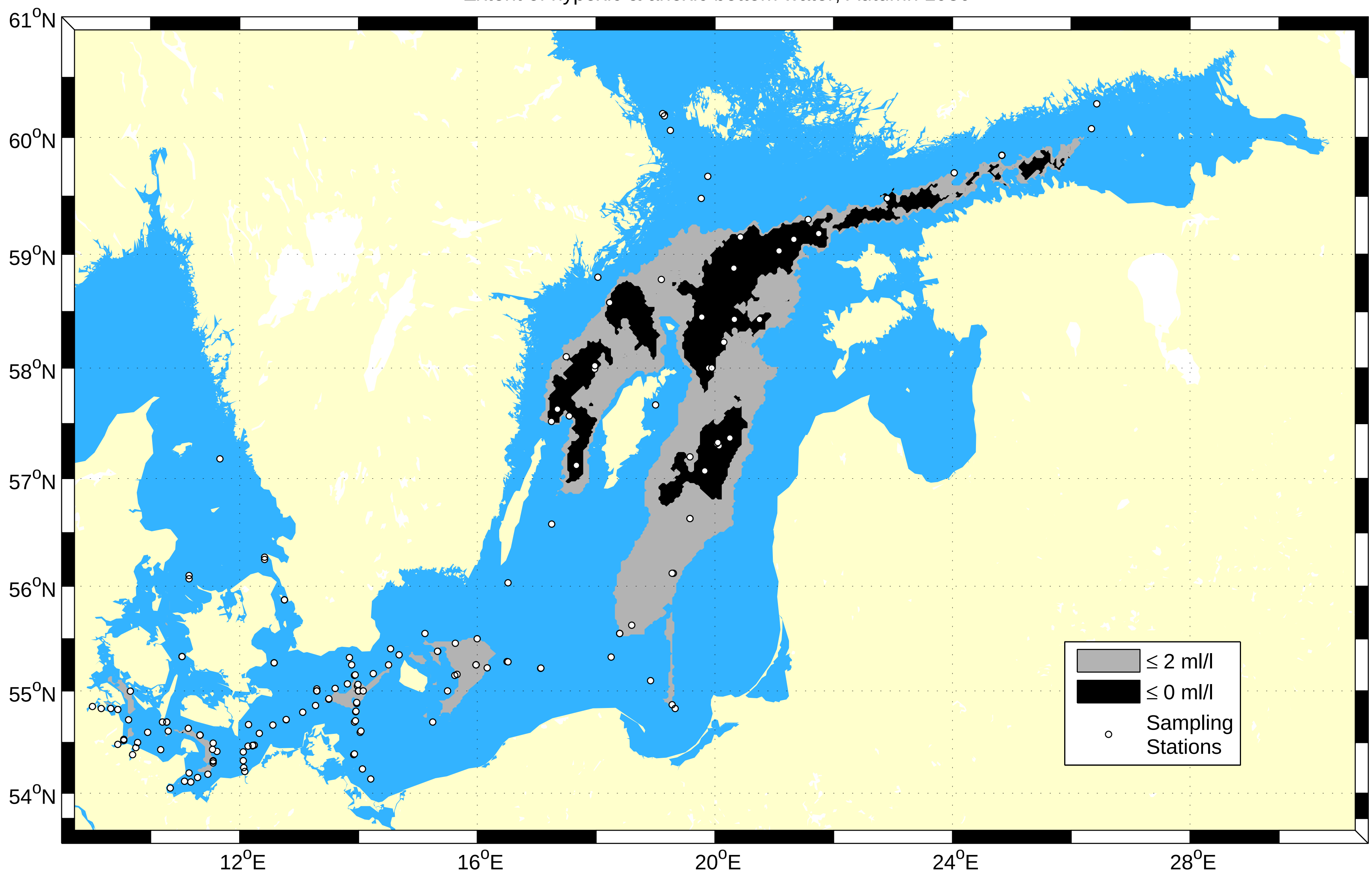


Extent of hypoxic & anoxic bottom water, Autumn 1982

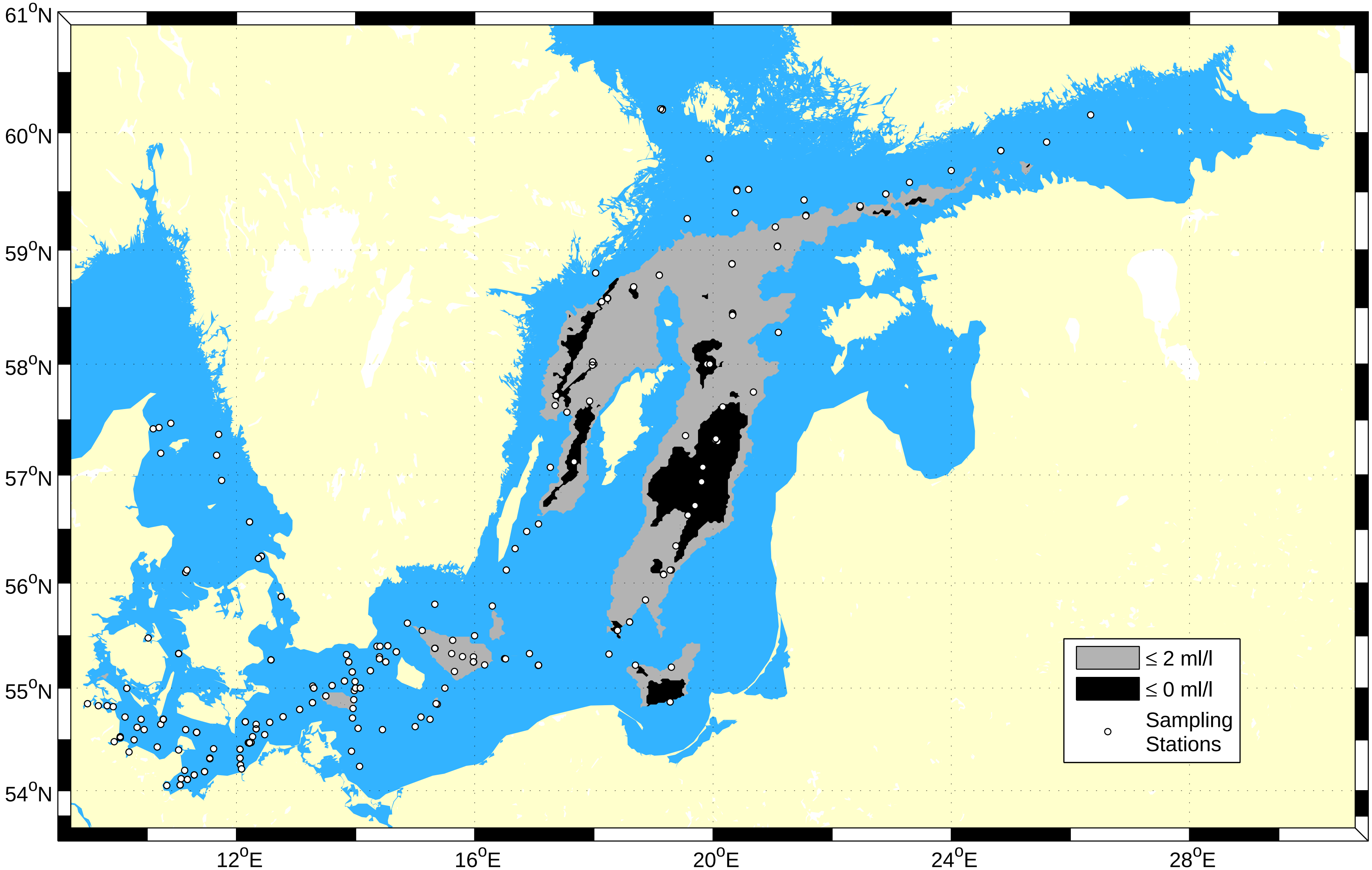



Extent of hypoxic & anoxic bottom water, Autumn 1981
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

