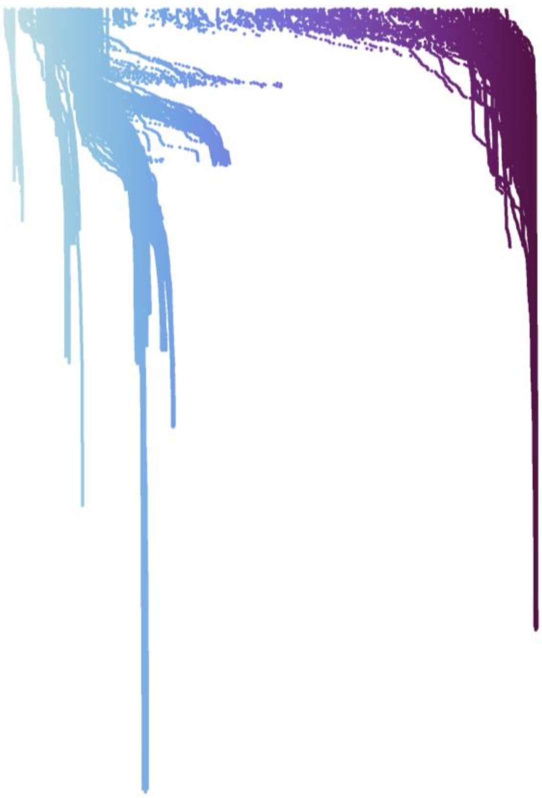
REPORT OCEANOGRAPHY No. 73, 2022

The Swedish National Marine Monitoring Programme 2021

Hydrography, Nutrients, Phytoplankton

Ann-Turi Skjevik, Karin Wesslander, Lena Viktorsson, Madeleine Nilsson



Front: The image illustrates density profiles from all CTD-observations made by SMHI during 2021. The colour reflects the density. Image is produced with ODV (Schlitzer, Reiner, Ocean Data View, odv.awi.de, 2021).

ISSN: 0283-1112

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Classification / Klassificering

Public / Publik

Key words / Nyckelord

Oceanography, marine monitoring, nutrients, Baltic Sea, Gulf of Bothnia, Skagerrak, Kattegat

Oceanografi, marin miljöövervakning, näringsämnen, Östersjön, Bottniska viken, Skagerrak, Kattegatt

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Summary

2021 was a year with more normal temperatures compared to 2020, which was record warm. Not a single classified storm occurred in our Swedish coastal waters during the year. There were no larger inflows to the Baltic Sea, but three smaller inflows were observed during the autumn.

The temperature in the surface water was above normal throughout the Baltic Sea during the winter, and the coldest month was March which is normal for this sea area. In the Skagerrak and the Kattegat, it was colder than in the Baltic Sea and the coldest month was February and, unlike the previous year, the surface water temperature was not above normal. In mid-February, the entire Gulf of Bothnia was covered in ice, which did not happen last season. The ice winter of 2021 was classified as normal. In the Bothnian Sea, the minimum temperature was unusually high this winter. The highest concentrations of nutrients, although within the normal range, were measured in January in the Skagerrak and the Kattegat and in March in the Baltic Sea. Silicate levels were still high and above normal in the Baltic Sea.

Surface water temperatures were normal during spring and in May it started to get warmer. The spring bloom started earlier in the Skagerrak than in the Kattegat this year, normally it is the other way around. In the Baltic Sea the spring bloom started later, in March-April which is normal for this sea area. In the Bothnian Sea the spring bloom started in April and in the Gulf of Bothnia in May-June.

Surface water temperatures were at their highest and above normal in July at many stations in the Baltic Sea, the Skagerrak and the Kattegat. In August, surface water temperatures were below normal in coastal parts of the Bornholm Basin, which was caused by upwelling of colder deep water. The nutrient levels were mostly normal, but an interesting detail was the unusually high silicate content measured in the Kattegat in June, which was the result of outflowing water from the Baltic Sea. This summer's cyanobacterial blooms were less intense than last year. The accumulations were most intense in the Bothnian Sea and the southern Baltic Sea, especially southeast of Öland. At the mouth of the Gulf of Finland, the blooms were also intense.

The autumn was relatively undramatic, but in November surface water temperatures above normal could be measured at several stations in the Skagerrak and the Kattegat and below normal at some stations in the Bothnian Sea during September and October.

The oxygen situation in the Baltic Sea continues to be severe and increasing oxygen deficiency in the form of increasing hydrogen sulphide levels was noted during 2021. The concentrations are now approaching the highest levels of hydrogen sulphide in the Western Gotland Basin since the measurements started. In the Eastern Gotland Basin, the levels of hydrogen sulphide are at their highest and continue to increase since the last major Baltic inflow in 2014. In the Bothnian Sea, a decreasing oxygen concentration was observed in the bottom water during 2021. However, the levels are close, but not below the limit for oxygen deficiency (<4ml/l). In the Skagerrak and Kattegat, the oxygen concentration in the bottom water was lowest during the autumn and below normal at a couple of stations but returned to normal levels towards the end of the year.

Sammanfattning

2021 var ett år av mer normala temperaturer jämfört med 2020, som var rekordvarmt. Inte en enda storm inträffade i våra svenska kustfarvatten under året. Det förekom inga stora inflöden till Östersjön under året, men tre mindre inflöden observerades under hösten.

Temperaturen i ytvattnet var över normal i hela Östersjön under vintern, men kallast var det i mars vilket är normalt för havsområdet. I Västerhavet var det kallare än i Östersjön och kallast var det i februari och till skillnad från föregående år så var inte ytvattentemperaturen över normal. I mitten av februari var hela Bottenviken istäckt, vilket inte skedde förra säsongen. Isvintern 2021 blev klassad som normal. I Bottenhavet var minimitemperaturen ovanligt hög den här vintern. De högsta koncentrationerna av närsalter uppmättes som vanligt under januari månad i Västerhavet och under mars i Östersjön. Kiselhalterna var fortsatt höga och över det normala i Östersjön.

Ytvattentemperaturerna var normala under våren och i maj tog uppvärmningen fart. Vårblomningen startade i februari i Västerhavet och något senare, i april, i Östersjön vilket är normalt för havsområdena. Avvikande var att vårblomningen startade tidigare i Skagerrak än i Kattegatt. I Bottenhavet startade vårblomningen i april och i Bottenviken i maj-juni.

Ytvattentemperaturerna var som högst och över det normala i juli på många stationer i både Östersjön och Västerhavet. I augusti uppmättes ytvattentemperaturer under det normala i Bornholmsbassängen som orsakades av uppvällning av kallare djupvatten. Närsaltsnivåerna var mestadels normala i båda havsområdena, men en intressant detalj var den ovanligt höga silikathalt som uppmättes i Kattegatt under juni som var resultatet av utflödande vatten från Östersjön. Sommarens cyanobakterieblomningar var mindre intensiva än föregående år. Som intensivast blommade det i Bottenhavet och södra Östersjön, framförallt sydost om Öland. I mynningen till finska viken var blomningarna också intensiva.

Hösten var förhållandevis odramatisk men under november kunde ytvattentemperaturer över det normala uppmätas på flera stationer i Västerhavet och under det normala på några stationer i Bottenhavet under september och oktober.

Syresituationen i Östersjön fortsätter att vara allvarlig och det råder en förvärrad syrebrist i form av ökande svavelvätehalter. Koncentrationen av svavelväte är nu de högsta i Västra Gotlandsbassängen sedan mätningarna startade. I Östra Gotlandsbassängen är halterna av svavelväte som högst och fortsätter att öka sedan det senaste inflödet 2014. I Bottenhavet ses en minskande syrgashalt i bottenvattnet, med halter nära, men inte än under, gränsen för syrebrist (<4mL/L). I Västerhavet var syrgashalten i bottenvattnet som lägst under hösten och under det normala på ett par stationer i Kattegatt och vid den kustnära stationen Släggö, men återgick till det normala mot slutet av året.

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Appendix III Nutrient content per basin.

Appendix IV CTD-transects from the Kattegat to the Western Gotland Basin for the SMHI cruises.

1 The monitoring programme

The current Swedish marine monitoring programme of the pelagic has been in place since 1994, with only smaller changes. The focus of the programme is eutrophication and oxygen deficiency, and has been 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 stations 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 is performed during the autumn because it's the season with the most severe oxygen

[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.

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] during 2021. 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). 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 there. 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, in Swedish, is published by the Swedish Agency for Marine and Water Management[6].

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. During the 1960's nutrients entered the picture; first phosphorus then nitrogen and finally silica. However, the frequency was still variable between years, in 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

[5] Hansson M., Viktorsson L., Oxygen Survey in the Baltic Sea 2021 - Extent of Anoxia and Hypoxia, 1960-2020, REPORT OCEANOGRAPHY No. 72, 2021

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

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 the commitment within HELCOM and OSPAR.

2 Performance in 2021 and description of the current programme

The marine monitoring programme of the pelagic in Sweden currently consists of about 40 standard stations distributed in the seas surrounding Sweden, deep blue and red dots in Figure 1. 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.

In 2020 three bottom mounted systems that measure salinity, temperature and oxygen were installed at Laholm Bay, Hanö Bight and Understen in the entrance to the Bothnian Sea from the Baltic Proper. This project ended in 2021 and an evaluation of the systems and the data collected is available in a separate SMHI report[7].

The number of visits at the standard stations during 2021 is presented in Figure 2. Two stations in the Skagerrak Å-transect were visited only 10 times instead of 12, this is somewhat misleading since the stations were instead sampled with the Moving Vessel Profiler on R/V Svea. This means that there instead are profiles along the Å-transect taken with around 5 min intervals along the transect. There were 19 visits instead of 24 to the station Anholt E in Kattegat, since the station is only sampled twice monthly when the SMHI cruise with R/V Svea start and stops in Lysekil on the west coast. Data from the coastal station Ref M1V1 was only reported by SMHI at the time of writing and not from the coastal monitoring and is therefore only listed as visited 12 times during 2021. In the beginning of the year some visits in the Gulf of Bothnia had to be cancelled due to problems with the vessel (KBV 181) used in this area. At station BY31 Landsort deep the high frequency during summer could be maintained despite some difficulty for Stockholm University to get vessel time during summer, the station was visited 23 times out of the planned 24. Through coordination between Stockholm University and SMHI it was possible for SMHI to visit stations BY29 in March, May, June and August to avoid cancelling the stations due to difficulties for Stockholm University to get enough shiptime. During the August cruise SMHI also visited station BY31 Landsort deep and

[7] Bottenmonterade mätsystem, Anna Willstrand-Wranne m. fl., 2020–2021, OCEANOGRAFI NR 131, 2021.

took nutrient and dissolved inorganic carbon samples according to the procedures at Stockholm University and sent the samples to their laboratory for analysis and comparison to the results from the samples analysed onboard R/V Svea as per the normal routine on SMHI cruises. There were two more intercalibration events during cruises in 2021. One with the German institute IOW in March in the Arkona basin when the German R/V Elisabeth Mann-Borgese and R/V Svea sampled at the same position (BY2). The last one was on the December cruise to the Gulf of Bothnia which was performed on board R/V Svea with staff from both SMHI and UMF (Umeå Marine Sciences Centre). During this cruise both the nutrient mapping stations and the regular monthly stations were visited. UMF brought all needed instruments for their analysis and water samples for analysis were taken simultaneously. The main focus was on comparison of the nutrient analysis. The results of the intercalibrations are not presented in this report but will be published when ready at SMHIs and UMFs website.

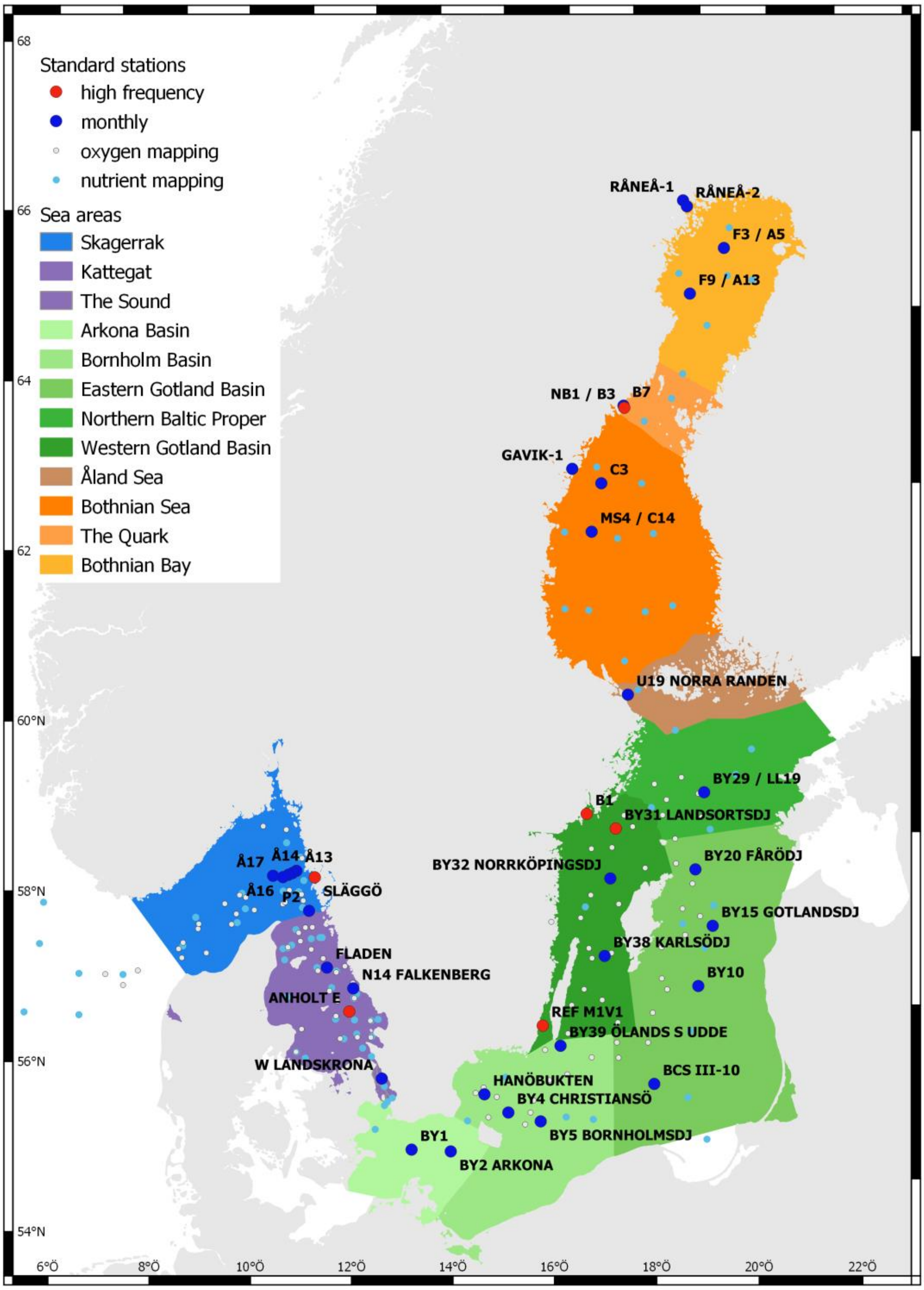

Figure 1. Map of the visited stations in the national monitoring programme during 2021. Blue: stations visited monthly, red: stations visited two times per month or more frequently, white: stations visited for oxygen mapping, light blue: stations visited for nutrient mapping.

