SMHI

REPORT OCEANOGRAPHY No. 66 2019

The Swedish National Marine Monitoring Programme 2018

Hydrography

Nutrients

Phytoplankton

Front.
The image illustrates salinity profiles from all CTD-observations made by SMHI during 2018. Image is made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019).

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Karin Wesslander, Lena Viktorsson and Ann-Turi Skjevik

Swedish Meteorological and Hydrological Institute

Contractor / Utförare	Contact / Kontakt
SMHI 601 76 Norrköping	Lena Viktorsson 031-751 8996 lena.viktorsson@smhi.se
Client / Kund	**Contact / Kontakt**
Havs- och vattenmyndigheten Box 11 930 404 39 Göteborg	Karl Norling 010-698 61 38 karl.norling@havochvatten.se

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Author / Författare

Karin Wesslander, Lena Viktorsson and Ann-Turi Skjevik (SMHI)

Control / Granskare

Martin Hansson och Maria Karlberg (SMHI)

Summary

This report presents the main results of the Swedish national marine monitoring programme of the pelagic during 2018. The monitoring data of hydrography, nutrients and phytoplankton are analysed for the seas surrounding Sweden: the Skagerrak, the Kattegat, the Sound, the Baltic Proper, the Bothnian Sea and the Bothnian Bay.

The national environmental monitoring of the pelagic is carried out by SMHI (Swedish Meteorological and Hydrological Institute), Stockholm University and UMF (Umeå Marine Sciences Centre). Data is collected, analysed and reported with support from Swedish environmental monitoring and on behalf of by SwAM (Swedish Agency for Marine and Water Management). The SMHI monitoring is made in cooperation between the national environmental monitoring of the pelagic and the SMHI oceanographic sampling programme for the seas surrounding Sweden and is co-financed by SwAM and SMHI. This annual summary of the national monitoring is made by SMHI and is financed by the contract between SwAM and SMHI.

The weather in 2018 was characterized by high air temperatures and a few storms that implied consequences for the state in the sea. The spring arrived quickly and the sea surface temperature increased rapidly from April to May. In August and September two storms, named Johanne and Knud, passed the region and the surface layer was well-mixed at several stations. At the East coast upwelling events were noted in both the Baltic Proper and the Bothnian Sea.

During the year there were two small deep water inflows to the Baltic Proper that temporarily improved the oxygen condition in the southern parts. No improvements of the oxygen condition were seen in the Eastern and Western Gotland Basins, instead the amount of hydrogen sulphide increased in these basins during the year.

The spring bloom had arrived in the Skagerrak and the Kattegat in March and concentrations of dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) were close to or at the detection limit from April to September. In the Skagerrak and the Kattegat the spring bloom was dominated by the diatom *Skeletonema marinoi.* In the Baltic Proper the spring bloom was observed a month later, in April. The extensive cyanobacteria bloom in the Baltic Proper started already in May and during the late September cruise cyanobacteria were still abundant. The dinoflagellate *Prorocentrum compressum* was found in high cell numbers during the autumn at all stations on the West coast. This flagellate has rarely been observed previously and although it is not harmful it is interesting when species suddenly occur and stay for a longer period. The potentially harmful diatom genus *Pseudo-nitzschia* bloomed in the beginning of December.

Surface concentrations of DIP and DIN were mainly normal except from in the Skagerrak and the Kattegat where concentrations were lower than usual in December. Concentrations of silicate were above normal levels before the spring bloom at most of the stations and in the Baltic Proper silicate was also high in the autumn.

In 2018 there were some difficulties with available research vessels for the planned cruises and some cruises needed to be cancelled with short notice. Many planned observations were therefore missed, in particular during the summer period.

Sammanfattning

Den här rapporten sammanfattar de huvudsakliga resultaten av det svenska nationella marina övervakningsprogrammet av pelagialen under 2018. Resultat från mätningar av hydrografi, näringsämnen och växtplankton diskuteras för haven runt Sverige; Skagerrak, Kattegatt, Öresund, Egentliga Östersjön, Bottenhavet och Bottenviken. Den nationella miljöövervakningen inom delprogrammet fria vattenmassan utförs av SMHI (Sveriges meteorologiska och hydrologiska institut), Stockholms Universitet och UMF (Umeå marina forskningscentrum). Data är insamlade, analyserade och rapporterade med stöd från svensk miljöövervakning och på uppdrag av HaV (Havs- och vattenmyndigheten). SMHIs övervakningsprogram sker genom ett samarbete mellan den nationella miljöövervakningen inom delprogrammet fria vattenmassan och SMHIs oceanografiska mätprogram för övervakning av haven runt Sverige och samfinansieras av HaV och SMHI. Denna årliga sammanställning av den nationella miljöövervakningen görs av SMHI i en rapport som finansieras genom avtalet mellan HaV och SMHI.

Vädret under 2018 präglades av hög värme och ett par stormar som fick konsekvenser för tillståndet i havet. Våren kom snabbt och havsvattentemperaturen ökade mycket mellan april och maj. I augusti och september drog två stormar förbi, benämnda Johanne och Knud, och ytlagret blev på flera håll väl omblandat. På östkusten noterades uppvällning både längs med kusten i Egentliga Östersjön och i Bottenhavet.

Under året var det två mindre djupvatteninflöden till Östersjön och dessa förbättrade syresituationen temporärt i de sydligaste delarna. Ingen förbättring av syresituationen noterades i Östra- och Västra Gotlandsbassängen och istället ökade mängden svavelväte i dessa bassänger under året.

I mars var vårblomningen igång i Skagerrak och Kattegatt, och koncentrationerna av fosfat och löst oorganiskt kväve var nära eller på detektionsgränsen från april till september. I Skagerrak och Kattegatt dominerades vårblomningen av kiselalgen *Skeletonema marinoi.* I Östersjön startade vårblomningen i april. Den omfattande blomningen av cyanobakterier i Östersjön var igång redan i maj och var fortfarande pågående under expeditionen i andra halvan av september. Under hösten observerades dinoflagellaten *Prorocentrum compressum* i höga cellantal vid alla stationer på Västkusten. Den här flagellaten är sällsynt och även om den inte är skadlig så är det intressant när en art plötsligt dyker upp och stannar under en längre period. Det potentiellt skadliga kiselalgsläktet *Pseudo-nitzschia* blommade i början av december.

Koncentrationerna av fosfat och löst oorganiskt kväve i ytvattnet var i huvudsak normala förutom i Skagerrak och Kattegatt där de var lägre än normalt i december. Koncentrationerna av kisel var högre än normalt före vårblomningen vid de flesta stationerna och i Östersjön var de även höga under hösten.

Under 2018 var det en del svårigheter med tillgängliga fartyg för expeditionerna och några expeditioner behövde ställas in. Många planerade observationer uteblev därför, speciellt under sommarperioden.

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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. In Sweden there are national environmental goals, EU legislation and commitments to the sea conventions OSPAR and HELCOM to consider. The Swedish agency for marine and water management (SwAM) is responsible for the marine monitoring programme of the pelagic and there are three institutes that implement the main parts of the monitoring; Swedish Meteorological and Hydrological Institute (SMHI), Stockholm University and Umeå Marine Sciences Centre. 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 2018. The report summarizes and presents data from the national marine monitoring of the pelagic with the aim to describe the general environmental conditions in Swedish waters the past year and show deviations from the normal situation. All data that are used in the report is quality controlled, open access and available at the national data host (SMHI). To download the data visit https://sharkweb.smhi.se or http://sharkdata.se/about/.

The main parameters discussed in this report are salinity, temperature, oxygen, DIP (dissolved inorganic phosphorus), DIN (dissolved inorganic nitrogen), dissolved silica and phytoplankton. The data are presented in Appendix I as seasonal cycles of the surface water (0-10 m). In Appendix II longer time series for surface waters (0-10 m) and bottom waters of the parameters above, as well as total phosphorus, total nitrogen and chlorophyll are also presented. Content of total and inorganic nutrients are calculated for all basins in the Baltic Proper, as well as the Bothnian Sea and the Bothnian Bay and are presented in Appendix III. Transects of CTD-observations of salinity, temperature, oxygen and density from the Skagerrak to the Western Gotland Basin are presented in Appendix IV. Other parameters also included in the marine monitoring programme of the pelagic, but not presented here, are Secchi depth, zooplankton, humus, primary production, pH and alkalinity.

1.1 The monitoring programme

1.1.1 Performance in 2018 and description of the current programme

The pelagic marine monitoring programme 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) and six of the standard stations (red) are visited every other week. The pool of winter nutrients in the surface layer (light blue) and oxygen during autumn (pink) is mapped once per year at additional stations. The number of visits at the standard stations during 2018 is presented in Figure 2.

[1] Link to HELCOM COMBINE manual

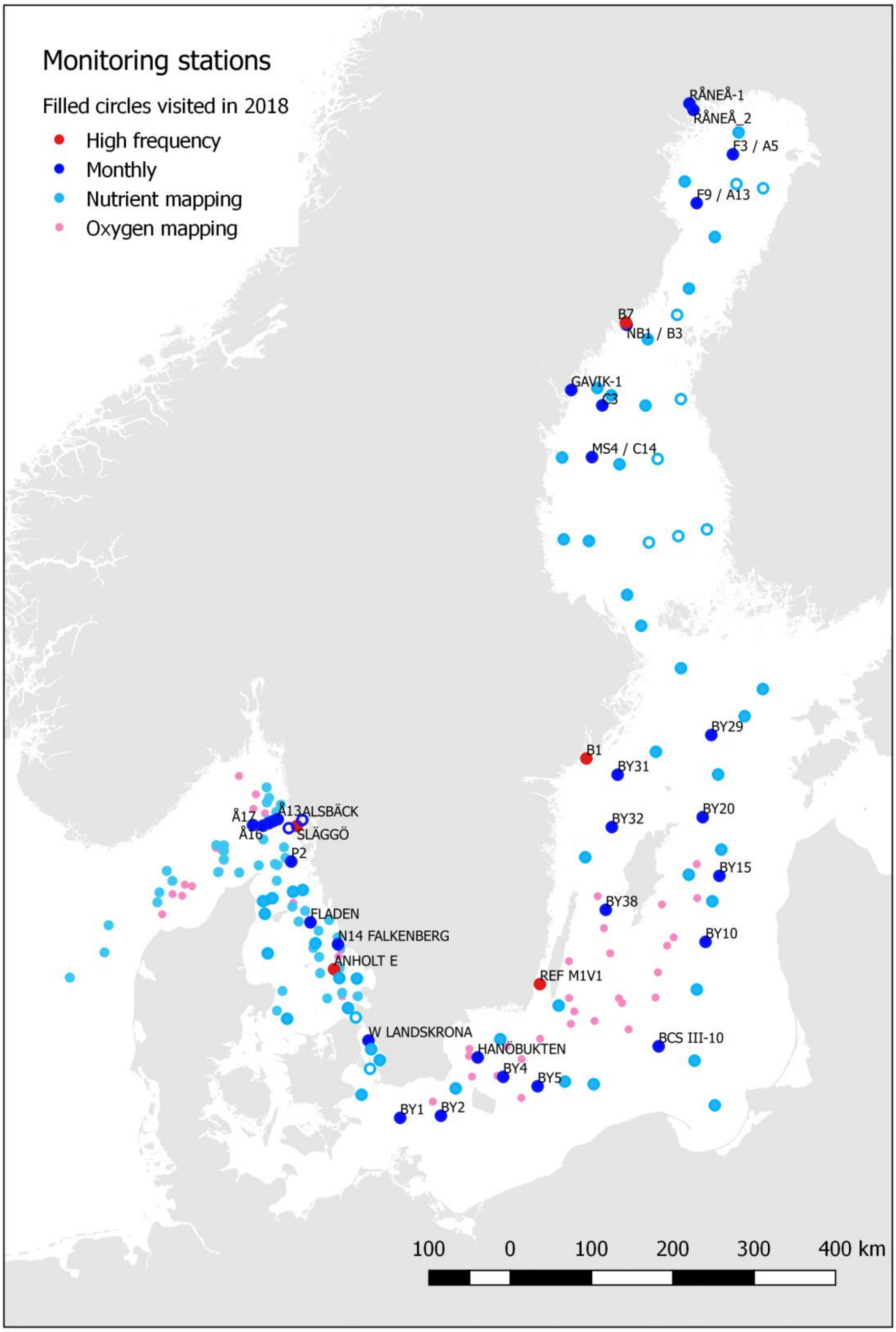


Figure 1 Map of the Swedish monitoring stations of the pelagic. Filled circles represent stations sampled in 2018, open circles represent stations that are included in the programme but were not sampled in 2018. Four types of stations are shown, high frequency sampling (red), monthly sampling (deep blue), winter nutrient mapping (light blue) and autumn oxygen mapping (pink).

