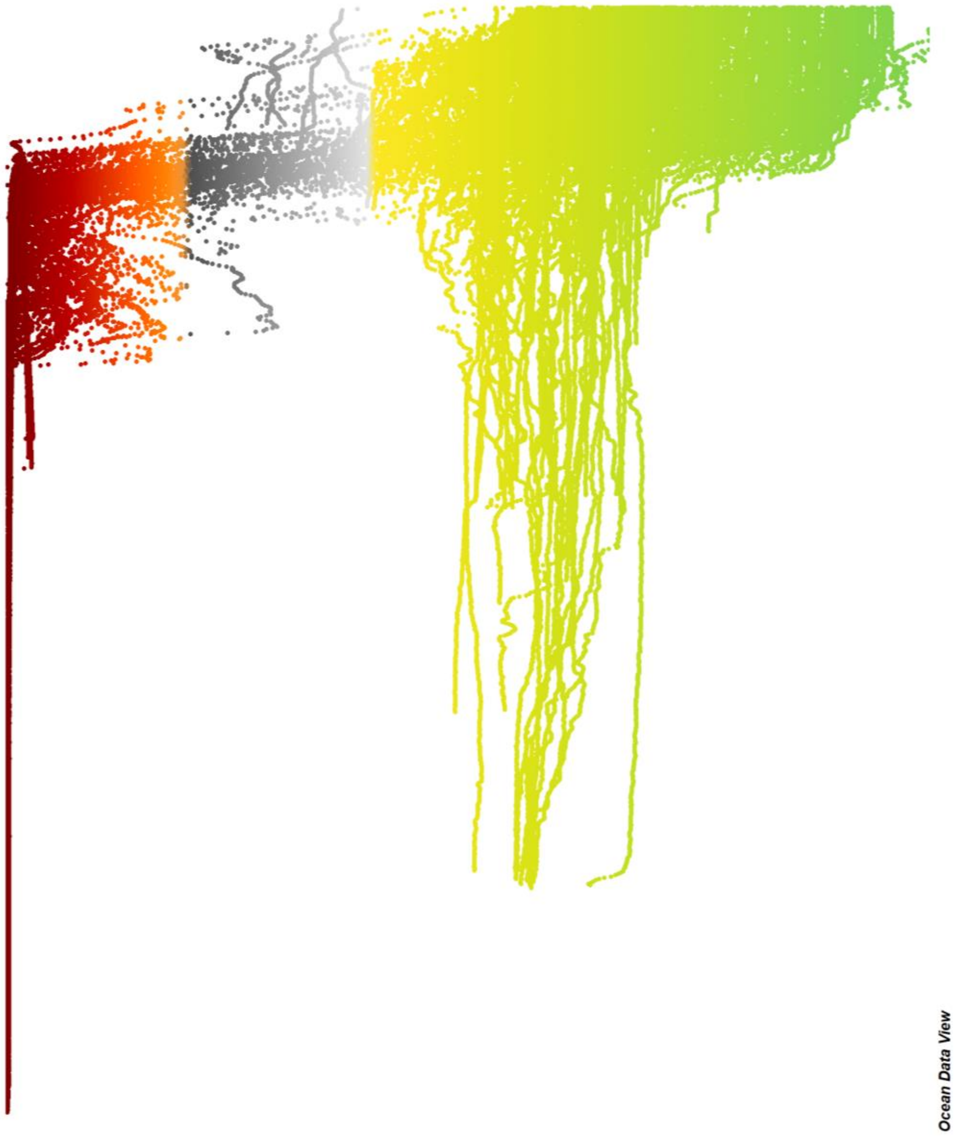
REPORT OCEANOGRAPHY No. 69 2020



The Swedish National Marine Monitoring Programme 2019

Hydrography

Nutrients

Phytoplankton

Front.
The image illustrates salinity profiles from all CTD-observations made by SMHI during 2019. The colour shows the oxygen concentration, from low to high, red-grey-yellow. Image is made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019).

ISSN: 0283-1112 © SMHI

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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

The Swedish national marine monitoring programme of the pelagic, the water column, includes monthly measurements of hydrography, nutrient concentration and phytoplankton for the seas around Sweden; the Skagerrak, the Kattegat, the Sound, the Baltic Proper and the Gulf of Bothnia. Data is collected, analysed and reported on behalf of SwAM (Swedish Agency for Marine and Water Management).

This annual report describes interesting observations from the monitoring and summarizes the main results of 2019. At the end of the report and in the Appendix time series from 1960 to 2019 are also presented.

2019 was the 10th warmest year since reporting started in 1860 and the precipitation was also higher than normal, despite this; groundwater levels were low, especially in southern Sweden. Two stronger storms passed Sweden during the beginning of the year, Alfrida (January 1-2) and Jan (January 10-11). This year's winter was very mild and the maximum ice spread was only 88,000 km2 which is less than normal, the ice season ended in mid-May. There were no autumn storms in 2019 and the autumn was slightly colder than normal in the north but warmer in the south.

During the year, only a few minor inflows of water from the Kattegat to the Baltic Sea occurred through the Sound. Three inflows were large enough to improve the oxygen situation in the southern Baltic Proper. The largest occurred in late November to mid-December. The effects of this inflow will be observable in spring 2020. A small change was observed in the oxygen concentration in the Eastern Gotland Basin at the beginning of the year, as a result of an inflow during the fall of 2018.

The spring bloom started in February in the Kattegat and sometime between March and April in the Skagerrak. In April, a small bloom of the fish toxic genus *Pseudochattonella* was observed at stations Anholt E and N14 Falkenberg. The nontoxic coccolitophoride *Emiliania huxleyi* was found in the Kattegat and Skagerrak from May to November in varying quantities. The potentially toxic diatom genus *Pseudo-nitzschia* was present in high cell numbers in October and November. In the Baltic Proper, the spring bloom was observed from March to April with high cell numbers of diatoms and a dinoflagellate typical for the spring, *Peridiniella catenata*. Cyanobacteria were observed in elevated quantities as early as May and increased in late June to culminate at the end of July when they had also spread into the Bothnian Sea. The amount of filamentous cyanobacteria decreased in August, and colony forming pico cyanobacteria increased.

Nutrient concentrations in the surface water were mainly within normal levels except in the Skagerrak and the Kattegat at the start of the year when slightly lower levels of phosphate, silicate and dissolved inorganic nitrogen were measured. Even in Skagerrak's and Kattegat's deep waters, the levels of dissolved inorganic nitrogen were lower than normal during parts of the first half of the year, and in the Kattegat and the Sound phosphate levels were also low. The levels of dissolved inorganic nitrogen were also low during the beginning of the year in the Baltic Proper, while phosphate levels were more normal. In the Baltic Proper, elevated silicates and phosphate levels were observed in deep water with little or no oxygen.

Sammanfattning

Det svenska nationella marina övervakningsprogrammet av pelagialen, den fria vattenmassan omfattar månatliga mätningar av hydrografi, halten av näringsämnen och växtplankton för haven runt Sverige; Skagerrak, Kattegatt, Öresund, Egentliga Östersjön, Bottenhavet och Bottenviken. Uppdraget att samla in, analysera och rapportera data kommer från HaV (Havs och vattenmyndigheten).

Den här årsrapporten tar upp intressanta observationer från övervakningen och sammanfattar de huvudsakliga resultaten från 2019. I slutet av rapporten och i appendix redovisas även tidsserier från 1960 till 2019.

2019 blev det 10e varmaste året sedan rapporteringen startade år 1860 och var också rikare på nederbörd än normalt, men trots det var grundvattennivåerna låga framförallt i södra Sverige. Några kraftigare stormar passerade Sverige under början av året, Alfrida (1-2 januari) och Jan (10-11 januari). Höststormarna uteblev under 2019 och hösten var något kallare än normalt i norr men varmare i söder. Årets vinter var mycket mild och den maximala isutbredningen blev endast 88 000 km^2 vilket är mindre än normalt, issäsongen klassades också som mild. Issäsongen var slut i mitten av maj.

Under året skedde endast några mindre inflöden av vatten från Kattegatt till Östersjön genom Öresund som beräknats genom vattenståndsskillnader mellan norra (Viken) och södra (Klagshamn) Öresund (www.smhi.se/hfa_coord/BOOS/Oresund.html). Tre inflöden var tillräckligt stora för att förbättra syresituationen i södra Egentliga Östersjön, men hade ingen effekt längre in i Egentliga Östersjön. Det största skedde i slutet av november till mitten av december, effekterna av detta inflöde kommer att kunna observeras under våren 2020. I början av året observerades en liten förändring i syrekoncentrationen i Östra Gotlandsbassängen till följd av ett inflöde under hösten 2018.

Vårblomningen startade i februari i Kattegatt och pågick mellan mars och april i Skagerrak. I april observerades en mindre blomning av det för fisk skadliga släktet *Pseudochattonella* vid stationerna Anholt E och N14 Falkenberg. I Egentliga Östersjön observerades vårblomningen i mars-april med höga cellantal av kiselalger och en dinoflagellat typisk för våren, *Peridiniella catenata*. Cyanobakterier observerades i förhöjda mängder redan i maj och ökade i juni för sen att kulminera i slutet av juli då de även hade spridit sig upp i Bottenhavet. Mängden trådlika cyanobakterier minskade i augusti, och kolonibildande pico cyanobakterier ökade.

Näringsämneskoncentrationer i ytvattnet var i huvudsak inom normala nivåer förutom i Skagerrak och Kattegatt under början av året då något lägre nivåer av fosfat, silikat och löst oorganiskt kväve uppmättes. Även i Skagerraks och Kattegatts djupvatten var halterna av löst oorganiskt kväve lägre än normalt under delar av första halvåret, i Kattegatt och Öresund var också fosfathalterna låga. Halterna av löst oorganiskt kväve var också låga under början av året i Egentliga Östersjön, medan fosfat halterna var mer normala. I Egentliga Östersjön observerades förhöjda silikat och fosfathalter i djupvatten med lågt eller inget syre.

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Appendices

1 Introduction

The purpose of the Swedish national marine monitoring programme of the pelagic is to document the status and changes in the marine environment through a selection of parameters. The programme conforms to the Swedish national environmental goals, EU legislation and commitments to the sea conventions OSPAR and HELCOM. The Swedish agency for marine and water management (SwAM) is responsible for the marine monitoring programme of the pelagic and three institutes implement the main parts of the monitoring; Swedish Meteorological and Hydrological Institute (SMHI), Stockholm University and Umeå Marine Sciences Centre. In addition, the University of Gothenburg carries out monitoring at three coastal stations (BroA, Släggö and Alsbäck) which are also part of the national programme and the coastal station Ref M1V1 is sampled in the Kalmar coastal monitoring program (Kalmar läns kustvattenkommitté, KVK) so that the frequency become bi-weekly together with the visits to the station by SMHI. SMHI performs the major part of the pelagic offshore monitoring with monthly cruises in the Skagerrak, the Kattegat and the Baltic Proper, as well as mapping surveys in the Gulf of Bothnia and joins the trawls surveys organized by SLU-Aqua. The monitoring programme is co-funded by SwAM and SMHI. Sampling and laboratory analyses are carried out according to Swedish guidelines as well as the HELCOM COMBINE manual[1].

This report is written by SMHI as a part of the SMHI monitoring contract with SwAM for the year 2019. The report summarises and presents data from the national marine monitoring of the pelagic with the aim to describe the general environmental conditions in Swedish waters during the past year, as well as deviations from a 15-year mean (2001-2015). All data used in the report are quality controlled, open access and available at the national data host (SMHI). To download data visit https://sharkweb.smhi.se.

The parameters discussed in this report are salinity, temperature, oxygen, phosphate, dissolved inorganic nitrogen, dissolved silica, pH, alkalinity, chlorophyll and phytoplankton. The data are presented in Appendix I as seasonal cycles of the surface water (0-10 m), including humic substances in addition to the parameters listed above. In Appendix II time series from 1960 to today for surface waters (0-10 m) and bottom waters (depths specified in each figure, generally 1-3 m above the bottom) of the parameters above, as well as total phosphorus, total nitrogen and chlorophyll are also presented. Appendix III shows time series with winter mean values of salinity, temperature, oxygen, total nutrients and dissolved inorganic nutrient of surface and bottom waters for each basin as well as summer mean values for temperature. Contents of total and dissolved inorganic nutrients are calculated for all basins in the Baltic Proper, as well as the Bothnian Sea and the Bothnian Bay and these are presented in Appendix IV. Transects of CTD-observations of salinity, temperature, oxygen and density from the Skagerrak to the Western Gotland Basin are presented in Appendix V. Other parameters also included in the marine monitoring programme of the pelagic, but not presented here, are Secchi disk depth, zooplankton, and primary production.

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[1] HELCOM COMBINE MANUAL

2 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 has had focus on fishery hydrography, while plankton and chlorophyll has been 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)[2] and the Marine Strategy Framework Directive 2008/56/EC (MSFD)[3].

In 1991 SMHI published an investigation of the Swedish marine monitoring programme, its station network and sampling frequency (Rahm et al 1991[4]). In 1992 an international evaluation panel recommended implementation of the changes suggested by SMHI (SNV Report 4170[5]) and a revised monitoring programme started in 1994. This led to significant change, mainly in the frequency of expeditions so that a number of 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 since sampling is performed in combination with fisheries cruises led by Swedish University of Agricultural Sciences (SLU). In the Baltic oxygen is mapped during the Baltic International Acoustic Surveys (BIAS) programme in September-October, while the oxygen mapping in Kattegat is done during the IBTS Q3 (quarter 3). Thus the oxygen mapping, with focus on the deep water is performed during the autumn because it's 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, the combined results from all countries are presented in a separate SMHI report on the Oxygen situation[6]. 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

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[2] Water Framework Directive

[3] Marine Strategy Framework Directive

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

[5] 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.

[6] Hansson M., Viktorsson L., Andersson L., *Oxygen Survey in the Baltic Sea 2019 - Extent of Anoxia and Hypoxia, 1960-2019*, REPORT OCEANOGRAPHY No. 67, 2019

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 and Ref M1V1. 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[7].

In addition to the national pelagic programme, municipalities and counties perform monitoring in coastal waters. In the open sea there are several fixed platforms mainly run by SMHI, including wave buoys, coastal buoys and one offshore buoy. Two cabled platforms are currently under development; west of Gothenburg and 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 done 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 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 measurements were only done 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 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 are 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

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[7] SwAM, *Beskrivning av delprogrammet Fria vattenmassan*, Version 3:1, 2019-02-14

countries around the Baltic Sea started sharing data. The programme continued until 1993 when it was revised as described above.

2.1 Performance in 2019 and description of the current programme

The marine monitoring programme of the pelagic in Sweden consists of 32 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 weekly at six stations (red). Concentrations of winter nutrients in the surface layer (light blue) and oxygen during autumn (pink) are mapped once per year at additional stations. Coastal stations that are part of gradient studies are shown in orange. The number of visits at the standard stations during 2019 is presented in Figure 2.

The responsible institutes for performing the monitoring are: Umeå Marine Sciences Centre, Stockholm University, the University of Gothenburg, Kalmar county coastal committee (Kalmar läns kustvattenkommitté, KVK) and SMHI. The programme is financed by the Swedish government through SwAM and SMHI.

SMHI used R/V Aranda (Finnish Environment Institute, SYKE) for the monitoring from January to November and the new Swedish research vessel R/V Svea for the regular monthly cruise in December as well as the nutrient mapping of the Gulf of Bothnia for the winter 2019-2020 (the December data will be included in the report 2020). SMHI also performed the autumn oxygen survey during the Baltic International Acoustic Surveys (BIAS) in October in cooperation with SLU Aqua on R/V Svea, positions sampled are shown in pink in Figure 1, in total 41 stations in were visited in the Baltic Proper during this cruise. The samples, together with data from other countries, and Swedish monthly monitoring data from August-October is used for SMHIs annual report on the calculated area of anoxic and hypoxic bottoms in the Baltic Proper[6]. The winter mapping of nutrients in the Skagerrak was performed by SMHI in cooperation with the first quarter International Bottom Trawl Survey (IBTS Q1) led by SLU Aqua in January-February. During this cruise nutrients, salinity, temperature and oxygen were sampled at 46 stations in the Skagerrak and the Kattegat.

Stockholm University used M/S Fyrbyggaren for sampling at the offshore stations BY31 Landsortsdjupet and BY29/LL19. The smaller vessels R/V Limanda and R/V Electra (during sea ice conditions) were used for sampling at station B1.

Umeå Marine Sciences Centre used KBV181, KBV201, R/V Botnica for their sampling. At some occasions Umeå Marine Sciences Centre also used a hoovercraft or a scooter for the sampling during winter when sea ice did not permit sampling from a ship.

The winter mapping cruise of the Gulf of Bothnia for the winter 2018-2019 was performed with R/V Aranda by the Finnish Environment Institute (SYKE) in January-February 2019. Those data are not available in the Swedish data base accessed from https://sharkweb.smhi.se/, but will be reported to ICES by SYKE and are then available for download from the ICES data portal.

The University of Gothenburg have sampled zooplankton at Alsbäck and primary production together with chlorophyll-a, salinity, temperature and Secchi disk depth was measured at BroA and Släggö. These visit stations and visits are not represented in Figure 2.

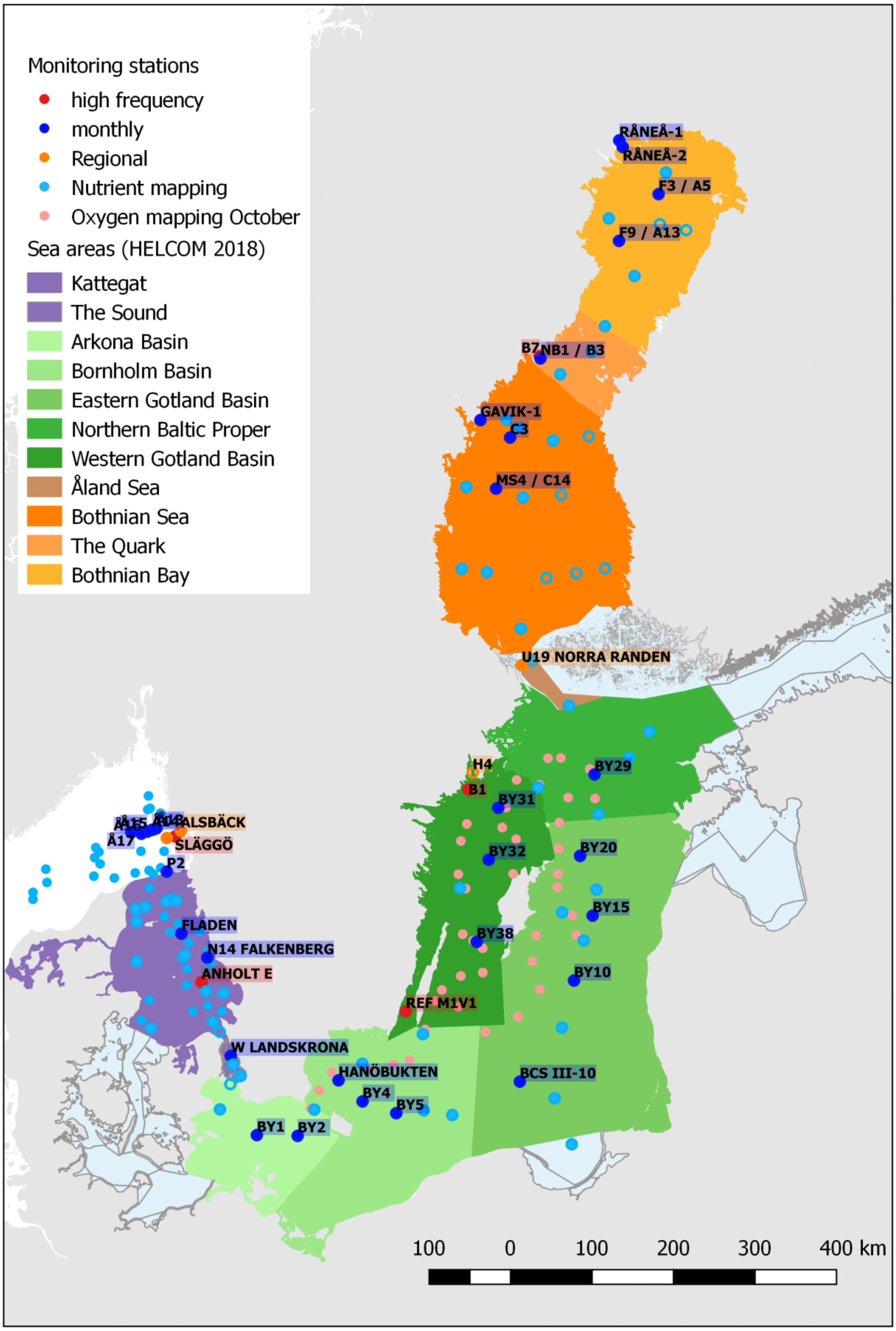

Figure 1. Map showing sea areas and Swedish monitoring stations. Open circles show stations included in the programme but not visited in 2019. Full circles shows stations visited in 2019.

