REPORT OCEANOGRAPHY No. 78, 2024

The Swedish National Marine Monitoring Programme 2023

Hydrography, Nutrients, Phytoplankton

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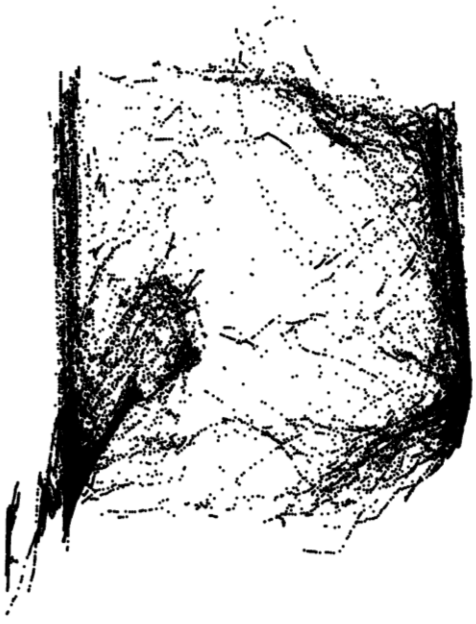

Front: TS-plot from CTD-profiles made by SMHI during 2023. Image is produced with ODV (Schlitzer, Reiner, Ocean Data View, https://odv.awi.de, 2024).

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Summary

The temperatures in the surface layer were above normal in January, February (Figure 1), June and September. In August the surface temperature was below normal at many stations and for the rest of the year the surface temperature was generally normal. The minimum temperatures in the surface layer in 2023 were reached in March in Skagerrak, Kattegat and the Baltic Proper. In the Gulf of Bothnia, the maximum ice extent was reached in March and water temperatures remained low until May. By May 28, 2023, the ice had completely melted, and the 2022-2023 ice season was classified as mild. The next season, 2023-2024, started early on October 23, 2023.

Temperatures above normal were measured in the deep and intermediate waters in the Baltic Proper. In the Baltic Proper the temperature in the deep waters show an increasing trend and the temperature in the bottom water is record high.

The nutrient surveys in winter showed that the concentrations of dissolved inorganic nitrogen were below normal in the Baltic Proper and the Bothnian Bay, whereas silicate and phosphate were above normal in the Bothnian Bay. The latter is consistent with a trend of increasing phosphate and silicate concentration in the Bothnian Bay. The nutrients decreased during the spring bloom. In 2023, the spring bloom started in February in the Kattegat and March at the Skagerrak stations, with high biomasses and chlorophyll concentrations. At N14 Falkenberg the summer biomass was dominated by dinoflagellates. In the Baltic Proper the spring bloom occurred between the March and April cruises. In the Bothnian Sea the spring bloom occurred in April with a consequently drop of inorganic nitrogen to levels near the detection limit in May. In the Bothnian Bay the levels did not drop until July due to the later spring bloom. At station NB1/B3 in the Bothnian Sea, an unusual autumn bloom occurred in October.

The largest areas of cyanobacteria surface accumulations occurred during the last week of June. In August, the storm Hans caused nutrients to come up towards the surface and become available making the cyanobacteria blooms start all over and continue until mid-September.

No new inflows occurred that could renew the deep water, and therefore concentrations of nutrients in the deep basins of the Baltic Proper continued to increase during 2023. The deep waters show increasing concentrations of nutrients as well as hydrogen sulphide. The concentrations of both ammonium and hydrogen sulphide are at record high levels in both the eastern and western Gotland basins.

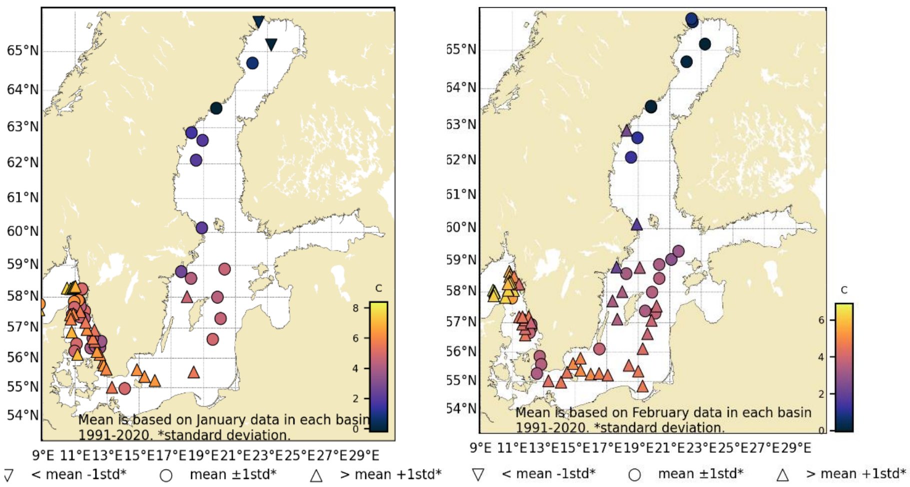


Figure 1. Surface (0-10m) temperature in January (left) and February (right), 2023.

Sammanfattning

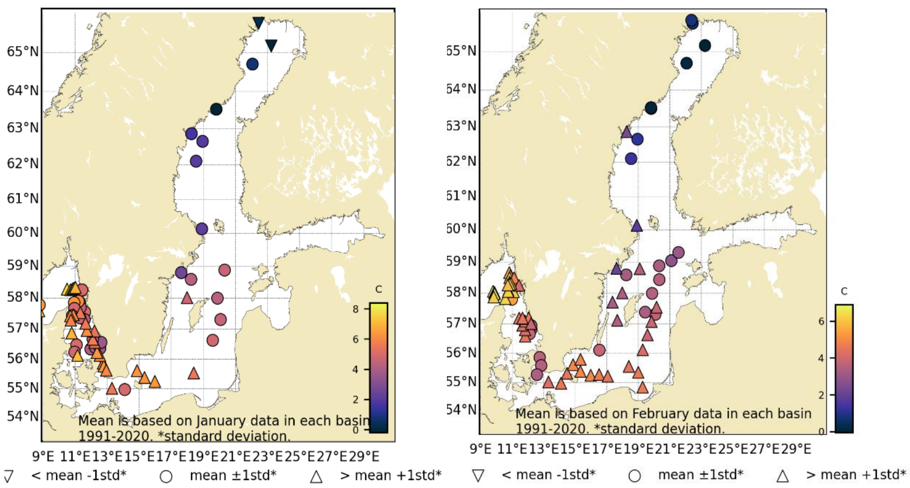
Temperaturen i ytskiktet var över det normala i januari, februari (Figur 1), juni och september. I augusti var yttemperaturen under det normala vid många stationer och under resten av året var yttemperaturen generellt normal. De lägsta temperaturerna i ytskiktet under 2023 uppmättes i mars i Skagerrak, Kattegatt och Egentliga Östersjön. I Bottniska viken nåddes den maximala isutbredningen i mars och det fortsatte vara kallt i vattnet fram till maj. Den 28 maj 2023 hade isen smält helt, och issäsongen 2022—2023 klassificerades som mild. Nästa säsong, 2023—2024, började tidigt den 23 oktober 2023.

Temperaturer över det normala uppmättes i de djupa och intermediära vattnen i Egentliga Östersjön. I Egentliga Östersjön visar temperaturen i de djupa vattnen en ökande trend och temperaturen i bottenvattnet är rekordhög.

Näringsämnesundersökningarna under vintern visade att koncentrationerna av löst oorganiskt kväve var under det normala i Egentliga Östersjön och Bottenviken, medan kisel och fosfat var över det normala i Bottenviken. Detta överensstämmer med en trend av ökande fosfat- och kiselkoncentrationer i Bottenviken. Näringsämnena minskade under vårblomningen. År 2023 började vårblomningen i februari i Kattegatt och i mars vid stationerna i Skagerrak, med hög biomassa och höga klorofyllkoncentrationer. Vid N14 Falkenberg dominerades sommarbiomassan av dinoflagellater. I Egentliga Östersjön inträffade vårblomningen mellan expeditionerna i mars och april. Vårblomningen skedde i april i Bottenhavet med en efterföljande minskning av oorganiskt kväve till nivåer nära detektionsgränsen i maj. I Bottenviken minskade nivåerna inte förrän i juli på grund av den senare vårblomningen. En ovanlig höstblomning med hög biomassa förekom vid station NB1/B3 i Bottenhavet i oktober.

Den största ytansamlingen av cyanobakterier inträffade under sista veckan i juni. I augusti orsakade stormen Hans att näringsämnen fördes upp mot ytan och blev tillgängliga, vilket gjorde att blomningen av cyanobakterier började om och fortsatte till mitten av september.

Inga nya inflöden inträffade som kunde förnya djupvattnet, och därför fortsatte koncentrationerna av näringsämnen att öka i de djupa bassängerna i Egentliga Östersjön under 2023. Djupvattnen visar ökande koncentrationer av näringsämnen såväl som svavelväte. Koncentrationerna av både ammonium och svavelväte är på rekordhöga nivåer i både östra och västra Gotlandsbassängerna.



Figur 1. Yttemperaturen (0-10m) i january (vänster) och februari (höger), 2023.

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1 The monitoring programme – history and development

The current Swedish marine monitoring programme of the pelagic has been in place since 1994, with only smaller changes. The focus of the programme has been eutrophication and oxygen deficiency since the end of the 1970's. Historically, the programme focused on fisheries hydrography, while biological parameters were added later. Phytoplankton and chlorophyll were added in the 1980's and extended zooplankton sampling was introduced in 2007. The data from the Swedish marine monitoring are widely used in research and management for e.g. trend analysis, modelling, climate studies and assessments for EU directives such as the Water Framework Directive 2000/60/EC (WFD)[1] and the Marine Strategy Framework Directive 2008/56/EC (MSFD)[2]. The long timeseries with high quality data from fixed positions has been essential for the understanding of the Swedish seas and development of the current models used for both research and management of our open seas.

In 1991 SMHI published an investigation of the Swedish marine monitoring programme, its station network and sampling frequency (Rahm et al 1991[3]). In 1992 an international evaluation panel recommended implementation of the changes suggested by SMHI (SNV Report 4170[4]) and a revised monitoring programme started in 1994. This led to significant changes, mainly in the frequency of cruises. The number of cruises were increased while the number of stations were decreased. This was mainly done to achieve time series with a frequency and length that is suitable for trend analysis. Most stations are now sampled monthly and additional stations are sampled at high frequency (bi-weekly) in all basins. The high frequency stations were introduced to better monitor changes in biological parameters that change rapidly, especially during spring and summer.

In addition to the monthly and high frequency stations, a denser network of stations was set up to map winter nutrient pools to allow estimates of the potential spring phytoplankton production. Winter nutrient mapping is normally done in the Skagerrak and the Kattegat in January, in the Baltic Proper in February, while in the Gulf of Bothnia mapping has usually been performed in December. Nutrient mapping in the Skagerrak is done during the International Bottom Trawl Survey (IBTS Q1, quarter 1) and positions for sampling vary from year to year.

In the Kattegat and the Baltic Proper, where oxygen deficiency had been documented during parts of the year, an autumn mapping of oxygen was also started with the revision of the programme 1994. For the oxygen mapping there are no fixed stations, instead stations vary from year to year. The oxygen mapping is performed in combination with fisheries cruises led by Swedish University of Agricultural Sciences (SLU). In the Baltic Sea oxygen is mapped during the Baltic International Acoustic Surveys (BIAS) programme in September-October, while the oxygen mapping in the Kattegat is done during the IBTS Q3 (quarter 3). The oxygen mapping, with focus on the deep water

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[1] Water Framework Directive

[2] Marine Strategy Framework Directive

[3] Rahm L., Sjöberg B., Håkansson B., Andersson L., Fogelqvist E., 1991. *Utredning om Optimering av utsjö-monitoringprogrammet vid SMHI.*

[4] Report / Swedish Environmental Protection Agency, ISSN: 0282-7298 ; 4170, 1993. *Swedish National Marine Monitoring Programme, Report of an Evaluation Panel.* Stored at the library of SwAM.

is performed during the autumn because it is the season with the most severe oxygen deficiency. Since many countries around the Baltic Sea also perform BIAS-cruises in their national waters and take oxygen samples during these cruises, the coverage of autumn oxygen data is generally good and the combined results from all countries are presented in a separate annual SMHI report on the oxygen situation[5]. The good spatial resolution of oxygen data during the most severe period of the year is essential for the calculations of the maximum extent of anoxic and hypoxic bottoms in the Baltic Sea.

In recent years coastal stations have been added to the programme. In 2007 two coastal stations were added to support the work associated with the EU Water Frame Work Directory; N14 Falkenberg (Kattegat) and Ref M1V1 (Baltic Proper). The latter station was excluded from the program in 2023 and replaced by the station BY39 Ölands södra udde. The replacement station is part of the winter monitoring and represent the transition area between the Western Gotland Basin and the Hanö Bay/Bornholm Basin. Recently two stations have been added on the west coast to monitor the gradient from the Gullmar fjord to the open sea. The two new stations are Alsbäck (in the fjord) and BroA (outside the sill). Together with the station Släggö they represent the gradient from fjord to archipelago. Also, in the Baltic Proper, stations have been added to represent a gradient from coast to open sea. The station H4 in Himmerfjärden together with B1 and BY31 represent the gradient in the area. In the Bothnian Sea two coastal stations have been added, U19 Norra Randen (NR) north of Stockholm and Gavik-1 in the northern part of the Bothnian Sea. In the Bothnian Bay two stations have been added, Råneå-1 and Råneå-2. A full description of the current national monitoring programme of the pelagic, is published by the Swedish Agency for Marine and Water Management[6], in Swedish.

In addition to the national pelagic programme, municipalities and counties perform monitoring in coastal waters. In the open sea there are also several fixed platforms mainly run by SMHI, including wave buoys, coastal buoys and one offshore buoy. One cabled platform is operational in the Sound between Denmark and Sweden. SMHI and the Swedish maritime administration are also responsible for a network of stations measuring sea water level. Many of these stations also measure surface water temperature.

The first oceanographic measurements in Swedish waters were performed on the initiative of Gustav Ekman who in 1877 initiated a mapping of all Swedish seas with the warships HMS Alfhild and HMS Gustav af Klint. The data from this first mapping were not analysed until 1901 by Otto Petterson. Otto Petterson was the permanent secretary of the Hydrographic-biologic commission 1901-1930 and the initiator of the formation of the International Council for the Exploration of the Sea (ICES). In 1948 the Hydrographic-biologic commission became the National board of fisheries (Fiskeristyrelsen) with the main aim to explain what oceanographic conditions controlled the variations in herring stocks. The first Swedish research vessel R/V Skagerrak I was used and the measurements were mainly salinity, temperature and oxygen. Stations were sampled at 1-2 cruises per year and after a few years alkalinity and pH were added to the measurements. In the 1950's, the frequency of cruises increased and from 1958 the Swedish monitoring became part of an internationally coordinated sampling effort.

[5] Hansson M., Viktorsson L., Oxygen Survey in the Baltic Sea 2023 - Extent of Anoxia and Hypoxia, 1960-2023, REPORT OCEANOGRAPHY No. 76, 2024

[6] Beskrivning av delprogrammet Fria vattenmassan version 3:1 2019-02-04, Havs- och vattenmyndigheten

During the 1960's nutrients entered the picture; first phosphorus, then nitrogen and finally silica. However, the frequency was still variable between years. During some periods the measurements were only performed during summer and in others only in spring. This makes it difficult to create continuous time series and trend analyses with data from this period. Furthermore, conditions are relatively more stable in the deep basins of the Baltic Sea than in surface waters and for these areas data from the deep basins are better fitted for long trend analysis. Although the frequency still varied between one and three visits per year, the network of stations was roughly the same as today. At the end of the 1960's monitoring became more structured; the Skagerrak and the fjords were visited 4 times per year, the Kattegat and the Sound five times per year, the Baltic Proper four times per year and the Bothnian Bay two times per year. Sampling was made of both physical and chemical parameters as well as biological, including bottom fauna.

1969-1970 was the International Baltic Year and this is why many of the station still have names starting with BY. In 1978 the Programme for Environmental Control (Programmet för Miljökontroll, PMK) was started and the following year HELCOM started its Baltic Monitoring Programme (BMP). The Swedish commitment in BMP 1979 included nutrients, oxygen, salinity and temperature and all countries around the Baltic Sea started sharing data. The programme continued until 1993 when it was revised as described above. The current programme is part of Sweden's commitment within HELCOM and OSPAR.

2 Performance in 2023 and description of the current programme

The marine monitoring programme of the pelagic in Sweden currently consists of 36 standard stations distributed in the seas surrounding Sweden, deep blue and red dots in Figure 2. The visiting frequency is monthly at most standard stations (blue) but bi-weekly at six stations (red). Concentrations of winter nutrients in the surface layer (light blue) and oxygen during autumn (white) are mapped once per year at additional stations.

The number of visits at the standard stations during 2023 is presented in Figure 3. Most stations were sampled as planned or with only 1 or 2 visits cancelled due to weather conditions. Cancellations due to weather conditions were, January BY38; BY39, October BY31, BY29, N14 Falkenberg. In Skagerrak the stations Å14 and Å16 profiles from the ship-board CTD are in the process of being replaced by profiles from the Moving Vessel Profiler on R/V Svea and profiles from this instrument are not included in the count in Figure 3. From most cruises there are complementary profiles every 5th minute from Å13-Å17. There were 17 visits instead of the planned 24 to the station Anholt E in Kattegat, since the station is only sampled bi- monthly when the SMHI cruise with R/V Svea start and stops in Lysekil on the west coast and during the IBTS cruises in February and August/September. In 2023 SMHI cruises on Svea with start and stop in Lysekil were only made possible in January, April and August.