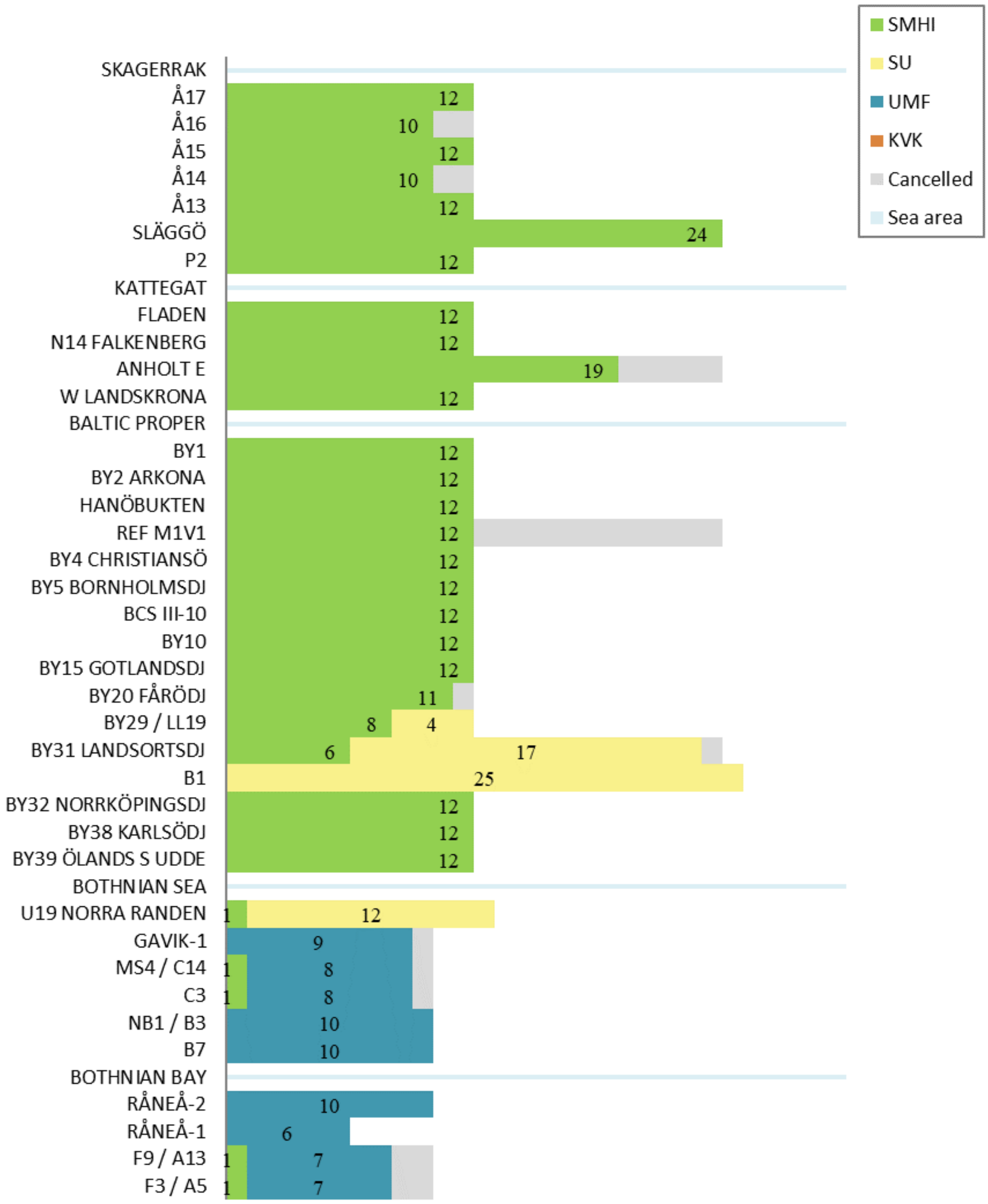

Figure 2. Number of visits at each standard monitoring station during 2021. The stations with one visit from SMHI in the Bothnian Sea and Bothnian Bay was performed during the joint December cruise where both SMHI and UMF participated.

3 Weather 2021

The year 2021 had both warm and cold periods but in relation to the new normal period (1991-2020) the air temperature was generally normal. Even though there were occasions with windy weather along the coast, none of them were classified as a storm.

January was rather cold and the maximum ice extent was reached 15th of February with 127 000 km^2. At that time the Bothnian Bay and parts of Bothnian sea were ice covered. The ice winter 2021 was classified as normal. The last ice had disappeared from the northern Bothnian Bay around 20th of May. In the end of February low pressure systems took over and more windy and milder weather followed.

March and April were mainly dominated by dry weather and March was unusually warm. May was unusually cold and heavy rain falls hit the West Coast. The summer offered a varying weather. Especially June was very hot with some records in air temperature. July was also warm but with several heavy rain falls.

Compared to the summer, the autumn offered less drama and the temperature did not drop considerably until late November. The year ended with a predominantly cold December month in the whole country.

4 Oceanographic conditions

Annual cycles of the surface water (0-10m), vertical sections from the Skagerrak to the Western Gotland Basin and time series from 1960-2021 are presented in Appendices I-IV. In the text, reference to normal condition or values means the average +/- one standard deviation for the period 2001-2015. 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[8].

The Swedish seas have large variations, especially in salinity, which gives the seas their different characteristics, Figure 3. 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 other levels of and ratios between nutrients than the Baltic Proper.

[8] Cruise reports from SMHI

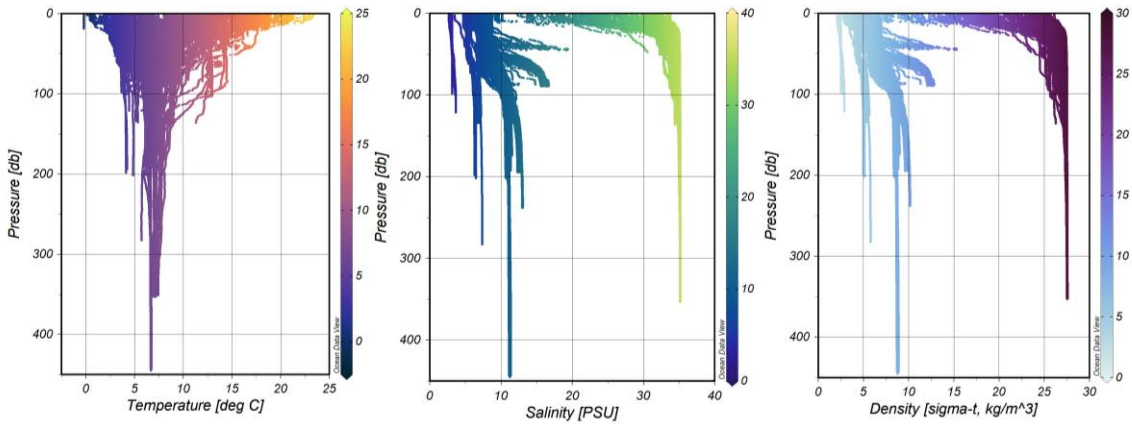

Figure 3. All temperature, salinity and density profiles from the SMHI monitoring cruises during 2021, the colours refer to the plotted parameter.

To illustrate the highly variable seas around Sweden a selection of parameters and stations from the different sea areas Figure 4 presents mean values in surface water (0-10 m) at each sampling occasion during 2021 Besides the difference in salinity mentioned above, other parameters show differences between the areas. For example, the concentration of phosphate is much lower in the northern parts 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.

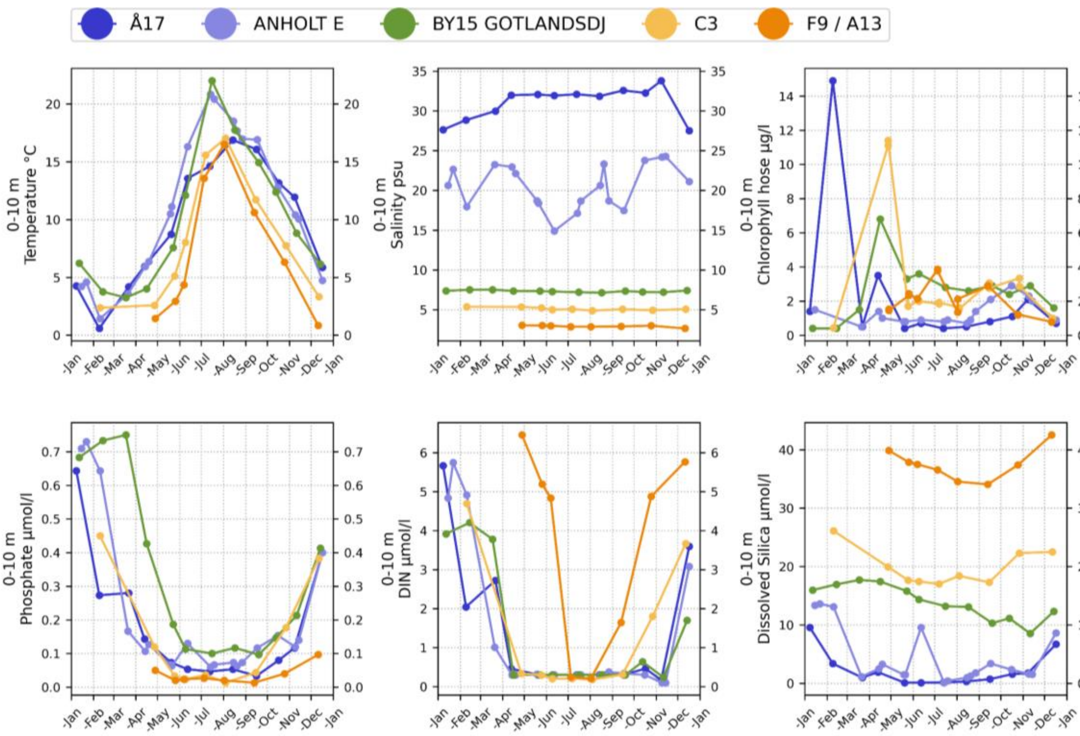

Figure 4. Temperature, salinity, chlorophyll, phosphate, dissolved inorganic nitrogen and dissolved silica from the different sea areas around Sweden: the Skagerrak (Å17), the Kattegat (Anholt E), the Baltic Proper (BY15), the Bothnian Sea (C3) and the Bothnian Bay (F9/A13). All parameters are mean values of surface water (0-10 m) during 2021.

4.1 Skagerrak, Kattegat and the Sound

4.1.1 Temperature and salinity

The seasonal development of the temperature in the surface layer follows the air temperature with a certain time delay. Below the surface, the temperature is more controlled by mixing and advection processes both vertically and horizontally.

The temporal development of temperature and salinity in the surface water (timeseries 1990 - 2021) are shown in Figure 5. The temporal development of temperature and salinity from surface to bottom (profiles) during 2021 are shown in Figure 6 (Skagerrak), Figure 7 (Kattegat) and Figure 8 (the Sound). In 2021, the temperature in the surface layer in Skagerrak, Kattegat and the Sound dropped to its minimum in February. At several stations, the surface temperature in February was below normal and at station Å17 in Skagerrak the surface temperature went down to 0.5°C (see the seasonal temperature cycles in appendix). The trend of high winter temperatures from the previous years did thus not continue this year, see Figure 5a.

Temperature and Salinity in the surface layer: Skagerrak, Kattegat and the Sound

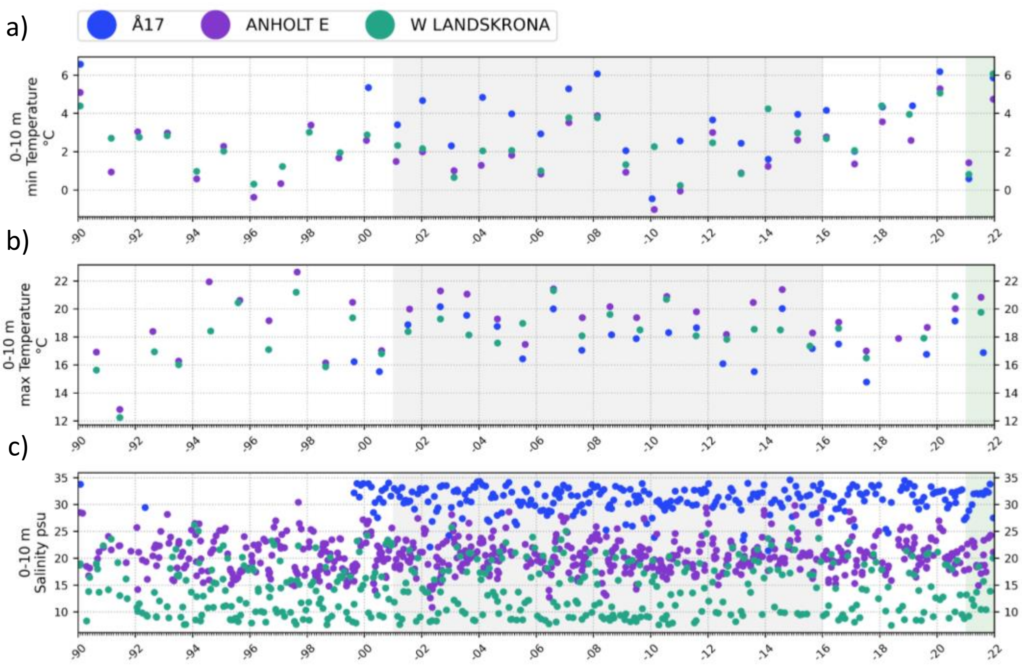

Figure 5. a) Minimum winter temperature in the surface layer, 0-10 m, during December – February.
b) Maximum summer temperature in the surface layer, 0-10 m, during June – August.
c) Salinity in the surface layer, 0-10 m, for all observations. The stations presented are Å17 in the Skagerrak, Anholt E in the Kattegat and W Landskrona in the Sound. The shadowed grey area highlights the time period that statistics is based on in this report, 2001-2015. The shadowed green area highlights the year 2021.