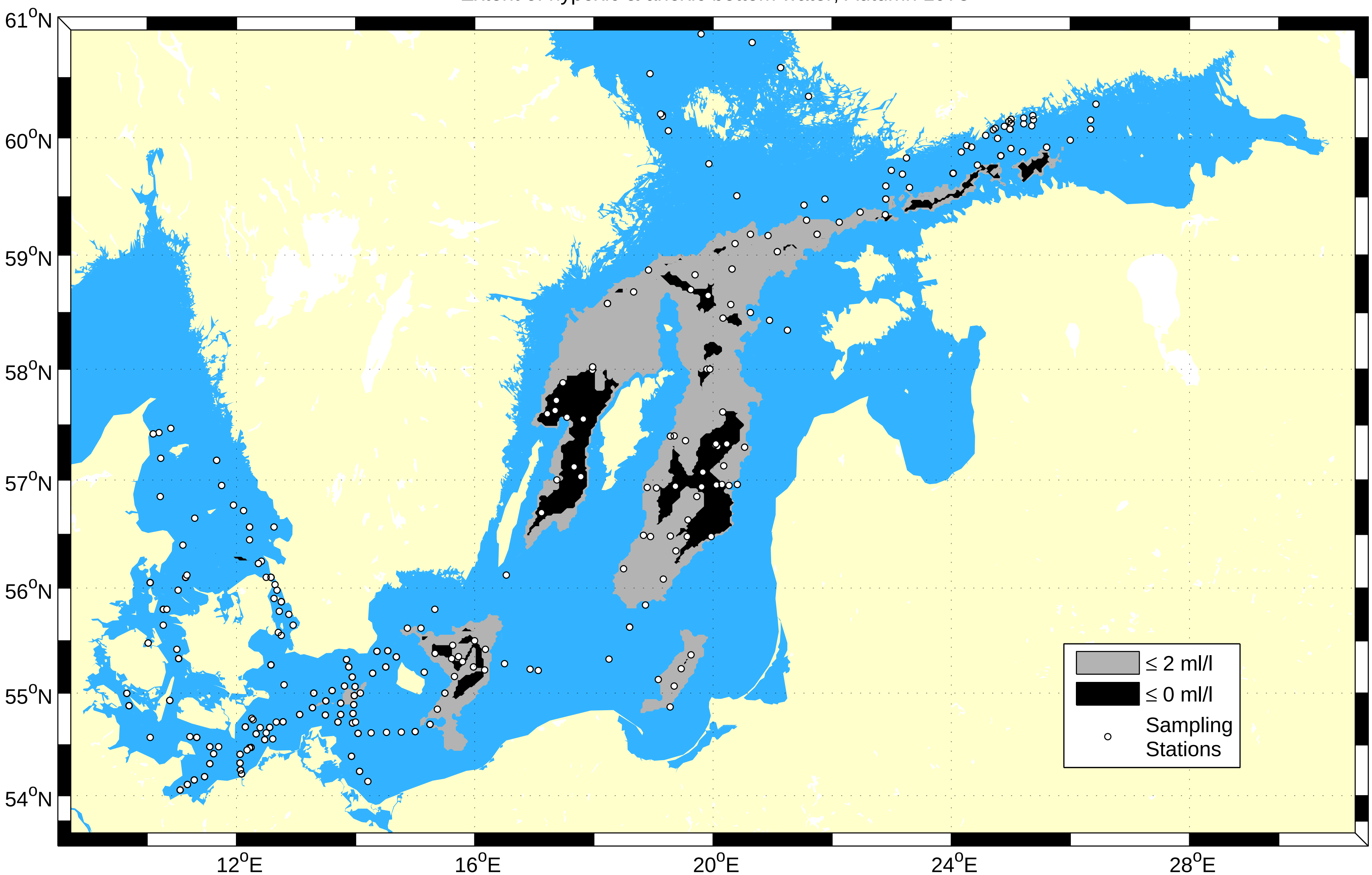
Extent of hypoxic & anoxic bottom water, Autumn 1980



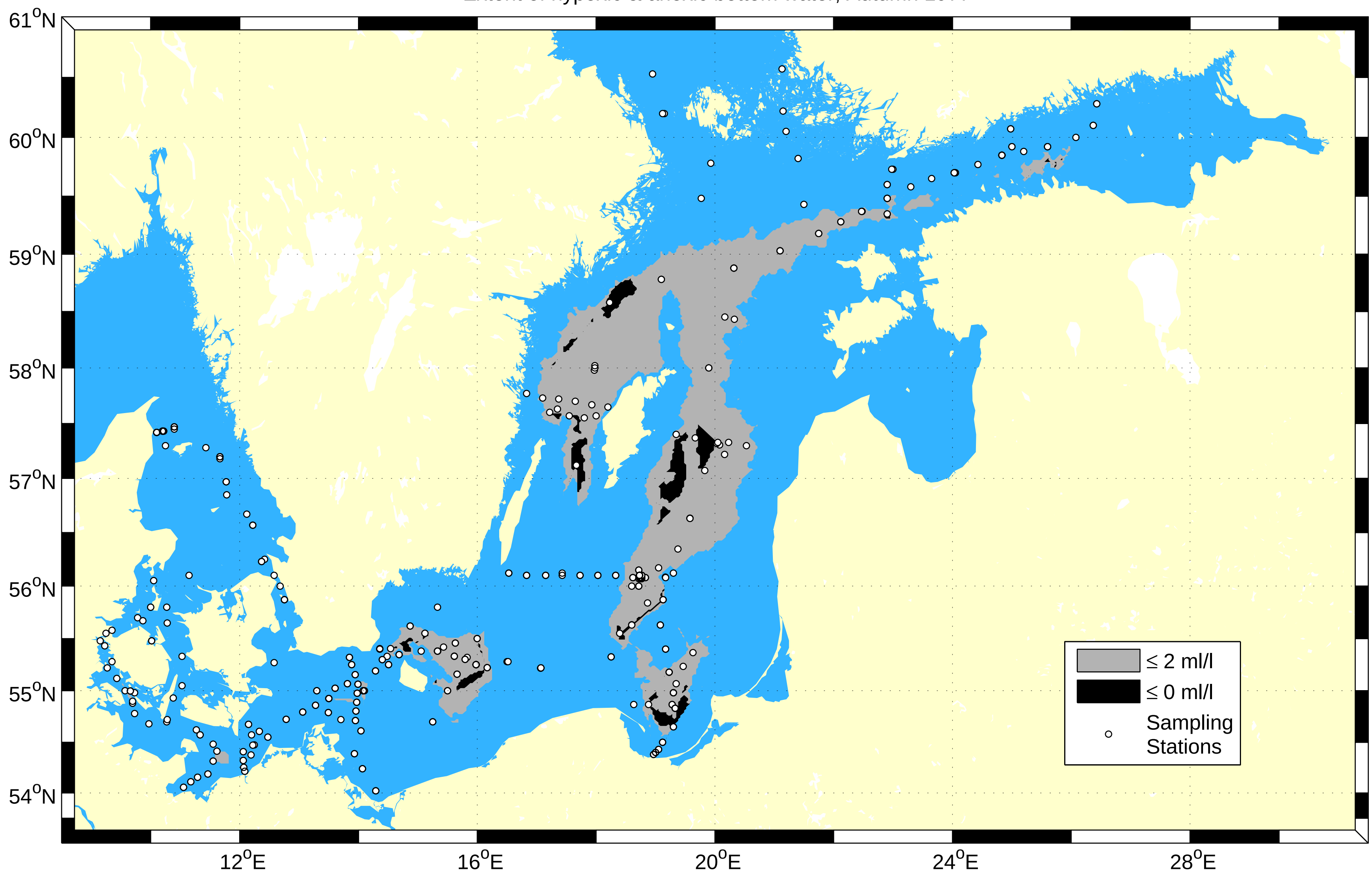
Extent of hypoxic & anoxic bottom water, Autumn 1979



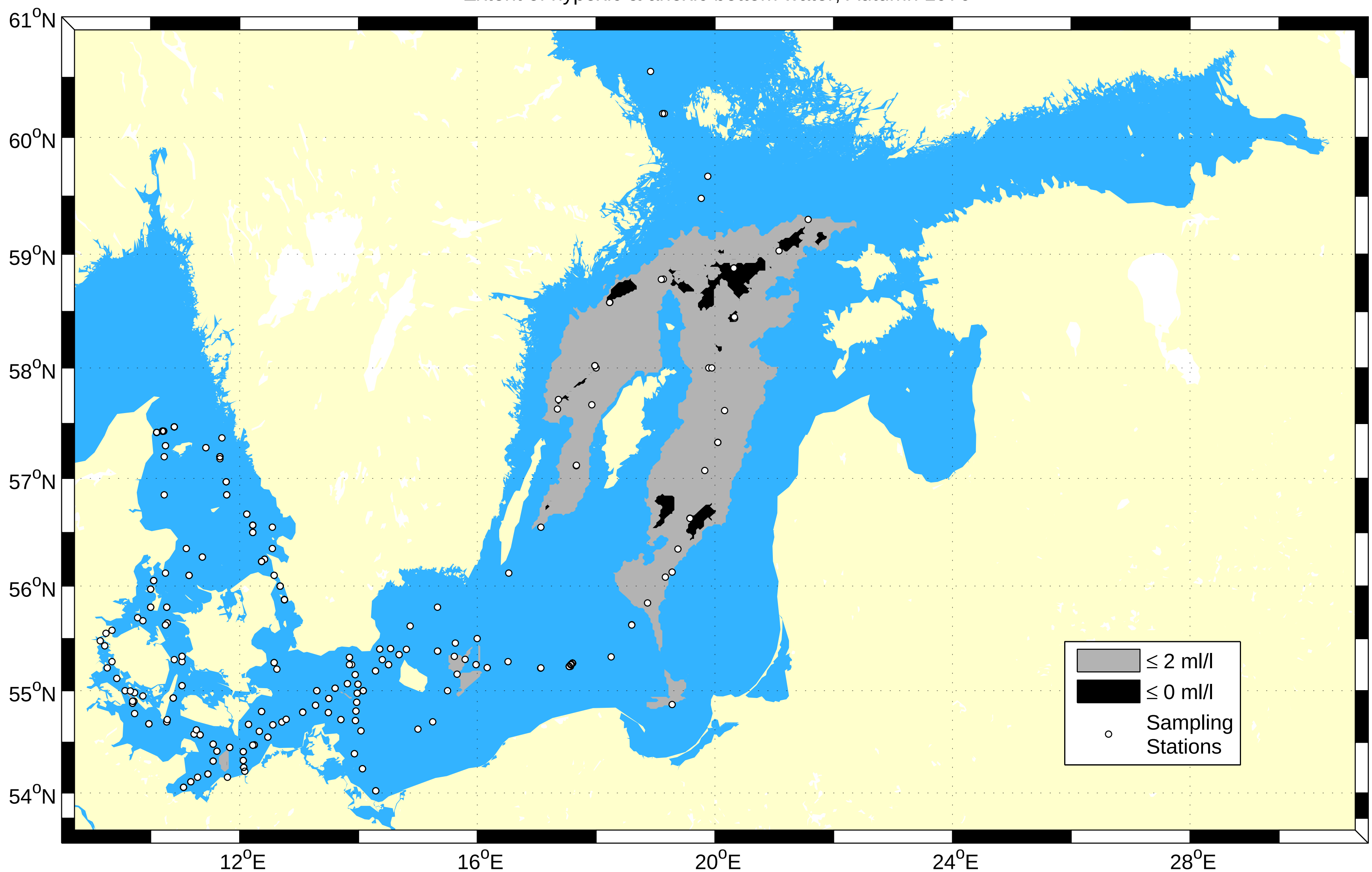
Extent of hypoxic & anoxic bottom water, Autumn 1978