During 2023 Stockholm university was not able to sample at the stations BY29 in the Northern Baltic Proper. SMHI could cover a few of the missing visits to BY29 (March, July, August, September) and for 2024 the plan is that SMHI cover all 12 visits to the station. SMHI also visited BY31 in March, June, July, August and September to help cover the high frequency sampling at the station during the production season, the visits were made in conjunction with service of the ocean buoy at Huvudskär.

After the test in December 2021 to perform a joint cruise with SMHI and Umeå Marine Sciences Centre (UMSC) on board R/V Svea, this was continued 2022 and 2023 and is now a well-established cooperation. This cruise cover both the stations in the nutrient survey of the Gulf of Bothnia as well as the regular monthly sampling from the UMSC part of the national programme.

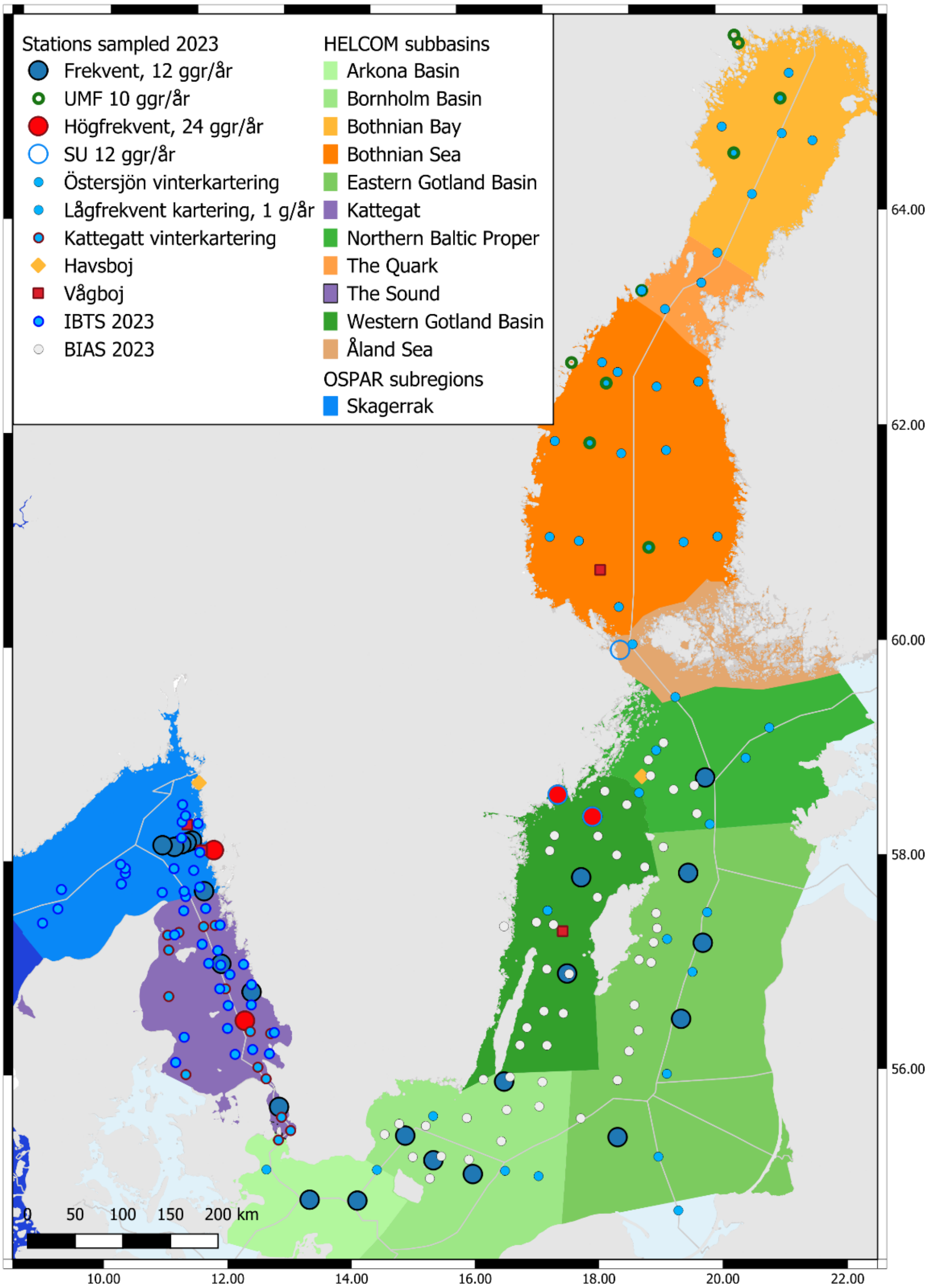

Figure 2. Map of the visited stations in the national monitoring programme during 2023. Blue: stations visited monthly, red: stations visited two times per month or more frequently, white: stations visited for oxygen mapping during BIAS, light blue: stations visited for nutrient mapping.

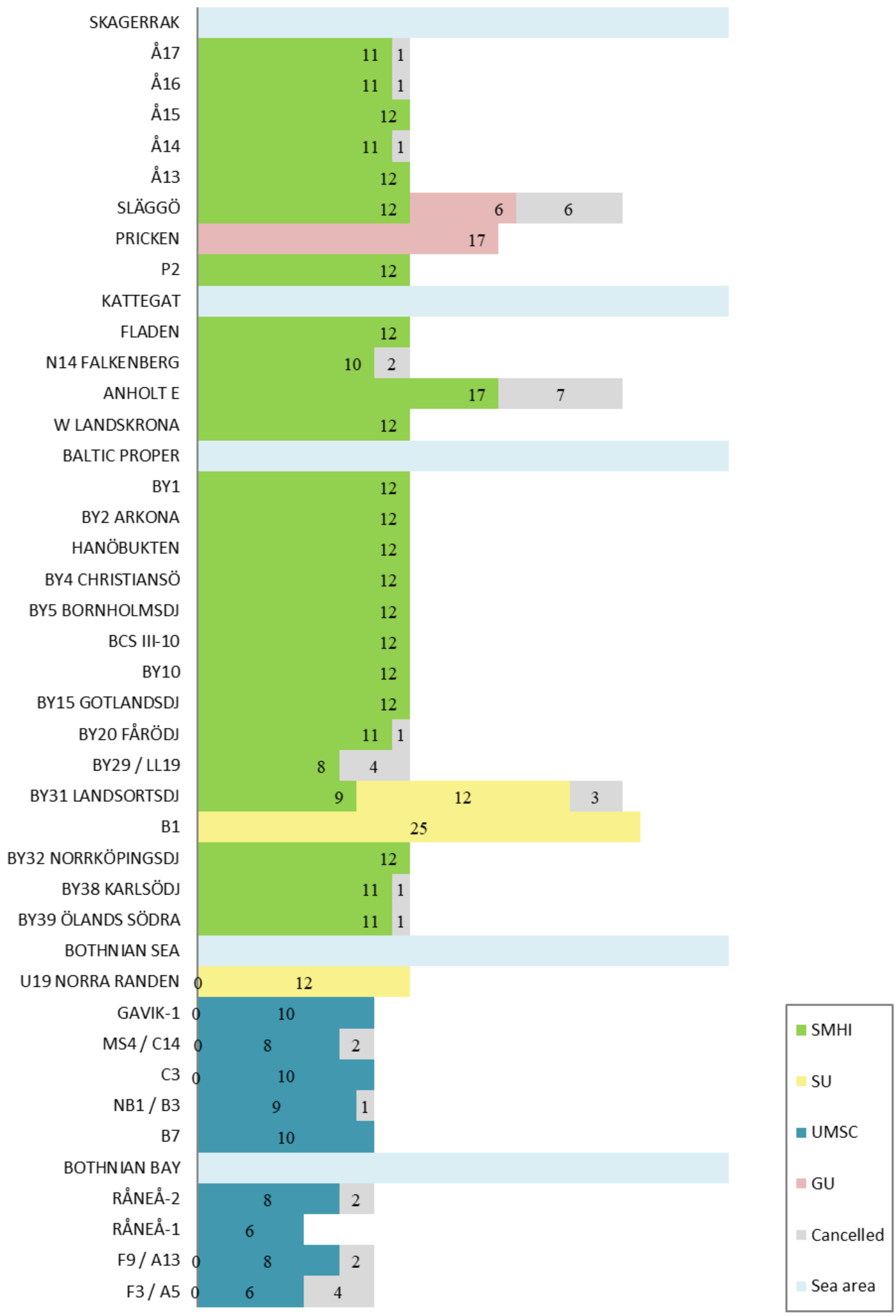

Figure 3. Number of visits at each standard monitoring station during 2023.The stations with a zero at the y-axis represent the stations that were sampled jointly by SMHO and UMF in December. Station Pricken I sampled by GU as a replacement for station Släggö due to logistical reasons.

3 Weather 2023

3.1 Summary of the weather

The winter was overall normal, with slightly milder temperatures than usual in the south and northern Norrland, and slightly cooler in northern Svealand and southern Norrland. The only named storm during the winter was Otto, which moved in from the North Sea on February 17-18.

Spring started off chilly, with March being both cold and unstable. It also turned out to be a record wet month in some areas. April was dominated by high pressure systems with locally heavy rainfall. High pressure persisted into May, which was sunny, warm, and mostly dry.

Summer began with a very warm and dry June, followed by cooler and rainier weather. The notable weather event of the summer was the storm named Hans, which brought wind, thunder, and extensive rainfall during August 6-11.

Fall started with a record warm September, but October turned out to be colder than usual across the entire country. On October 21, the autumn storm named Babet swept in, causing high waves and water levels in the southern waters. November continued the trend of cold weather. The year's final weather event was the low-pressure system named Pia, which passed through southern Sweden on December 21-22, causing high water levels along the west coast.

For more detailed summaries of the year's weather, visit smhi.se[7].

3.2 Summary of the ice season

In the fall of 2022, the weather was mild, and the first sea ice of the 2022-2023 season was observed on November 17th. During January and February, the ice cover fluctuated back and forth in response to cold days and mild south and southwest winds in between. The maximum ice extent of the year was measured on March 12, 2023, at 81,000 km2. At that time, the Bothnian Bay, Northern Quark, the northernmost parts of the Bothnian Sea, and the eastern Gulf of Finland were covered with ice. By May 28, 2023, the ice had completely melted, and the 2022-2023 ice season was classified as mild. The next season, 2023-2024, started early on October 23, 2023.

For a detailed summary of the ice season, visit smhi.se[8].

4 Oceanographic conditions

Annual cycles of the surface water (0-10m), time series from 1960-2023 and nutrient content per basin are presented in Appendices I-III. In the text, reference to normal condition or normal values means the average +/- one standard deviation for the period 1991-2020. There is also extra material, as vertical profiles for each station from the stations sampled by SMHI, in the cruise reports available at the SMHI webpage[9].

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[7] https://www.smhi.se/klimat/klimatet-da-och-nu/arets-vader/aret-2023-mycket-nederbordsrikt-i-sodra-sverige-1.203029

[8] https://www.smhi.se/klimat/klimatet-da-och-nu/arets-vatten/havsis-vintern-2022-2023-1.201784

[9] Cruise reports from SMHI

The Swedish seas have large variations, especially in salinity, which gives the seas their different characteristics, Figure 4. The Skagerrak on the West Coast has almost open ocean salinities >30 psu, with lower salinities closer to the coast due to river runoff and the Baltic current bringing the outflowing Baltic water northward along the Swedish West Coast. The Baltic Proper has typical fjord-like hydrography with a strong stratification separating the deep water from the surface water. This makes the Baltic Proper naturally sensitive to increases in nutrient input leading to a eutrophic state and oxygen deficiency in the deep basins. The Gulf of Bothnia in the north is the less saline sea in Swedish waters with salinities <7 psu. It is an oligotrophic sea with different levels and ratios between nutrients than the Baltic Proper.

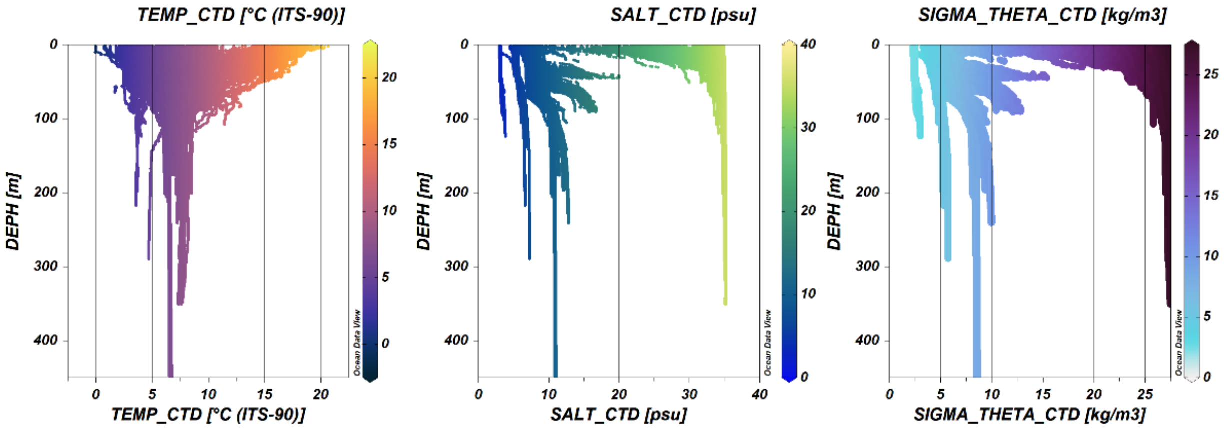

Figure 4. All temperature, salinity and density profiles from the SMHI monitoring cruises during 2023

To illustrate the highly variable seas around Sweden, a selection of parameters at stations from the different sea areas are presented in Figure 5 with mean values in the surface water (0-10 m) at each sampling occasion during 2023. Besides the difference in salinity mentioned above, other parameters also show differences between the areas. For example, the concentration of phosphate is much lower in the Bothnian Bay while the concentration of dissolved inorganic nitrogen is higher. It is also visible from the chlorophyll concentrations and the inorganic nutrients that the spring bloom occurs at different times.

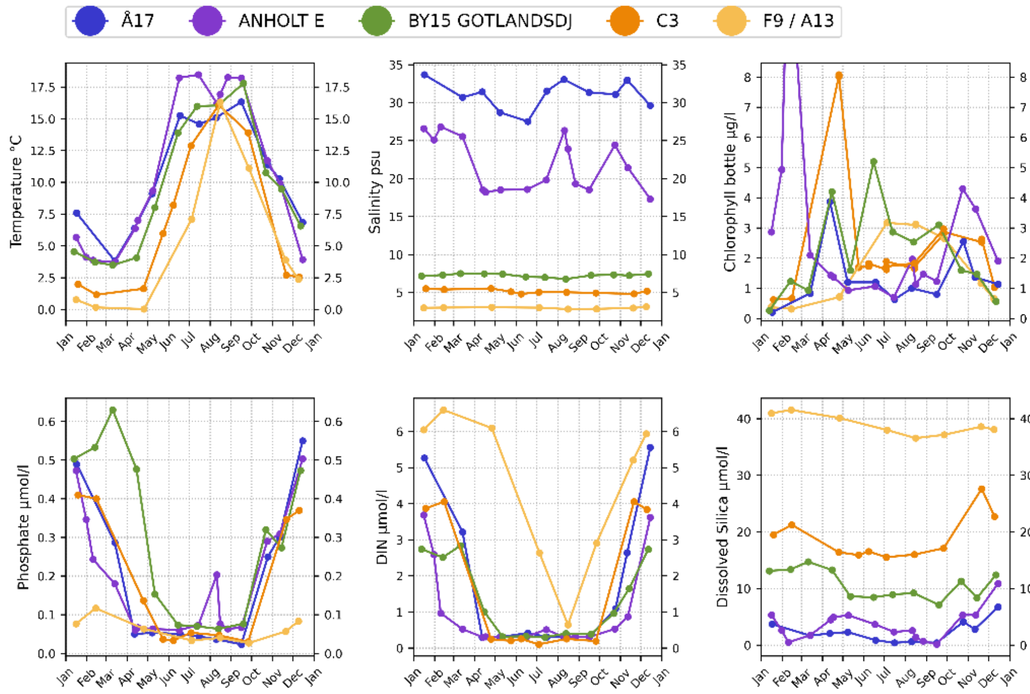

Figure 5. Temperature, salinity, chlorophyll, phosphate, dissolved inorganic nitrogen and dissolved silica from the different sea areas around Sweden: the Skagerrak (Å17), the Kattegat (Anholt E), the Baltic Proper (BY15), the Bothnian Sea (C3) and the Bothnian Bay (F9/A13). All parameters are mean values of surface water (0-10 m) during 2023.