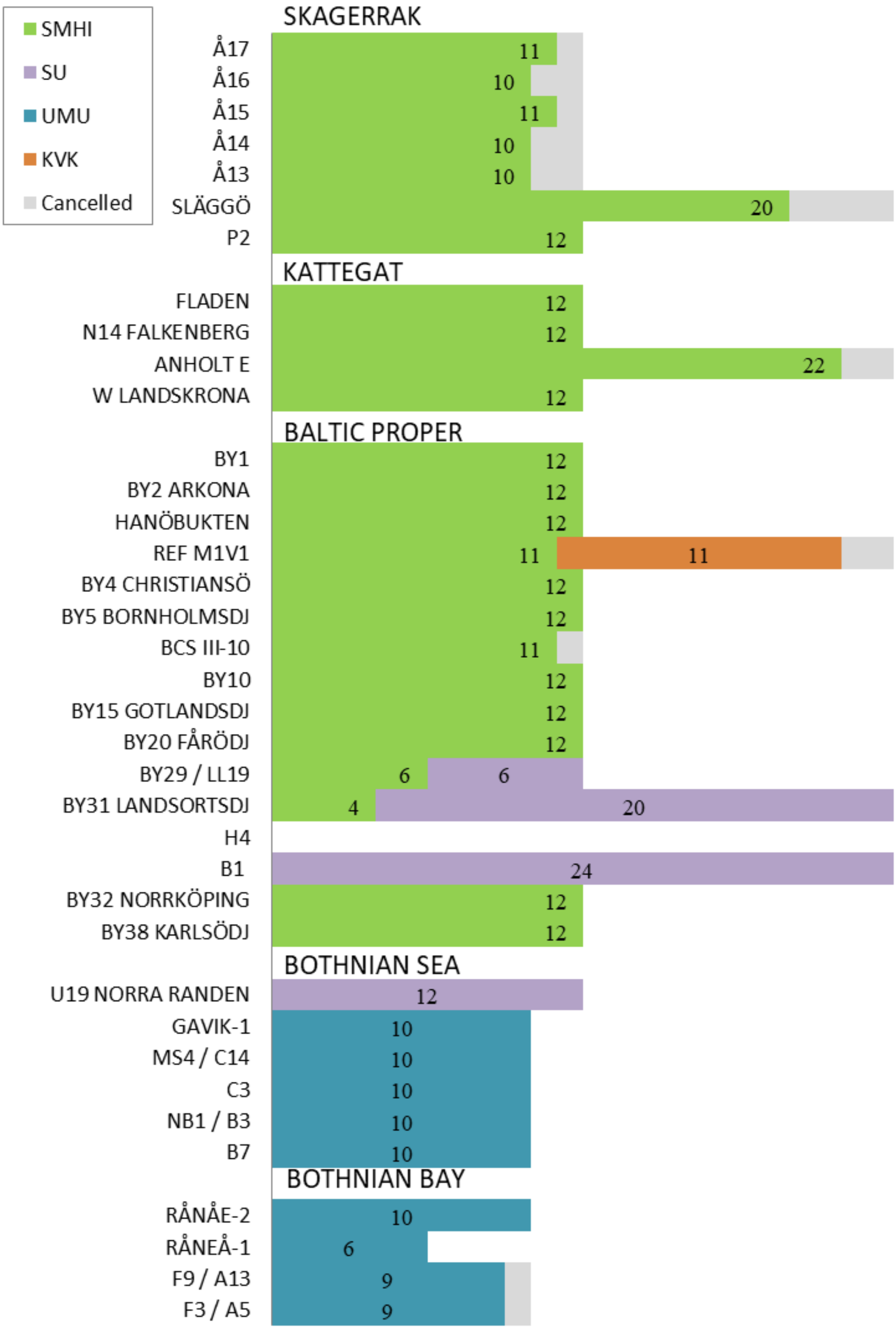

Figure 2. Stations sampled in 2019; number of visits and sampling institute, the shadowed area shows cancelled visits. The list only includes stations with sampling for hydrographical parameters, which means samples from station Släggö for primary production and stations BroA and Alsbäck are not included, but were sampled by the University of Gothenburg in 2019. Station H4 in Himmerfjärden was visited in 2019 but data was not fully reported to the data host at the time of writing.

3 The weather 2019

The year of 2019 became the 10th warmest year since the first publication of national statistics in 1860. It was also more precipitation than normal which may seem like a paradox since there were also low groundwater levels in especially southern Sweden.

The year was initiated by the storm Alfrida, 1-2 January, an intense low pressure system that passed Sweden and brought very strong northerly to north-westerly winds. The significant wave height at Knolls Grund, a wave buoy west of Gotland, reached 5.7 m (the wave record is 6.0 m, 2018). Soon thereafter, 10-11 January, the next storm arrived, named Jan. After this stormy beginning, weather got calmer and colder and the ice continued to grow in the north. The Bothnian Bay was ice covered at the end of the month and the Bothnian Sea had mainly ice along the coast. The maximal ice extent was reached on the 27th of January with 88 000 km^2 and the ice season was considered mild. February was milder than normal and there were two storms, Julia and Mats that mainly passed over the mountain areas.

Unstable and rainy weather prevailed during early spring, but in April weather was dry, warm and sunny. The ice season ended in the middle of May. The summer was warm but it did not reach the same record levels as 2018.

The autumn became colder than normal in the northern parts and warmer than normal in the southern parts. There were no storms during the autumn but remnants of the tropical cyclone Dorian reached the west coast of Sweden on the 15th of September with hard winds. The ice season started in the end of October when the surface water in the northern parts had cooled enough and ice began to grow in the archipelago (in the Bothnian Bay). However, the last two months of the year were not as cold and the ice growth halted.

The winter 2019-2020 began with a predominantly mild and rainy December with several front passages. One of these passing low pressures caused a minor inflow to the Baltic Sea, recorded from the sea level difference north and south of the Sound at the end of November to around mid-December.

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 1960-2019 are presented in Appendices I-IV. In the text, we often refer to a normal condition or value and by this we mean 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, with lower salinities closer to the coast due to 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

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[8] Cruise reports from SMHI

the deep basins. The Gulf of Bothnia in the north is the freshest sea in Swedish waters with salinities <7. It is an oligotrophic sea with different levels and ratios of nutrients than the Baltic Proper.

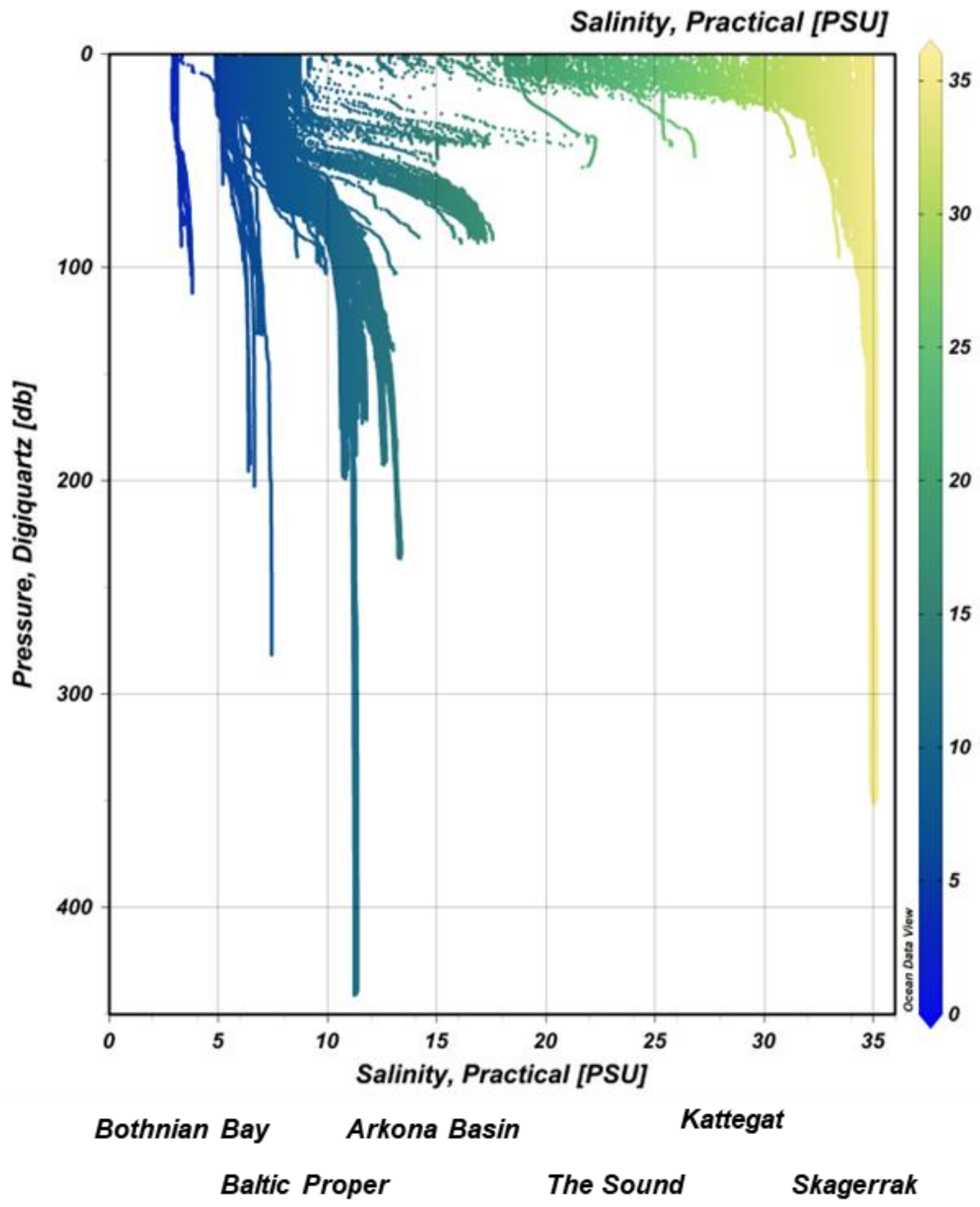

Figure 3. Salinity profiles from all CTD-observations made by SMHI in 2019. The Gulf of Bothnia is represented only with measurements from the December winter mapping survey. The image is made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019).

To illustrate the highly variable seas around Sweden a selection of parameters and stations from the different sea areas are presented in Figure 4, where mean values of surface water (0-10 m) at each sampling occasion are displayed. Besides the different salinities 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 that the spring bloom occurs at different times. In the Gulf of Bothnia the spring bloom is generally not as distinct as in the other areas.

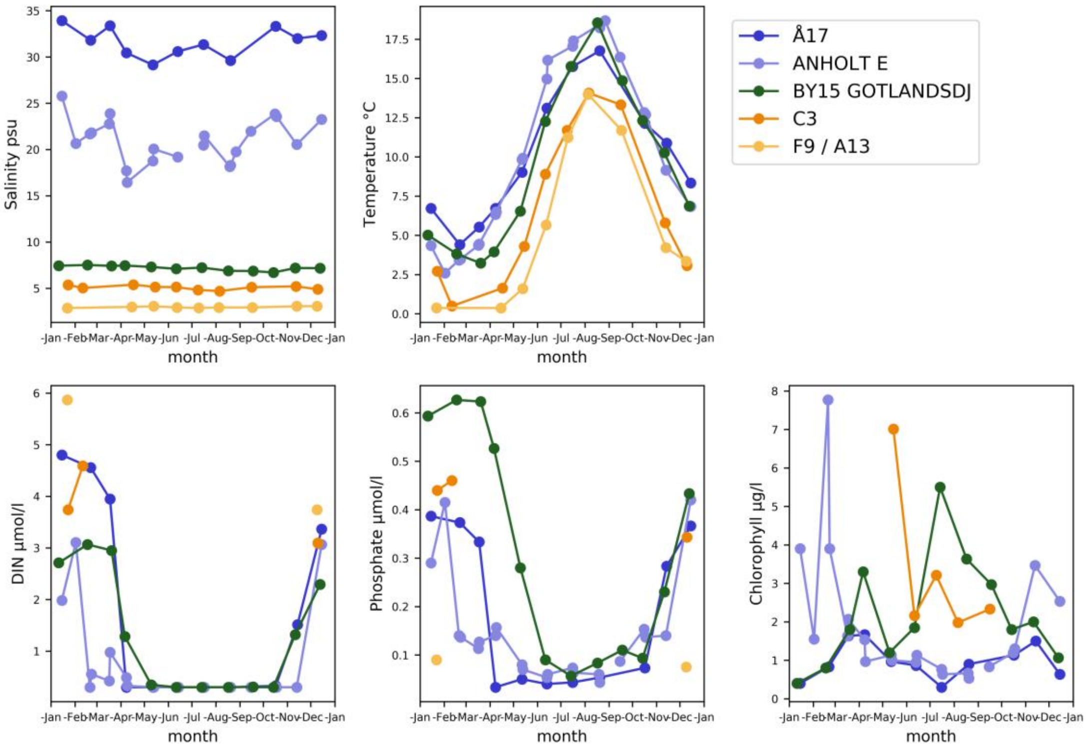

Figure 4. Selection of parameters from the different sea areas around Sweden: the Skagerrak (Å17), the Kattegat (Anholt E), the Baltic Proper (BY15), the Bothnian Sea (C3), the Bothnian Bay (F9/A13). All parameters are mean values of surface water (0-10 m).

4.1 Skagerrak, Kattegat and the Sound

4.1.1 Temperature and salinity

The surface water temperature overall followed the 15-year mean value and was within the normal range during most of the year. The lowest temperatures in the surface layer were observed in February with 2-4°C and the highest in July-August when it measured 17-18°C.

Salinity in the surface water (0-10 m) was mostly within the normal range. The effect of the Baltic current was seen in the surface water as highly variable salinity at the stations closer to the coast. Salinity outside the normal range was mostly observed in Skagerrak and Kattegat at the coastal stations Släggö and N14 Falkenberg, as well as at and W Landskrona in the Sound (Figure 5). The salinity was remarkably high in the surface waters at Släggö in January and the beginning of February but within normal ranges at the end of February and beginning of March. In the offshore Skagerrak the temperature and salinity in the water above the pycnocline were just above the mean values during the beginning of the year (January-March), but still close to or within the normal range.

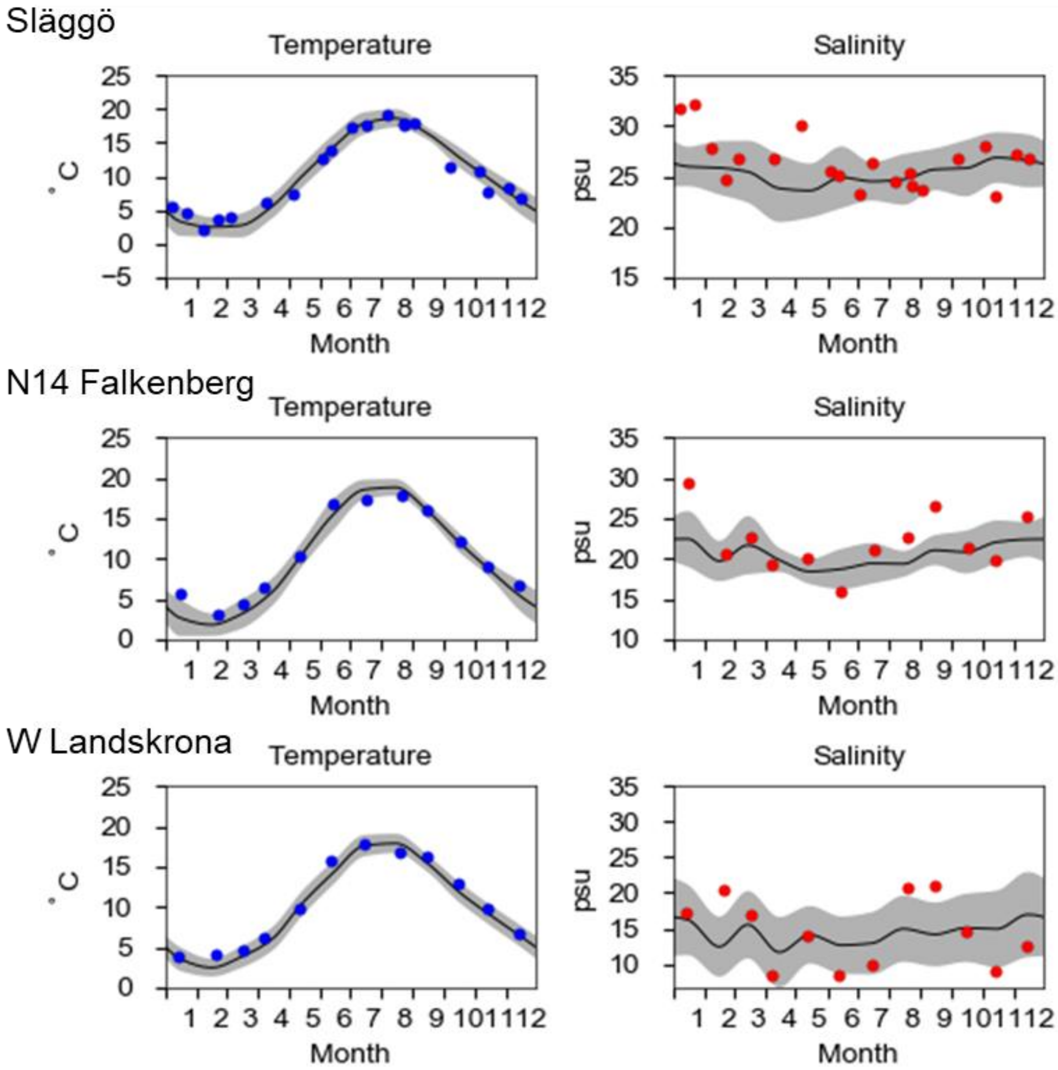

Figure 5. Surface (0-10 m) temperature (left, blue) and salinity (right, red) from top to bottom at coastal stations: Släggö, N14 Falkenberg and W Landskrona.

The largest deviation from the mean was observed in Skagerrak at stations Å13, Å14 and Å15 in November when salinities were below 25 psu, compared to the mean for November of 30 psu. The low salinity in the surface water at this time led to a sharp halocline at 10 m (Figure 6). The two dominating sources of water in the Skagerrak other than the North Sea are the Jutland current and the Baltic current. The Jutland current brings water with higher salinity from the North Sea and the Baltic current brings water with lower salinity from the Baltic Sea. Both normally have higher nutrient concentrations compared to the Skagerrak water from the North Sea. The low salinity observed in November would indicate high influence of water from the Baltic current. However, the nutrient concentrations (Figure 7 and Figure 8) are also very low in this water, which is not characteristic for water from the Baltic, which rather has higher concentration of phosphate and dissolved silica. The origin of this water is not clear. However, already in December the salinity was back to normal, which indicate that this was a local phenomenon, possibly a low saline, low nutrient vortex circulating through the area.

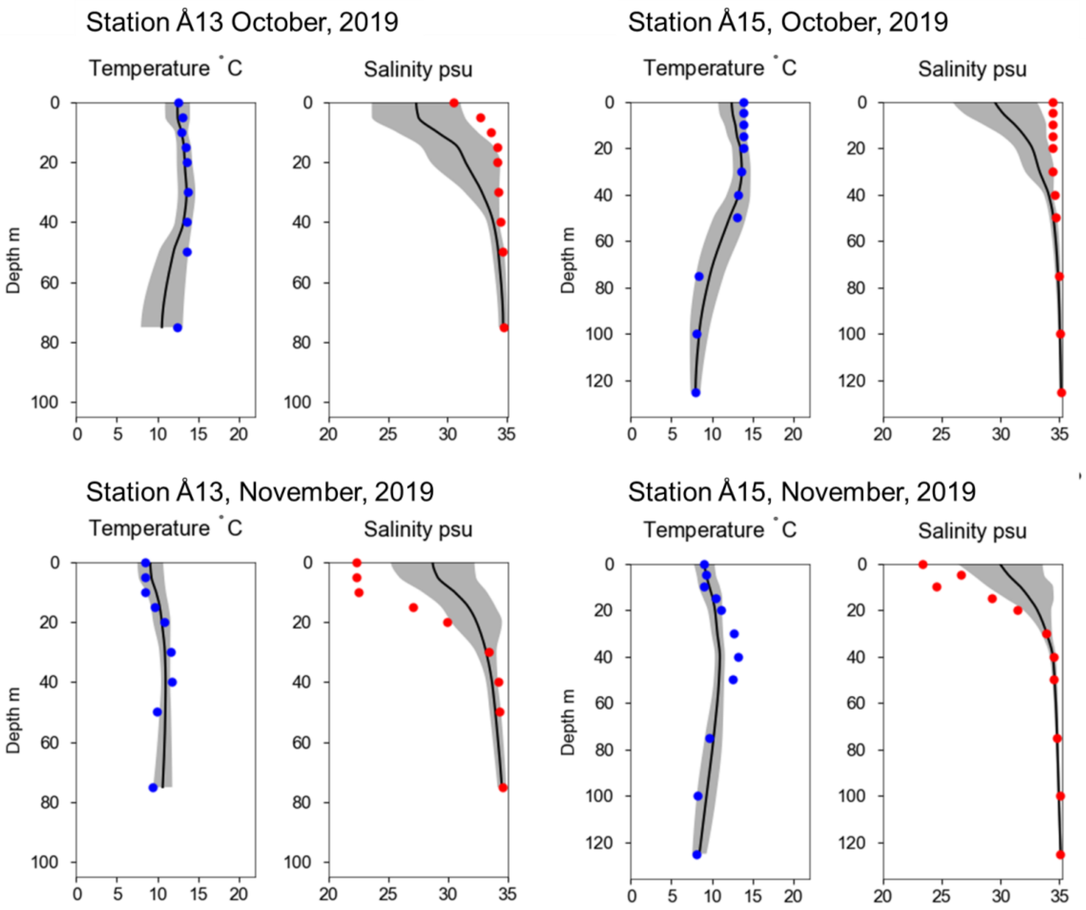

Figure 6. Temperature (blue) and salinity (red) profiles from two stations in the Skagerrak, Å13 (left) and Å15 (right), from October (top) and November (bottom). Note the unusually low salinities in the surface waters in November.

