SMHI

REPORT OCEANOGRAPHY No. 72, 2021

Oxygen Survey in the Baltic Sea 2021

- Extent of Anoxia and Hypoxia, 1960-2021

Front: A completely oxygen free and dead bottom in the Western Gotland Basin (at ~200m depths at the Norrköping's deep - BY32). Photo taken with the video camera mounted on R/V Svea's CTD-rosette. The green dots originate from two laser pointers on the bottom of the CTD-rosette that helps the CTD-operator to hold the instrument approx. 1 meter above the bottom.
Photo by SMHI during the March cruise 2021.

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Oxygen Survey in the Baltic Sea 2021
- Extent of Anoxia and Hypoxia, 1960-2021

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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 2020 have been updated and the preliminary results for 2021 are presented. Oxygen data from 2021 have been collected from various sources such as international ICES coordinated trawl survey, national monitoring programmes and research projects with contributions from Poland, Estonia, Latvia, 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 2020 and the preliminary results for 2021 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 continues to increase in the deep water. No major inflow has occurred during 2021.

Sammanfattning

En klimatologisk atlas över syresituationen i Östersjöns djupvatten publicerades 2011 i SMHI:s Report Oceanography No 42. Sedan 2011 har årliga uppdateringar gjorts då kompletterande data från länder runt Östersjön har rapporterats till ”International Council for the Exploration of the Sea” (ICES) datacenter. I denna rapport har resultaten från 2020 uppdaterats och preliminära resultat för 2021 tagits fram. Resultaten för 2021 baseras på preliminära data insamlade under internationella fiskeriundersökningar koordinerade av ICES, nationell miljöövervakning och forskningsprojekt med bidrag från Polen, Estland, Lettland, Danmark, Sverige och Finland.

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 1960-2021.

Resultaten för 2020 och de preliminära resultaten för 2021 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, fortsätter att ökar i dessa bassängers djupvatten. Inget större inflöde till Östersjön har inträffat under 2021.

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1 Background

In the central deep parts of the Baltic Sea low oxygen conditions are historically a natural phenomenon caused by its topography as an almost completely enclosed sea and “fjordlike” shape. 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.

The large catchment area around the Baltic Sea produce a large freshwater runoff and 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. It is only during specific wind, weather and sea level conditions when the direction of the flow through the straits gets reversed and an inflow occurs. Large inflows, which are rare, 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 follows 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 the 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 the volume is large enough to move over the sills between the different basins of the Baltic Proper and the density is high enough to settle the inflow along the bottom. Major Baltic Inflows (MBI) are rare, the latest large MBI occurred as a series of large inflows during 2014-2016 [Volker 2018]. The oxygen situation in the Baltic Proper 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 oxygen deficiency last longer and more organic matter is supplied to the deep-water anoxic condition spreads. 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 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.

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

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.

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 2021. The time series were first published in 2011 and the results have been updated annually as new additional data have become available at International Council for the Exploration of the Sea (ICES) [ICES, 2009]. In the report from 2011 and in newly published article a distinct regime shift in the oxygen situation in the Baltic Proper was found to occur around 1999 [Hansson et al, 2011; Almroth et al., 2021]. During the first regime, 1960-1999, hypoxia affected large areas while anoxic conditions were found only in minor deep areas. After the regime shift in 1999, both areal extent and volume of anoxia have been constantly elevated to levels that only occasionally have been observed before 1999.

The report includes maps of bottom areas affected by oxygen deficiencies during 2020 and 2021. 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 2021 are based on oxygen data collected during the annual trawl surveys coordinated by the ICES in the Baltic Sea and North Sea; The Baltic International Acoustic Survey (BIAS), International Bottom Trawl Survey (IBTS) and Polish Multiannual Fisheries Data Collection Programme complemented by data from national and regional marine monitoring programmes and mapping projects with contributions from Finland, Estonia, Latvia, Poland, Denmark and Sweden.

These data have not been fully quality controlled; only preliminary checks have been performed. The time series and the results presented for 2021 will be updated when additional data are reported to ICES in 2022/2023. In this report the results for 2020 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: 2022-02-16).

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 in Swedish at the SMHI website under the title “Vattenåret”. For the years 2020 and 2021 see Figure 5 and 6. [SMHI, 2022]

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, 2022] and regional [Volker, 2018] perspectives of the two methods.

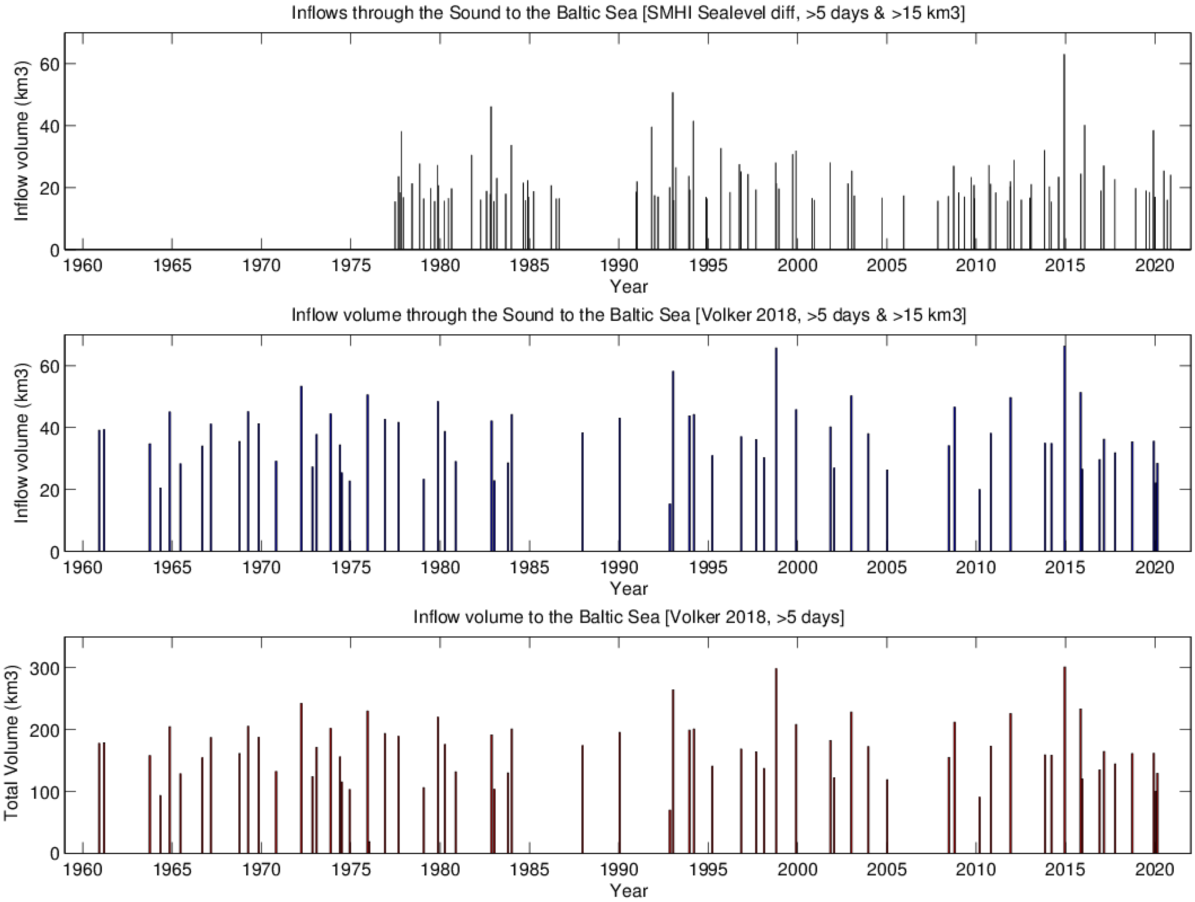

Figure 1. Two different estimations of inflow to the Baltic Sea through the Sound (Öresund). Top: Inflow through the Sound estimated from 1977-2022 by [SMHI, 2022]. Middle: Inflow through the Sound 1960-2020 estimated by [Volker, 2018]. Bottom: Total volume transport through the Sound and the Danish Straits to the Baltic Sea for inflows, 1960-2020 [Volker 2018]. Note that the time series from [Volker 2018] has not been updated with data after 2020, 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].

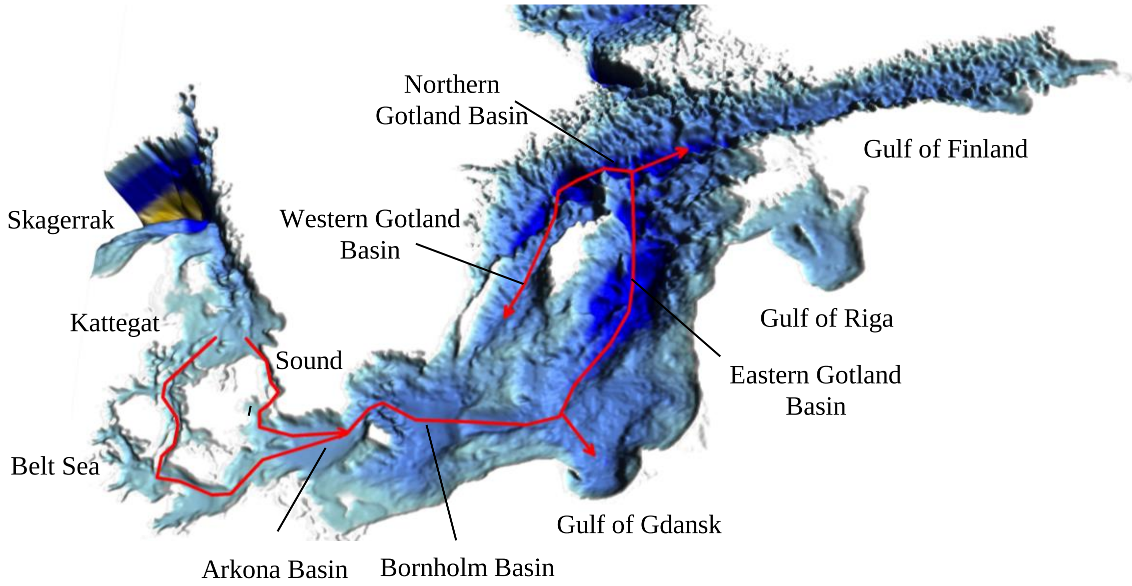

Figure 2. Bathymetry [Seifert, 2001] of the south Baltic Sea and pathways of inflowing deep-water during inflows. The Baltic Proper includes the Arkona Basin, the Bornholm Basin, the Gulf of Gdansk, the Gulf of Riga and the Eastern-, Western- and Northern Gotland Basin [Fonselius, 1995].

4 Result

Extent and volume affected by hypoxia and anoxia during the period 1960 - 2021 are presented in Figures 3 and 4, respectively. Maps presenting bottom areas affected by hypoxia and anoxia during the autumn period 2020 and 2021 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 2021 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.

in %	1960 – 1998		1999 – 2020		2021(Preliminary)	
	Hypoxia	Anoxia	Hypoxia	Anoxia	Hypoxia	Anoxia
Mean Areal extent	22	5	29	16	31	20
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	20	13
Max Volume (Year)	19 (1965)	8 (1969)	22 (2019)	15 (2018)	-	-
Min Volume (Year)	5 (1993)	0.1 (1994)	15 (2000)	4 (1999)	-	-

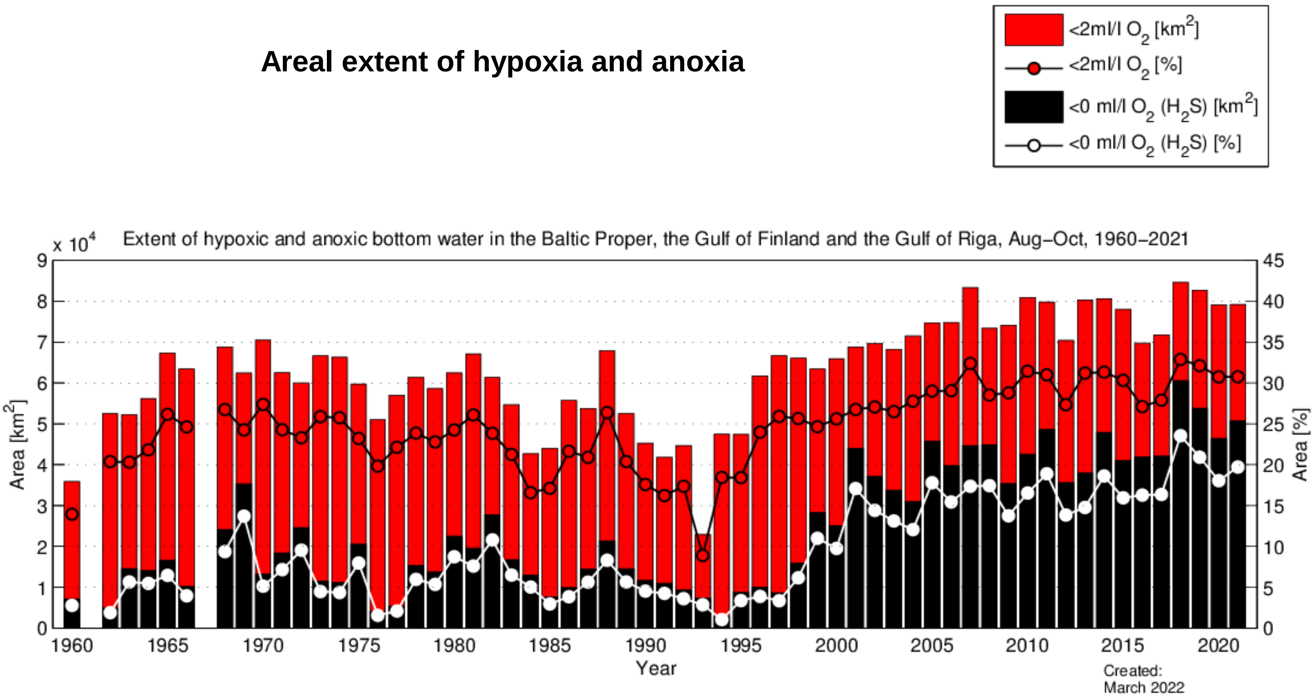

Figure 3. Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

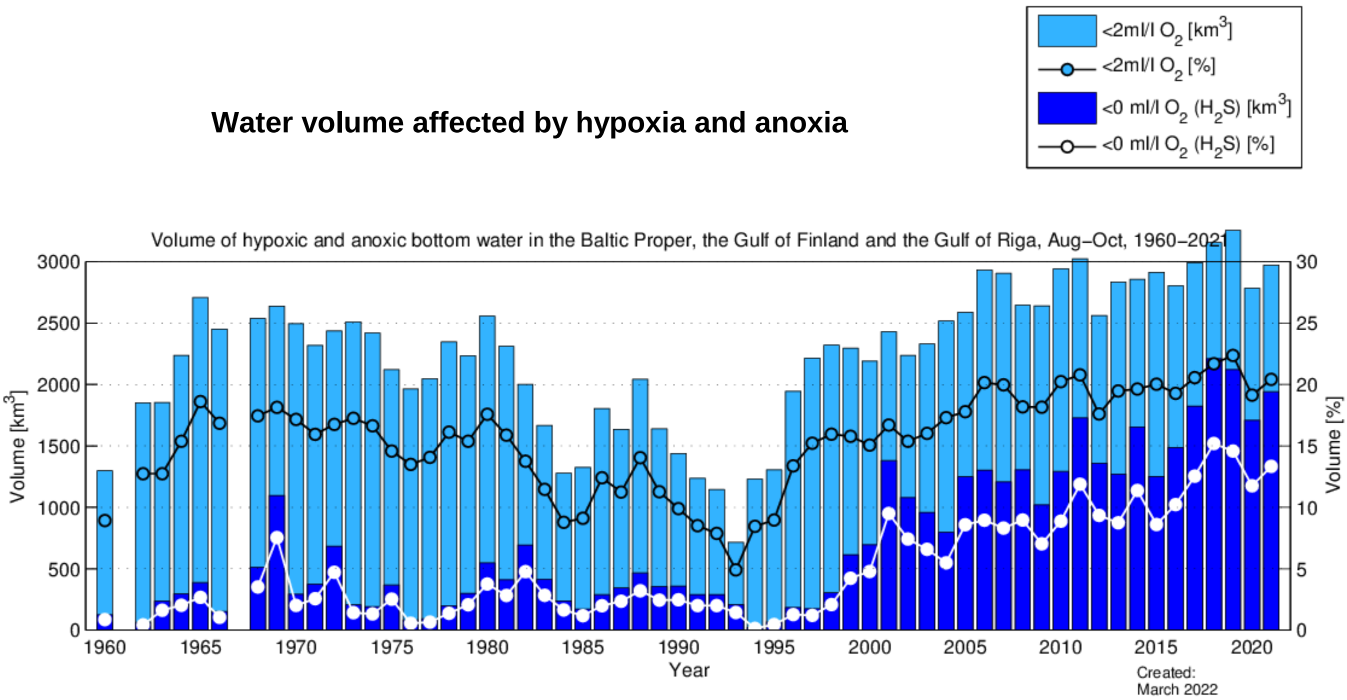

Figure 4. Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

4.1 Updated results for 2020

The result for 2020 has been updated as additional hydrographic data from 2020 has been reported to ICES. After the update the anoxic area increased around the Gulf of Gdansk while it decreased in the Belt Sea. In the Arkona Basin anoxia vanished and only small areas of hypoxia remained. Overall the update resulted in minor changes to the areas and volumes of both anoxia and hypoxia.

The proportion of areas affected by anoxia and hypoxia was unchanged, 18% and 31% respectively. Small changes (increase by 1%) were found for water volume affected; volume of anoxic water increased to 12% and the volume of hypoxia water increased to 19%. The results for 2020 are all above the mean for the period after the regime shift in 1999, see Table 1. Hence, the areal extent and volume of anoxia and hypoxia continues to be elevated and the oxygen development in the Baltic Proper that has prevailed since the regime shift in 1999 continues, see Figure 3-4.

Four inflow events with volume larger than 15 km^3, occurred in 2020. Inflows in June/July and in November contributed with about 25 km^3 and two smaller inflows of ~16 km^3 occurred in January and September.

The total inflow to the Baltic Sea through the Sound during 2020 was 339 km^3 which is higher than normal (compared to the time period 1977-2019 with mean 318 km^3). The outflow was 617 km^3, which is smaller than normal when (mean 623 km^3). The accumulated inflow through the Sound (Öresund) during 2020, compared to the mean inflow 1977-2019 can be seen in Figure 5.

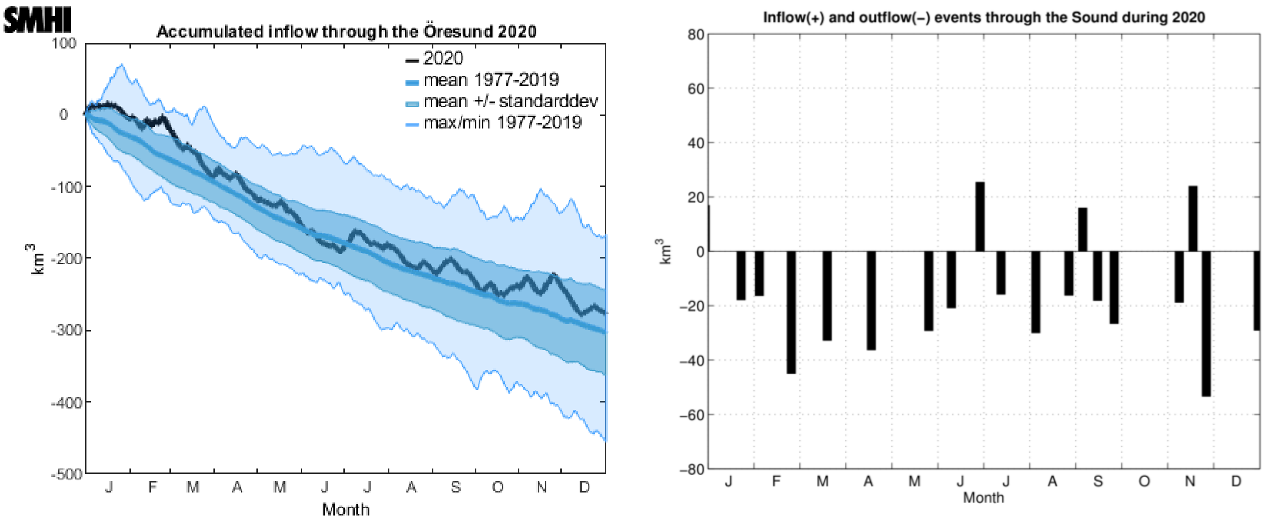

Figure 5. Left: Accumulated inflow (volume transport) through the Sound (Öresund) during 2020 in comparison to mean inflow/outflow 1977-2019. Right: Inflow (+) and outflow (-) events during 2020 with volume larger than 15 km^3. [SMHI, 2021].

4.2 Preliminary results for 2021

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 larger inflow was noted. During 2020 four small inflows through the Sound was noted. During 2021 there was three small inflows (larger than 15 km^3) in July/August, September and October. Even smaller inflows, approx. 10 km^3, did occur throughout the year in April, August and October.

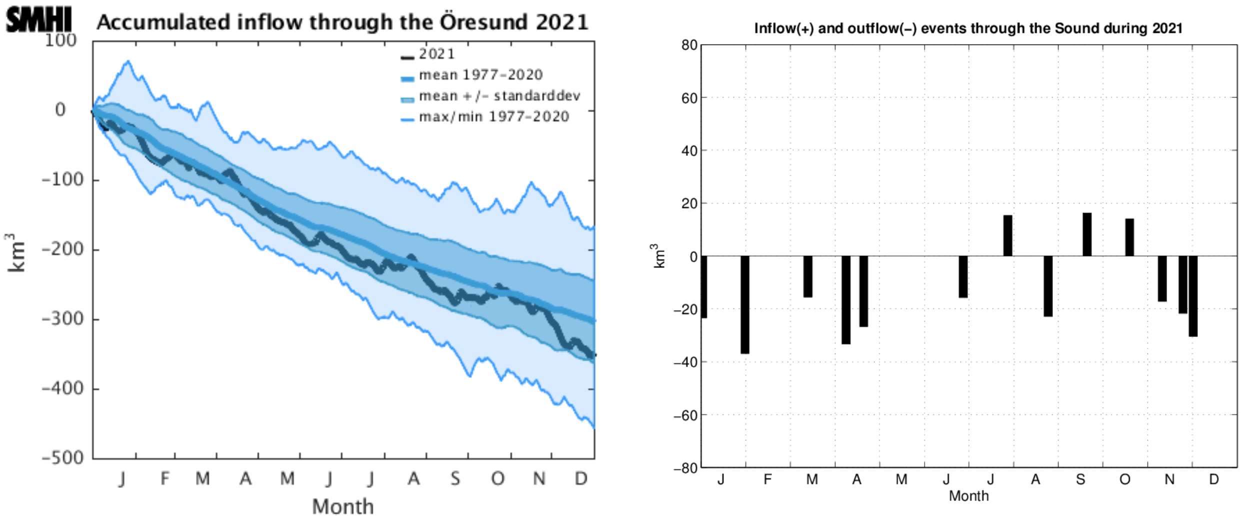

Figure 6. Left: Accumulated inflow (volume transport) through the Sound (Öresund) during 2021 in comparison to mean inflow/outflow 1977-2020. Right: Inflow (+) and outflow (-) events during 2021 larger than 15 km^3. [SMHI, 2022].

In the Arkona Basin the oxygen situation in the deep water normally follows the annual cycle with well oxygenated conditions during winter and spring, followed by decreased oxygen concentrations during summer. However, in 2021 at BY1 hypoxia in the bottom water was found already in May with oxygen concentrations below 2 ml/l in the bottom water which is much lower than normal for this time of the year. From June to October the oxygen concentration increased somewhat and ranged between 2-4 ml/l. At BY2, east of BY1, hypoxia was found from August to October. [SMHI, 2021]

The oxygen conditions, below 60-70 meters depth at Hanö Bight, were hypoxic and in the bottom water near-anoxic conditions, with oxygen concentrations close to 0 ml/l was found throughout most parts of the year. Hydrogen sulphide was found during June and July from depths exceeding 70 meters depth.

In the Bornholm Basin hypoxia was found from depths exceeding 60-70 meters. Oxygen concentrations close to 0 ml/l was found from January to April/May at depths exceeding 70-80 meters. From May/June through out the year the bottom conditions were anoxic with hydrogen sulphide present. Signs of improvement in the bottom were observed in November at BY4 as the bottom oxygen concentration increased to about 2 ml/l. However, in December the anoxic conditions were back. At the station BCSIII-10, further into the southern Baltic Proper the bottom water oxygen concentrations varied around 0-2 ml/l over the year, probably due to short pulses of oxygenated water passing through. Anoxic conditions, with hydrogen sulphide present was found in November. In February a pulse of oxygenated water increased the oxygen concentration near the bottom to 4 ml/l, next month, in March, hypoxic condition was again present. Hypoxia was found from 60-70 meters depth throughout the year.

At the Gotland Deep (BY15) in the Eastern Gotland Basin the oxygen situation remained relative stable over the year. Hypoxic conditions, below 2 ml/l, was found just below the permanent halocline situated at approximately 60-70 meters depth. From 70-125 meters depth near anoxic conditions prevailed with oxygen concentrations near zero or low concentrations of hydrogen sulphide. Higher concentrations of hydrogen sulphide were found from depth exceeding ~125 meters depth and the concentrations increased with depth to around as high as 100 - 140 µmol/l in the bottom water. The pool of hydrogen sulphide is increasing and the concentrations in the deep water are much higher than normal. The hydrogen sulphide concentrations are now back at levels comparable to those before the last major inflow in 2014. See Figure 7, Appendix 1 and SMHI cruise reports from 2021. [SMHI, 2021]

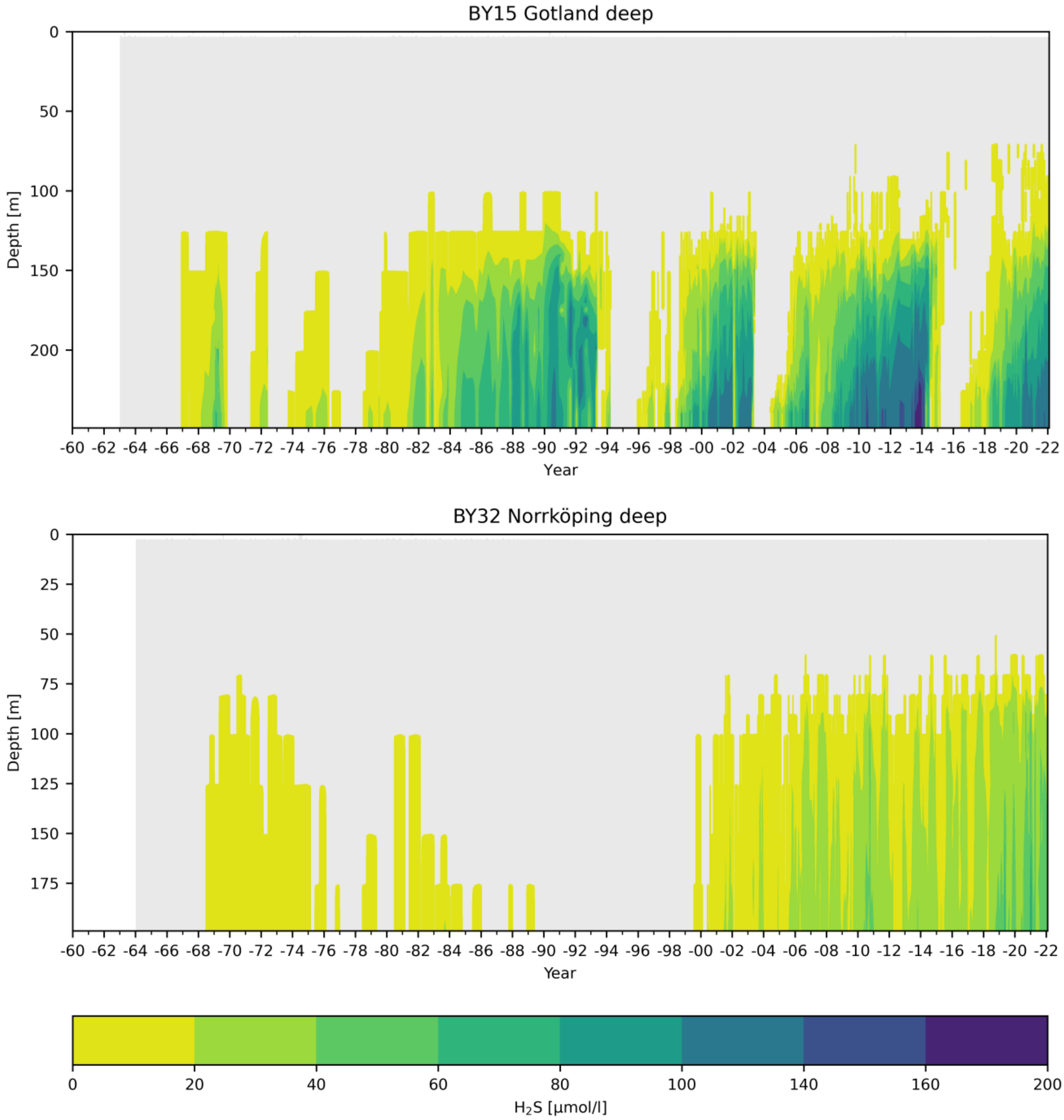

Figure 7. Concentration of hydrogen sulphide (H_2S) at Gotland Deep (BY15) in Eastern Gotland Basin (top) and Norrköping Deep (BY32) in the Wester Gotland Basin from 1960-2021.
Grey color signifies no hydrogen sulphide present and white indicate that data is missing.

The deep-water oxygen conditions in the Northern Gotland Basin shows similar development as the Eastern Gotland Basin. 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 even though the concentrations of hydrogen sulphide is lower than in the Eastern Gotland Basin there are high concentrations of hydrogen sulphide ranging from 30-80 µmol/l in the bottom water. From January to March hypoxic conditions were found from 80-90 meters depth and anoxia from 90-100 meters depth. But in April the low oxygen zones moved shallower and hypoxia could be found from 60-65 meters depth and anoxia from 80 meters depth throughout the year. [SMHI, 2021]

The updated results for 2020 and the preliminary for 2021 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 new results for 2020 and 2021 the area and volume levels of hypoxia and anoxia are now back at the same levels as was noted during the period 2000-2017.

The small improvements seen during 2020 in the southern parts of the Baltic Proper could be connected to the medium 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. In 2021 the anoxic areas seem to have increased further south in the Eastern Gotland Basin, however there is a lack of measurements in this area and the results might change as more data becomes available. The anoxic areas in the Bornholm Basin and Hanö Bight is larger in 2021 than in 2020 an increase that is probably due to the low inflow activity after the inflow at the end of 2019.

It should be noted that the 2021 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 note the data contributors in the Acknowledgement below.

5 Conclusions

- In 2020 anoxia was found in 18% of the bottom areas and 31% suffered from hypoxia during the autumn period.

- Preliminary results show that anoxia affected 20% of the bottom areas and 31% suffered from hypoxia during the autumn 2021.

- The results for 2020-2021 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 anoxic areas in the Bornholm Basin and Hanö Bight increased from 2020 to 2021, probably due to the low inflow activity during 2020 and 2021.
- The pool of hydrogen sulphide is increasing in the Eastern Gotland Basin and are reaching the levels before the latest major inflow in 2014. No inflows reached the deep water in this basin during 2021.