4.1 Skagerrak, Kattegat and the Sound

4.1.1 Temperature and salinity

Surface water, 0-10 m

In both Skagerrak and Kattegat, the surface water at most stations was warmer than normal in January and February. In March, the temperature was normal, making it the coldest month before the warming of the surface water began. The coldest temperatures occurred closest to the coast, where it reached about 3 degrees, while in the open sea it was coldest around 4 degrees. The surface water temperature then remained normal until May. It was a somewhat unusual summer in terms of temperature. In June, the surface water had warmed up significantly, being warmer than normal at all stations, and at several stations, June was actually the month with the warmest surface layer during the summer, around 18 degrees. However, just below the surface, it is usually warmer than the average for 0-10 meters because a thermocline forms where heat gradually spreads downward into the water mass. The highest observed temperature was 20.5 degrees at station Å17 in June, at a depth of 1 meter. The summer month of July had normal temperatures, but in August it shifted to cold weather, and it was colder than normal at all stations. In September, it was again warmer than normal, and several stations had similar temperatures to those in June. By October-November, the surface water had cooled to normal temperatures, and by the last cruise of the year in December, it was colder than normal, reaching as low as 2 degrees.

The salinity of the surface water was mostly within the normal range, with annual average values around 30 psu in Skagerrak and 24 psu in Kattegat. In June, the salinity was lower than normal along the Å-transect. The surface salinity along the Å-transect often varies due to the location of Baltic current. In August, the salinity rose above normal due to the storm Hans, which stirred up the water.

Figure 6 below presents monthly measurements from one station in Kattegat and one in Skagerrak.

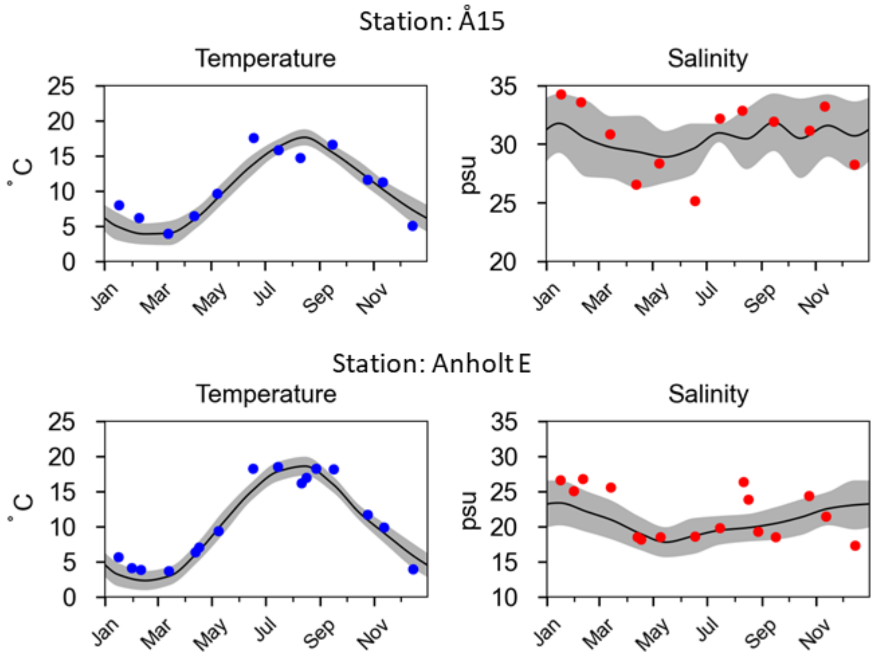

Figure 6 Surface(0-10 m) temperature (left) and salinity (right) at Å15 in the Skagerrak (upper panel) and at Anholt E in the Kattegat (lower panel). Monthly measurements (dots) during 2023 are shown in relation to the average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

Stratification

The stratification in the upper layer along the Å-transect in Skagerrak depends largely on the position of the Baltic current. However, in general, the surface layer was deepest at the beginning of the year when it was well-mixed down to 30 meters. In March, when it was coldest, the surface water cooled down to 15 meters. As the surface water warmed up, a thermocline formed. In June, the thermocline was at its shallowest, 5 meters, and coincided with a shallow halocline. In December, the winter had cooled just the first metres that had similar temperature as in March. Below this layer, there was still a layer of warmer water that remained from the summer.

There are typically small seasonal variations in the deep waters of Skagerrak. This is because of the effects of weather events such as fluctuations in air temperature and wind mixing, which does not reach that far below the surface layer. Along the Å-transect below 100 meters, the temperature was around 7-8 degrees Celsius, and the salinity was around 35 psu throughout the year, see Figure 7.

Station: Å15

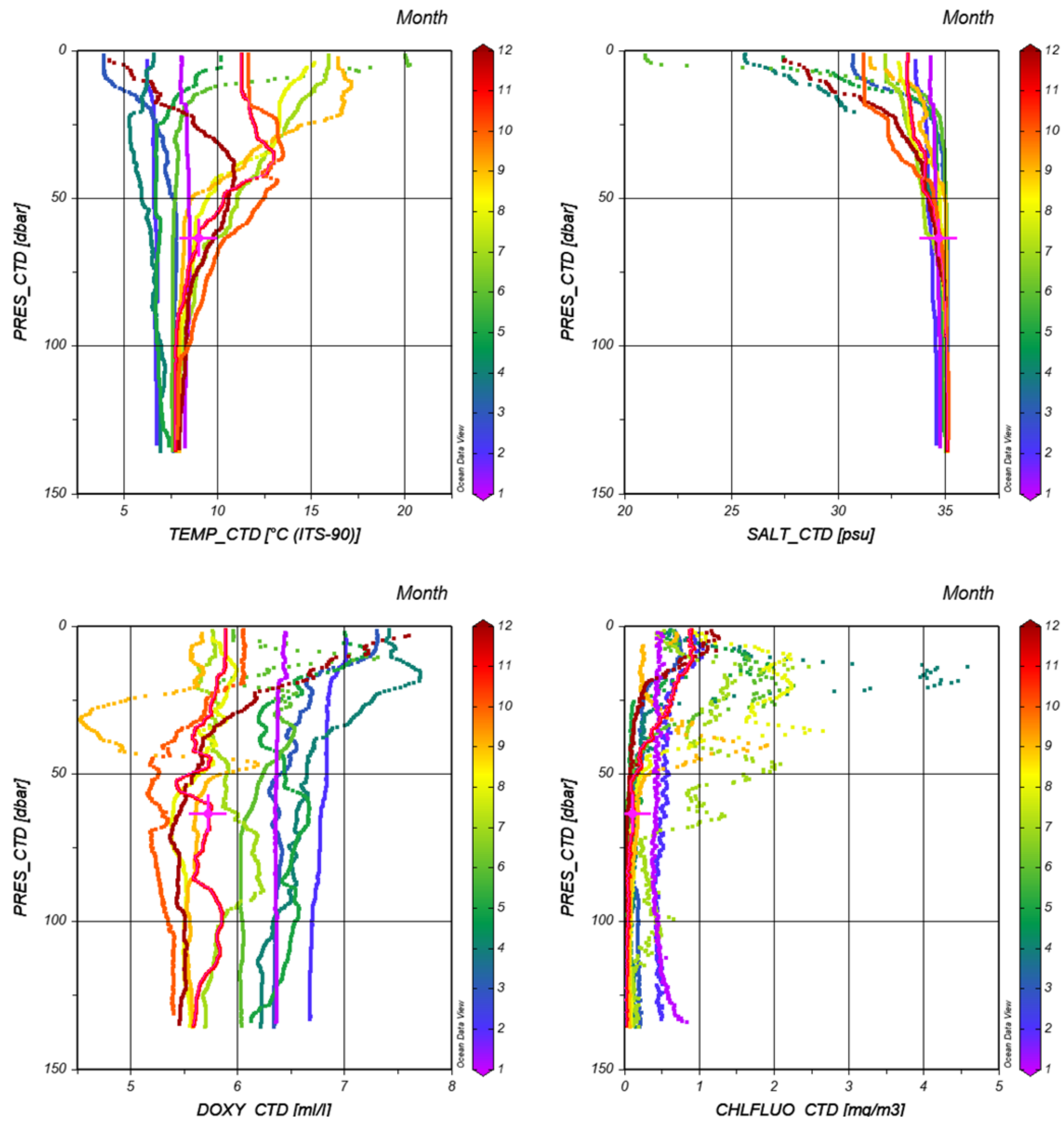

Figure 7. CTD-profiles at station Å15 in Skagerrak during 2023. Upper panel: temperature and salinity. Lower panel: oxygen and chlorophyll fluorescens. Colours indicate the sampling month.

The stratification in the Kattegat upper layer was similar to Skagerrak. In Kattegat, the cooling in the beginning of the year reached down to 20 metres where there was both a thermocline and halocline. The thermocline nearest the surface developed to 10 metres in June, and after the storm Hans the warmer water had been mixed down to 35 metres.

In Kattegat, which is not as deep as Skagerrak, the seasonal variations in the deep water are more similar to those at comparable depths in Skagerrak. The conditions were most stable below 40 meters, with temperatures ranging from 6-15 degrees Celsius and salinity between 33-35 psu, see Figure 8.

Station: Anholt E

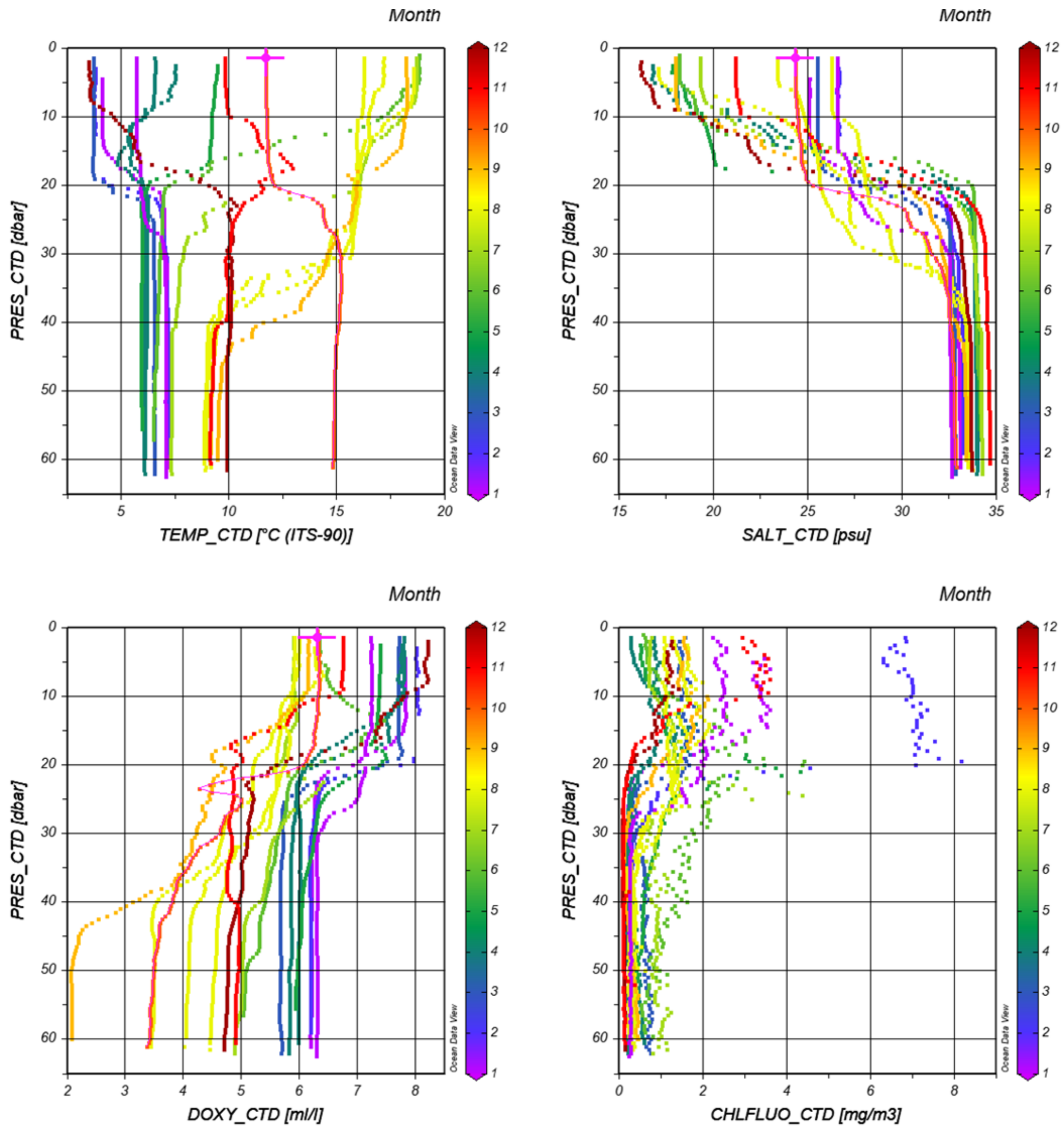

Figure 8. CTD-profiles at station Anholt E in Kattegat during 2023. Upper panel: temperature and salinity. Lower panel: oxygen and chlorophyll fluorescens. Colours indicate the sampling month.

In the Sound, the stratification is typically around 15 metres, Figure 9.

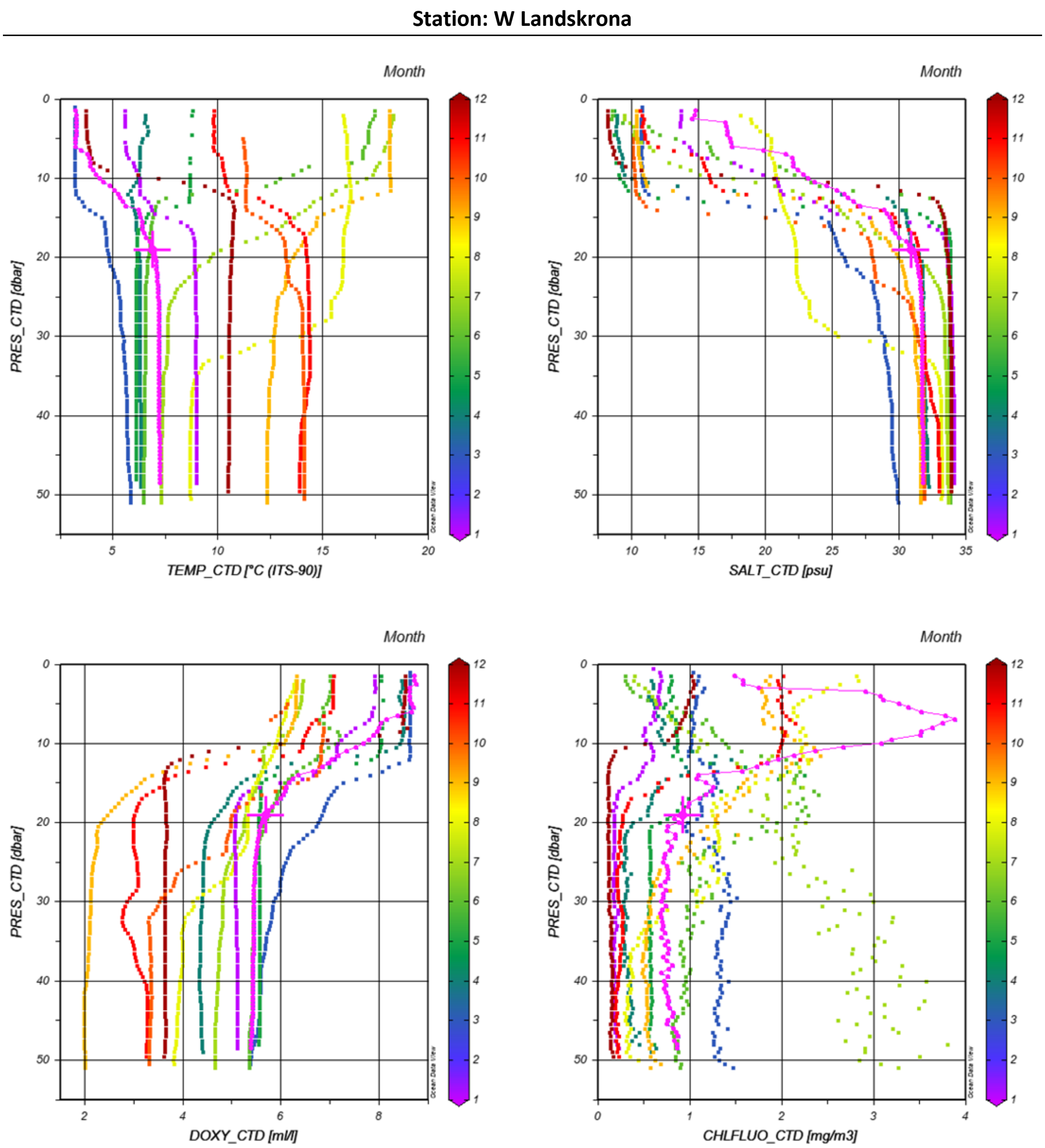

Figure 9. CTD-profiles at station W Landskrona in the Sound during 2023. Upper panel: temperature and salinity. Lower panel: oxygen and chlorophyll fluorescens. Colours indicate the sampling month.

4.1.2 Oxygen conditions in the bottom water

In the open sea Skagerrak, there are generally good oxygen conditions in the bottom water, and this was also the case in 2023. Along the Å-section (stations Å13-Å17), the bottom depth varies from 100 to 350 meters, and at these depths, the oxygen concentration was around 6 ml/l with only minor seasonal variations linked to temperature variation. At the coastal station Släggö, which is also shallower ~70 meters, there are greater variations in the bottom water, and the oxygen concentration can approach 2 ml/l during autumn. In 2023, the lowest concentration of oxygen in the bottom water was in September when it was 3.9 ml/l, see Figure 10.