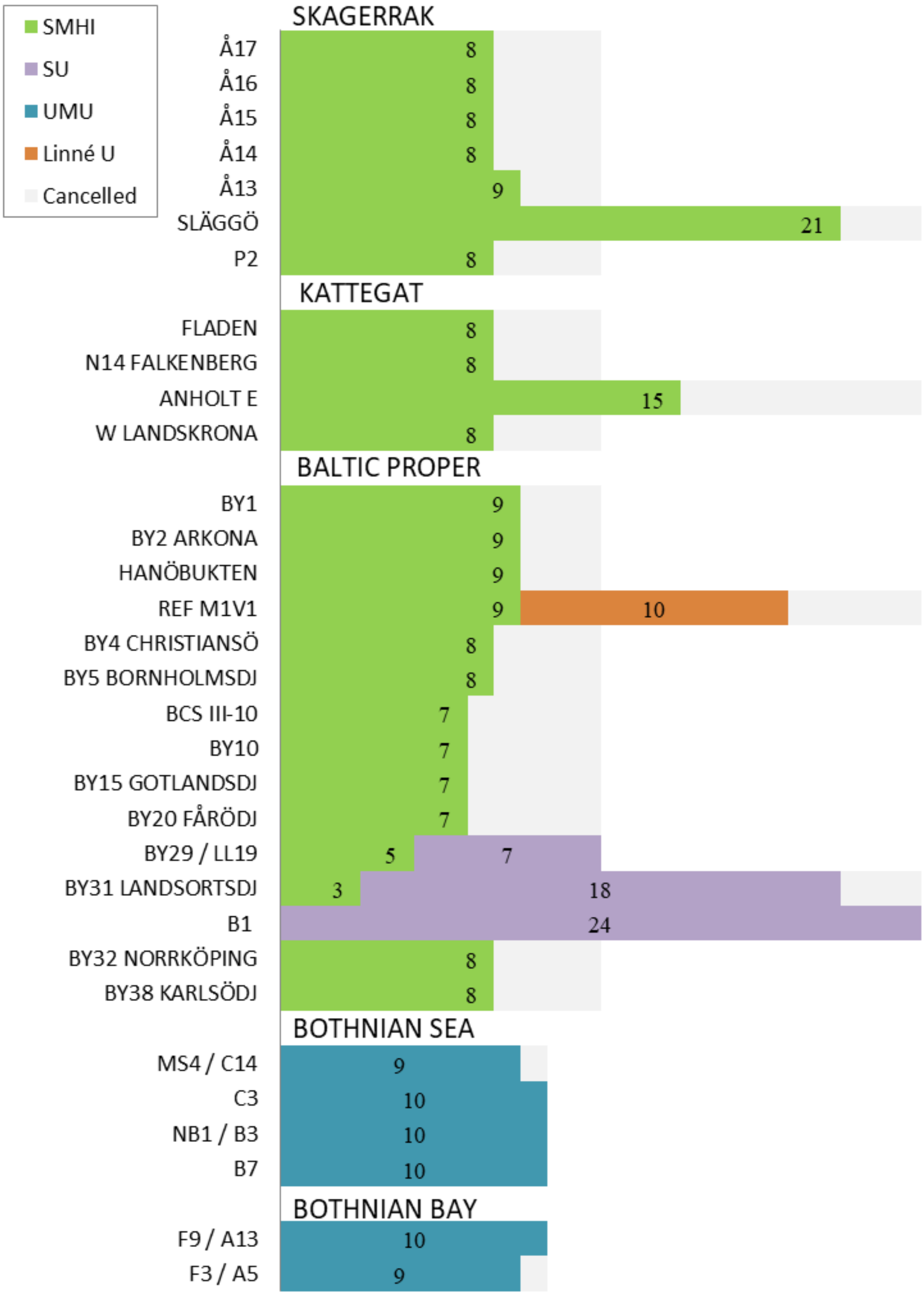


Figure 2 Stations sampled 2018; number of visits and sampling institute, the shadowed area shows cancelled visits.

SMHI has, since 2014, contracted the Finnish research vessel R/V Aranda for SMHI's monitoring purpose in the open sea. In August 2017, R/V Aranda was brought to the shipyard to be renovated and modernised and the plan was that she would be back in full function in the spring 2018. However, the delivery of R/V Aranda from the shipyard was delayed several times and the ship was not available for a full cruise for SMHI until October 2018. When R/V Aranda was at the shipyard, until May 2018, the SMHI cruises were made with the Finnish cargo ships M/V Meri and M/V Aura. These ships are not constructed for research, thus sampling work and analyses were made from specially designed laboratory containers placed on deck. Due to difficulties in working conditions and planning of cruises with the cargo ships many of the expeditions during spring had to be changed. The January and February cruises where combined into one cruise. Since R/V Aranda was meant to be ready for service in June, the working containers were removed from the cargo ships in May and plans were made to continue the expeditions from July with R/V Aranda. However, R/V Aranda was still at the shipyard in July and was not available for SMHI until September. An overview of the expeditions by SMHI 2018 is presented in Table 1 .

Table 1 Overview of the SMHI expeditions in 2018.

Expedition	Ship	Comment	dates
January		Cancelled	
January	U/F Dana	Mapping of nutrients in the Skagerrak and parts of the Kattegat	2018-01-17 - 2018-01-30
January-February	M/V Meri	Mapping of nutrients, the Baltic Sea and the Kattegat	2018-01-24 - 2018-02-04
March	M/V Meri	Partly cancelled due to icing and hard weather	2018-03-14 - 2018-03-20
April	M/V Aura	Regular	2018-04-15 - 2018-04-21
May	M/V Aura	Delayed	2018-05-26 - 2018-06-01
June		Cancelled	
July		Cancelled	
August		Cancelled	
August	U/F Dana	Oxygen mapping of the Kattegat	2018-08-20 - 2018-08-31
September	U/F Dana	Extra to replace parts of the planned August cruise with R/V Aranda	2018-09-02 - 2018-09-07
September	R/V Aranda	Partly cancelled	2018-09-20 - 2018-09-24
October	U/F Dana	Oxygen mapping of the Baltic Proper	2018-10-03 - 2018-10-13
October	Aranda	Regular	2018-10-14 - 2018-10-21
November	Aranda	Regular	2018-11-08 - 2018-11-15
December	Aranda	Regular	2018-12-04 - 2018-12-11

Stockholm University used M/S Fyrbyggaren and at some occasions R/V Electra for sampling at the open sea stations BY31 and BY29. The smaller vessels R/V Limanda and R/V Electra (in conditions with sea ice) were used for sampling at B1. Umeå Marine Sciences Centre used R/V Lotty, KBV181, R/V Botnica and Gråsuggan for their sampling. At some occasions Umeå Marine Sciences Centre also used a helicopter or a scooter for the sampling during winter when sea ice did not permit sampling from a ship. In 2018 Umeå Marine Sciences Centre was commissioned by SwAM to perform the winter mapping of nutrients in the Gulf of Bothnia since R/V Aranda was in the shipyard. The winter mapping cruise of the Gulf of Bothnia was performed in January and February 2018.

1.1.2 History of the monitoring programme

The current Swedish open sea monitoring programme has been in place since 1994, with only smaller changes. The focus of the current programme is eutrophication and oxygen deficiency, and has been since the end of the 1970’s. The programme has historically had focus on fishery hydrography, while plankton and chlorophyll has been added in the later years. The data from the Swedish open sea monitoring are used widely in research, as well as management. The data are among other purposes used for 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 monitoring programme, its station network and sampling frequency (Rahm et al 1991[4]). In 1992 an international panel was formed to make an evaluation of the Swedish monitoring programme and this panel recommended that the changes suggested by SMHI (SNV Report 4170[5]) should be made and the new monitoring programme was fully implemented in 1994. This led to a large change of the monitoring programme, mainly in the frequency of expeditions. It was decided to have a number of stations with monthly sampling in all sea areas and a few stations with high frequency monitoring (twice a month). The main aim of the high frequency stations is 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. The winter nutrient pool determines how large the phytoplankton production in spring and summer can become. Winter nutrient mapping is normally done in the Skagerrak and the Kattegat in January, in the Baltic Proper in February and in the Gulf of Bothnia it has been mostly in December. The nutrient mapping in the Skagerrak is done during the International Bottom Trawl Survey (IBTS) 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. For the oxygen mapping there are no fixed stations, instead stations vary from year to year and the sampling is performed in combination with cruises led by Swedish University of Agricultural Sciences (SLU). The oxygen mapping in the Baltic Sea is done during the Swedish Baltic Sea Information on the Acoustic Soundscape (BIAS) and the mapping in the Kattegat is done during the IBTS in the third quarter. The aim with the oxygen mapping is to monitor the part of the year with the most severe oxygen deficiency, with focus on the deep water. 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 oxygen data during the autumn is generally good. Good spatial resolution of oxygen data is essential for the calculations of the extent of anoxic and hypoxic bottoms in the Baltic Sea.

In recent years some coastal stations have been added to the programme. In 2007 two coastal stations were added to support the work associated to the EU Water Frame Work Directory, N14 Falkenberg and Ref M1V1. Two stations have been added on the west coast to monitor the gradient from the fjord Gullmaren to the open sea. The two new stations were 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 this type of gradient. The station H4 in Himmerfjärden together with B1 and BY31 represent a gradient there. In the Bothnian Sea two coastal stations have been added, 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.

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 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

[2] Link to WFD
[3] Link to MSFD
[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.

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 homogenous time series with data from this period, for example to make a trend analysis. In the deep basins of the Baltic Sea conditions are more stable than in the surface waters and for these areas data are easier to use for long time series analysis. Although the frequency still varied between 1-3 times per year the network of stations was roughly the same as today. At the end of the 1960's the 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 both oceanographic and biologic, including bottom fauna sampling.