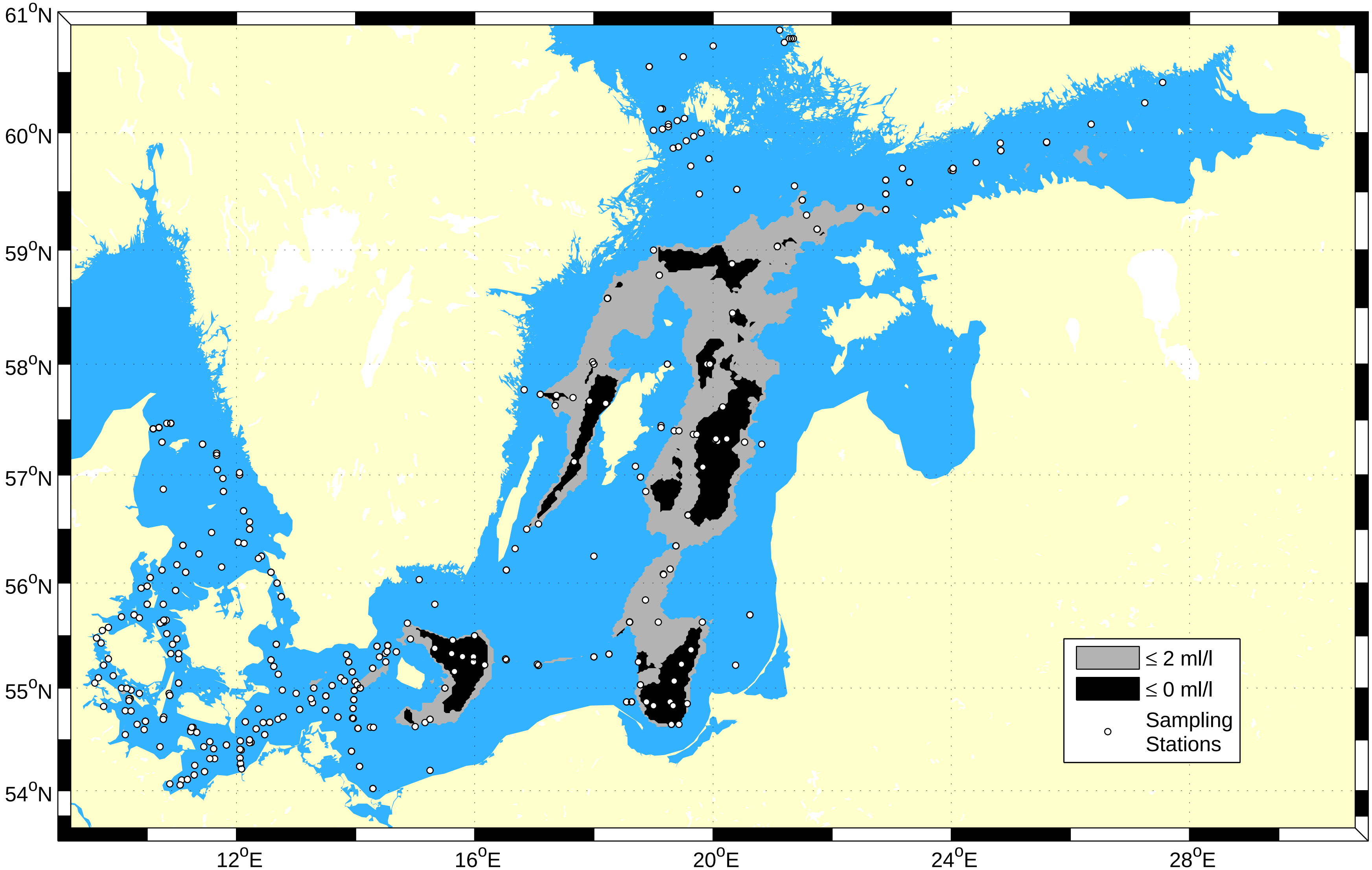
Extent of hypoxic & anoxic bottom water, Autumn 1977



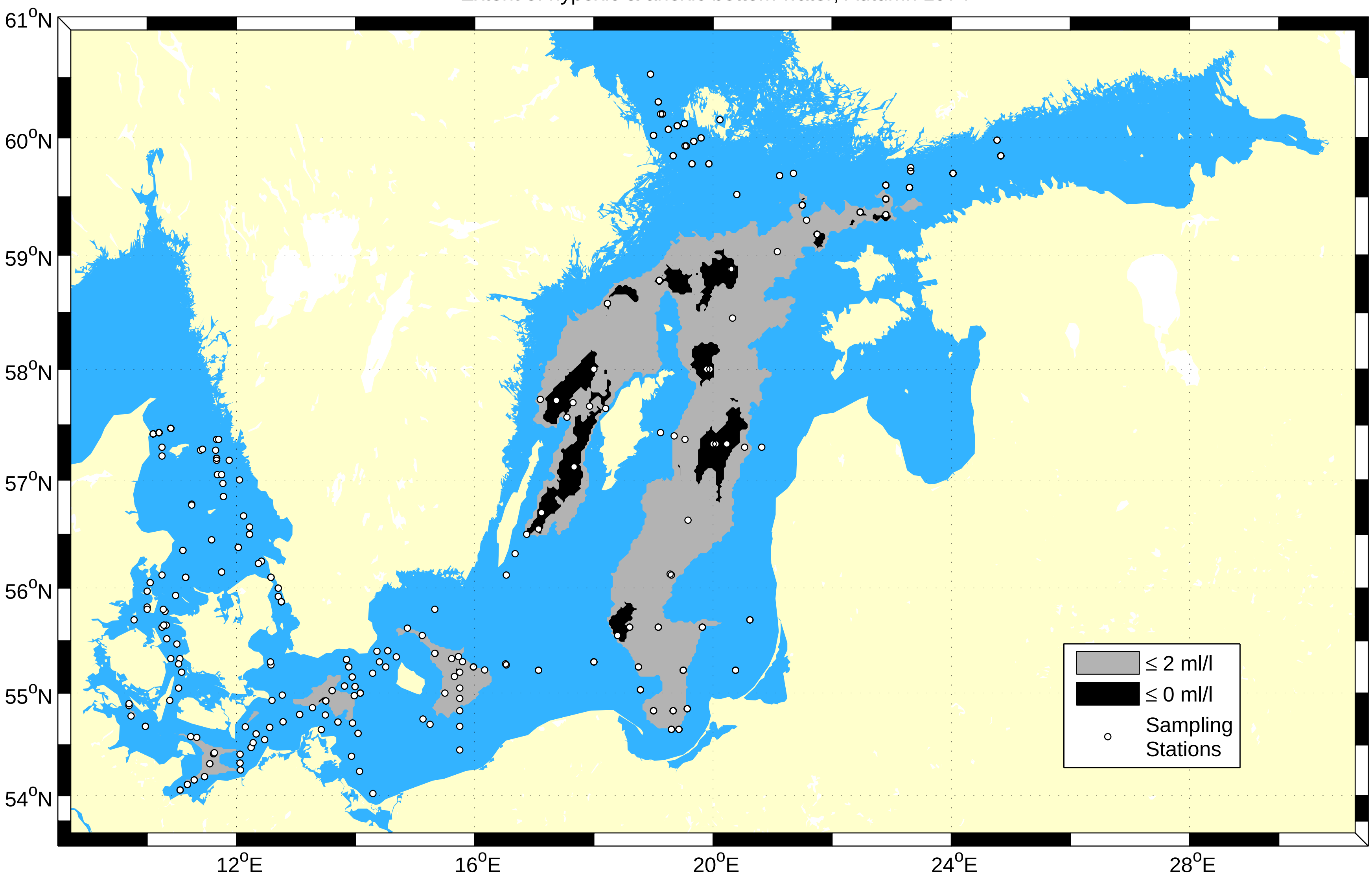
Extent of hypoxic & anoxic bottom water, Autumn 1976