In the Kattegat and the Sound, there are greater variations in the bottom water compared to the Skagerrak, and the lowest concentrations are usually observed during autumn. Since the Kattegat is a relatively shallow area, with an average depth of 50 meters, and has a significant water exchange, the water tends to mix or be replaced during autumn/winter. In 2023, there were normal oxygen concentrations in the bottom water, and the lowest levels were observed in September. At Anholt E, it was 2.09 ml/l, and at station W Landskrona in the Sound, it was 2.03 ml/l, see Figure 10.

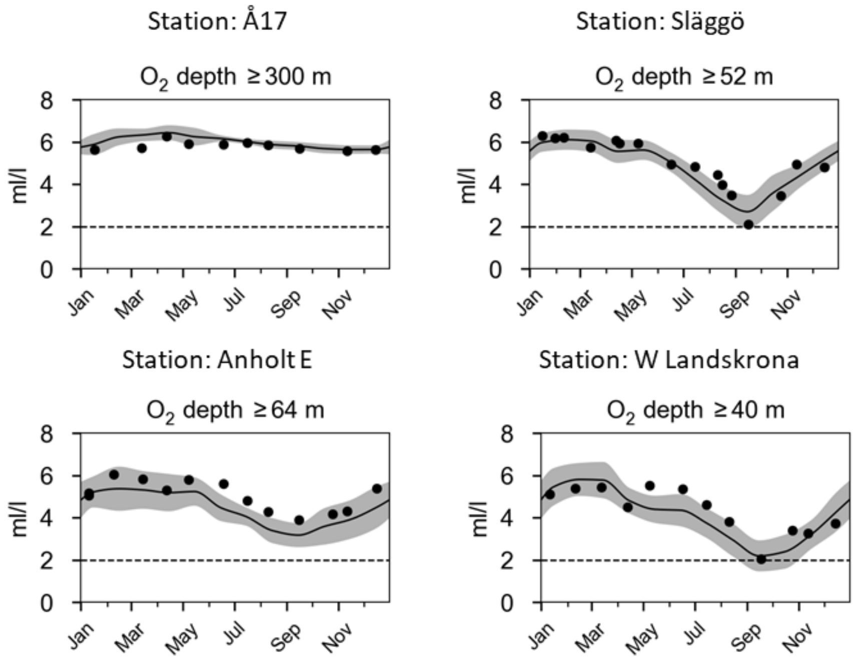

Figure 10. Concentration of oxygen in the bottom water at the open sea stations Å17 in Skagerrak and Anholt E in Kattegat and at the coastal station Släggö in Skagerrak and at station W Landskrona in the Sound. Monthly measurements (circles) during 2023 are shown in relation to average values for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

4.1.3 **Nutrients**

The concentration of inorganic nutrients in the surface water was within normal ranges at the beginning of the year. The significant decrease in nutrients, due to the spring bloom, occurred in the Skagerrak between March and April. In the Kattegat, nutrient levels were also normal at the beginning of the year, but the spring decrease in nutrients happened slightly earlier than usual, resulting in somewhat below-normal levels in February. From April to September, concentrations of PO4 and DIN were generally very low to depleted down to 20 meters. Silica had a slight increase in concentration at the beginning of summer and was then above normal. The levels of inorganic nutrients increased as normal during the autumn.

The seasonal variability of total nutrients is much smaller and they never get depleted. The total phosphorus had normal concentrations at most stations and visits but the total nitrogen was lower than normal at several stations.

One example of the nutrient conditions in the Kattegat is presented in Figure 11.

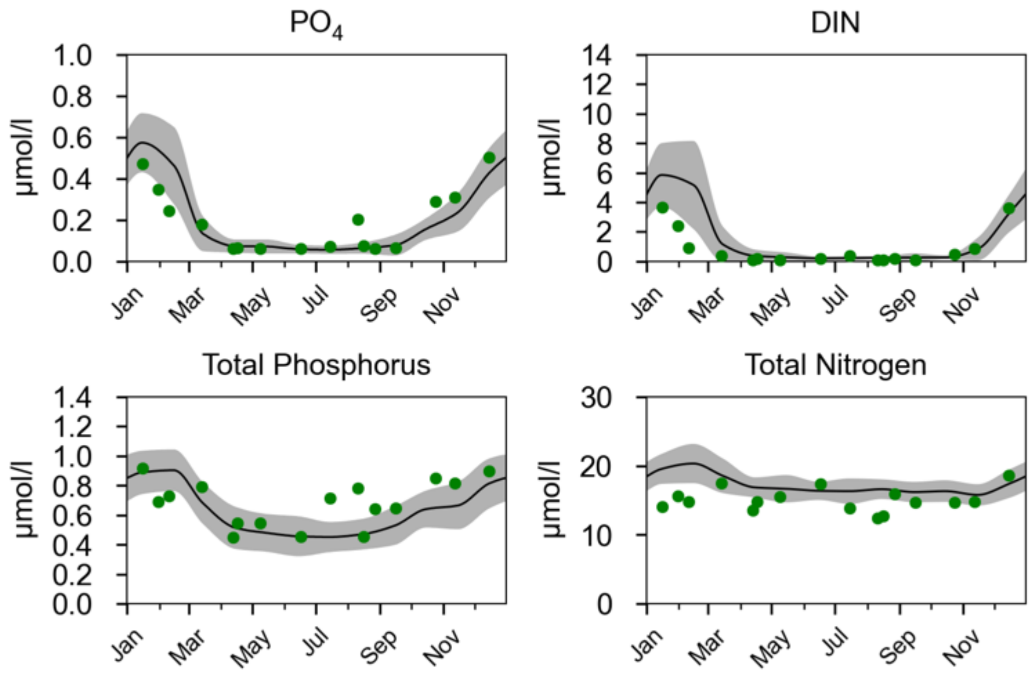

Figure 11. Concentrations of phosphate, DIN, total phosphorus and total nitrogen in the surface layer, 0-10 m, at station Anholt E in Kattegat in 2023. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

4.1.4 **Phytoplankton**

On the Swedish west coast, spring bloom usually starts in the Kattegat area and spreads northwards into the Skagerrak. This was the case even this year with high chlorophyll (Figure 12) and biovolume concentrations (Figure 13) at the February sampling event at stations Anholt E and N14 Falkenberg with consequently low nutrient concentrations in March (Figure 14). Diatoms dominated the cell counts as well as the biovolume concentrations. In the Skagerrak area, a lack of nutrients in April tells us that spring bloom occurred somewhere between the sampling events in March and April. The chlorophyll and biovolume concentrations on the other hand tell that a diatom bloom was still ongoing in April, at least at Å17, the outermost station in the Skagerrak.

Biovolume peaks at the Kattegat stations in April were caused by diatoms, but the high values are not mirrored in the chlorophyll concentrations. The reason is that there was a shift in diatoms dominating from small chlorophyll rich species during spring bloom to larger species with less chlorophyll per cell, still contributing to high total biovolumes hence biomass.

In May the phytoplankton samples were dominated by small cells like unidentified cells with or without flagelles and at Å17 in the Skagerrak, the small coccolithophorid *Emiliania huxleyi* was the most numerous species. *E. huxleyi* is a nontoxic bloom forming phytoplankton, it is calcified and spherical, features that cause reflections of the light which makes the water turn beautifully turquoise, visible as far as from space. Despite the grand effects, the small size of *E. huxleyi* makes small impacts on the total biomass.

There is a second diatom biomass peak at Å17 and Släggö in the Skagerrak in June, this time dominated by the typical summer species *Dactyliosolen fragilissimus*, which is a relatively large species with low chlorophyll content. Although in lower cell numbers, the same species was present at the Kattegat stations, Anholt E and N14 Falkenberg.

At N14 Falkenberg, the summer biomass was dominated by dinoflagellates. The usual picture is diatom dominance with a few large species low in chlorophyll which was more of the case at the other Skagerrak and Kattegat stations. In August and September however, the biomass was dominated by dinoflagellates at Släggö as well, with *Prorocentrum micans* being one of the main contributors. The chlorophyll a-concentrations were interestingly enough enhanced, although within one standard deviation, at Släggö during the same period as dinoflagellates dominated (August—October), insinuating high chlorophyll a content in the dinoflagellate cells.

Yet another diatom biomass peak was noted in October at Anholt E. The most numerous species was the small *E. huxleyi* though, and the starshaped flagellate *Octactis speculum* was abundant. The life cycle of *O. speculum* is complicated and at some point, this organism lets go of its starshaped skeleton and becomes a “naked blub”. In this stage, which we call dictyochales in the monitoring, the organism is potentially harmful and it was found in significant amounts in the total biomass of October.

The diatom dominance continued throughout November and December with contributions of dinoflagellates, dictyochales and several other groups. The high chlorophyll a-concentrations at Släggö in December was mainly caused by diatoms, of which one was the potentially harmful genus *Pseudo-nitzschia*.

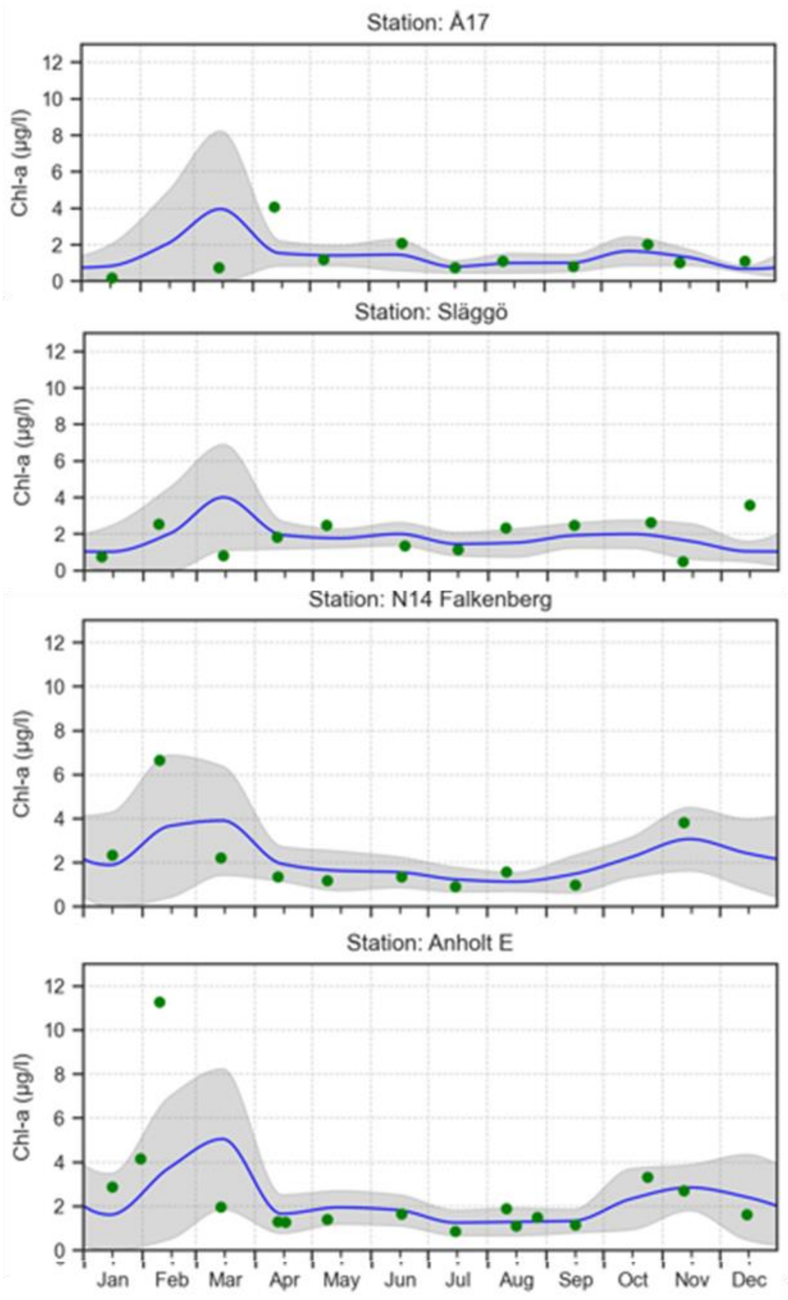

Figure 12. Integrated (0-20 m) chlorophyll a (µg/l) from Å17 and Släggö in the Skagerrak and N14 Falkenberg and Anholt E in the Kattegat. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (blue line) and +/- 1 standard deviation (grey area).

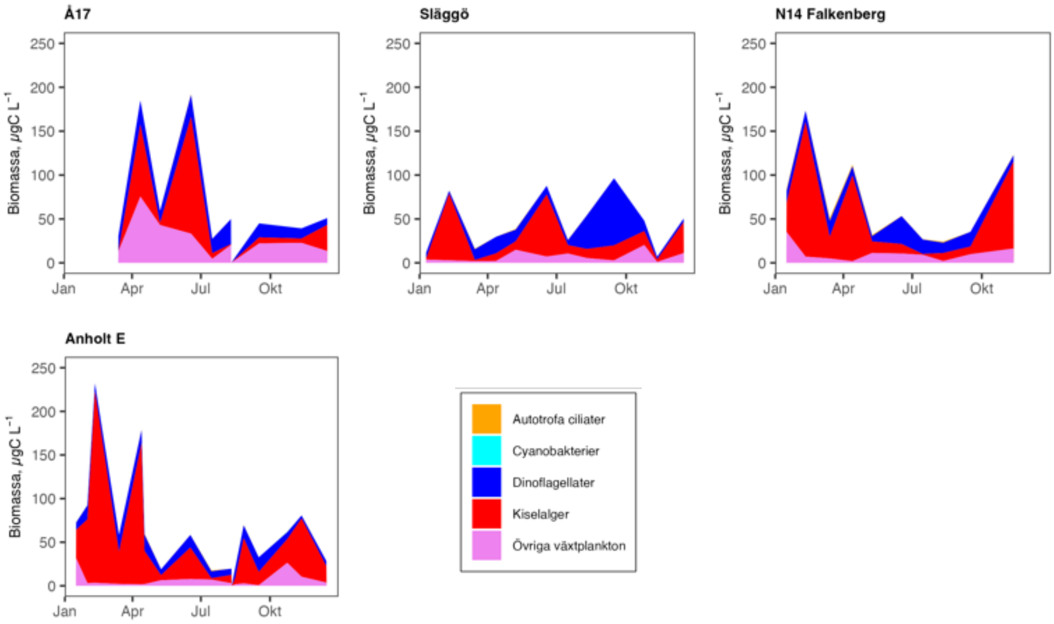

Figure 13. Total phytoplankton biomass per month (µg C/l) at the Skagerrak and Kattegat stations.

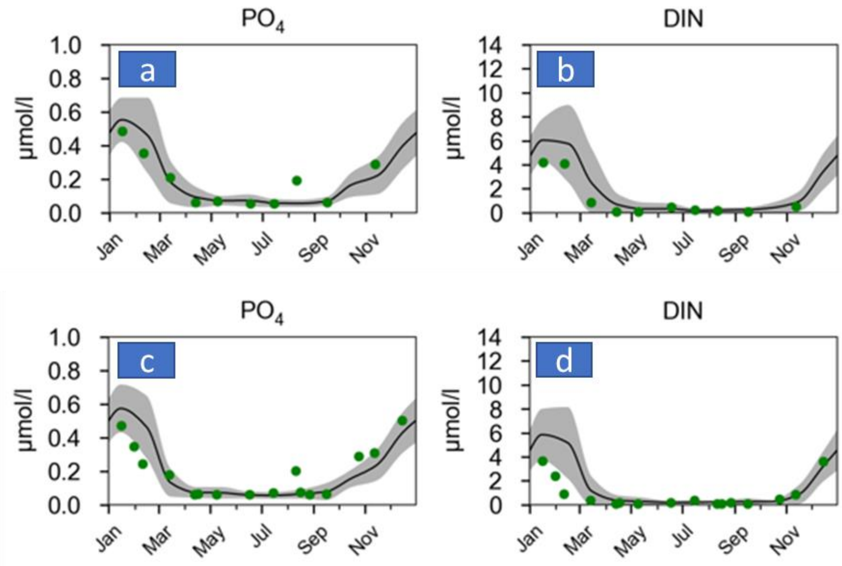

Figure 14 a-d. Phosphate (PO4) and dissolved inorganic nitrogen (DIN) at N14 (a and b) and Anholt E (c and d) in the Kattegat.

4.2 **Baltic Proper**

4.2.1 **Temperature and salinity**

Surface water, 0-10 m

The surface water temperature in the Baltic Proper was mostly above normal at the time of the winter mapping cruise in February. Only in the Northern Baltic Proper temperatures were normal. In the Baltic Proper the water becomes mixed by the wind down to the halocline (ca 60 m, see Figure 15) during winter and the coldest surface temperature was observed in March. The surface water began to warm up in May and the surface water was above normal at most stations in June. August, that normally has high summer temperatures, had this year lower temperatures than normal in the surface because of the storm Hans that caused mixing and strong upwelling that could be seen even in the open sea stations, Figure 16. In September temperatures had increased and were above normal and this was the month where most stations had their highest temperatures.