A pycnocline was present at 20 m in the deep offshore Skagerrak (station Å17) during the whole year except in August, when the surface water became warmer than normal down to a depth of 50 m and increased the pycnocline depth. Towards the coast the pycnocline depth was shallower, around 10-15 m and varied more. Below the pycnocline there were only small variations in temperature and salinity during the year.

4.1.2 Nutrients

In the open Skagerrak the spring bloom started between the February and March cruises, as seen by the drop in concentrations of phosphate and dissolved inorganic nitrogen in surface water from high winter levels in March to low and almost depleted in April (Figure 7).

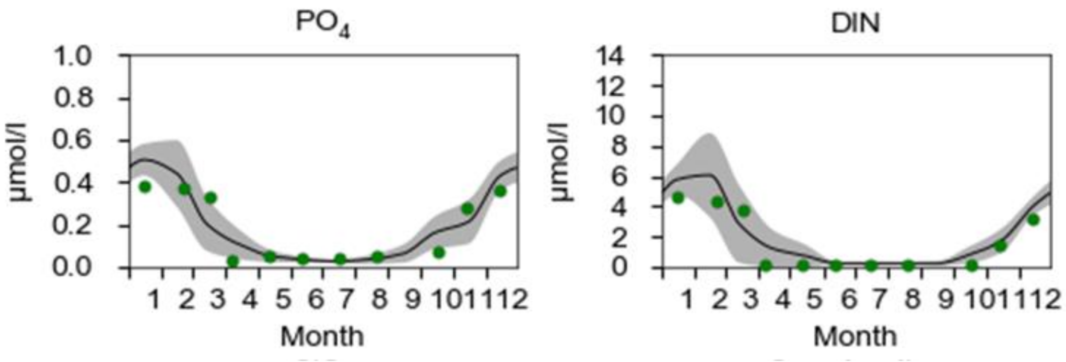

Figure 7. Phosphate and dissolved inorganic nitrogen concentrations in surface waters (mean 0-10 m) at station Å17 in central Skagerrak. Concentrations dropped from high winter levels (January-March) to low summer levels (March-October) between the March and April cruise.

At stations Å13 and Å15 the nutrient concentrations in the surface water were lower than normal in November and also unusually low salinity were observed at the same time (Figure 6 and Figure 8). As described above this does not match the characteristics of low saline water in the Skagerrak, originating from the Baltic current which usually has higher nutrient concentrations than normal for Skagerrak. Low dissolved inorganic nitrogen concentration was observed in the Skagerrak deep water from January-March, except at the deep, off-shore station Å17. At station Å17 nutrient concentrations below the pycnocline was instead lower than normal from March to April, but in April the very deepest measurement at 300 m show higher than normal inorganic nutrient concentration. Nutrient concentrations reached normal levels again in May. At the coastal station Släggö, the concentrations of nutrients decreased between February and March but were not depleted until May. At Släggö the dissolved inorganic nitrogen and silicate concentrations were lower than usual in January and the beginning of February and then unusually high at the end of February and early March (Appendix I).

In the open Kattegat and the Sound concentration of all nutrients were lower than normal from January to February but normal for the rest of the year.

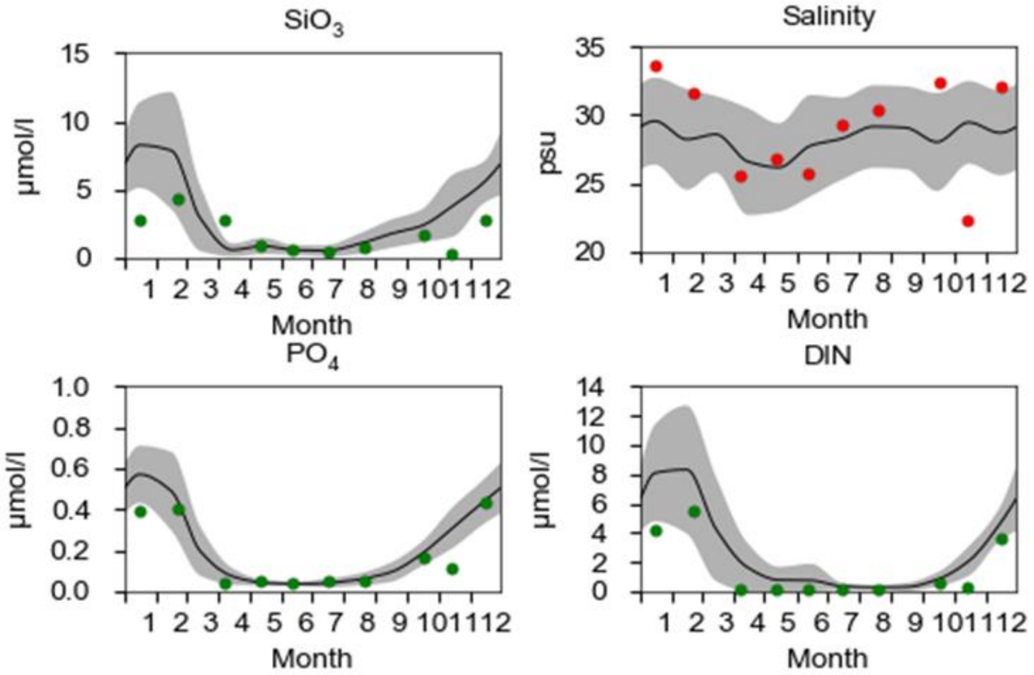

Figure 8. Surface concentrations of inorganics nutrients (green) and salinity (red) at station Å13 in Skagerrak. Unusually low salinity in November together with low nutrient concentrations.

In September an inflow occurred as water from the Kattegat was flowing into the Baltic Proper through the Sound. The effects of this are clear in both nutrients and salinity from the observations at station W Landskrona in the Sound. Phosphate and silicate concentrations were lower in September than in August and salinity was high for this station, above 20 psu.

4.1.3 pH and alkalinity

In accordance with HELCOM COMBINE manual, SMHI has been measuring pH with a glass membrane electrode which is calibrated with fresh water buffers with low ionic strength and pH is reported on the NBS scale (NBS is short for National Bureau of Standards). The method is less suitable for sea water samples with higher ionic strength. Data on pH should therefore be used with care. Spectrophotometric pH measurements using a detector dye will be initiated on R/V Svea during 2020. This method circumvents the shortcomings of the electrode measurements and can be used in all basins.

In Skagerrak, pH and alkalinity, are sampled at one station (Å17), and in the Kattegat two stations are sampled (Anholt E and N14 Falkenberg) Figure 9. At all stations the pH was lower than the 15-year mean throughout the year and the seasonal variation seemed to be lower than the 15-year mean implies. Conversely, alkalinity was higher than the 15-year mean at all stations. Higher alkalinity would under normal circumstances build a stronger buffering capacity so it is noteworthy that pH nonetheless fell below the 15-year mean. The pH trends follow the Atlantic mean[9] at the Skagerrak and Kattegat stations indicating primarily acidification originating from an increased atmospheric CO_2 partial pressure.

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[9] Olafsson, J., S. Olafsdottir, A. Benoit-Cattin, M. Danielsen, T. Arnarson and T. Takahashi (2009). *Rate of Iceland Sea acidification from time series measurements,* Biogeosciences 6(11)

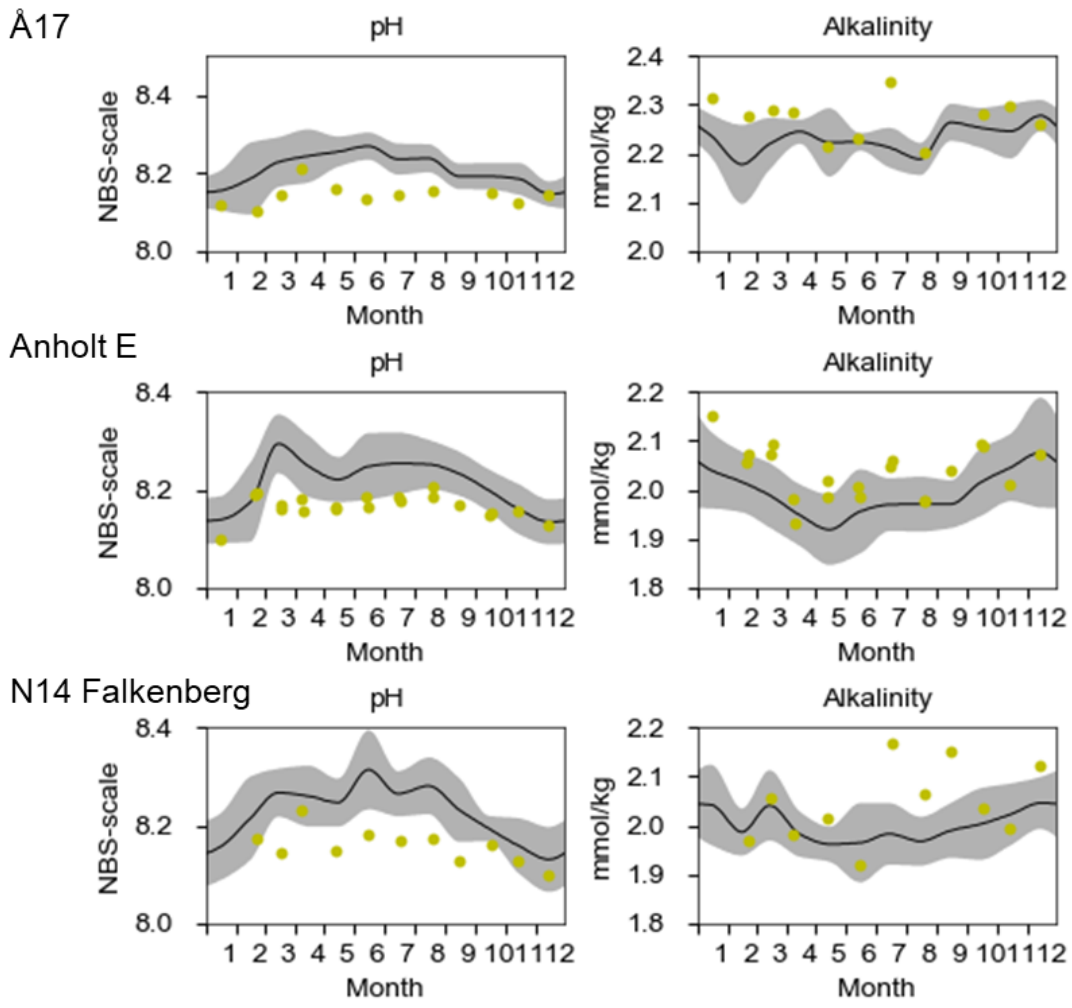

Figure 9. pH and alkalinity in surface water at stations Å17, Anholt E and N14 Falkenberg.

4.1.4 Phytoplankton

Already in January there was a high diversity of diatoms in the Kattegat area, which also was reflected in the chlorophyll concentration at Anholt E. In February, a diatom spring bloom was observed in the Kattegat.

Anholt E is a so called high frequency station with samplings 20-24 times a year. During the February cruise, sampling was performed with two days apart and the difference was apparent. At the second visit the chlorophyll concentration was half of what was found at the first occasion. The amount of phytoplankton however, had not decreased as much. This example clearly shows that the spring bloom process can be quick and easily missed with monthly and even bi-weekly sampling.

In the Skagerrak the spring bloom most likely occurred between two monitoring events and was thus not captured in the monitoring data. Instead the Skagerrak spring bloom could be indicated by the decline of nutrients and hence was probably located between the March and April sampling occasions.

In April a small bloom of the flagellate *Pseudochattonella*, which is potentially harmful to fish, was observed in the Kattegat area with the highest cell counts at N14 Falkenberg. Nearby, in Skälderviken, a larger bloom of 2.4 million cells was found of the same genus (Per Olsson, NIRAS, personal communication).

The coccolithophorid *Emiliania huxleyi*, which colours the ocean beautifully turquoise, but is nonetheless harmless, was abundant at Å17 in the outer Skagerrak in May.

The phytoplankton diversity was low in June and July and mainly consisted of the coccolithophorid *E. huxleyi*, the diatom *Proboscia alata* and the dinoflagellate genus *Tripos* in different concentrations.

E. huxleyi was abundant in the samples again in August and was found in various cell numbers until November. The potentially toxic diatom genus *Pseudo-nitzschia* was found in high cell numbers at all of the Kattegat and Skagerrak stations in October and November.

4.1.5 Oxygen condition in the bottom water

The bottom water oxygen concentration in both the Skagerrak and the Kattegat followed the normal seasonal pattern with lowest concentrations from August to October. The only station where the oxygen concentration was lower than usual was Å17 in the open Skagerrak. Although the concentration was unusually low here, 5.6 ml/l at 300 meters in April, there was no oxygen deficiency. At the same time as this unusually low oxygen concentration the inorganic nutrient concentration was above normal at 300 m, however there were no deviations from normal in temperature or salinity.

However, during the oxygen survey in August, performed during the fishery survey (IBTS-Q3), low oxygen concentrations, near hypoxic (<2 ml/l), were found in coastal areas of Kattegat in the bay Skälderviken and in the Laholms Bight. Near hypoxic conditions were also found at W Landskrona in October and November.

4.2 The Baltic Proper

4.2.1 Temperature and salinity

As in the Skagerrak and the Kattegat temperature in the surface water (0-10 m) was normal throughout the year in the Baltic Proper, with one exception at the coastal station B1 where surface water temperature was above normal in the end of July with temperature close to 20°C. The surface water temperature in the open Baltic Sea was lowest in February-March, 3.5°C in the southern parts and 2.5°C in the northern parts. Summer temperatures were highest in August and went up to 18-19°C (Figure 10), about one degree warmer than in Skagerrak and Kattegat (section 4.1) and about 5°C colder than in the Gulf of Bothnia (section 4.3).

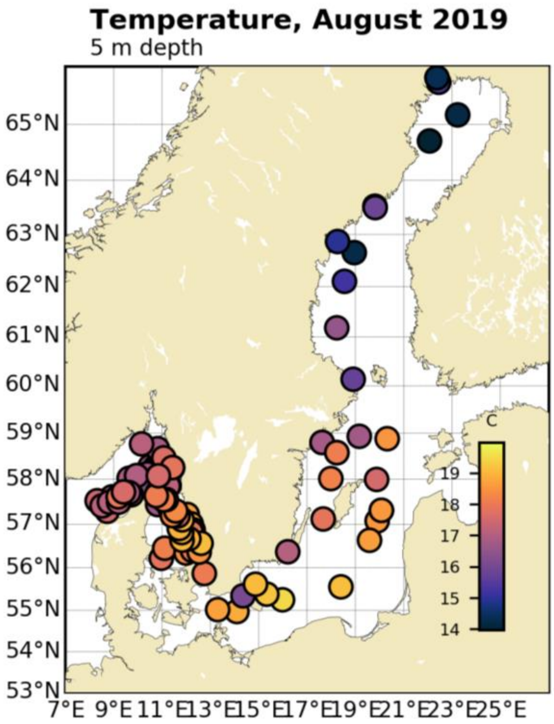

Figure 10. Temperature at all stations visited in august 2019, at 5 m depth. Temperatures were coldest in the north and warmest in the southern Baltic Proper.

After winter the warming of the surface waters in the open Baltic Proper formed a thermocline in May-June which persisted until the cooling started in September-October. The thermocline reached its deepest in August when the surface water was warmed to around 20-30 m, while at BY5 as deep as 30 m already in July. At the coastal station B1 the thermocline reached down to 30 m in mid-July, but with further warming of the surface water in July-August a shallower thermocline at 5 m was developed and persisted until September.

Surface water salinity was mostly close to or within one standard deviation from the 15-year mean. When it deviated from this it was mostly higher than normal. In the southern part of the Eastern Gotland Basin at station BCSIII-10 the salinity in the surface water was above normal from January-October. At the remaining stations in the Baltic Proper the surface salinity was generally above normal throughout the year with some exceptions. Salinities below normal in the surface water was observed at the station BY29 in the Northern Baltic Proper in April, June and August and at stations BY4 (Bornholm Basin) and BY38 (Western Gotland Basin) in November.

In the deep water of the Baltic Proper most stations had higher than normal salinity and temperature, something that has been observed since the latest major Baltic inflow in 2014.

The Arkona Basin is a shallow, 45 m deep, transition area where the salinity and temperature in the bottom water is highly variable, due to the impact of inflowing water from the Kattegat. A halocline was observed at 30 meter at almost all cruises and the temperature was most of the time vertically homogenous except during the summer when a thermocline was established at 15 to 20 m, the water below this was slightly warmer than normal at this time.

The Bornholm Basin is deeper than Arkona Basin, 90 m, and the halocline was located deeper, around 50 meters. A minor inflow was seen in October as a thin layer of warmer water at 60-70 meter, the temperature of this water was the same as in the deep water in the Arkona Basin at the same time (Figure 11).

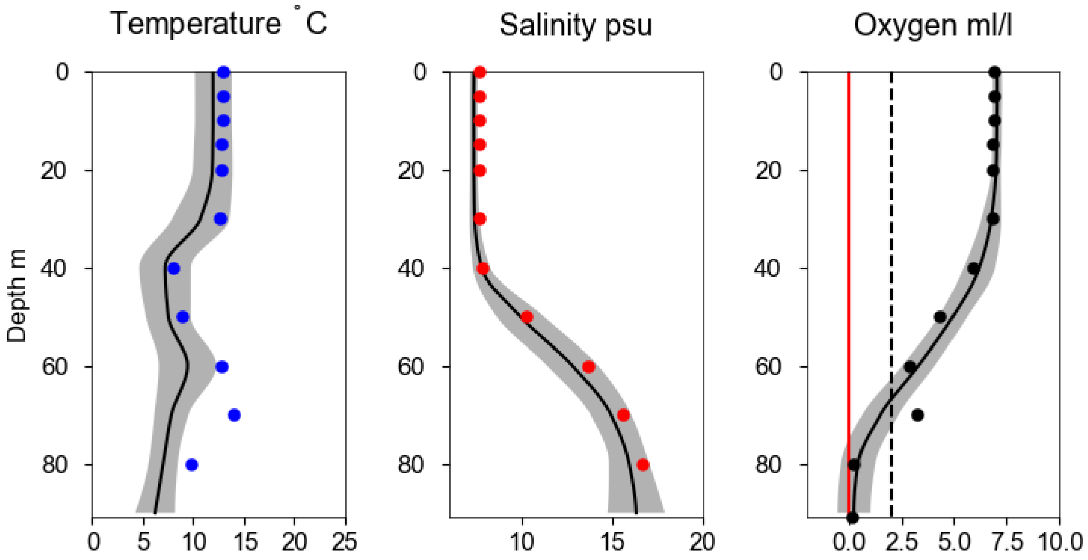

Figure 11. Temperature (blue), salinity (red) and oxygen (black) profiles from station BY4 in Bornholm Basin, October 15th 2019. The vertical lines in the right panel show the limit for zero oxygen (red) and 2 ml/l (black dashed) oxygen concentration, negative values represent hydrogen sulphide recalculated to equivalent oxygen concentration. The higher temperature at 60-70 m, and higher oxygen levels indicates that the water at this depth comes from an inflow of warm Kattegat surface water.

The Eastern Gotland Basin is the largest of the Baltic Proper basins with the Gotland Deep (240 meter) in the central part. The halocline in the Eastern Gotland Basin was found between 60-70 m over the year. A mixing event was noted in September at BCSIII-10 when the thermocline deepened from 20 m in August to 50 m in September. There were no storms passing the area during this time, but strong winds around 15-20 m/s prevailed during the September cruise.

Like in the surface water, the salinity and temperature were higher than normal in the deep water in the Eastern Gotland Basin the whole year, which has been observed since the inflow 2014 that brought warmer and more saline water to the deep basins of the Baltic Proper. The temperature and salinity have been decreasing slowly since 2014 but are still higher than before the inflow in 2014 (Figure 12). However, the decrease temperature, salinity and oxygen was interrupted in February 2019 when the remnants of the inflow that occurred in the autumn of 2018 reached station BY15. This can be seen in all three parameters in Figure 12 but is most striking in temperature. This is also seen in the profiles from BY15, shown in Figure 13 and further described below.