6 Acknowledgement

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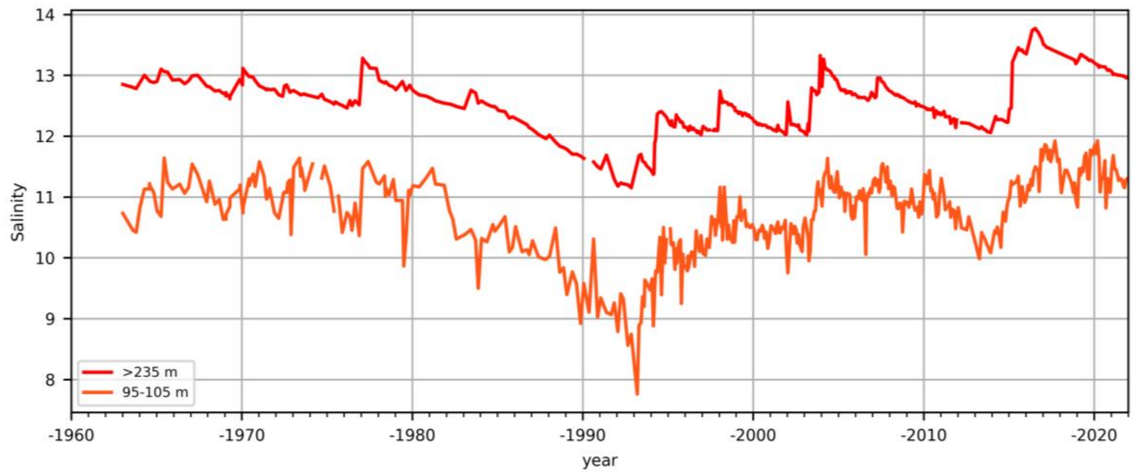
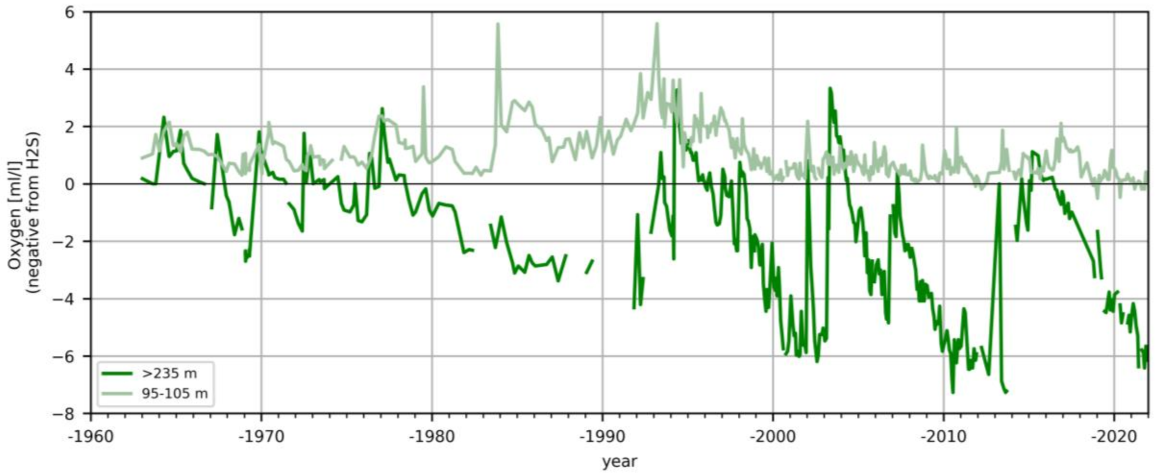
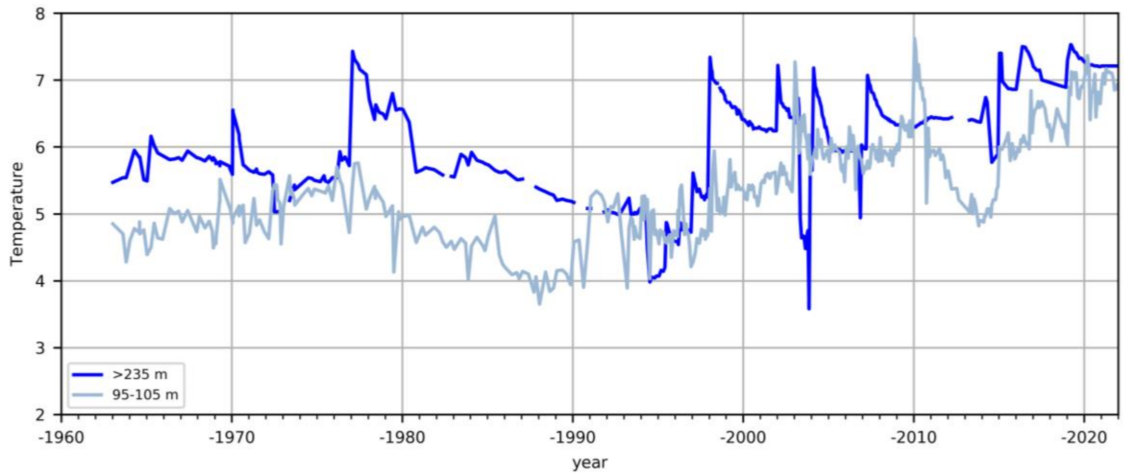
Appendix 1 – Temperature, salinity and oxygen in Eastern Gotland Basin at station BY15, 1960-2021

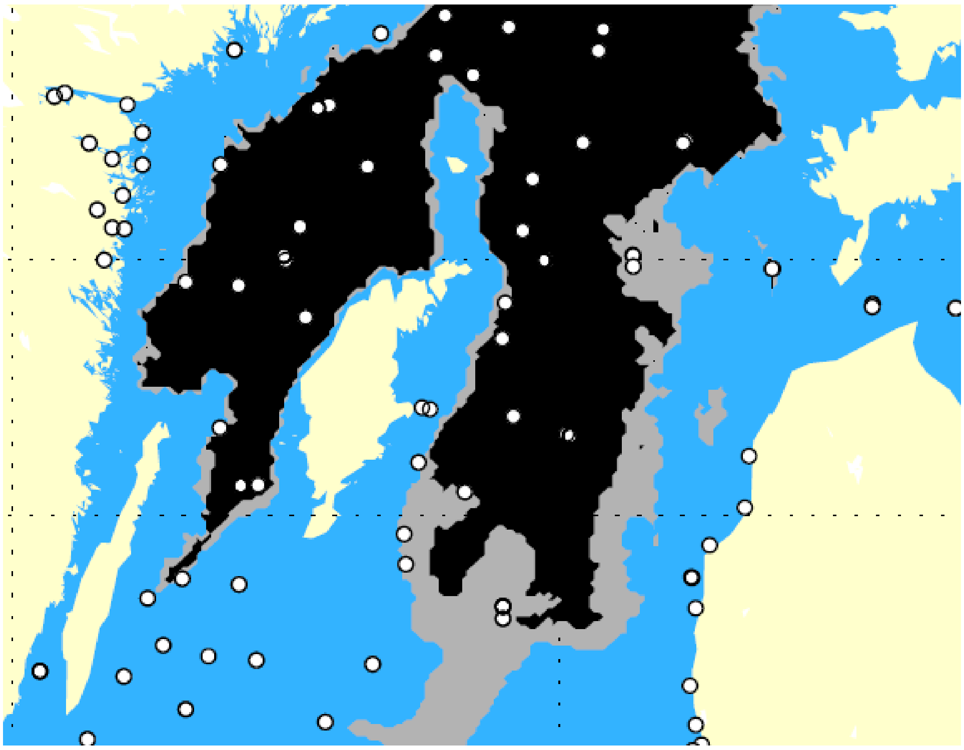




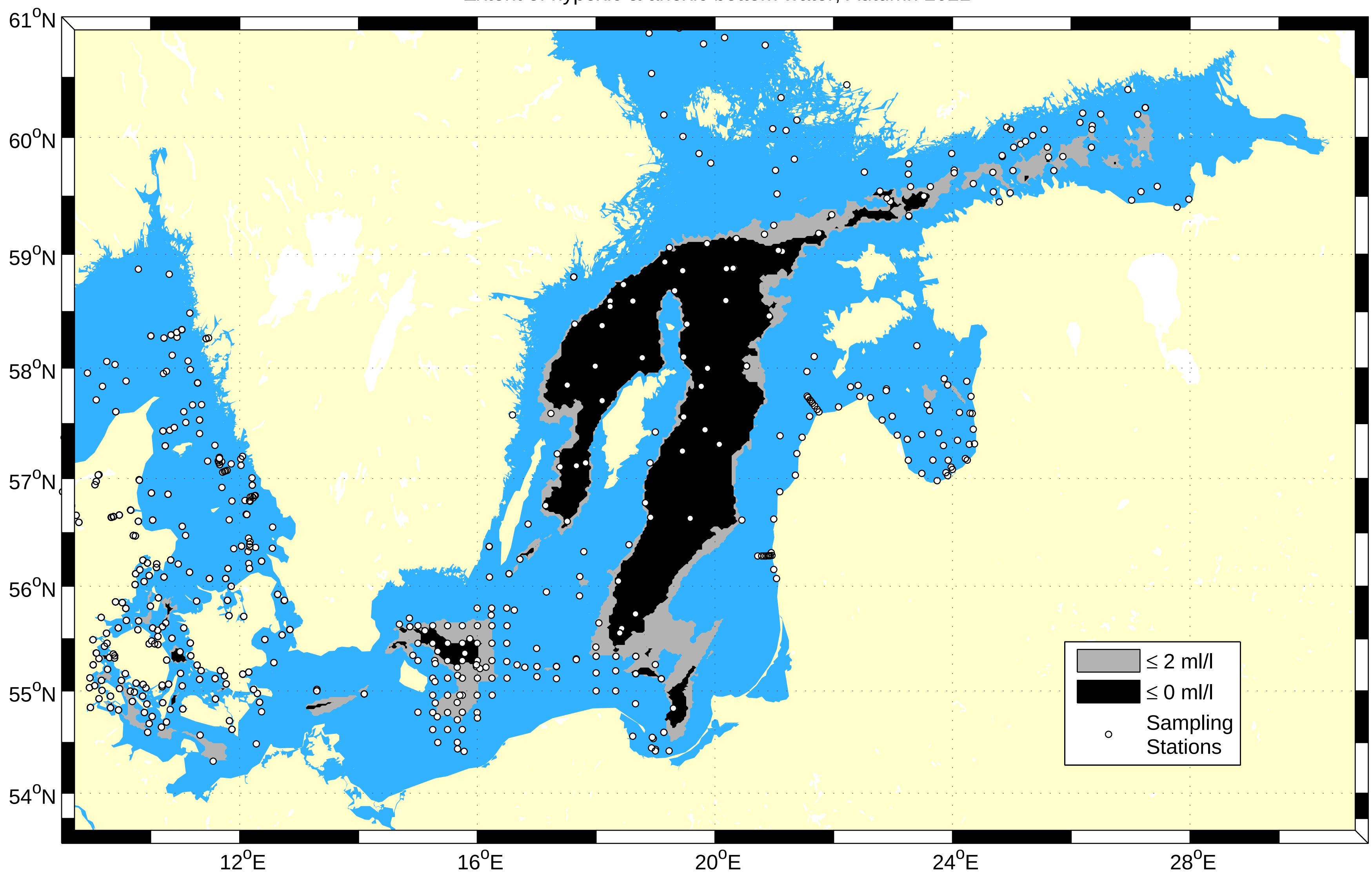


Appendix 2 - Anoxic and hypoxic areas in the Baltic Sea

- updated maps 1960-2021

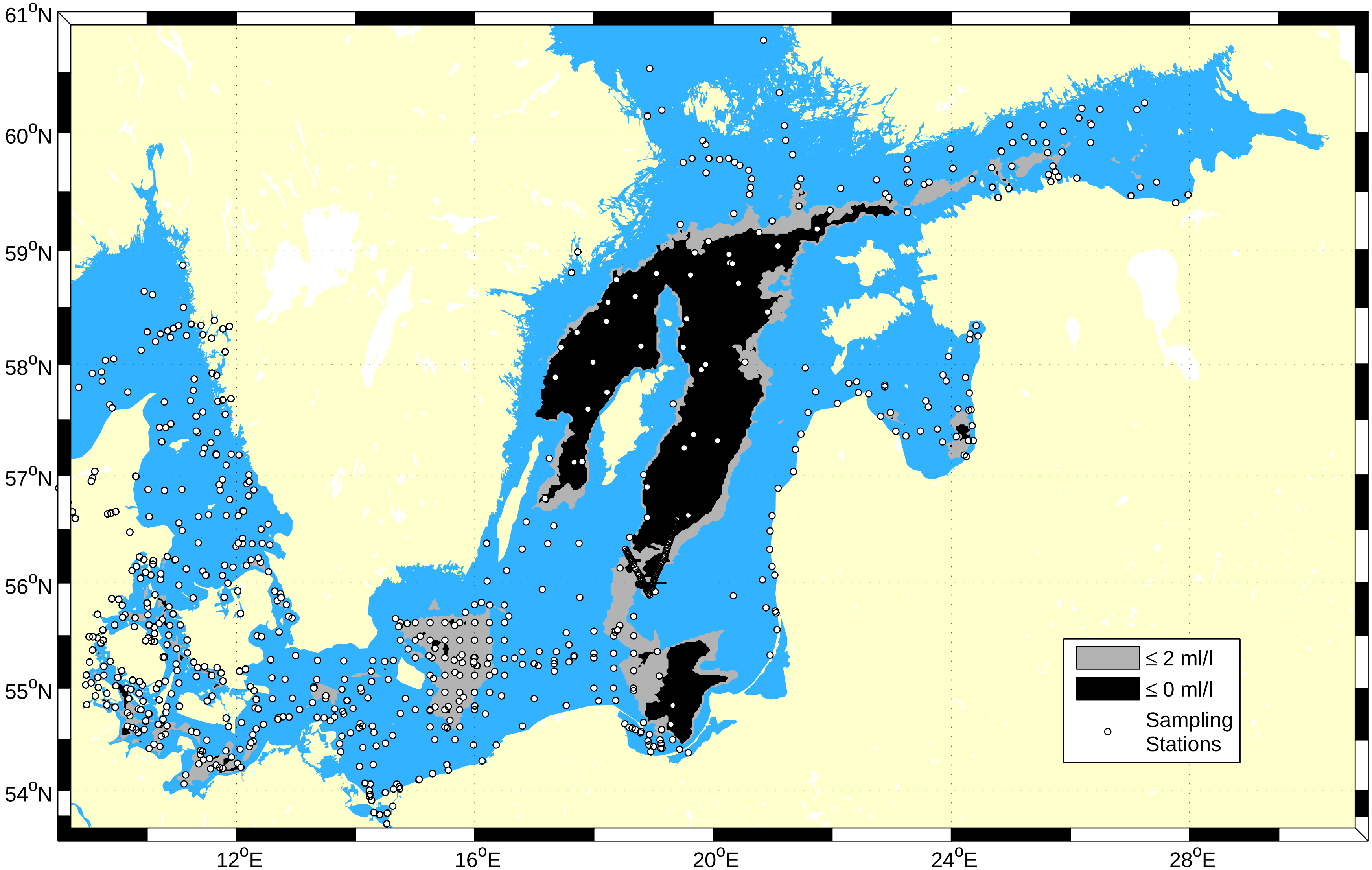


Extent of hypoxic & anoxic bottom water, Autumn 2021



Created:
March 2022

Extent of hypoxic & anoxic bottom water, Autumn 2020



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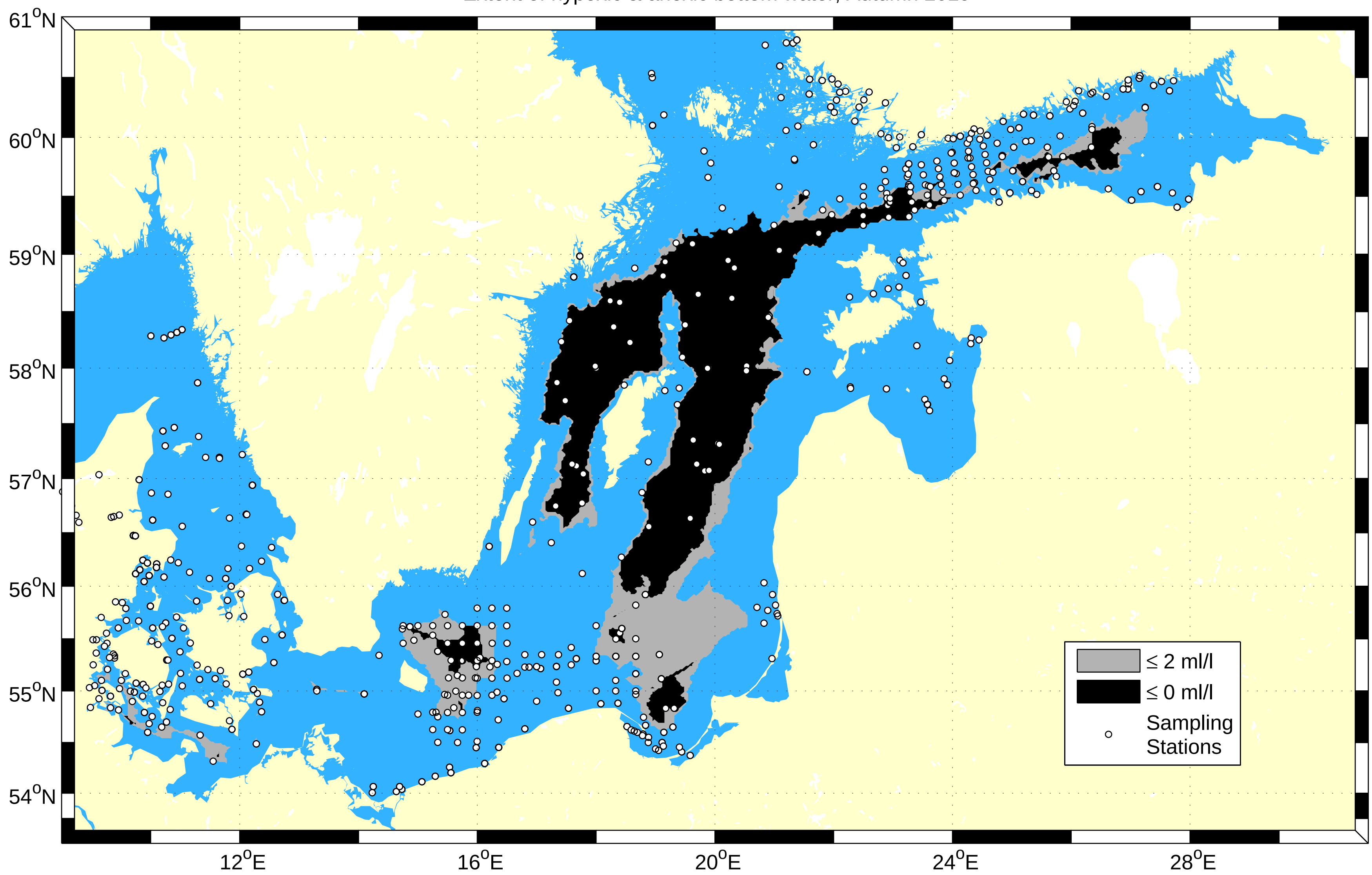
Extent of hypoxic & anoxic bottom water, Autumn 2019



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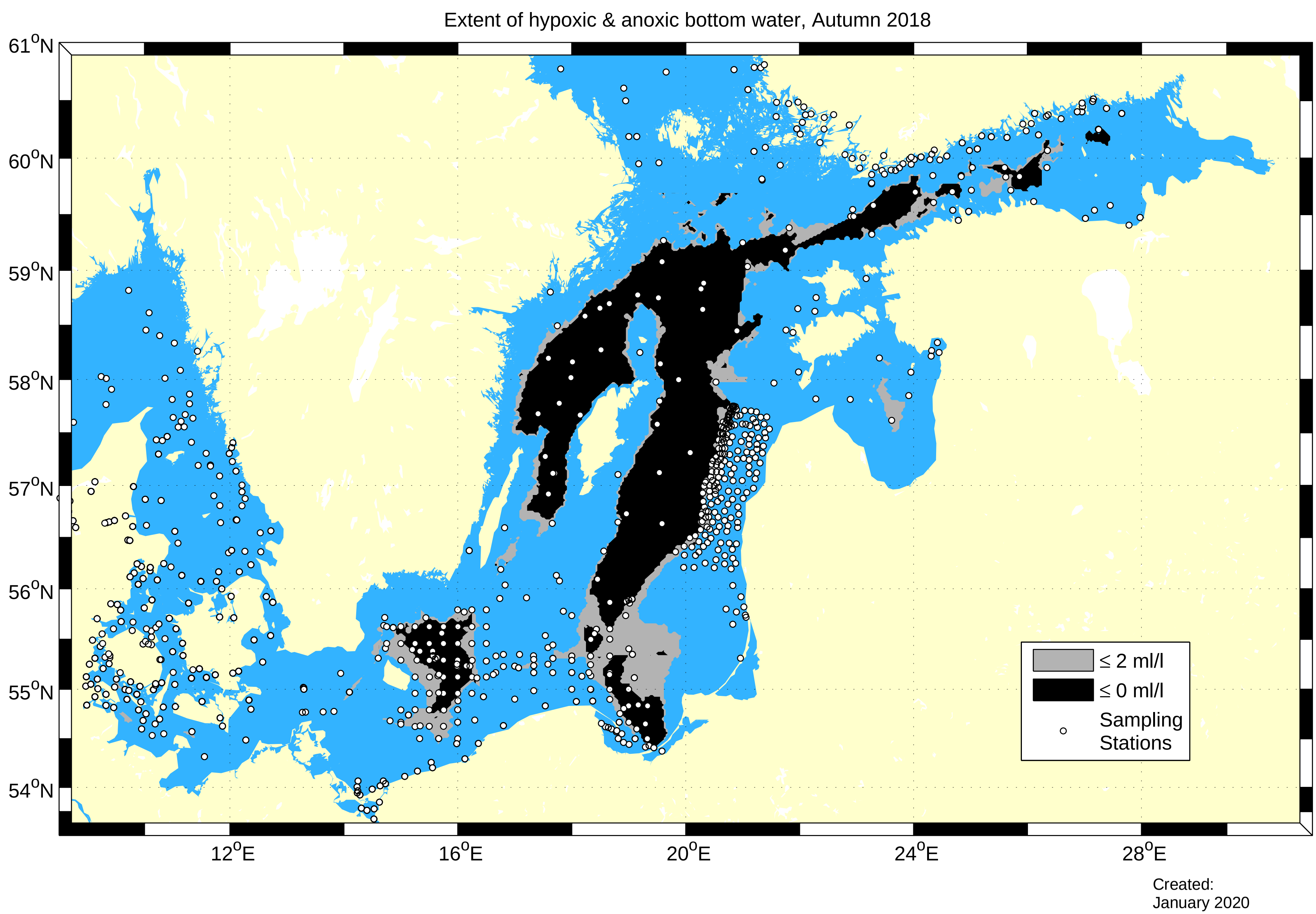
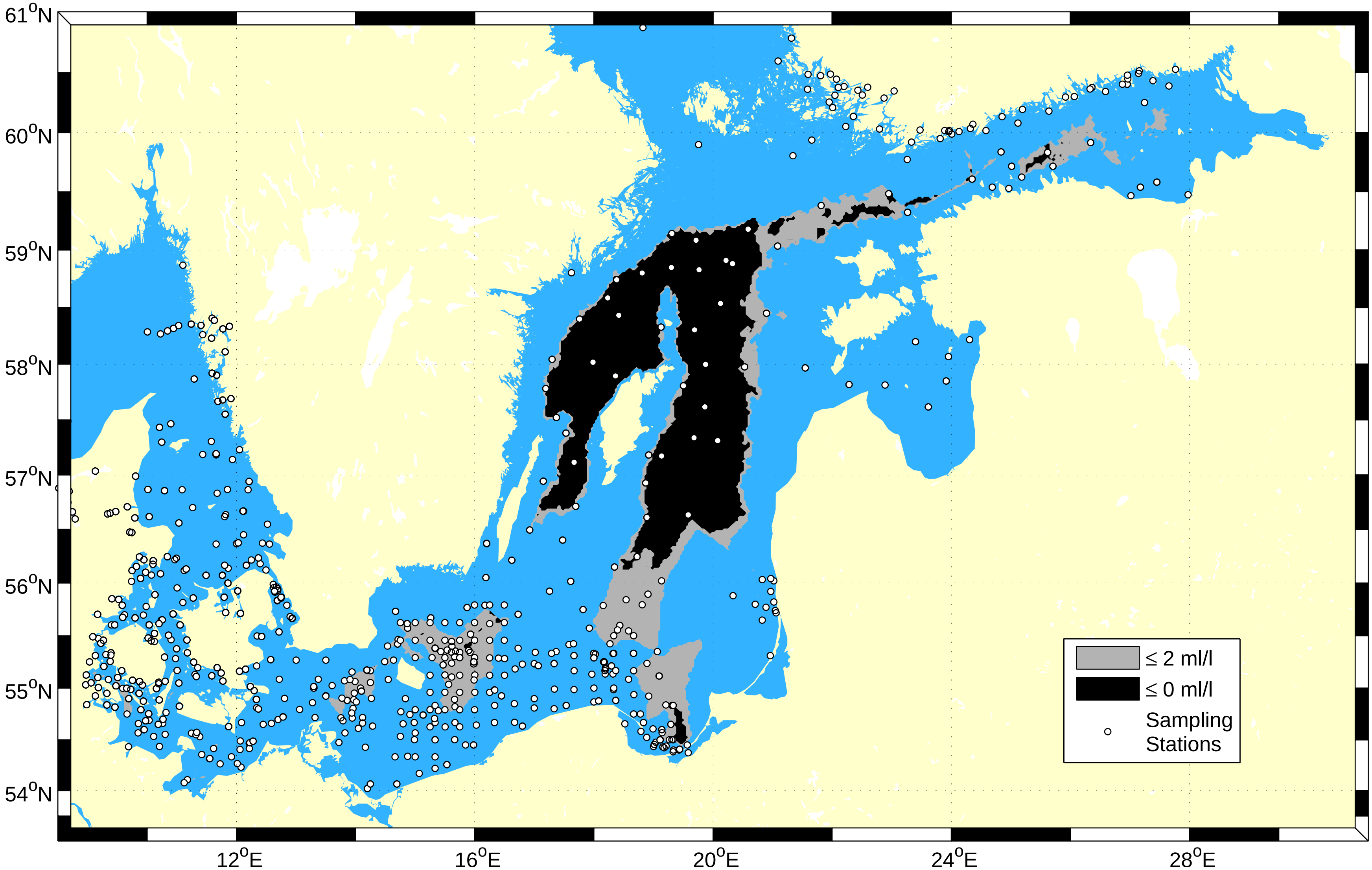
February 2021



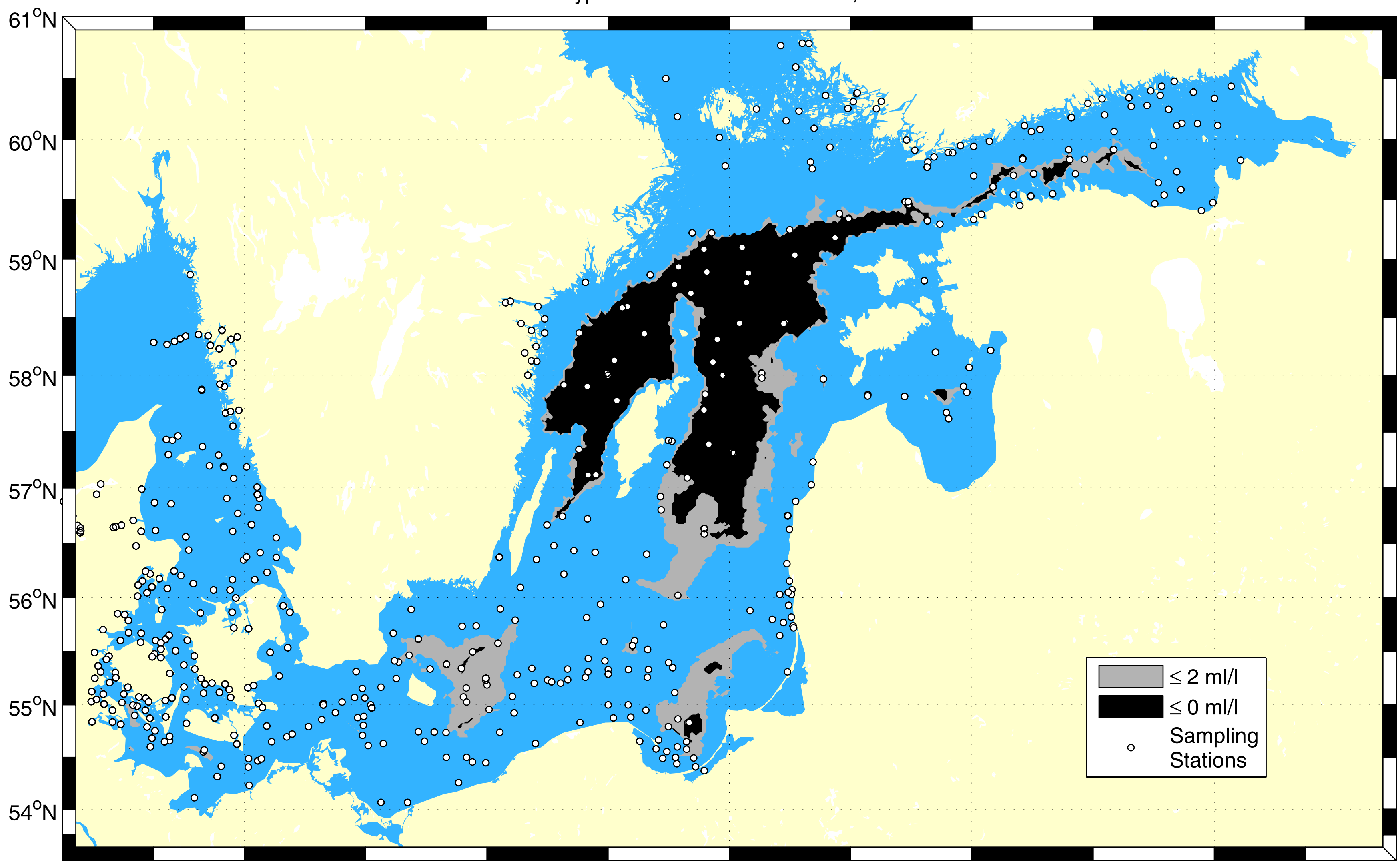
Extent of hypoxic & anoxic bottom water, Autumn 2018
61⁰N
60⁰N
59⁰N
58⁰N
57⁰N
56⁰N
55⁰N
54⁰N
12⁰E
16⁰E
20⁰E
24⁰E
28⁰E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations
Created:
January 2020