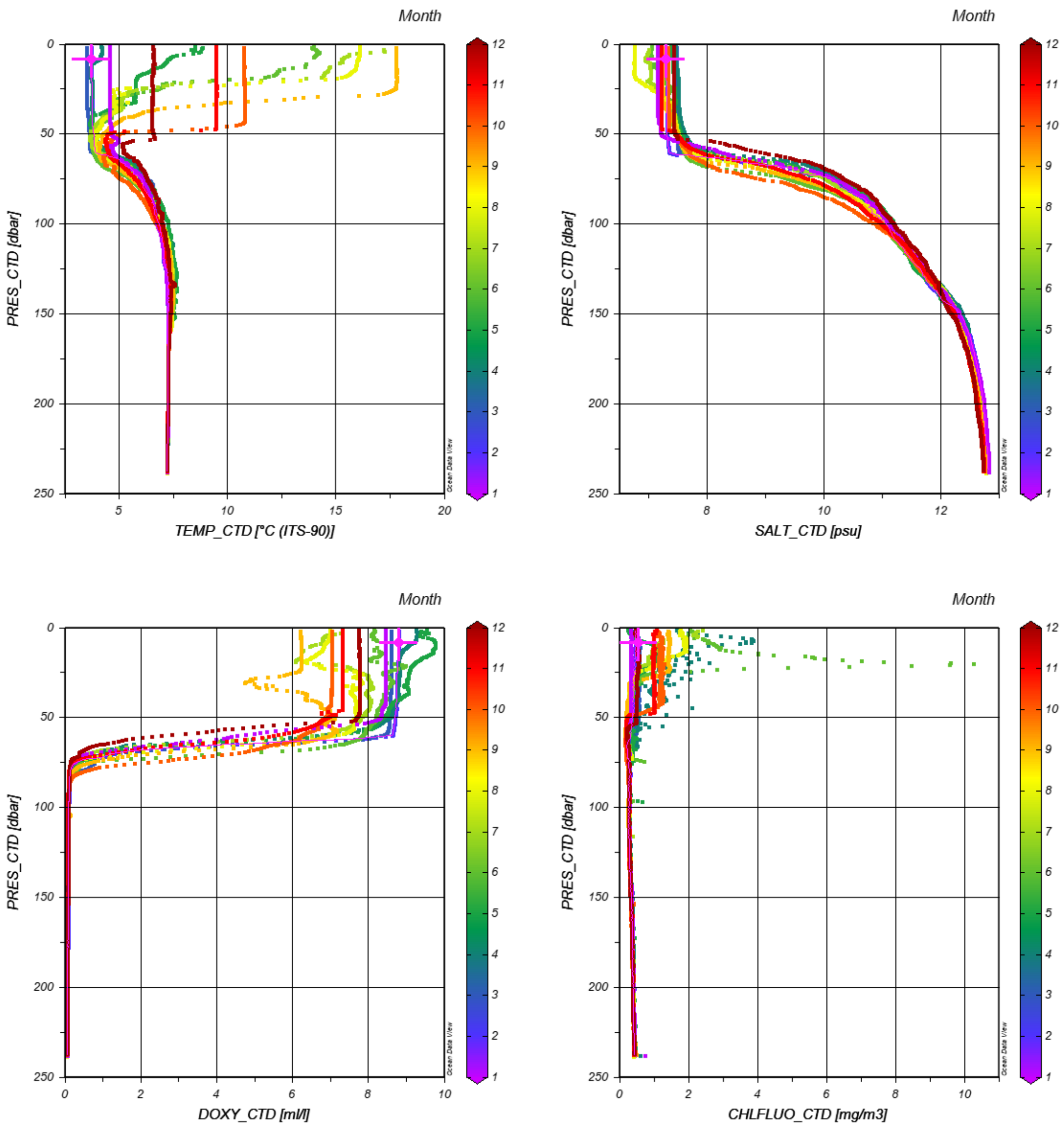

Figure 15. CTD-profiles at station BY15 in the Baltic Proper during 2023. Upper panel: temperature and salinity. Lower panel: oxygen and chlorophyll fluorescens. Colours indicate the sampling month.

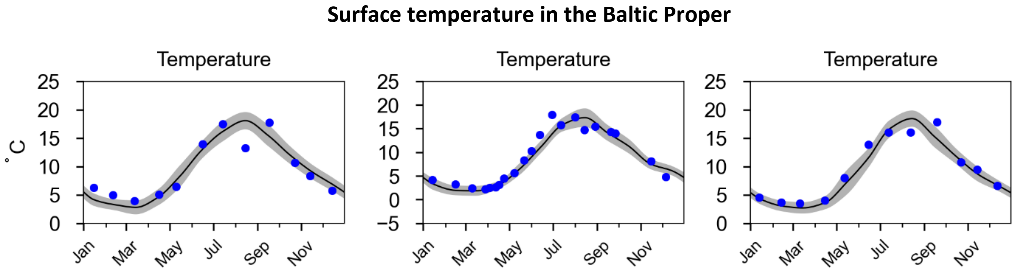

Figure 16. Surface temperature (0-10 m) at; a) Hanö Bay, b) BY31 Landsort deep, c) BY15. At all stations the temperature in August is below normal, which is most visible in Hanö Bay where the upwelling event causing this is most evident. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

During 2023 the salinity in the surface water was mostly normal, except in the fall and early winter in the Eastern Gotland Basin where it was somewhat elevated, see Figure 17. In Arkona, where the salinity variations are larger, the salinity was well above normal, close to 9 psu in August and October. In October the high salinity was caused by the storm Babet. In August there were no strong winds but there had been short inflow event a few days prior to the cruise. In the longer time series (1960-2023) we can see that the surface salinity was highest at the end of the 1970's and then decreased until the end of the 1990's, Figure 17 d.

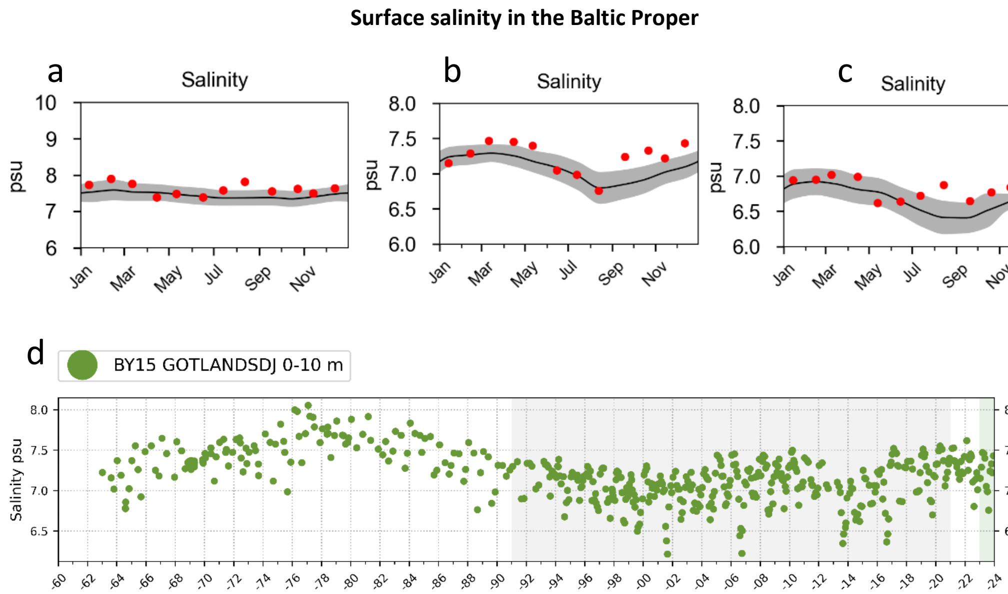

Figure 17. Salinity in surface water (0-10 m) during 2021 at the stations: a) BY5 in the Bornholm Basin, b) BY15 in the Eastern Gotland Basin, c) BY32 in the Western Gotland Basin. Monthly measurements (red dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area). d) a timeseries from 1960-2022 from BY15. The shadowed grey area highlights the time period that statistics is based on in this report, 1991-2020. The shadowed green area highlights the year 2023).

The temporal development of temperature and salinity from the surface to the 150 m in the Baltic Proper during 2023 are presented in more detail in Figure 15 and Figure 19. This shows the seasonal variation of thermocline and halocline depths above the permanent halocline and also the difference in variability of the permanent halocline between the eastern and Western Gotland basins.

After the inflow in the winter 2014-2015 the surface salinity increased and was mostly above normal compared to the time period 1991-2020. In the deep water, below the permanent halocline the salinity was above normal, as it has been since the large inflow in the winter 2014-2015, see Figure 18. The halocline in the Baltic Proper is situated around 60 m but with seasonal fluctuations and also geographic variations. In the Arkona and Bornholm basins, which are shallower, the halocline is at about 40-50 m. The halocline in the Eastern Gotland Basin is sharper and less dynamic compared to the Western Gotland Basin, Figure 19. In the Western Gotland Basin, the halocline position fluctuated more than in the Eastern Gotland Basin, Figure 19.

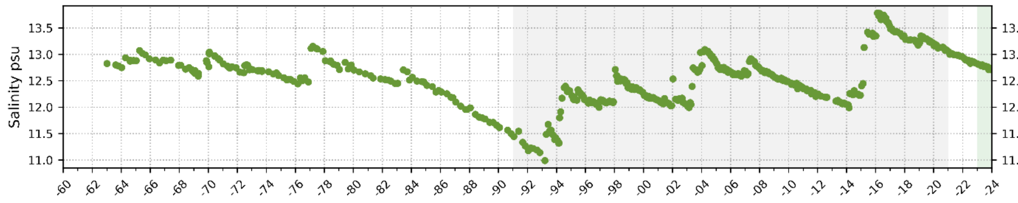

Figure 18. Salinity in the bottom water at station BY15 Gotland deep, data points are average values from samples >=225 m at each visit. The shadowed grey area highlights the time period that statistics is based on in this report, 1991-2020. The shadowed green area highlights the year 2023.

Stratification in the Baltic Proper

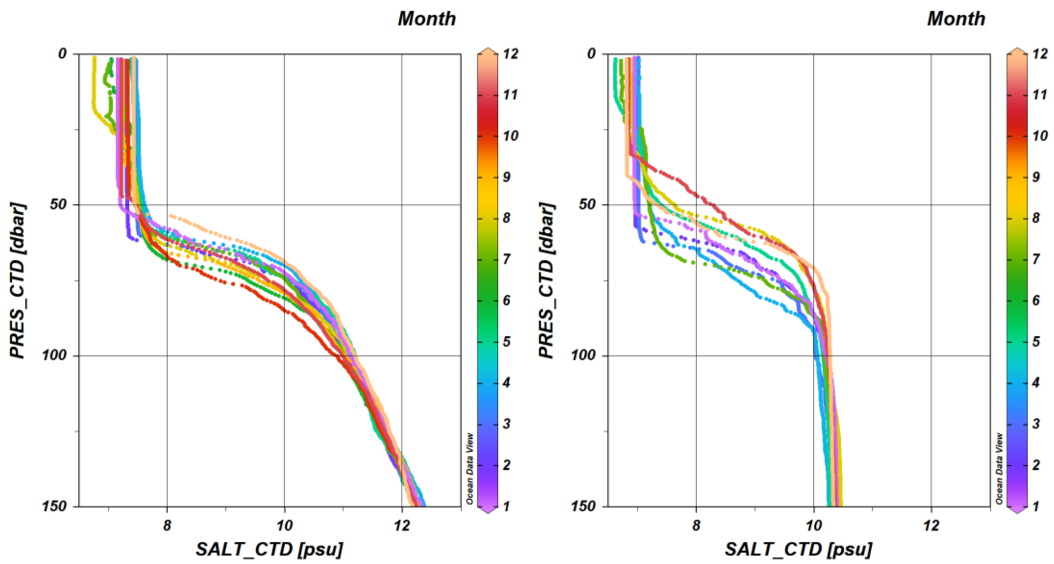

Figure 19 Profiles of salinity at a) BY15 Gotland deep and b) BY32 Norrköping deep from 2023. The figure shows the more variable halocline depth in the Westerns Gotland Basin (b) compared to the Eastern Gotland Basin (a).

Salinity and temperature are less variable below the halocline. In the Arkona and Bornholm basins, the variability in the deep water is somewhat larger because of the influence from salt water inflows from Kattegat. After the inflow event in 2014 both salinity and temperature increased in the bottom water of the basins in the Baltic Proper (Figure 20b and c). During 2023 both temperature and salinity were above normal in the deep basins in the Baltic Proper. The salinity is steadily decreasing in the stagnant water below the halocline but the temperature has not decreased significantly since the last Major Baltic Inflow (MBI) and in the Western Gotland Basin it has even increased after the last MBI. In the Eastern and Western Gotland basins salinity and temperature are above normal not only in the bottom water but at all depths below the halocline (profiles can be found in expedition reports[9]) and the temperature in the bottom water is record high.

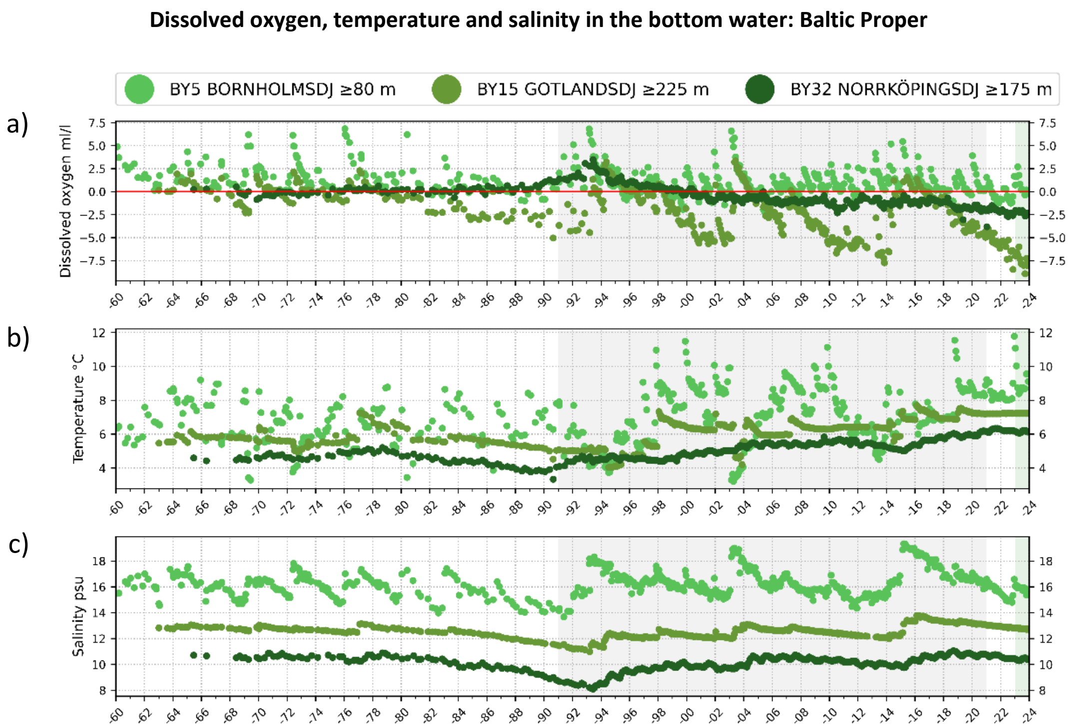

Figure 20. a) Dissolved oxygen, b) temperature and c) salinity in the bottom water at three stations in the Baltic Proper representing the basins Bornholm Basin (BY5), Eastern Gotland Basin (BY15), Western Gotland Basin (BY32). The shadowed grey area highlights the time period that statistics is based on in this report, 1991-2020. The shadowed green area highlights the year 2023.

4.2.2 **Oxygen conditions in the bottom water**

During 2023 there were no major inflows to the Baltic Proper that could improve the oxygen conditions in the bottom water to any larger extent. Two smaller inflows of just below 20 km^3 occurred in April and June but did not have any effect on the oxygen conditions in the deep water. At the end of 2023 a larger inflow occurred, the inflow data indicated that it could potentially be large enough to reach the central Baltic Proper. However, preliminary data from 2024 show that it did not reach as far as the first inflow data indicated. The latest annual report on the oxygen situation in the Baltic Sea 2023 published by SMHI[5], the severe oxygen conditions continues in the Baltic Proper. The concentration of hydrogen sulphide continued to increase in the Eastern and Western Gotland Basins, shown as negative oxygen in Figure 20a above. In both basins the hydrogen sulphide concentration reached record high levels during 2023. However, the increase is faster and the concentration is more than twice as high in the Eastern Gotland Basin compared to the Western Gotland Basin. In the Bornholm Basin hypoxia is regularly found in the autumn and more seldom anoxia and hydrogen sulphide.

4.2.3 **Nutrients**

The winter pool of inorganic phosphorus and silicate in the Baltic Proper was mostly within normal ranges while dissolved inorganic nitrogen was below normal at most stations during the nutrient survey in February, Figure 21.