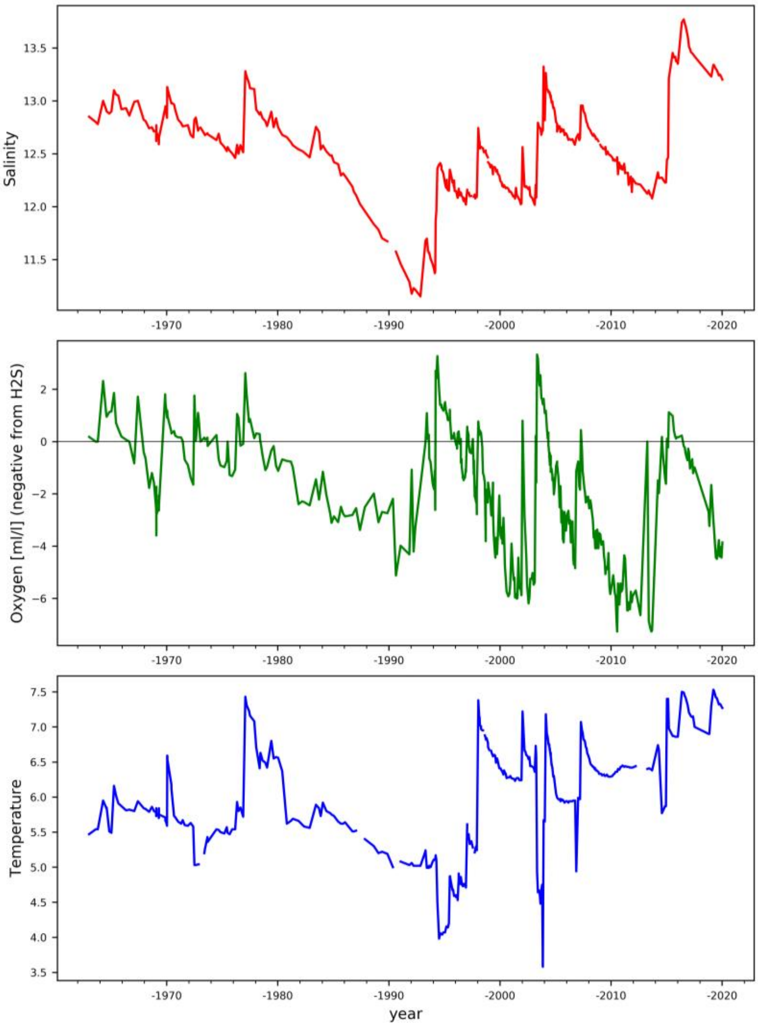

Figure 12.Time series of salinity (top, red), oxygen (middle, green) and temperature (bottom, blue) at ≥235 m depth at BY15. The horizontal line in the middle panel shows the limit for zero oxygen concentration, negative values represent hydrogen sulphide recalculated to equivalent oxygen concentration. Salinity and temperature are higher now than before the last inflow event in 2014.

Increased salinity, but also temperature was observed below the halocline at stations BY15 and BY20 in February (Figure 13), but the increase were not as distinct at the more southerly two stations in the same basin (BCSIII-10 and BY10). There were three minor inflows to the Baltic Sea recorded in the Sound during 2019, one in June-July, one in September and one in the beginning of December. The event in September is most likely the source of this warmer and more saline water.

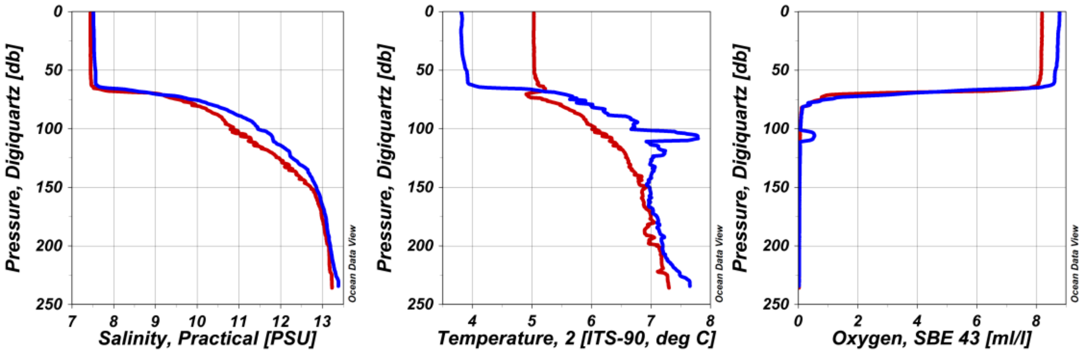

Figure 13. CTD-profiles from station BY15 in the Eastern Gotland Basin, with profiles from January 2019 (red) and February 2019 (blue). Parameters shown from left to right panel are salinity, temperature and oxygen. Image is made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019).

Traces of two inflows were noted in the water below the halocline at stations BCSIII-10 and BY10 in the southern parts of the Eastern Gotland Basin, in May and in November. In May this was seen in temperature, salinity and oxygen but in November there were no traces of this in the oxygen concentration. In May the oxygen was above 4 ml/l at 120 m depth, which is a large change compared to April when there was hydrogen sulphide at the same depth, i.e. completely oxygen free. The event in May did not affect the depth of the halocline but in November the halocline was lifted from 60 m to 50 m (Figure 14). The change in salinity below the halocline at station BY10 between the two cruises was about 1 psu.

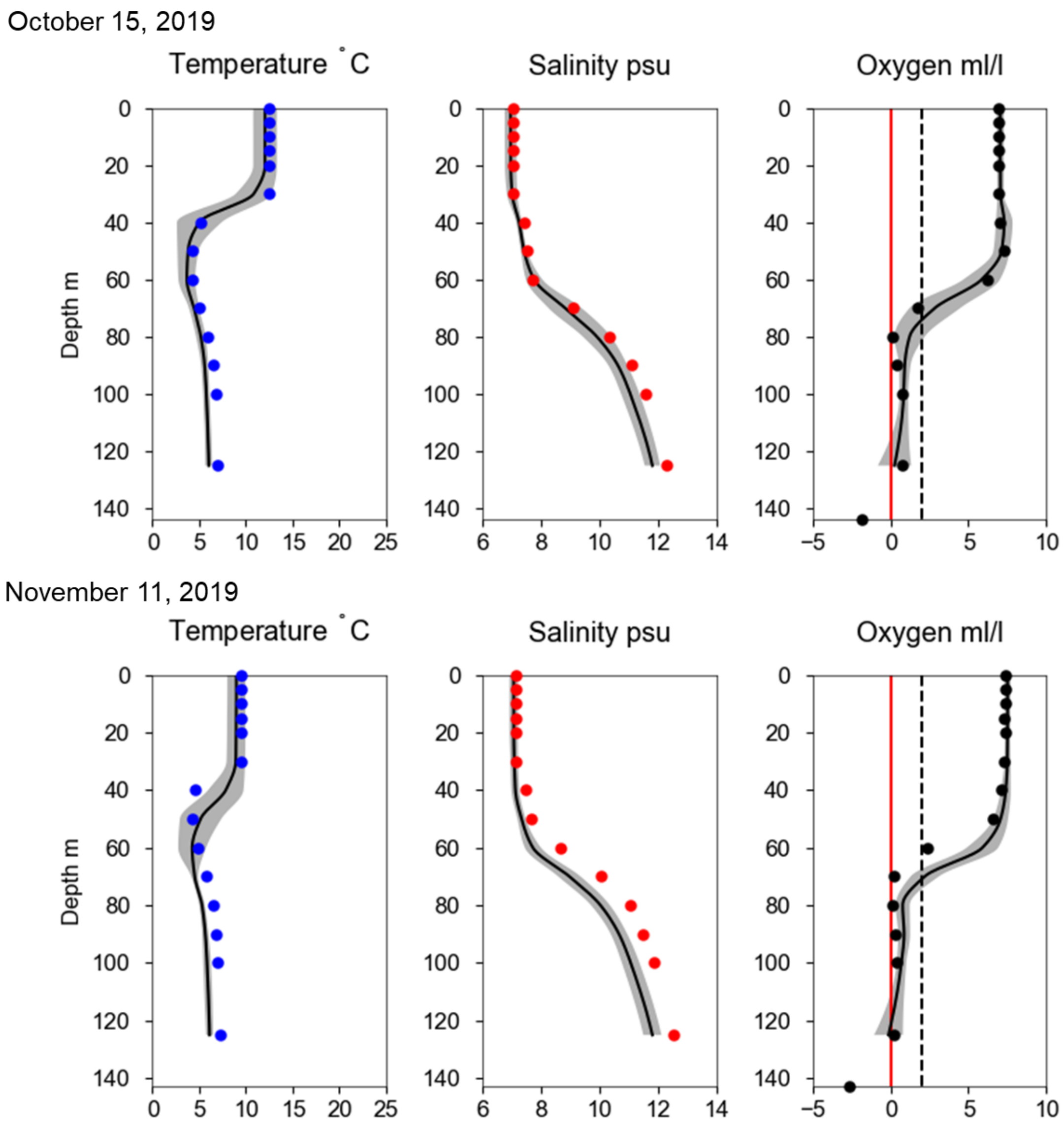

Figure 14. Temperature (blue), salinity (red) and oxygen (black) profiles from station BY10, top panel is from October 15th 2019 and bottom panel from November 11th 2019. The vertical lines in the right panel show the limit for zero oxygen (red) and 2 ml/l (black dashed) oxygen concentration, negative values represent hydrogen sulphide recalculated to equivalent oxygen concentration. The salinity had increased between the two observations which indicate inflowing water originating from the more saline Kattegat.

4.2.2 Nutrients

The concentration of dissolved inorganic nitrogen was lower than normal in January and February in the Arkona and Bornholm Basins and at some stations in the Eastern Gotland Basin. The concentration of dissolved inorganic nitrogen started to decrease at most stations in the southern Baltic Proper (Arkona and Bornholm Basins) between February and March, this indicate the start of the spring bloom there. Dissolved inorganic nitrogen was fully depleted in April in those basins. In the central and northern Baltic Proper the decrease in dissolved inorganic nitrogen was observed later, between March and April and was not depleted until May at some stations (BCS III-10, BY29 and BY15). An example of the difference between station BY31 and BY15 is given in Figure 15. At the station BY31 Landsortsdjupet (also at B1, shown Appendix I), which is sampled twice a month, a sharp drop in concentration of dissolved inorganic nitrogen can be seen between the two close sampling occasions in

March and clearly illustrates the start and the intensity of the spring bloom. At BY15 the decrease in dissolved inorganic nitrogen may appear slower, since the drop from high winter concentrations to low/depleted summer concentrations takes place over the course of two months. However, the lower sampling frequency might overlook the start and/or intensity of the bloom.

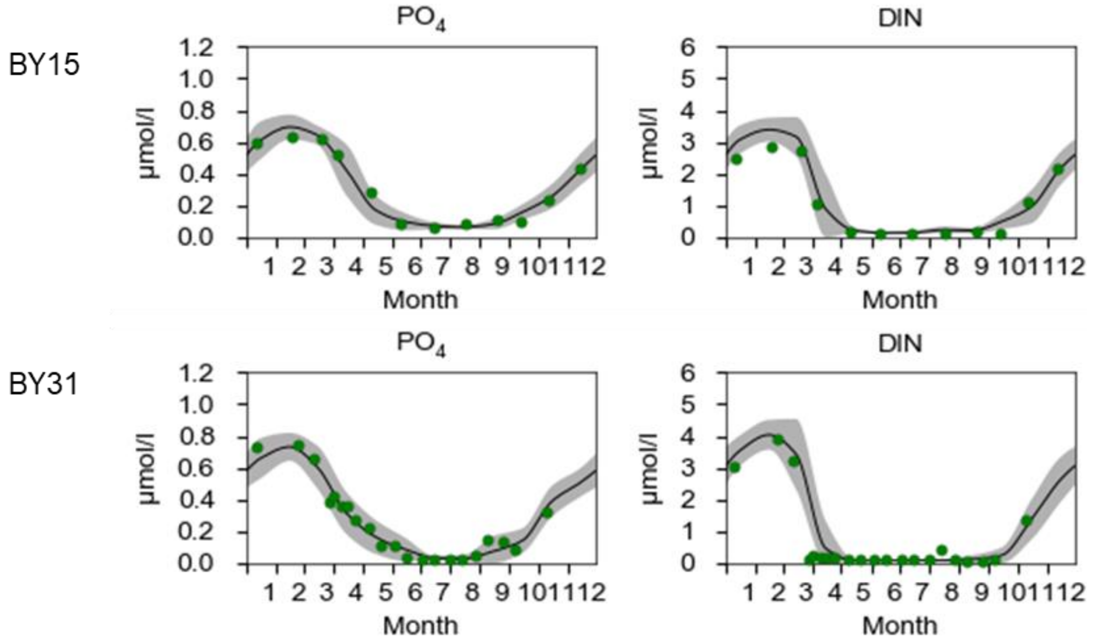

Figure 15. Surface mean (0-10 m) of phosphate (left) and dissolved inorganic nitrogen (right) at two stations in the Baltic Proper, BY15 in the Eastern Gotland Basin (top) and BY31 in the Western Gotland Basin (bottom). The decrease in dissolved inorganic nitrogen in spring shows variation in the time of the spring bloom.

Phosphate concentration in the surface water was normal throughout the year and silicate was above normal throughout the year in all basins except Arkona and Bornholm. The high silicate concentrations are a part of a pattern over several years and are further discussed in the section about trends.

In May the primary producers had depleted not only the surface water of dissolved inorganic nitrogen, but all the water above the halocline in the Baltic Proper. This can be seen in the nutrient profiles at all stations in the Baltic Proper, an example is given from station BY20 Fårödjupet in Figure 16. This should be seen in contrast to phosphate that are low but not depleted in the water above the halocline giving the nitrogen fixing cyanobacteria an advantage and stimulates cyanobacteria blooms.

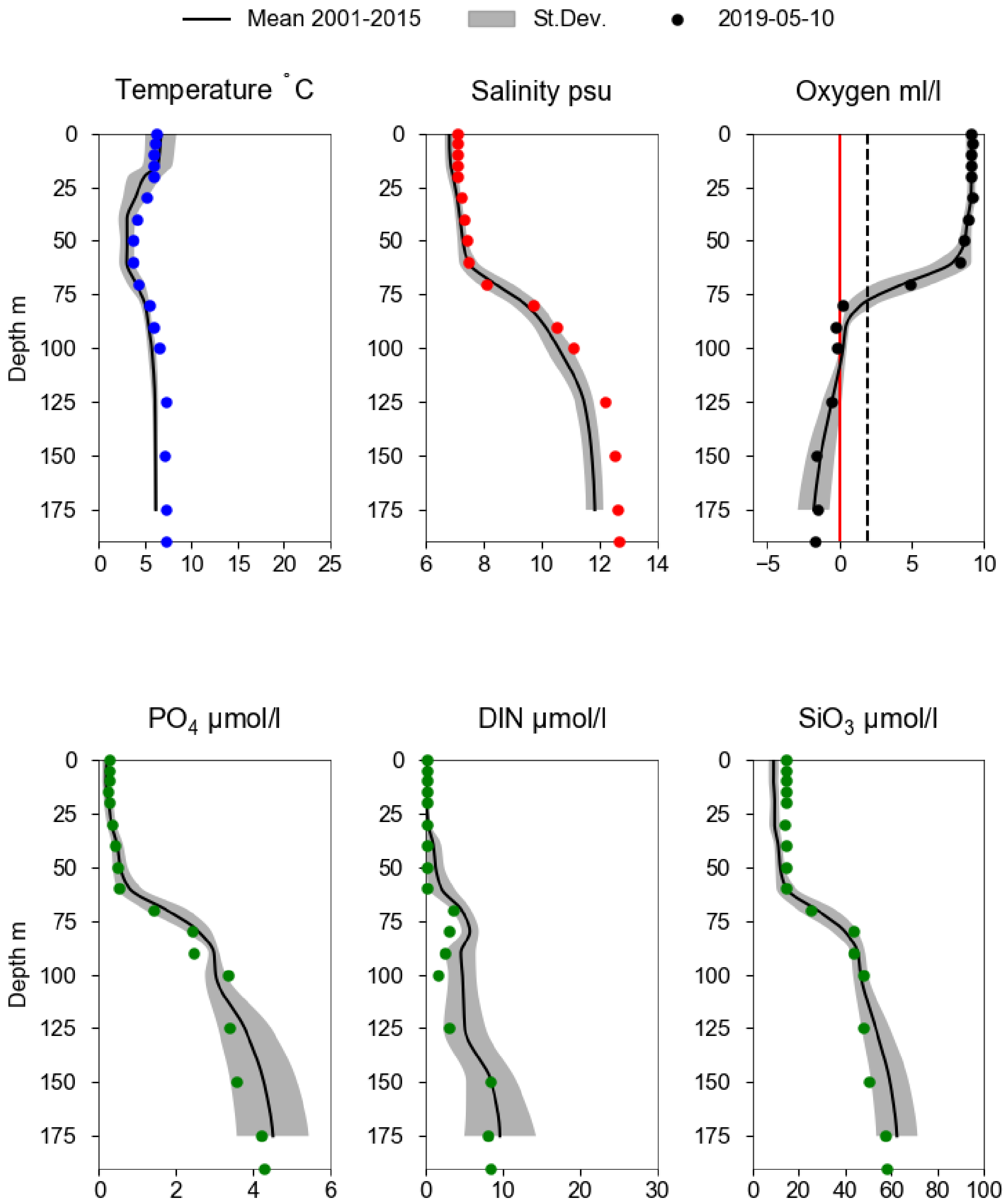

Figure 16. Vertical profiles from station BY20, Fårödjupet in the Eastern Gotland Basin in May 2019. Parameters shown in the top panel, from left to right are; temperature (blue), salinity (red), oxygen (black) and nutrients (green).. In the bottom panel, from left to right; phosphate, dissolved inorganic nitrogen and silicate. The vertical lines in the top, right panel show the limit for zero oxygen (red) and 2 ml/l (black dashed) oxygen concentration, negative values represent hydrogen sulphide recalculated to equivalent oxygen concentration.

The concentrations of nutrients are often higher in the deep water than in the surface water due to degradation of organic matter that release nutrients back to the water and the absence of primary production which is limited to the shallower illuminated surface waters. In the Baltic Proper deep water inorganic nutrients accumulate due to the stratification which limits the mixing between surface and deep water.

Higher phosphate and silicate concentrations than normal were found in the bottom waters when oxygen was low or absent at many of the stations in the Baltic Proper. At the same time there were often large differences in the dissolved inorganic nitrogen concentration between the sample depths, which can be caused by bacterial activity in the zones between anoxic and oxic waters, where denitrifying bacteria are common.

It is difficult to determine the exact cause of the rapid changes in nutrient concentrations associated with the bacterial activity in the zone between anoxic and oxic waters. These biogeochemical processes work on small spatial scales whereas the monitoring programme is set up to follow large scale changes and sampling is done only with a 10 m interval.

However, in general terms low concentrations of dissolved inorganic nitrogen could be explained by denitrification which reduce nitrate to nitrous gas and takes place in the zone between anoxic and oxic waters; high phosphate and silicate concentration can be caused be reduction of metal oxides which then release previously adsorbed phosphate and silicate.

The deep waters, below the halocline, of Arkona Basin had normal nutrient concentrations throughout the year. However, during autumn there were a temporary enrichment of both phosphate and dissolved inorganic nitrogen when hypoxic conditions (≤2 ml/l oxygen) were found in the deep water, from August at BY2 and from September BY1 to the end of the year. In October some oxygen was brought back to the basin but did only reach BY1, and it was quickly consumed which was noted during the November sampling. This short oxygenation led to lower concentrations of phosphate and dissolved inorganic nitrogen in October at station BY1. Station BY2 did only get small amount of this incoming water, and phosphate and dissolved inorganic nitrogen was consistently high but within normal values in the bottom water during the autumn. In December oxygen bottom water concentrations were above 6 ml/l in the Arkona Basin and dissolved nutrients decreased as a consequence.

In the Bornholm Basin the concentration of phosphate in the deep water was higher than normal in February and May. It coincided with a loss of oxygen to just below 2 ml/l below 70 m in February, but did not show any effect in dissolved inorganic nitrogen concentrations which stayed within normal levels until May. In May the oxygen was depleted and now also dissolved inorganic nitrogen concentrations were elevated to above normal values. Dissolved inorganic nitrogen concentrations stayed high but within normal levels in the bottom waters during the summer, whereas phosphate levels were higher than normal.

In the Eastern Gotland basin (BCS III-10, BY10 and BY15) an intermediate water layer below the halocline (around 80-100 m) occasionally had lower dissolved inorganic nitrogen concentrations than normal, often in combination with elevated phosphate concentrations. This was coupled to low oxygen concentrations, as described above. An example of this can be seen at station BY10 in November in Figure 17. Further north in the Eastern Gotland Basin, at station BY20 the same pattern was not observed, but during autumn (September-November) both dissolved inorganic nitrogen and phosphate was elevated above normal values from 75 to 100 m due to the anoxic conditions and thus sulfidic water that developed in this layer during the year. Phosphate concentrations were occasionally also higher than normal and reflected oxygen conditions in the water column.