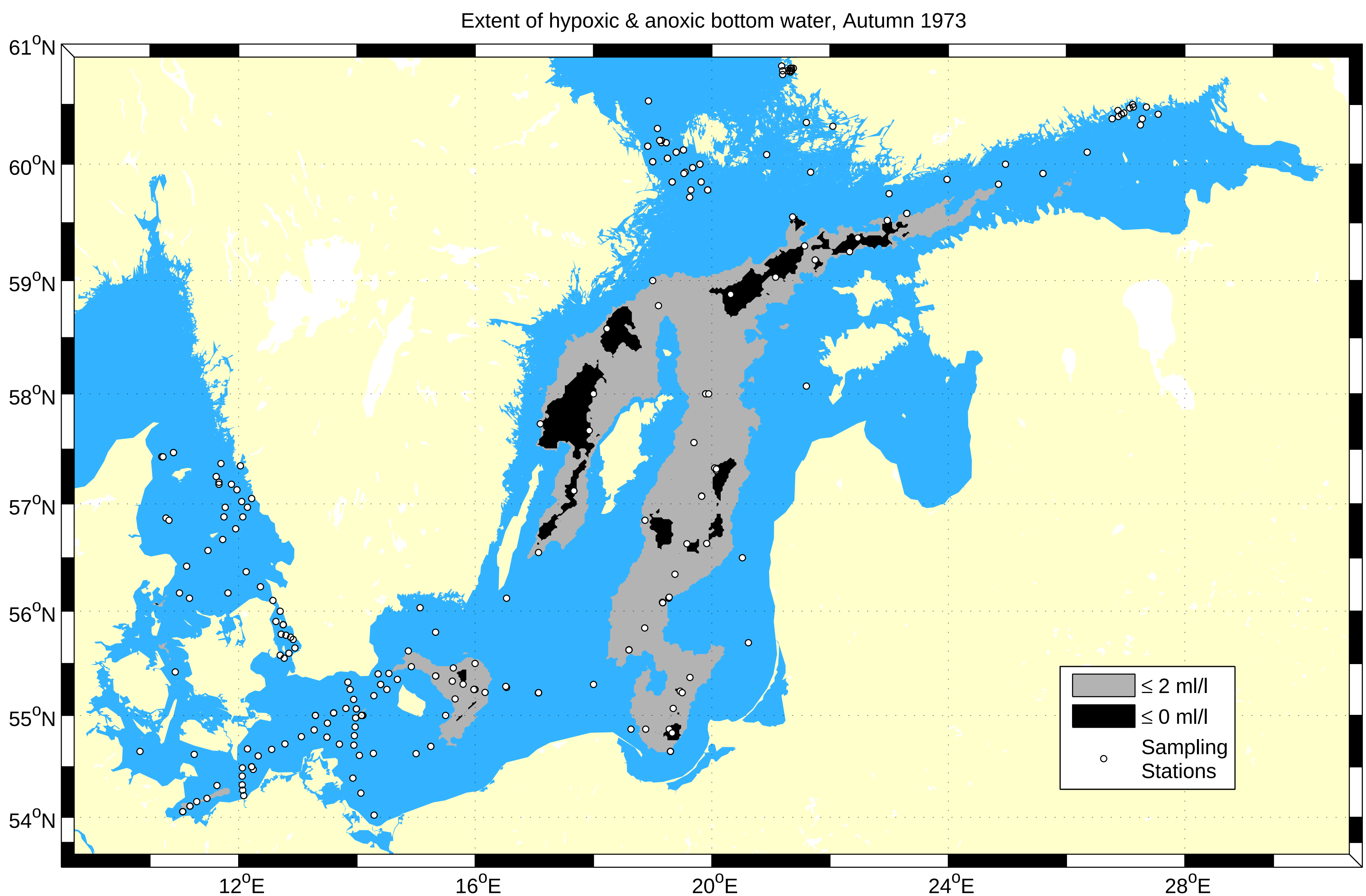


Extent of hypoxic & anoxic bottom water, Autumn 1975

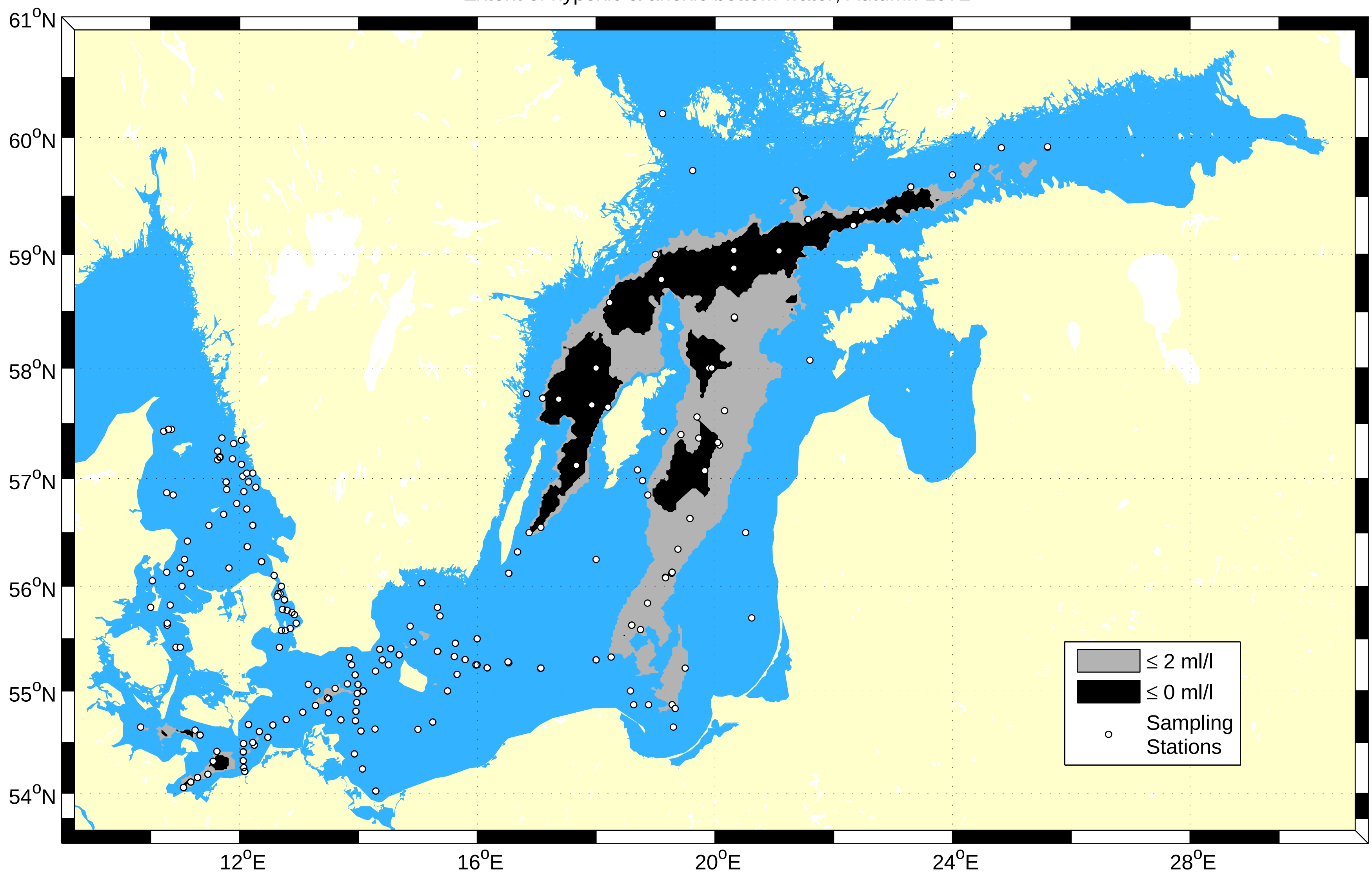


Extent of hypoxic & anoxic bottom water, Autumn 1974

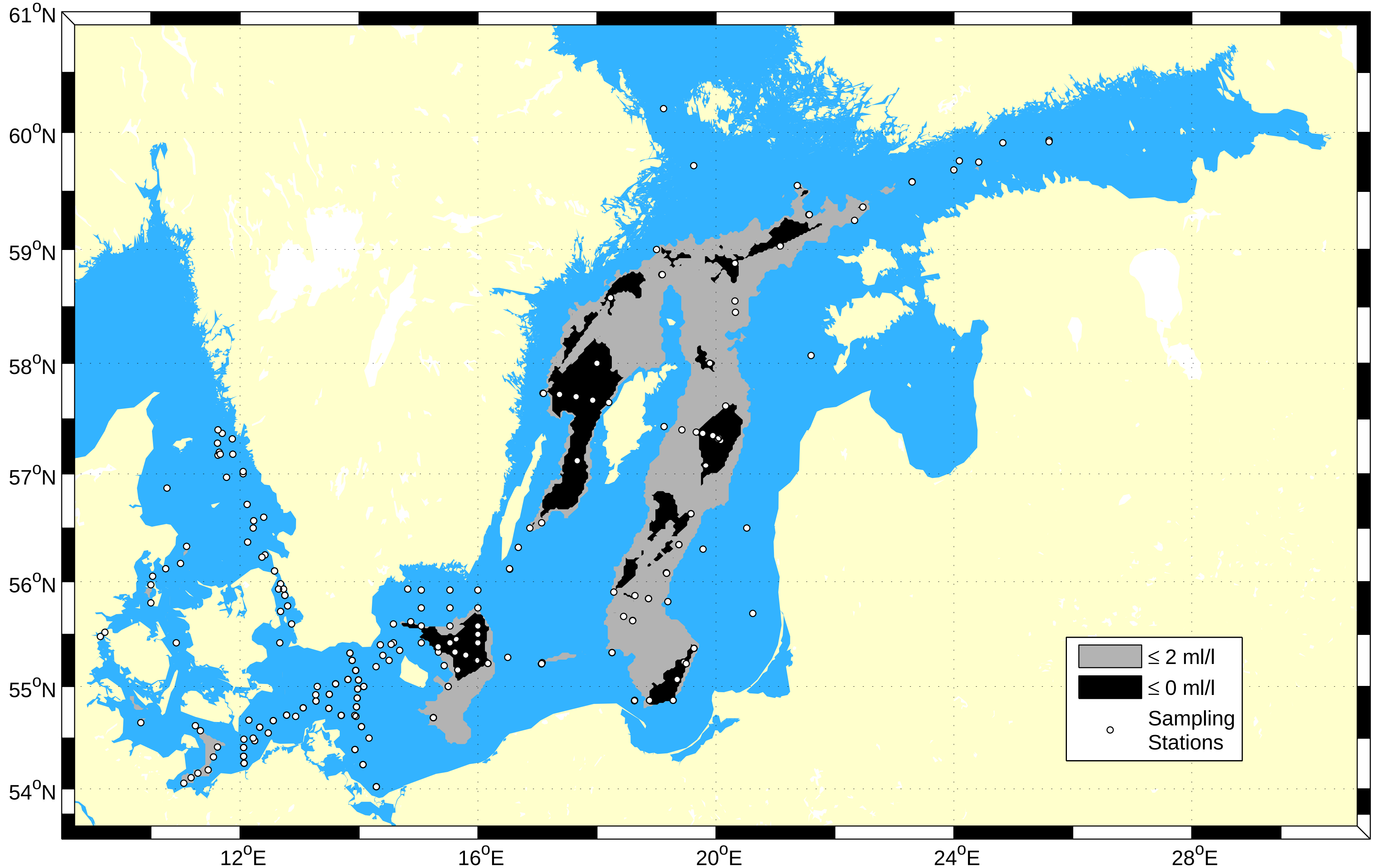



Extent of hypoxic & anoxic bottom water, Autumn 1973
61^{0}N
60^{0}N
59^{0}N
58^{0}N