Extent of hypoxic & anoxic bottom water, Autumn 2017



Created:
January 2019

Extent of hypoxic & anoxic bottom water, Autumn 2016



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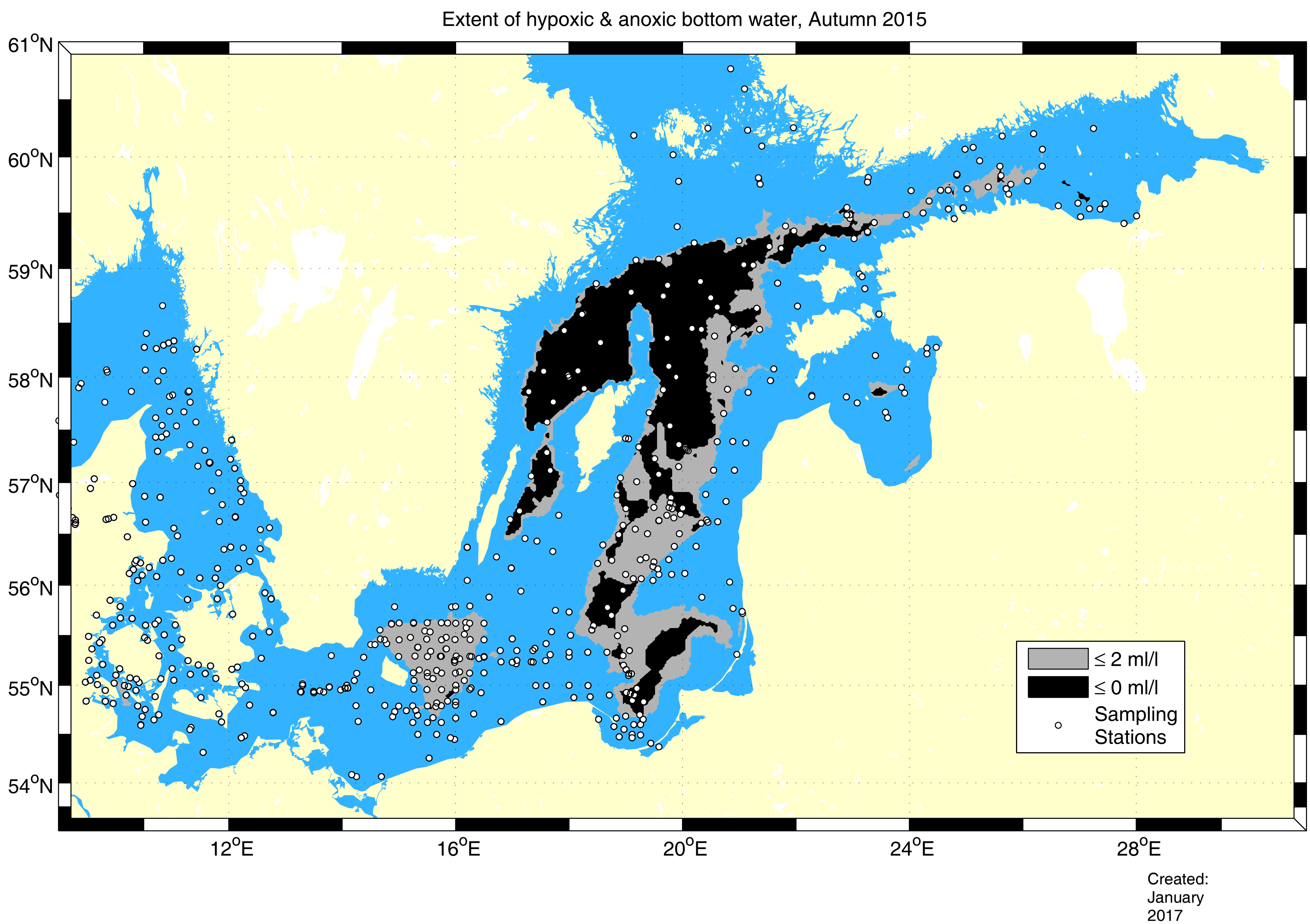
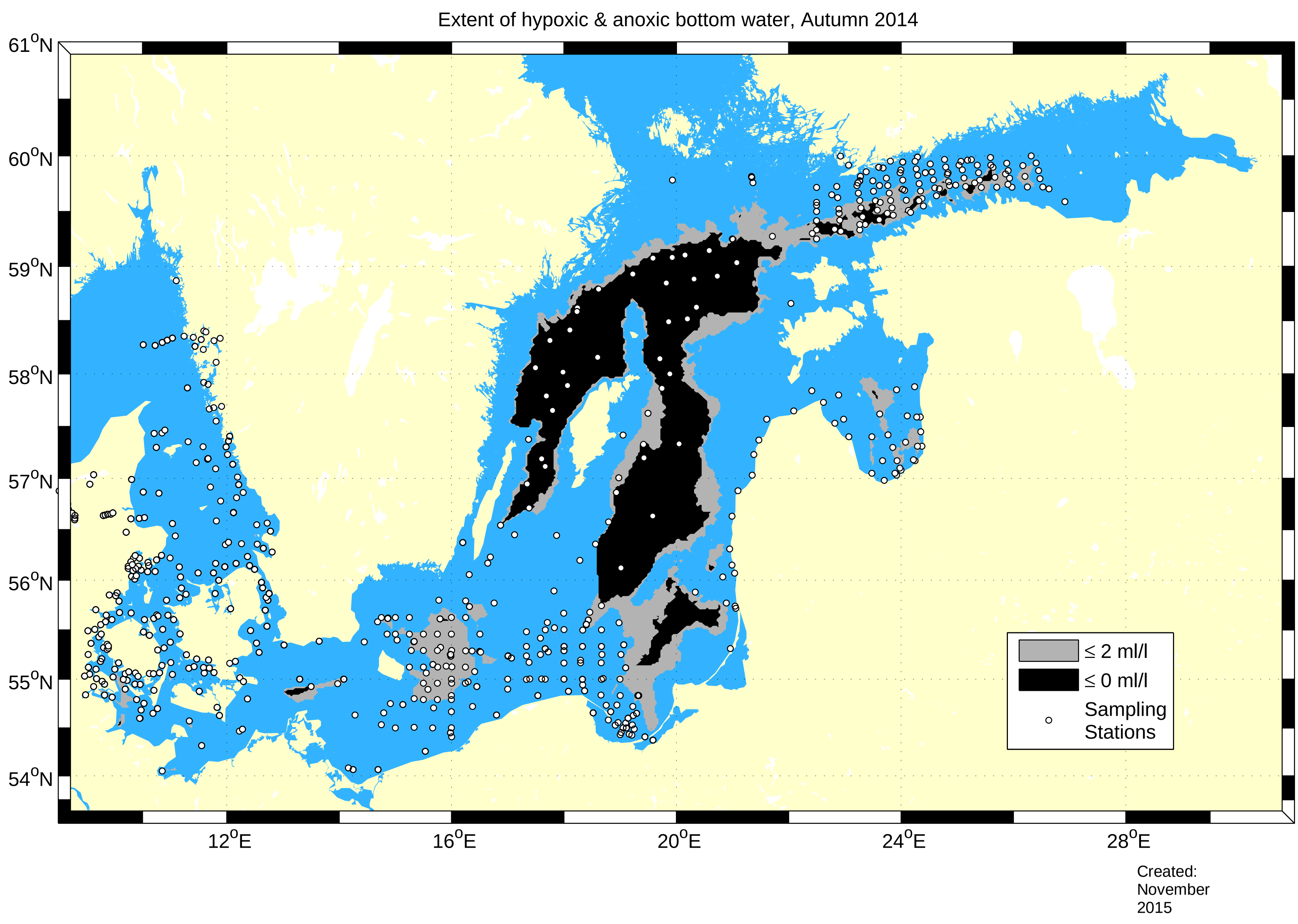
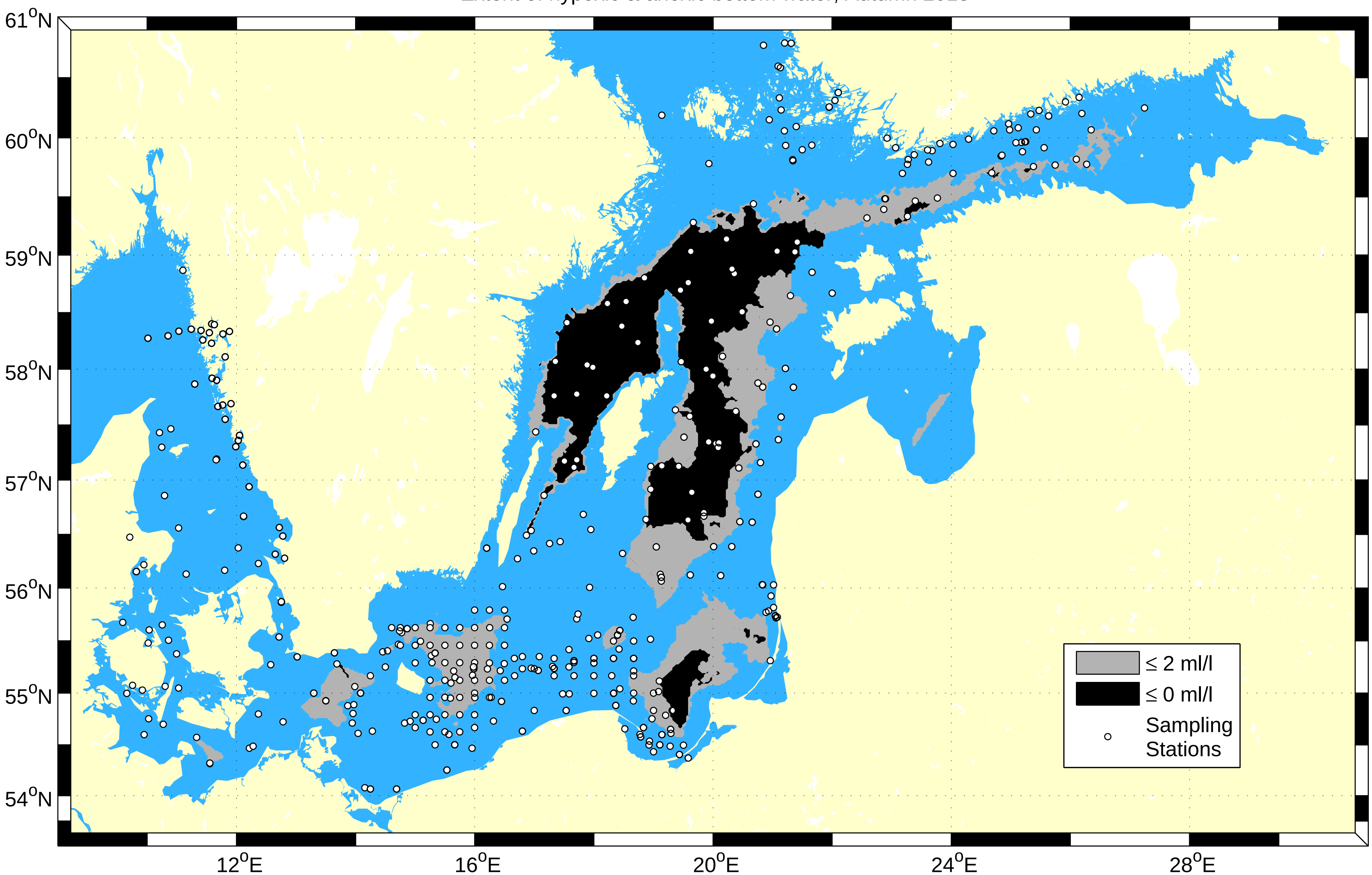
January
2018


Extent of hypoxic & anoxic bottom water, Autumn 2015
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 2017


Extent of hypoxic & anoxic bottom water, Autumn 2014
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: November 2015

Extent of hypoxic & anoxic bottom water, Autumn 2013



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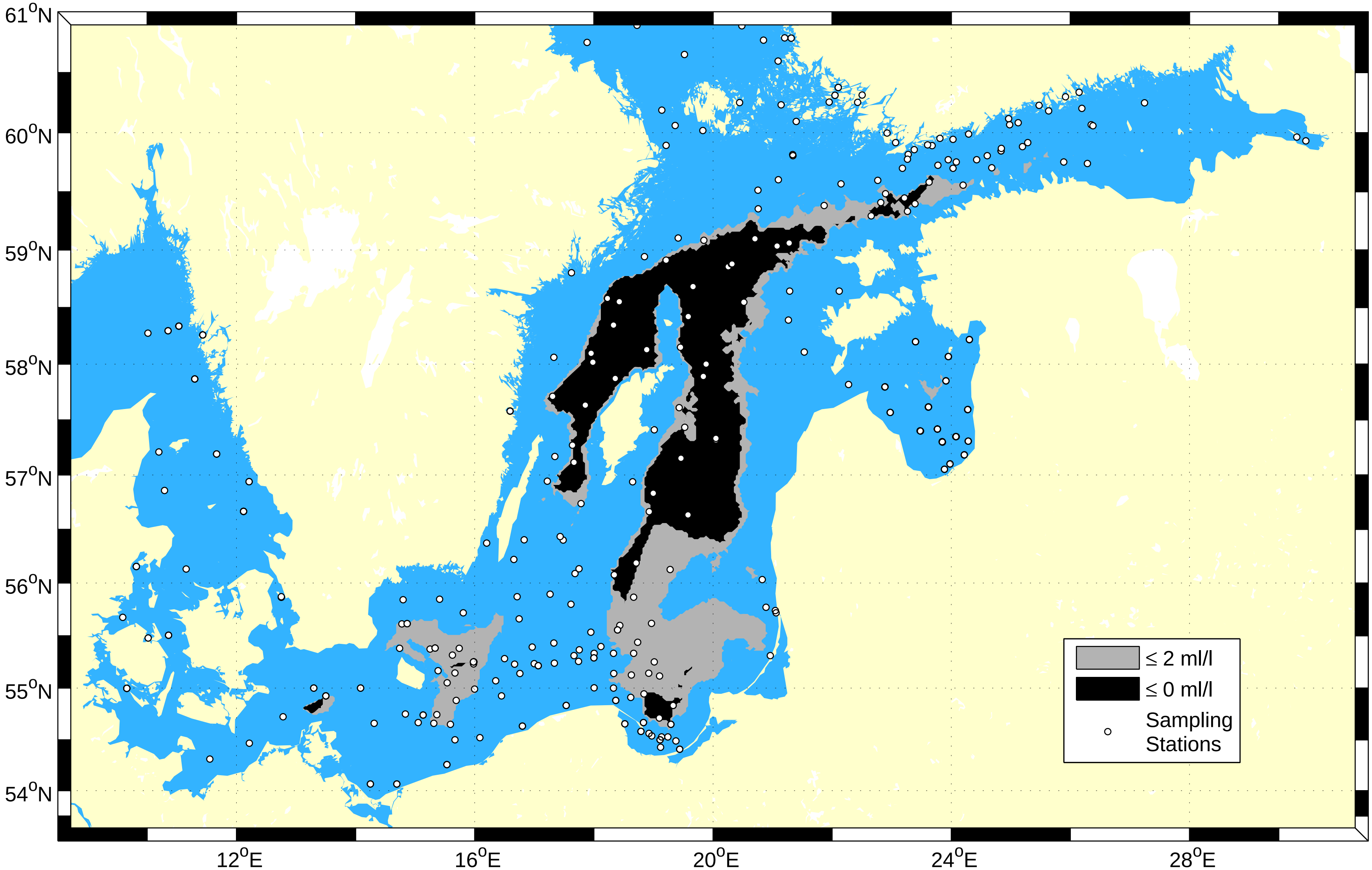
December 2014

Extent of hypoxic & anoxic bottom water, Autumn 2012



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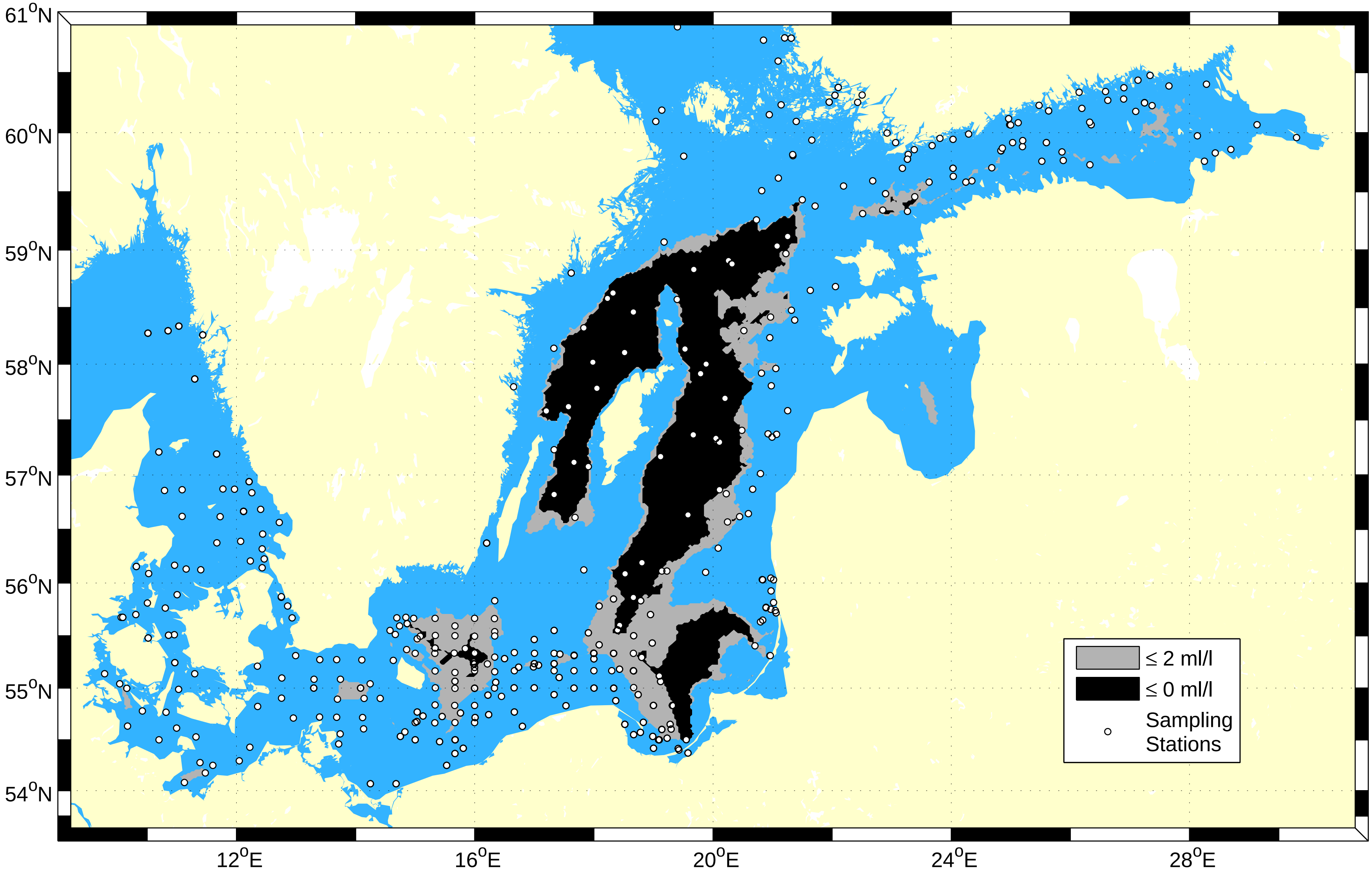
December 2013

Extent of hypoxic & anoxic bottom water, Autumn 2011



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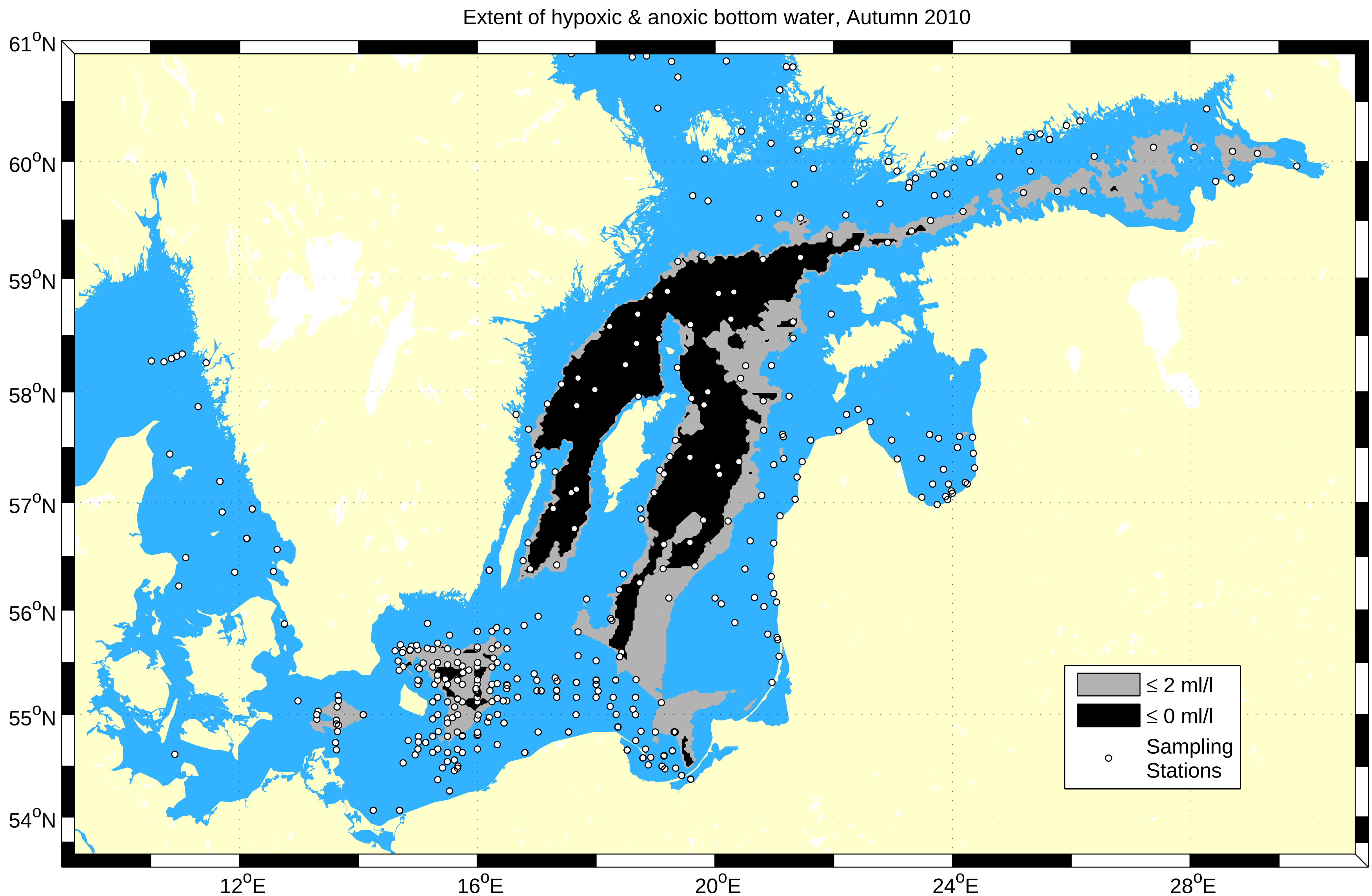
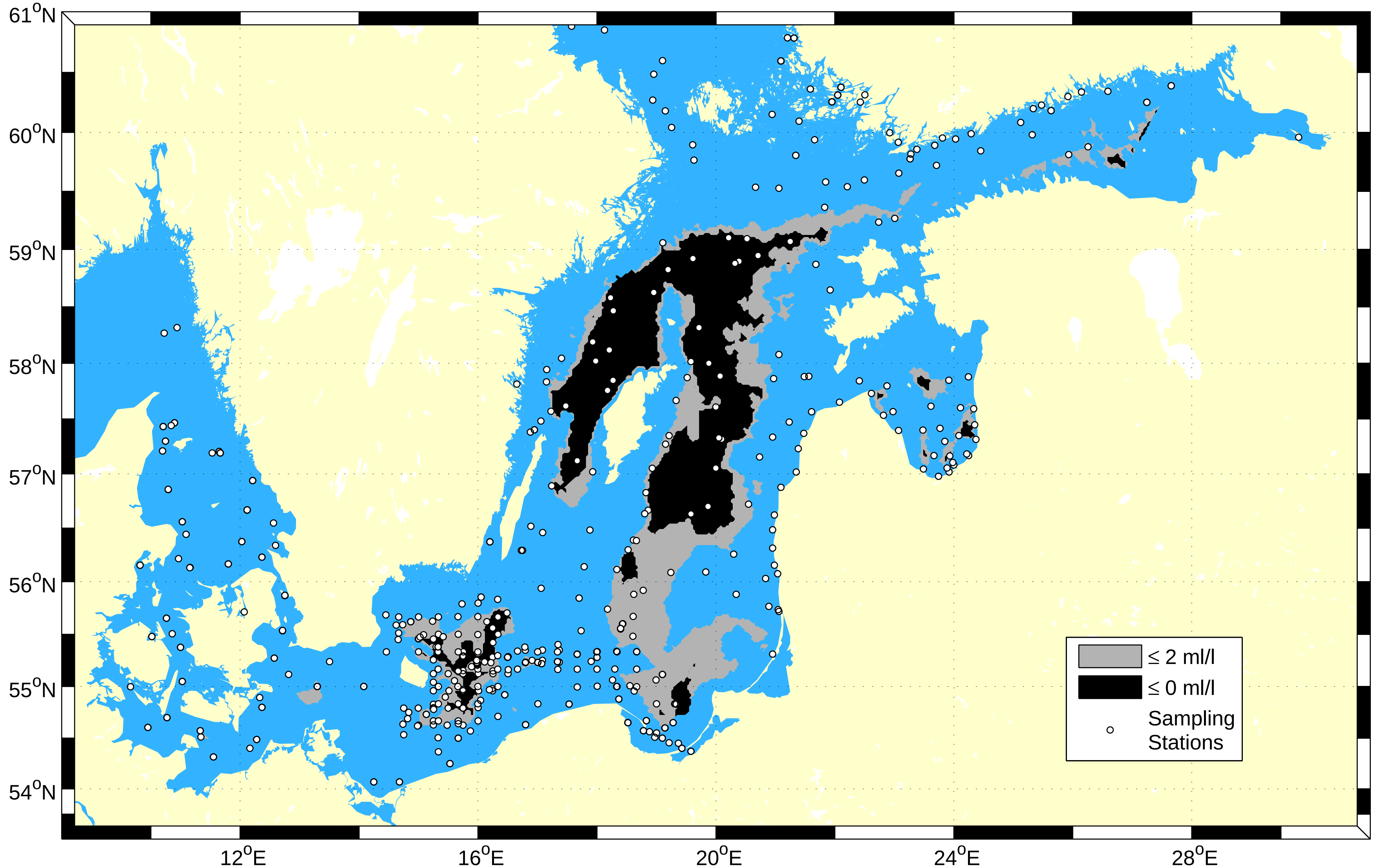
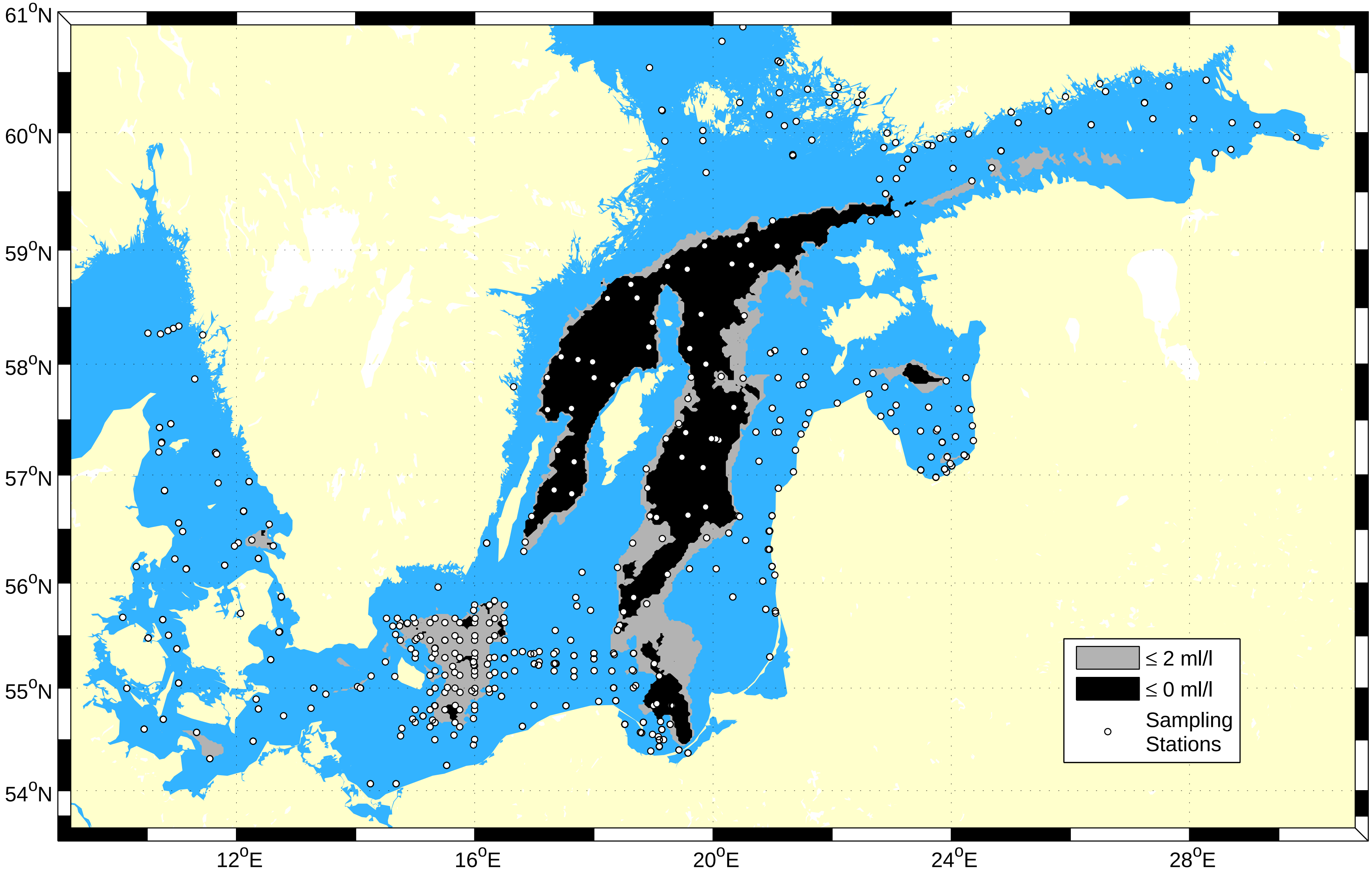


Extent of hypoxic & anoxic bottom water, Autumn 2010
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

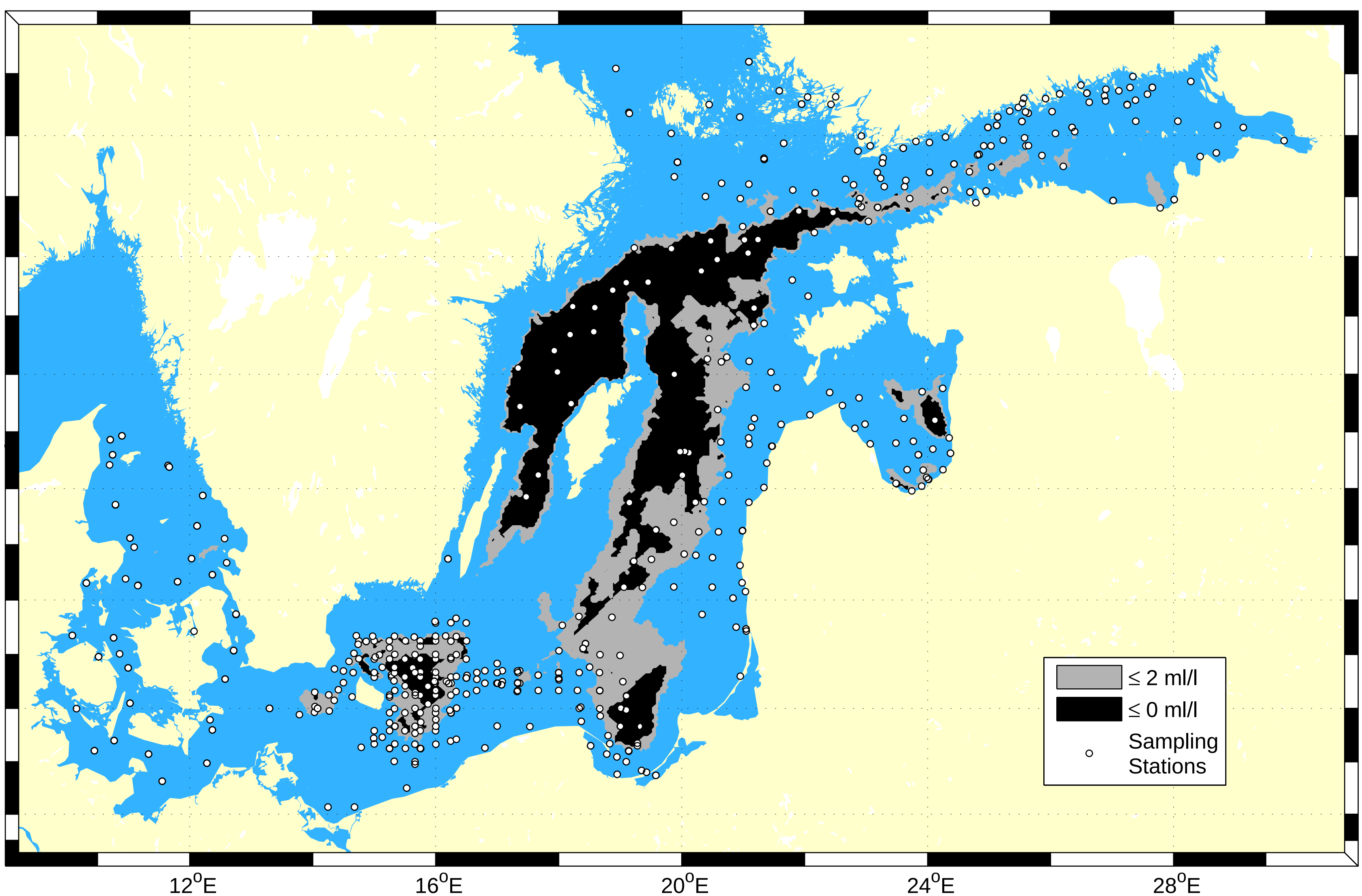
Extent of hypoxic & anoxic bottom water, Autumn 2009



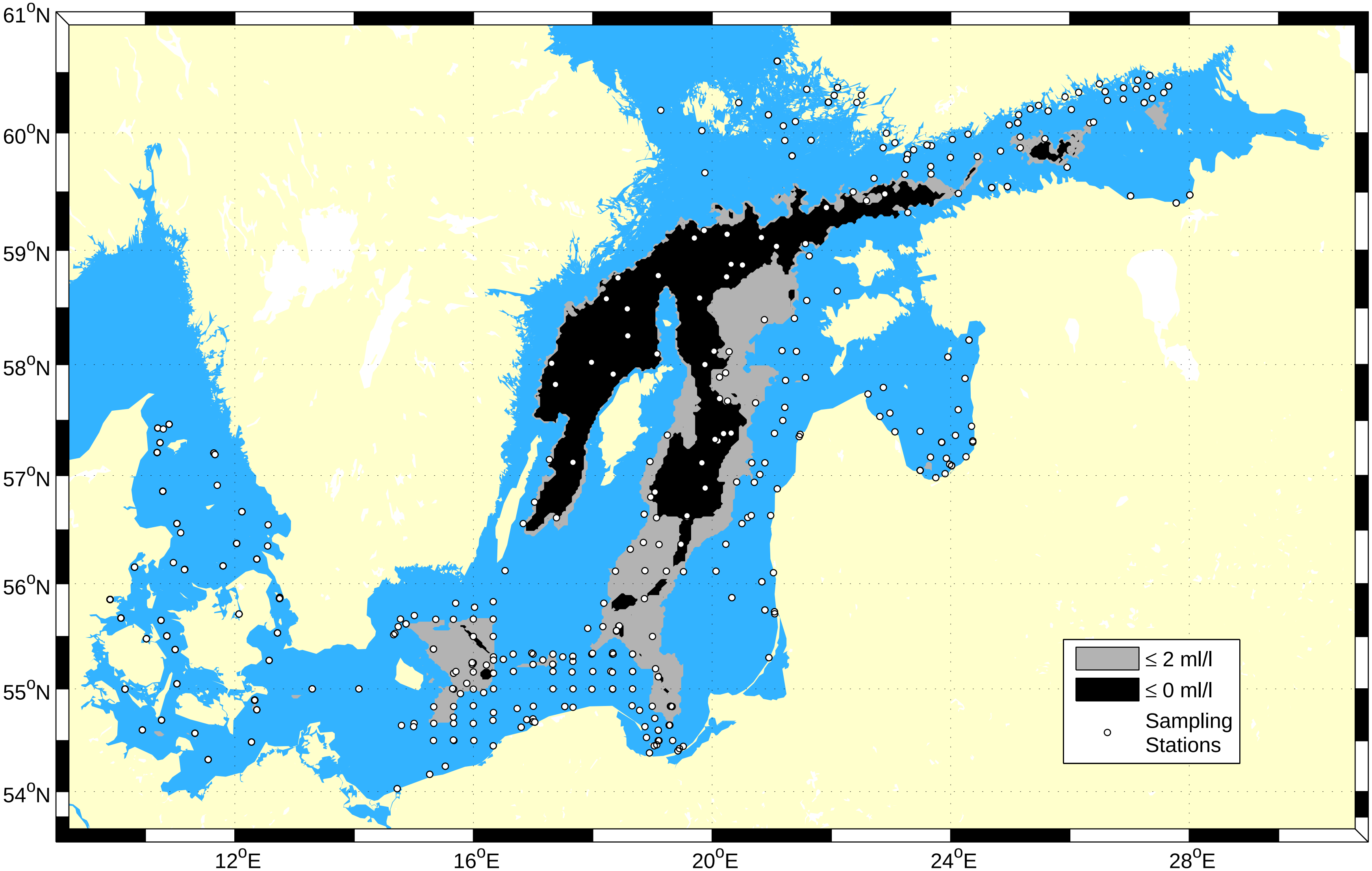
Extent of hypoxic & anoxic bottom water, Autumn 2008