During spring, the surface temperature was normal and the warming of the surface layer continued until July when the maximum temperatures were reached, Figure 6, Figure 7 and Figure 8. In Kattegat and the Sound, 20-21°C was observed in the surface in July and all stations were warmer than normal. The summer temperature in the Skagerrak surface water were some degrees lower, and the stations Å15 and Å14 were warmer than normal, while station Å17 were colder than normal. In Figure 5b it can be noted that stations both in Kattegat and the Sound were warm in relation to the longer time period 2001-2015 while the station in Skagerrak were rather cold.

After summer the surface layer cooled off and the year ended with surface temperatures between 5 and 7°C. Temperatures in autumn were normal with the exception of somewhat higher than normal surface temperatures in Skagerrak in November.

The surface layer in Skagerrak and Kattegat was separated from the deeper waters by a halocline at 10-20 m. Below 20 m the salinity increased in the deep part of Skagerrak until 100 m from where the salinity stabilises at around 35 psu and temperature around 7-8°C, Figure 6. Kattegat is shallower and its bottom water are of similar properties as the Skagerrak intermediate water, Figure 7. The annual variations of both temperature and salinity are larger in the Kattegat bottom water compared with Skagerrak where it is less variations, Figure 9b and c. The Kattegat surface layer is influenced by the surface water from the Baltic Sea and its salinity is lower than in Skagerrak, Figure 5c. The salinity in the Kattegat surface water therefore vary a lot but were mostly within normal ranges in 2021.

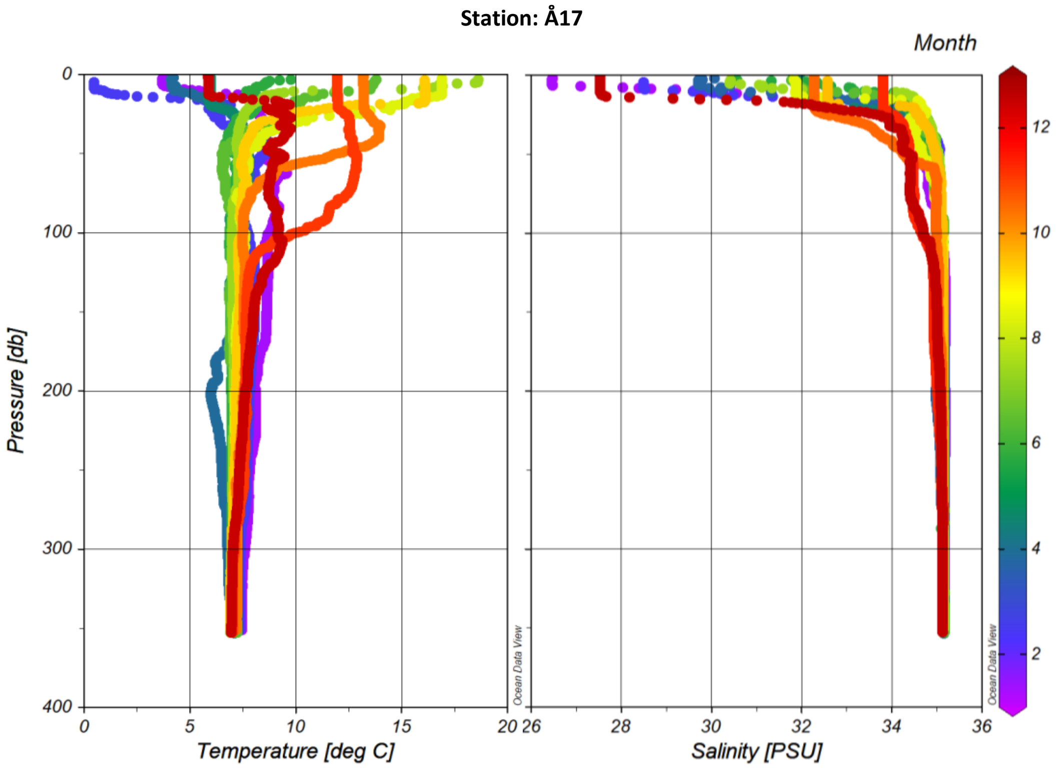

Figure 6. CTD-profiles at station Å17 in Skagerrak during 2021: temperature and salinity. Colours indicate the sampling month.

Station: Anholt E

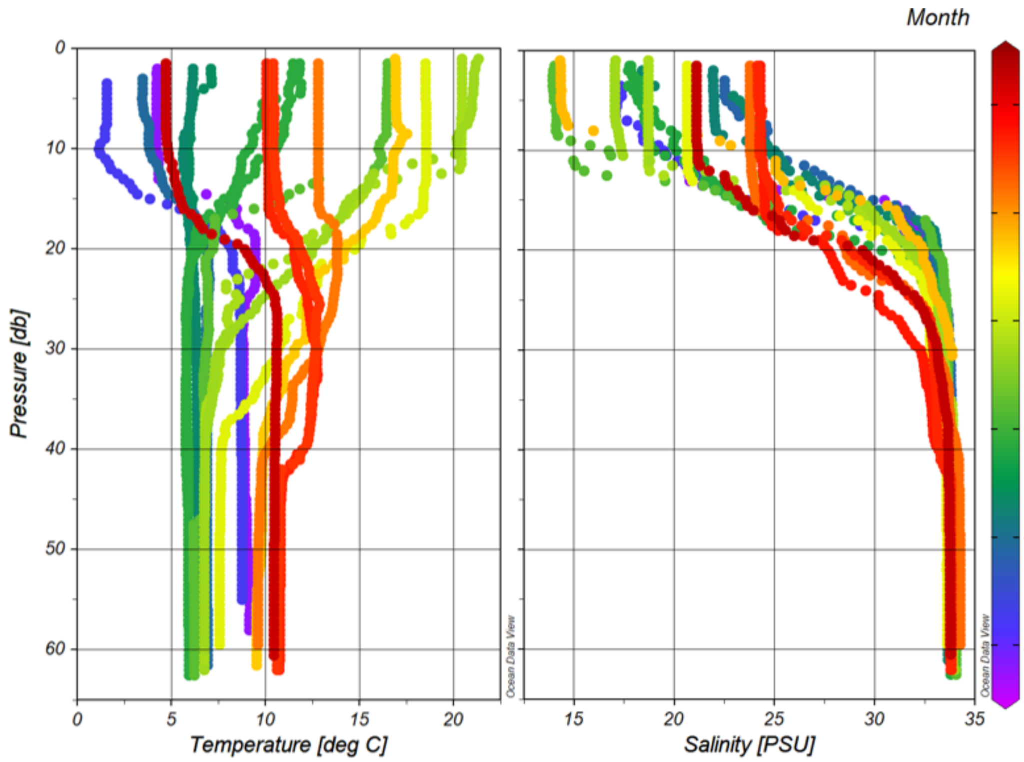

Figure 7. CTD-profiles at station Anholt E in Kattegat during 2021: temperature and salinity. Colours indicate the sampling month.

Station: W Landskrona

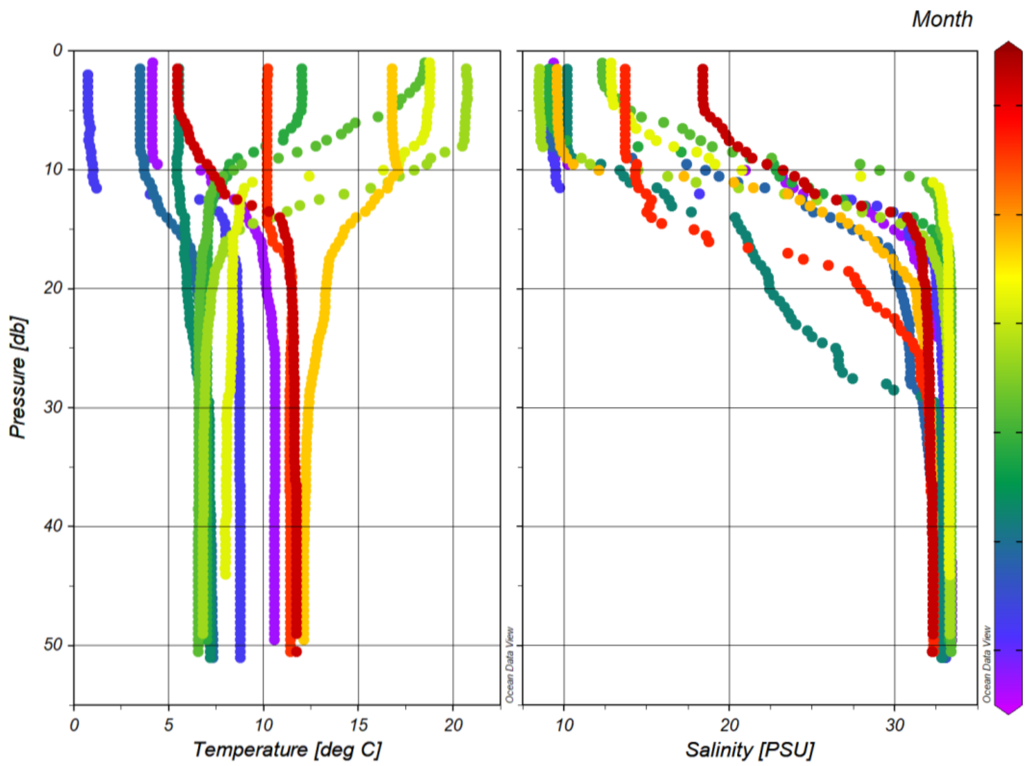

Figure 8. CTD-profiles at station W Landskrona in the Sound during 2021: temperature and salinity. Colours indicate the sampling month.

4.1.2 Oxygen conditions in the bottom water

The concentration of oxygen in the bottom water was lowest in October and November. As seen in Figure 9a, the Skagerrak bottom water is normally well saturated with oxygen. But along the Å-section from the open sea towards the coast there are still variabilities. At the station Å13 the oxygen concentration was normal except from in October when it was just below 4 ml/l in the bottom water. This might be due to the higher temperature at the same time. At the coastal station Släggö the concentration in the bottom water had dropped to 2.7 ml/l in November which is lower than normal, Figure 10.

Temperature, salinity and dissolved oxygen in the bottom water: Skagerrak, Kattegat and the Sound

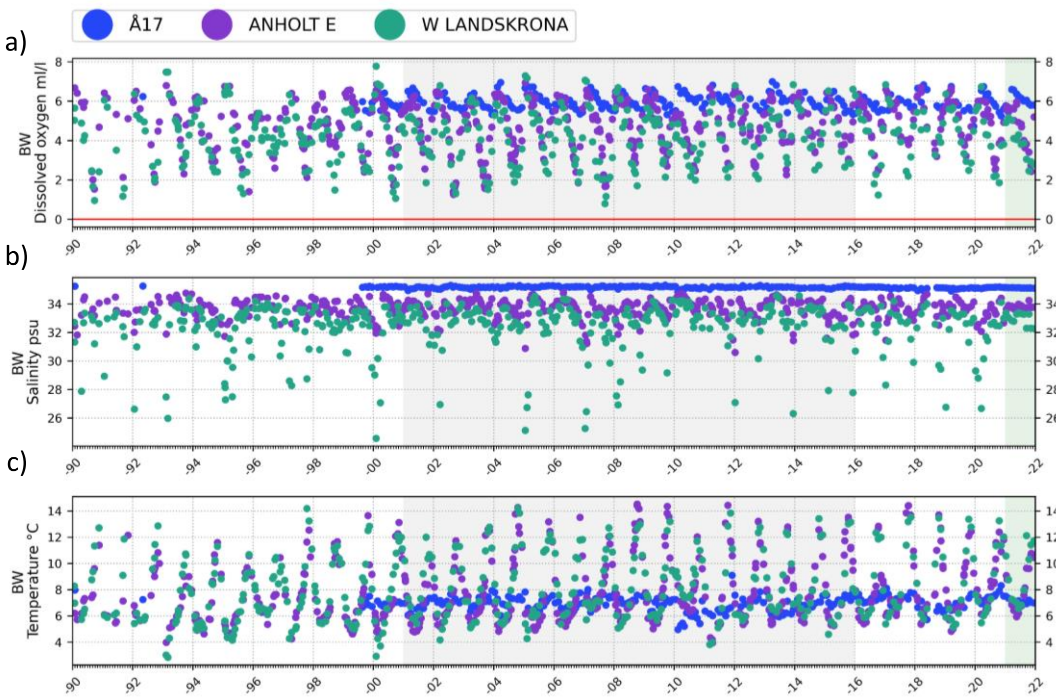

Figure 9. a) Dissolved oxygen, b) salinity and c) temperature in the bottom water for all observations. The stations presented are Å17 in the Skagerrak, Anholt E in the Kattegat and W Landskrona in the Sound. The shadowed grey area highlights the time period that statistics is based on in this report, 2001-2015. The shadowed green area highlights the year 2021.

The oxygen concentration was lower than normal in the Kattegat bottom water; at station Anholt E 2.4 ml/l and at station Fladen 3.7 ml/l. The oxygen concentration at these stations were back to normal in December. During autumn, the intermediate 'old' and warmer summer water is preventing the bottom water to be exchanged and this effect together with the timing of degradation of biological material cause these low oxygen events. The water column is often mixed in December which increases the oxygen concentration near the bottom. In Kattegat and the Sound, this variability in the oxygen concentration is normal, Figure 9a.

The lowest oxygen concentration in the Sound was noted in October (2.5 ml/l) which is normal for the season. However, the oxygen concentration did not increase as usual and stayed low for the rest of the year. In December it was 2.8 ml/l which is lower than normal.