1969-1970 was the International Baltic Year and this is when many of the stations were named BY. In 1978 the Programme for Environmental Control (Programmet för Miljökontroll PMK) was started and the following year HELCOM started its Baltic Monitoring Programme (BMP). The Swedish commitment in BMP 1979 included nutrients, oxygen, salinity and temperature and all countries around the Baltic Sea shared their data with each other. The programme continued until 1993 when it was revised as described above.

2 Weather situation 2018

The year of 2018 was a very warm and dry year. The mean air temperature in Sweden was above normal and in particular the summer was extremely warm. The mean precipitation was lower than normal in almost all parts of Sweden.

The year began with generally mild weather and the sea surface temperature in the central parts of all sea basins were 1-2 degrees above normal. At the end of January temperatures had decreased to, for the month, normal values. Several low pressures passed in January which gave high sea levels around the entire coast and also high waves. On both sides of Sweden significant wave heights of about 6 meters was observed. The first storm event for the year was named Cora and passed the northern parts of Sweden on the 7th of January.

From the middle of February and into March it was colder than normal in all of Sweden and the ice extent more than doubled in February. Together with the prevailing high pressure in the end of February the sea levels reached very low values. A sea level minima record was noted in Gothenburg at -87 cm which was the lowest sea level since 1976.

In March the northern parts of the Bothnian Sea, the Åland Sea, the Gulf of Finland and the Gulf of Riga were ice covered. The maximum ice extent was reached on the 5th of March with 175 000 km^2.

April began with a lot of precipitation and snow but at the end of the month the spring arrived and April was overall warmer than normal. The spring was considered to be very dry.

May was very warm and many temperature records were reached this month. The high air temperatures implied a rapid increase in the water temperatures in the surface layer, see Figure 3. May was also very dry, particular in the southern parts of Sweden. The ice season at sea ended 24th of May and it was considered normal regarding both time length and extent.

The high pressure system together with very low sea levels continued to prevail in spring and the summer was extremely warm in most parts of the Sweden. June was normal or cold in the northern parts but warm in the south. July was, just like May, an extreme month when considering high air temperatures and drought, with many forest fires. This situation continued in August. On the 10th of August the summer storm Johanne passed the West coast and thereafter temperatures were more normal in both air and sea.

The autumn was very mild and dry. The storm Knud passed the country on the 21st of September and a mean wind speed of 28 m/s was observed at Väderöarna on the West coast. The westerly winds resulted in upwelling events on especially the East coast of Sweden and colder water reached the sea surface. Knud also brought high waves and there was a new wave record at Väderöarna with a significant wave height of 8.5 m.

The ice season started in November with thin ice in the sheltered archipelagos in the northern parts of the Baltic Sea. The year ended with a month of several low pressure systems and fluctuating sea levels.

There were no major inflow events to the Baltic Sea during 2018 but two small inflows occurred during the autumn/winter. The first one was in mid-September (~40 km^3) and the next in the beginning of December (~30 km^3). The inflow in September oxygenated the whole Bornholm Basin, although with very low oxygen concentrations. A pulse of the September inflow was also found at 80 meters depth in the south-eastern Baltic Proper (BCSIII-10) in November and December.[6]

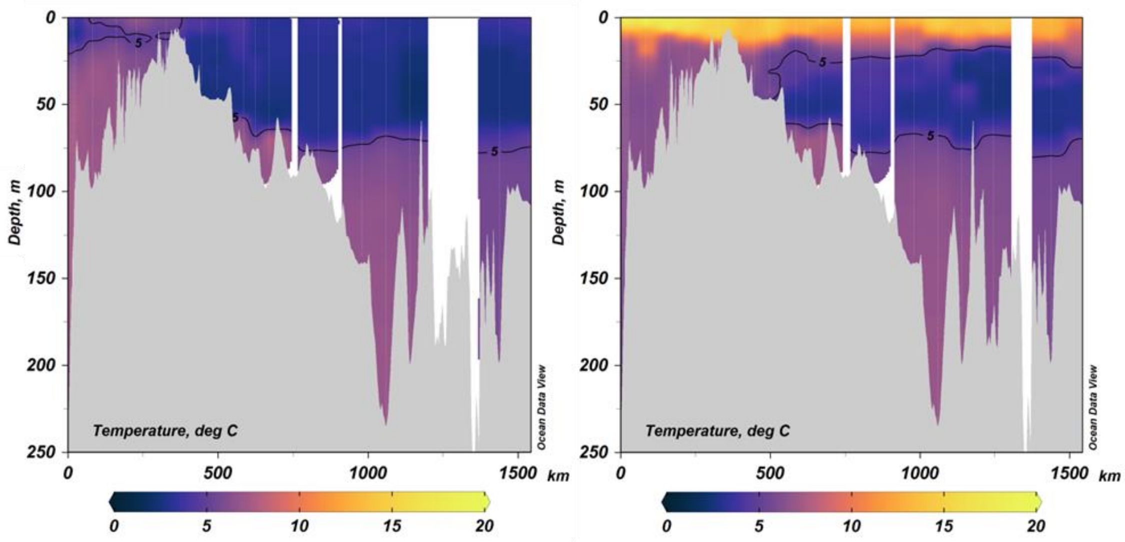


Figure 3 Transect from the Skagerrak (distance 0 km) to the Western Gotland Basin (distance 1500 km) presenting the water temperature in April (left) and May (right). Image is made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019).

3 Oceanographic conditions

The oceanographic conditions in the Swedish seas during 2018 are discussed in this section. Annual cycles of the surface water, 0-10 m, vertical sections from the Skagerrak to the Western Gotland Basin and time series 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, in the cruise reports available at SMHI publications[7].

The Swedish seas have large variations in especially salinity, which gives the seas their different characteristics (Figure 4). The Skagerrak on the West coast has almost open ocean salinities, with lower salinities closer to the coast due to the Baltic current bringing the outflowing Baltic water northward (blue colours in Figure 4). The Baltic Proper has typical fjord-like hydrography with a strong stratification separating the deep waters from the surface waters. This makes the Baltic Proper naturally sensitive to increases in nutrient input leading to oxygen deficiency. The Bothnian Sea is the freshest sea in Swedish waters (not included in Figure 4) and is still an oligotrophic sea with lower nutrient concentrations than the Baltic Proper.

[6] Hansson M., Viktorsson L., Andersson L., SMHI Rapport RO 65, 2018. *Oxygen Survey in the Baltic Sea 2018 - Extent of Anoxia and Hypoxia, 1960-2018*

[7] Link to cruise reports at SMHI.se

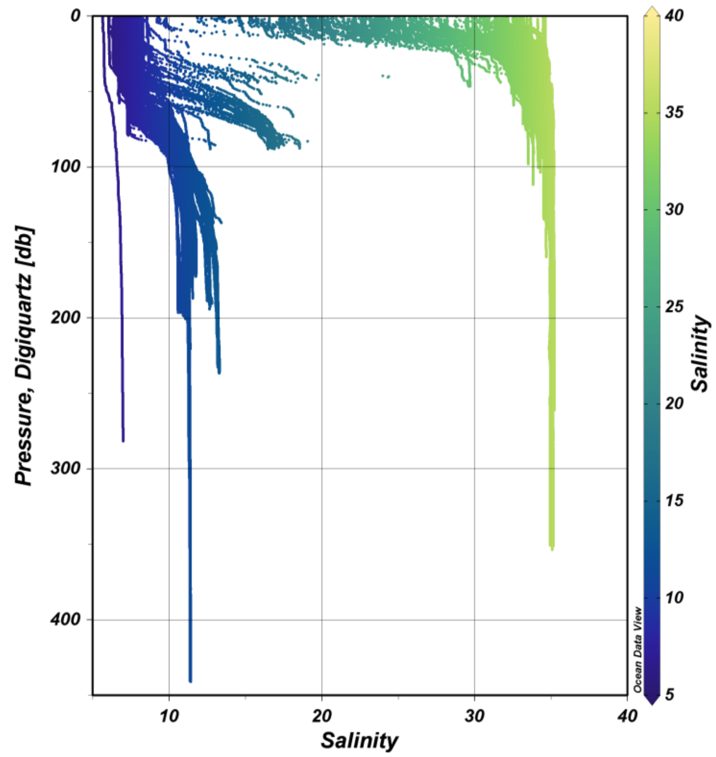


Figure 4 Salinity profiles from all CTD-observations made by SMHI in the Swedish national marine monitoring programme of the pelagic in 2018. The Gulf of Bothnia is not represented in this diagram. The colours are related to the salinity. Image is made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019).

In Figure 5 a selection of parameters are presented from one station in the Kattegat (Anholt E), the Baltic Proper (BY15), the Bothnian Sea (MS4/C14) and the Bothnian Bay (F3/A5) respectively to illustrate these highly variable sea areas around Sweden. Besides from the different salinities in the sea areas, already mentioned above, other parameters are also different between the areas. The concentration of DIP is for example much lower in the northern parts while the concentration of nitrate is higher. It is also visible in the chlorophyll concentrations that the spring bloom occurs in different time periods.

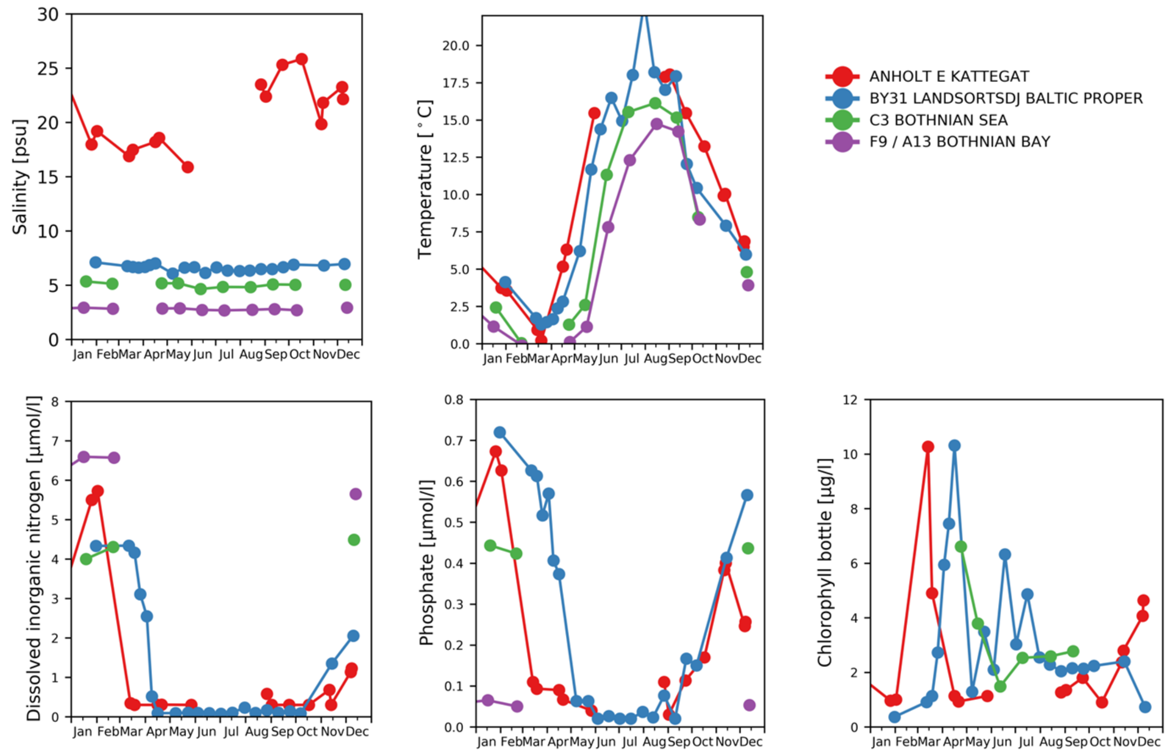


Figure 5 Concentrations in the surface water during 2018. Top panel from left to right: salinity, temperature (°C). Lower panel from left to right: DIN (µmol/l), DIP (µmol/l) and chlorophyll (mg/l). The stations are Anholt E in the Kattegat (red), BY31 in the Baltic Proper (blue), C3 in the Bothnian Sea (green) and F9/A13 in the Bothnian Bay (purple).