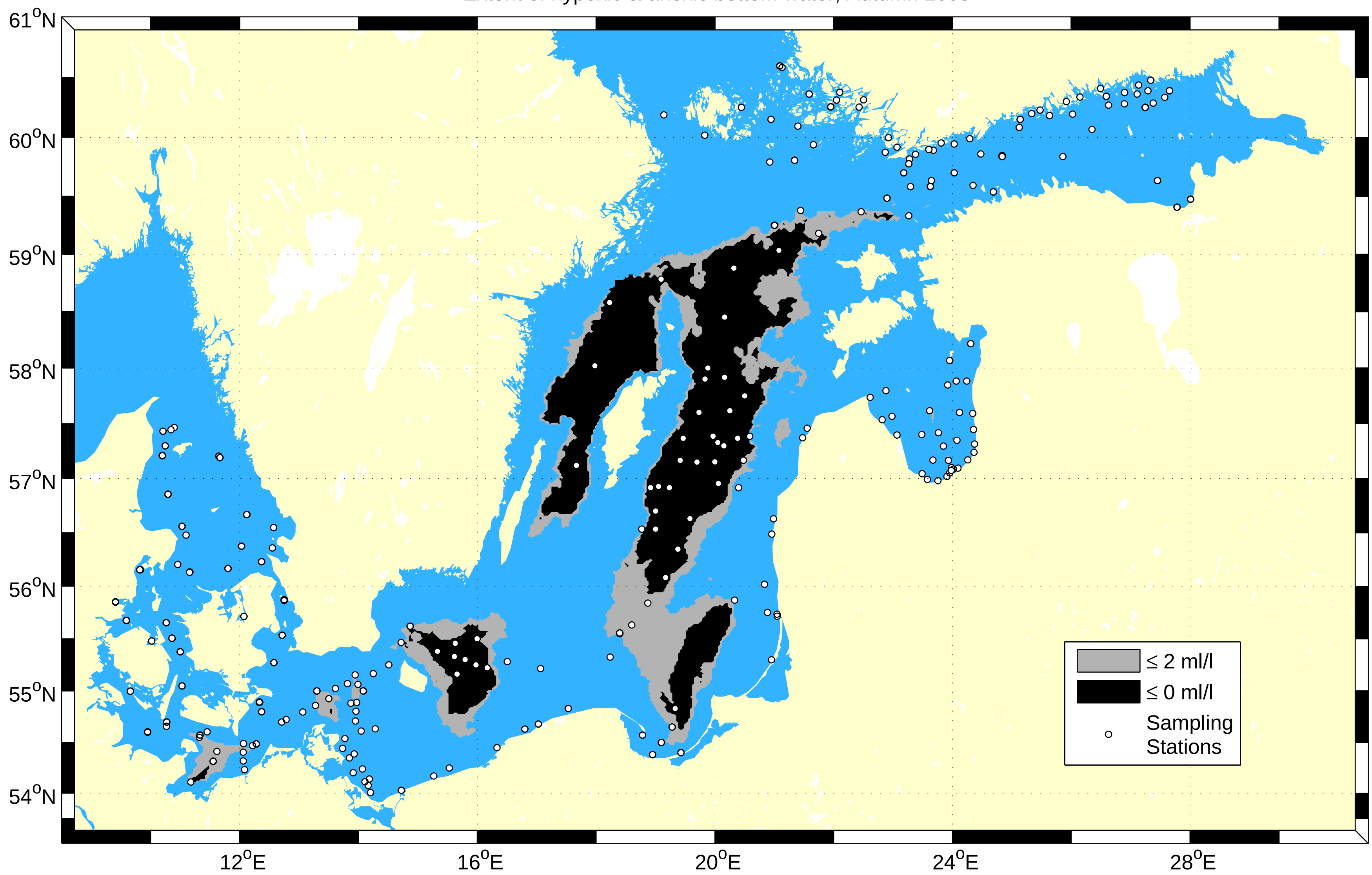
Extent of hypoxic & anoxic bottom water, Autumn 2007



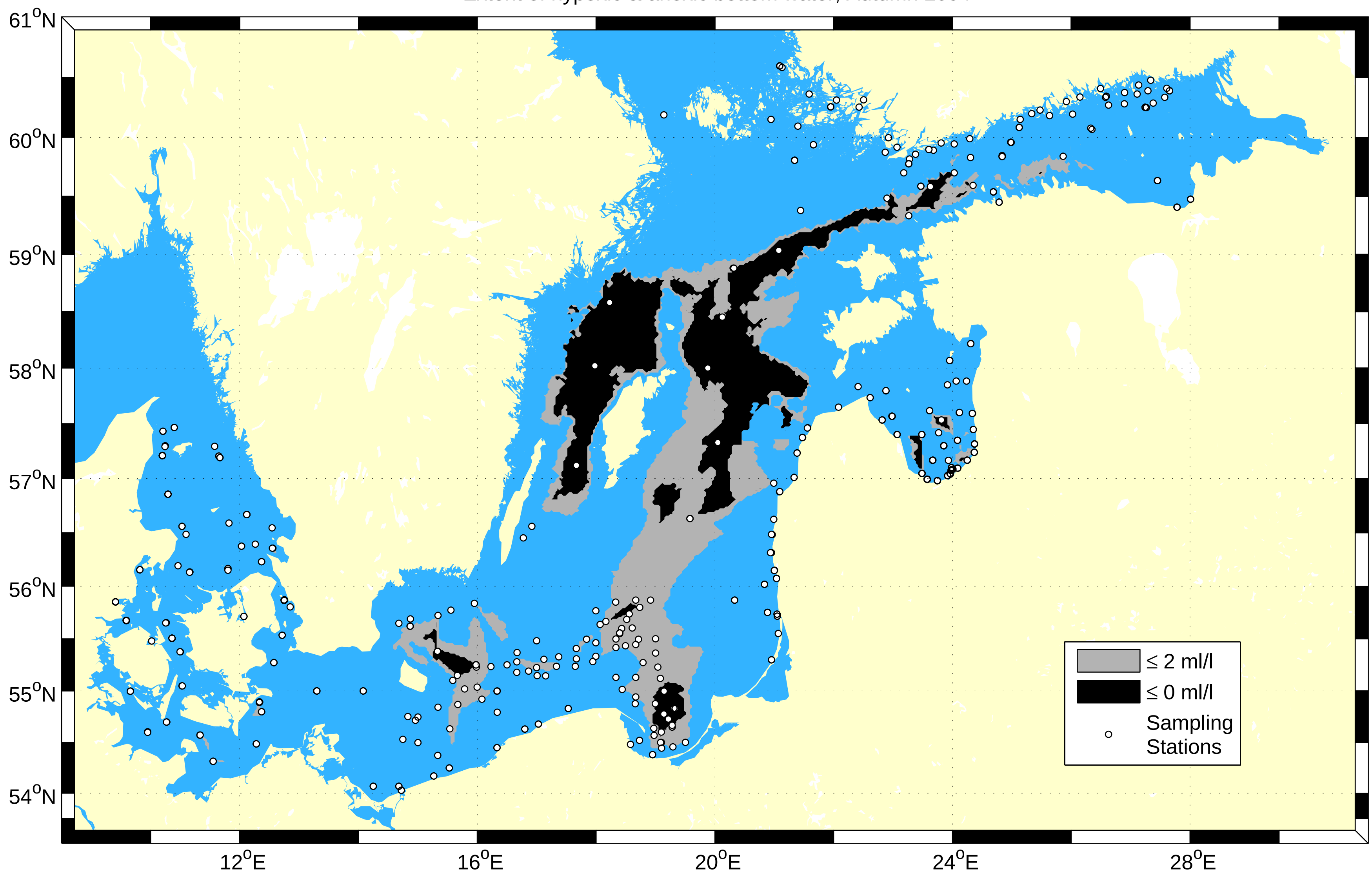
Extent of hypoxic & anoxic bottom water, Autumn 2006



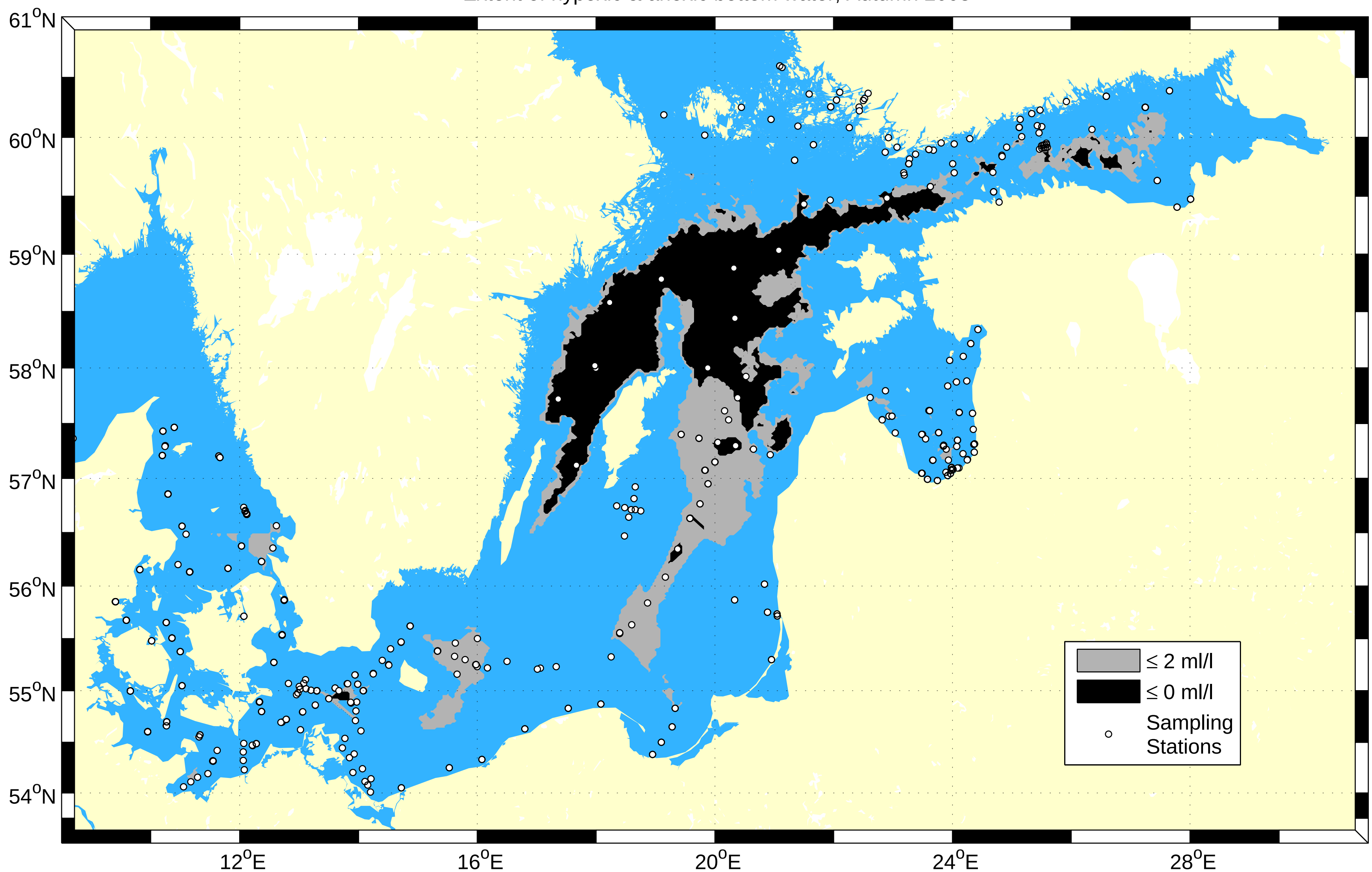
Extent of hypoxic & anoxic bottom water, Autumn 2005

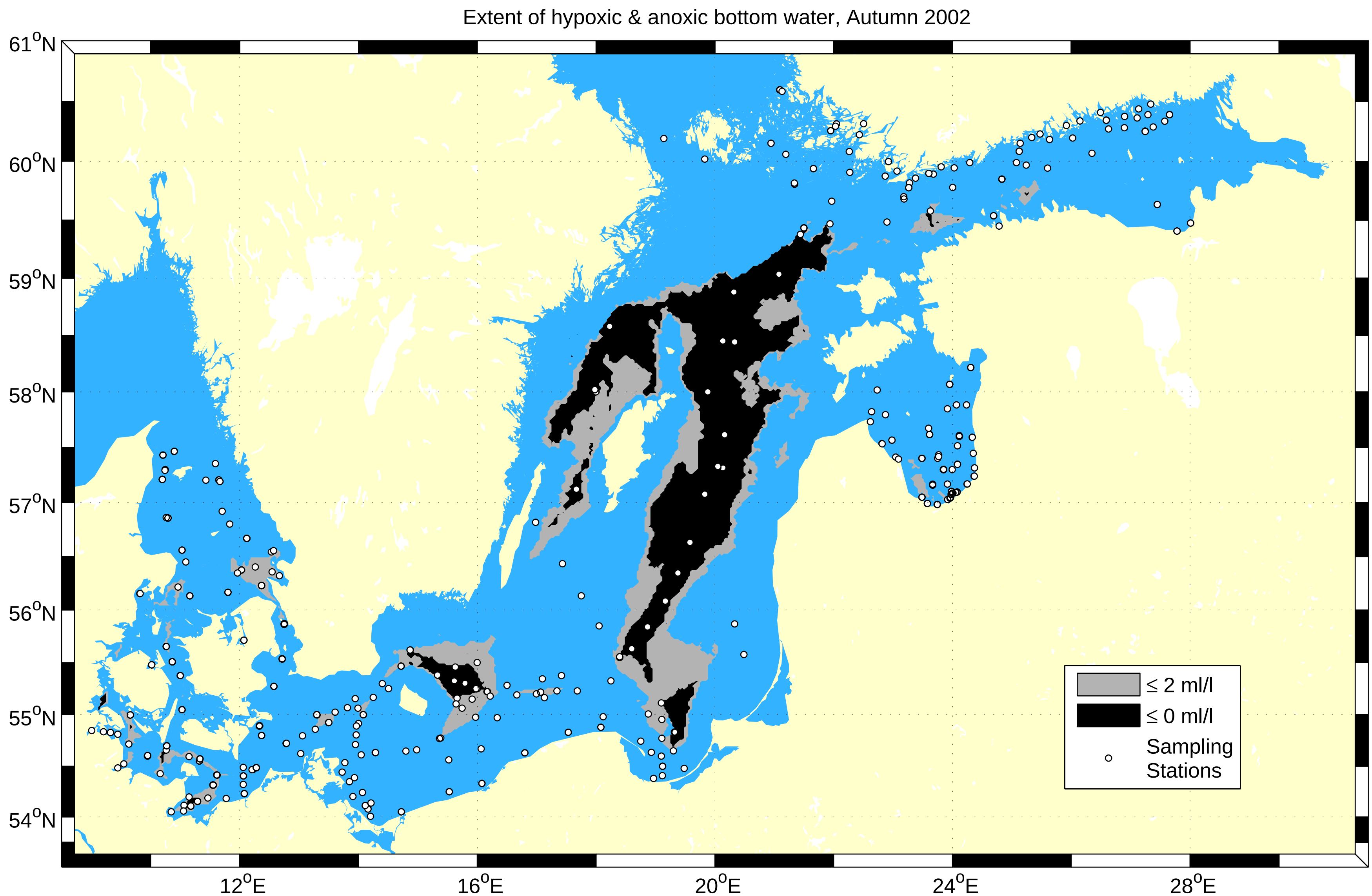


Extent of hypoxic & anoxic bottom water, Autumn 2004

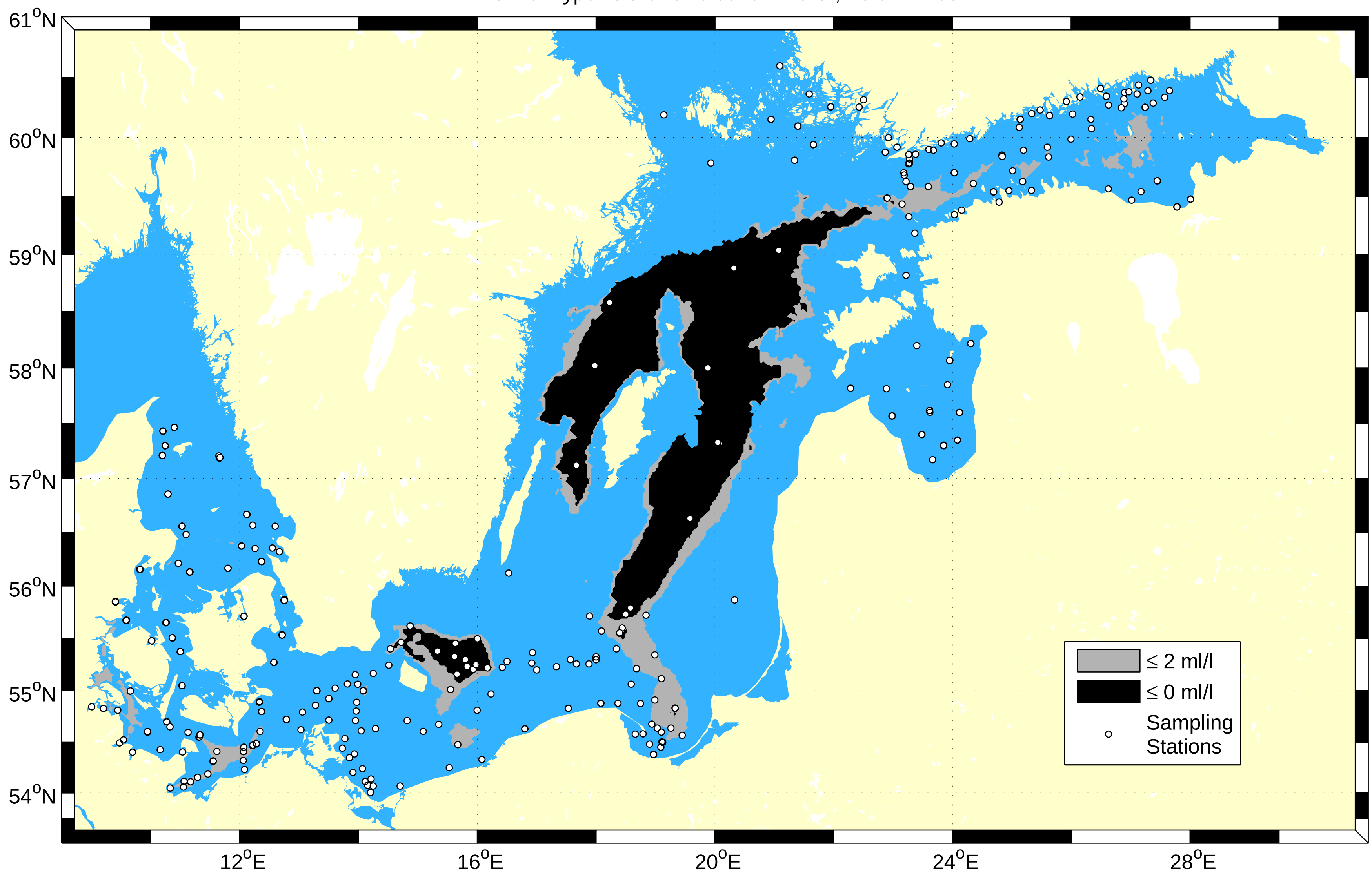


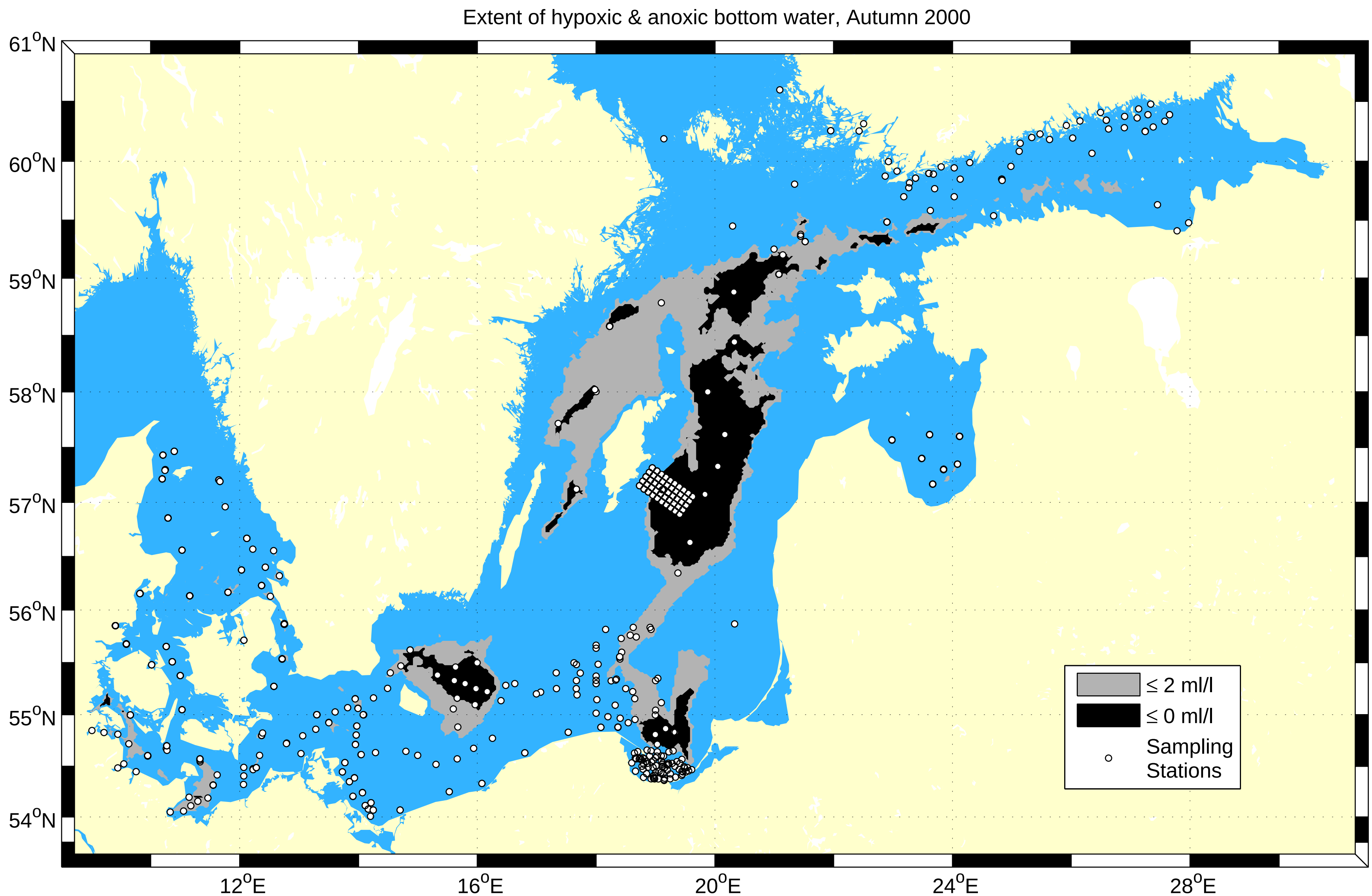
Extent of hypoxic & anoxic bottom water, Autumn 2003



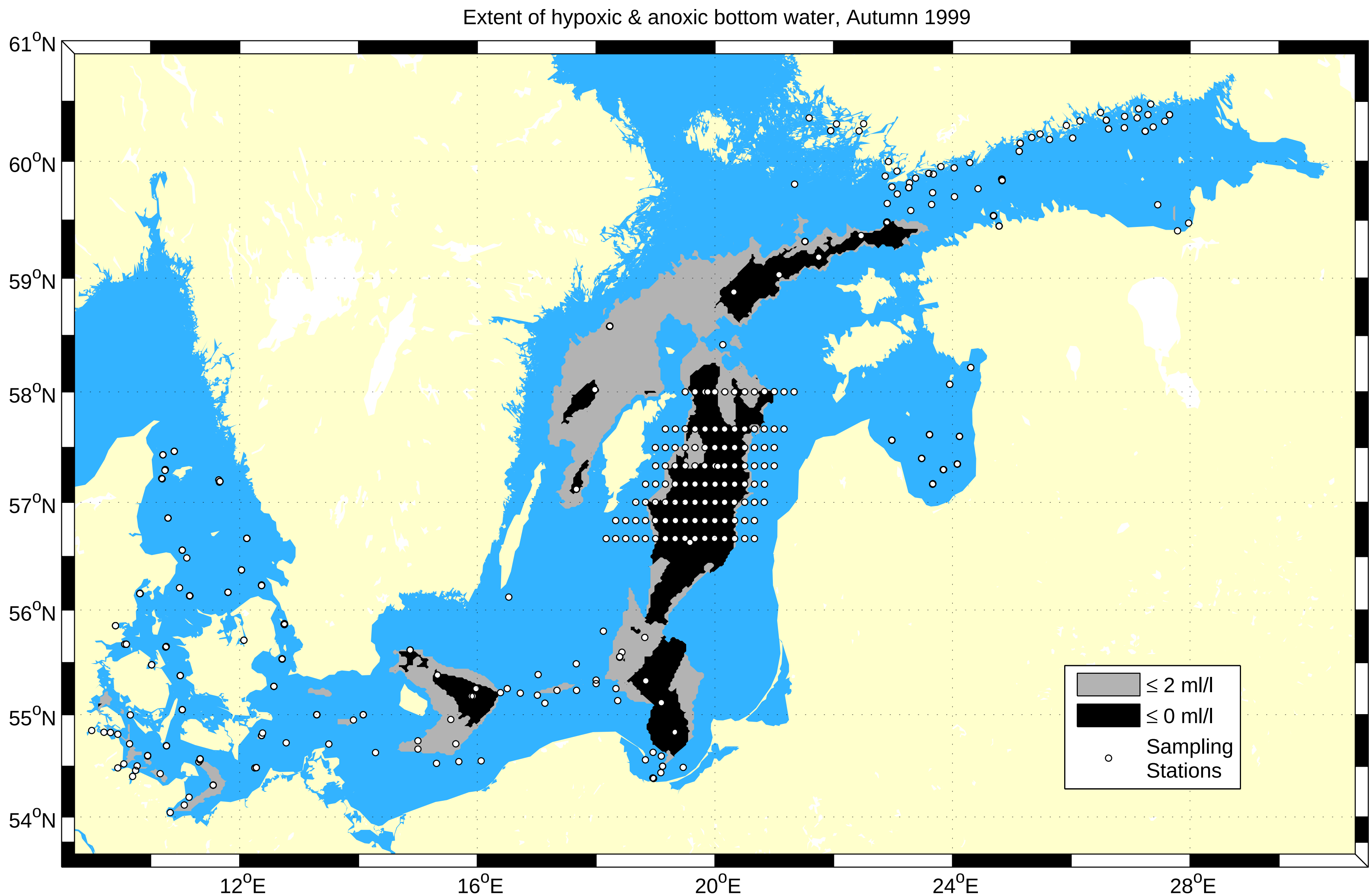

Extent of hypoxic & anoxic bottom water, Autumn 2002
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E

Extent of hypoxic & anoxic bottom water, Autumn 2001

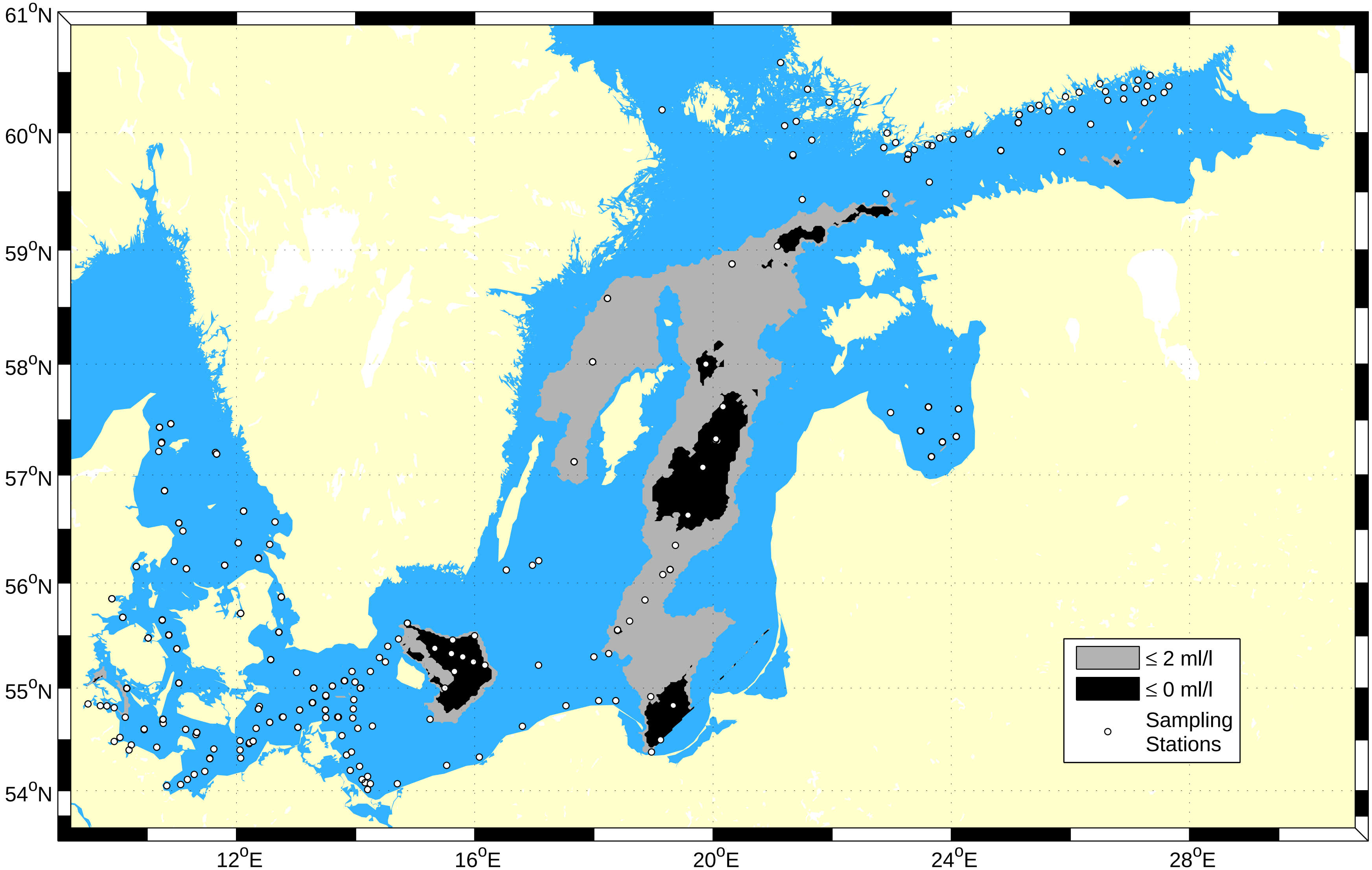




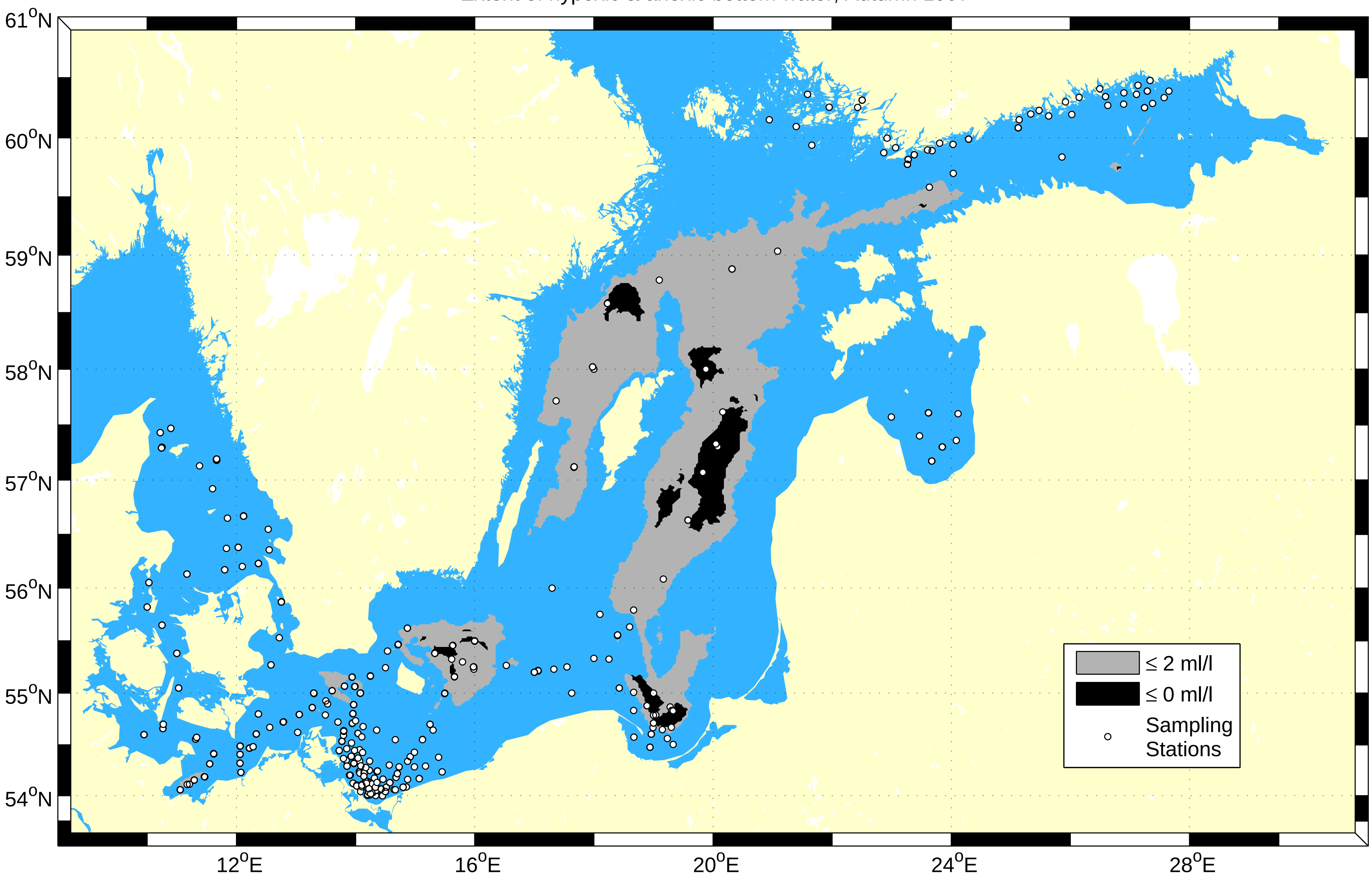
Extent of hypoxic & anoxic bottom water, Autumn 2000
61^{o}N
60^{o}N
59^{o}N
58^{o}N
57^{o}N
56^{o}N
55^{o}N
54^{o}N
12^{o}E
16^{o}E
20^{o}E
24^{o}E
28^{o}E
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations


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

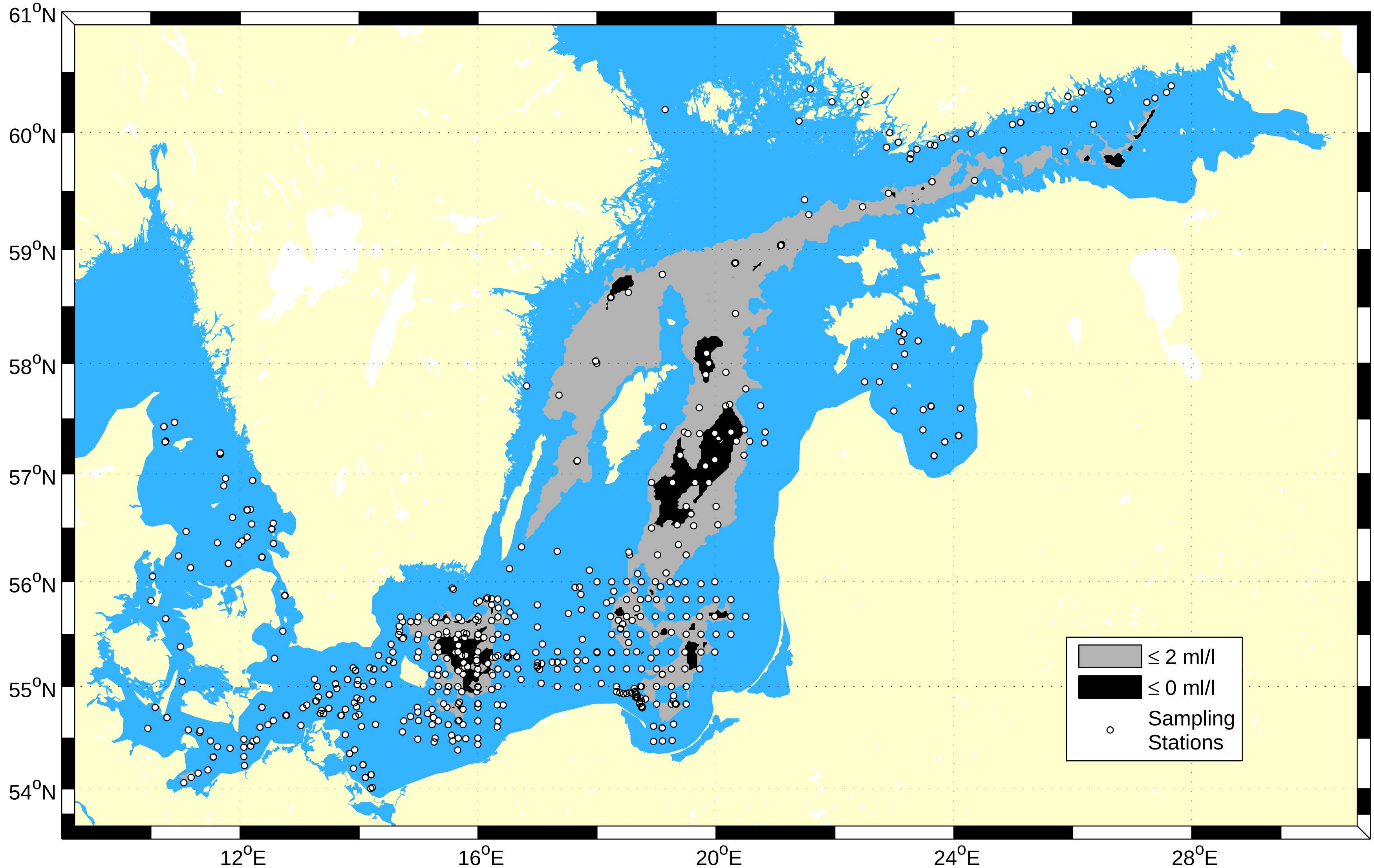
Extent of hypoxic & anoxic bottom water, Autumn 1998

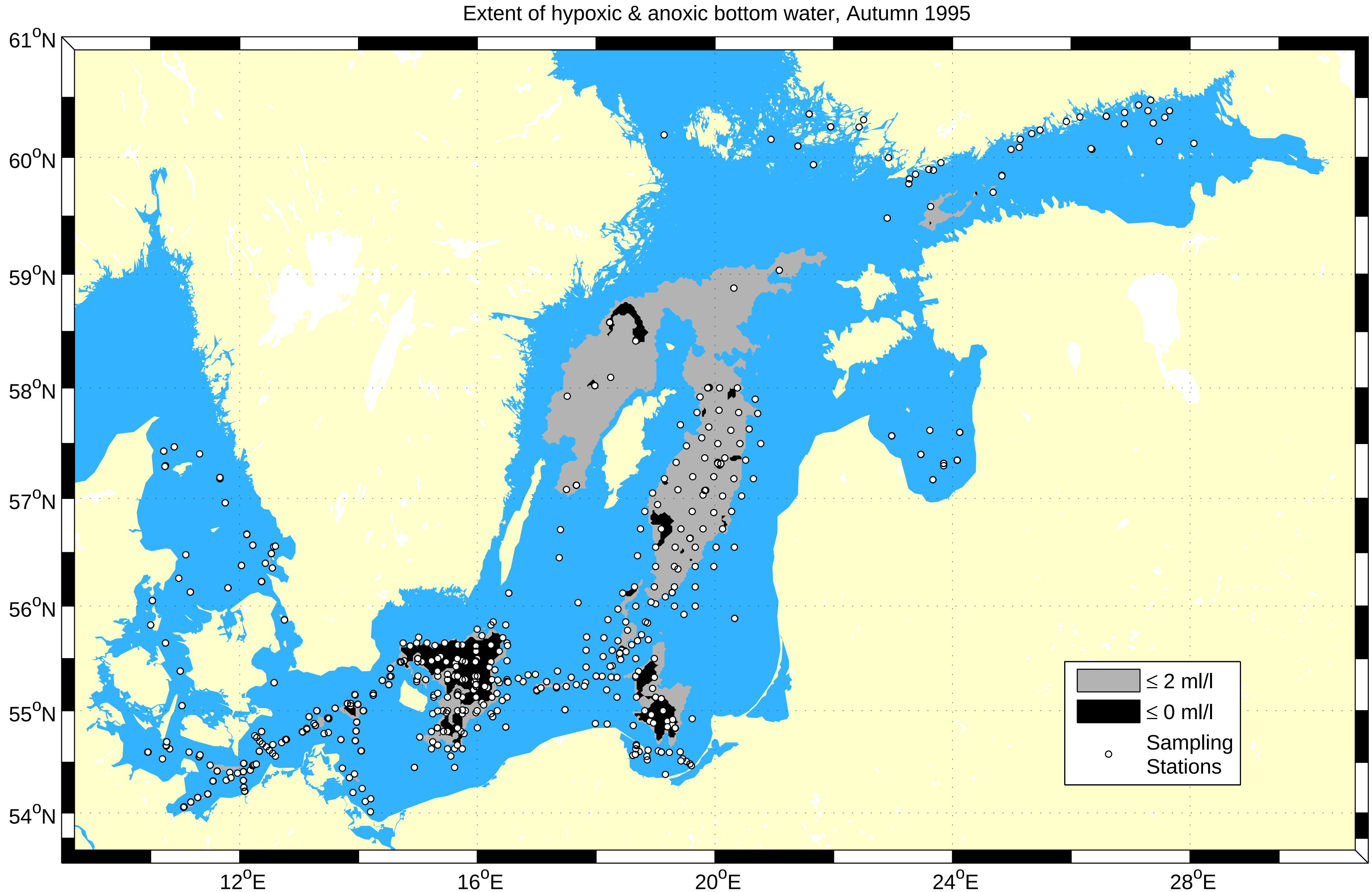


Extent of hypoxic & anoxic bottom water, Autumn 1997



Extent of hypoxic & anoxic bottom water, Autumn 1996




Extent of hypoxic & anoxic bottom water, Autumn 1995
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
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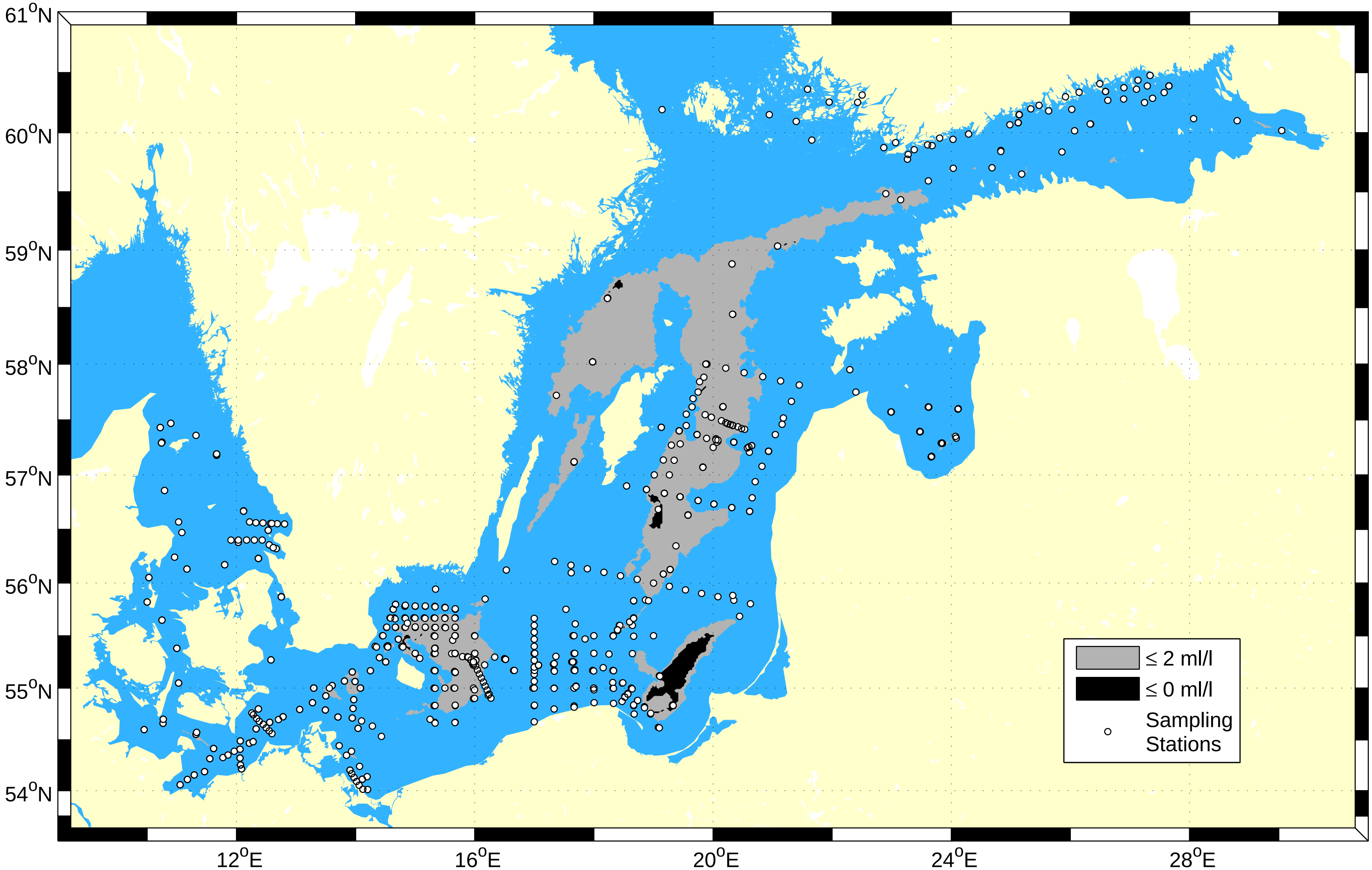
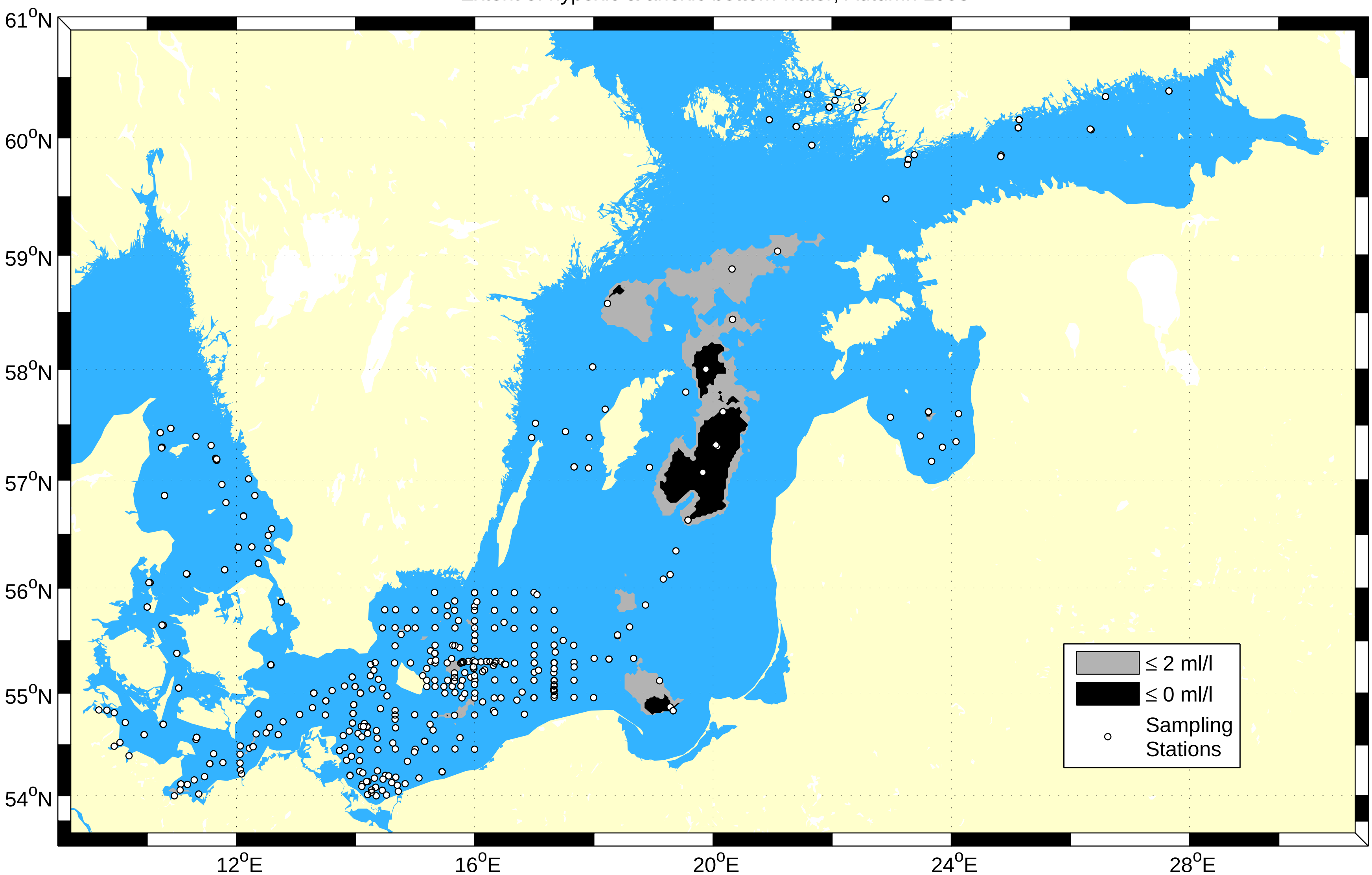
≤ 2 ml/l
≤ 0 ml/l
Sampling Stations

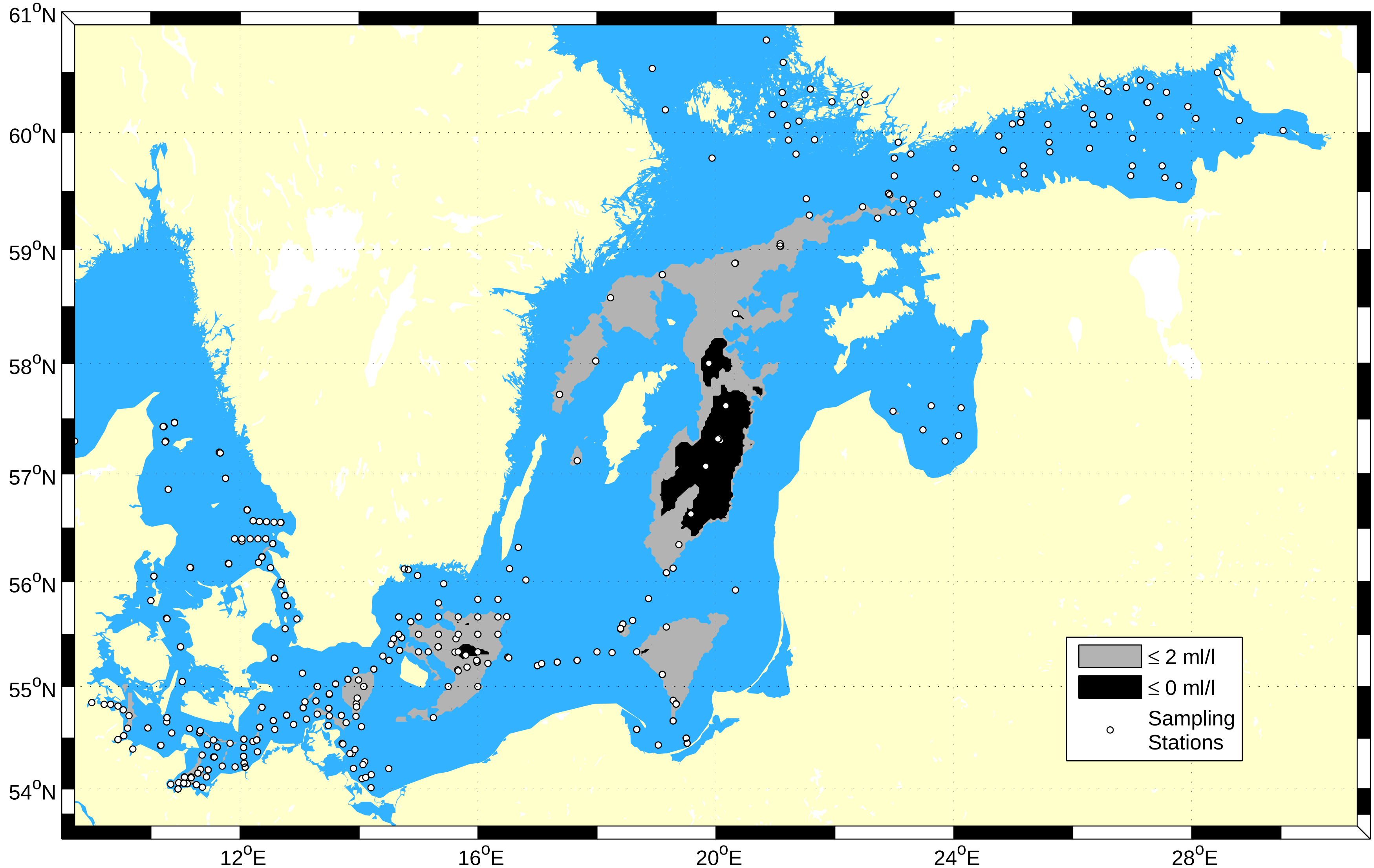
Extent of hypoxic & anoxic bottom water, Autumn 1994



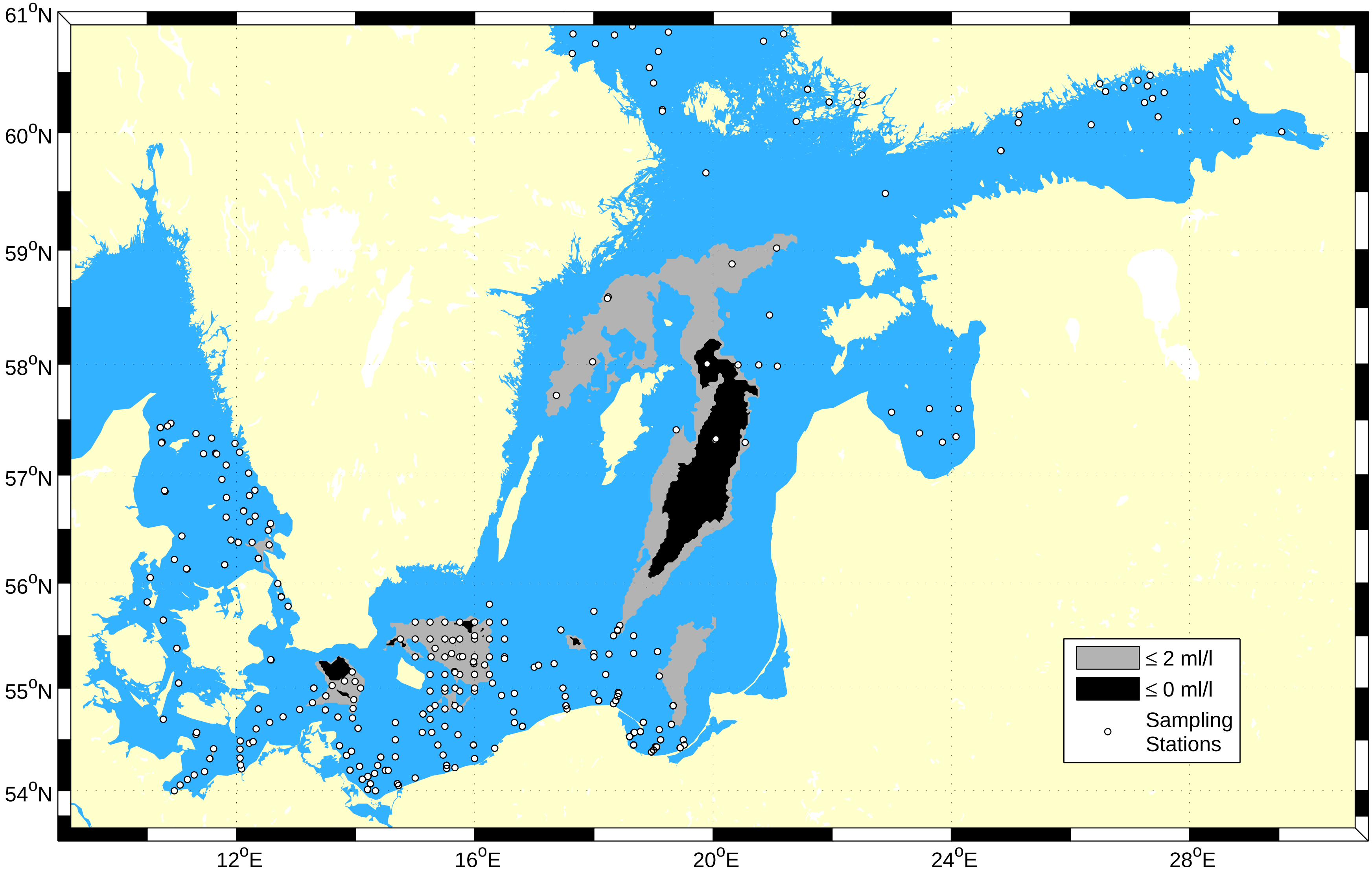
Extent of hypoxic & anoxic bottom water, Autumn 1993



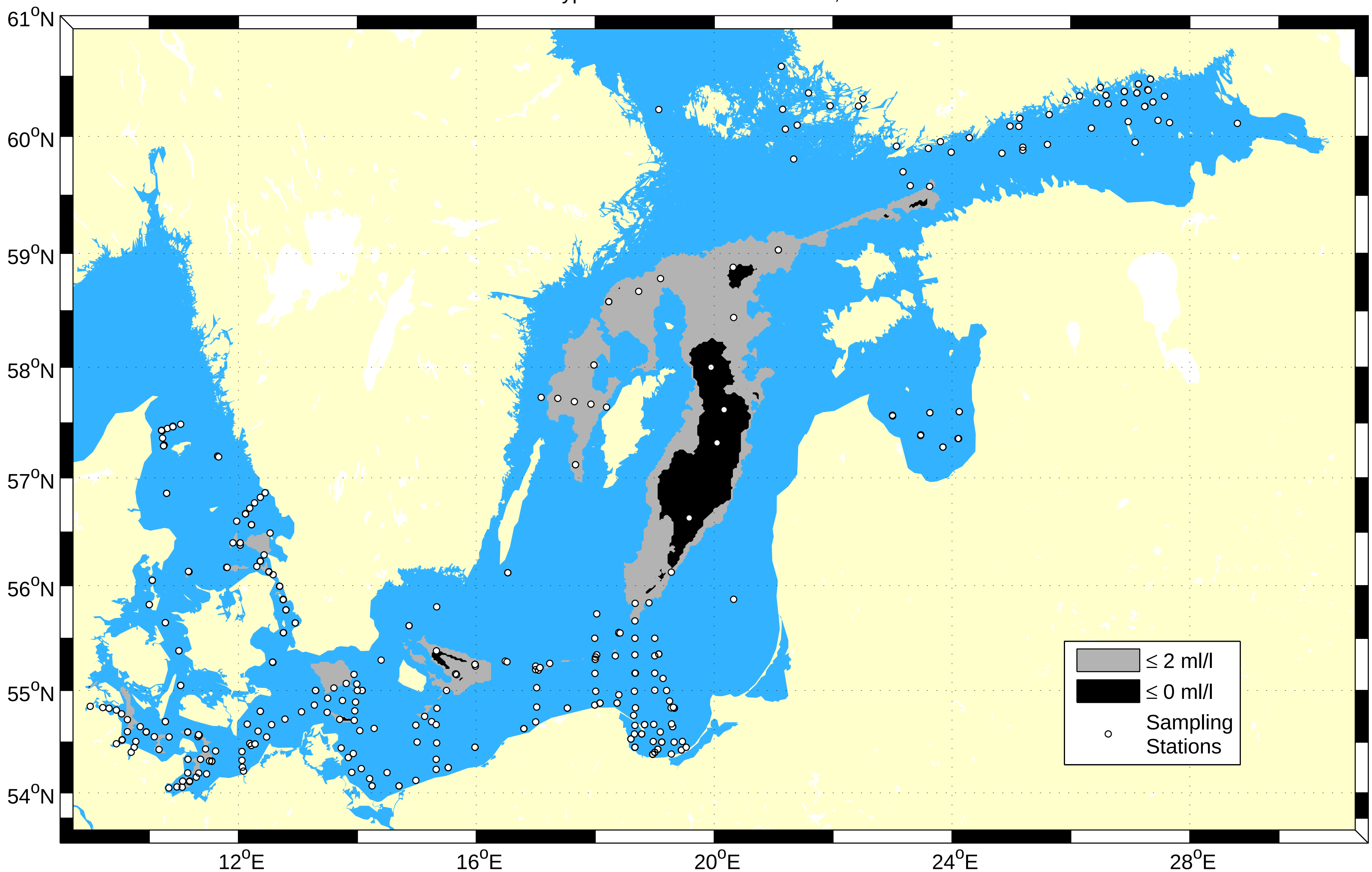
Extent of hypoxic & anoxic bottom water, Autumn 1992



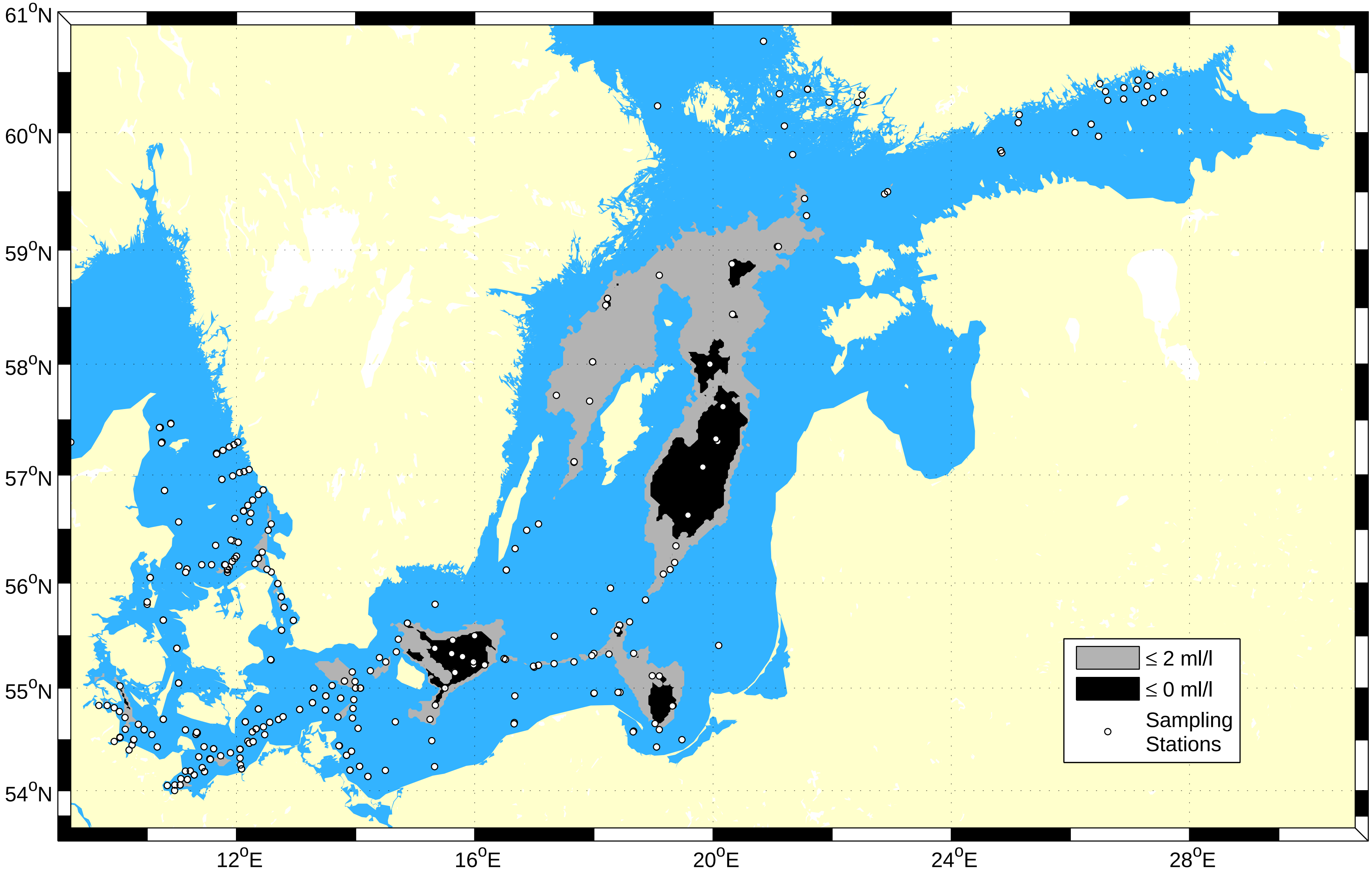
Extent of hypoxic & anoxic bottom water, Autumn 1991



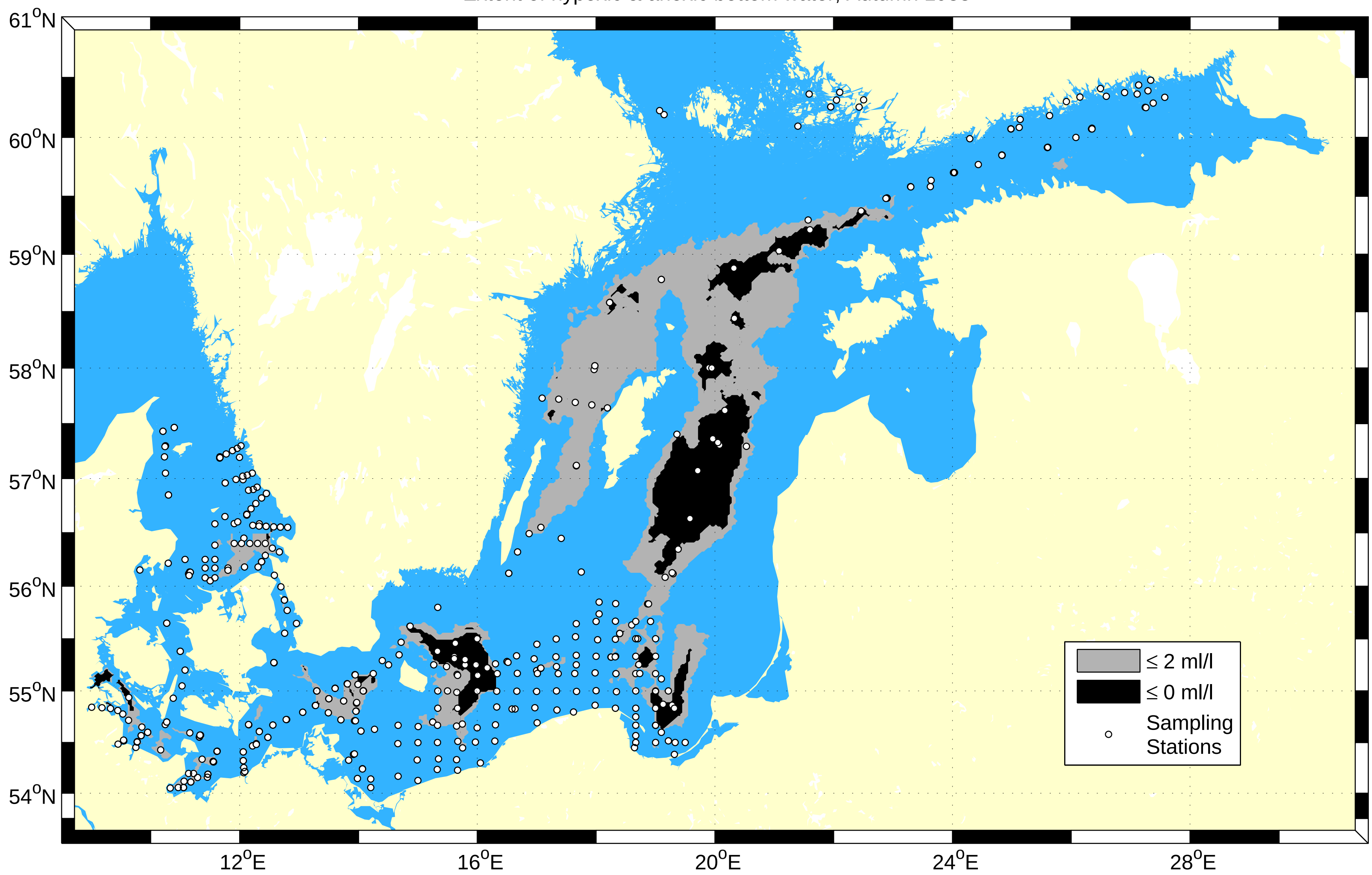
Extent of hypoxic & anoxic bottom water, Autumn 1990