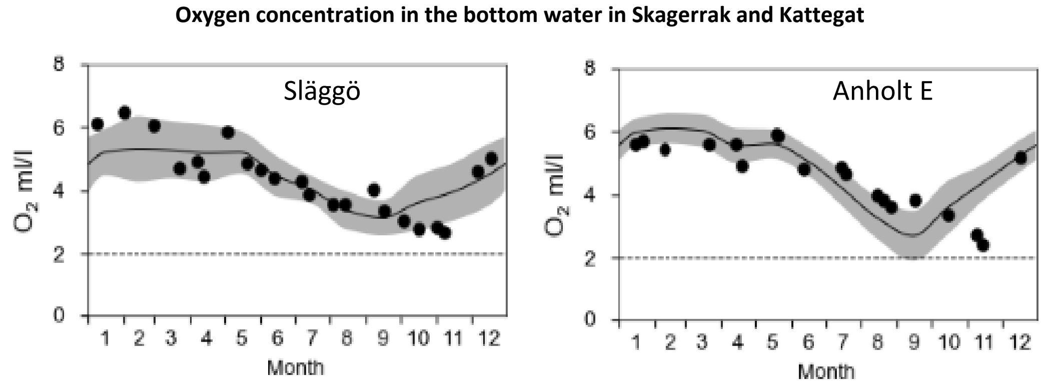

Figure 10. Concentration of oxygen in the bottom water ≥64 m at the coastal station Släggö in Skagerrak and ≥52 m at station Anholt E in Kattegat. Monthly measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

4.1.3 Nutrients

Concentrations of inorganic nitrogen and phosphorus was mostly normal in Skagerrak, Kattegat and the Sound during the year. The highest concentrations were measured in January in both the Skagerrak and the Kattegat. Normally the decrease in nutrients caused by the start of plankton activity (spring bloom) is earlier in Kattegat compared to Skagerrak. In 2021, however, it was the other way around. The decrease in nutrients was seen between the January and February cruise in the Skagerrak and a month later in the Kattegat (Figure 4).

In June silicate concentrations in the Kattegat were much higher than normal (Figure 11). After some consideration this was not judged to be erroneous data, but related to outflowing water from the Baltic Proper which is also showing in low salinity and elevated phosphate concentrations. At station W Landskrona in the Sound the concentrations were lower than normal in October due to a strong current carrying water from the Kattegat with relatively lower nutrient concentrations compared to normal at the station (Appendix I).

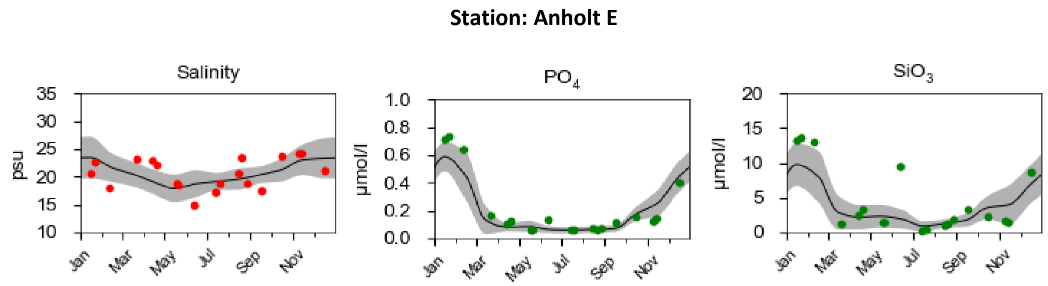

Figure 11.Annual cycles of salinity (red, left), phosphate (green, middle) and dissolved silica (green, right) at station Anholt E in the Kattegat in surface water (0-10 m). High nutrient concentrations in June associated to low salinities at the same time indicates a water mass originating from the Baltic Proper. Monthly measurements (dots) during 2021 in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

4.1.4 Plankton

Spring bloom was ongoing already in February at station Å17 in the Skagerrak, which is approximately one month earlier than normal when comparing to the time period 2001-2015 (Figure 12). The bloom at Å17 happened even earlier than at one of the Kattegat stations, Anholt E. Normally the spring bloom starts in the southern Kattegat and moves northwards. At N14 Falkenberg in the Kattegat, spring bloom also occurred in February, which is normal for this station. Diatoms dominated the spring bloom (Figure 13), only a small fraction of the phytoplankton was dinoflagellates and other algae. The nutrients also declined between January and February in the Skagerrak, whereas they were consumed one month later in the Kattegat area.

Somewhat high chlorophyll concentrations in May at Anholt E in the Kattegat were mainly caused by the diatom *Skeletonema marinoi* (Figure 14).

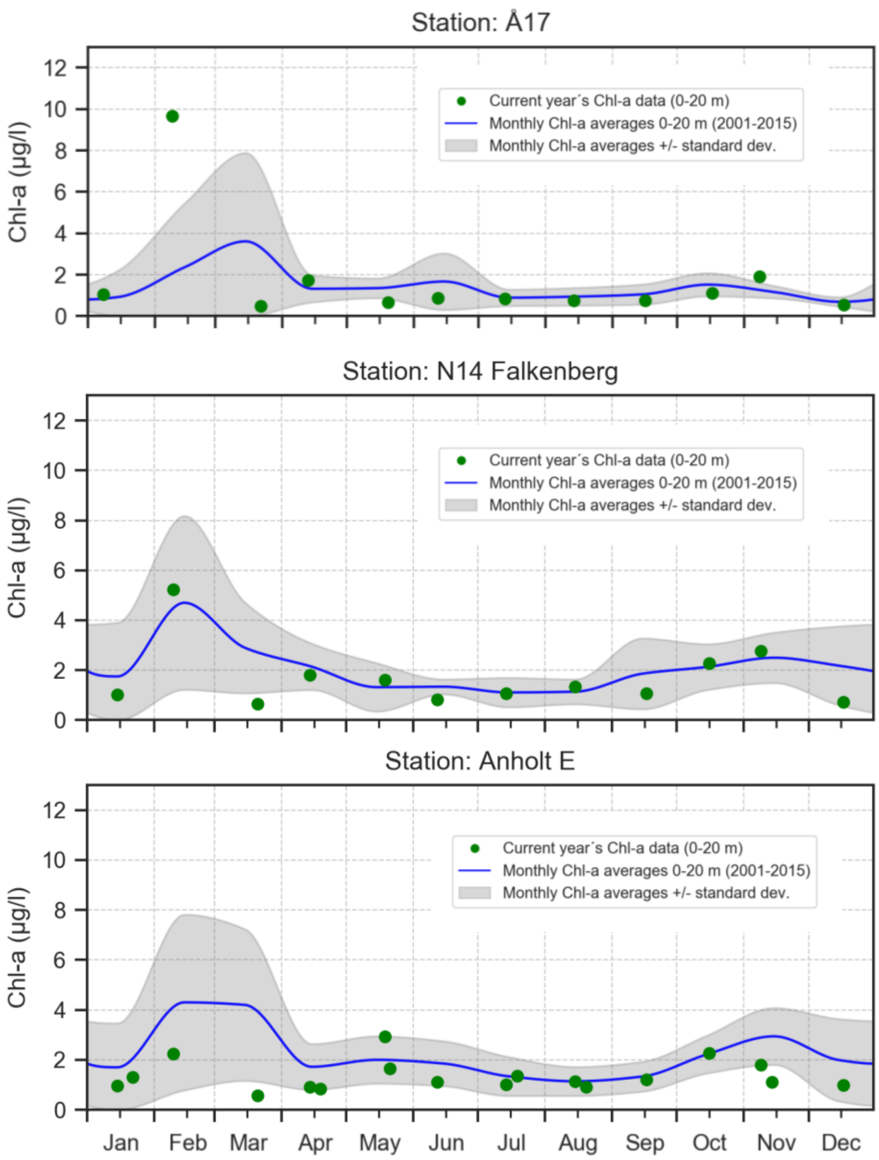

Figure 12. Integrated (0-20 m) chlorophyll a (µg/l) from Å17 in the Skagerrak, N14 Falkenberg and Anholt E in the Kattegat. Spring bloom was early at Å17.

In June-July enhanced biomasses were found at Släggö in the Skagerrak and N14 in the Kattegat respectively (Figure 13). During summer, large diatoms often occur, causing high biovolumes at low cell numbers, this also happened 2021. There are often low amounts of chloroplasts in large diatoms which is why the chlorophyll concentrations may be low at the same time. At Å17 in the Skagerrak in July, a chlorophyll fluorescence peak at approximately thirty meters was mainly caused by the dinoflagellate *Tripos macroceros* (Figure 14), a typical North Sea species.

An autumn bloom of diatoms was observed in the Kattegat in September-October at both N14 Falkenberg and Anholt E. In November, there was a phytoplankton peak at

N14 Falkenberg of which about 25 percent was diatoms and 75 percent various other phytoplankton.

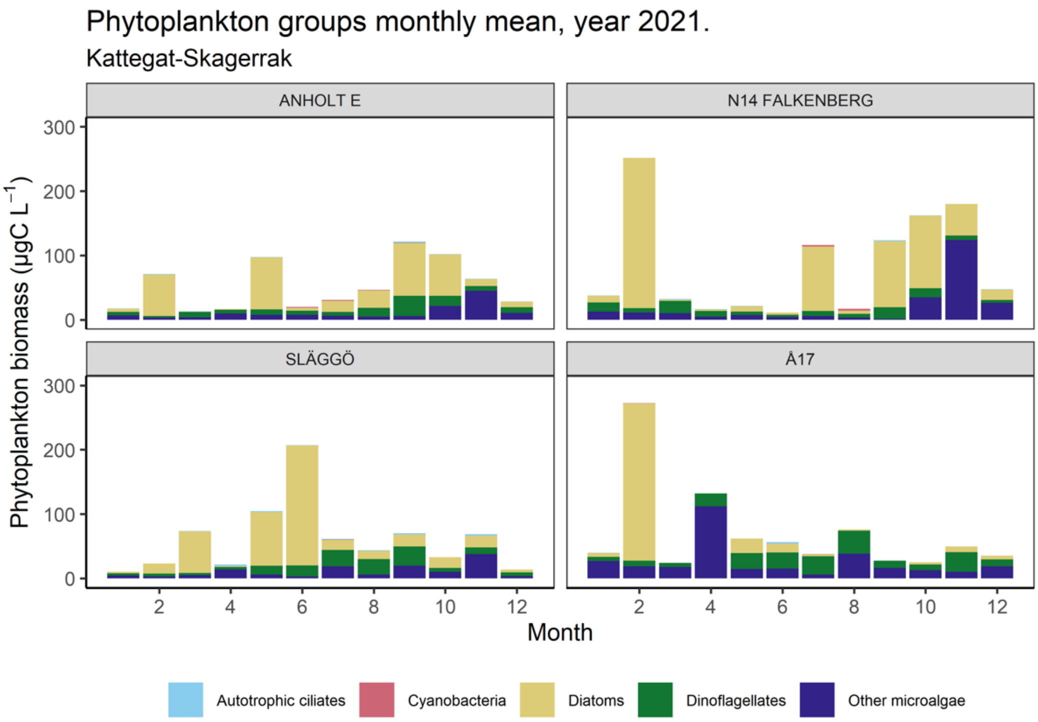

Figure 13. Phytoplankton biomass (µg C/l) at the four Kattegat phytoplankton stations.

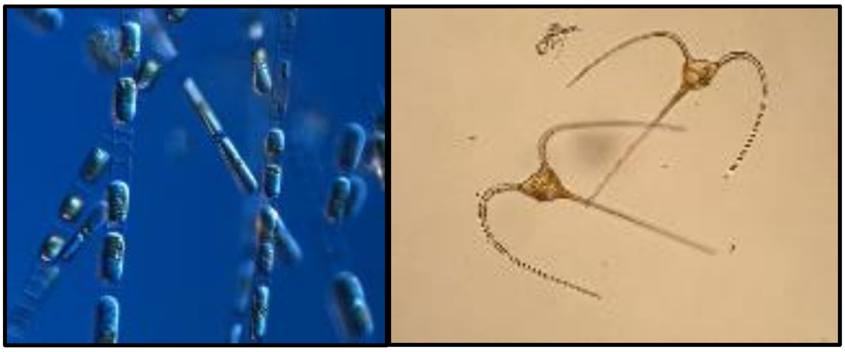

Figure 14. The diatom Skeletonema marinoi *(left) dominated the spring bloom in the Kattegat and Skagerrak. b) The dinoflagellate* Tripos macroceros *(right) partly caused a chlorophyll fluorescence peak at Å17 in the Skagerrak in July.*

4.2 Baltic Proper

4.2.1 Temperature and salinity

The temporal development of temperature and salinity in the Baltic Proper during 2021 are presented for two stations in more detail, BY15 in the Eastern Gotland Basin (Figure 21) and BY32 in the Western Gotland Basin (Figure 22).

The surface water temperature in the Baltic Proper was above normal during the winter (January and February). The surface layer is thick, 60 m (Figure 21 and Figure 22), and it takes a longer time to cool down this layer compared with the Skagerrak and Kattegat where the layer is shallower. Because of this, the lowest surface temperature was observed in March, for example 3.3°C at BY15 in the Eastern Gotland Basin (Figure 15a and Figure 21). At this time the water was well mixed down to the permanent halocline (ca 60 m). As seen in Figure 15a, even though the winter temperature in the Baltic

Proper was above normal when compared with the statistical period 2001-2015 it was colder than the previous winter 2019/2020.

Temperature and Salinity in the surface layer: Baltic Proper

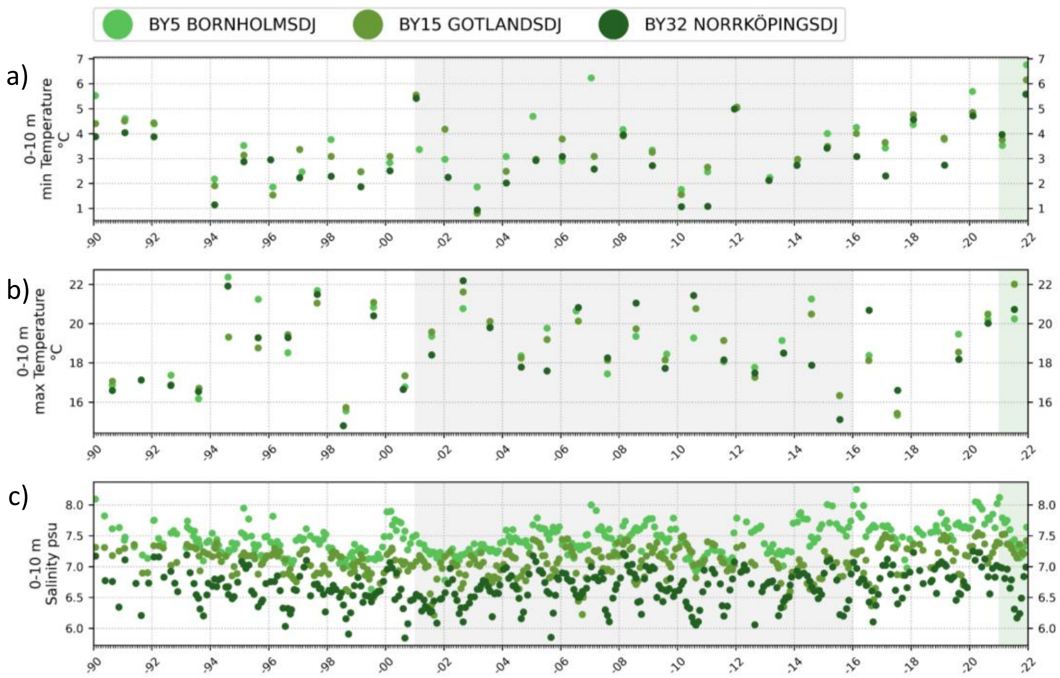

Figure 15. a) Minimum winter temperature in the surface layer, 0-10 m, during December – February. b) Maximum summer temperature in the surface layer, 0-10 m, during June – August. c) Salinity in the surface layer, 0-10 m, for all observations. The stations presented are BY5 in the Bornholm Basin, BY15 in the Eastern Gotland Basin and BY32 in the Western Gotland Basin. The shadowed grey area highlights the time period that statistics is based on in this report, 2001-2015. The shadowed green area highlights the year 2021.