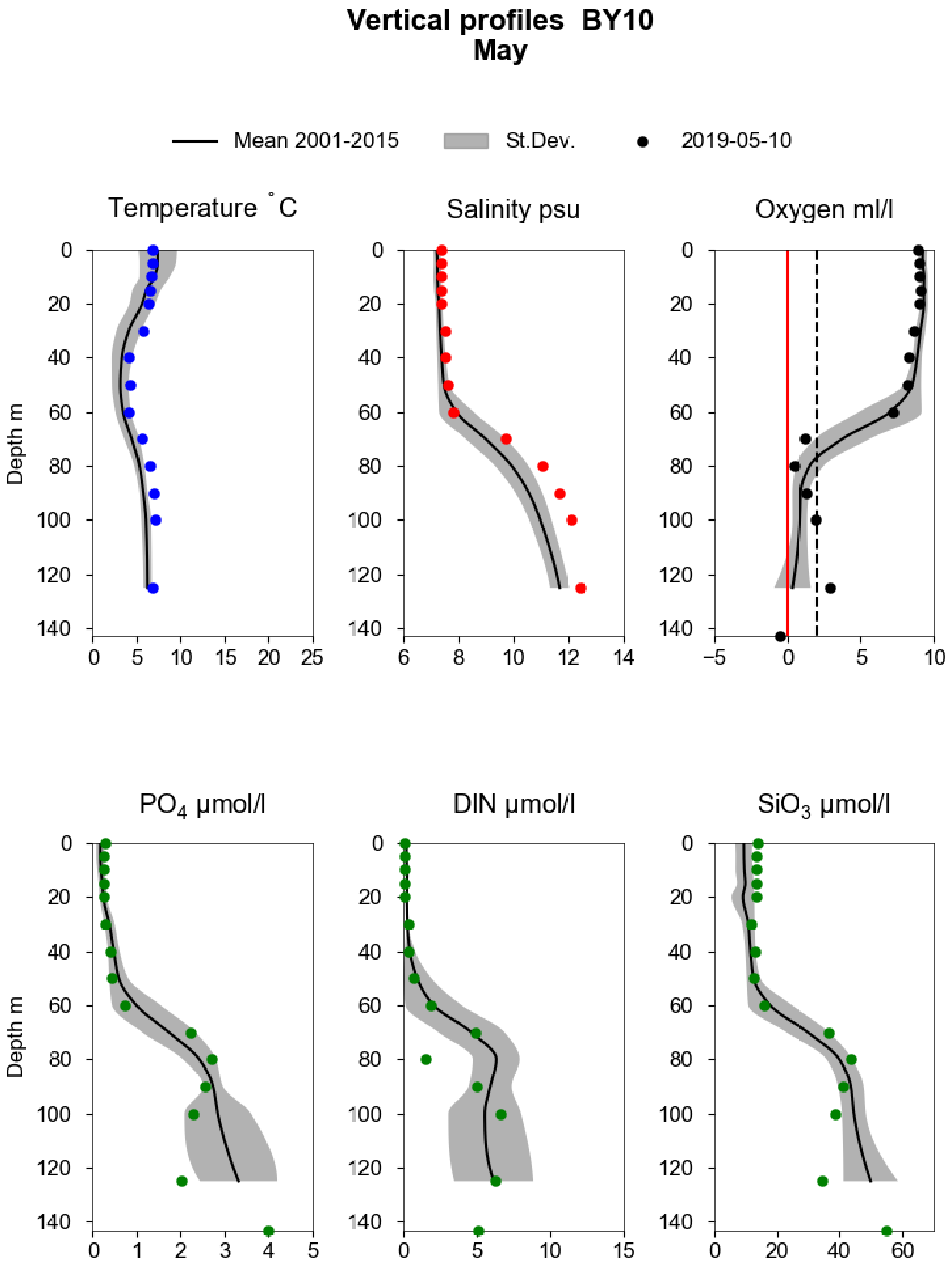

Figure 17. Vertical profiles from station BY10 in the Eastern Gotland Basin in May 2019. Parameters are temperature (blue), salinity (red), oxygen (black) and nutrients (green) in bottom row from left to right; phosphate, dissolved inorganic nitrogen and silicate. Traces of an inflow from the Kattegat can be seen in increase salinity and oxygen below 80 m. Associated with this are also changes in nutrient concentration. The vertical lines in the top, right panel show the limit for zero oxygen (red) and 2 ml/l (black dashed) oxygen concentration, negative values represent hydrogen sulphide recalculated to equivalent oxygen concentration.

In the deep water, below the halocline, in the Western Gotland Basin concentrations of dissolved inorganic nitrogen were above normal while phosphate concentrations were normal or below normal. During summer months a layer of elevated concentrations of dissolved inorganic nitrogen was formed at around 90-100 m in the transition from low oxygen to completely oxygen free, sulfidic water.

Phosphate in the deep waters was a little lower than normal in the beginning of the year, however it was not reflected in any particular low oxygen conditions, rather an increase in salinity was observed during the same time at station BY31.

At the station BY29 in the Northern Baltic Proper dissolved inorganic nitrogen below the halocline was above normal concentrations a large part of the year. In the summer an intermediate water layer with high dissolved inorganic nitrogen was formed and stayed high until the end of the year.

4.2.3 pH and alkalinity

pH and alkalinity is sampled at BY5 Bornholmsdjupet, BY15 Gotlandsdjupet, BY31 Landsortsdjupet (November-February) and Ref M1V1 (on visits by SMHI, monthly).

Similar to the stations in Skagerrak and Kattegat, pH was lower than the 15-year mean at all stations in the Baltic Proper (Figure 18). Similarly, alkalinity was higher than the 15-year mean except at BY31 Landsortsdjupet. In the Baltic Proper, changes in pH are driven primarily by variations in primary production, not by the atmospheric CO_2 partial pressure, and this is indicated by larger seasonal variations than in the more saline Kattegat and Skagerrak. pH thus varies with eutrophication in the surface water, and in the deep by oxygen depletion. Alkalinity is lower in the fresher Baltic Sea compared to the marine Skagerrak and Kattegat area, which is connected to the open Atlantic Ocean. The buffering capacity is therefore lower, and this also contributes to more variable and generally lower pH in the Baltic Sea.

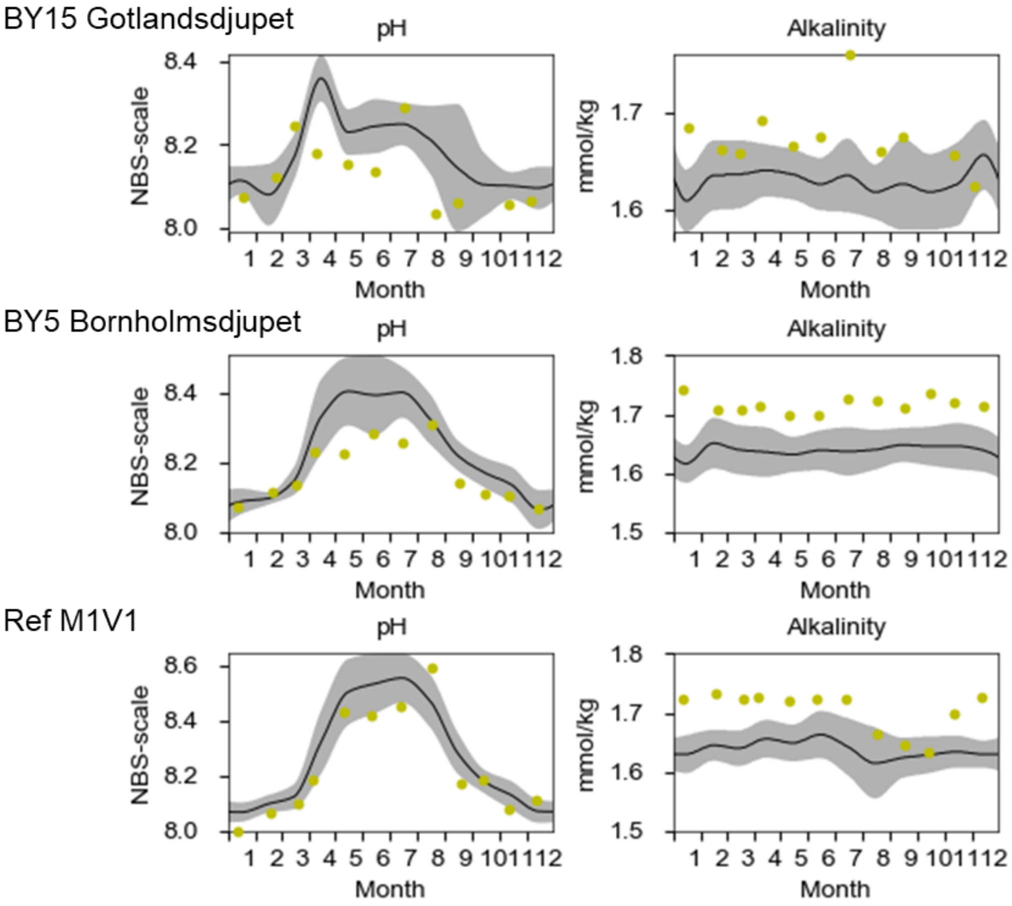

Figure 18. pH (left) and alkalinity (right) in surface water (0-10 m) at stations from top to botton: BY15 Gotlandsdjupet, BY5 Bornholmsdjupet and Ref M1V1.

4.2.4 Phytoplankton

The spring bloom was observed in March at the southernmost stations and in April in the northern Baltic Proper with high abundancies of diatoms and the typical spring dinoflagellate *Peridiniella catenata.* Already in May, low or moderate amounts of the filamentous cyanobacterium *Aphanizomenon flosaquae* were found.

There were generally low phytoplankton diversities in June. Among the filamentous cyanobacteria, *A. flosaquae* was definitely the most abundant, although the potentially toxic species *Nodularia spumigena* was present at many stations in low amounts. The green algae *Binuclearia lauterbornii* was present in various amounts at all stations this month.

In July the cyanobacteria bloom was extensive in all of the Baltic Proper with large amounts of the three most common summer cyanobacteria *A. flosaquae*, *N. spumigena* and *Dolichospermum* sp. During the July cruise the cyanobacteria were in different stages due to varying wind conditions. Winds and waves mix the cyanobacteria down in the water column. When there were calm winds, the accumulations immediately rose to the surface while they were mixed in the water column during windier weather. The 2019 cyanobacteria surface accumulations were most extensive at the end of July when the weather was sunny with calm winds. At this time the blooms covered large parts of the Baltic Proper and the Gulf of Finland and had spread to the Bothnian Sea. The total extent was the second largest since 2002 when SMHI started the Baltic Algae Watch System (BAWS). By August the filamentous cyanobacteria amounts had declined compared to July. However there was an increase in the pico cyanobacteria colonies. Relatively high chlorophyll concentrations in the Eastern Gotland Basin were caused by cyanobacteria while the diatom *Dactyliosolen fragilissimus* caused the increase of chlorophyll a in the Arkona Basin.

4.2.5 Oxygen condition in the bottom water

There were no major Baltic inflows during the year but three smaller inflows, the largest of them occurred in the end of November to beginning of December and could be traced from increased salinity and oxygen in the bottom waters of the Arkona basin during the December cruise and will likely be seen further into the Baltic Proper during 2020. The two other inflows were smaller and occurred in June-July and September.

There was a small increase in oxygen at BSC III-10 in September and the deep water still contained some of that oxygen by November, but it was almost completely consumed with oxygen concentrations just above 0 ml/l.

In May traces from an inflow was observed south of the Gotland Deep at station BY10 (see section 4.2.1). At this occasion the oxygen was around 3 ml/l at 125 m depth and the month before there was hydrogen sulphide and thus oxygen free at the same location (Figure 17).

At the station BY15 extra samples are taken at every 5 m close to the oxycline to get a better resolution, where the water goes from oxic to oxygen free (anoxic). Minor inflows through the Sound that reach the intermediary water at around 80-130 m are seen in changing oxygen and hydrogen sulphide concentrations at these depths from month to month (Figure 19). At the beginning of 2019 the water was oxygen free from 85 m depth, in February low concentrations of oxygen (0.2-0.5 ml/l) were found down to 115 m and in March this small amount of oxygen was no longer detectable. In March low oxygen concentrations was measured again down to 125 m (ca 0.2 ml/l, although difficult to see in Figure 19). After this the intermediary water stayed oxygenated until the end of the year, with concentrations varying from just above detection limit (0.1 ml/l) to up to 1.6 ml/l in July and August. After July the oxygen concentration in the intermediary layer stayed on low but measurable concentrations until the end of the year. Below 130 m hydrogen sulphide was measured at all cruises except in August and September when hydrogen sulphide were first measured at 150 m. Also at BY20 Fårödjupet further to the north, small changes in oxygen and hydrogen sulphide were found around 100 m during summer. At this station hydrogen sulphide was present from 80 or 90 m at all cruises, but a decrease in hydrogen sulphide was seen at 100 or 125 m depth during the year. In June no hydrogen sulphide was detected and low concentrations of oxygen could be measured. At the station BY10, to the south of BY15, fluctuations in oxygen concentrations were larger and the highest concentration was found in May when it reached almost 3 ml/l at 125 m depth. This is a large change compared to April when it was completely oxygen free at the same depth and hydrogen sulphide present (Figure 17). At the deepest measurement there was hydrogen sulphide present throughout the year, but clearly lower concentrations after from May to August.

Oxygen concentration in the water closest to the bottom (ca 4 m above the bottom) continued to decrease during the year at all open sea stations north of the station BY10 in the Baltic Proper.

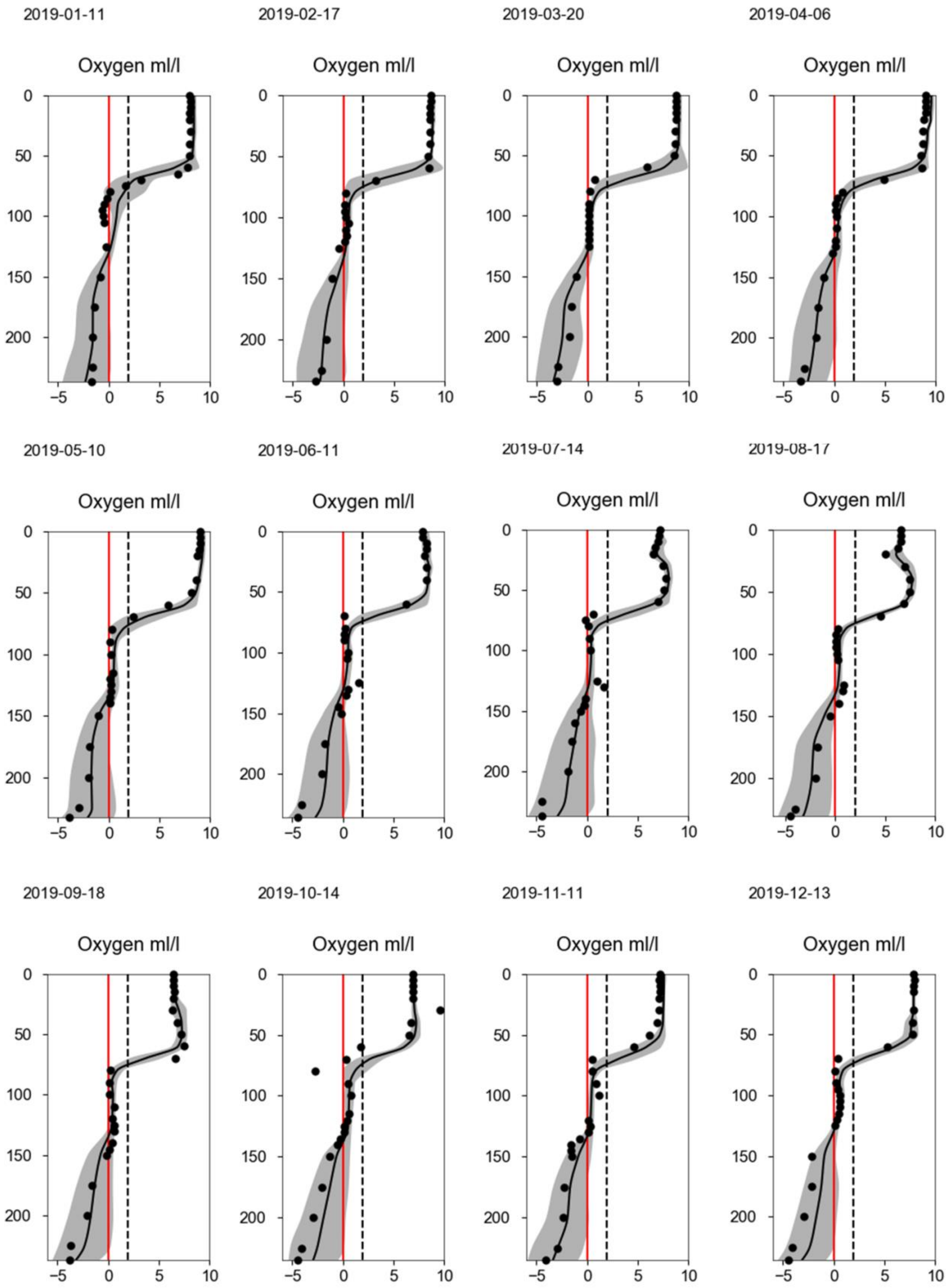

Figure 19. Vertical profiles of oxygen and hydrogen sulphide (as negative oxygen) from station BY15, Gotlandsdjupet 2019. Profiles from January in the top left corner to December in the bottom right corner. The vertical lines show the limit for zero oxygen (red) and 2 ml/l (black dashed) oxygen concentration, negative values represent hydrogen sulphide recalculated to equivalent oxygen concentration.

The deep water in the Western Gotland Basin has been anoxic since the beginning of the 21st century and hydrogen sulphide concentrations are steadily increasing below the halocline. At the end of the summer and in the autumn 2019 hydrogen sulphide was measured as shallow as 60 m at station BY38 Karlsödjupet. Also at station BY32 further to the south in the basin hydrogen sulphide was measured at 70 m in October, which is shallower than normal.

4.3 Bothnian Bay and Bothnian Sea

4.3.1 Temperature and salinity

The temperature in the surface water was normal throughout the year, only slightly lower than normal in June in the Quark and the Bothnian Sea. The surface water started to become warmer in May in the Bothnian Sea but was not over 5℃ until the cruise in June in the Bothnian Bay. When the surface water warmed up a summer thermocline was formed at 10-15 m that persisted until September. At most stations the highest surface temperature, round 15℃, was observed in August. The salinity in the surface water was normal as well, except in February and March at station B7 in the Quark where it was just above normal.

4.3.2 Nutrients

In the Gulf of Bothnia total nitrogen and total phosphorus are measured all months and inorganic nutrients are measured during winter, except at the coastal stations where they are measured all months.

In the Bothnian Sea phosphate and silicate was above normal in January and February. Total phosphorus was above normal at most measurements during the year. At the coastal station Gavik-1 the concentration was above normal all months, this is also the only station in the Bothnian Sea where silicate is measured all months. In the Quark only phosphate concentrations were above normal in January and February and silicate was normal all year. In the Bothnian Bay dissolved inorganic nitrogen was below normal and phosphate above in January and December. Total phosphorus was above normal at many of the sampling occasions during summer while total nitrogen was within normal. The same pattern was seen in the Quark and the opens sea stations in the Bothnian Bay (Figure 20), but not at the coastal stations Råneå-1, Råneå-2 and NB1/B3.

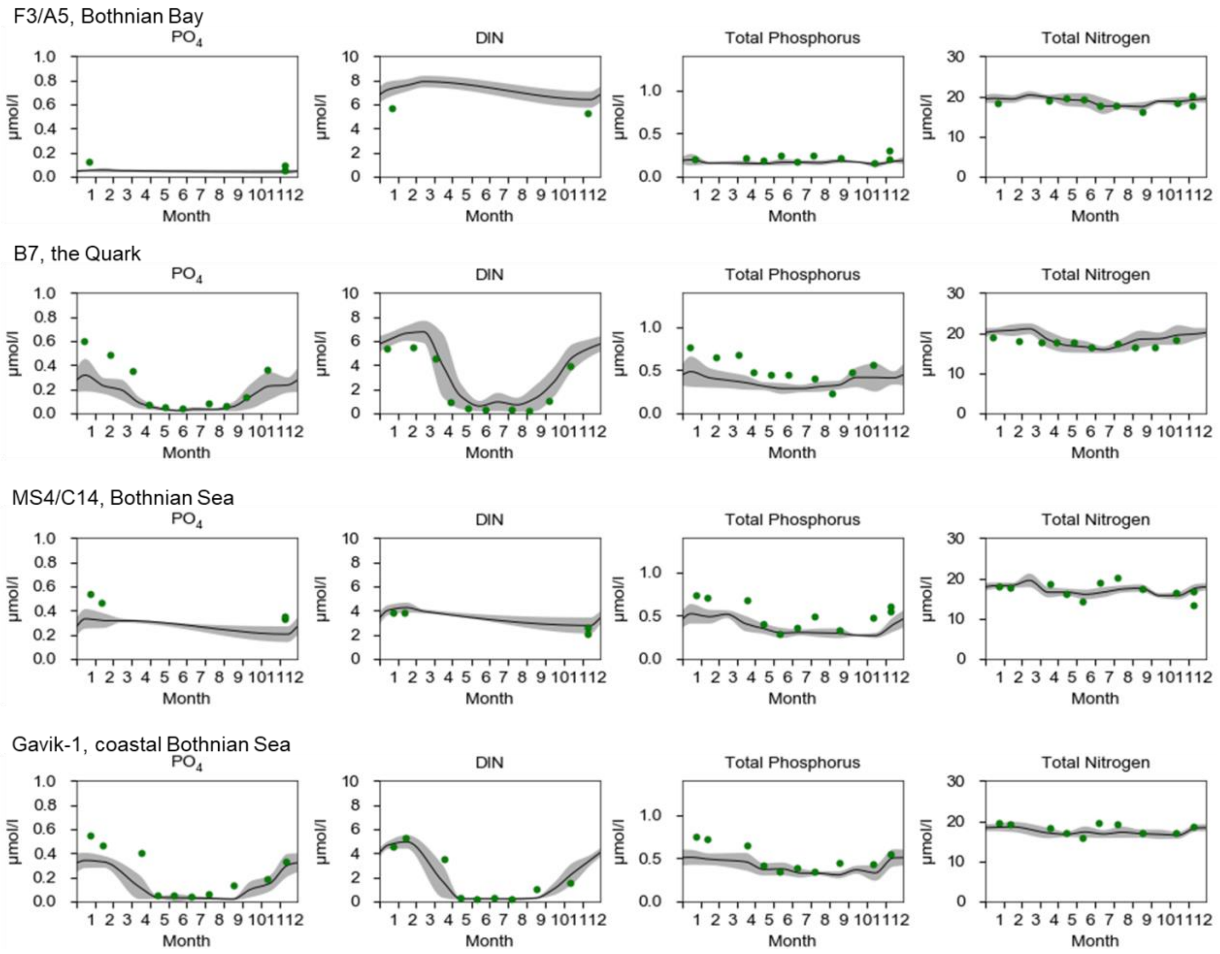

Figure 20. Surface (0-10 m) concentration of nutrients at four selected stations from top to bottom: F3/A5 in Bothnian Bay, B7 in the Quark, MS4/C14 in Bothnian Sea, Gavik-1 in coastal Bothnian Sea. Nutrients from left to right: phosphate, dissolved inorganic nitrogen, total phosphorus and total nitrogen. All stations show higher than normal phosphate in January and February.