Nutrient concentration in the surface water, February

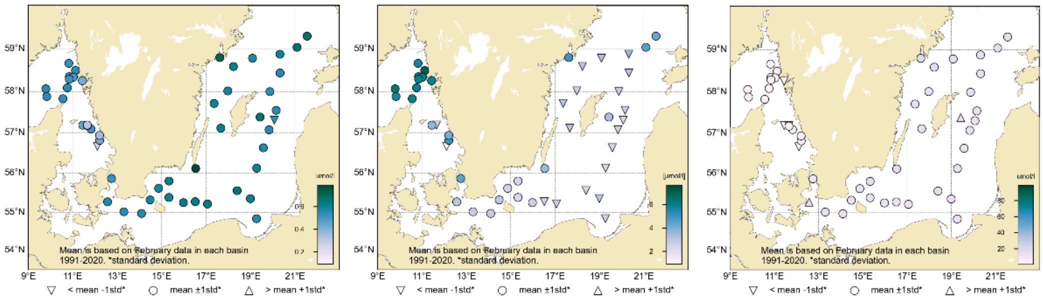

Figure 21. Maps showing the concentration of phosphate (a), dissolved inorganic nitrogen (b) and silicate (c) in February 2023. Circles represent values within +/- 1 standard deviation, upwards and downwards pointing triangles represent values that are above/below +/- 1 standard deviation.

In the Baltic Proper a sharp drop in the concentration of dissolved inorganic nitrogen indicates the time of the spring bloom. In 2023 the spring bloom occurred between the March and April cruises at all stations, Figure 22. Phosphate drops much slower during the spring bloom in the Baltic Proper and phosphate continued to decrease until June in the Eastern Gotland Basin and in the Arkona Basin phosphate stayed at relatively high concentrations (0.2 µmol/l) throughout the summer. The concentrations of dissolved inorganic nitrogen stayed at low levels until September and started to increase again in October.

Stations: BY2 Arkona, BY15 Gotland deep and BY31 Landsort deep

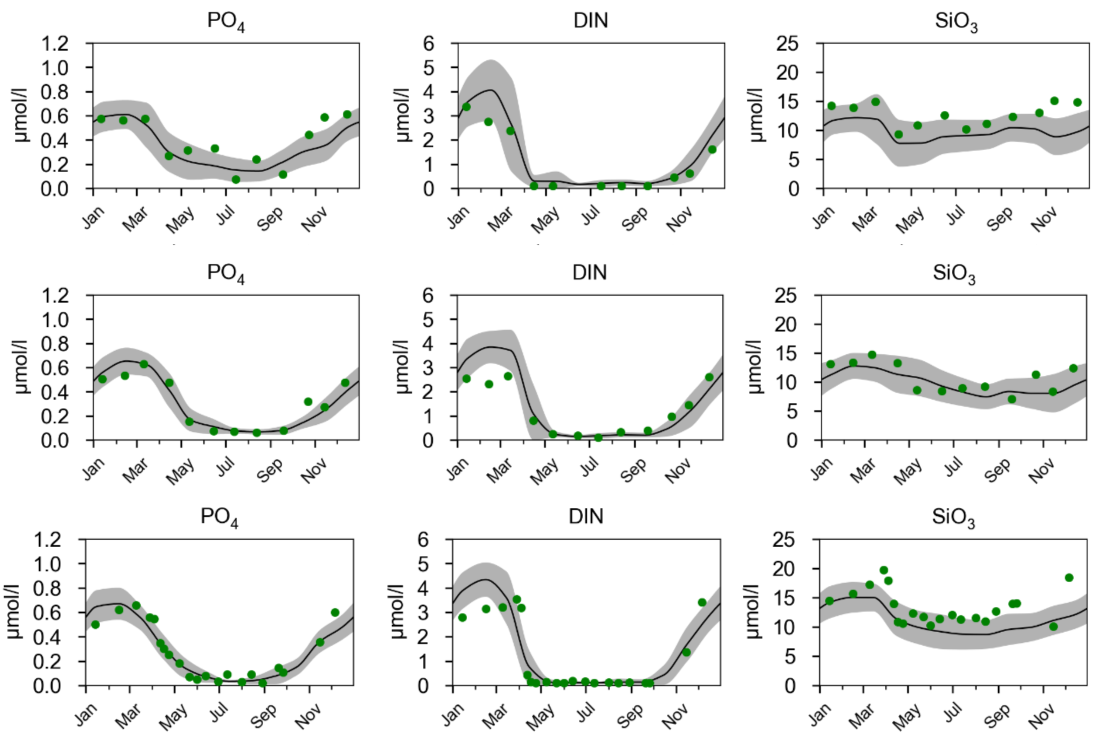

Figure 22. Concentrations of nutrients in the surface water (0-10 m) at stations BY2 in the Arkona Basin (a), BY15 in the Eastern Gotland Basin (b) and BY31 Landsort deep (c). To the left: phosphate, middle: dissolved inorganic nitrogen (DIN) and to the right: silicate. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

No inflows large enough to renew the deep water occurred and therefore concentrations of nutrients in the deep basins of the Baltic Proper continued to increase during 2023. In the Western Gotland Basin dissolved inorganic nitrogen was present in the form of nitrate until the year 2000 when the basin shifted to anoxia. After 2000 ammonium has been building up in the basin and the concentrations measured during 2023 are almost twice as high as the mean value for the normal period (Figure 23, dark green station BY32). In the Eastern Gotland Basin ammonium (Figure 23 a) and DIN (Figure 23 b) follow the same pattern because DIN consists mainly of ammonium through the time series (1960-2023). Another difference between the eastern and western basins is that the effects of the inflows are clearly seen in the Eastern Gotland Basin while the inflows have had none or only very little effect on the water chemistry in the Western Gotland Basin after year 2000. The differences in how the DIN and ammonium concentration looks in the two basins is caused by the difference in stratification, oxygen and hydrogen sulphide concentrations. As for hydrogen sulphide the ammonium concentration increases faster and the concentration is more than twice as high in the Eastern Gotland Basin compared to the Western Gotland Basin.

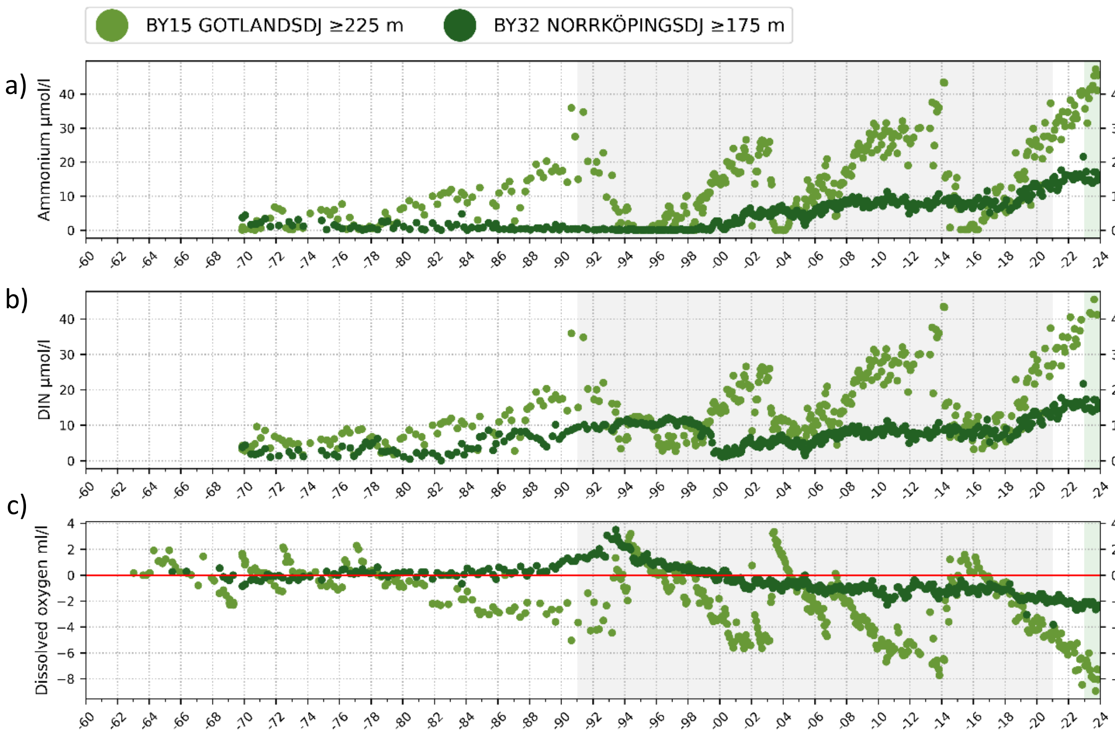

Figure 23. Concentration of a) ammonium, b) dissolved inorganic nitrogen (DIN) and c) dissolved oxygen, where hydrogen sulphide is expressed as negative oxygen in the bottom water, at two stations in the Baltic Proper representing the basins Eastern Gotland Basin (BY15) and Western Gotland Basin (BY32). The shadowed grey area highlights the time period that statistics is based on in this report, 1991-2020. The shadowed green area highlights the year 2023. The concentrations are increasing over time at stations BY15 and BY32 and the highest concentrations are found at stations BY15.

Profiles of dissolved inorganic nitrogen and oxygen/hydrogen sulphide can give some insight to the differences in DIN concentrations in the two basins. In the Western Gotland Basin, the increase in nutrients and decrease in oxygen happens over a relatively thin layer (ca 10-20 m thick), Figure 24. In the Eastern Gotland Basin, on the contrary, there is a thick layer (ca 40-50 m thick, from ca 80-120 m depth) where oxygen is close to zero, there is no or little hydrogen sulphide and DIN concentrations are also very low, almost at detection limit. The low DIN concentrations in this layer are likely an effect of the oxygen concentrations that are just around zero creating an environment where denitrification can occur and remove bio-available nitrogen. This situation with an anoxic but not sulphidic layer in the Eastern Gotland Basin is similar to the conditions in the Western Gotland Basin bottom water during the first part of the 2000's when oxygen concentrations were close to zero and there was no hydrogen sulphide.

As shown in Figure 23 the DIN concentration in the bottom water is higher in the Eastern Gotland Basin than in the Western Gotland Basin. This means that in the Western Gotland basin there are concentrations of DIN around 12-15 µmol/l from around 100 m to the bottom while in the Eastern Gotland Basin the layer with high DIN concentrations (here 15-30 µmol/l) starts at 150 m.

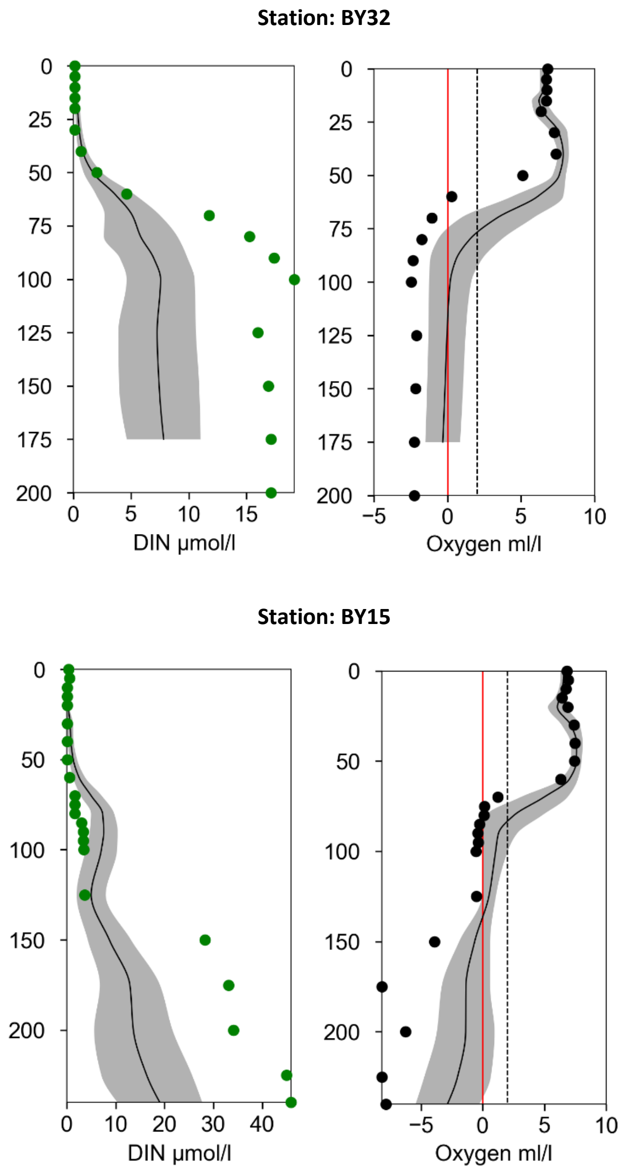

Figure 24. Profiles of oxygen (left, black) and dissolved inorganic nitrogen (right, green) from August 2023. Station BY32 in the Western Gotland Basin (top) and station BY15 in the Eastern Gotland Basin (bottom). Measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

4.2.4 Content of nutrients in the Baltic Proper basins

Appendix III contains time series of calculated content of nutrient concentrations in each basin in the Baltic Sea for the winter season. The content of nutrients in each basin was calculated from the monthly sampling station, i.e. the same data set that was used for the time series 1960-2023 presented in Appendix II. The resulting time series of nutrient content shows large scale changes of the nutrient pools as well as differences between the basins.

Starting in the south with the Arkona and the Bornholm basins, an increase in the content of both inorganic and total phosphorus is seen between the period 1994-2004 and the period from 2005-2023. In the Bornholm Basin in the period between 1994-2004 the total phosphorus content varied between 20-50 kilotonnes while the content from 2005-2023 varies between 50-70 kilotonnes (Figure 25). This could be a consequence of the inflow in the winter 2003-2004 that lifted phosphorus rich water from the deep basins in the Baltic Proper to surface waters. However, it should be noted that the total phosphorus method at the SMHI laboratory was changed at the same time which makes the changes in total phosphorus more difficult to connect to changes due to the inflow.

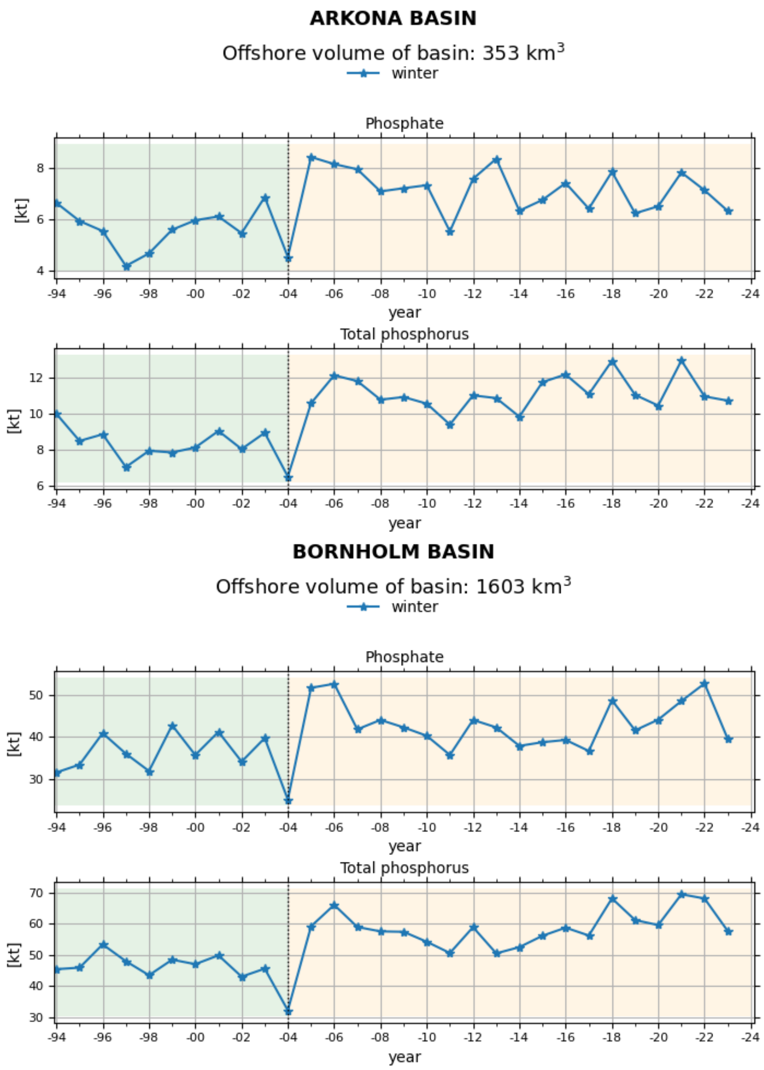

Figure 25. Content of phosphate and total phosphorus in Arkona Basin (top) and Bornholm Basin (bottom), 1994-2023. The content is higher in the period 2005-2023 (orange) than 1994-2004 (green).

In the rest of the Baltic Proper the phosphorus content increased in a more linear way from 1994 until around 2000 when it starts to level out. Since 2018 the phosphate content has increased each year. The nitrogen content in all basins around Gotland decreased from 1994 to the beginning of the 21st century (Appendix III). However, the past three years the total dissolve inorganic nitrogen content has increased again in the Western Baltic Proper. The drop in DIN at the end of the 20th century is most drastic in the Western Gotland Basin for the sub-basins around stations BY31 and BY32 (Appendix III). To some extent this can also be seen in the DIN concentration in the bottom water shown in Figure 23b.

In the Bothnian Sea the increasing phosphorus and silicate concentrations are clearly reflected in an increase in phosphorus and silicate content since year 2000. Here it could also be observed an increase in the DIN content the two last years (2022-2023). In the Bothnian Bay the silicate and phosphorus content is also increasing and here the nitrogen content is clearly decreasing over the same period (Appendix III).