In April there was a layer of less saline water in the upper 20 m creating a shallow pycnocline, Figure 16. This coincided with the time of the spring bloom (see section about phytoplankton below) and could also have helped promoting the start of the spring bloom by constraining the phytoplankton to the upper 20 m of the water column.

Station: BY15

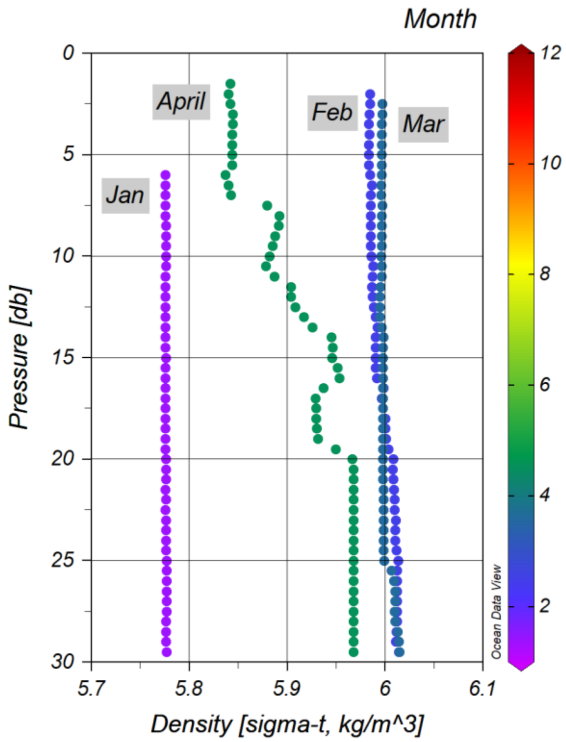

Figure 16. The density at BY15 in the Eastern Gotland Basin from the surface to 30 m. CTD-profiles are presented for January – March 2021. Colours indicate the sampling month.

The warming of the surface layer continued until July which became the warmest month and at most stations surface temperatures were above normal. The thermocline in July was at 10 m and the temperature in the Eastern Gotland Basin was 22°C, Figure 21. The summer temperature in the Baltic Proper was also warmer than the last two years, Figure 15b.

During the August cruise there was an up-welling event along the Swedish east coast. When the cruise stopped at station BY39 at the south of Öland the sea surface temperature was only 6°C which can be compared with 15°C at the nearby station RefM1V1 only three hours later, see Figure 17. The temperature difference between the bottom water and the surface water at station BY39 at this time was only 1°C.

Surface temperature at BY39 and Ref M1V1

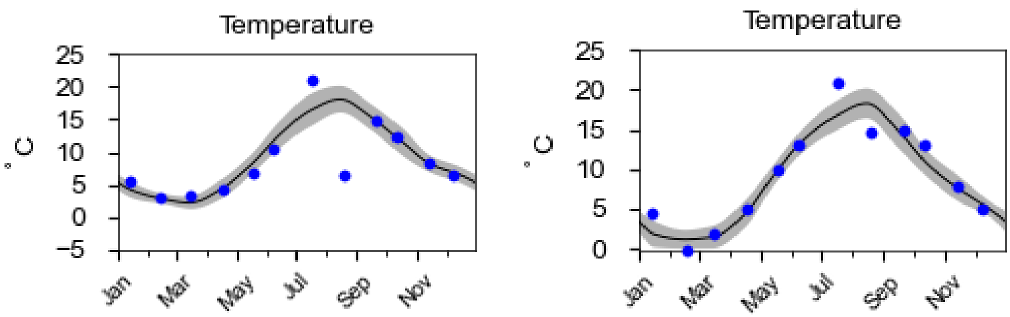

Figure 17. Sea surface temperature (0-10 m) during 2021 at the stations BY39 (left) and RefM1V1 (right) in the Baltic Proper. An up-welling event caused the low temperature at BY39 in August. Monthly measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

Because of increased wind mixing the surface mixed layer got deeper again after summer and in December it was well mixed down to the halocline with a temperature of 6°C.

During 2020, the salinity in the surface water was above normal in all basins in the Baltic Proper. But during 2021 salinity was above normal only in the Eastern Gotland Basin throughout the year, Figure 18. In Figure 15c we see the surface salinity in a longer time series (1990-2021) and here the decrease in surface salinity from 2020-2021 is clear.

Surface salinity in the Baltic Proper

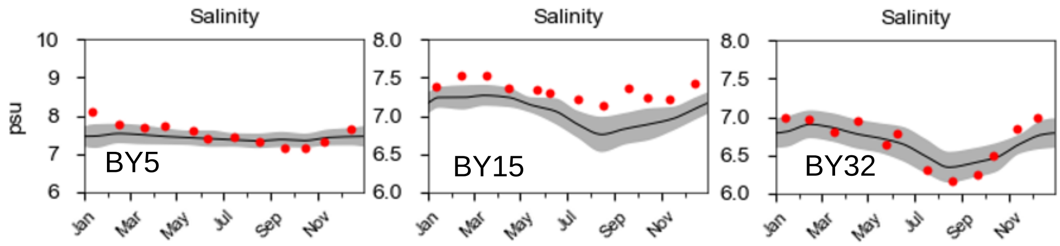

Figure 18. Salinity in surface water (0-10 m) during 2021 at the stations BY5 in the Bornholm Basin, BY15 in the Eastern Gotland Basin and BY32 in the Western Gotland Basin. Monthly measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

Temperature, salinity and dissolved oxygen in the bottom water: Baltic Proper

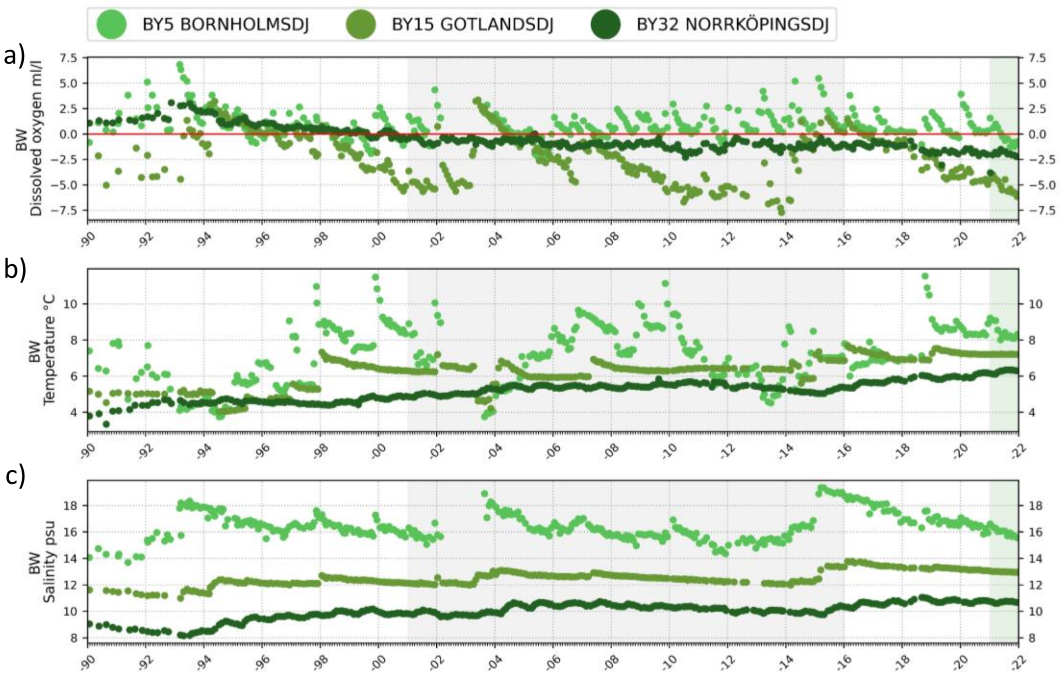

Figure 19. a) Dissolved oxygen, b) temperature and c) salinity in the bottom water at three stations in the Baltic Proper representing the basins Bornholm Basin (BY5), Eastern Gotland basin (BY15), Western Gotland Basin (BY32). The shadowed grey area highlights the time period that statistics is based on in this report, 2001-2015. The shadowed green area highlights the year 2021.

The halocline in the Baltic Proper is 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. In the Western Gotland Basin, the halocline position fluctuated more than in the Eastern Gotland Basin and in February it was pushed down to 70 m, which is deeper than normal, Figure 21 and Figure 22.

Salinity and temperature have less variability 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 and the weaker stratification in Arkona. After the inflow event in 2014 both salinity and temperature increased in the bottom water of the basins in the Baltic Proper (Figure 19b and c). During 2021 both temperature and salinity was still above normal in the deep basins in the Baltic Proper. Although the salinity is steadily decreasing in the stagnant water below the halocline, the temperature seems to remain higher and in the Western Gotland Basin it is still increasing. Profiles of salinity and temperature (Figure 20) show that salinity is above normal in almost the whole profile, while temperature is above normal only below the halocline.

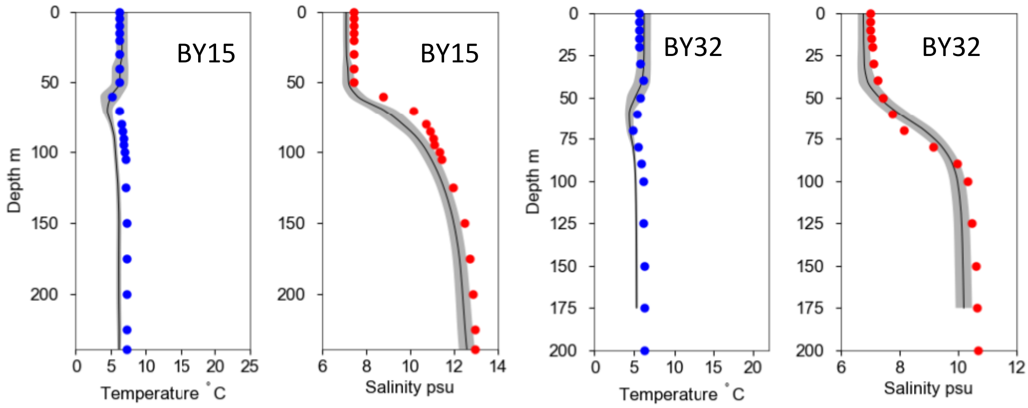

Figure 20. Profiles of temperature and salinity from the December 2021 cruise at BY15 and BY32 compared to statistics from the period 2001-2015. Measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

Station: BY15

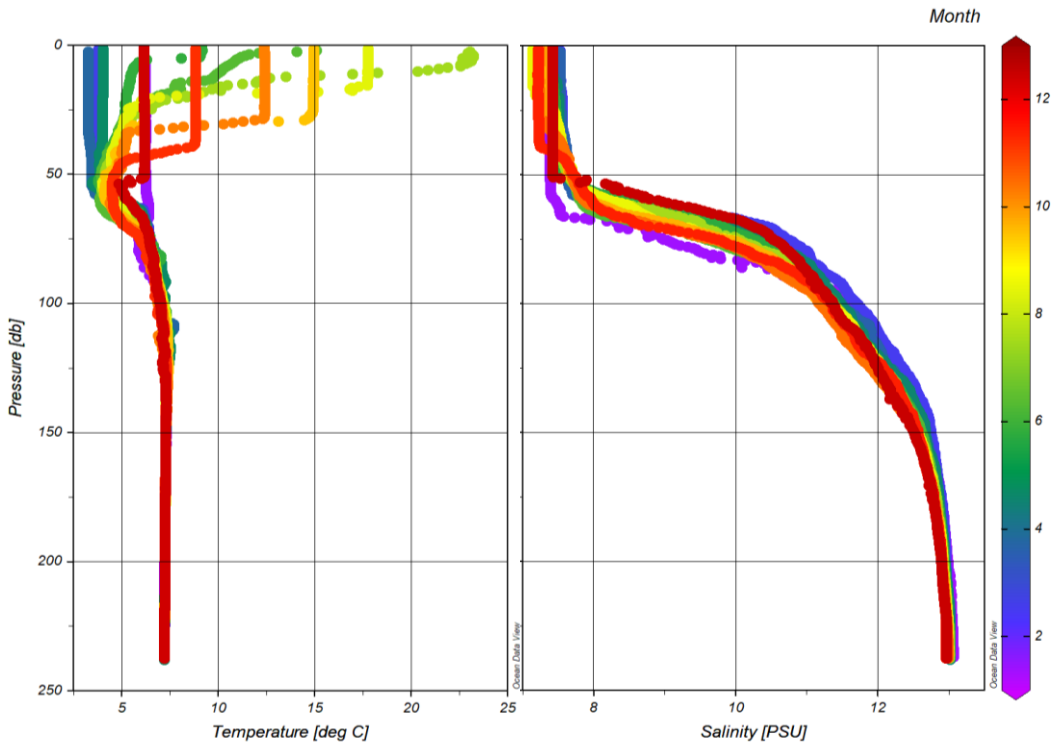

Figure 21. CTD-profiles at station BY15 in Baltic Proper during 2021: temperature and salinity. Colours indicate the sampling month.