4.3.3 Phytoplankton

Phytoplankton in the Gulf of Bothnia was mostly similar to the past years. The highest chlorophyll concentration was found in May in the Bothnian Sea (station C3) and in June in the Bothnian Bay (station F3/A5).

The most notable difference to past years was that dinoflagellates and the ciliate *M. rubrum* dominated the spring bloom at station C3 in the open Bothnian Sea. At all other stations diatoms dominated the spring bloom, which is normal in for the Gulf of Bothnia. In the southern Bothnian Sea the station C24, that is not part of the standard programme, was visited at some occasions in 2019. There were a lot of cyanobacteria in the samples from August, which is in accordance with the satellite data from the Baltic Algal Watch System (BAWS). The same amount of cyanobacteria was not found at stations C3 further to the north.

4.3.4 Oxygen condition in the bottom water

There was no oxygen deficiency in the open waters of the Gulf of Bothnia in 2019, which is normal. However, the oxygen concentration was slightly lower than normal at some occasions (January, February and November) at station MS4/C4 in the Bothnian Sea and in December at station F9/A3 in the Bothnian Bay. Also at the coastal station B7 in the Quark the oxygen concentration was slightly below normal in January and November, which corresponds to the overall decreasing bottom water oxygen trend in the Bothnian Sea, see below.

4.4 Winter mapping

Each winter the spatial distribution and availability of the nutrients are surveyed (Figure 21, Figure 22, Figure 23 and Figure 24). During these surveys all standard stations are visited, but also additional stations are visited. The winter surveys in the Kattegat, the Baltic Proper and the Gulf of Bothnia are made on the regular monitoring cruises and the same position can be visited from year to year also for the additional stations. In the Skagerrak, the winter survey is made in conjunction with the regular International Bottom Trawl Survey and the positions of the additional stations in the Skagerrak are therefore not exactly the same each year.

The results have been discussed in respective sea area in the sections above. In general the concentration of dissolved inorganic nitrogen was below normal in all sea areas. In the Skagerrak, Kattegat, the Sound and the southern Baltic Proper phosphate was also below normal, while phosphate was above normal in the Gulf of Bothnia. Silicate concentration was above normal in the Baltic Sea and below normal in the Skagerrak and the Kattegat.

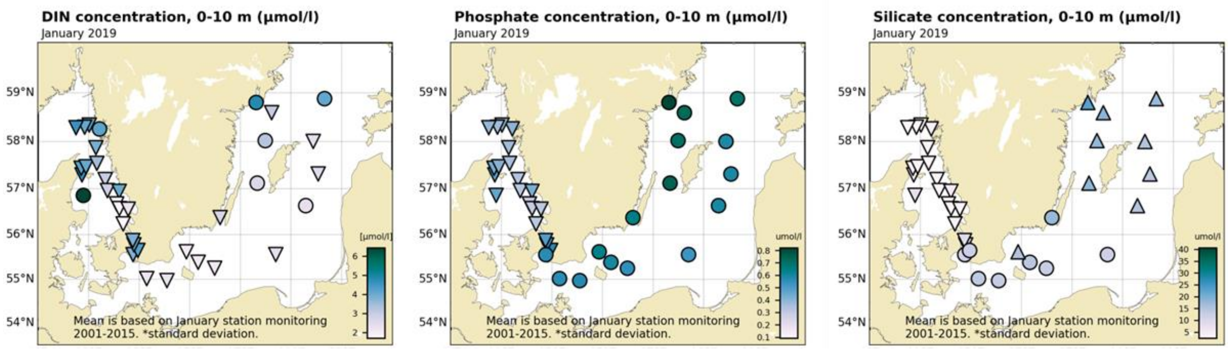

Figure 21. Result of winter nutrient mapping in the Skagerrak and Kattegat as well as at standard stations in the Baltic Proper, January 2019. From left to right, surface (0-10 m) concentration of dissolved inorganic nitrogen, phosphate and silicate. Circles indicate that the value is within 1 standard deviation from the mean value 2001-2015 at the station in December, upward and downward pointing triangles indicate values 1 standard deviation above and below the mean value, respectively.

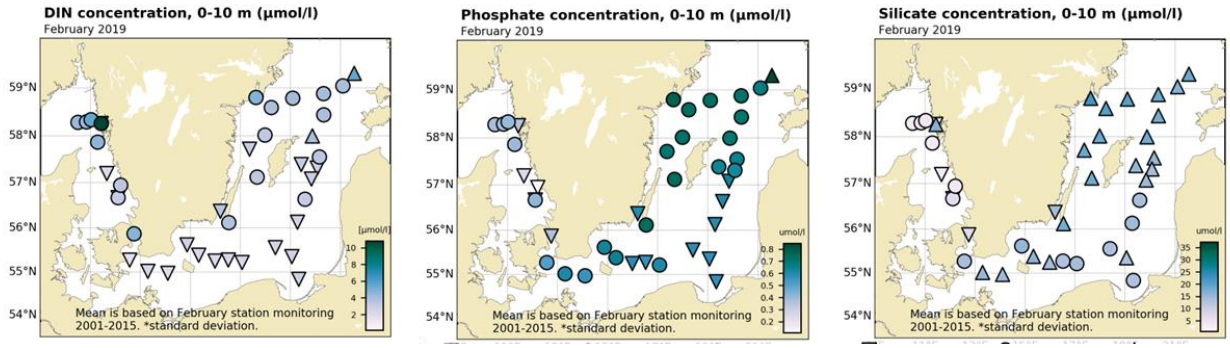

Figure 22. Result of winter nutrient mapping in the Baltic Proper as well as at standard stations in the Skagerrak and the Kattegat, February 2019. From left to right, surface (0-10 m) concentration of dissolved inorganic nitrogen, phosphate and silicate. Circles indicate that the value is within 1 standard deviation from the mean value 2001-2015 at the station in December, upward and downward pointing triangles indicate values 1 standard deviation above and below the mean value, respectively.

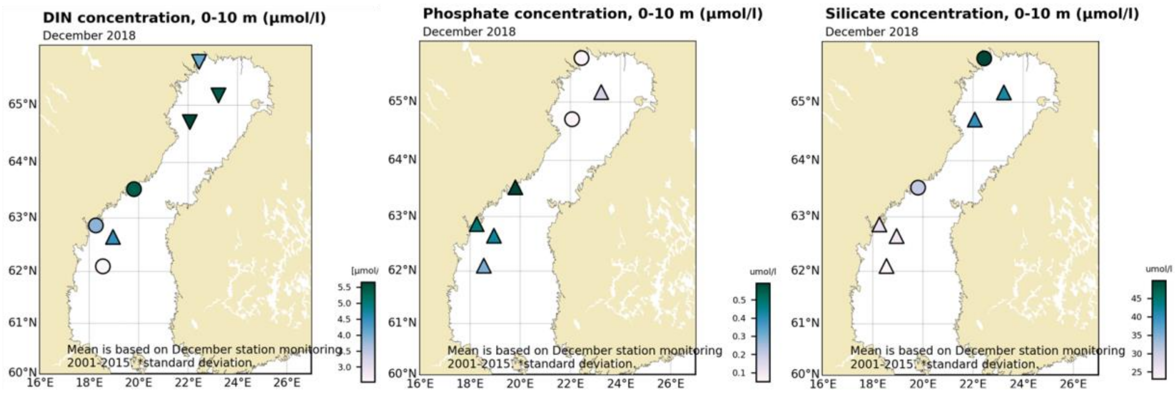

Figure 23. Result of monthly sampling in the Gulf of Bothnia, December 2018. From left to right, surface (0-10 m) concentration of dissolved inorganic nitrogen, phosphate and silicate. Circles indicate that the value is within 1 standard deviation from the mean value 2001-2015 at the station in December, upward and downward pointing triangles indicate values 1 standard deviation above and below the mean value, respectively.

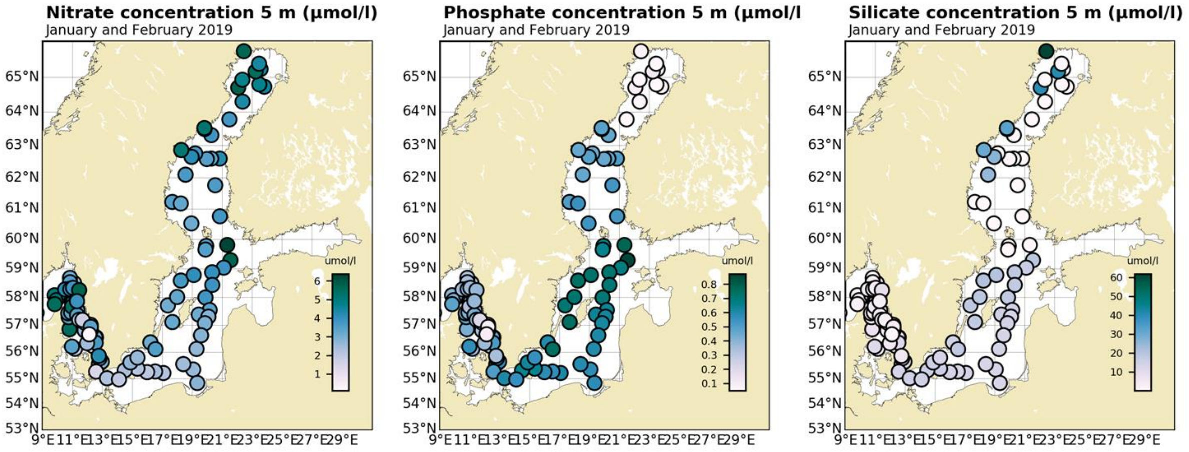

Figure 24. Result from winter mapping stations in the Gulf of Bothnia and monthly sampling at standard stations in January and February 2019. Winter mapping stations were sampled by SYKE and the standard stations by SMHI and Umeå Marine Sciences Centre. From left to right, surface (5 m) concentration of dissolved inorganic nitrogen, phosphate and silicate. There are not enough data from the winter mapping stations in the Gulf of Bothnia from January and February to calculate meaningful mean values for the period 2001-2015, therefore no statistics is shown.

4.5 Time series

Although the focus of this report is on the measurements in the pelagic monitoring programme of the past year, we also present longer times series of the physical and chemical data held by the data host (SMHI). For salinity, temperature, oxygen, nutrients and chlorophyll we present time series 1960-2019 of surface waters (mean of 0-10 m) and bottom waters (depths defined for each station) for each sampling occasion in Appendix II. These time series show the general picture at each monitoring station and also gives a view of the change of measurement frequency over the years. However, long term trends are not easily discernible in these plots due to strong seasonal variations in most parameters, and we also present time series of winter mean values of all salinity, temperature and nutrients and summer mean values of temperature for each basin in Appendix III. In these figures we choose to present significant trends for two periods due to a major reconfiguration of the sampling programme in 1994. The longer period starts from 1960 or from the earliest measurement and the shorter period from 1994. The post-1994 trend analysis is based on years with mostly the same frequency of sampling. Before 1994 the sampling frequency was more variable, this is most evident in temperature data from the Gulf of Bothnia were summer mean values have large variation before 1994. It should also be pointed out the data in the Quark is from stations closer to the coast compare to the other basins.

Linear trends were calculated for the winter or summer mean values for surface (0-10 m) and bottom waters for the two periods (hereafter referred to as long and post-1994 time series). Trend lines are shown in the figures when the p-value of the slope was ≤ 0.05. To avoid biasing towards stations visited more frequently, averages were first calculated per month and station, then winter or summer season for each basin. The summer season was defined as June, July, August and winter as December, January, February. These months were used for all basins although the seasons differ somewhat between the Gulf of Bothnia and the Skagerrak and Kattegat.

In addition to these two types of times series we also show time series of calculated content of nutrients nutrient concentrations in each basin in the Baltic Sea shown in the map in Figure 1.

Due to the recurring events of water inflow from the Kattegat to the Baltic Proper, linear trends are not to be expected in the bottom water in the Eastern Gotland Basin, the Northern Baltic Proper and the Western Gotland Basin. The water here is stagnant between inflows and aach inflow either increases or decreases many of the parameters measured and their values changes abruptly at each inflow. In the Northern Baltic Proper and the Western Gotland Basin inflows has had very minor impact on the bottom waters since the 1990’s, thus in these basins a linear trend can be found in the bottom water for most parameters. In the southernmost basin, Arkona, the bottom water largely reflects conditions and changes in surface waters in Kattegat and here some trends inherited from the changes in Kattegat can be found.

4.5.1 Trends

4.5.1.1 Temperature

The long time series of winter surface temperature shows an increasing trend for all basins, except the Gulf of Bothnia, (Figure 25). The increase is 0.18-0.36°C per decade. In the Arkona and Bornholm Basins there is also a significant trend for the shorter time series starting in 1994, with a higher increase rate of 0.43 and 0.61°C per decade in Bornholm Basin and Arkona Basin, respectively. No basins show a decreasing trend.

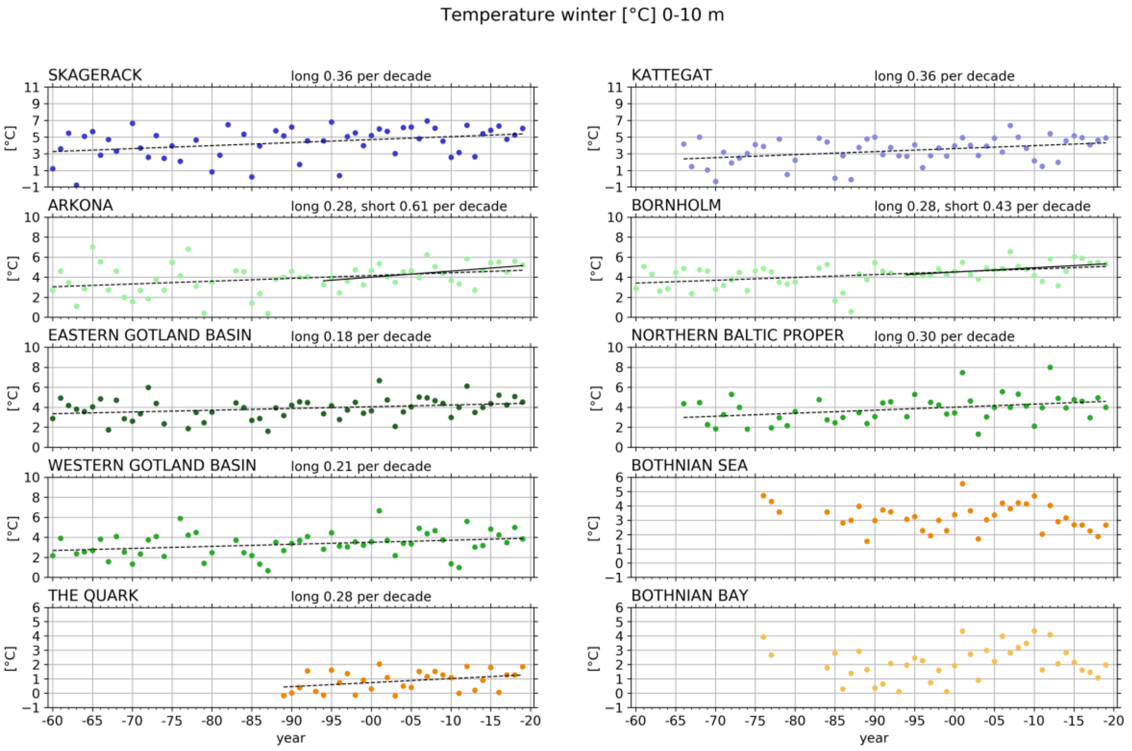

Figure 25. Winter mean values and trends for surface temperature, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. There are significant trends in all basins except the Gulf of Bothnia. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series and solid line for the post-1994 time series.

Like winter surface temperatures, summer surface temperatures show an increasing trend for the longer time series in most basins, also the increase rate is higher in summer than in winter for all basins except for the Skagerrak (Figure 26). For the summer mean values it is only in the Quark and the Bothnian Sea that there is no significant trend. There are no significant trends in the summer surface temperature for the post-1994 time series. The Northern Baltic Proper and the Bothnian Bay stand out with higher increase rates than the other basins, 1.11 and 0.94°C per decade respectively. In the summer there are more data available in the 1960’s and 1970’s in the Gulf of Bothnia than in the winter, however the data during the earliest years in the Gulf of Bothnia are more sparse and often include only one month per year. Thus, after further analysis there might be cause to exclude some data from the 1960’s and 1970’s and recalculate the trend.

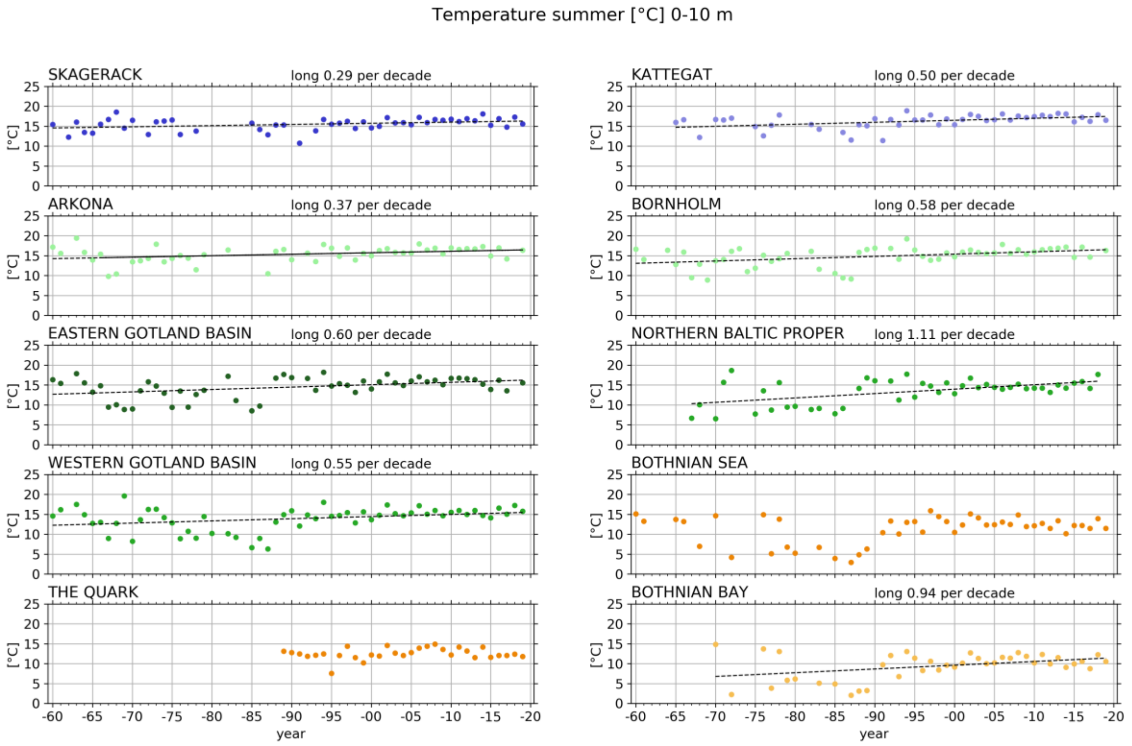

Figure 26. Summer mean values and trends for surface temperature, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. There are significant trends in all basins except the Bothnian Sea and the Quark. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series and solid line for the post-1994 time series.

In the bottom water the rate of temperature increase is higher during the post-1994 period than in the long period (Figure 27). Also, for each basin the trend is higher than in the surface waters, except for the Arkona Basin. In the Bornholm Basin, the Bothnian Sea and the Bothnian Bay there are no significant trends in either the long or the short period. In the Baltic Proper, while the temperature in the bottom water has been increasing by about 0.2-0.3°C per decade during the long period, the increase rate is more than double, 0.5-0.9°C per decade in the post-1994 series. In the Bothnian Sea and the Bothnian Bay there is no significant trend, but in the Quark the increase in ca 0.6°C per decade.