4.2.5 **Phytoplankton**

The spring bloom occurred in April with high chlorophyll a concentration (Figure 26) and high total biomasses (Figure 27), most obvious in the eastern and north-western parts of the Baltic Proper, where diatoms dominated. At station BY5 in the southern part, the mixotrophic ciliate *Mesodinium rubrum* dominated the biomass in April. The typical spring bloom dinoflagellate *Peridiniella catenata* was a considerable part of the biomass at all stations.

P. catenata dominated the biomass at station BY31 in May alongside *M. rubrum*. In cell numbers however, the small but beautifully flowerlike colony forming golden algae, *Dinobryon balticum* was the most abundant, as well as the potentially toxic flagellate group prymnesiales.

In June the filamentous cyanobacteria started appearing in large numbers throughout the Baltic Proper causing high chlorophyll concentrations. Cyanobacteria dominated the biomass at most stations in July, and at BY15 and BY31 also in August. *Aphanizomenon* spp. was the most abundant cyanobacterium in June, but in July the potentially toxic *Nodularia spumigena* as well as the nontoxic *Dolichospermum* spp. were found in high amounts.

M. rubrum dominated the biomass at station B1 in August and the cyanobacterium *Aphanizomenon* spp. was present in high amounts. At stations BY15 and BY31 the latter dominated and in the southern Baltic, at stations BY2 and BY5, the diatom *Dactyliosolen fragilissimus* was the predominant species.

Dinoflagellates dominated at stations BY2 in September whilst the potentially toxic cyanobacterium *N. spumigena* was noted with the highest biomass at the other southern phytoplankton station, BY5. Further north, *M. rubrum* and the potentially toxic group prymnesiales dominated.

The biomass was generally low during the fall with an obvious dominance of diatoms at stations BY2 causing relatively high chlorophyll concentrations and a peak of *M. rubrum* at station BY5 in December.

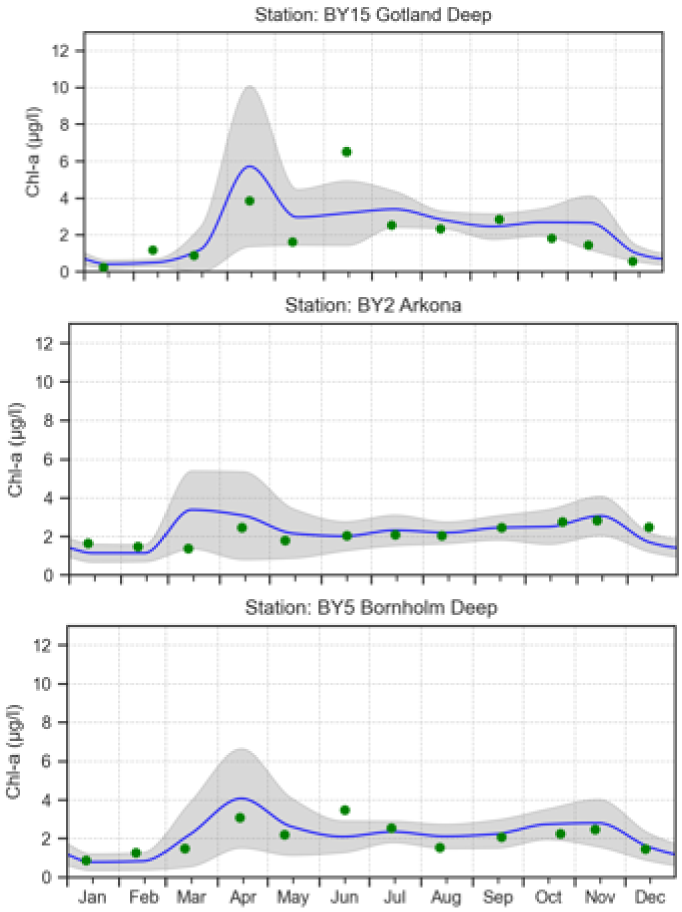

Figure 26. Integrated (0-20 m) chlorophyll a (µg/l) from the stations BY2 Arkona and BY5 Bornholm in the southwestern Baltic Proper and BY15 in the Eastern Gotland Basin. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (blue line) and +/- 1 standard deviation (grey area).

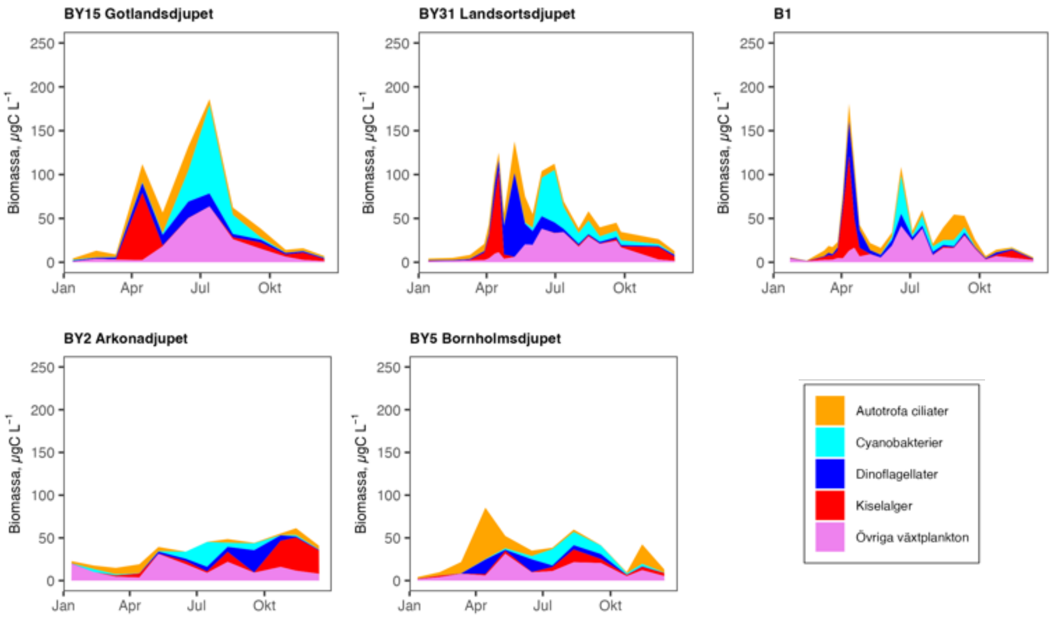

Figure 27. Total phytoplankton biomass per month (µg C/l) from five Baltic stations during 2023.

Satellite observations of the summer cyanobacteria accumulations

During the cyanobacteria season of 2023, blooms occurred in all of the Baltic Proper, the Gulf of Finland and the southeastern part of the Bothnian Sea. The largest coherent surface accumulations were observed in the last week of June from the Southern Baltic Proper all the way into the Gulf of Finland (Figure 28). The highest number of days with surface accumulations, 25 days, was found in the northern Baltic Proper and the central part of the Gulf of Finland. In the Bothnian Sea, the surface accumulations were the most extensive during the second half of July. In mid-September the cyanobacteria blooms started all over again due to the storm Hans in August which caused the water to mix and bring nutrients up to the surface making them available for the cyanobacteria. Figure 29 shows the accumulated number of days with observed cyanobacteria blooms.

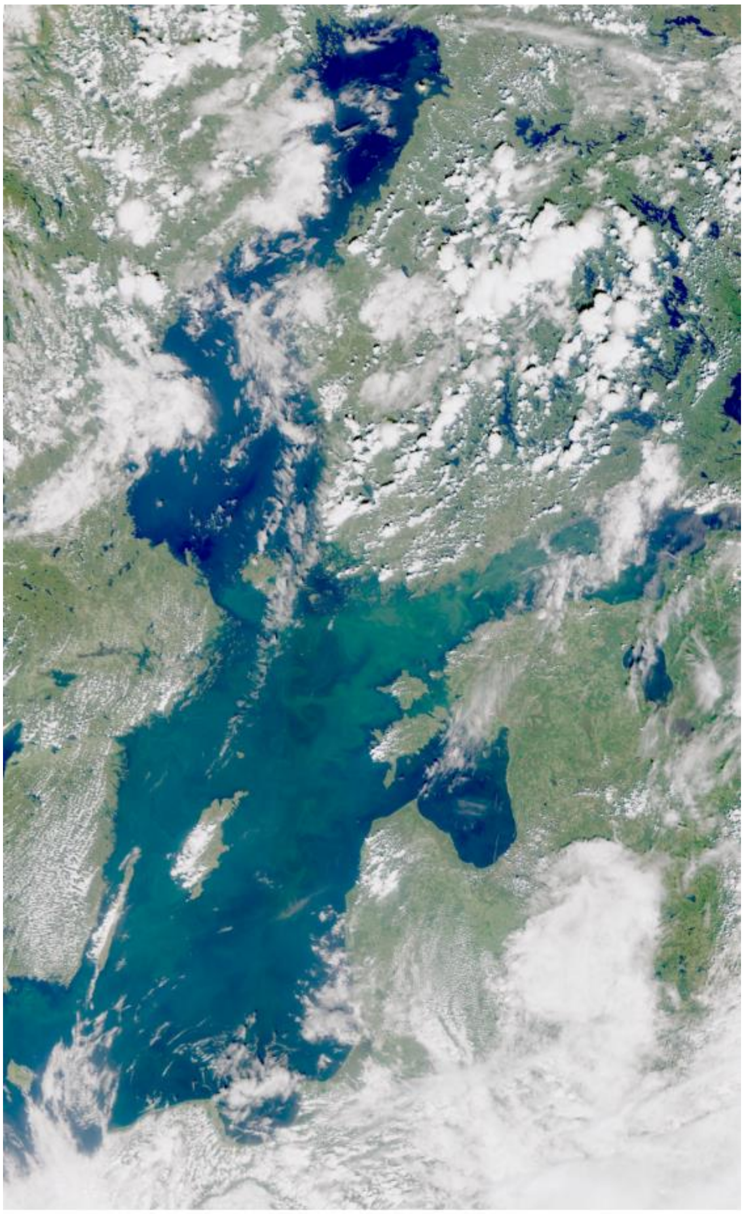

Figure 28. The largest areas of cyanobacteria surface accumulations were observed by satellite during the last week of June. This satellite picture is from the 28th of June.

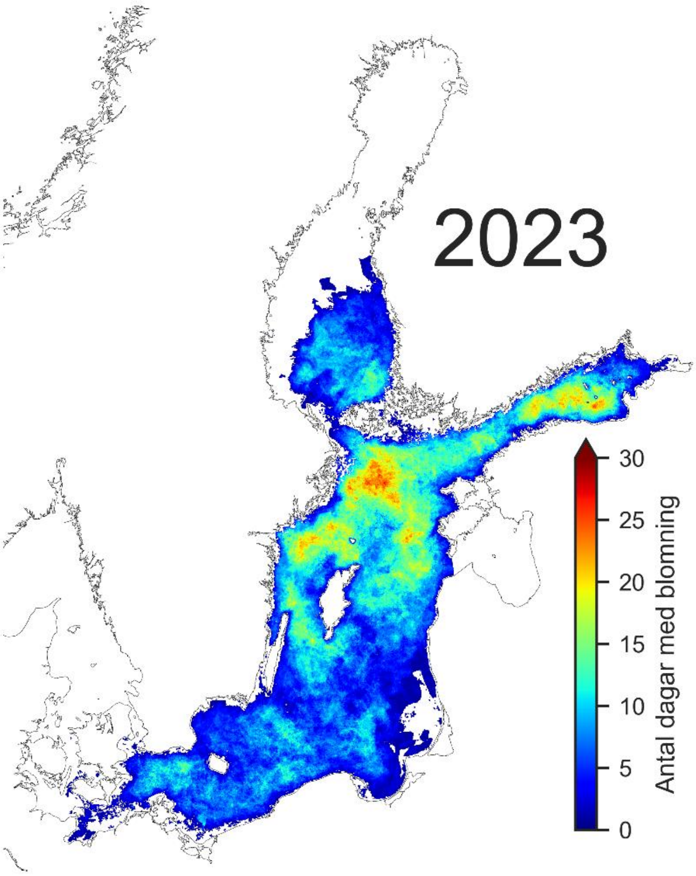

Figure 29. Number of days in 2023 with observed cyanobacteria bloom from satellite images.

4.3 **The Gulf of Bothnia (Bothnian Sea and Bothnian Bay)**

4.3.1 **Temperature and salinity**

Surface water, 0-10 m

The Bothnian Bay and parts of the Bothnian Sea was ice covered until the middle of March. The lowest sea surface temperature during winter was around zero degrees in the Bothnian Bay and 1 degree in the Bothnian Sea, open sea areas. During spring the surface water warmed up and the temperature was normal. In August, the temperature peaked with 16-17 degrees in the Bothnian Sea and 15-16 degrees in the Bothnian Bay. The summer temperature was a bit above normal in the Bothnian Bay. During fall, the temperature dropped and in December it was below normal in both Bothnian Bay and Bothnian Sea, Figure 30.

Surface temperature at C3 and F9/A13

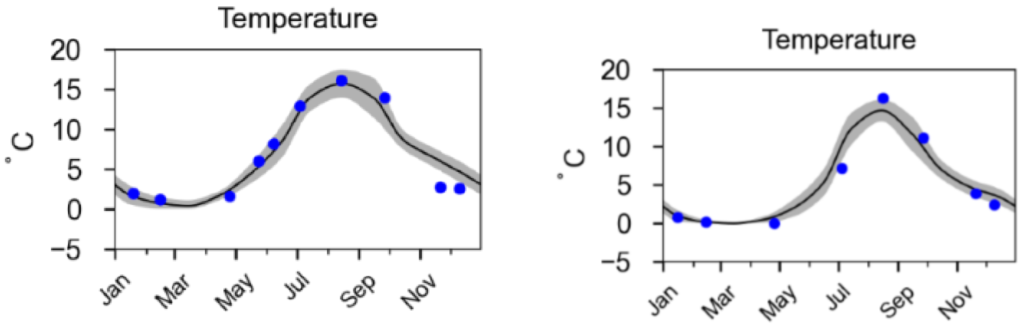

Figure 30. The temperature in the sea surface, 0-10 m, during 2023 at the stations C3 (left) in the Bothnian Sea and F9/A13 (right) in the Bothnian Bay. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

In the Bothnian Bay the surface salinity was mainly normal and in the Bothnian Sea it was above normal at several occasions, Figure 31. The salinity in the Bothnian Bay is lower than in the Bothnian Sea and there is a decreasing trend, Figure 32.

Surface salinity at C3 and F9/A13

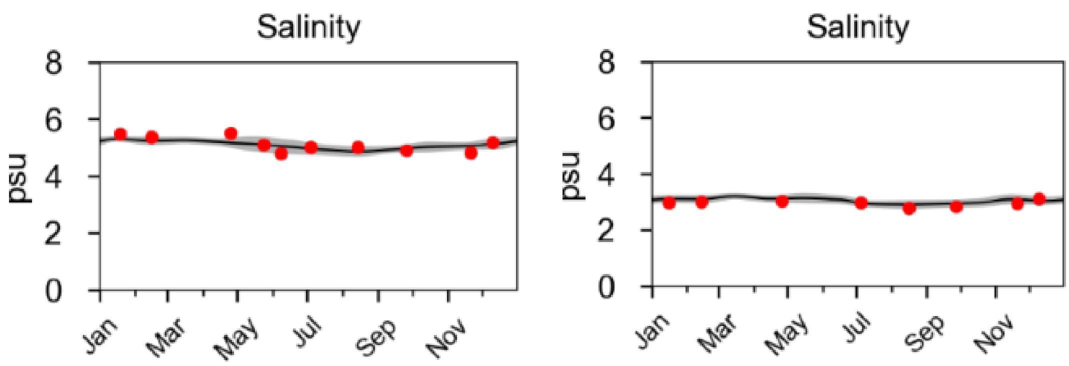

Figure 31. The salinity in the sea surface, 0-10 m, during 2023 at the stations C3 (left) in the Bothnian Sea and F9/A13 (right) in the Bothnian Bay. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area).

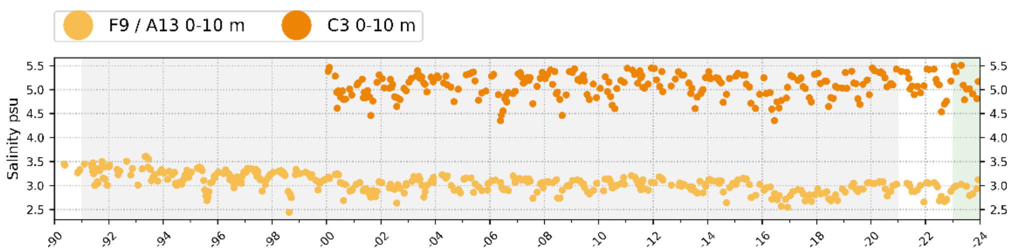

Figure 32. Surface water salinity in the Bothnian Bay (yellow) and the Bothnian Sea (orange) from 1990-2023. There is a decreasing trend in salinity in the Bothnian Bay.

Stratification

During winter the water is well mixed down to ca 50 metres in the Bothnian Bay and during summer the well mixed surface layer goes down to 15-20 metres. There is a very small difference in salinity between the surface and deeper layer. The surface water salinity varies between 2-3 psu and the deep water between 3-4 psu, Figure 33.