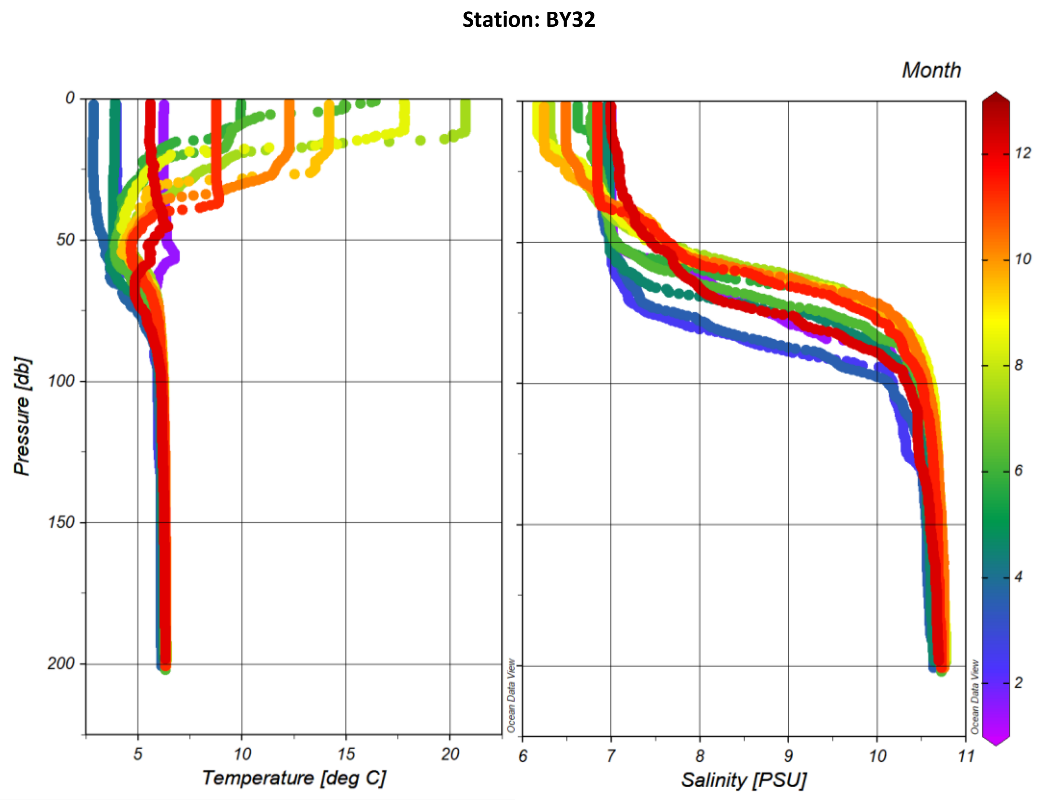

Figure 22. CTD-profiles at station BY32 in Baltic Proper during 2021: temperature and salinity. Colours indicate the sampling month.

4.2.2 Oxygen conditions in the bottom water

During 2021 there were no major inflows to the Baltic Proper that could improve the oxygen conditions in the bottom water to any larger extent. According to the latest annual report on the oxygen situation in the Baltic Sea 2021 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 19a above. The increase is faster in the Eastern Gotland Basin compared to the Western Gotland Basin, and the concentration is more than twice as high. However, the hydrogen sulphide concentration in the Western Gotland Basin is higher than at any point earlier in the time series. In the Eastern Gotland Basin, the hydrogen sulphide concentrations are approaching the highest values noted before, which was at the end of 2013, before the major Baltic inflow in 2014. In the Bornholm basin hypoxia is regularly found in the autumn and more seldom anoxia and hydrogen sulphide. In 2021 however, hydrogen sulphide was measured for the whole second half of the year, from June to December, Figure 23.

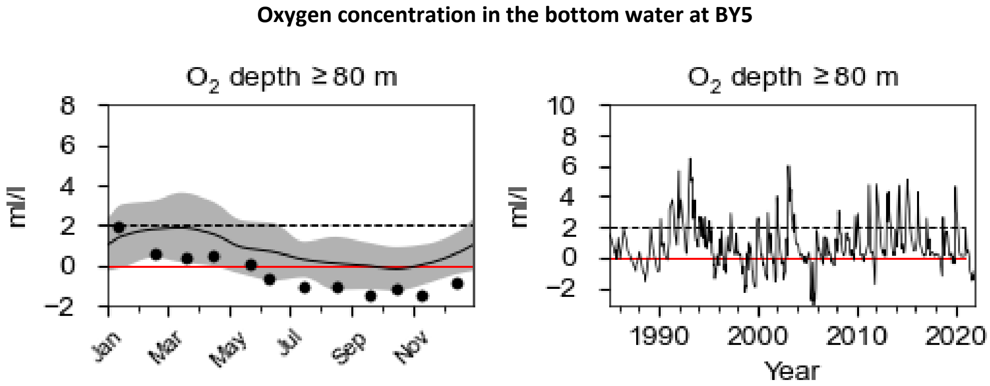

Figure 23. Oxygen and hydrogen sulphide (shown as negative oxygen) at station BY5 in the Bornholm basin. To the left monthly measurements (black dots) during 2021 in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

4.2.3 Nutrients

In the Baltic Proper the concentration of DIN dropped from winter maximum levels in March to under detection limit in April at most stations. This is the normal month that the spring bloom takes place in the Baltic Proper. The bi-weekly visits to station BY31 Landsort deep show that the drop in DIN took place during roughly two weeks at the end of March to the beginning of April, Figure 24. Phosphate drops much slower during the spring bloom in the Baltic Proper and phosphate continued to decrease until June and stayed at low summer levels until September and started to increase again in October when also DIN started to rise towards winter levels again.

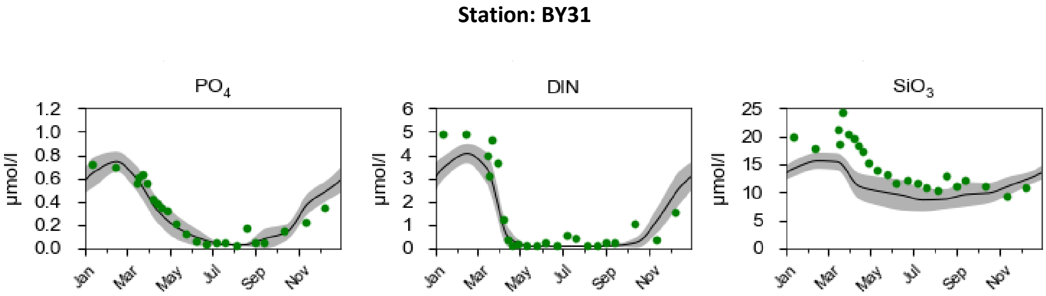

Figure 24. Concentrations of nutrients in the surface water (0-10 m) at station BY31 in the Northern Gotland Basin. To the left: phosphate, middle: dissolved inorganic nitrogen (DIN) and to the right: silicate. Monthly measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

No new inflows occurred that could renew the deep water and therefor concentrations of nutrients in the deep basins of the Baltic Proper continued to increase during 2021. Ammonium concentration in the Western Gotland Basin shows a clearly increasing trend since the year 2000 when the basin shifted to completely anoxic. The concentrations measured during 2021 are almost twice as high as the mean value for the normal period (Figure 25). However, the sum of dissolved inorganic nitrogen (DIN, ammonium, nitrate and nitrite) is increasing only towards the end of the time series. In the Eastern Gotland Basin ammonium and DIN follow the same pattern because DIN consists mainly of ammonium through the time series (1990-2021). Even here the DIN concentration is increasing but there are clear signals from inflows that cause a temporary decrease in the DIN concentration. The DIN concentration is above normal and in the bottom water the concentration is higher than in the Western Gotland Basin. 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.

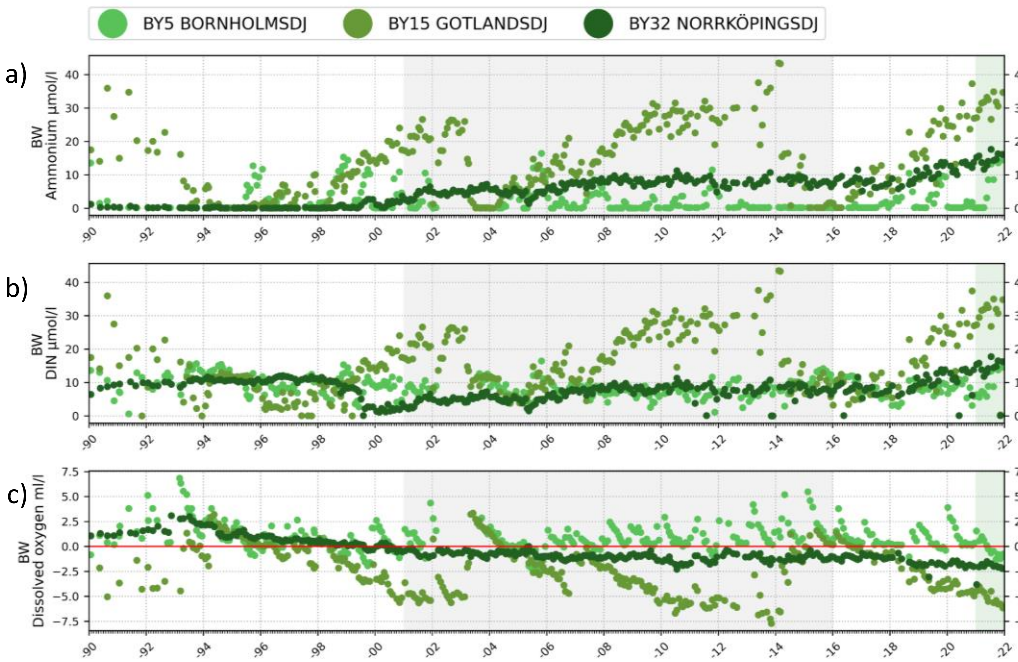

Figure 25. Concentration of a) ammonium, b) dissolved inorganic nitrogen (DIN) and c) dissolved oxygen, where hydrogen sulphide is expressed as negative oxygen in the bottom water, at three stations in the Baltic Proper representing the basins Bornholm Basin (BY5), Eastern Gotland Basin (BY15) and Western Gotland Basin (BY32). The shadowed grey area highlights the time period that statistics is based on in this report, 2001-2015. The shadowed green area highlights the year 2021. 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, depth depends on the depth of the halocline), Figure 26. 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.

The DIN concentration in the bottom water is still 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.

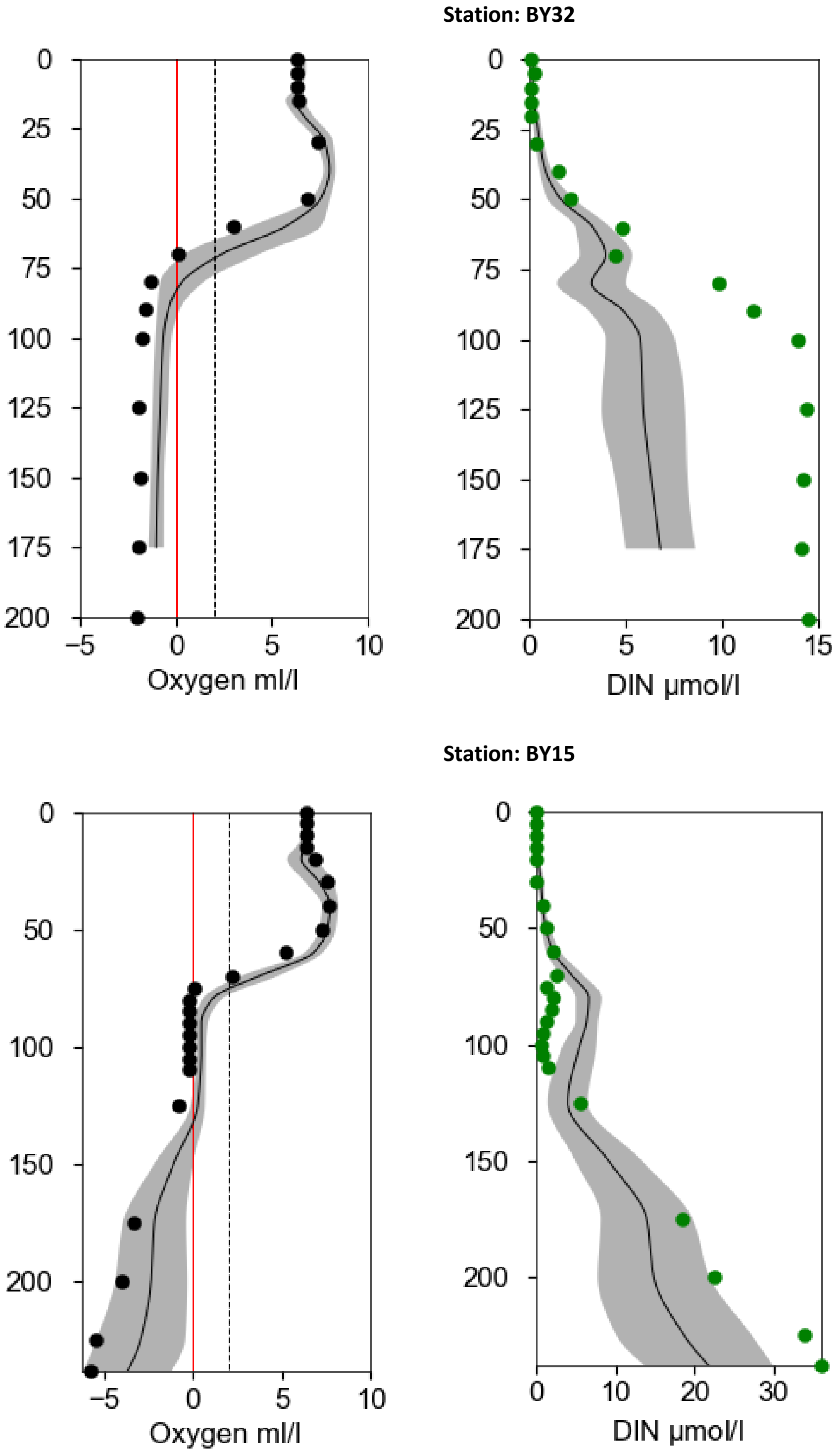

Figure 26. Profiles of oxygen (left, black) and dissolved inorganic nitrogen (right, green) from August 2021. Station BY32 in the Western Gotland Basin (top) and station BY15 in the Eastern Gotland Basin (bottom). Measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

4.2.4 Phytoplankton

The phytoplankton activity was typically low during January and February. In March spring bloom had begun at the most southwestern stations like BY2 Arkona and BY5 Bornholm with high cell numbers of diatoms, autotrophic ciliates and dinoflagellates, as well as high chlorophyll concentrations and a large decline in the amount of nutrients. At the more northern stations of the Baltic Proper, of which BY15 Gotland Deep is one, the spring bloom occurred one month later, in April and were mainly caused by dinoflagellates (Figure 27 and Figure 28).