3.1 Skagerrak, Kattegat and the Sound

Despite the difficulties with vessels to perform the monitoring in 2018, the Skagerrak and the Kattegat were fairly well covered. No stations in the open sea were sampled in June and July and in August only six stations were visited (Släggö, Å13, P2, Fladen, Anholt E and N14 Falkenberg). These stations were visited during the 3rd quarter IBTS cruise at the end of August. Since the coastal station Släggö is sampled once a month by a smaller vessel there is data from Släggö from all months, but with one visit instead of two in January, June and July. In the Kattegat the monthly stations were sampled in 9 of the 12 months, with no samples in June and July. W Landskrona in the Sound had only 8 visits, missing all the summer months June-August.

3.1.1 Temperature & Salinity

In the surface water (0-10 m) the temperature was below normal at all stations in the Skagerrak in March and April to rapidly increase as the spring quickly arrived in May. This resulted in temperatures above normal at all stations in May, except at the most westerly station Å17 where temperatures were close to the 15-year average (period 2001-2015) (Figure 6). In the Kattegat the temperature started to rise a little earlier and resulted in normal temperatures in April, but otherwise the pattern was the same as in the Skagerrak with colder than normal in March and warmer than normal in May.

The rapid increase in temperature was very clear at Släggö, at the sampling on May 3rd the temperature was 8 °C and on May 26th the temperature was 18 °C at 0 m. Släggö was also the only station that was visited during the summer months and the surface temperature (0-10 m) was above normal in June (7th) and August (7th), but not in July and the end of August (Figure 6).

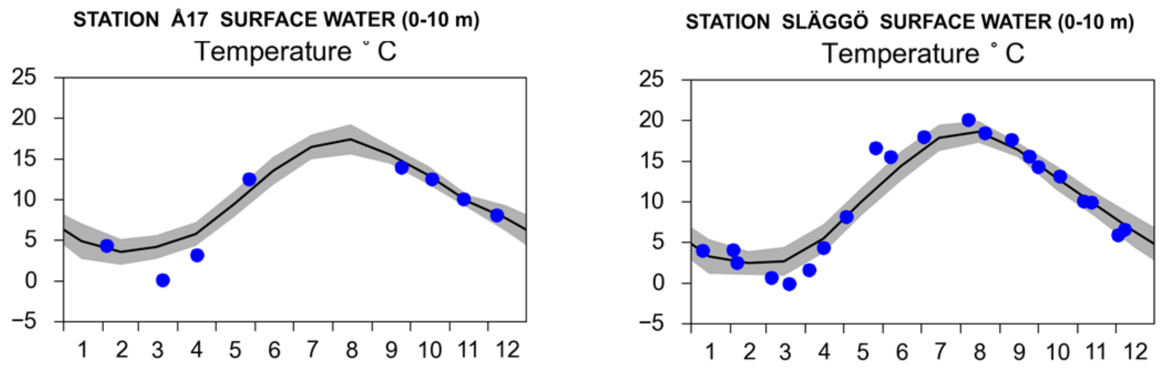


Figure 6 Surface temperature (0-10 m) from January-December at stations Å17 (left) and Släggö (right) in 2018.

The surface salinity was lower in the beginning of the year and higher at the end. This was especially clear for the Å-transect where both Å15 and Å17 had salinities below normal in March and April. In the Skagerrak the water was strongly stratified in March and April with salinities of just above 25 down to 10-15 m which then increased to 35 below the halocline. From September to the end of the year the surface salinities were high, especially in the Kattegat.

From the end of August to October the salinity at both Anholt E and Fladen were well above normal. The high surface salinity was caused by strong winds, the storms Johanne in August and Knud in September, which mixed the water in the Kattegat bringing saltier water from deeper layers to the surface. This also resulted in a small inflow to the Baltic Sea in September. The storm Knud caused mixing of the water in the Kattegat which resulted in an increase in salinity and a decrease in temperature between the beginning of September and the end of September which was seen at Anholt E (Figure 7).

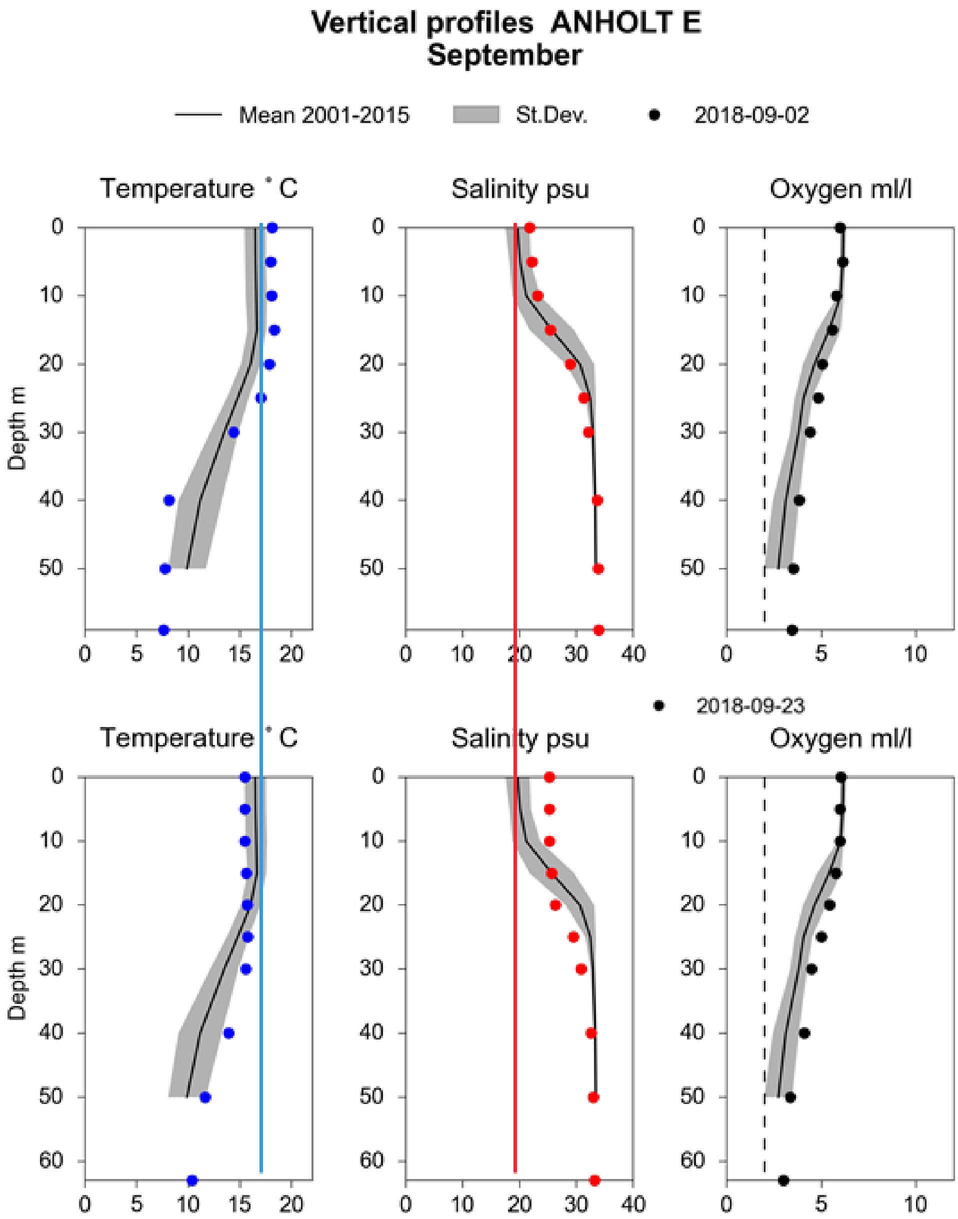


Figure 7 Profiles of temperature (blue), salinity (red) and oxygen (black) at station Anholt E in 2018. The top panel shows measurements from September 2nd and the bottom panel is from September 23rd. The storm Knud passed between the two occasions and mixed the water down to 20 m which caused higher salinity and lower temperatures in the surface water.

3.1.2 Nutrients

Surface nutrients in the Skagerrak and the Kattegat followed the normal seasonal variation with few occasions were the concentration of DIN and DIP were outside ±1 standard deviation of the 15-year mean. The highest concentrations for the year were noted in January-February with normal values for DIP and DIN at almost all stations. Silicate in the surface water was higher than normal in the winter before the spring bloom at all stations in the Kattegat and at most stations in the Skagerrak, while DIN and DIP were normal (see Figure 8 for example from Anholt E). The concentration of DIP and silicate generally decreased from the Sound to the Skagerrak while DIN increased towards the Skagerrak.