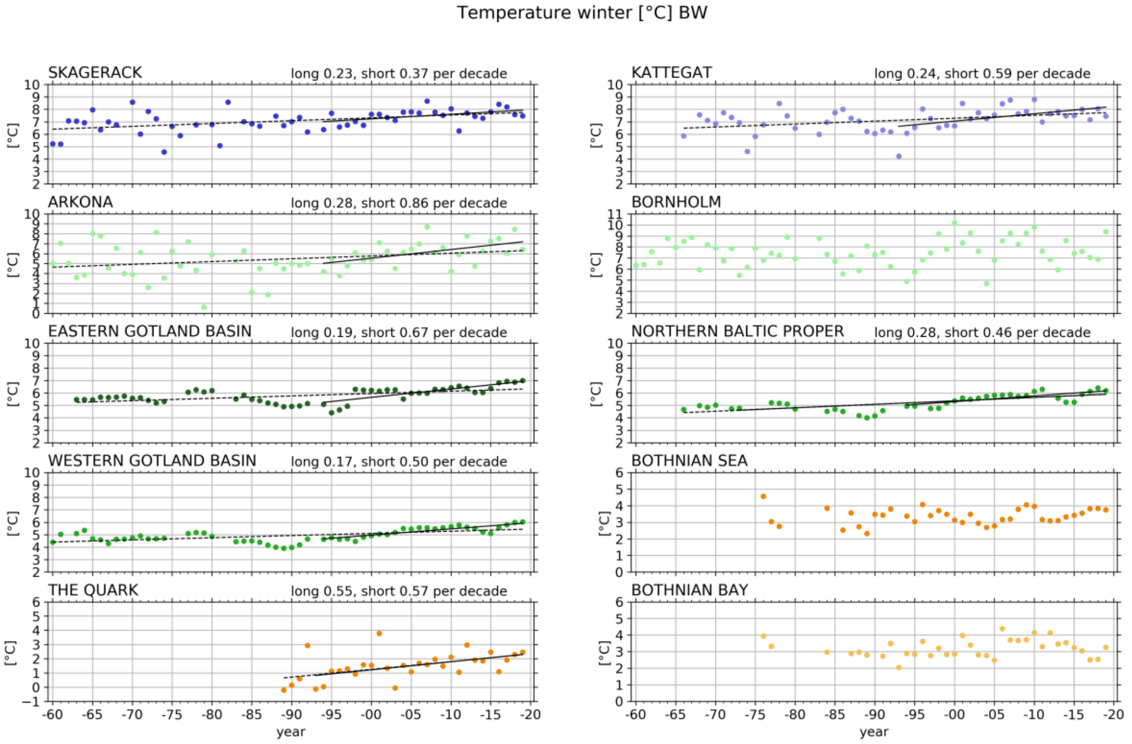

Figure 27. Winter mean temperature in the bottom water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series and solid line for the post-1994 time series.

4.5.1.2 Salinity

Surface winter salinity shows no trends in the Kattegat or the Skagerrak (Figure 28). However, in the Baltic Sea there is a significant decrease in all basins except the Arkona Basin and the Quark in the long time series. This long term decrease varies between 0.06-0.11 psu per decade. However, the trend here is not linear over the longer period but shows a peak around 1980 after which it decreases until about the start of the post-1994 period. Therefore salinity today is not much different from the beginning of the time series in the 1960's. This pattern also leads to the Western and Eastern Gotland Basins having an increase in salinity during the post-1994 period, but a decrease during the longer period. In the Gulf of Bothnia the salinity is decreasing in the surface waters with about 0.16 and 0.23 psu per decade, which means ca 1 psu from the start of the time series in 1975.

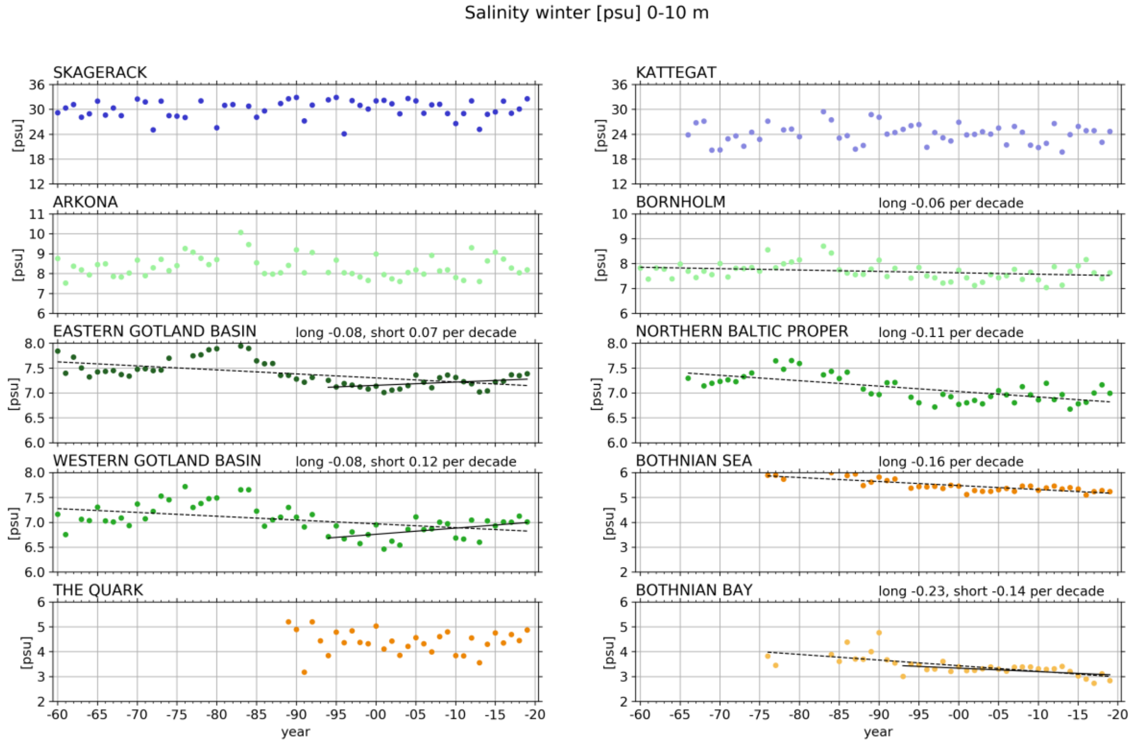

Figure 28. Winter mean salinity in the surface water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

Bottom water salinities in the Baltic Proper only show trends in the post-1994 period and only in the stagnant basins. The increase in salinity is 0.3-0.5 psu per decade for the post-1994 period in the Baltic Proper, but this increase only balance the decrease during the stagnation period 1985-1993 when salinity in the bottom water decreased by more than 1 psu in five years (Figure 29).There are also significant decreasing trends in the long time series in the Kattegat, the Bothnian Sea and the Bothnian Bay of ca 0.1 psu per decade.

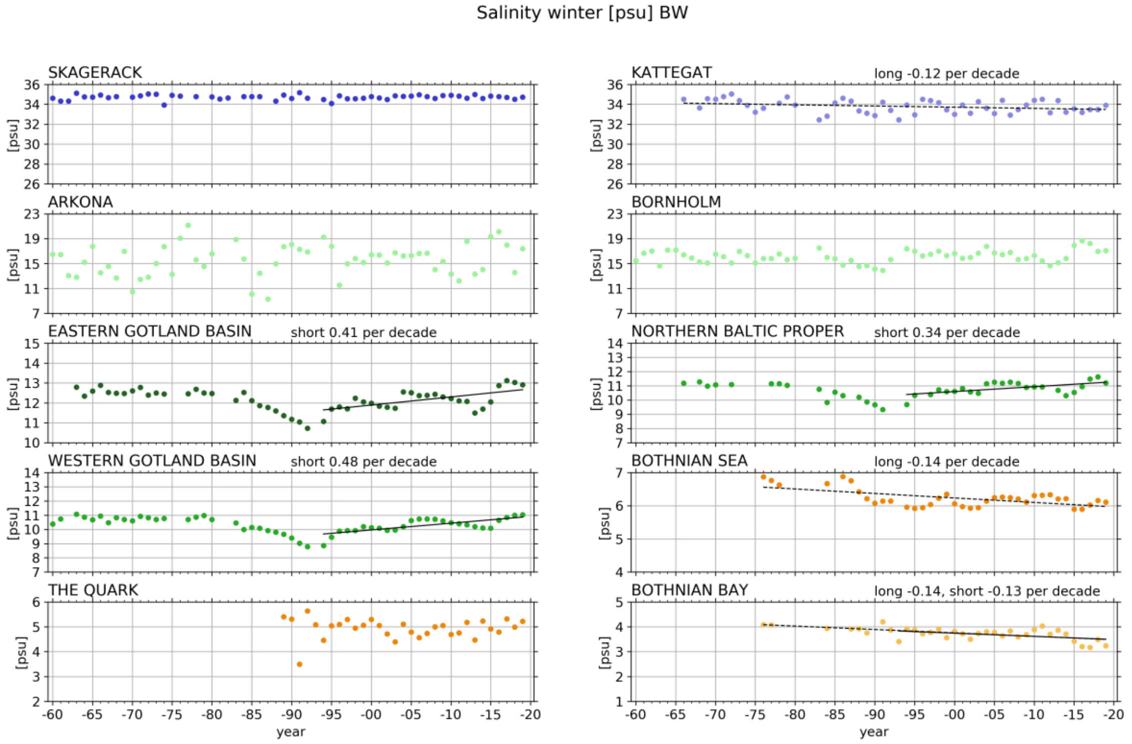

Figure 29. Winter mean salinity in the bottom water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

4.5.1.3 Oxygen

For the long period oxygen concentration in the bottom water shows a significant decreasing trend in all basins except the Arkona Basin, Bornholm Basin and Bothnian Bay. For the post-1994 period there is also a significant decrease in the Northern Baltic Proper, the Western Gotland Basin, the Bothnian Sea and the Quark (Figure 30). The decreasing trend in the Western Gotland Basin in the post-1994 time series is evident also when looking at the hydrogen sulphide data in this basin in Figure 31. Hydrogen sulphide concentration at five stations in the Baltic Proper showing the development since 1990. The colourbar shows hydrogen sulphide concentration in µmol/l from zero (yellow) to 200 (dark blue). Highest concentration in the Eastern Gotland Basin and largest change in the Northern Baltic Proper and the Western Gotland Basin. Prior to year 2000 there was only little or no hydrogen sulphide in these basins. The lack of a trend in the post-1994 time series in the Eastern Gotland Basin is caused by the inflows causing oxygen concentration not to decrease linearly. The development of oxygen conditions is described in more details in the report for the annual oxygen survey (Hansson et al 2020[6]).

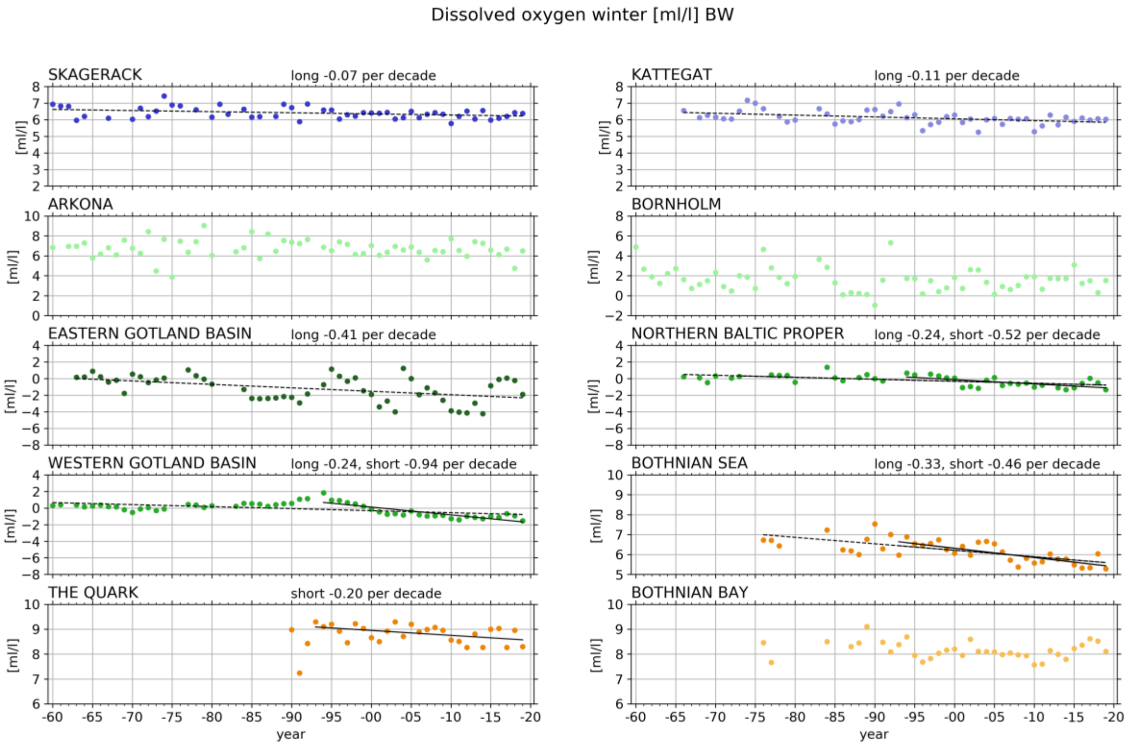

Figure 30. Winter mean oxygen in the bottom water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

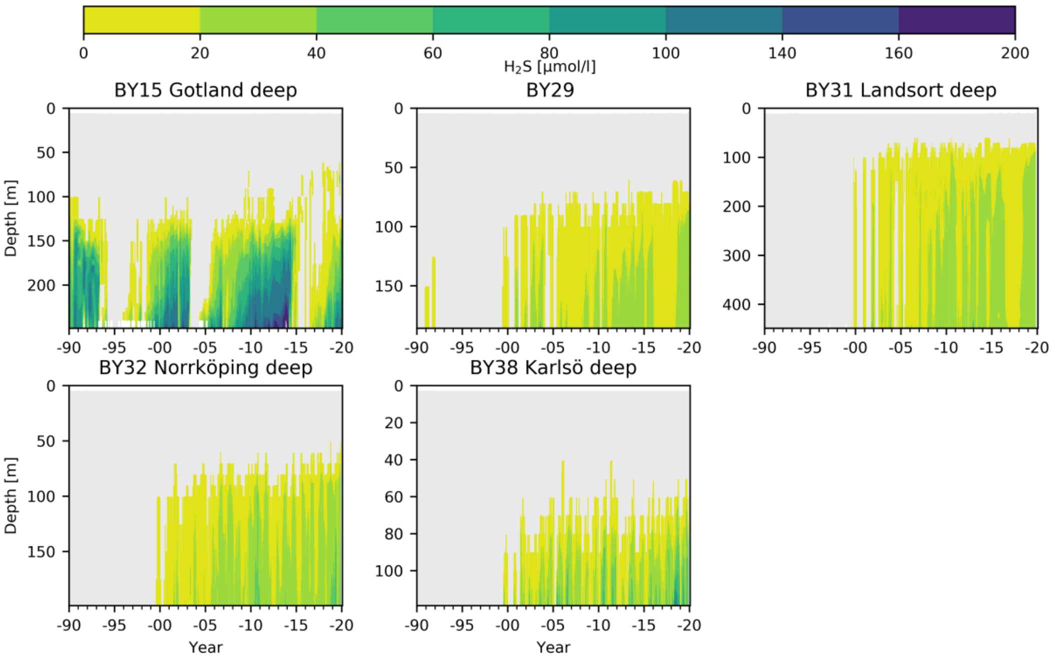

Figure 31. Hydrogen sulphide concentration at five stations in the Baltic Proper showing the development since 1990. The colourbar shows hydrogen sulphide concentration in µmol/l from zero (yellow) to 200 (dark blue). Highest concentration in the Eastern Gotland Basin and largest change in the Northern Baltic Proper and the Western Gotland Basin.

The winter mean surface concentration of oxygen show decreasing trends in the Skagerrak, the Baltic Proper and the Bothnian Bay. Since surface waters are well mixed during winter and gases are readily exchanged with the atmosphere the decreasing trend in surface winter oxygen is more likely to be related to increased temperatures than increased production of organic matter and the degradation of it.

4.5.1.4 Nutrients

The trends for total nitrogen and dissolved inorganic nitrogen in winter surface waters differ. In dissolved inorganic nitrogen the significant trends are decreasing and seen mostly in the post-1994 time series while there are significant increasing trends for total nitrogen in the long time series (Figure 32).

There is a decrease in dissolved inorganic nitrogen in winter surface waters in the post-1994 time series in the Skagerrak, the Kattegat, the Arkona Basin, the Bornholm Basin, the Western Gotland Basin and the Bothnian Bay. The decrease rate is higher in the Skagerrak and the Kattegat compared to the Baltic Proper and the Gulf of Bothnia. The only basin with an increasing trend in dissolved inorganic nitrogen in winter surface waters is the Northern Baltic Proper (0.22 µmol/l per decade in the long time series). In the Eastern Gotland Basin and the Bothnian Bay there is no significant trend. For total nitrogen, on the other hand, there is an increasing trend in the long time series in the basins of the Baltic Proper (0.82-1.36 µmol/l per decade) but no significant trend in the short time series.

In the Kattegat and the Skagerrak, in opposite to the Baltic Proper, the trend in total nitrogen follow the trend in dissolved inorganic nitrogen in the surface water in both the long and the post-1994 time series.

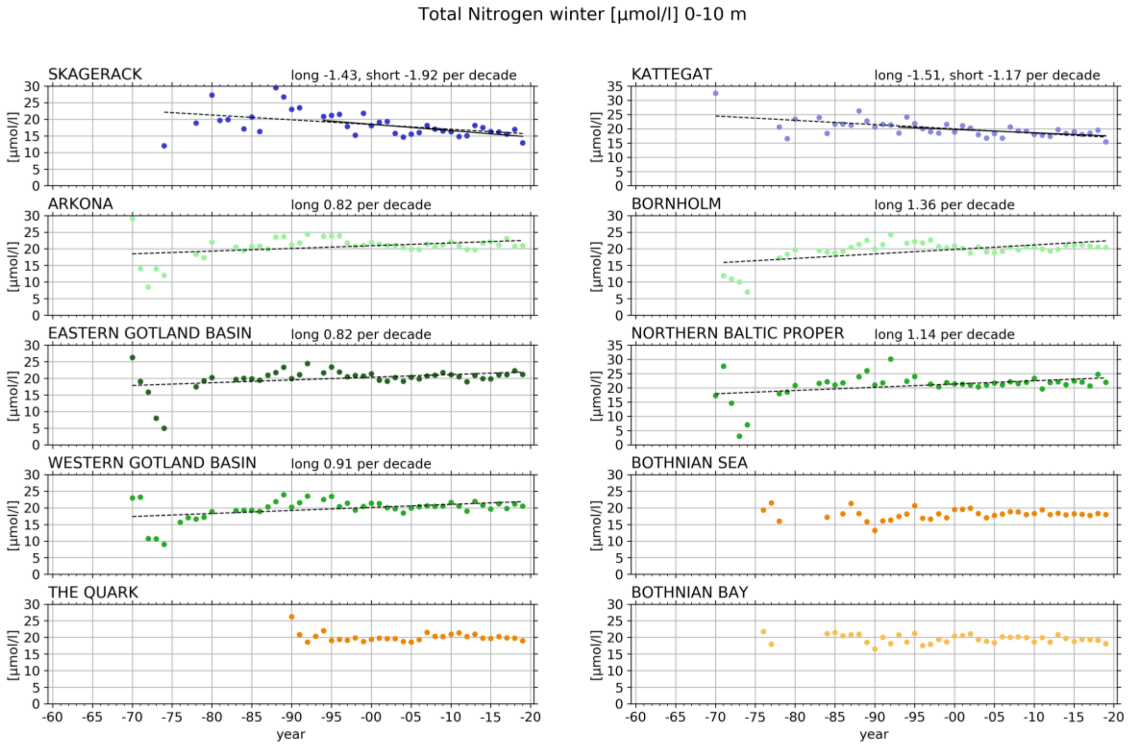

Figure 32. Winter mean concentration of total nitrogen in the surface water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

It is evident that the total phosphorus as well as phosphate concentration in the Baltic Sea is increasing, with significant trends for surface winter concentrations in all basins in both the long and the short time series (total phosphorus in Figure 33 and phosphate in Appendix III). Only in the Bothnian Bay is there no significant trend in the long time series. Moreover, the increase is faster during the post-1994 period than during the long period in most basins.

In the bottom water there are fewer significant trends compared to the surface water (Figure 34). There is an increasing trend in the Quark, the Bothnian Sea and the Western Gotland Basin and in the Arkona Basin. In the Arkona Basin and the Bothnian Bay the trend is only significant for the post-1994 time series and for the Western Gotland Basin only for the long time series. The reason that only the Western Gotland Basin of all the deep basins in the Baltic Proper shows a trend is probably because it is less influenced by inflows. By the time the inflowing water reaches the Western Gotland Basin phosphorus has been mixed into the water mass to the extent that the inflow leaves only a small fingerprint on the phosphorus concentration in this basin. In the bottom waters the largest increase rate is in the Bothnian Sea with an increase of 0.33 µmol/l per decade in the bottom water. This means roughly a doubling of the concentration from 2000 to 2019.

Trends for phosphate (not shown here but included in Appendix III) are similar to total phosphorus, increasing in the Gulf of Bothnia and in the northern and western basins of the Baltic Proper. For phosphate there is also a significant decreasing trend in the surface waters of the Skagerrak that cannot be seen in total phosphorus.