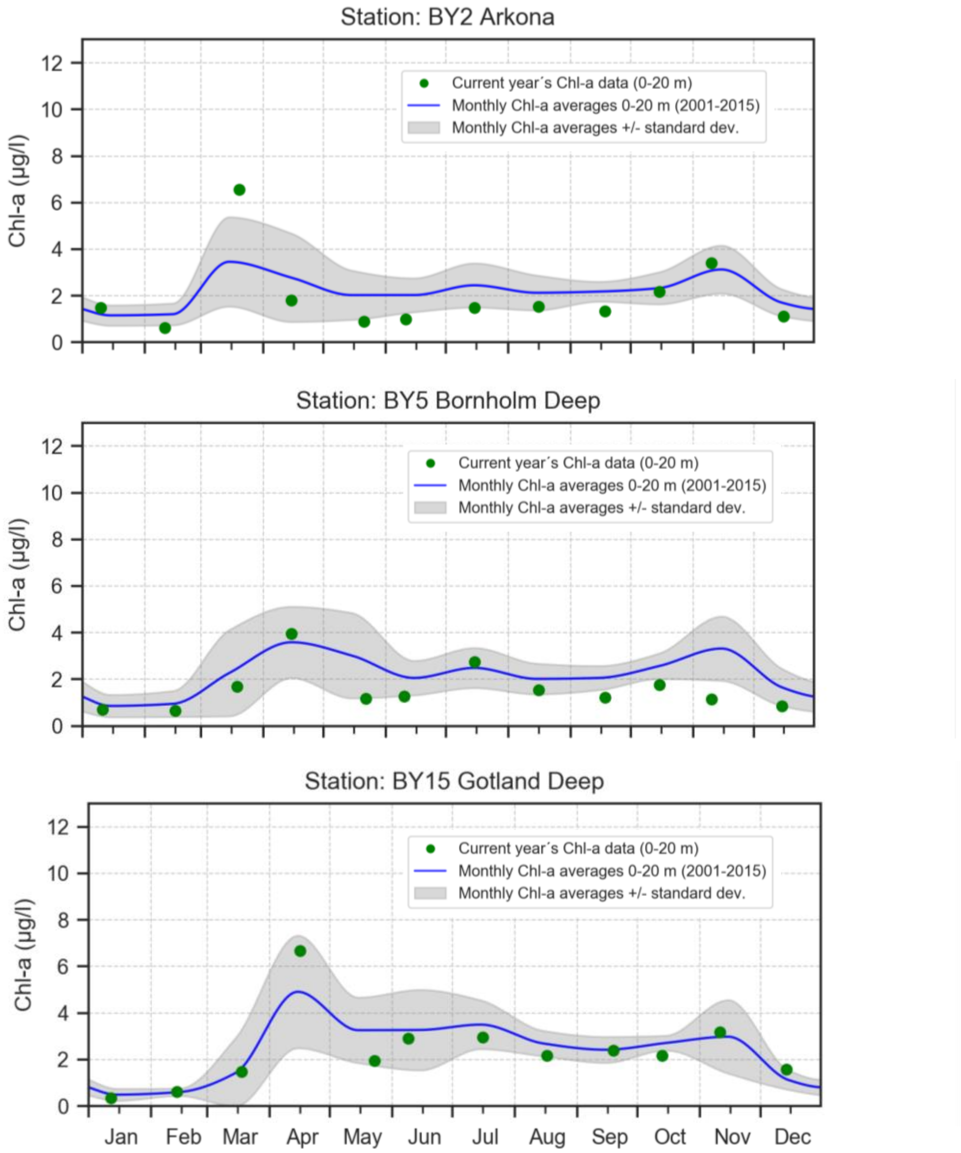

Figure 27. Integrated (0-20 m) chlorophyll a (µg/l) from the stations BY2 Arkona and BY5 Bornholm in the southwestern Baltic Proper and BY15 in the Eastern Gotland Basin.

In May and June, chlorophyll fluorescence peaks were observed at many stations in the Baltic Proper at depths varying between 15 and 30 meters. Microscope analysis of the peaks revealed an extensive bloom of the potentially toxic group Prymnesiales. Prymnesiales may cause fish death, but there were no reports about that in the Baltic Proper during this particular bloom.

The highest total biomasses were found in June at station BY15 (Figure 28) in the Eastern Gotland Basin and consisted largely of autotrophic ciliates, filamentous cyanobacteria and Prymnesiales. The filamentous cyanobacterium *Aphanizomenon flosaquae,* one of three species dominating the Baltic cyanobacteria blooms, was found in rather high amounts in the Eastern and Western Gotland Basins in June. In July, the potentially toxic cyanobacterium *Nodularia spumigena* was more abundant then *A. flosaquae*.

A diatom bloom was found at BY2 Arkona in August (Figure 28). The cyanobacteria had declined, but were present in low amounts.

The relatively large diatom *Coscinodiscus granii* was found at BY2 and BY15 in November and caused high biomasses (Figure 28) although cell numbers were moderate.

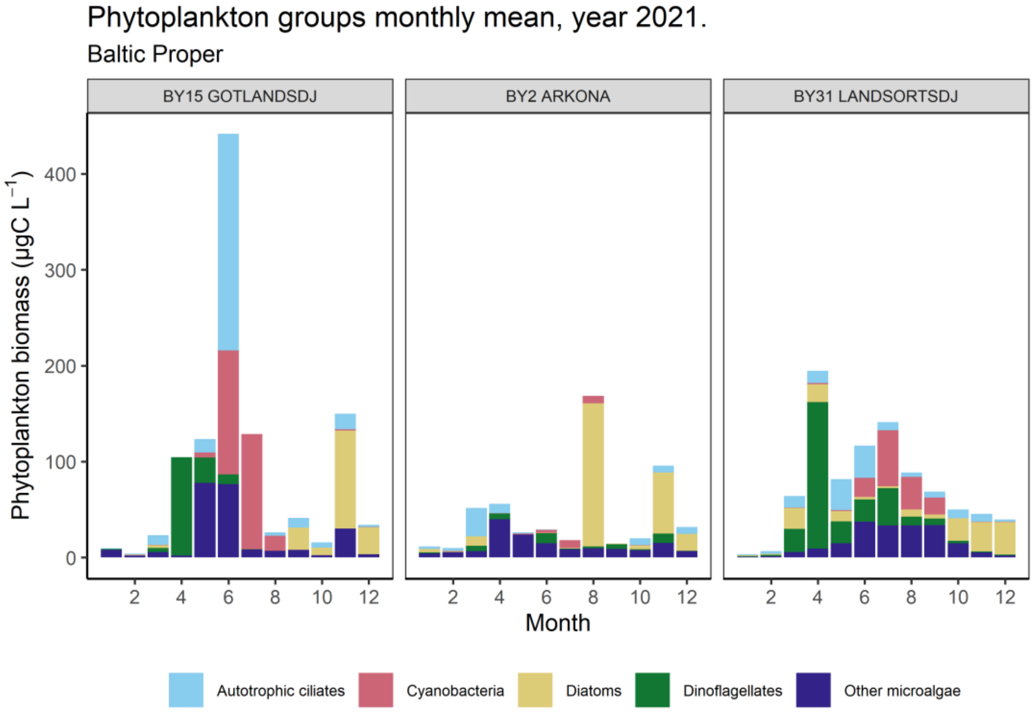

Figure 28.Phytoplankton biomass (µg C/l) at three stations in the Baltic Proper.

The first satellite observations of cyanobacteria accumulations were made the 10th of June. Furthermore, the largest expansion of the surface accumulations was found on the 29th of June. In July the cyanobacteria surface accumulations were intense and extensive. The first observations in the Bothnian Sea were made earlier than normal, the 8th of July, and stayed intense before all accumulations declined in August due to the cooler weather. All in all, the cyanobacteria season started and ended earlier in 2021 compared to the period 2002-2021 (Figure 29), which is as long as SMHI has been doing the satellite monitoring, and the last observations were made on the 1st of September[9].

[9] Cyanobakterier i Östersjön sommaren 2021, Jörgen Öberg m.fl., OCEANOGRAFI NR 130, 2021.

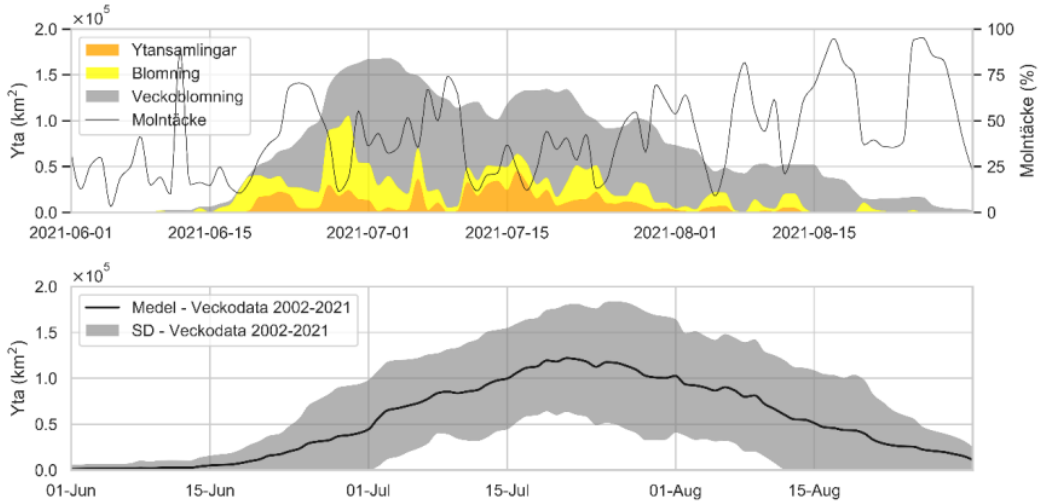

Figure 29. Upper diagram: The yellow colour shows the areas of cyanobacteria blooms detected from satellite pictures and the orange shows detected areas of surface accumulations. The grey field is based on week data of areas of cyanobacteria. Lower diagram: Mean and standard deviation of observed areas based on week data from 2002-2021.

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

4.3.1 Temperature and salinity

Because of problems with both weather and research vessels, all winter months could not be covered in the Gulf of Bothnia. In the Bothnian Sea cruises could not be made in January and March and in the Bothnian Bay the first cruise of the year was in April.

In the Bothnian Sea the sea surface temperature dropped to 2°C in February, and the water column was well mixed down to 50 m, Figure 31. In the Bothnian Bay no observations were made during January-March but in April the surface temperature was 1.5°C. The difference in salinity between the surface and bottom water is even smaller in the Bothnian Bay than in the Bothnian Sea but there is a weak stratification at 75 m, Figure 32. The temperature increased during spring and summer and was at its maximum in August at about 17°C. Throughout the year, the sea surface temperature was normal except February that was warmer than normal and December that was colder than normal, Figure 30.

Surface temperature at C3 and F9/A13

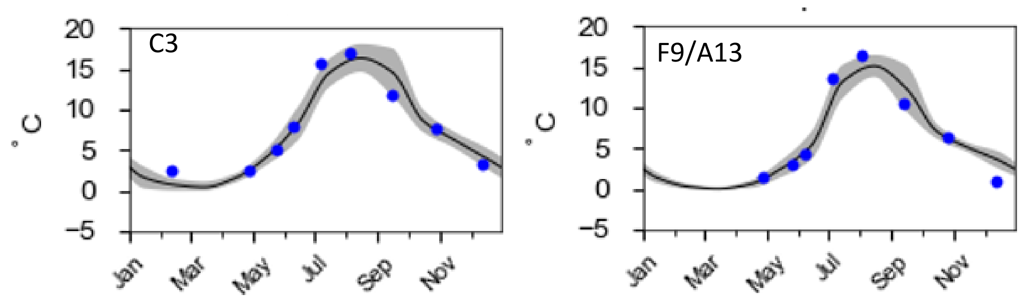

Figure 30. The temperature in the sea surface, 0-10 m, during 2021 at the stations C3 in the Bothnian Sea and F9/A13 in the Bothnian Bay. Monthly measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area).

The sea surface salinity had small variations during the year within the normal ranges and was about 5 psu in the Bothnian Sea and 3 psu in the Bothnian Bay. The temporal development during 2021 of temperature and salinity at the station C3 is seen in Figure 31 and at station F9/A13 in Figure 32.

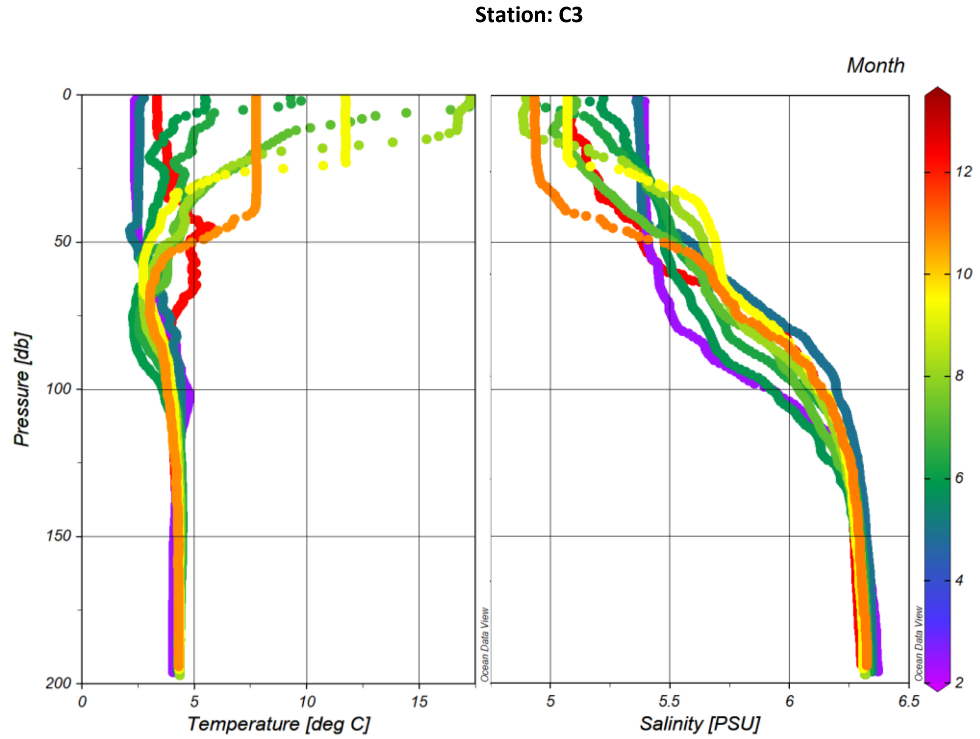

Figure 31. CTD-profiles of temperature and salinity from the cruises during 2021 at station C3 in the Bothnian Sea. Colours indicate the sampling month.