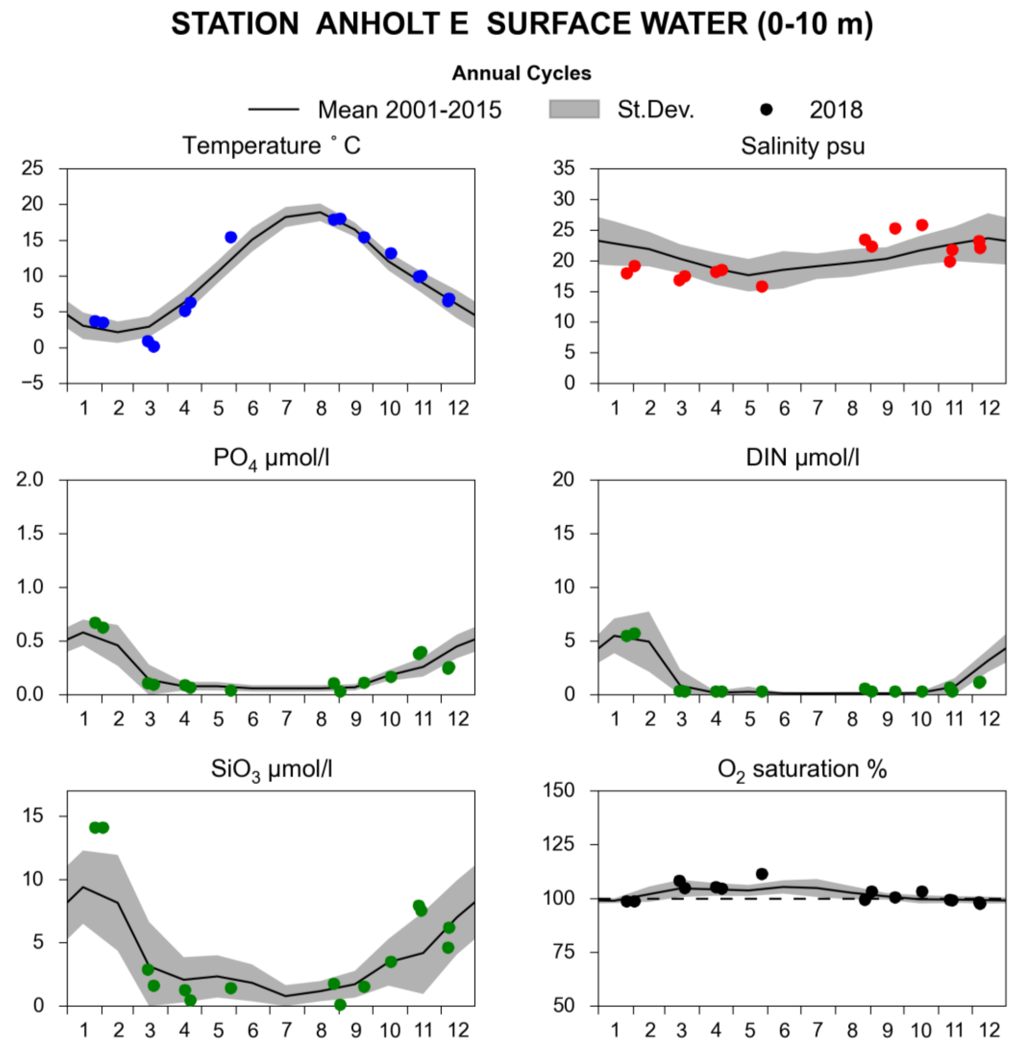


Figure 8 Temperature (blue), salinity (red) and oxygen (black) and nutrients (green), mean values from 0-10 m at stations Anholt E. Note the high silicate concentrations in January and February 2018.

The spring bloom had started in March and the inorganic nutrient concentrations were close to or at the detection level from April to September. There were also peaks in chlorophyll fluorescence in March which also indicates that the spring bloom was ongoing.

In the Sound however the concentrations of nutrients were still high and above normal at the measurement in March indicating that the spring bloom started later there, sometime between March and April. The high levels of nutrients indicate that there probably was water from Arkona flowing out from the Baltic Sea in March. There had been strong north-easterly winds for a few days and this could have caused mixing in Arkona and outflow of this water through the Sound (Figure 9).

No measurements were made in June and July, except at station Släggö, but the inorganic nutrient concentrations were still low at all stations at the visits in August, which is normal since primary production continues throughout the summer months. In September, DIP started to increase again while DIN started to increase a little later, in October. The increase halted during the autumn and in December surface nutrients were below normal at most stations in both the Skagerrak and the Kattegat.

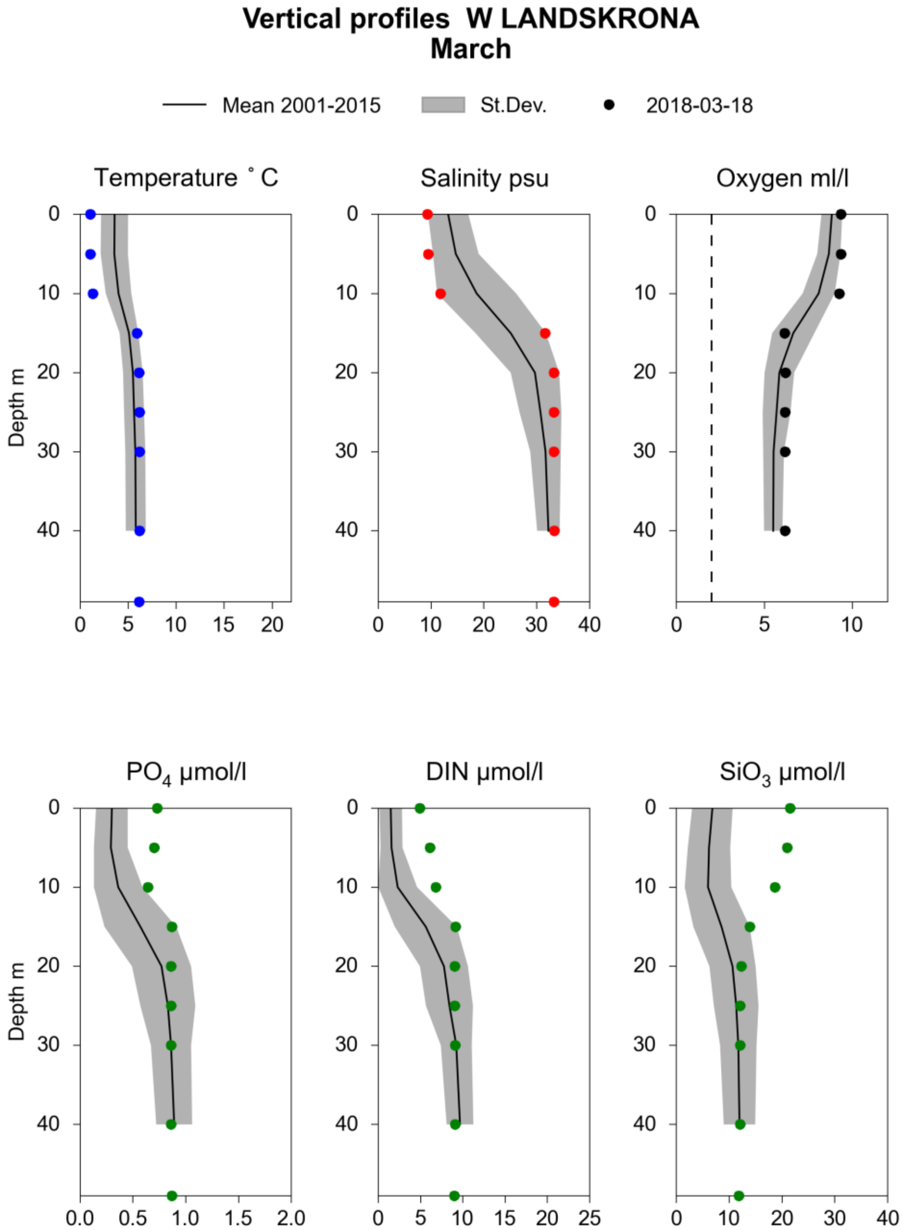


Figure 9 Profiles of temperature (blue), salinity (red) and oxygen (black) and nutrients (green) at stations W Landskrona in the Sound from March 18th 2018. Strong winds caused high outflow of water from the Arkona Basin which can be seen in the sharp stratification at 10 m, low salinities and high nutrients.

For most of the year nutrient concentrations in the deep water was within normal ranges. However, there were some elevated concentrations in the deep water during spring. In March and April concentrations of DIP and silicate in the deep water was higher than normal in the Skagerrak at Å13, P2 (Figure 10) and the coastal station Släggö (Figure 11). These elevated nutrient concentrations below the halocline are most likely caused by input from the spring bloom in the surface layer. At Släggö there was also a peak in inorganic nutrients at 30 m (March) and 20 m (April) together with minima in oxygen at the end of March and beginning of April (Figure 11).

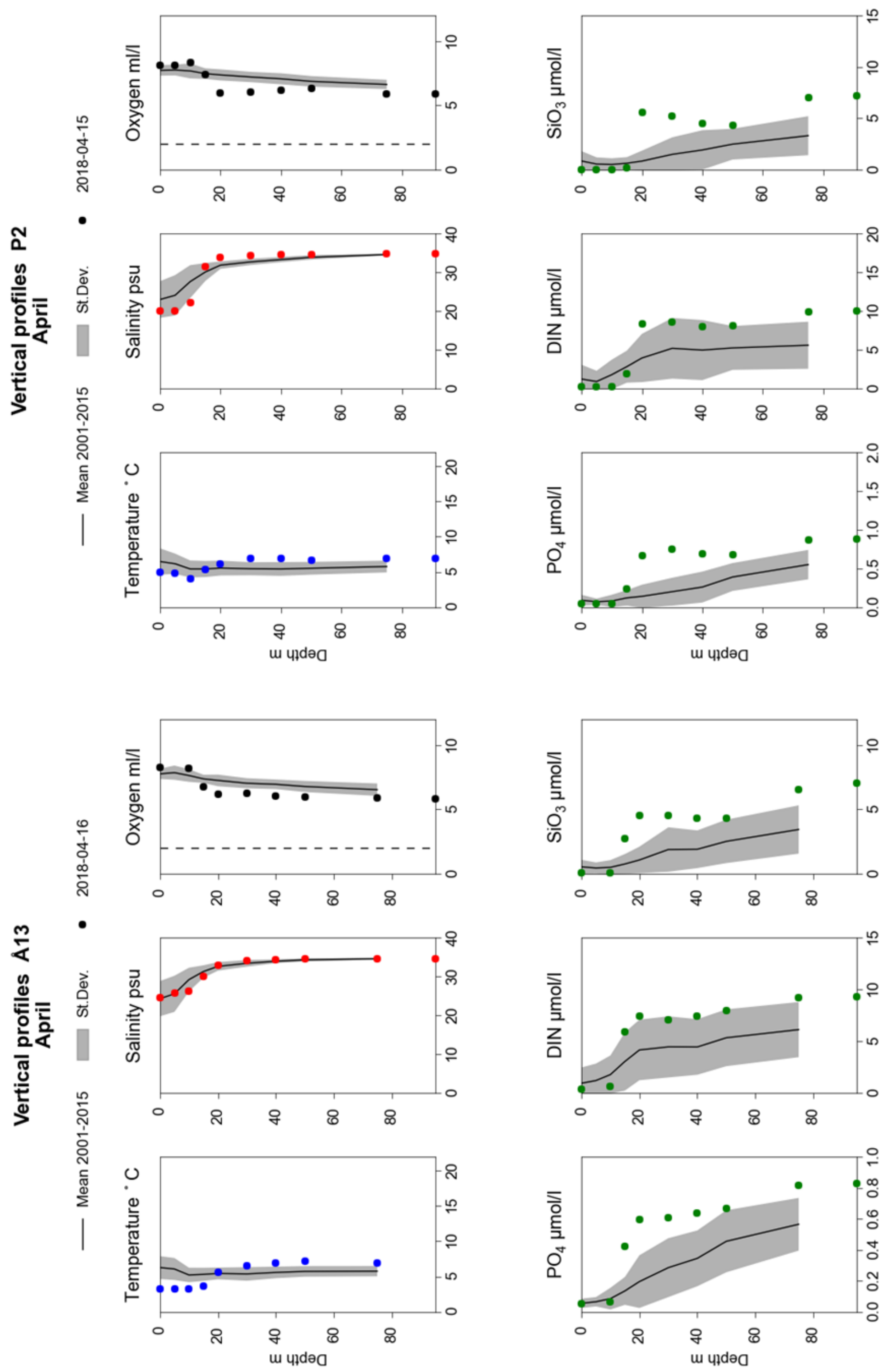
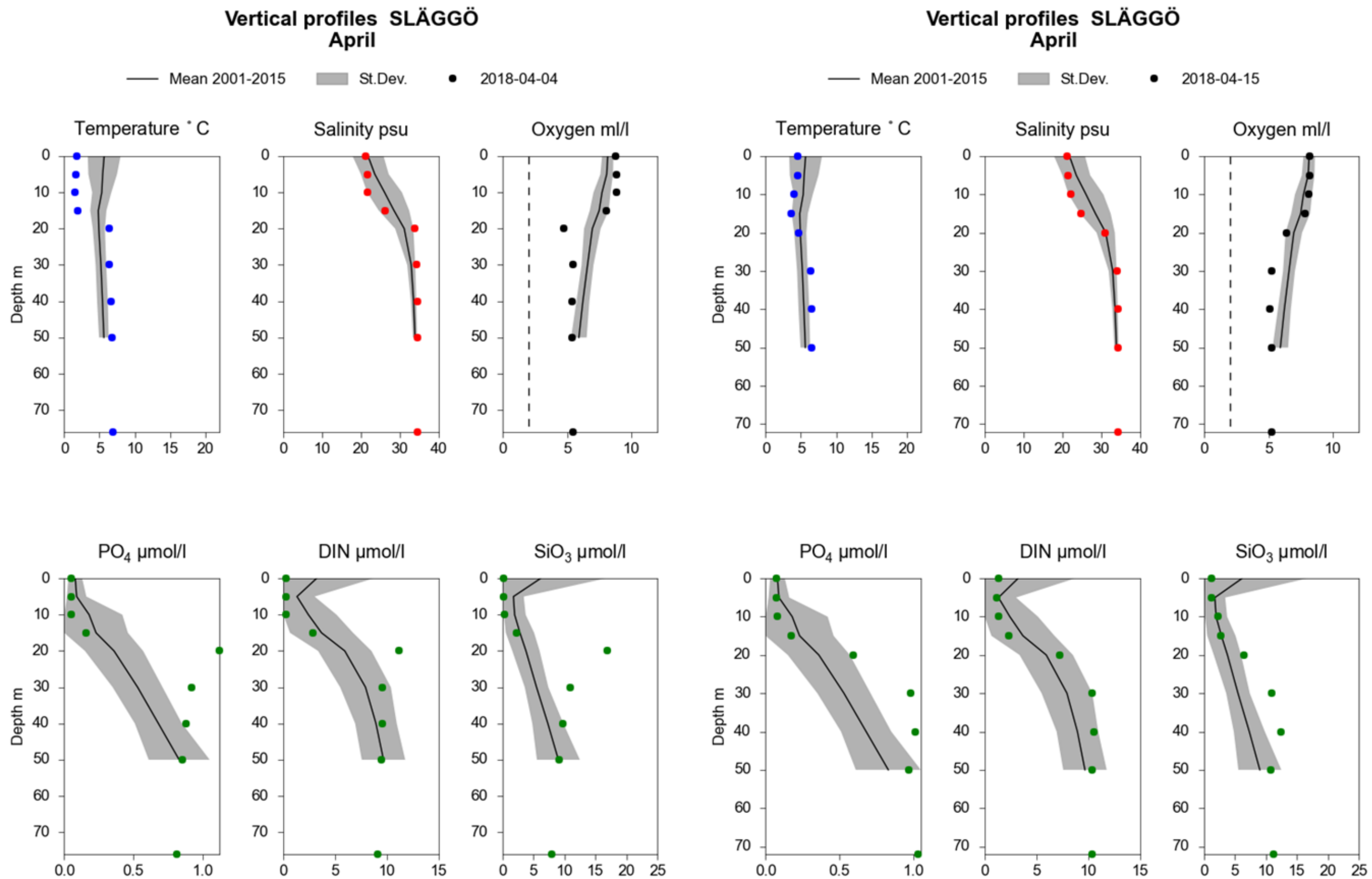