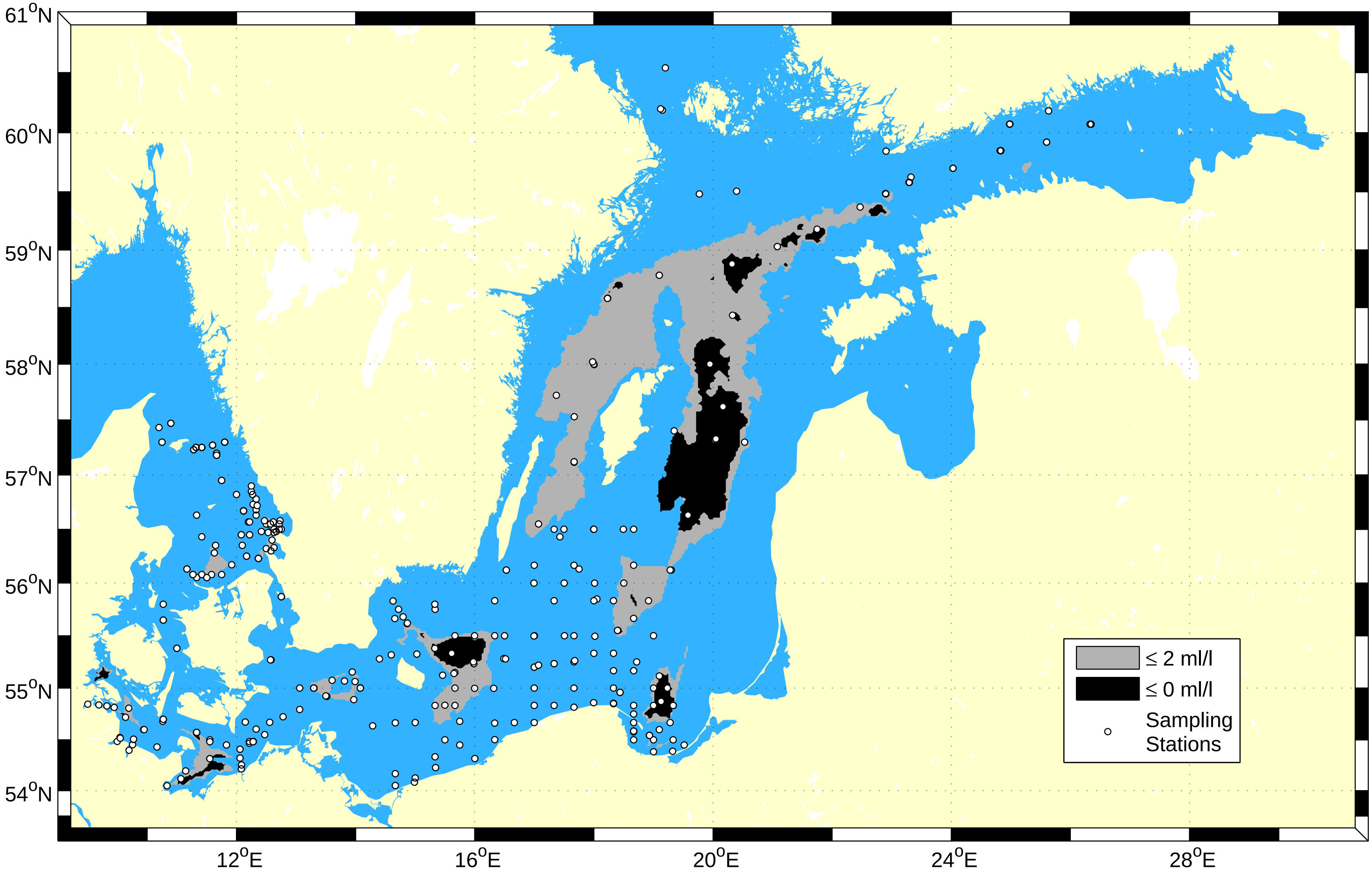
Extent of hypoxic & anoxic bottom water, Autumn 1989



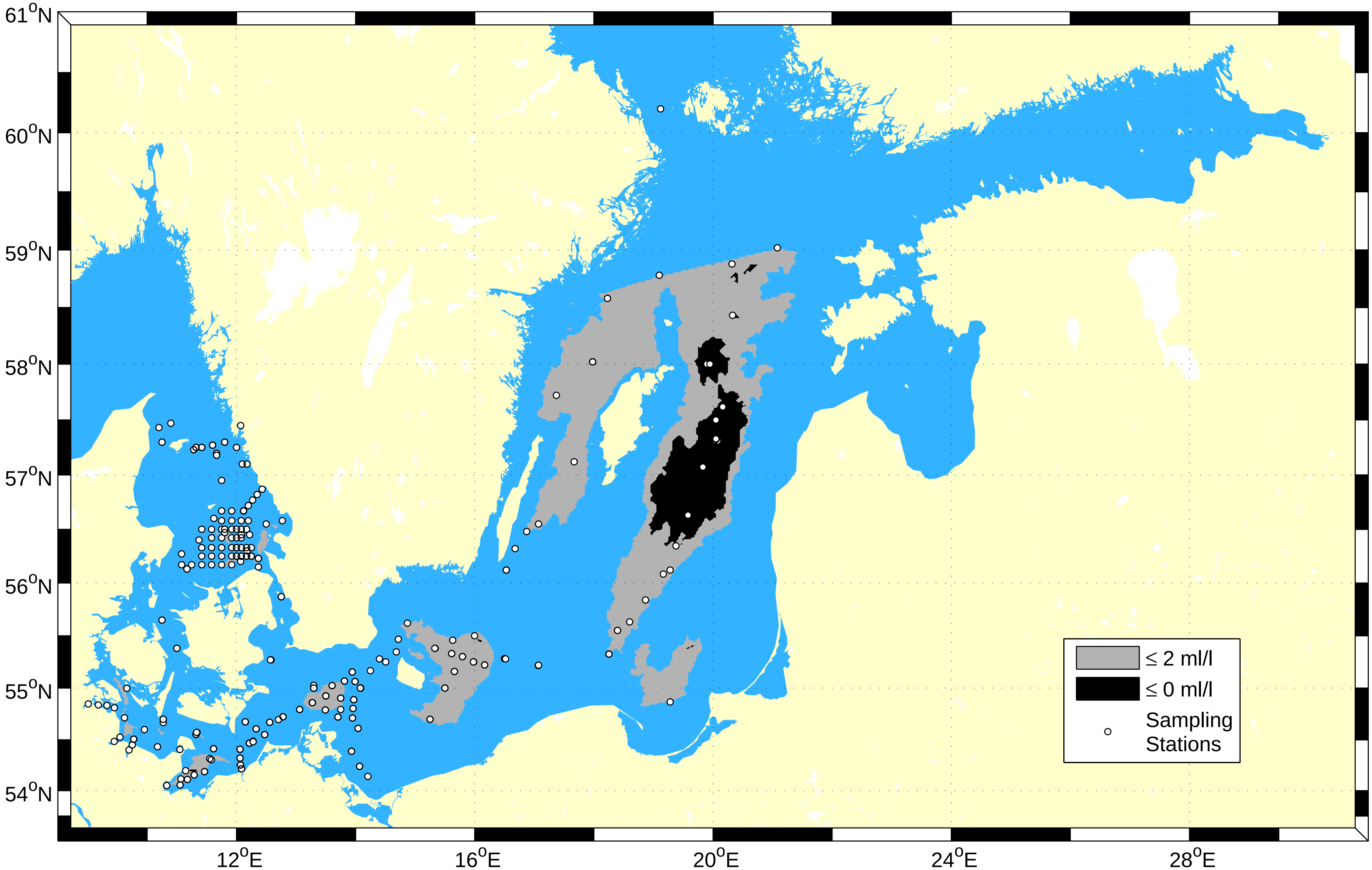
Extent of hypoxic & anoxic bottom water, Autumn 1988



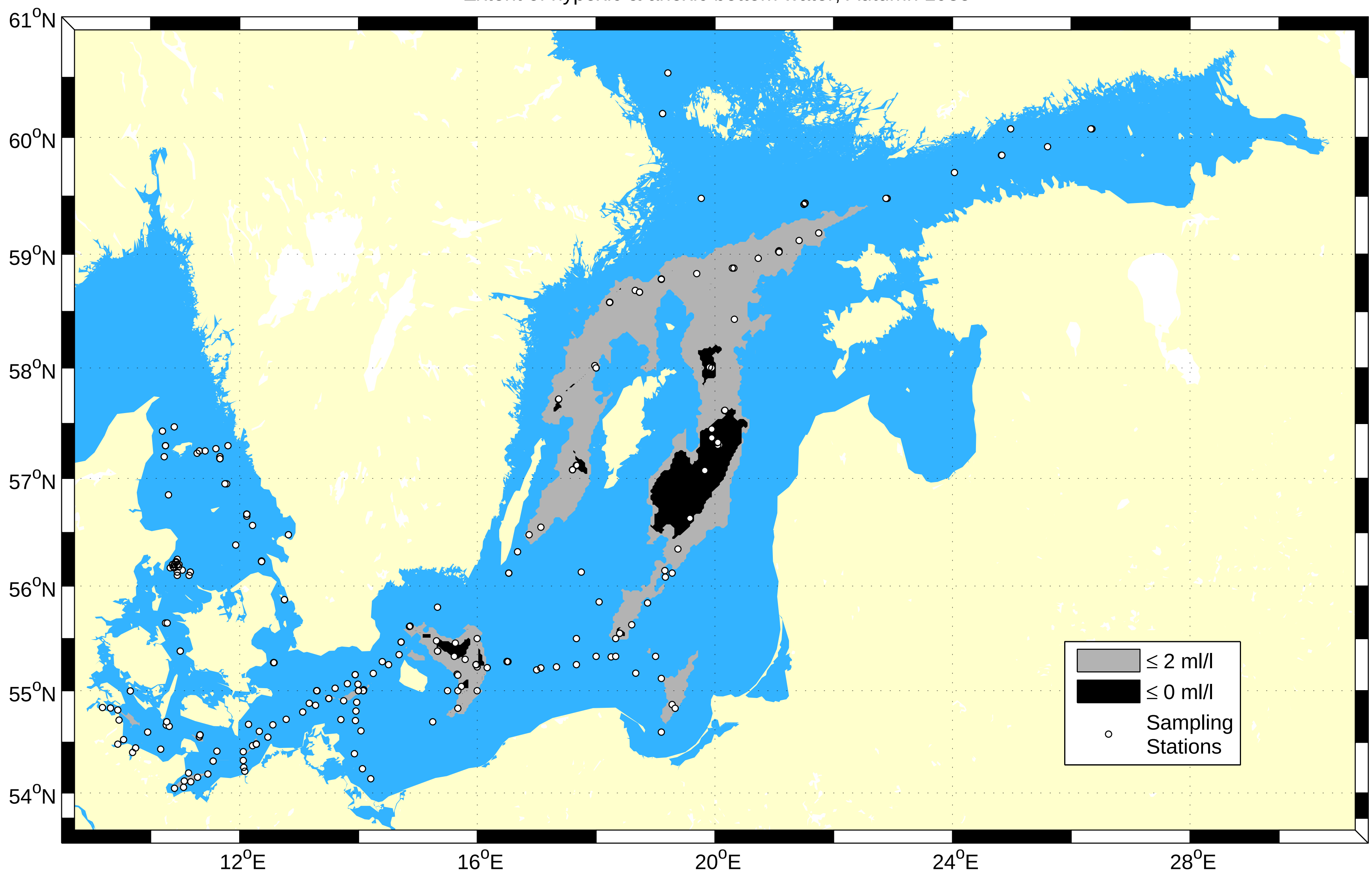
Extent of hypoxic & anoxic bottom water, Autumn 1987



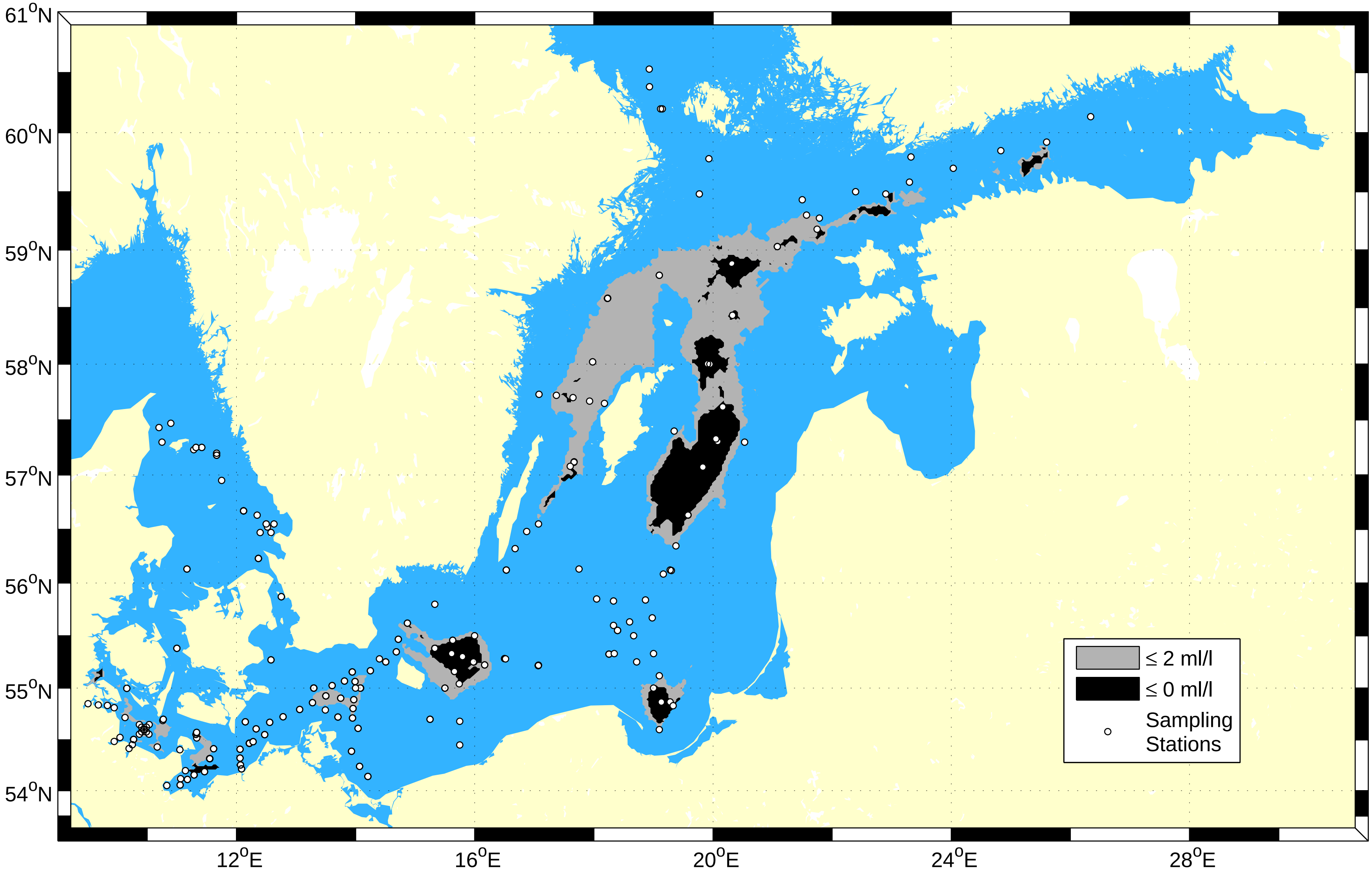
Extent of hypoxic & anoxic bottom water, Autumn 1986



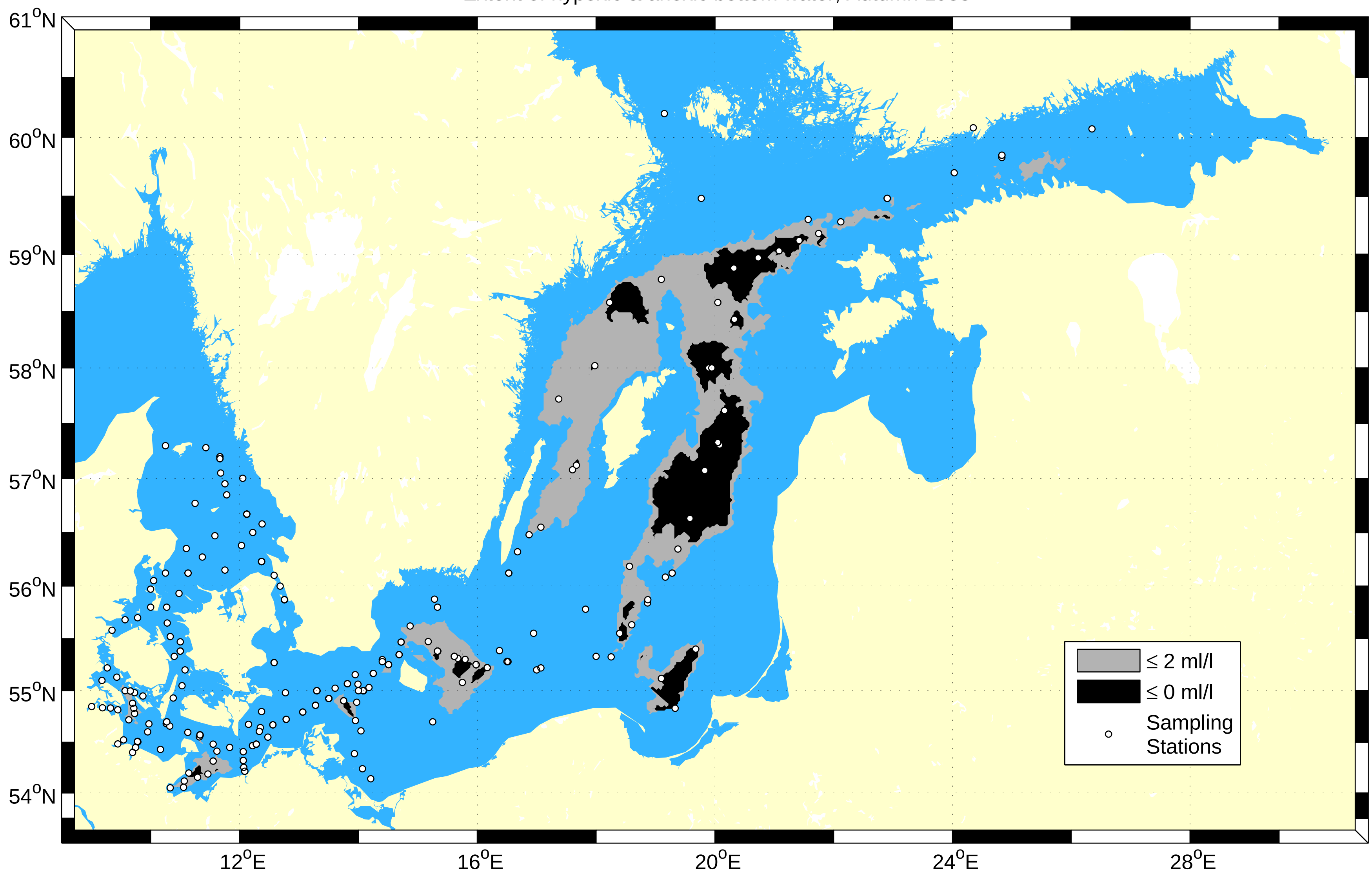
Extent of hypoxic & anoxic bottom water, Autumn 1985

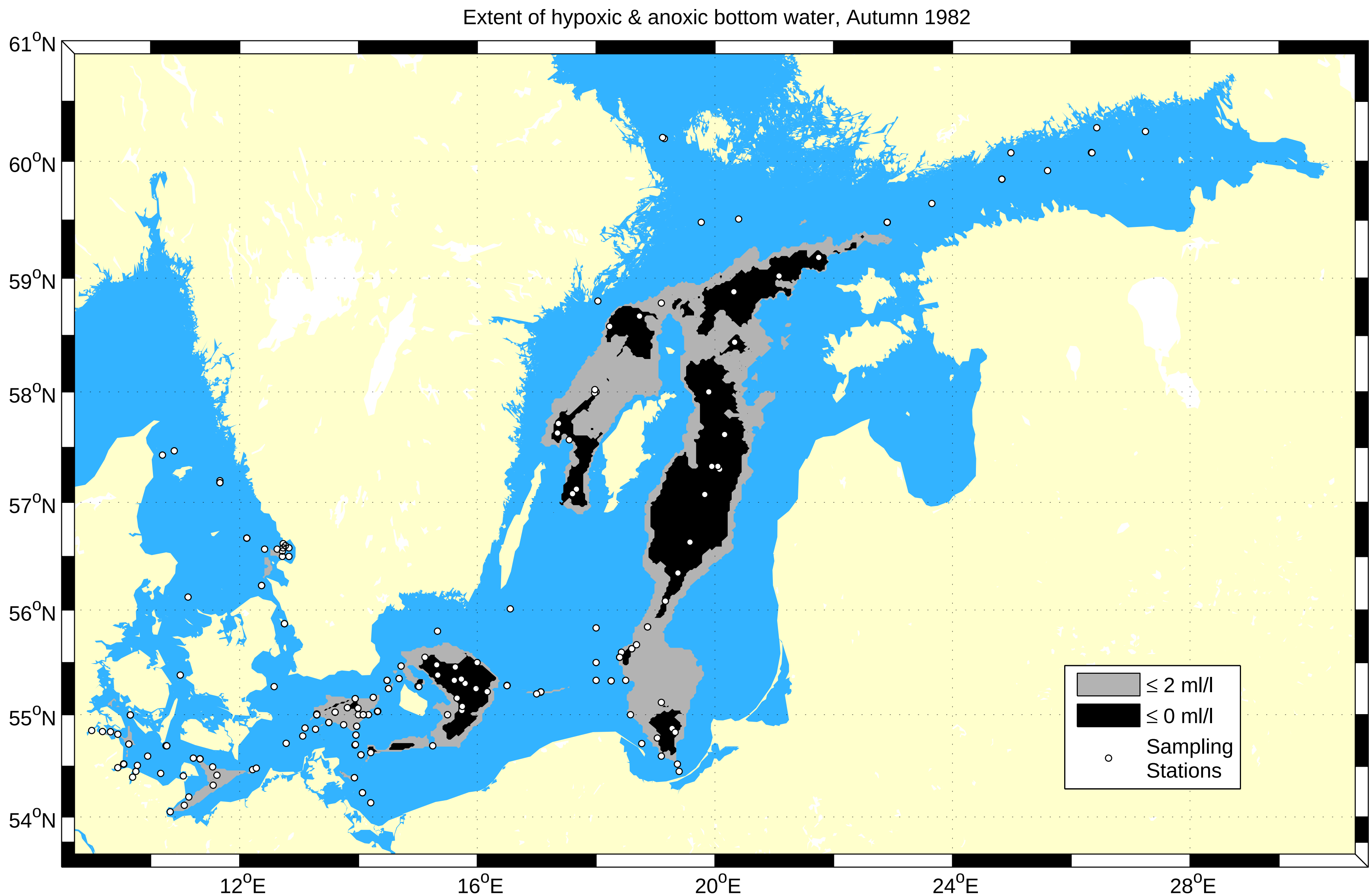


Extent of hypoxic & anoxic bottom water, Autumn 1984

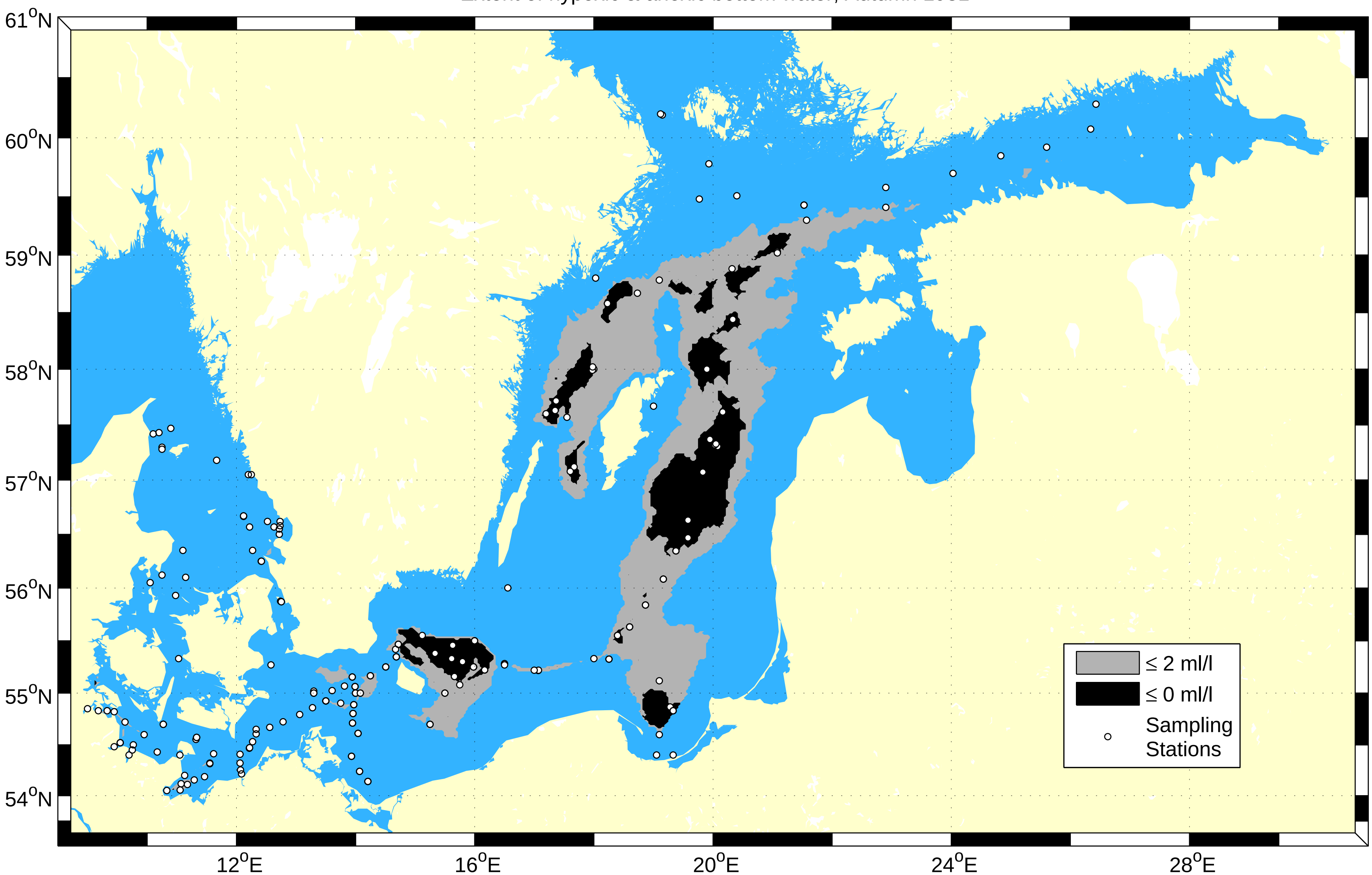


Extent of hypoxic & anoxic bottom water, Autumn 1983

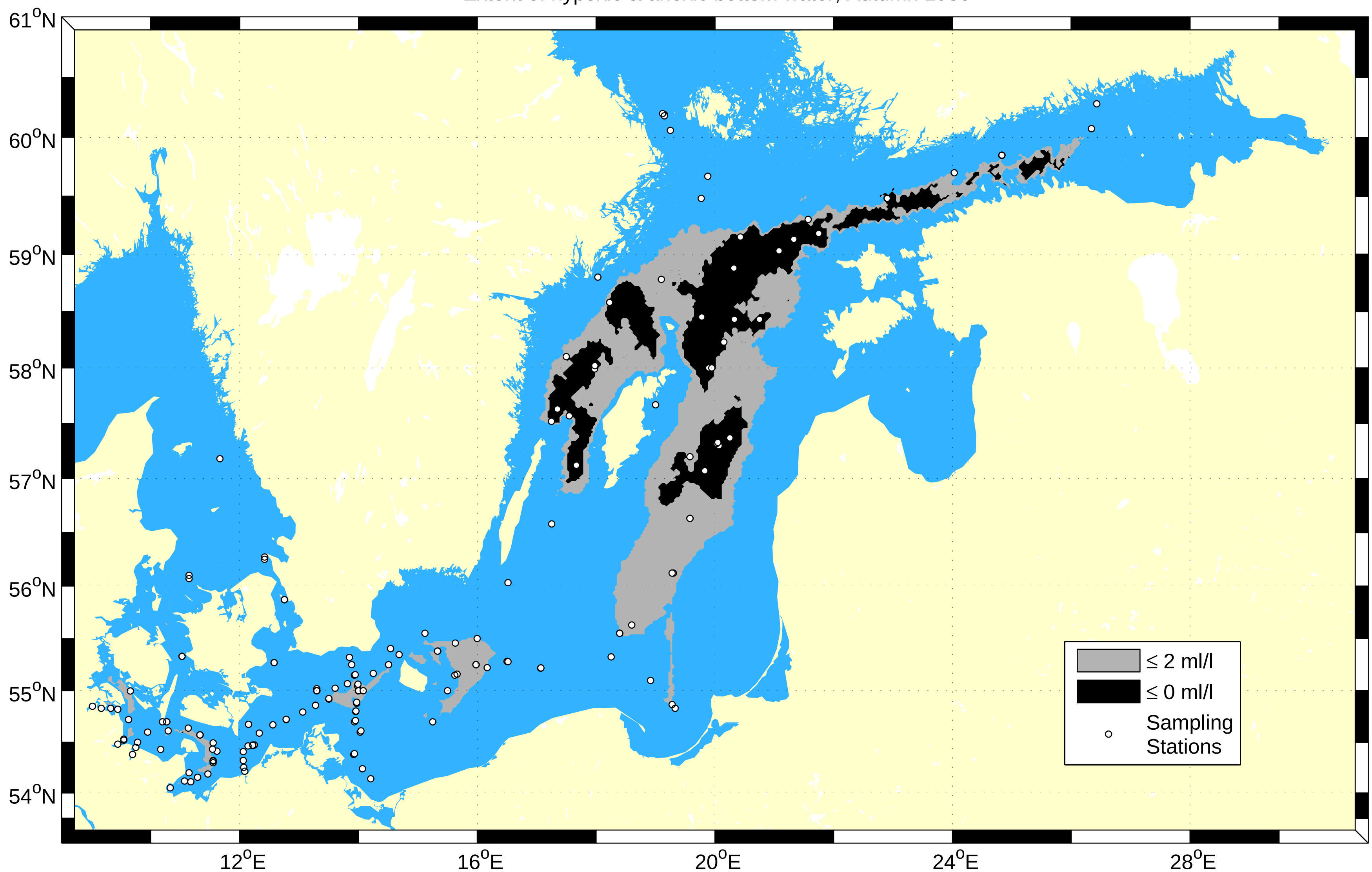



Extent of hypoxic & anoxic bottom water, Autumn 1982
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling
Stations

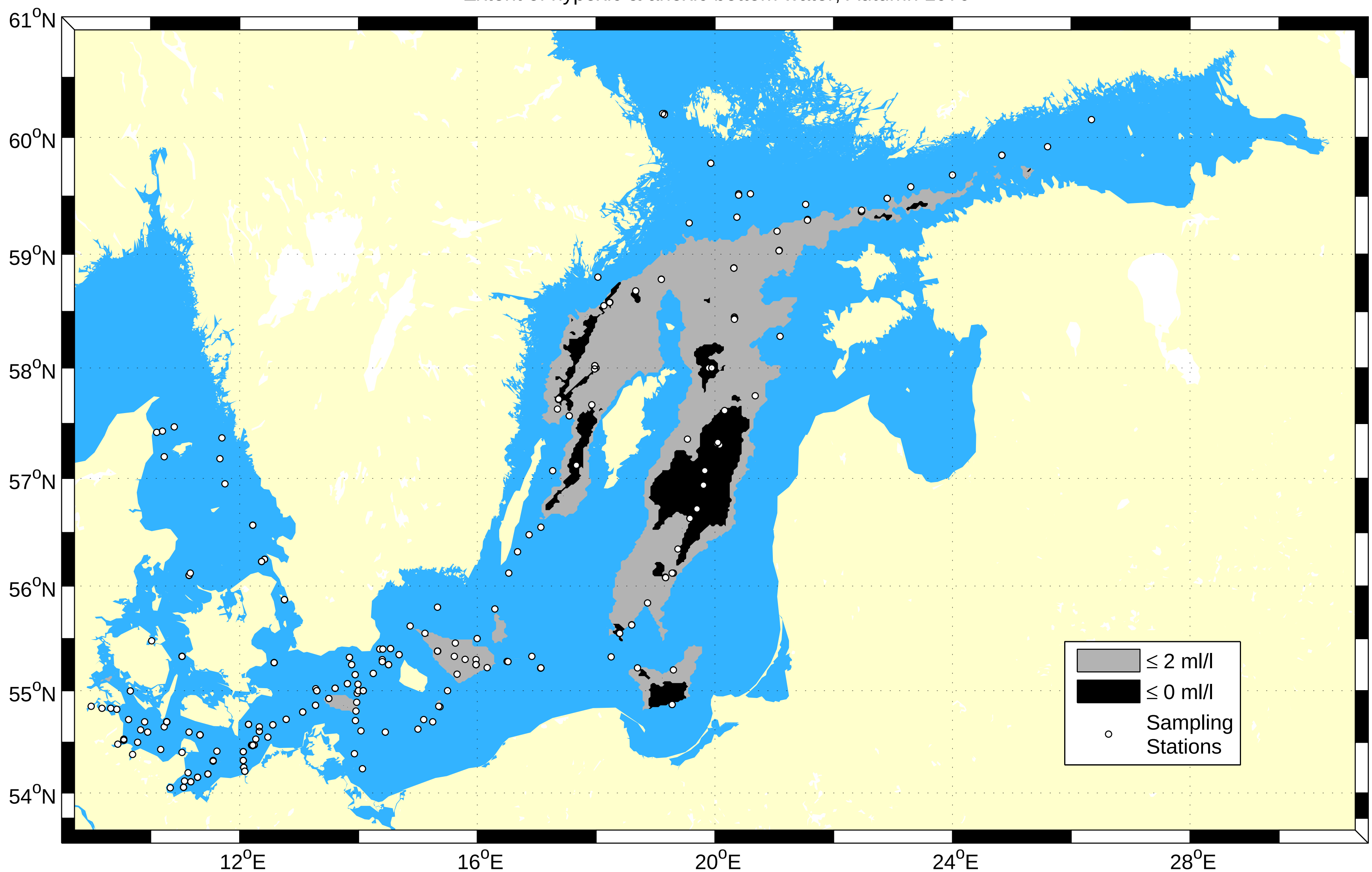
Extent of hypoxic & anoxic bottom water, Autumn 1981