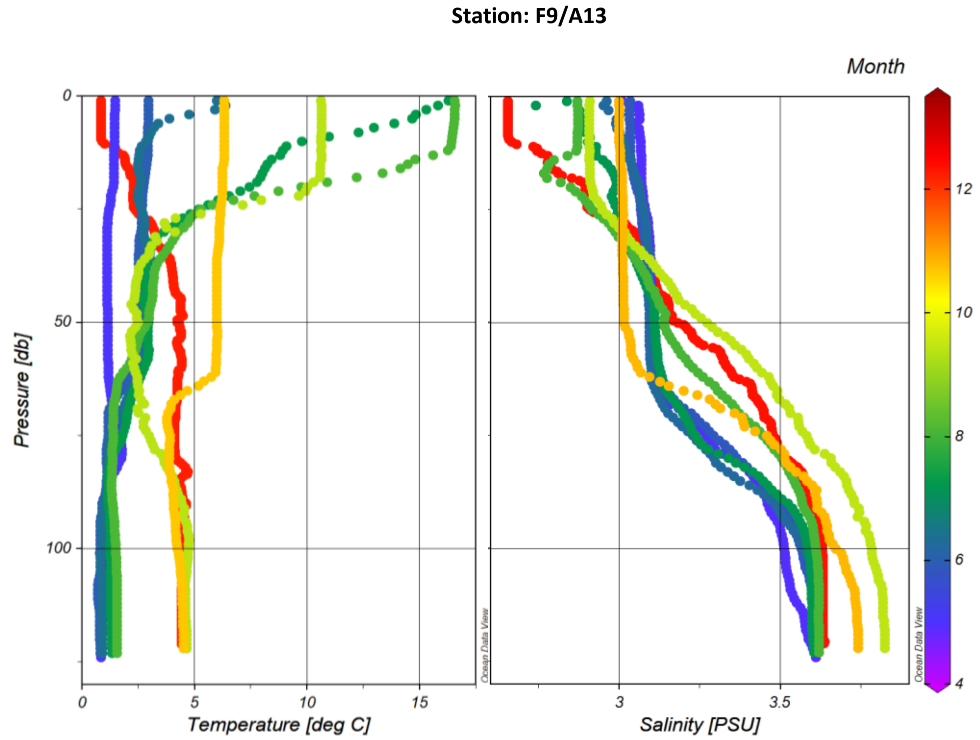

Figure 32. CTD-profiles of temperature and salinity from the cruises during 2021 at station F9/A13 in the Bothnian Bay. Colours indicate the sampling month.

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 week and the sea area is mainly oligotrophic. 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. At the deepest station in the Bothnian Sea (C3) oxygen concentration in the bottom water was below normal and close to the limit for oxygen deficiency (4 ml/l) throughout the year. There is a trend with decreasing oxygen concentrations in the Bothnian Sea deep water[10]. Despite the seasonal variations in Figure 33 it shows that the oxygen concentration at station C3 was low in 2021 compared to the previous years and that the oxygen concentration was clearly higher in the beginning of the 2000's.

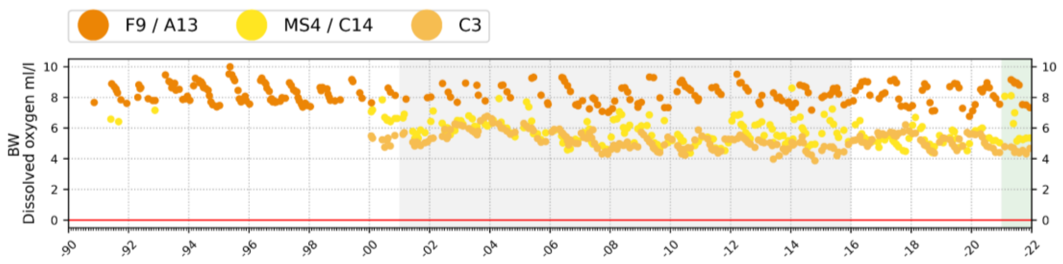

Figure 33. Dissolved oxygen in the bottom water at three stations in the Gulf of Bothnia (F9/A13 Bothnian Bay, MS4/C14 Bothnian Sea, C3 Bothnian Sea. The shadowed grey area highlights the time period that statistics is based on in this report, 2001-2015. The shadowed green area highlights the year 2021.

4.3.3 Nutrients

In the Gulf of Bothnia phosphate was above normal in the winter (December 2020, not shown here) and silicate concentrations were above normal only in the Bothnian Sea but not the Bothnian Bay. DIN was normal in winter in the both sea areas. 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 little lower than in the Skagerrak and Kattegat. We do not have a mean value for the normal period (2001-2015) to compare with for all months so we cannot see deviations from the normal period as easily as in the other sea areas. But the data from 2021 (Figure 34) show that both phosphate and DIN are depleted or close to depleted during summer. In the Bothnian Bay DIN did not decrease to very low levels until July and were at its lowest in July and August to increase again in September. In the Bothnian Sea there is a clear decrease in DIN in May and phosphate follows in June. Here, DIN stays at low levels about a month longer than in the Bothnian Bay. In a longer perspective phosphate and silicate is increasing in the surface waters in the Gulf of Bothnia while DIN is decreasing, see Figure 35.

[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.

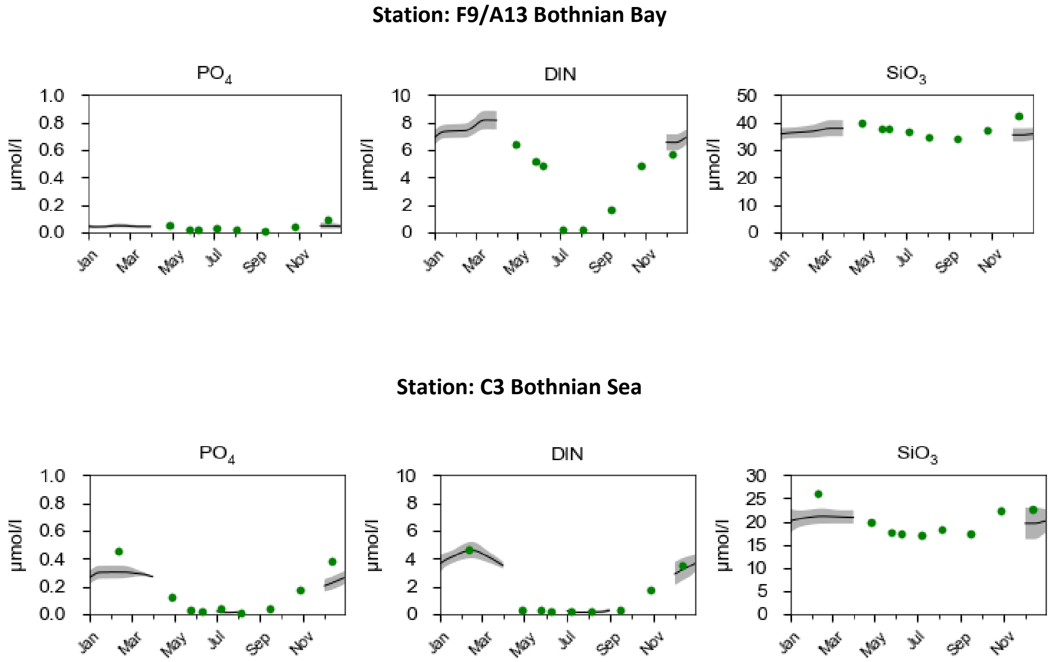

Figure 34. Concentrations of inorganic nutrients in the surface water (0-10 m) in the Gulf of Bothnia. Top row station F9/A13, Bothnian Bay, bottoms row stations C3 Bothnian Sea. Monthly measurements (dots) during 2021 are shown in relation to average value for the period 2001-2015 (black line) and +/- 1 standard deviation (grey area). Missing black line and grey area indicates that there are too few data in the period 2001-2015 to calculate statistics.

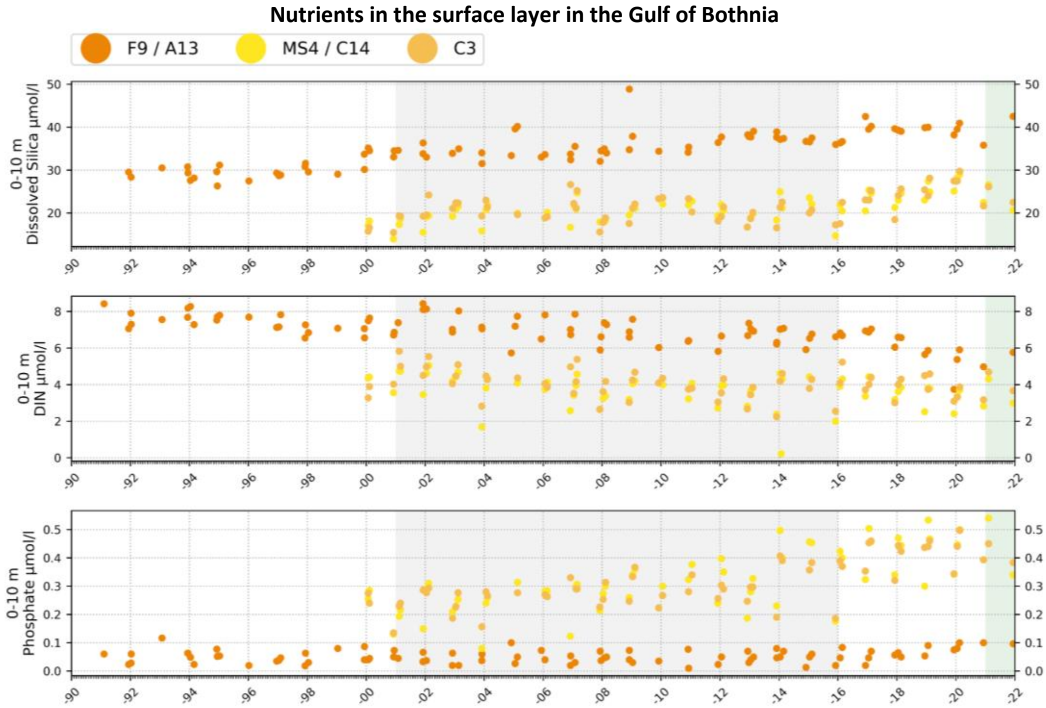

Figure 35. Timeseries of winter (Dec-Feb) inorganic nutrients in the surface water (0-10 m) at three stations in the Gulf of Bothnia (F9/A13 Bothnian Bay, MS4/C14 Bothnian Sea, C3 Bothnian Sea. The shadowed grey area highlights the time period that statistics is based on in this report, 2001-2015. The shadowed green area highlights the year 2021.

4.3.4 Phytoplankton

The spring bloom generally starts later in the Gulf of Bothnia compared to the Baltic Proper and the Kattegat and Skagerrak area, and started in the Bothnian Sea in April and in the Bothnian Bay in May-June.

At the station C3 in the Bothnian Sea, diatoms dominated the spring bloom (Figure 36). During previous years, dinoflagellates and the ciliate *Mesodinium rubrum* have been more abundant than they were 2021. Cyanobacteria were observed from June and dominated the species composition in August and September.

At the station F9/A13 in the Bothnian Bay, the ciliate *Mesodinium rubrum* dominated in the April samples. Spring bloom occurred in May, which is early for this area. Diatoms dominated in May and June and dinoflagellates were present in low amounts. *M. rubrum* dominated again in July and the potentially toxic flagellate *Chrysochromulina* sp. was abundant. *M. rubrum* kept being abundant throughout August and September, whilst diatoms were the most numerous during late autumn.

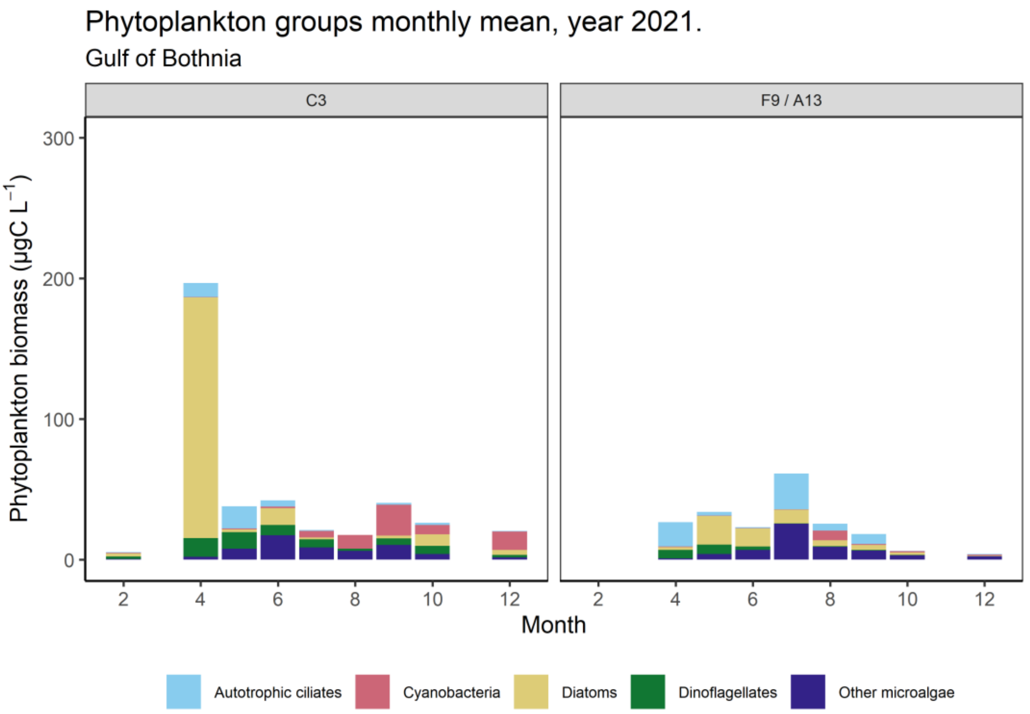

Figure 36. Phytoplankton biomass (µg C/l) at C3 in the Bothnian Sea and F9/A13 in the Bothnian Bay.

4.4 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. 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 1960-2021 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 Basin and the Bornholm Basins, a sudden increase in the content of both inorganic and total phosphorus is seen between 2004 and 2005 (Appendix III). 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.

In the rest of the Baltic Proper the phosphorus content increased 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 basin around Gotland decreased from 1994 to the beginning of the 21st century (Appendix III). The drop in DIN 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 25b.

In the Bothnian Sea the increasing phosphorus and silicate concentrations are clearly reflected in an increase in phosphorus and silicate content since year 2000. 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).

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ISSN 0283-1112