Figure 10 Profiles of temperature (blue), salinity (red), nutrients (green: DIP, DIN and silicate) and oxygen (black) at the stations Å13 and P2 in the Skagerrak in mid-April, note the high nutrient concentrations below the halocline. This is likely due to the degradation of the spring bloom.

Figure 11 Profiles of temperature (blue), salinity (red), nutrients (green: DIP, DIN and silicate) and oxygen (black) at the station Släggö in the Skagerrak at two occasions in April. DIP is higher than normal below the halocline at the two occasions and at the first occasion all nutrients peak at 20 m where the oxygen is well below normal.



3.1.3 Phytoplankton

The diatom spring bloom was observed in the middle of March this year, with high cell numbers of the diatom *Skeletonema marinoi* above all, but also of other diatoms. The chlorophyll concentrations were high in both the Kattegat and the Skagerrak. Diatoms still dominated in the Kattegat in April, but the species composition differed compared to March. During the same period, in the Skagerrak, diatoms were few, however, the potentially harmful dinoflagellate *Dinophysis norvegica* was found in relatively high cell numbers. The integrated chlorophyll concentrations were within normal in May, but several interesting chlorophyll peaks between 10-20 meters were noted. The phytoplankton analysis showed that the peaks were caused by various species of *Dinophysis* and the diatom genus *Chaetoceros*.

No sampling was performed during the period June to August and in the beginning of September, Anholt E was the only phytoplankton station sampled in the West coast area. An autumn bloom with high species diversity was observed in early September and at the visit later the same month, the phytoplankton community was still species rich. High cell numbers of the coccolithophorid *Emiliania huxleyi* was found that colours our seas in a characteristic turquoise blue nuance.

Worth noticing during the autumn was that the dinoflagellate *Prorocentrum compressum* was found in high cell numbers a long period of time at all stations. *P. compressum* has rarely been observed previously and although it is not harmful it is interesting when species suddenly occur and stay, the dinoflagellate was present from September to November in various amounts. In the beginning of December, a bloom of the potentially toxic diatom genus *Pseudo-nitzschia* was observed.

3.1.4 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 in August-October. The bottom water oxygen concentration was lower than normal at only one occasion, see Figure 12. This occasion was in the end of May at the coastal station N14 Falkenberg in the Kattegat where the concentration had dropped to ~4.5 ml/l which is unusual for this time of the year. It is likely that this low oxygen concentration was also caused by high amount of organic matter from to the early spring bloom. Since no measurements were made in June and July it is not possible to know if this situation continued throughout summer, although it is a likely scenario. At the next visit in August the concentration was just above 4 ml/l.

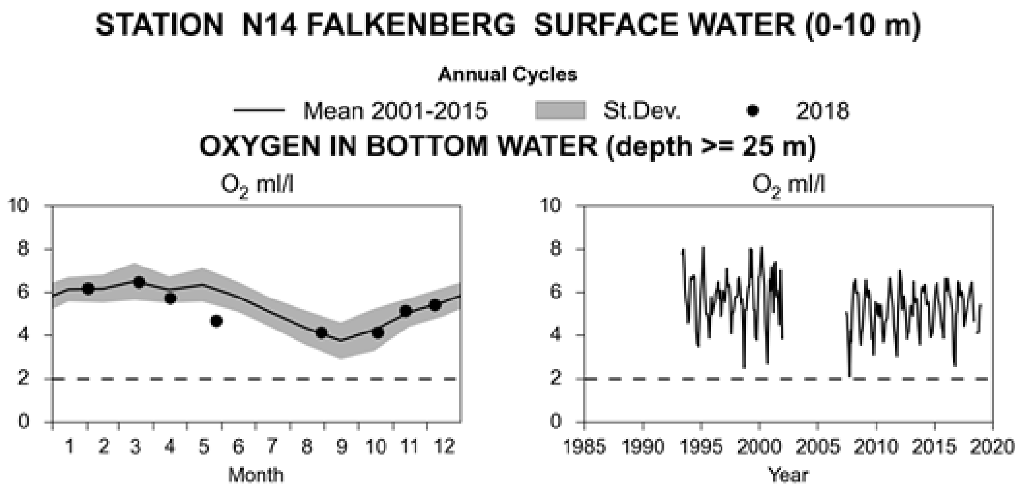


Figure 12 Oxygen in the bottom water at N14 Falkenberg 2018. There were lower than normal concentrations in May at N14 Falkenberg.

3.2 The Baltic Proper

The monitoring of the Baltic Proper 2018 was affected by the difficulties with getting R/V Aranda fully operational after her rebuilding and improvements during 2017-2018. The winter nutrient mapping was performed during a combined January-February cruise and standard stations were visited only once instead of twice during this time. After this, March followed with strong winds and cold weather which made it impossible to sample any stations in the Eastern Gotland Basin due to severe icing. Cruises in April, May and October-December could however be performed as planned. No stations were sampled by SMHI in June-August, but the stations in the Northern Baltic Proper that are sampled by Stockholm University were sampled as planned. An extra cruise was made with U/F Dana by SMHI in the beginning of September and all stations in the Baltic Proper were sampled during that cruise. In mid-September the regular cruise with R/V Aranda was planned, but due to a double booking of the vessel no stations in the Eastern Gotland Basin and Bornholm Basin could be sampled.

3.2.1 Temperature & Salinity

The year started with normal surface temperatures at all stations in January-February, and even towards the lower end in March and April. After the rapid onset of spring in May the surface temperature was above normal at the end of May at all stations. At the two stations that were visited in June and July (BY31 and BY29) the temperature was above normal during summer, except at the visit at the end of July. In August and the beginning of September the surface temperature was still high and above normal at many, but not all stations. At the end of September and in October the surface water had cooled down and temperatures were normal. The storm Knud in September mixed the water column and helped to cool down the unusually warm surface layer.

The high temperatures were very evident at the coastal station B1 and BY31 where the temperatures were well above normal at almost every occasion from May 21st to July 30th (Figure 13). The colder surface water events were caused by mixing and upwelling due to storms. First it was the storm Johanne in August that lowered the temperature so that it was within the normal range. The surface temperature then increased again and was above normal in the beginning of September before the next storm, Knud, hit the country. At station B1 the cooling and freshening of the water was very evident with a decrease in temperature of 10 °C in two weeks and an increase in salinity of ~1 (Figure 13 top). After the autumn storms, the temperature at the end of September was below normal at around 5 °C.

The surface salinity was normal or slightly above normal in Arkona, Bornholm, the Northern Baltic Proper and the Eastern Gotland Basin. But in the Western Gotland Basin the salinity was higher than normal at the end of summer and during the autumn, the rest of the year the salinity was on the higher end of the scale. The high salinity was likely caused by upwelling and/or mixing during the autumn storm Knud.