57^{0}N
56^{0}N
55^{0}N
54^{0}N
12^{0}E
16^{0}E
20^{0}E
24^{0}E
28^{0}E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

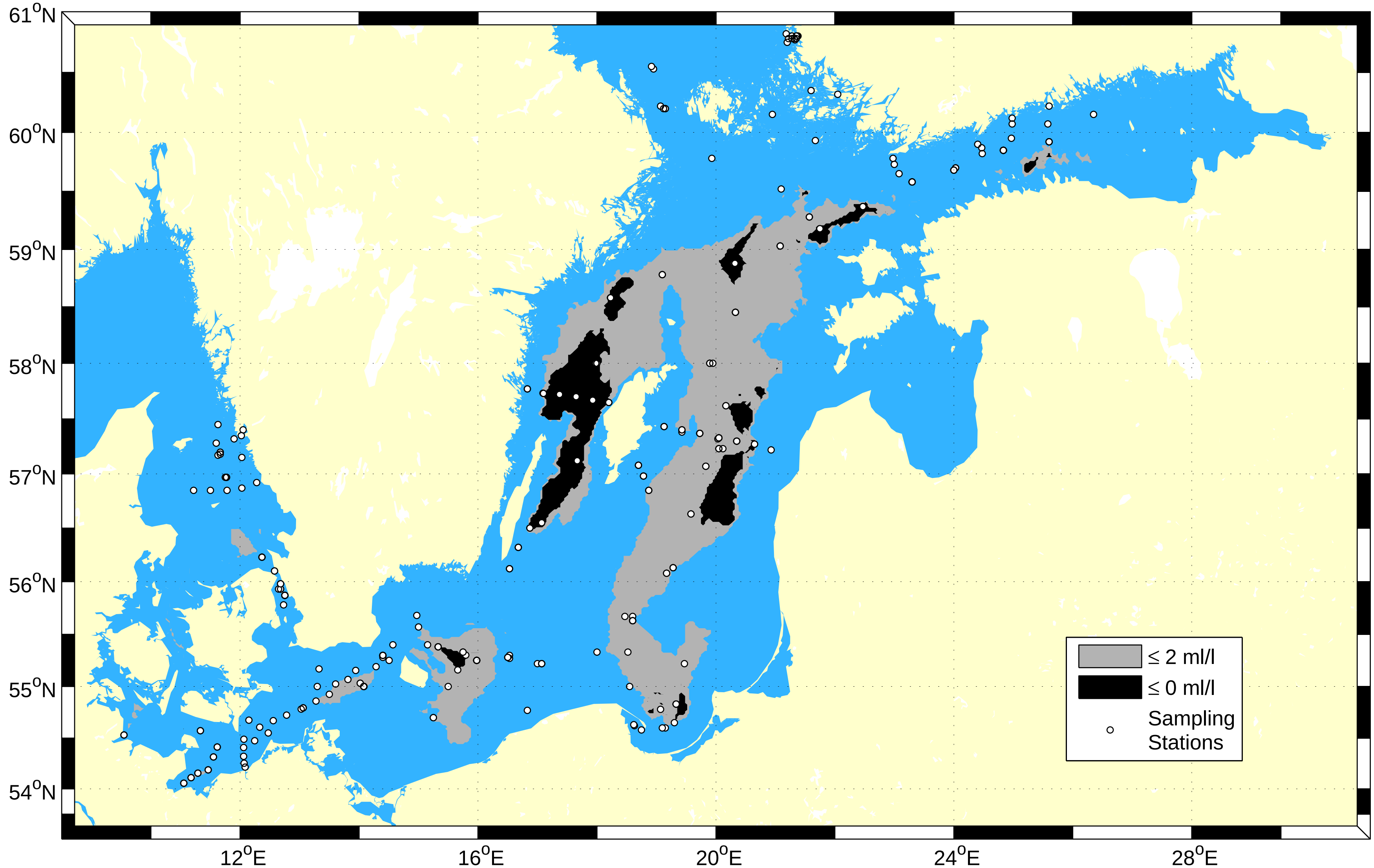
Extent of hypoxic & anoxic bottom water, Autumn 1972



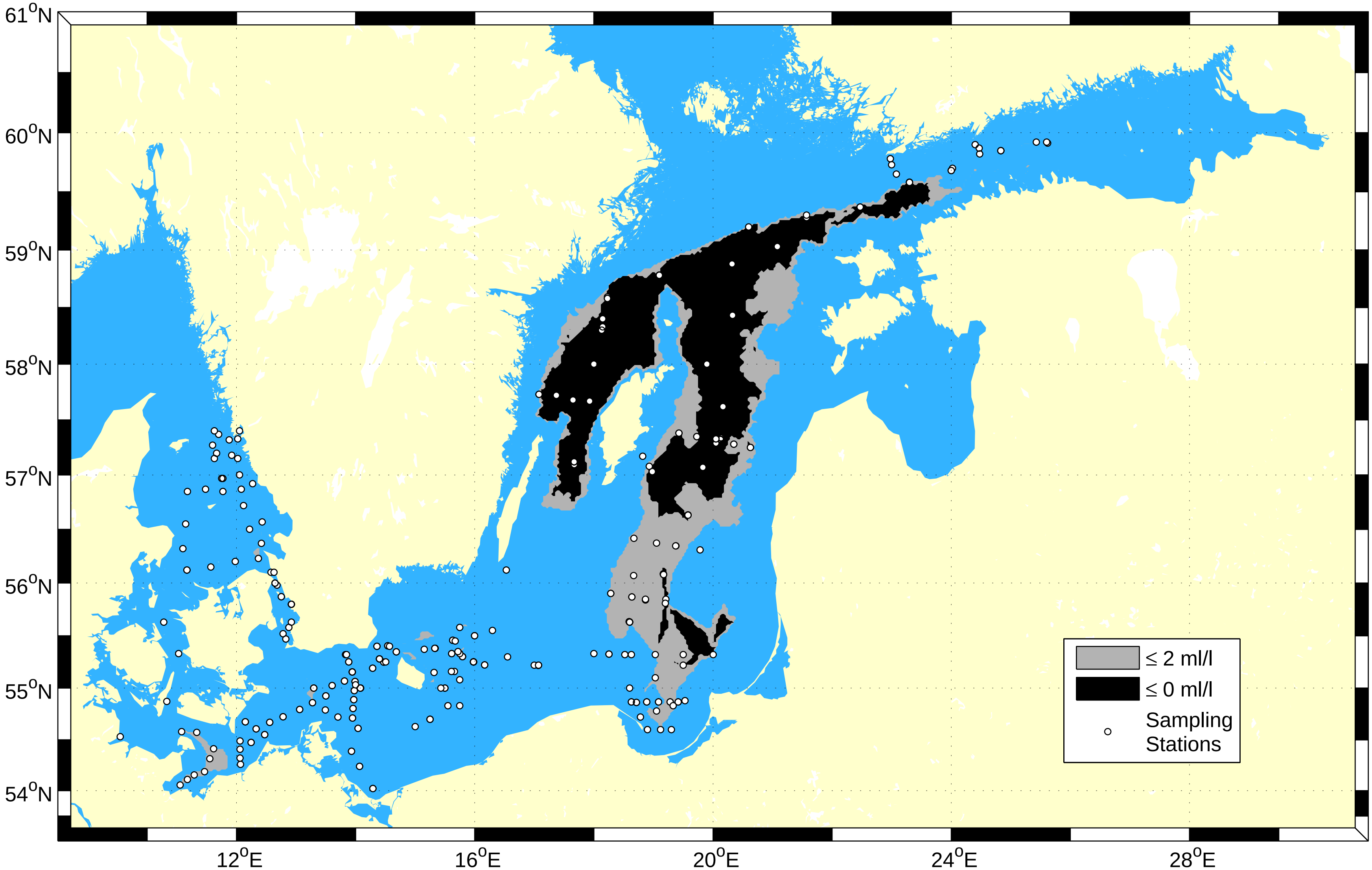
Extent of hypoxic & anoxic bottom water, Autumn 1971