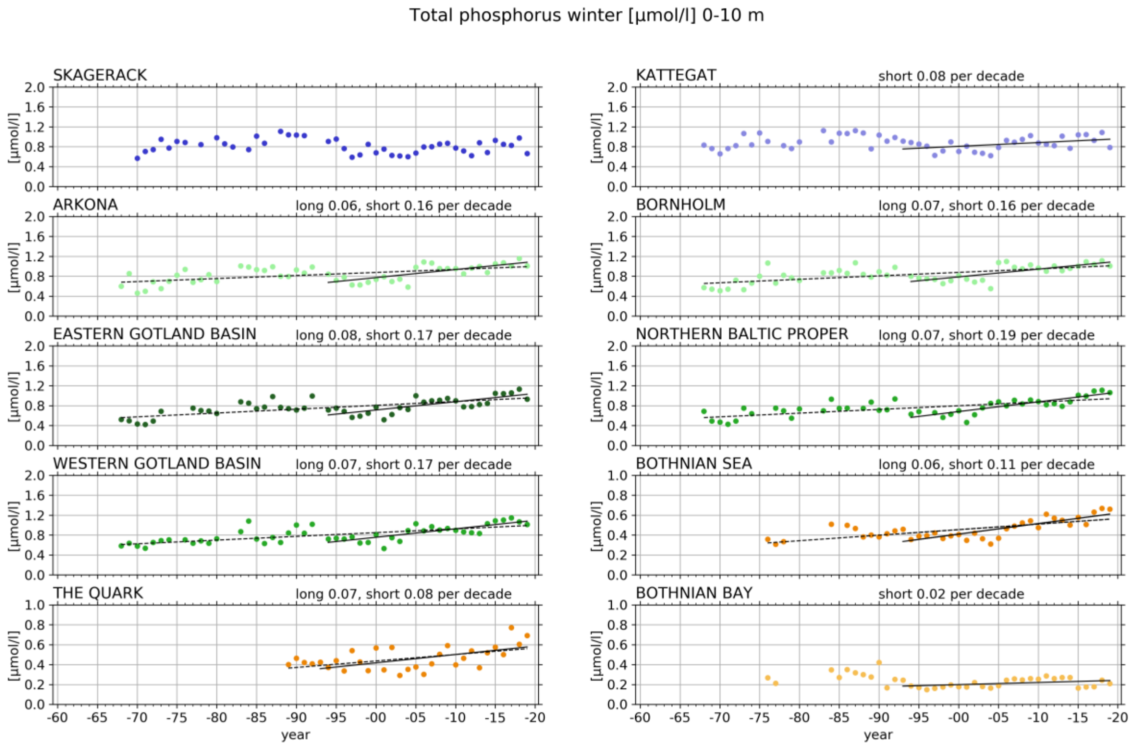

Figure 33. Winter mean concentration of total phosphorus in the surface water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

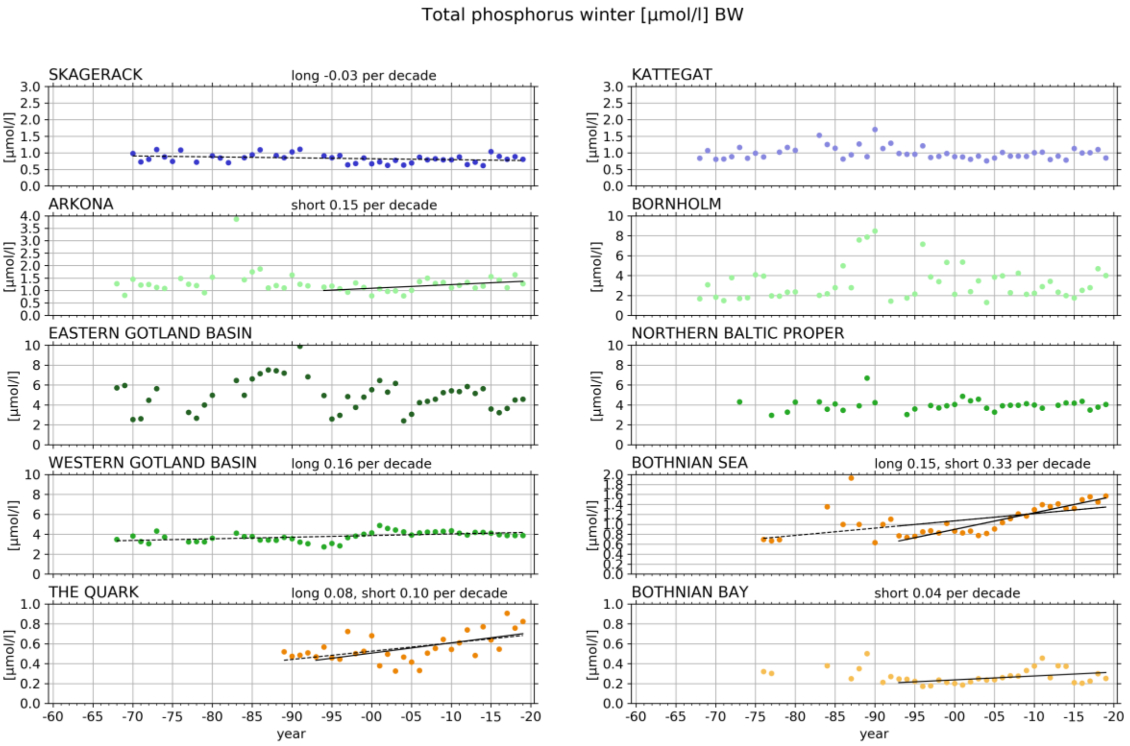

Figure 34. Winter mean concentration of total phosphorus in the bottom water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

The trends for the post-1994 period for silica are similar to those for phosphorus, with increasing concentration in the surface waters of the Baltic Proper and the Gulf of Bothnia (Figure 35). The difference to phosphorus is that there is no increase for the long period and in Arkona there is a significant decrease for the long period in the surface waters. There are no trends in silicate in the surface waters of the Skagerrak and the Kattegat.

In the Gulf of Bothnia there is an increase in silicate concentration in the bottom waters, just as in the surface waters (Figure 36), the increase in largest in the Bothnian Sea. In the Baltic Proper, the trends in the bottom water for silicate differ from those for phosphorus, with a decreasing trend for the long period and an increasing trend for the post-1994 period. The Northern Baltic Proper and the Western Gotland Basin show an increase for the post-1994 time series of 3.34 and 5.30 µmol/l per decade, respectively. For the long period there is a significant decrease in all Baltic Proper basins except Bornholm, this decrease is largest in the Eastern Gotland basin with 4.18 µmol/l per decade and smallest in Arkona with 1.41 µmol/l per decade.

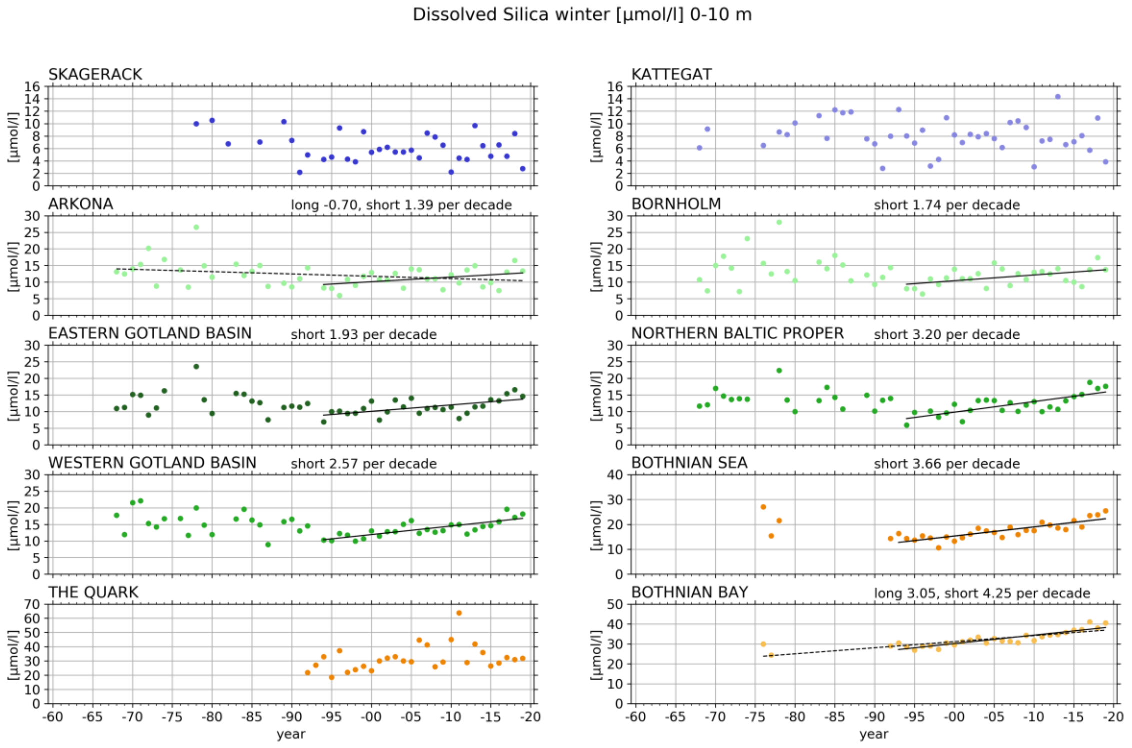

Figure 35. Winter mean concentration of dissolved silica in the surface water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

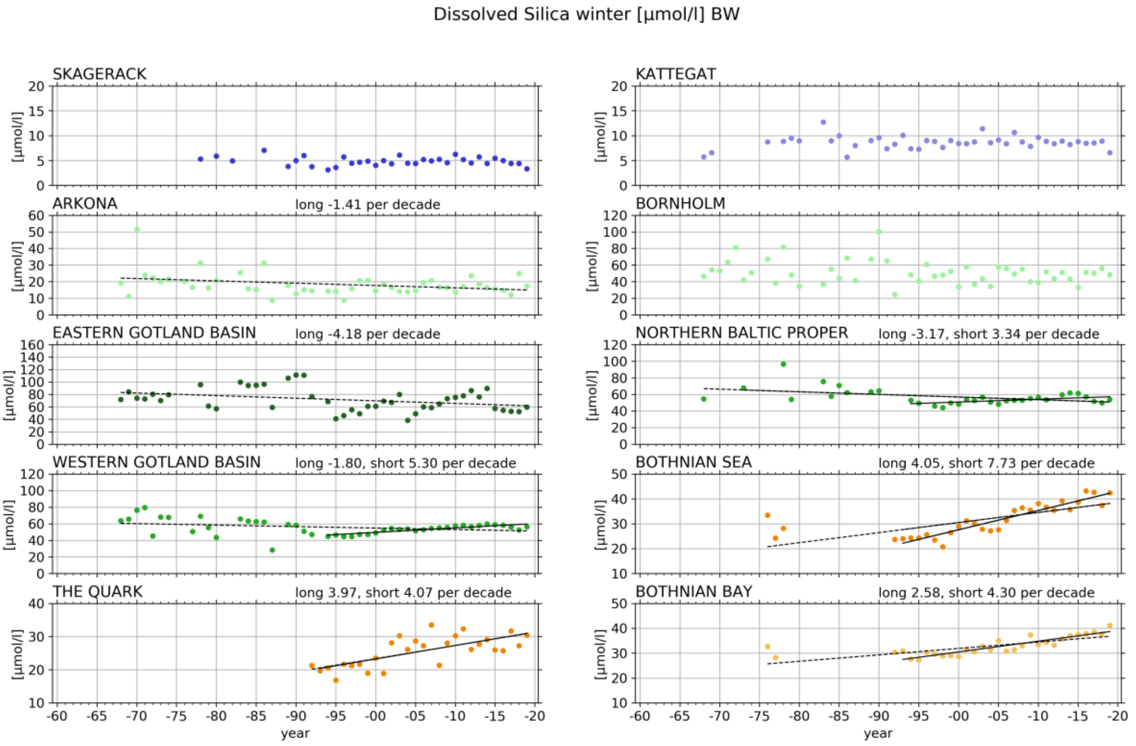

Figure 36. Winter mean concentration of dissolved silica in the bottom water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series.

4.5.1.5 pH and Alkalinity

The pH data are very variable prior to the revision of the monitoring programme in 1994 and should be interpreted with care. The method for measuring pH is primarily suitable for fresh water and less so for sea water samples with higher ionic strength (as described in 4.1.3 pH and alkalinity). Data on pH should therefore be used with care.

Only Kattegat showed significant trends in the long period, however the reliability of this result depends on the data which seems to have a higher variability before 1994 (Figure 37). Data are too scarce for analysis in the Skagerrak and no trends were calculated there. Winter surface water pH decreased by 0.003 pH units per year in Kattegat during the long period (Figure 37). Kattegat is connected to the North Sea and the Kattegat trend is close to the observed trend of an atmospheric CO_2 driven decrease of 0.002 pH units per year in the North east Atlantic's surface waters (Olafsson et al. 2009[9]). Post-1994 there is a significant negative trend in the Western Gotland Basin and a positive trend in the Quark. Bottom waters shows significant negative trends Skagerrak, Kattegat, the Bornholm Basin, Western Gotland Basin, and the Gulf of Bothnia.

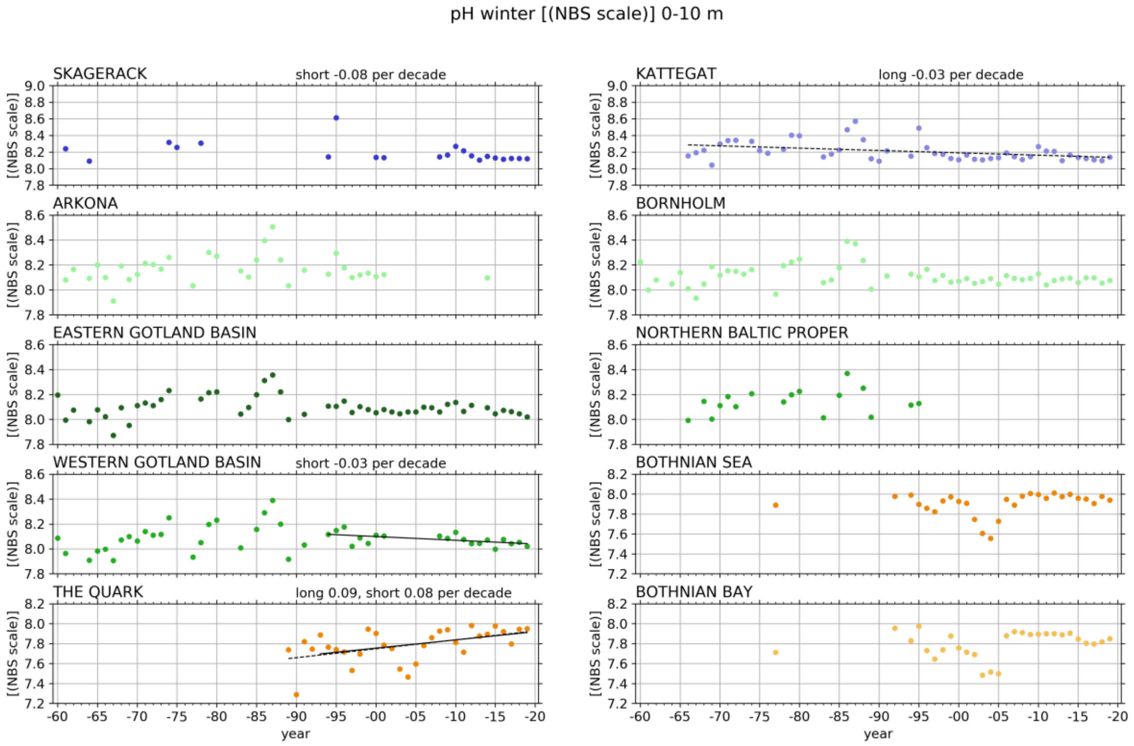

Figure 37. Winter mean pH in the surface water, the Skagerrak and the Kattegat in blue, the Baltic Proper in green and the Gulf of Bothnia in orange. A line is shown when the p-value of the slope is ≤0.05, dashed line are shown for the longer time series. No trend was calculated for the Skagerrak due to little and unreliable data.

Alkalinity has been measured since 1993. For winter surface waters, alkalinity shows increasing trends in the Baltic Proper and the Bothnian Sea. Alkalinity is unchanged in the Kattegat, Skagerrak and the Bothnian Bay, whereas there are no data in the Quark. Similar trends are detected for winter bottom waters in the Baltic Proper. Arkona show a significant negative trend but the data are scarce and interpretations should be careful.

4.5.2 Content of nutrients in the Baltic Proper basins

In Appendix III 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 1960-2019 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 an effect of higher concentrations in the surface waters which 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. The last three years show a tendency towards decreasing phosphorus content in the Eastern Gotland Basin, but it is still too early to determine if it is a persistent or temporary decline, see Figure 38, and the trend for total phosphorus in the surface water is increasing in the post-1994 time series presented above in Figure 33. The nitrogen content decreased from 1994 to the beginning of the 21st century (Figure 38). The drop in dissolved inorganic nitrogen is most drastic in the Western Gotland Basin for the sub-basins around stations BY31 and BY32 (Appendix III). The decrease in nitrogen content is most likely due to decreased loading of nitrogen from land while the absence of a decrease in phosphorus is explained by recycling of phosphate from sediment and decreased burial capacity of phosphorus in anoxic sediment. With continued efforts to reduce phosphorus and nitrogen loading the content should also decrease in the future.

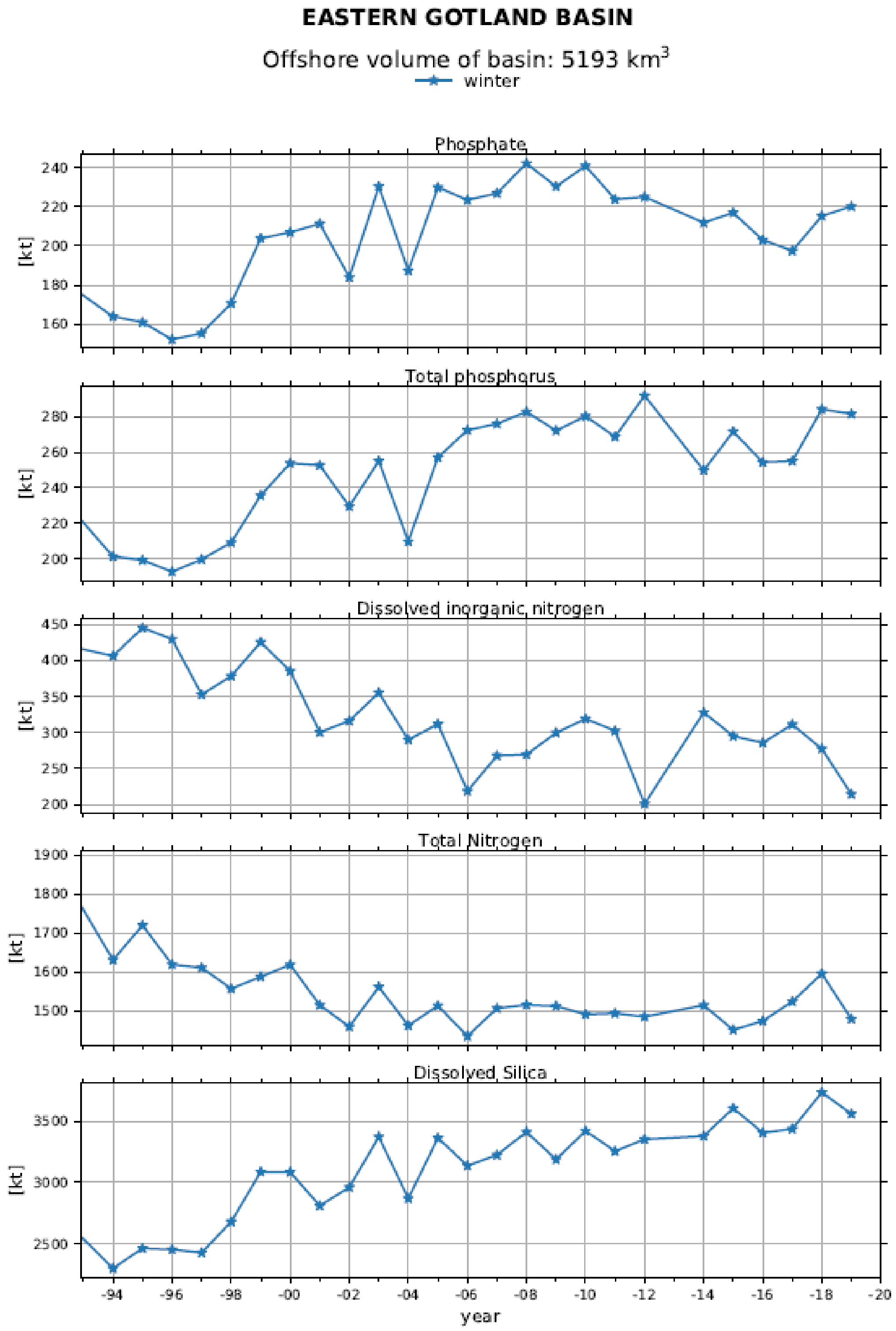

Figure 38. Calculated content of nutrients in the Eastern Gotland Basin, 1994-2019. From top to bottom, phosphate; total phosphorus; dissolved inorganic nitrogen; total nitrogen; dissolved silica. Content was calculated from interpolated profiles of nutrients.

Dissolved silica shows an increase from 1994 and continues to increase in all basins. The increase is most pronounced in the Eastern Gotland Basin. The cause of this increase is not evident but the cause is likely different between the Baltic Proper and the Gulf of Bothnia.

In the Gulf of Bothnia there is less data for this analysis. In the Bothnian Sea there is an increase in winter phosphate as well as an increase in total phosphorus content. Also there is an indication of increasing content of dissolved silica in the Bothnian Sea. Increased phosphorus and silicate concentrations can also be seen in the time series in Appendix III and are described above in section 4.5.1.4 Nutrients

When comparing the content between the basins the most striking pattern is the difference in dissolved inorganic nitrogen and phosphate content between the Eastern Gotland Basin and the Bothnian Bay. These two areas are similar in size and dissolved inorganic nitrogen content, but the Eastern Gotland Basin contains nearly twice the amount of phosphorus in comparison to the Bothnian Sea.

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ISSN 0283-1112