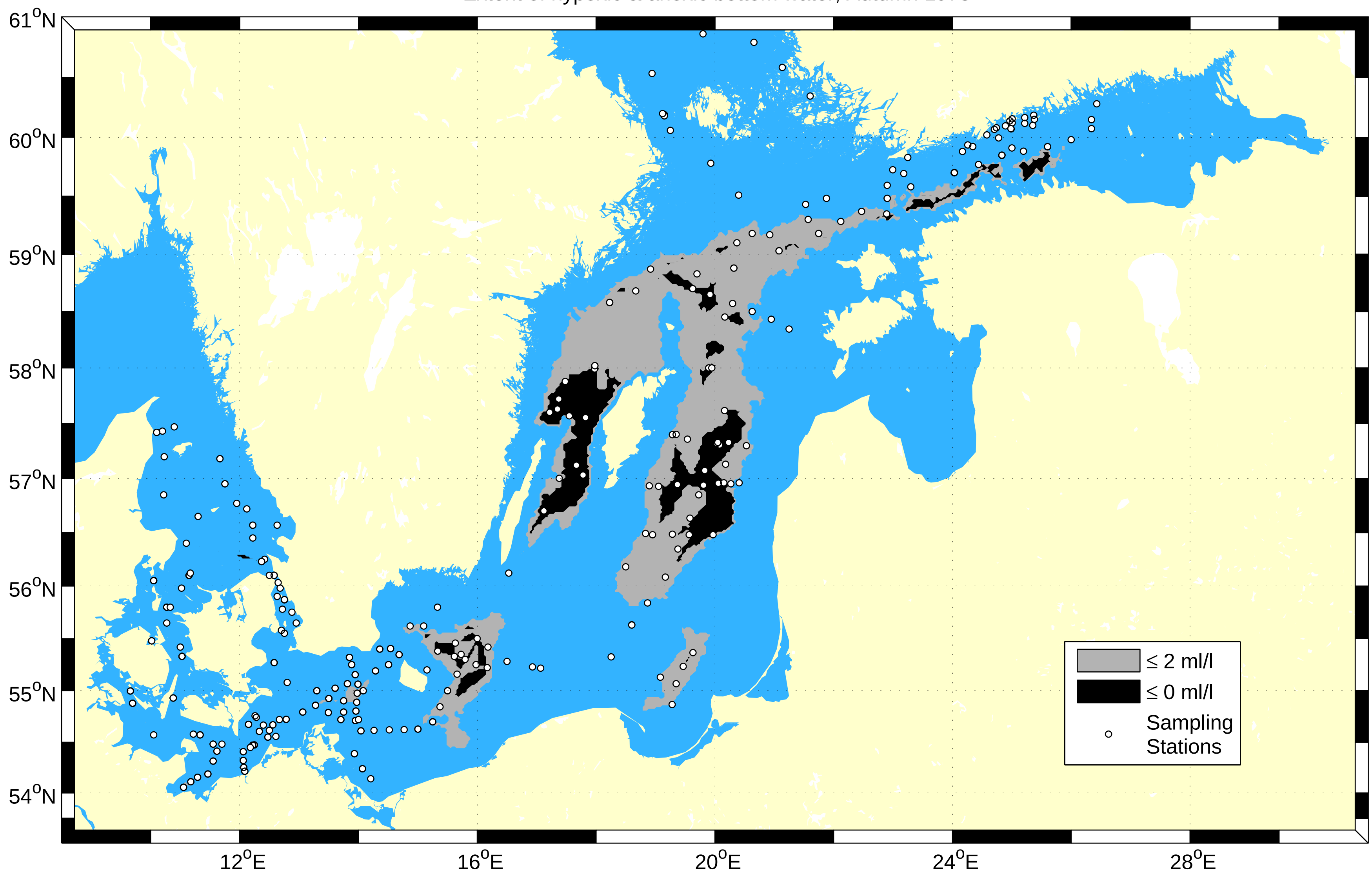
Extent of hypoxic & anoxic bottom water, Autumn 1980



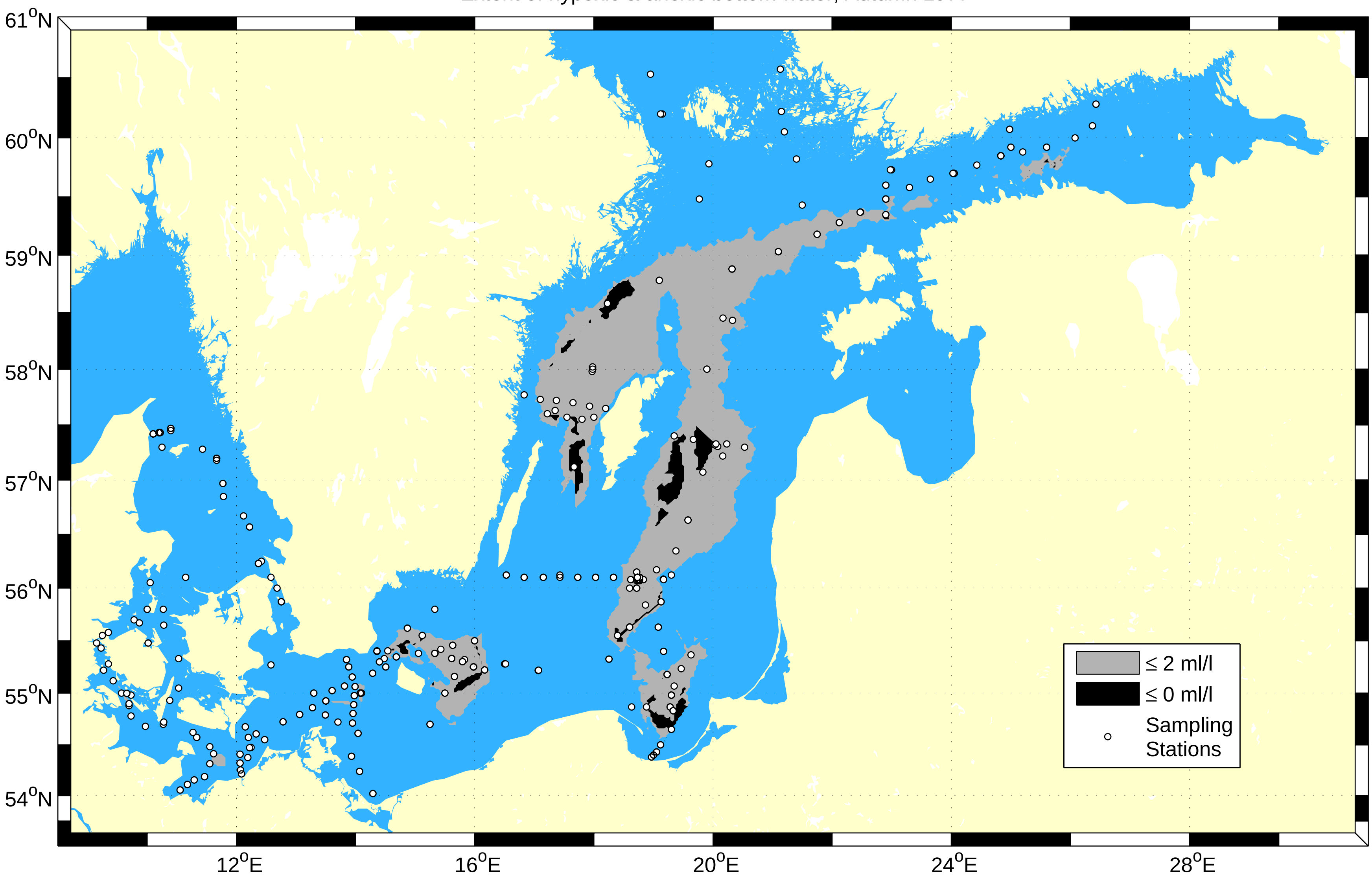
Extent of hypoxic & anoxic bottom water, Autumn 1979



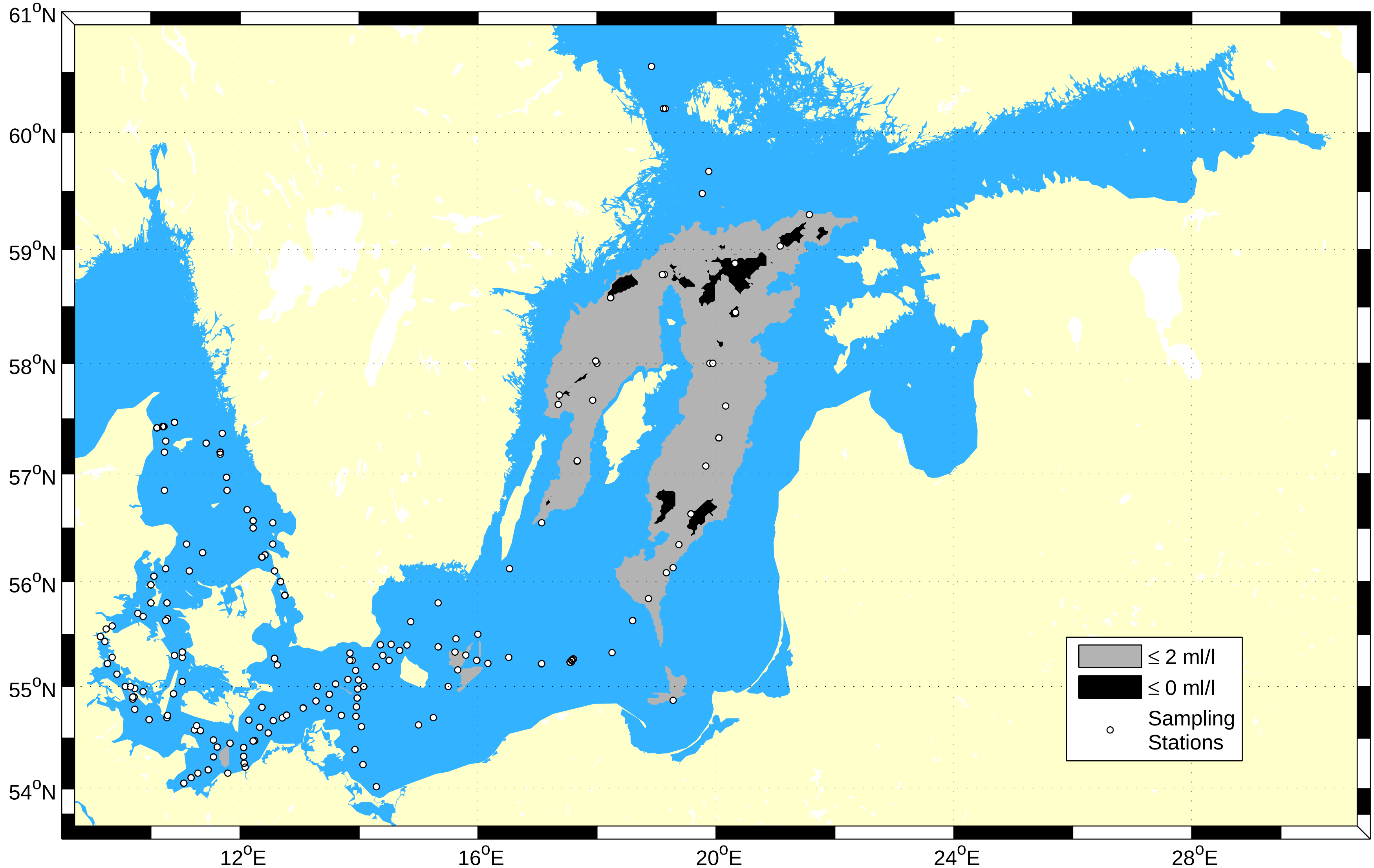
Extent of hypoxic & anoxic bottom water, Autumn 1978



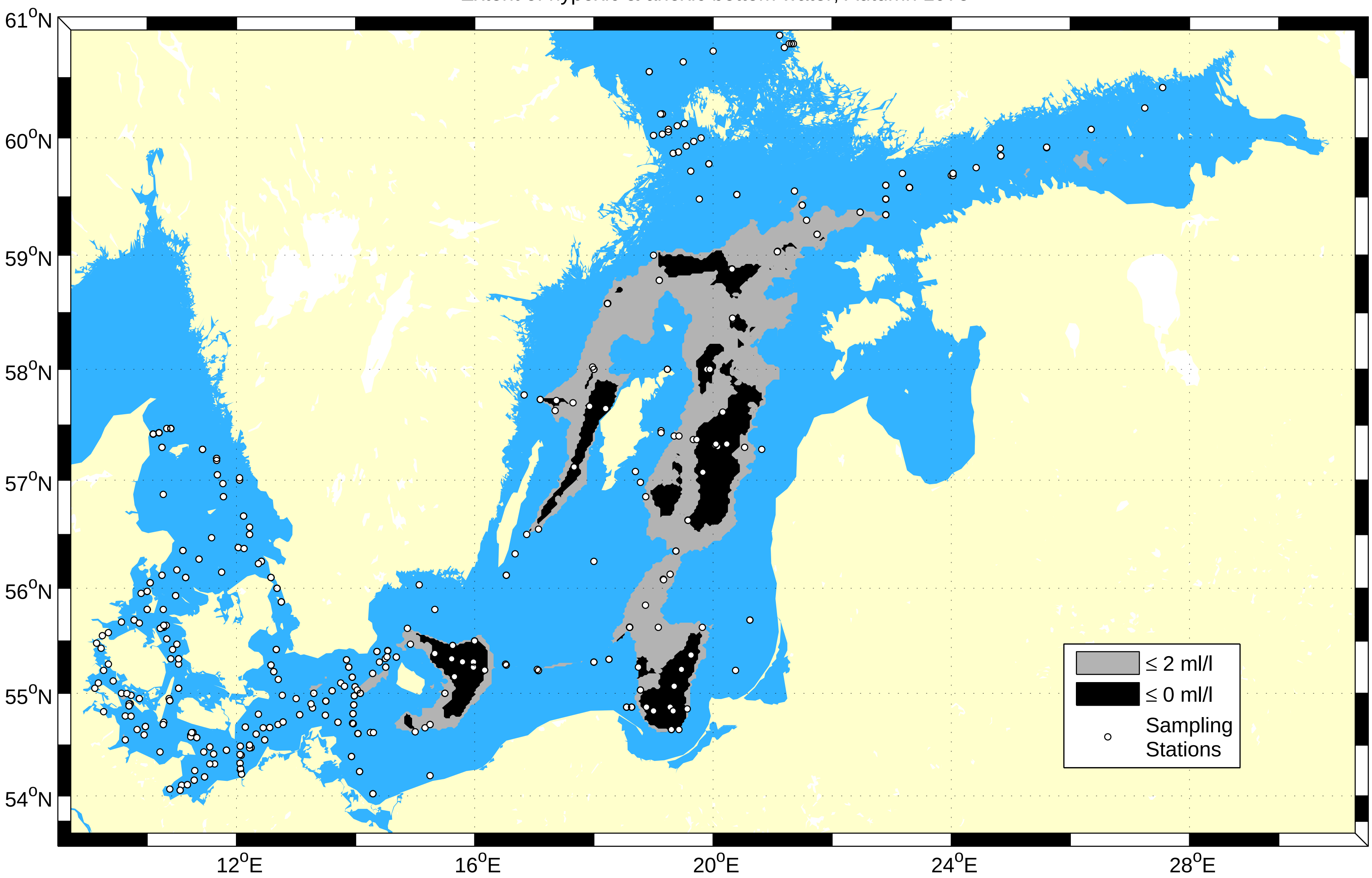
Extent of hypoxic & anoxic bottom water, Autumn 1977

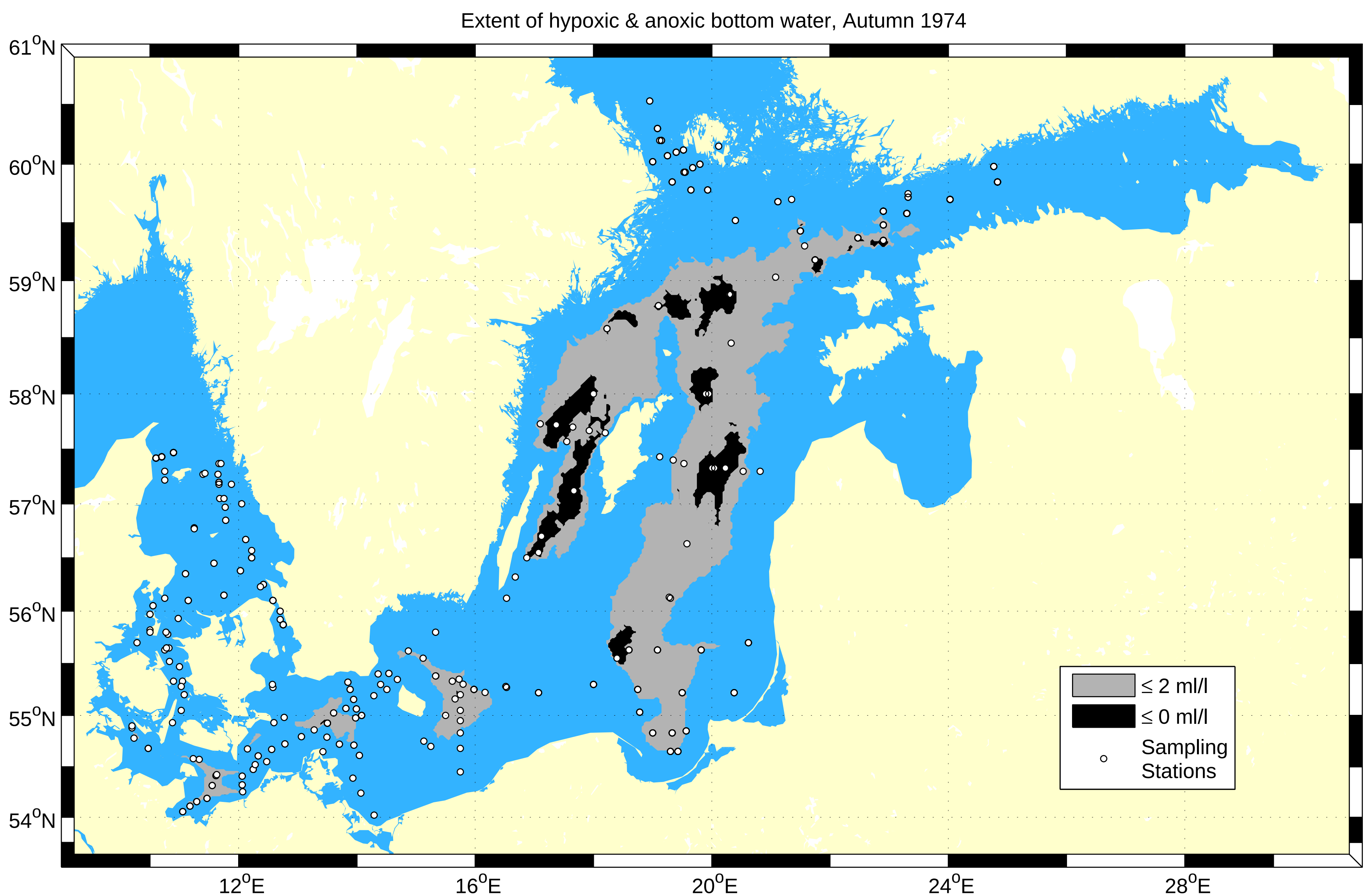


Extent of hypoxic & anoxic bottom water, Autumn 1976

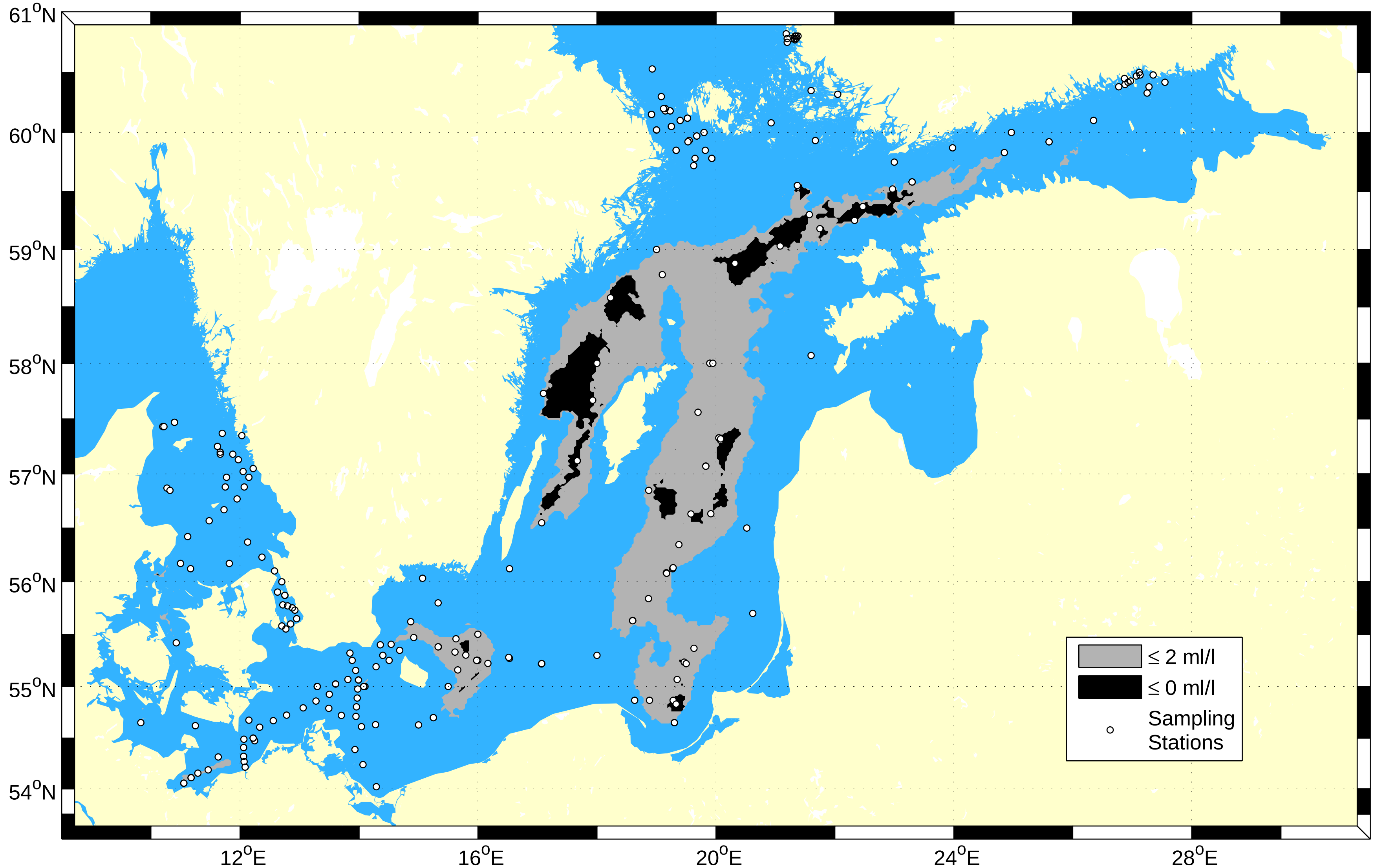


Extent of hypoxic & anoxic bottom water, Autumn 1975

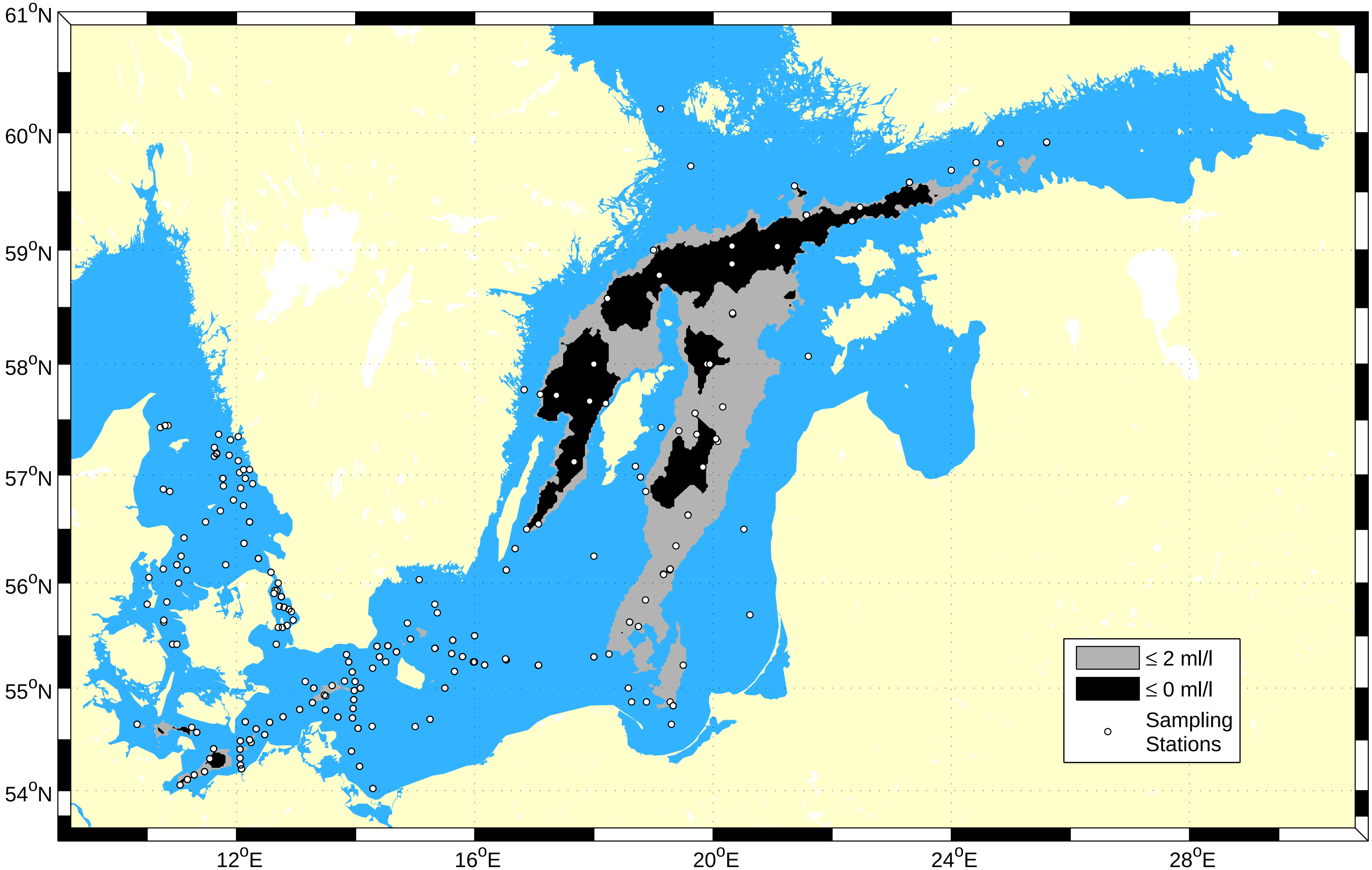



Extent of hypoxic & anoxic bottom water, Autumn 1974
61°N
60°N
59°N
58°N
57°N
56°N
55°N
54°N
12°E
16°E
20°E
24°E
28°E
≤ 2 ml/l
≤ 0 ml/l
Sampling
Stations

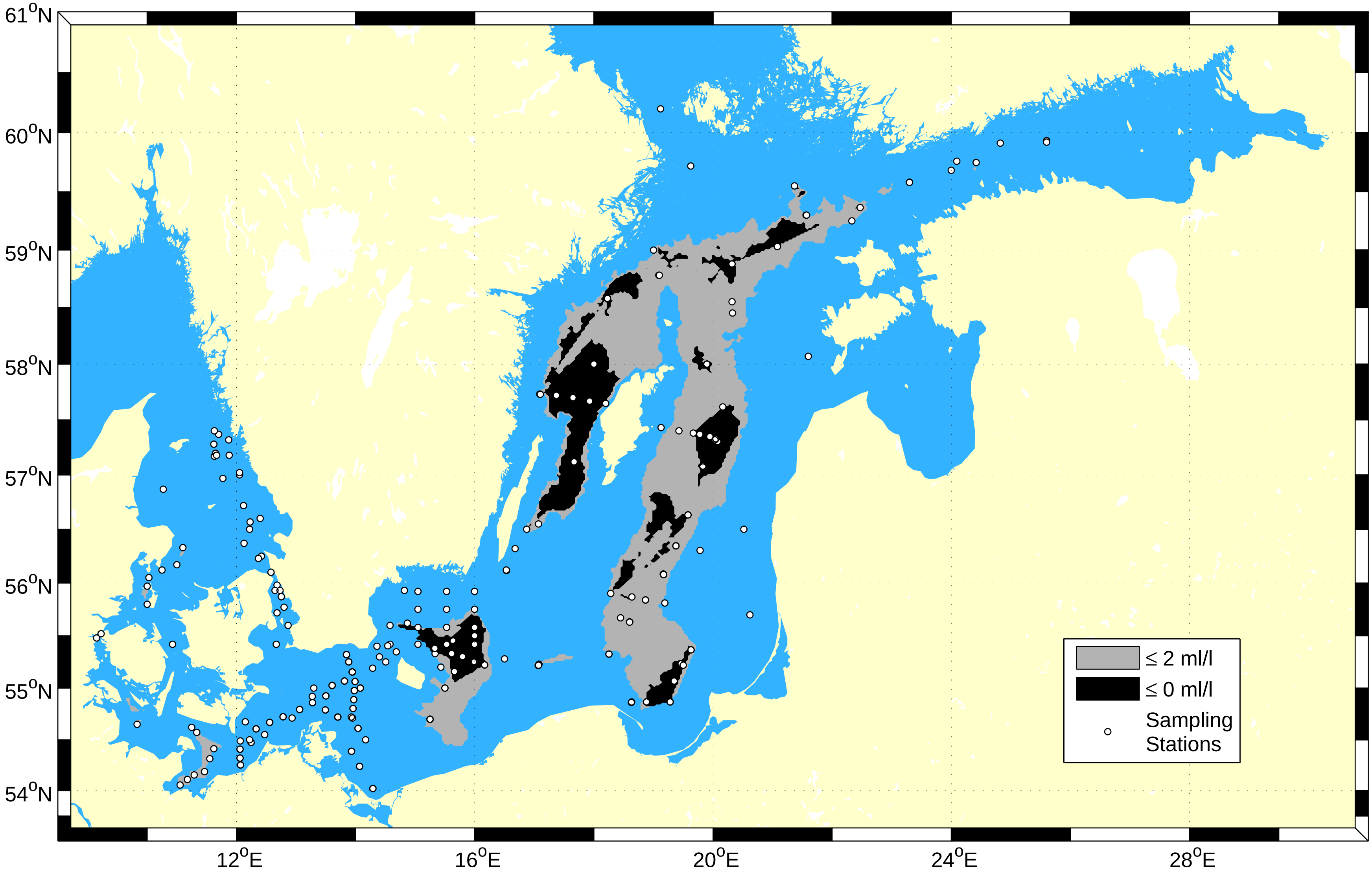
Extent of hypoxic & anoxic bottom water, Autumn 1973