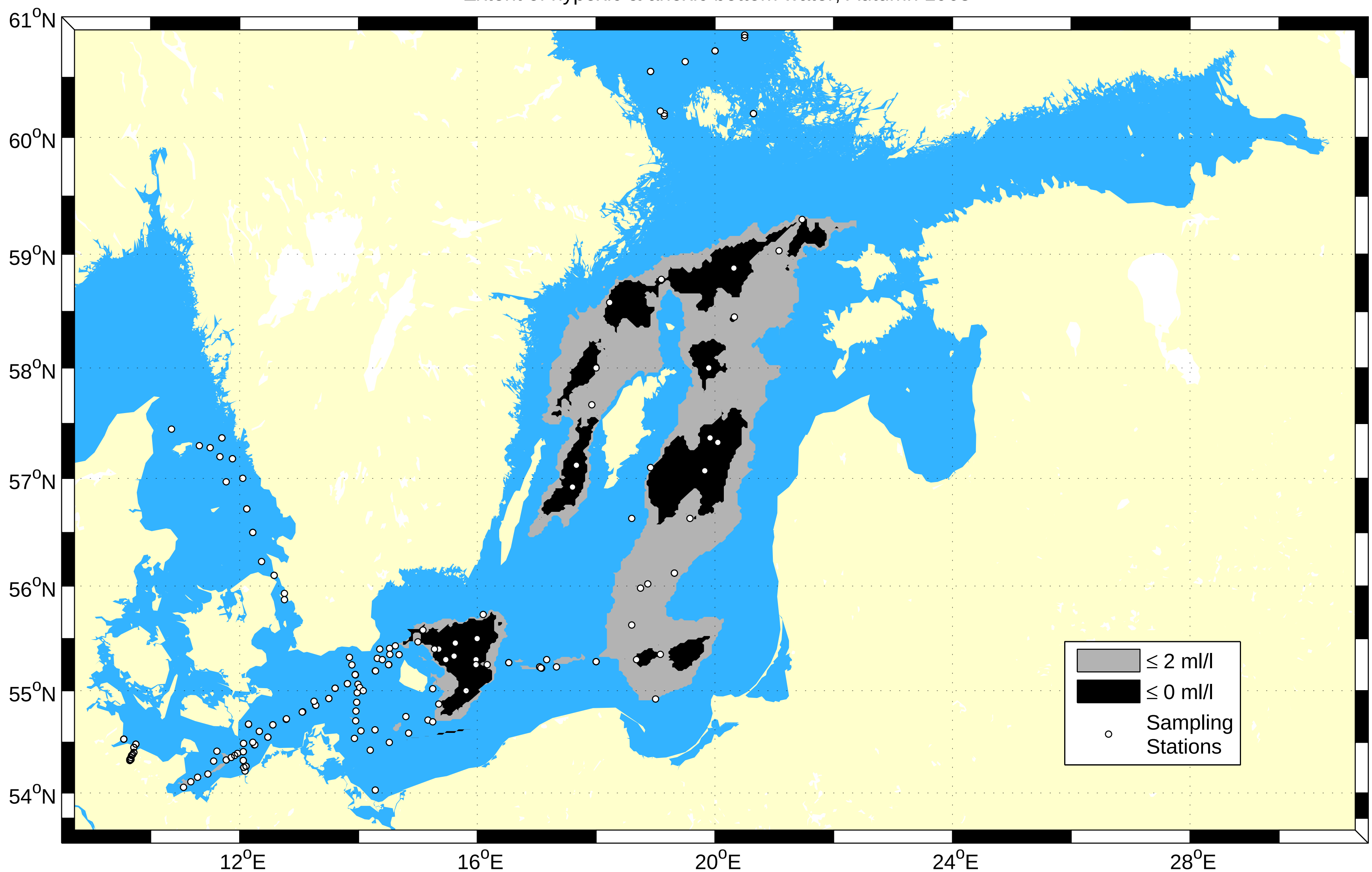
Extent of hypoxic & anoxic bottom water, Autumn 1970



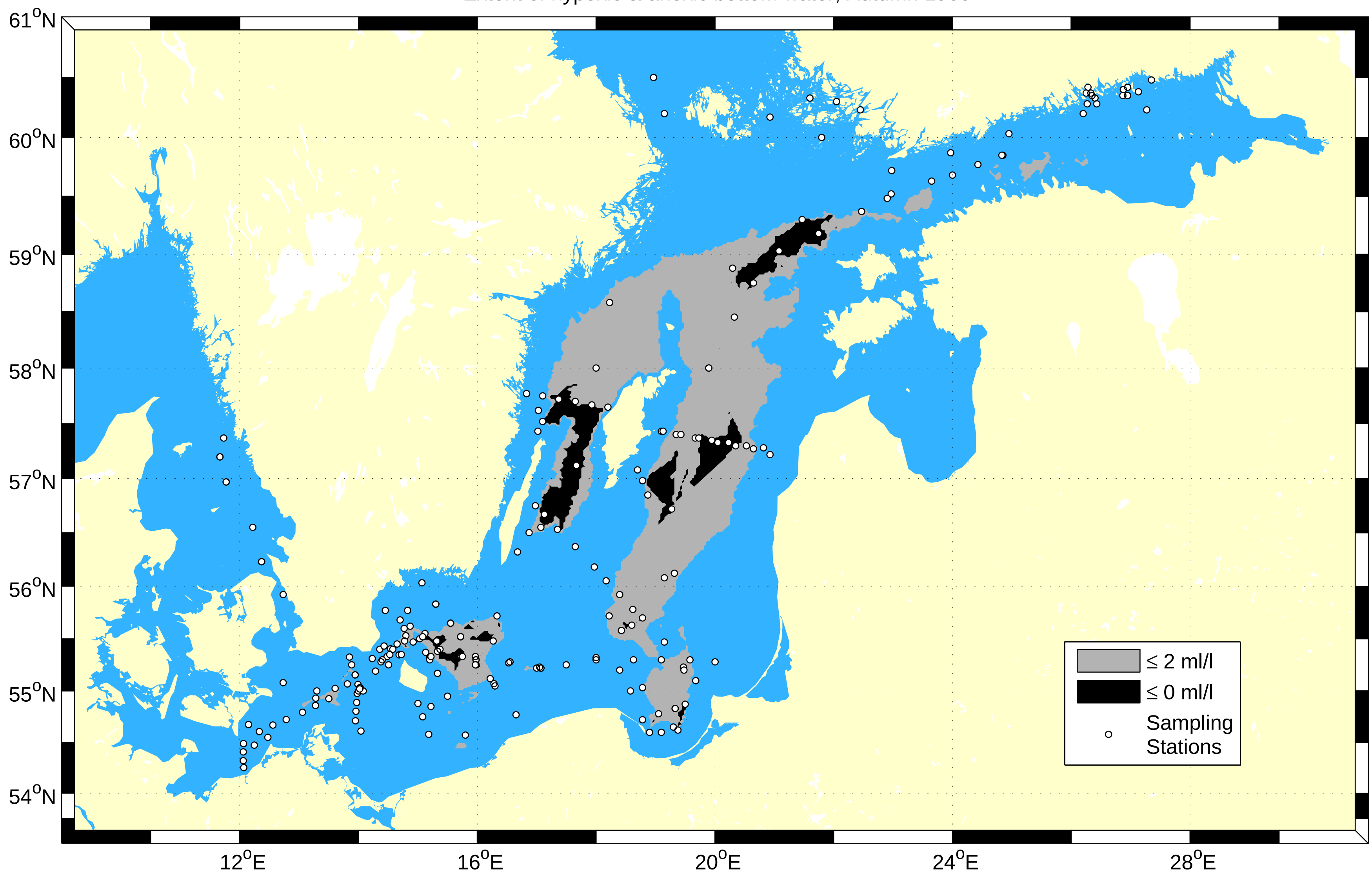
Extent of hypoxic & anoxic bottom water, Autumn 1969