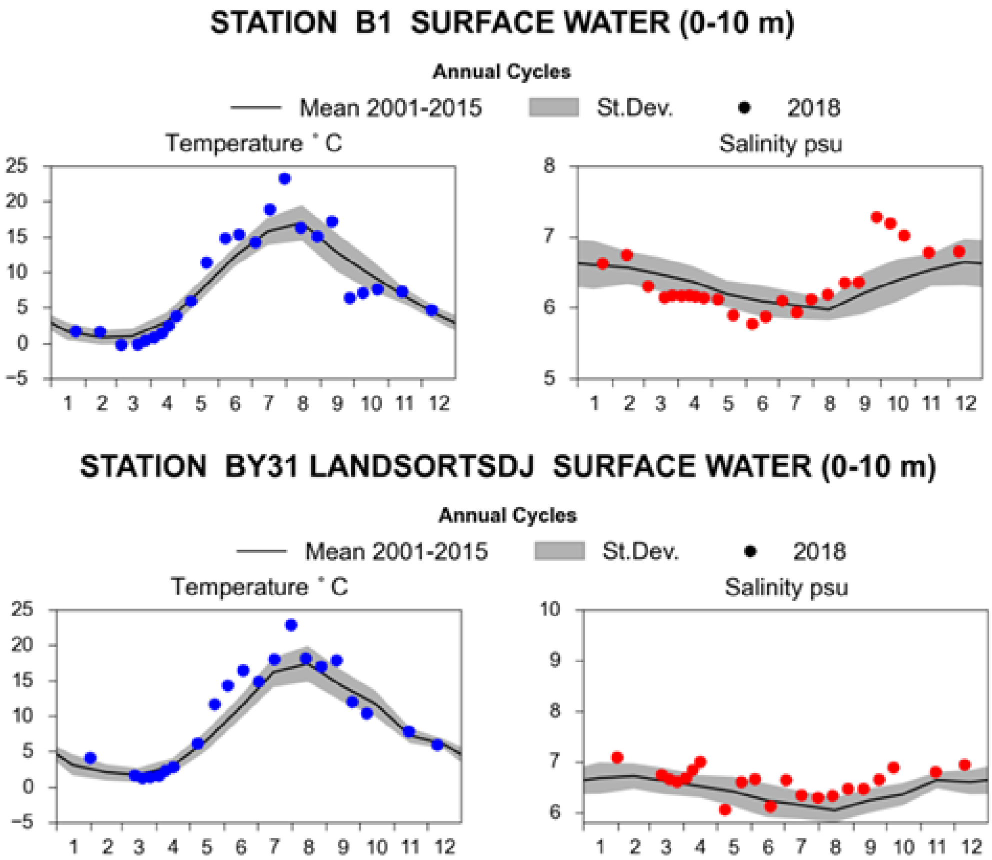


Figure 13 Temperature (blue) and salinity (red) from two stations in the Northern Baltic Proper in 2018. The coastal station B1 (top) and the open sea station BY31 (bottom). The surface water was unusually warm during summer with interruptions of two upwelling events. In September an upwelling event causes the surface temperature to decrease rapidly to unusually low temperatures.

After the storm Knud in September the halocline at BY32 in the Western Gotland Basin had lifted from 75 m depth in September to 50 m depth in October (Figure 14). The halocline was then back to 75 m in November. The reason for this is not easy to find out, but a likely explanation can be found when comparing with the station BY38, south of BY32. At BY38 the halocline was at the same depth before and after the storm. We may note that after the storm, at BY32 we find the halocline at the same depth and with the same shape as BY38 in October. Hence, it seems that saltier watermasses with a shallower pycnocline have moved from BY38 towards BY32 after the storm. This movement might be caused by the large variations in water levels observed across the Baltic Sea which may force the entire water column to move (barotropic transports).

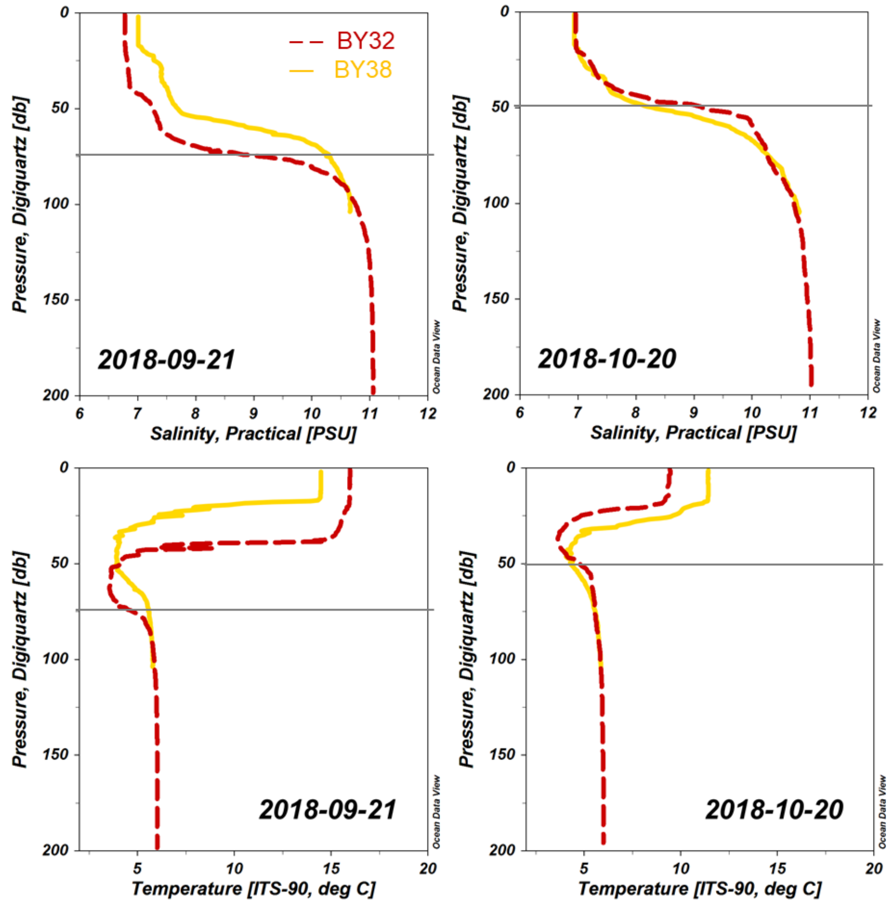


Figure 14 Salinity (top) and temperature (bottom) profiles from BY32 (red) and BY38 (yellow) before/during the storm Knud (left) and one month after the storm (right). The halocline at BY32 was at ~75 m before the storm and ~50 m after. The comparison between the two stations shows that the storm likely had an effect on the water mass in the whole Western Gotland Basin. Image is made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019).

A thermocline at 10-20 m formed in May, and in September the warm surface layer still extended down to around 20 m at most stations. The temperature and salinity in the deep water was a little higher than normal at many stations and has been since the latest major Baltic inflow in 2014. In the deep waters of Arkona and Bornholm there were traces of warmer saline water in early September. A minor inflow during summer had filled the Arkona Basin with warm saline water and interleaved at 50-60 m in the Bornholm Basin. Below this warm water in the Bornholm Basin the water was anoxic, which led to an unusually large volume of anoxic water, see more details in section 3.2.4. The sharp halocline in the Eastern Gotland Basin stayed at around 70 m the whole year but was sharper before the summer than after. The halocline was less sharp in the Western Gotland Basin. With the winter cooling and mixing the halocline became deeper again during November and December.

3.2.2 Nutrients

The concentrations of DIN and DIP in the surface were at normal winter levels during the nutrient survey (Figure 20 and Figure 21) and throughout the year with a few exceptions. Most notably was the coastal station B1 that was clearly affected by the storms in August and September. This was also seen in temperature and salinity data, as described above. Silicate concentrations however, were higher than normal at all stations in the Baltic Proper, both during the winter survey (Figure 22) and up until the production started in May. Although there were little data from the summer it seems like silicate concentrations were at normal low levels during summer. This can be seen at BY31, where there were measurements throughout the summer. Also, at most other stations silicate concentrations were normal or just slightly above normal at the visit in August. The silicate concentrations then increased in the autumn and early winter and were above normal again in December at most stations. In the southern parts (Arkona and Bornholm) as well as the southernmost station in the Eastern Gotland Basin (BSC III-10) the silicate concentration did not increase as much and stayed at normal levels also after the summer.

At the coastal station B1 the warm summer with high productivity was seen in the rapid and early depletion of DIN and DIP in the surface water (Figure 15). DIN was depleted already in April and the DIP concentration was also unusually low in April. Phosphate was not depleted until the beginning of June. Both DIN and DIP continued low during summer until August. Then the storm Johanne hit and caused upwelling at the coast, seen as increased salinity and nutrients and a decrease in oxygen saturation. DIN also increased at this time, but less markedly. All inorganic nutrients then decreased until the end of September when the same pattern was repeated when the storm Knud passed. The upwelling was stronger in September than in August, which is seen in the large changes in temperature and salinity.

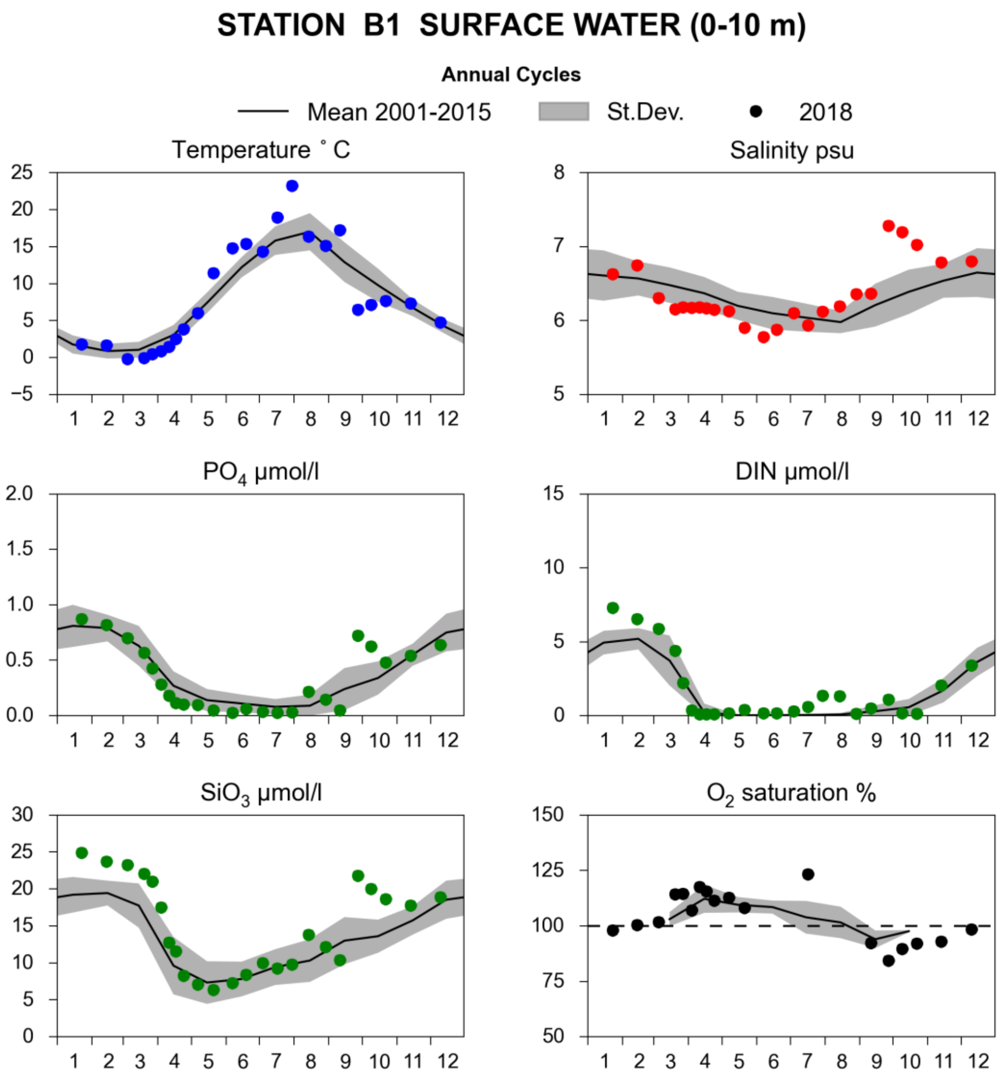


Figure 15 Surface temperature (blue), salinity (red), nutrients (green: DIP, DIN and silicate) and oxygen saturation (black) at the coastal station B1 in 2018. Oxygen data from the surface is missing from most visits during summer due to difficulties with calibration of the sensor for warm waters.