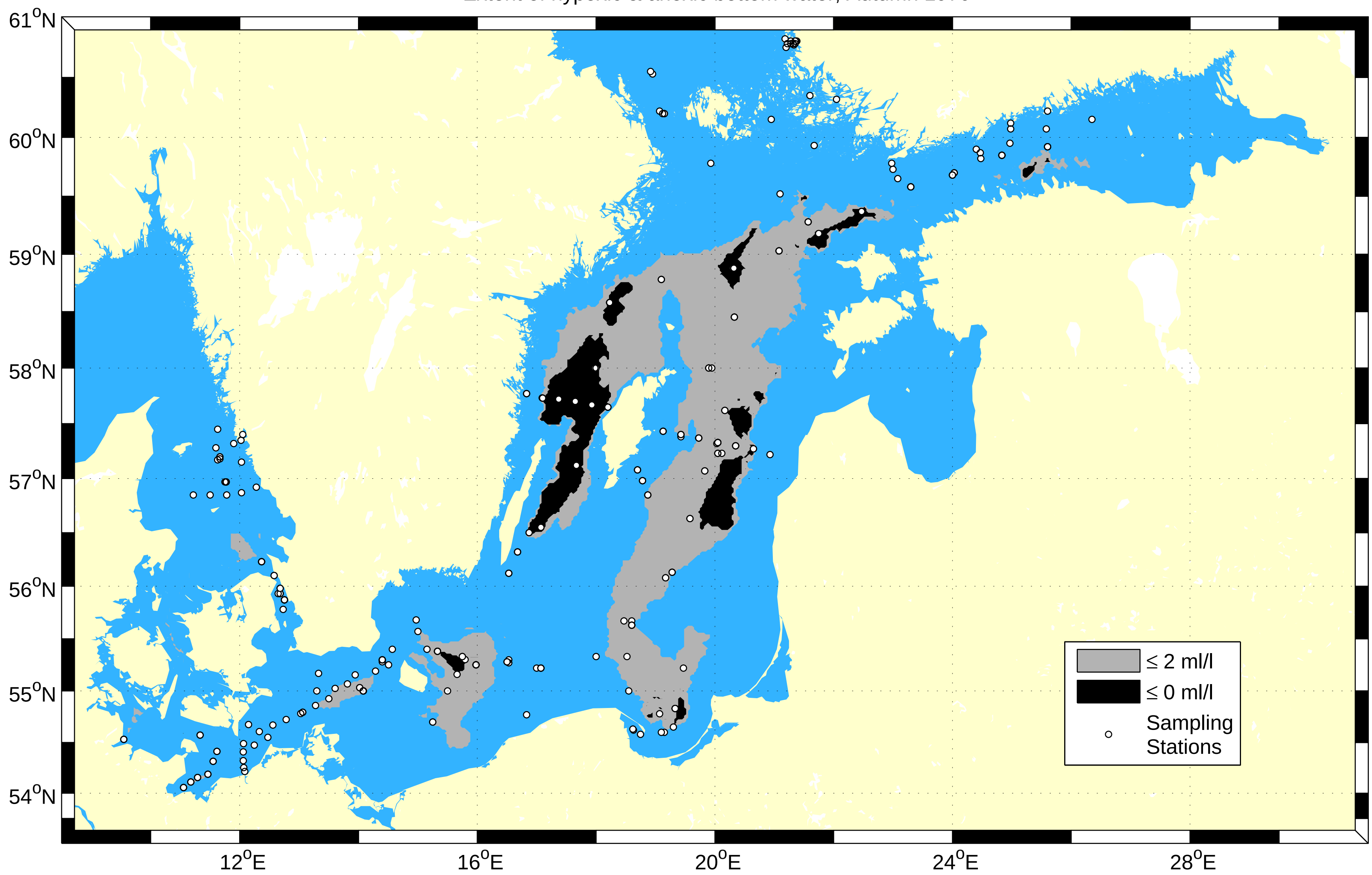
Extent of hypoxic & anoxic bottom water, Autumn 1972



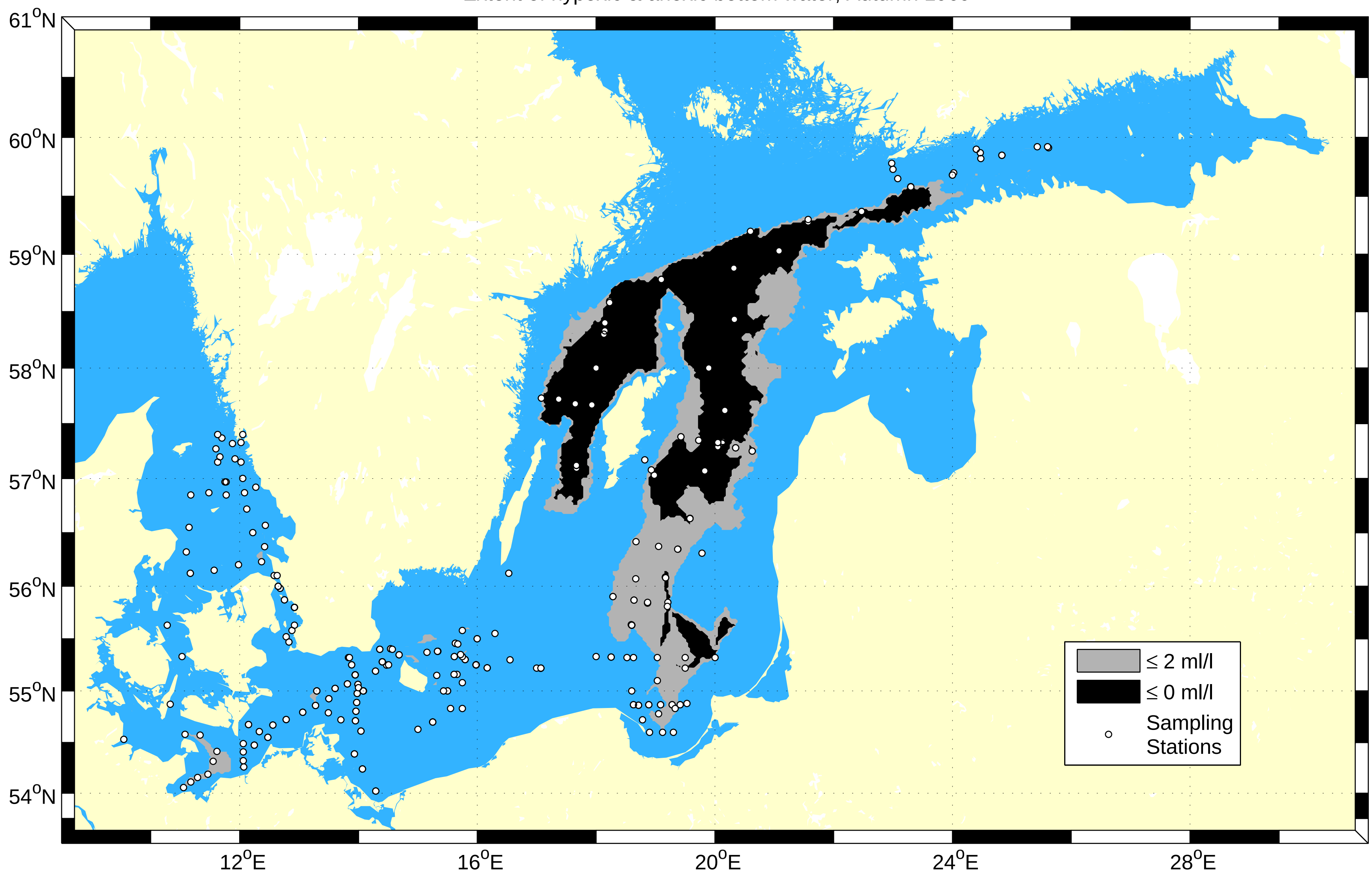
Extent of hypoxic & anoxic bottom water, Autumn 1971



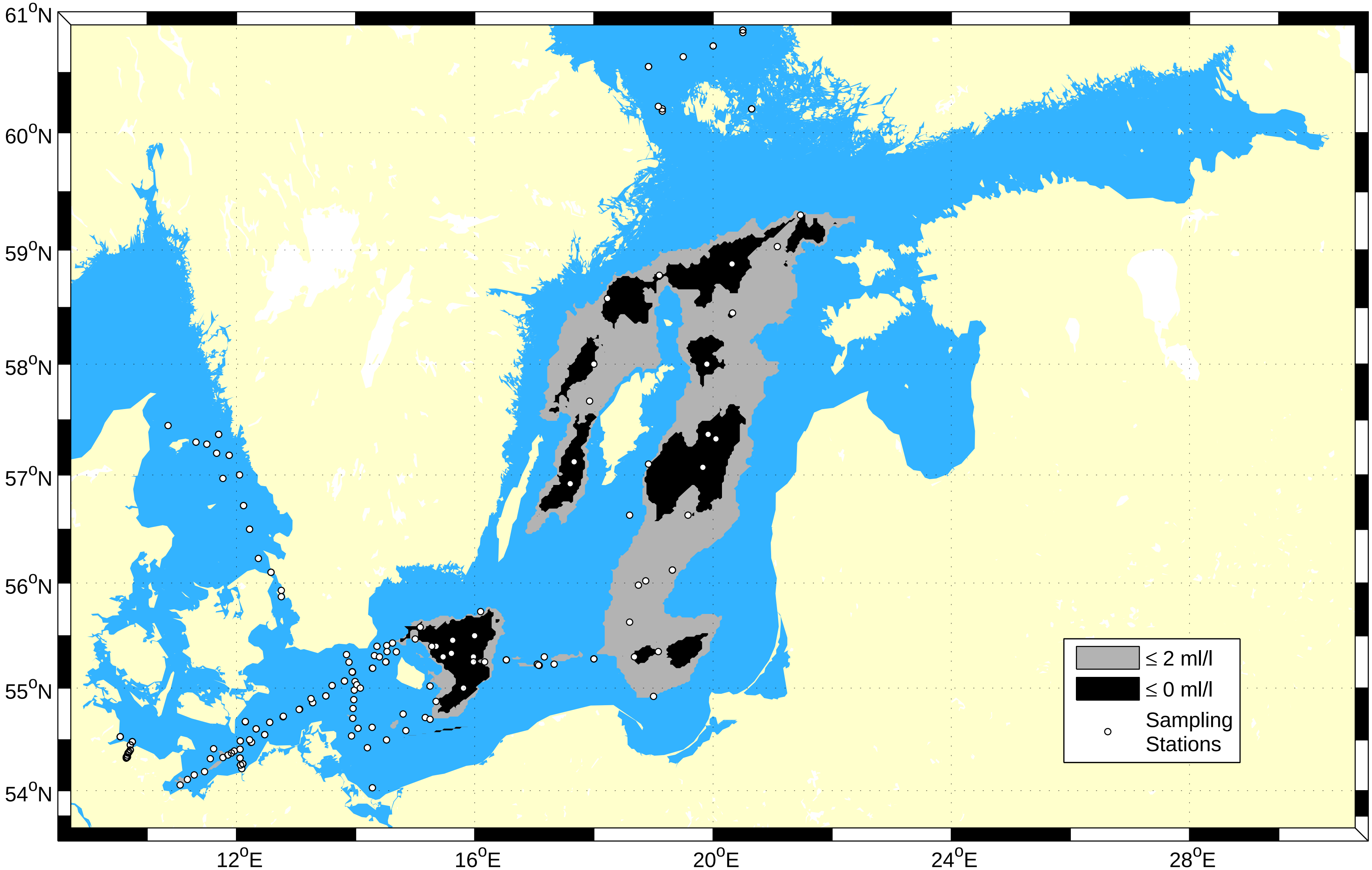
Extent of hypoxic & anoxic bottom water, Autumn 1970



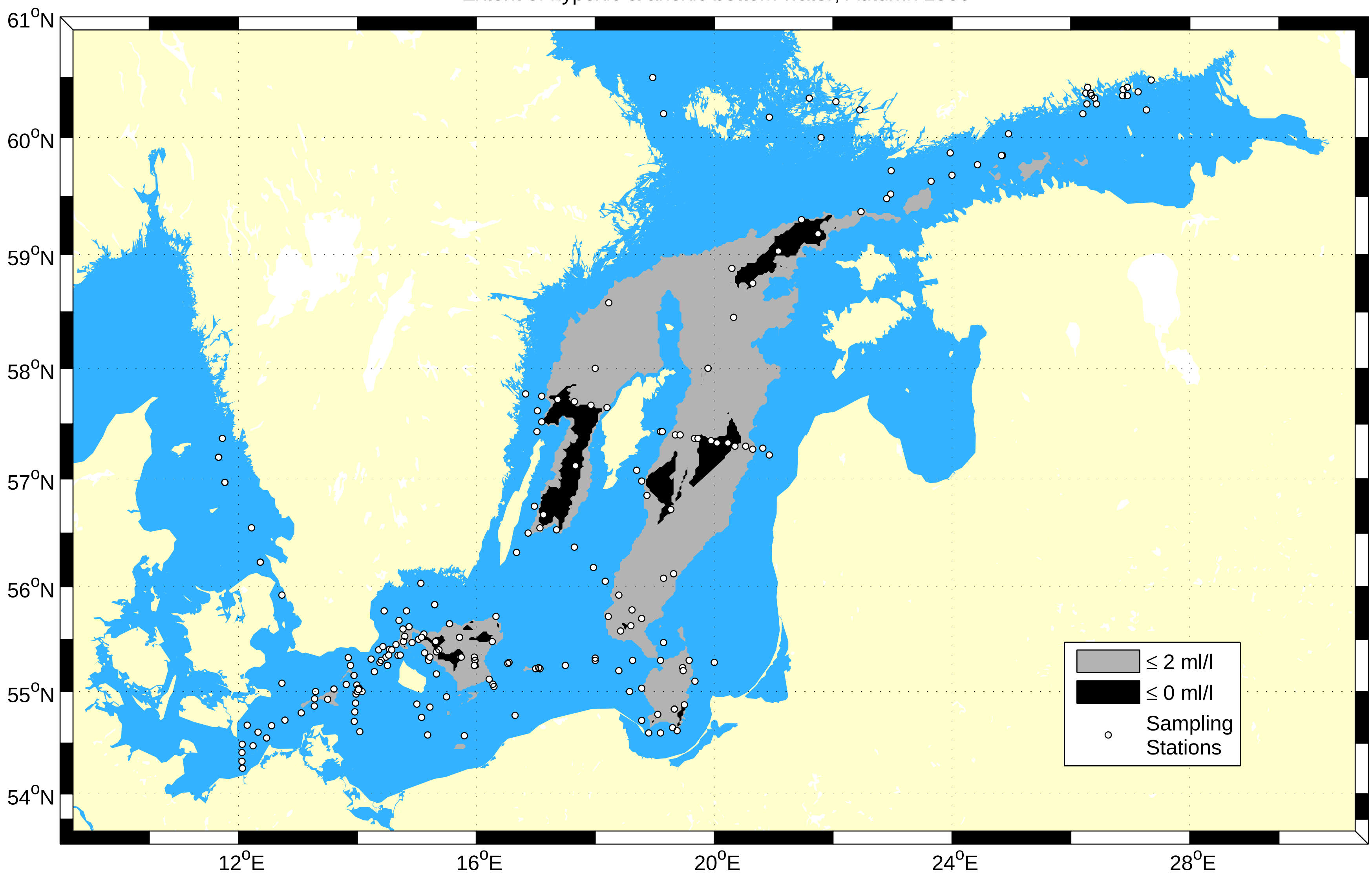
Extent of hypoxic & anoxic bottom water, Autumn 1969



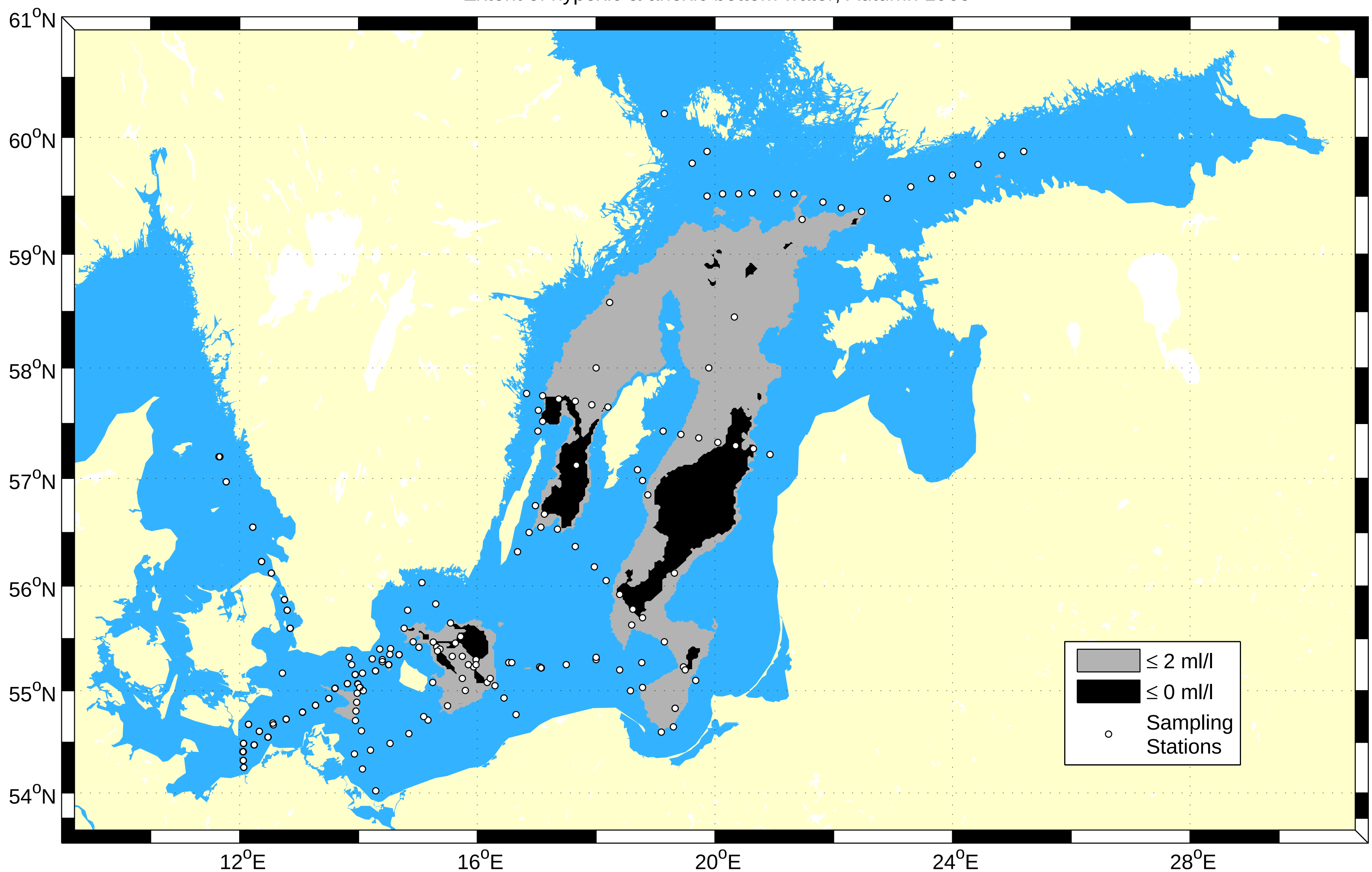
Extent of hypoxic & anoxic bottom water, Autumn 1968



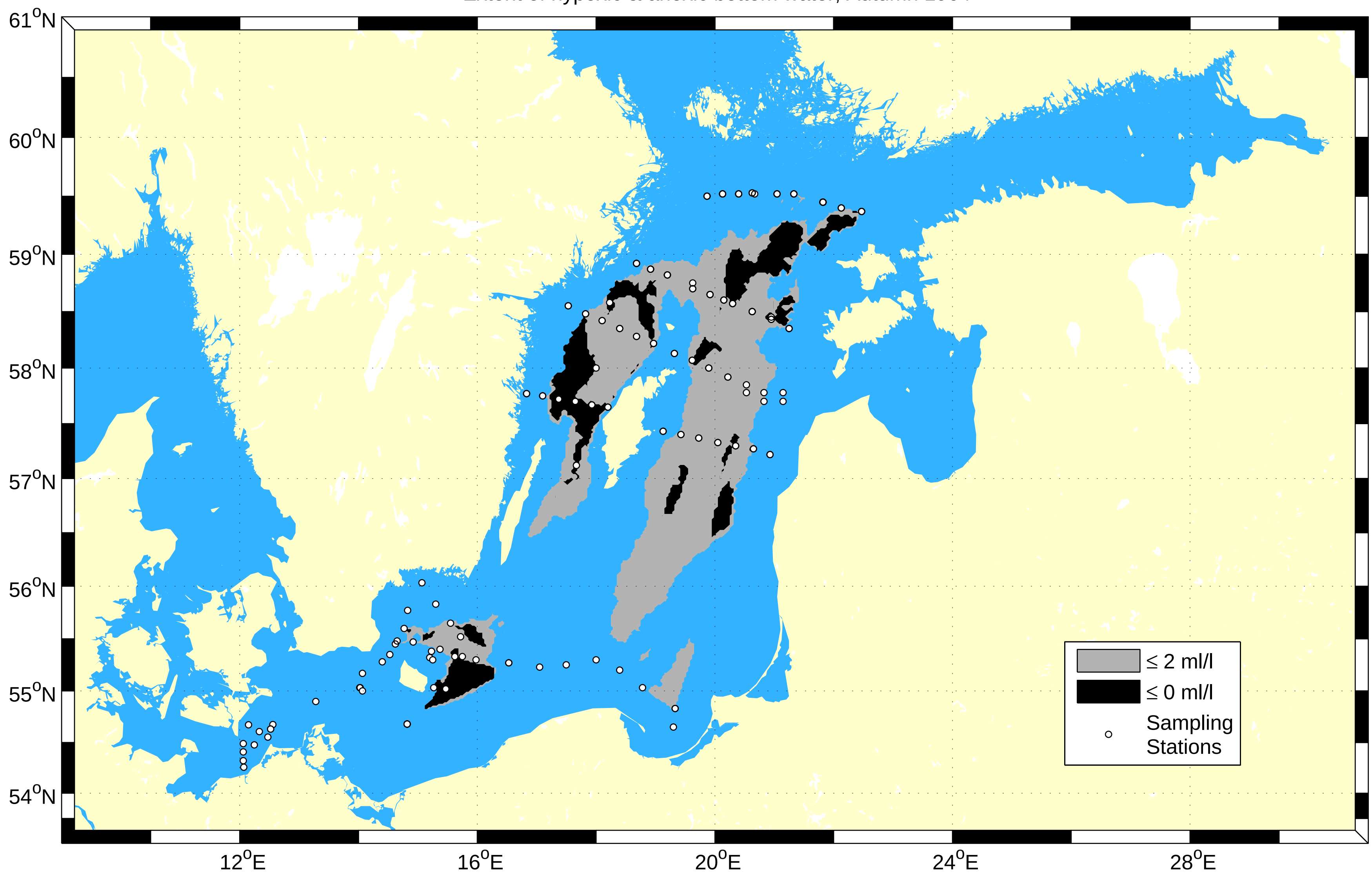
Extent of hypoxic & anoxic bottom water, Autumn 1966



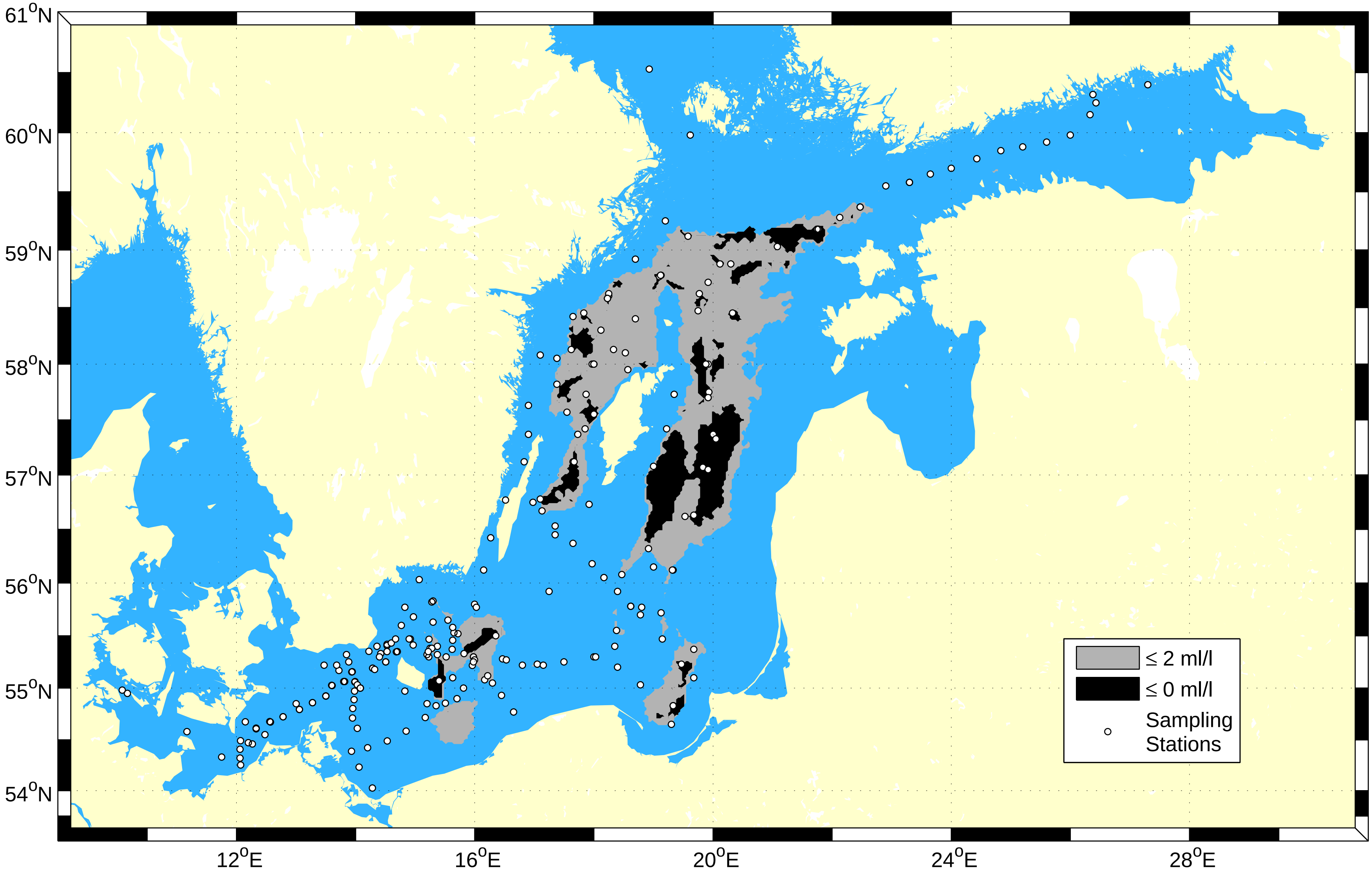
Extent of hypoxic & anoxic bottom water, Autumn 1965



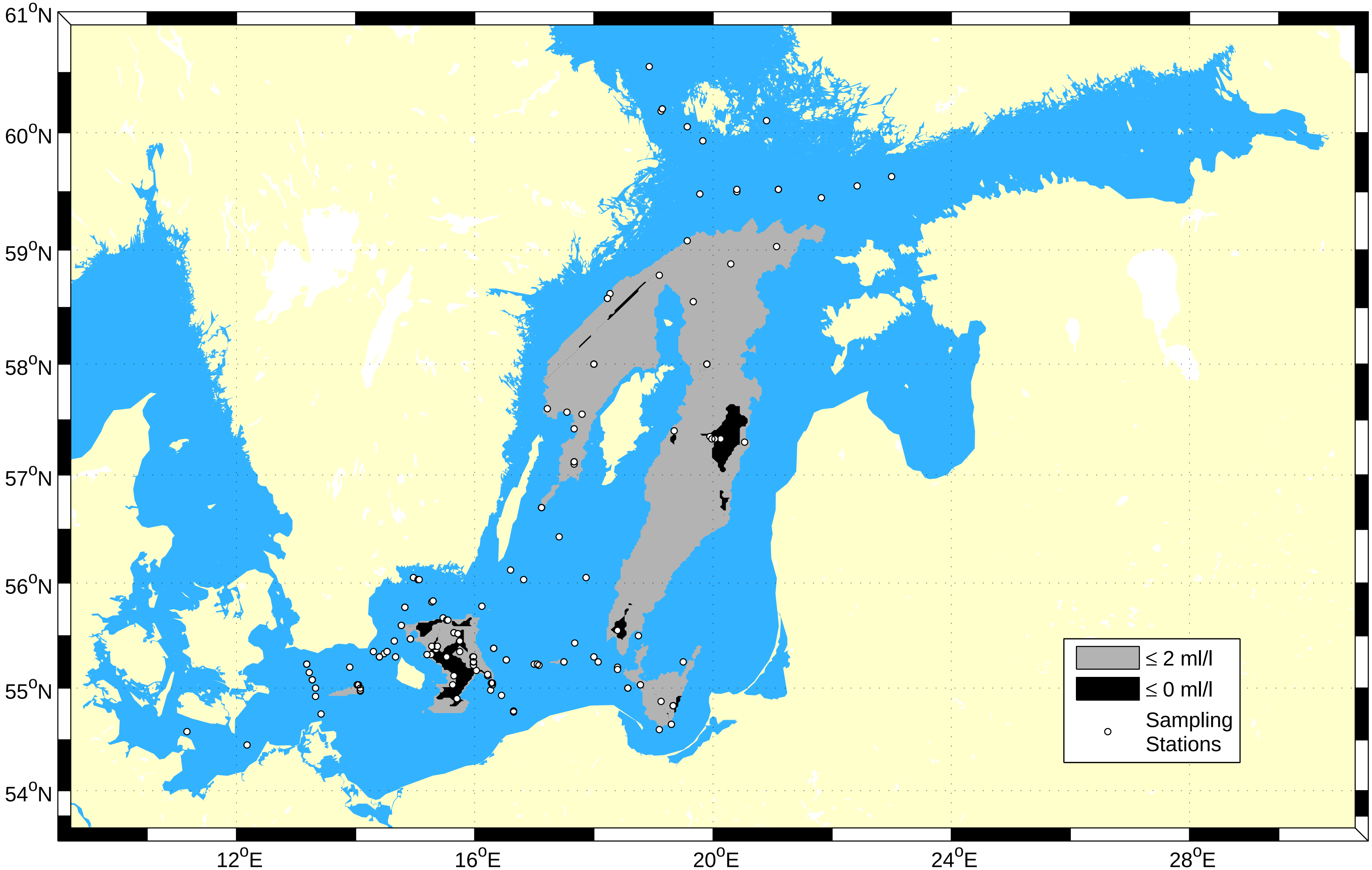
Extent of hypoxic & anoxic bottom water, Autumn 1964



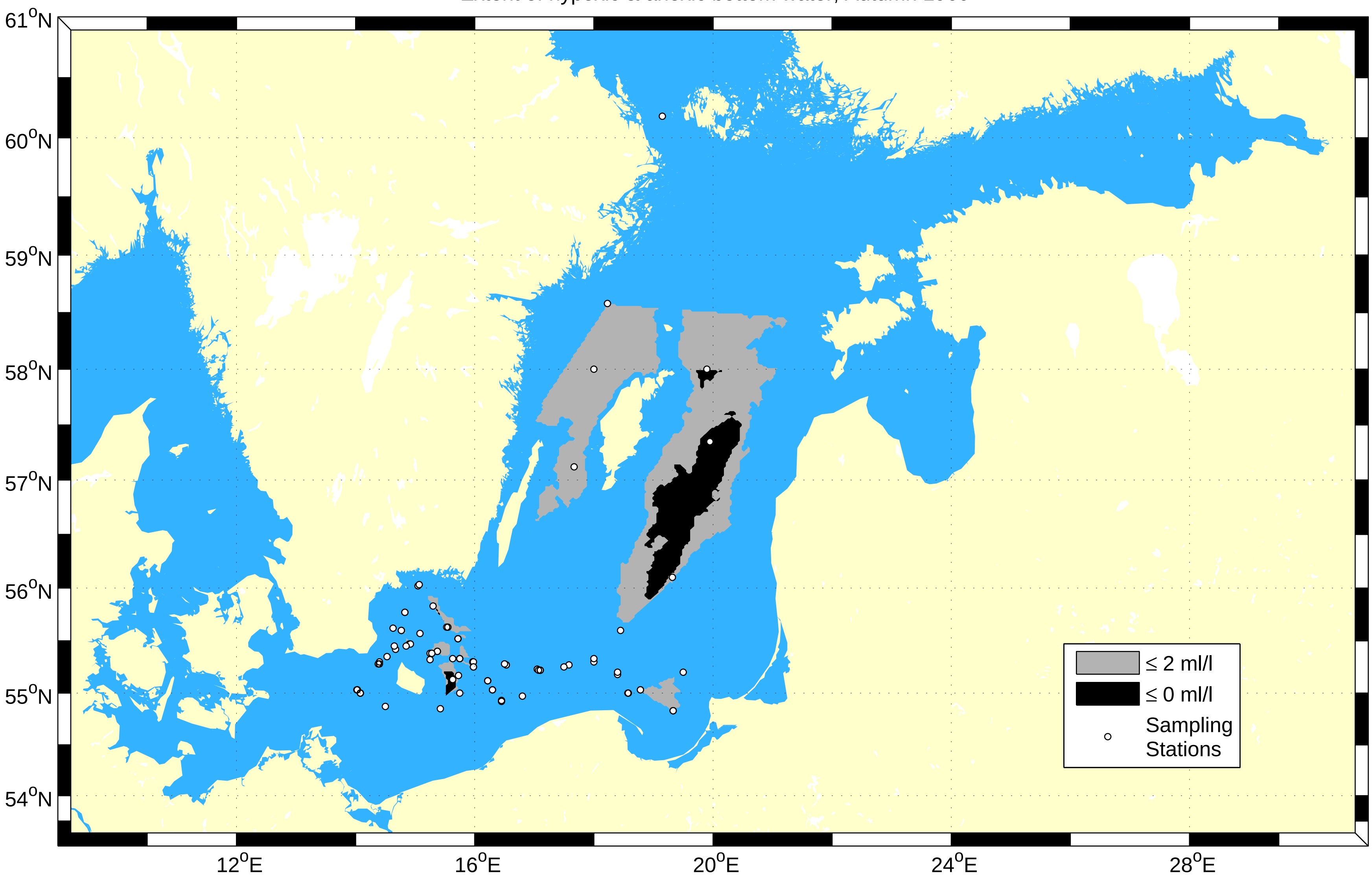
Extent of hypoxic & anoxic bottom water, Autumn 1963



Extent of hypoxic & anoxic bottom water, Autumn 1962



Extent of hypoxic & anoxic bottom water, Autumn 1960



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