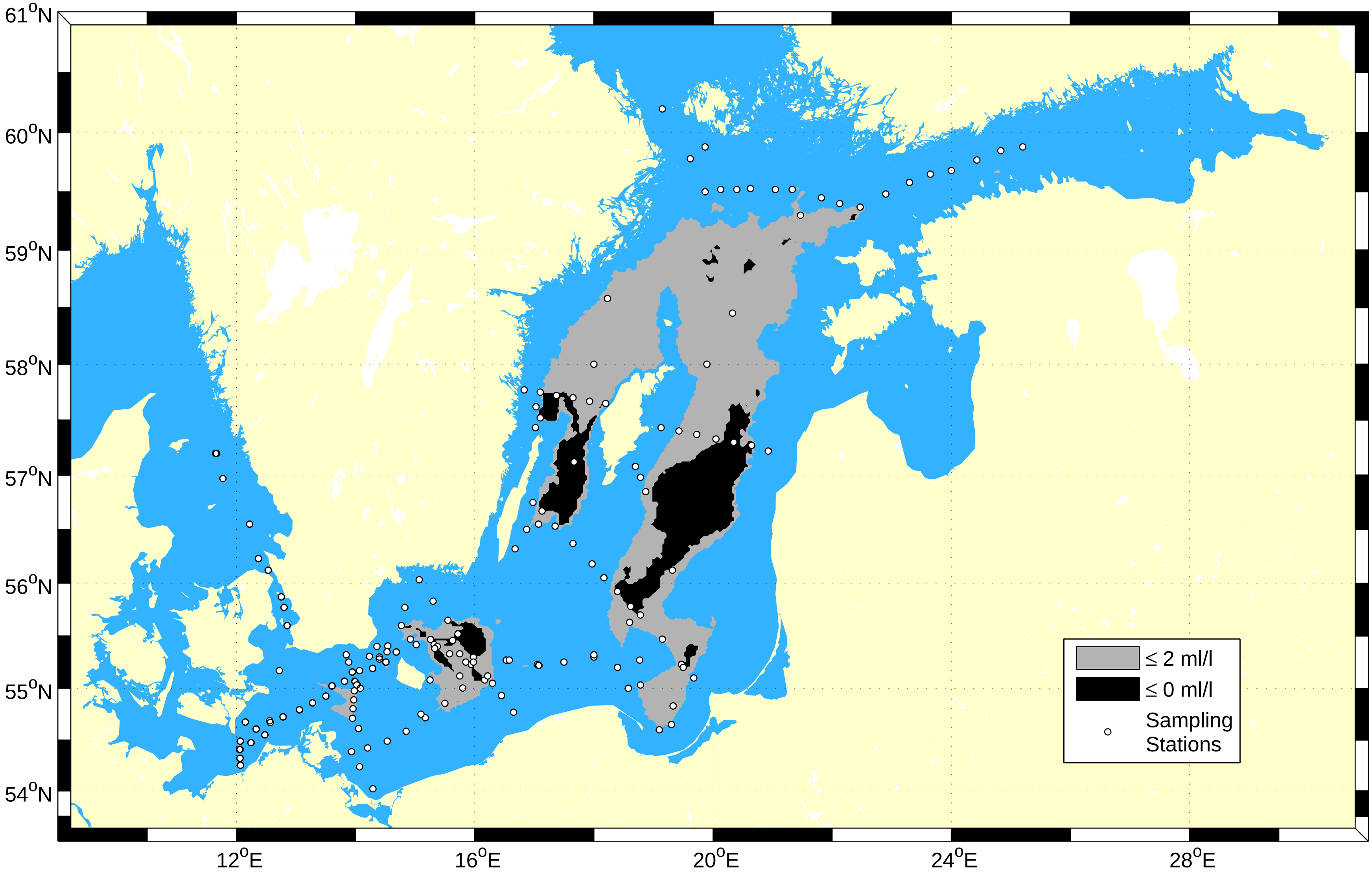
Extent of hypoxic & anoxic bottom water, Autumn 1968



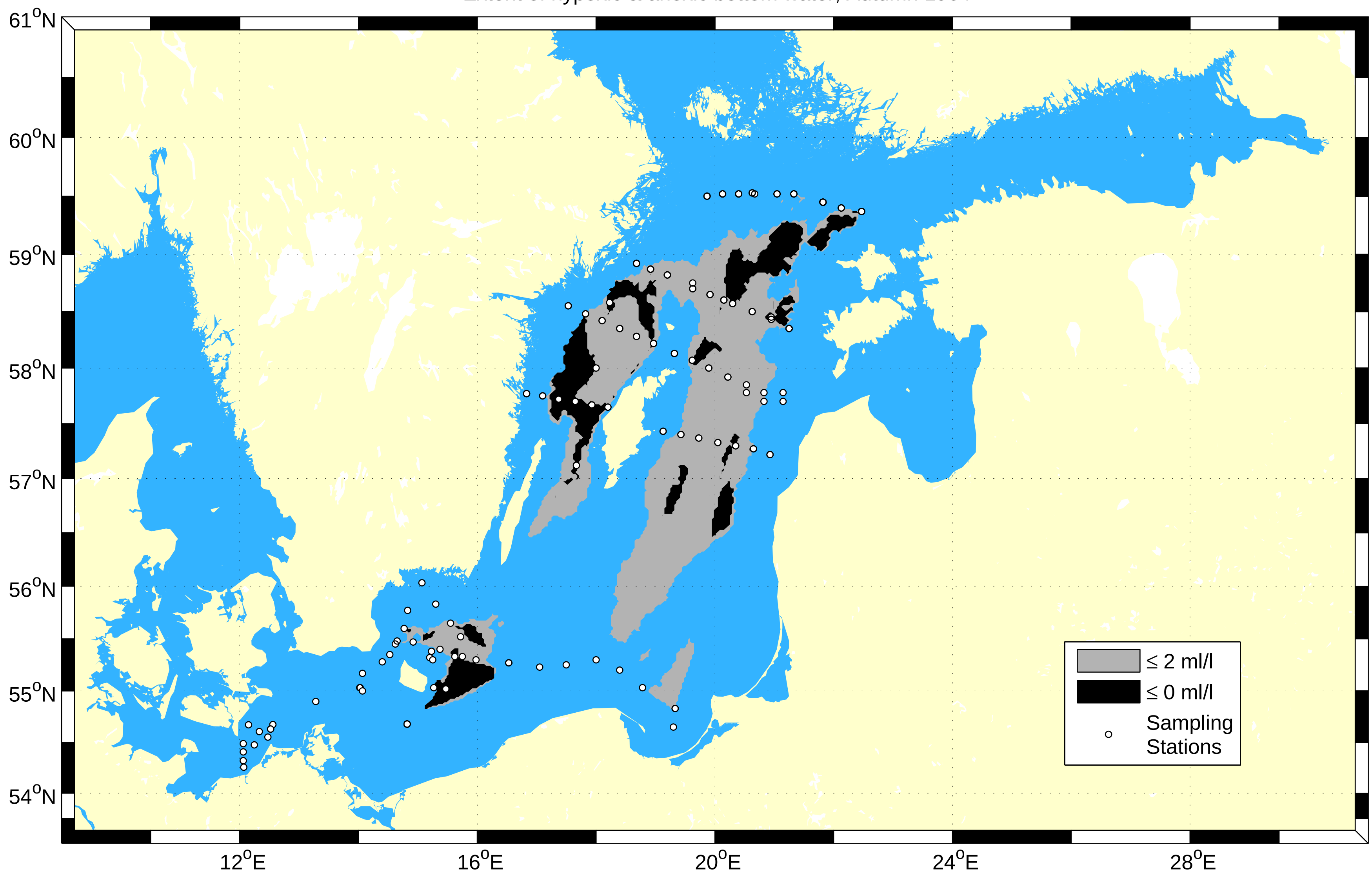
Extent of hypoxic & anoxic bottom water, Autumn 1966