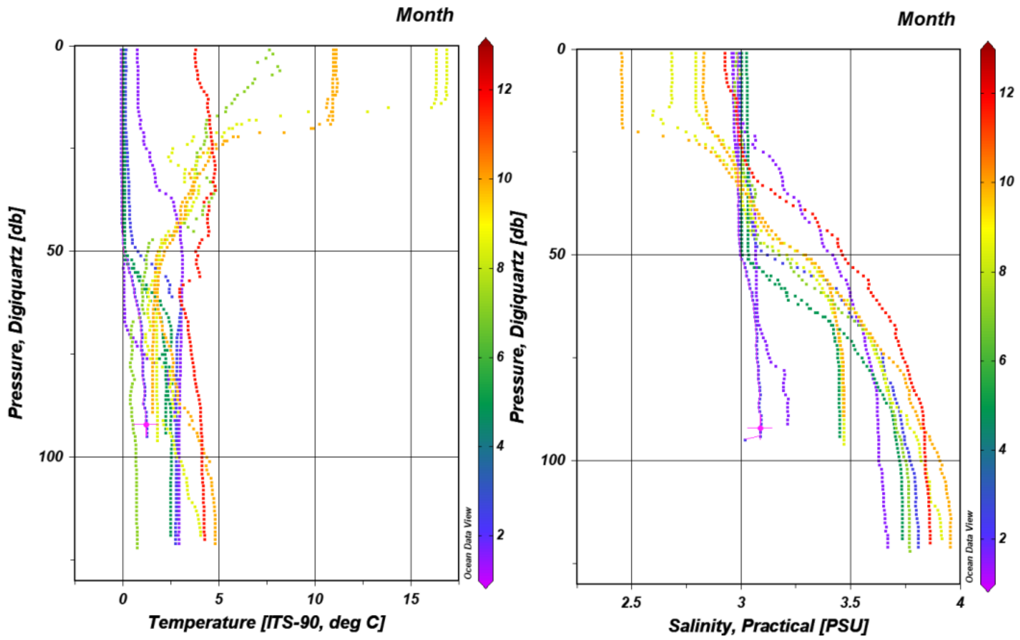

Figure 33. CTD-profiles of temperature and salinity from the open sea stations F3/A5 and F9/A13 in the Bothnian Bay during 2023. Colours indicate the sampling month.

The Bothnian Sea is deeper and the salinity is higher than in the Bothnian Bay, Figure 34. The winter mixing at the station C3 goes down to about 90 m. As the temperature rises in the surface layer the stratification also moves closer to the surface. During the warmest period, there is a thermocline at 20 metres.

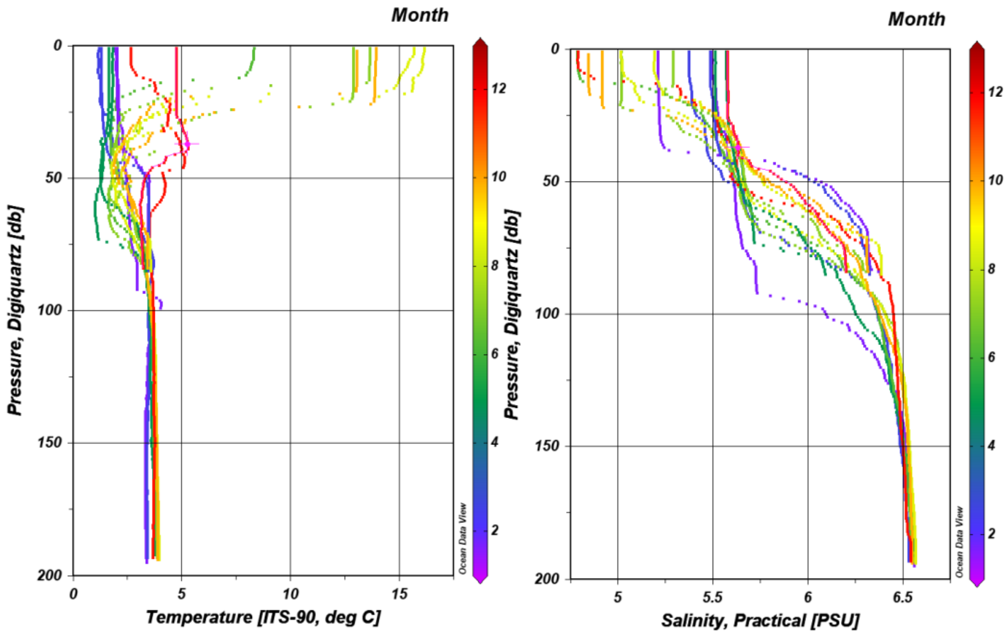

Figure 34. CTD-profiles of temperature and salinity from the open sea stations C3 and MS4/C14 in the Bothnian Sea during 2023. Colours indicate the sampling month.

4.3.2 Oxygen conditions in the bottom water

The bottom water in the Gulf of Bothnia is generally well oxygenated since the stratification is weak and the sea area is mainly oligotrophic, Figure 35. At the coastal stations Råneå-1, Råneå-2 and B7 the bottom water oxygen becomes lower during summer months but there is no oxygen deficiency. There is a trend with decreasing oxygen concentrations in the Bothnian Sea deep water[10]. However, oxygen concentrations in 2023 in the deep water in the Bothnian Sea did not follow this trend, Figure 36.

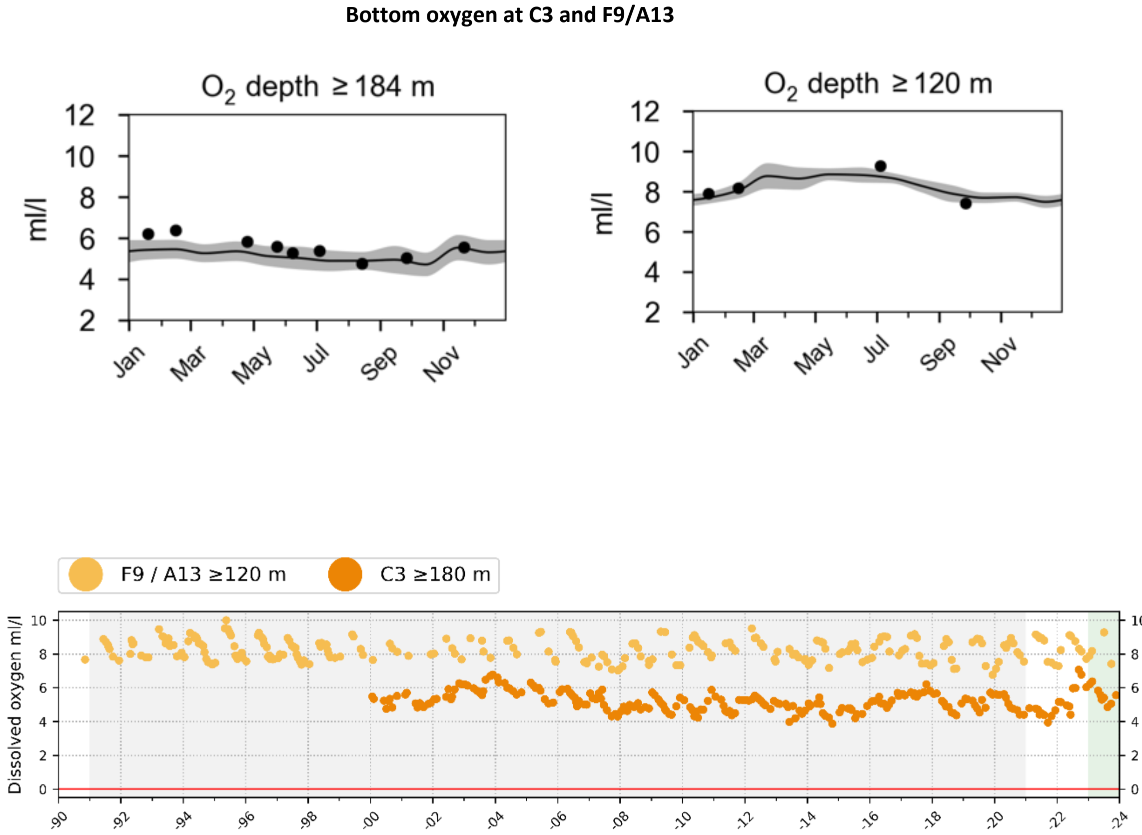

Figure 36. Dissolved oxygen in the bottom water at two stations in the Gulf of Bothnia; F9/A13 Bothnian Bay, C3 Bothnian Sea. The shadowed grey area highlights the time period that statistics is based on in this report, 1991-2020. The shadowed green area highlights the year 2023.

4.3.3 Nutrients

At the Gulf of Bothnia open sea stations, phosphate levels were above normal in the winter (January – February). The winter concentration in February of silicate were above normal in the Bothnian Bay but normal in the Bothnian Sea. Winter levels of DIN were below normal in the Bothnian Bay and normal in the Bothnian Sea.

The Bothnian Bay has the lowest phosphate levels and the highest silicate levels of all Swedish open sea areas and DIN concentrations are just a bit higher than in the Skagerrak and Kattegat, Figure 5. We do not have a mean value for the normal period (1991-2020) to compare with for all months so we cannot see deviations from the

[10] Ahlgren J., Grimvall A., Omstedt A., Rolff C., Wikner J., 2017, Temperature, DOC level and basin interactions explain the declining oxygen concentrations in the Bothnian Sea. Journal of Marine Systems 170 (2017) 22–30.

normal period as easily as in the other sea areas. But the data from 2023 (Figure 37) show that both phosphate and DIN are depleted or close to depleted during summer. In the Bothnian Bay, DIN did not decrease to the lowest levels until August and increased again in September. In the Bothnian Sea there is a clear decrease in DIN and phosphate in the end of April. Here, the production season is markedly longer with low concentrations of phosphate and DIN from the end of April until September. In a longer perspective phosphate and silicate is increasing in the surface waters in the Gulf of Bothnia while DIN is decreasing, see Figure 38.

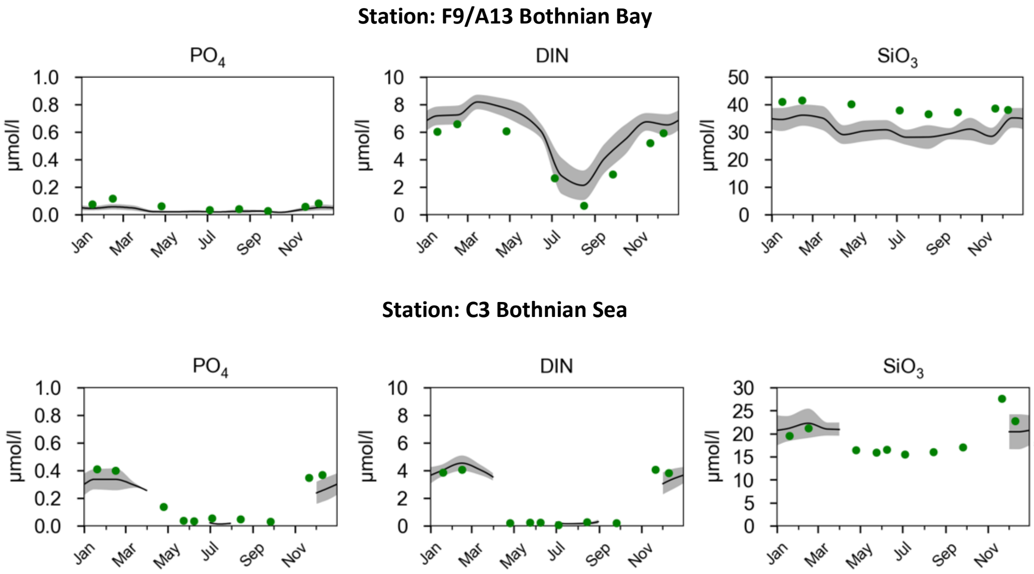

Figure 37. Concentrations of inorganic nutrients in the surface water (0-10 m) in the Gulf of Bothnia. Top row station F9/A13, Bothnian Bay, bottom row station C3 Bothnian Sea. Monthly measurements (dots) during 2023 are shown in relation to average value for the period 1991-2020 (black line) and +/- 1 standard deviation (grey area). Missing black line and grey area indicates that there are too few data in the period 1991-2020 to calculate statistics.

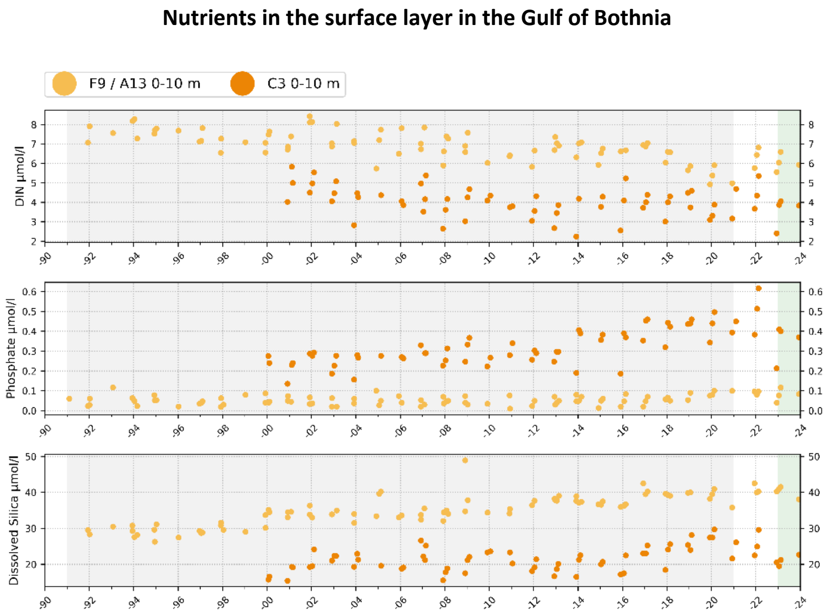

Figure 38. Timeseries of winter (Dec-Feb) inorganic nutrients in the surface water (0-10 m) at two stations in the Gulf of Bothnia (F9/A13 Bothnian Bay andC3 Bothnian Sea. The shadowed grey area highlights the time period that statistics is based on in this report, 1991-2020. The shadowed green area highlights the year 2023.

4.3.4 **Phytoplankton**

The spring bloom occurred in April at the Bothnian Sea stations NB1/B3, B7 and C3 with the highest biomasses of the year (Figure 38). At both stations in the Örefjärd, diatoms dominated during most of the year. In springtime species from the genus *Chaetoceros* with e.g. *C. wighamii* dominated but several other diatoms were abundant, like *Melosira arctica, Skeletonema marinoi, Thalassiosira baltica* and *Thalassiosira levanderi*. The dinoflagellate *Peridiniella catenata* was found in considerable amounts. The species composition within the diatoms shifted to large, centric cells during summer and autumn and coexisted with the mixotrophic ciliate *Mesodinium rubrum*. The total biomasses decreased during summer before increasing during autumn when the filamentous cyanobacterium *Aphanizomenon* spp. was present in high amounts. At station NB1/B3, an unusual autumn bloom occurred in October where the euglenoid algae *Eutreptiella* spp. dominated the biomass.

The spring bloom at C3 in the Bothnian Sea was almost as dense as the previous year, which reached the highest value since 2015. The bloom was dominated by a variety of diatoms, like *Chaetoceros wighamii*, *Skeletonema marinoi, Thalassiosira baltica*, *Thalassiosira levanderi* and *Coscinodiscus granii* (relatively few but large cells). The dinoflagellate *P. catenata* was present in considerable amounts. During summer, the species composition shifted primarily to *M. rubrum* and dinoflagellates and then to cyanobacteria of which *Aphanizomenon* spp. dominated. Towards the end of the year, large centric diatoms dominated once again.

At the Bothnian Bay station F9/A13 the low biomasses during late winter and spring consisted of diatoms, dinoflagellates and green algae. Data from May and June are missing due to the decreased budget for the environmental monitoring. The maximum biomass peak was found in August when *M. rubrum* and large centric diatoms dominated; the small flagellate genus *Pyramimonas* was numerous. *M. rubrum* dominated in the beginning of autumn before there was a shift towards large centric diatoms.

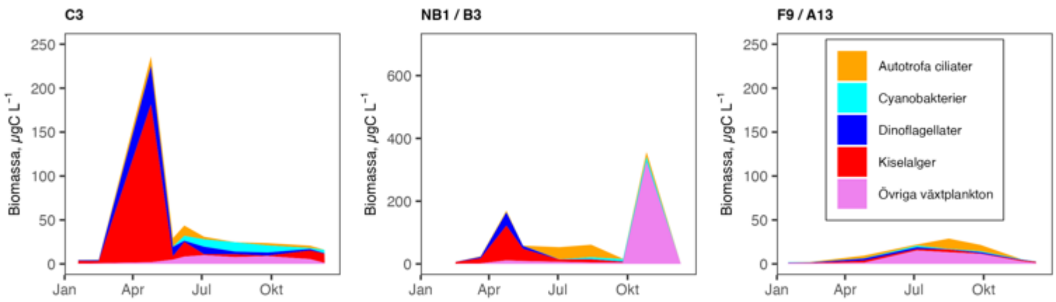

Figure 39. Phytoplankton biomass (µg C/l) at the Bothnian Sea and the Bothnian Bay stations C3, NB1/B3 and F9/A13.

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