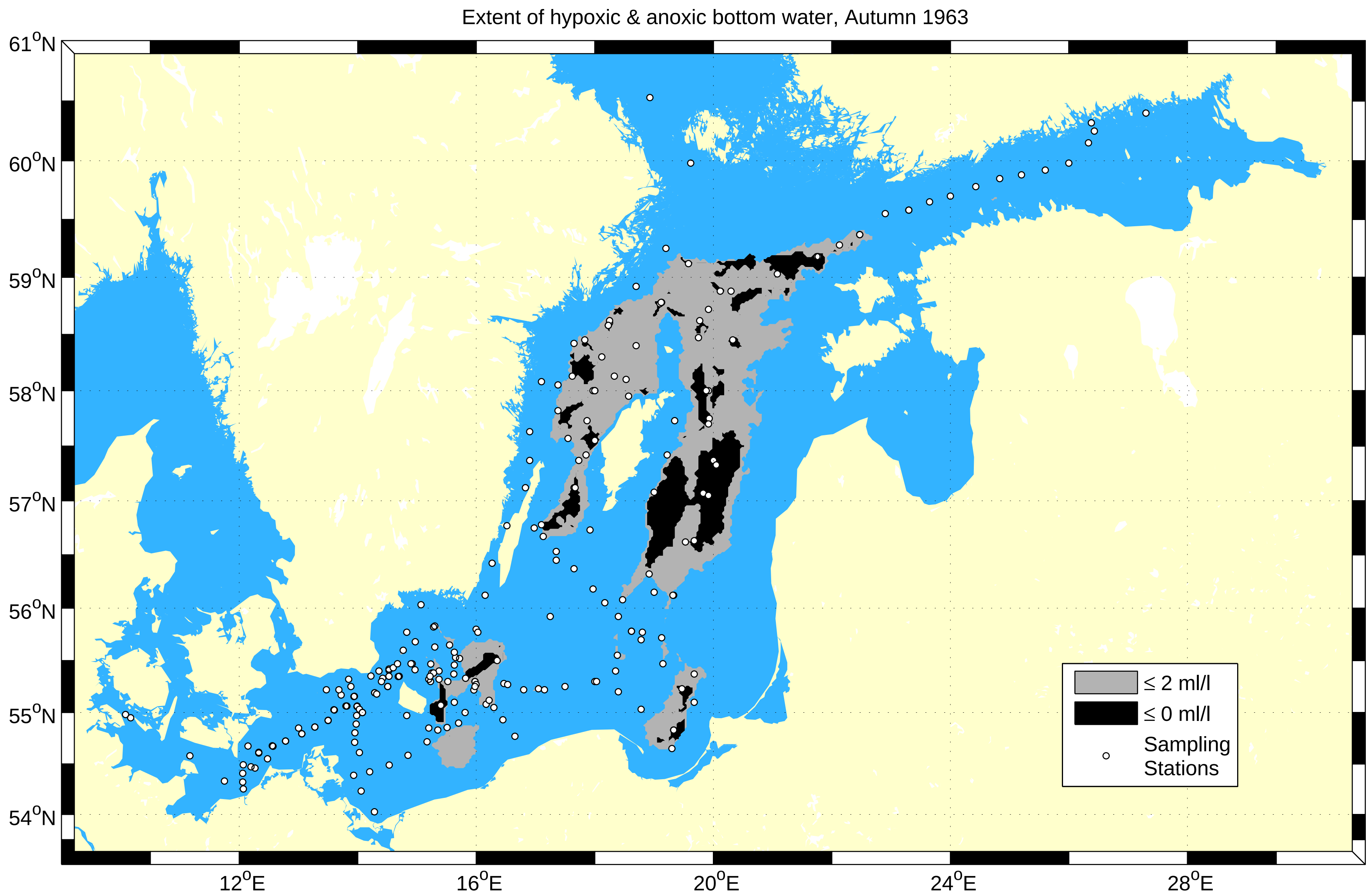


Extent of hypoxic & anoxic bottom water, Autumn 1965

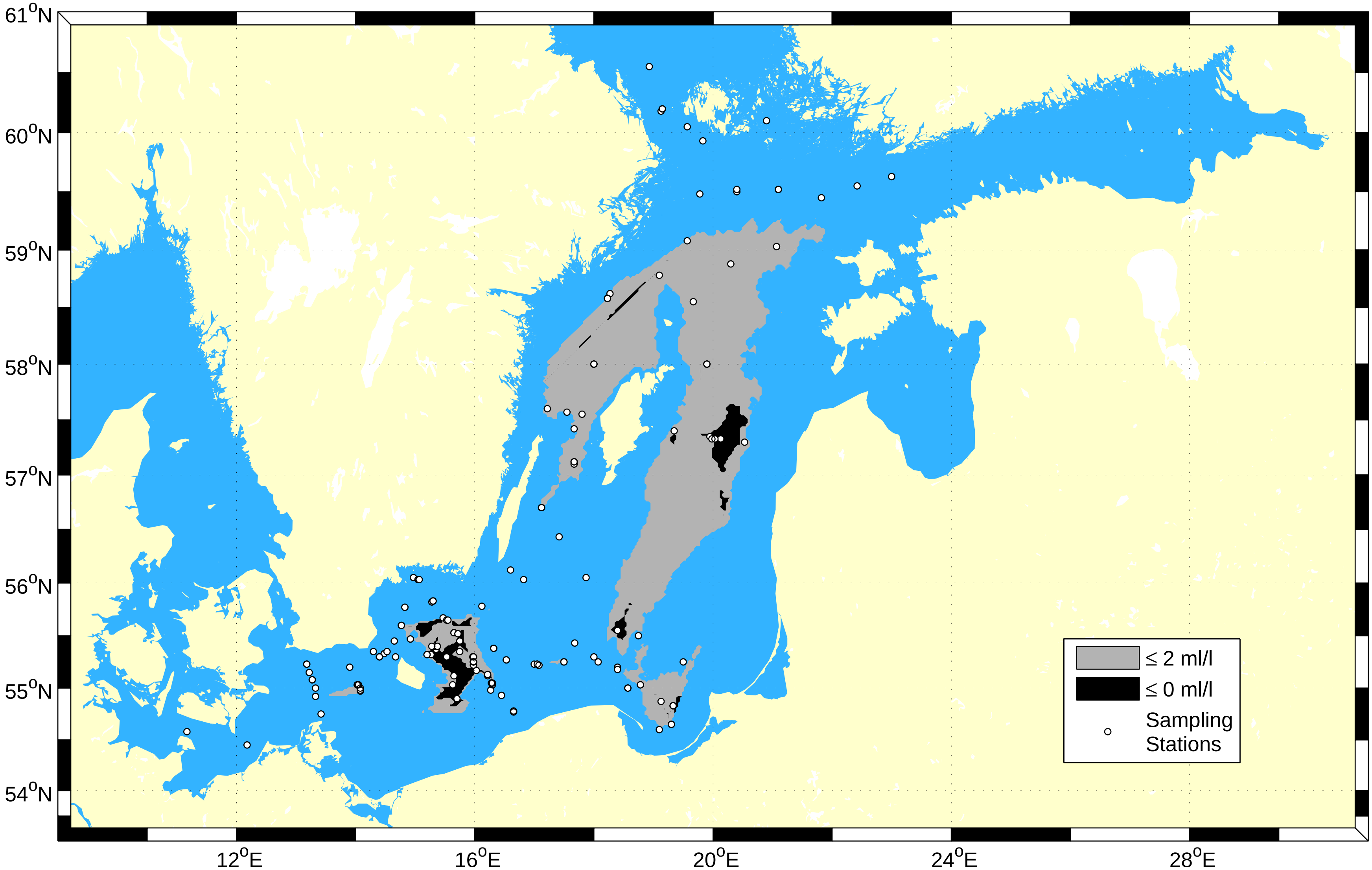


Extent of hypoxic & anoxic bottom water, Autumn 1964

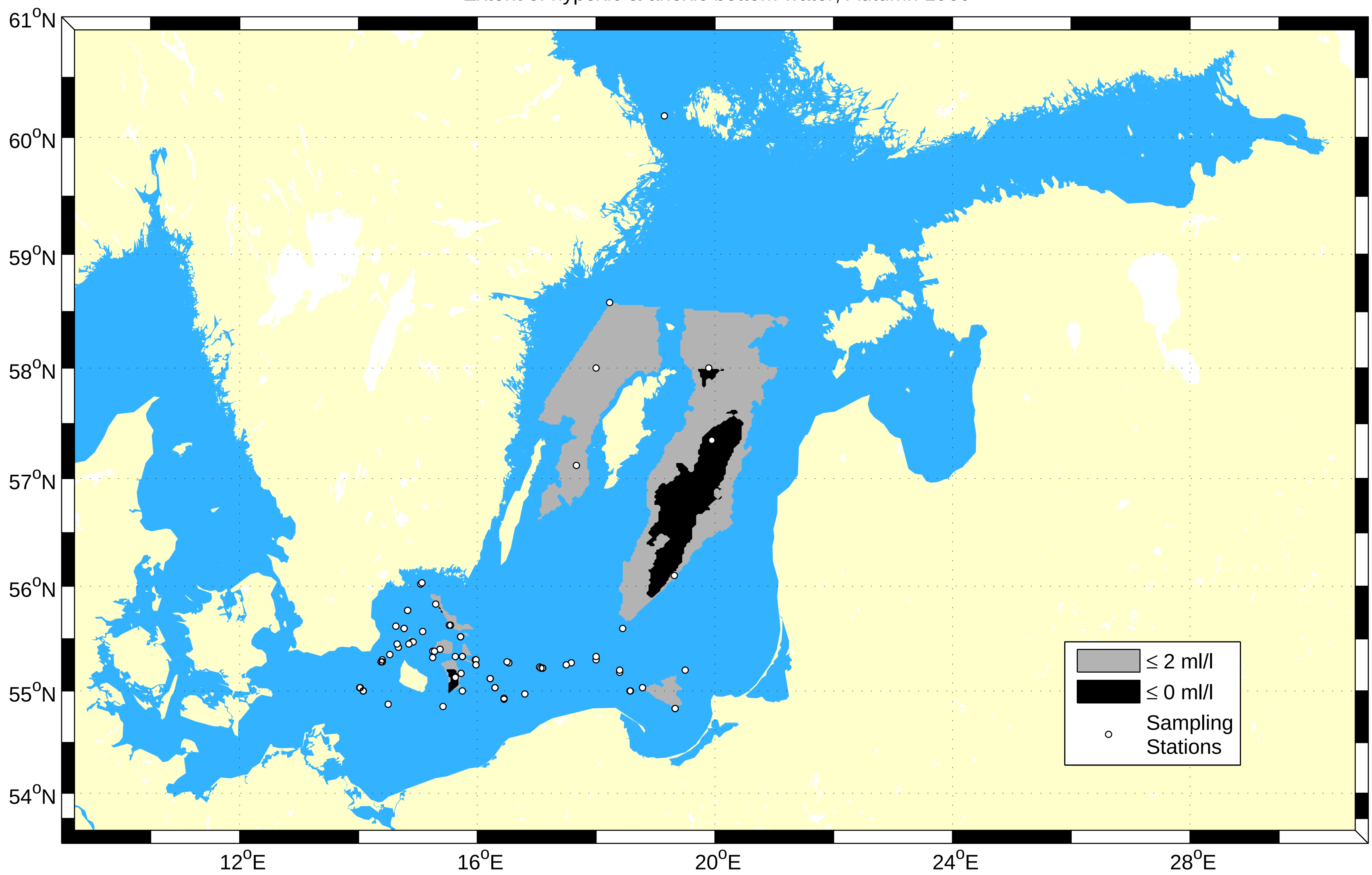



Extent of hypoxic & anoxic bottom water, Autumn 1963
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

Extent of hypoxic & anoxic bottom water, Autumn 1962



Extent of hypoxic & anoxic bottom water, Autumn 1960



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