The unusually warm summer with high productivity was also seen in nutrient concentrations in the deep waters at B1 (Figure 16). In April DIN was depleted in the whole water column at B1, while DIP and silicate still increased towards the bottoms. In June both DIP and silicate increased a lot close to the bottom, this is explained by the oxygen profile that shows that the bottom water was anoxic here at this time. Anoxic conditions cause DIP and silicate to be released from the sediment due to the reduction of iron oxides in the sediment. As the bottom water became oxic again a week later, the DIP and silicate concentration in the bottom water decreased again.

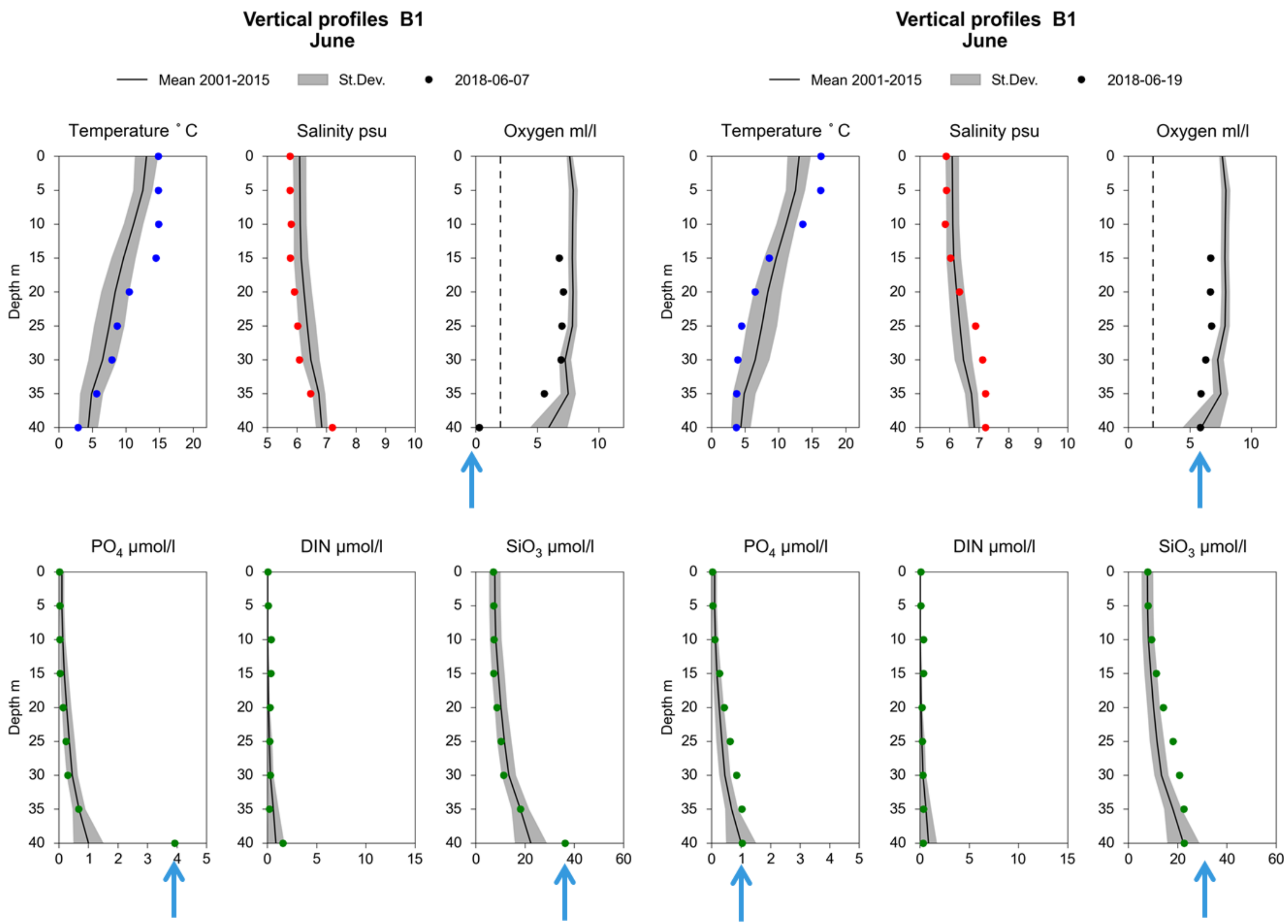


Figure 16 Profiles of temperature (blue), salinity (red), nutrients (green: DIP, DIN and silicate) and oxygen (black) at the coastal station B1 on 7th of June (left) and 19th of June (right) in 2018. At the first visit, note the low concentration of oxygen near the bottom and the associated high levels of nutrients, whereas on the second visit concentrations were restored to normal values.

3.2.3 Phytoplankton

The beginning of the spring bloom could be seen in March at station REF M1V1 in Kalmar Sound with many species of diatoms, however, in low cell numbers. No sampling was performed at the stations in the Western Gotland Basin and in the Eastern Gotland Basin during the March expedition due to very bad weather conditions. High cell numbers and chlorophyll concentrations were observed at several stations in April. In addition to various diatoms, other typical spring species were present. The cyanobacterium *Aphanizomenon flos-aquae*, one of the three filamentous species dominating the cyanobacteria blooms in the summer, was found in high numbers at BY15 and BY20. The following month, the bloom of *A. flos-aquae* was a fact at most stations and, in hindsight we know that it was the start of an extensive cyanobacteria summer bloom. Unfortunately, there are no measurements of this, as the lack of research vessels made sampling impossible from June to August. However, the monitoring from satellite worked as planned, for more details see https://www.smhi.se/klimatdata/oceanografi/algsituationen.

In the beginning of September cyanobacteria were numerous in the samples and the chlorophyll concentrations were high at many stations. During the late September cruise cyanobacteria were still abundant and at the coastal station REF M1V1 there were high cell counts of the diatom *Skeletonema marinoi*. During the remainder of the year, the phytoplankton community was at rest with small species in low total cell numbers and low chlorophyll concentrations.

3.2.4 Oxygen condition in the bottom water

The bottom water in the Baltic Proper was sulphidic throughout the year and the concentrations of hydrogen sulphide increased during the year. In the beginning of the year the hydrogen sulphide was around 15 µmol/l in the Eastern Gotland Deep (station BY15) and in December it had increased to around 50 µmol/l. The hydrogen sulphide concentration also increased in the Northern Baltic Proper and at some stations in the Western Baltic Proper, but not as much as in the Eastern Gotland Basin. In the southern parts of the Eastern Gotland Basin the small inflow in September had oxygenated the bottom water at stations BCS III-10 and BY10 in December. This small inflow was also visible at the Eastern Gotland Deep (BY15) in February 2019 with low but measureable oxygen concentrations at around 115 m.

In the Bornholm Basin the bottom water was anoxic both in May and in the beginning of September when the next measurement was made. No measurements were made in the Swedish national monitoring programme in this basin during June-August, but data from the National Marine Fisheries Research Institute in Poland show that the Bornholm Basin was anoxic also in August[8]. The small inflow in September that was caused by the storm Knud after the visit in the beginning of September oxygenated the whole Bornholm Basin, although oxygen concentrations were still low after the inflow. This is seen in from the visit in October when the oxygen situation was slightly better, with most of the hydrogen sulphide gone (Figure 17). Figure 18 shows the bottom concentration of oxygen in the Skagerrak, the Kattegat, the Baltic Proper and the Gulf of Bothnia from the monitoring in 2018.

A more detailed description of the oxygen conditions in the Baltic Proper is found in Hansson et al 2019[8].

[8] Hansson M., Viktorsson L., Andersson L., SMHI Rapport RO 65, 2018. *Oxygen Survey in the Baltic Sea 2018 - Extent of Anoxia and Hypoxia, 1960-2018*

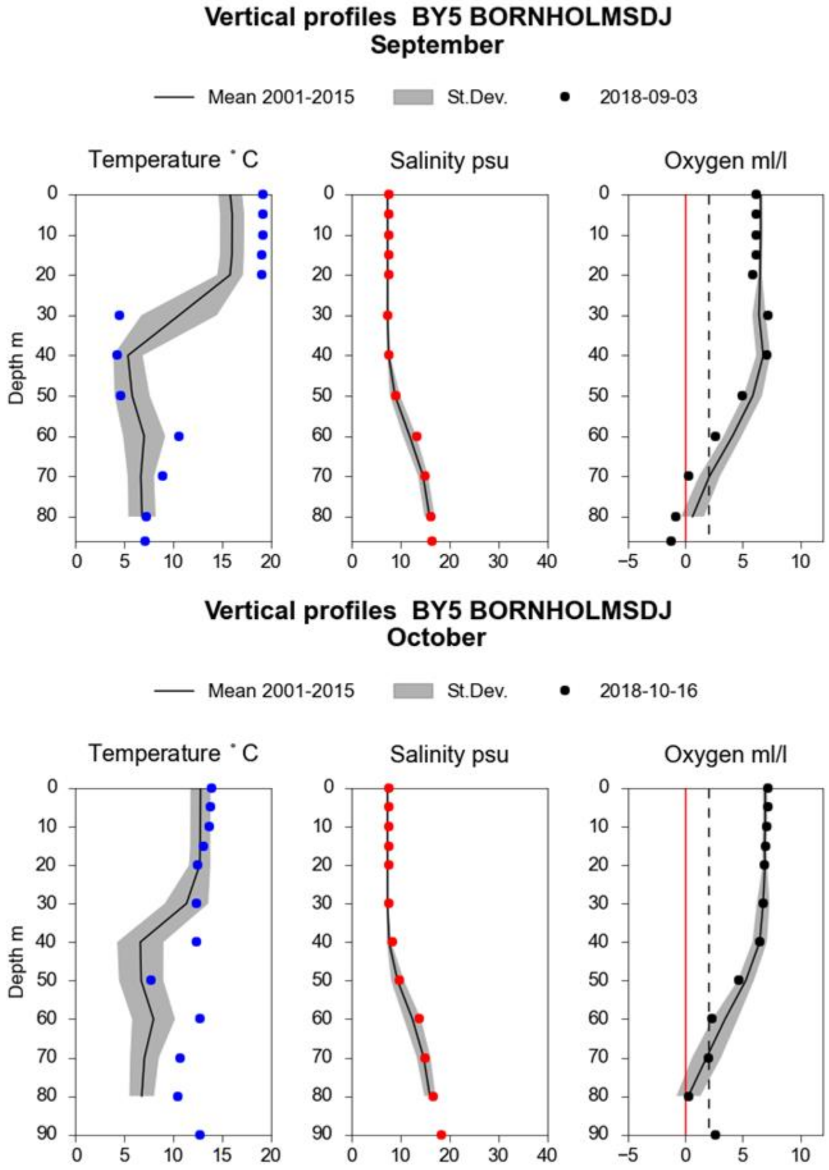
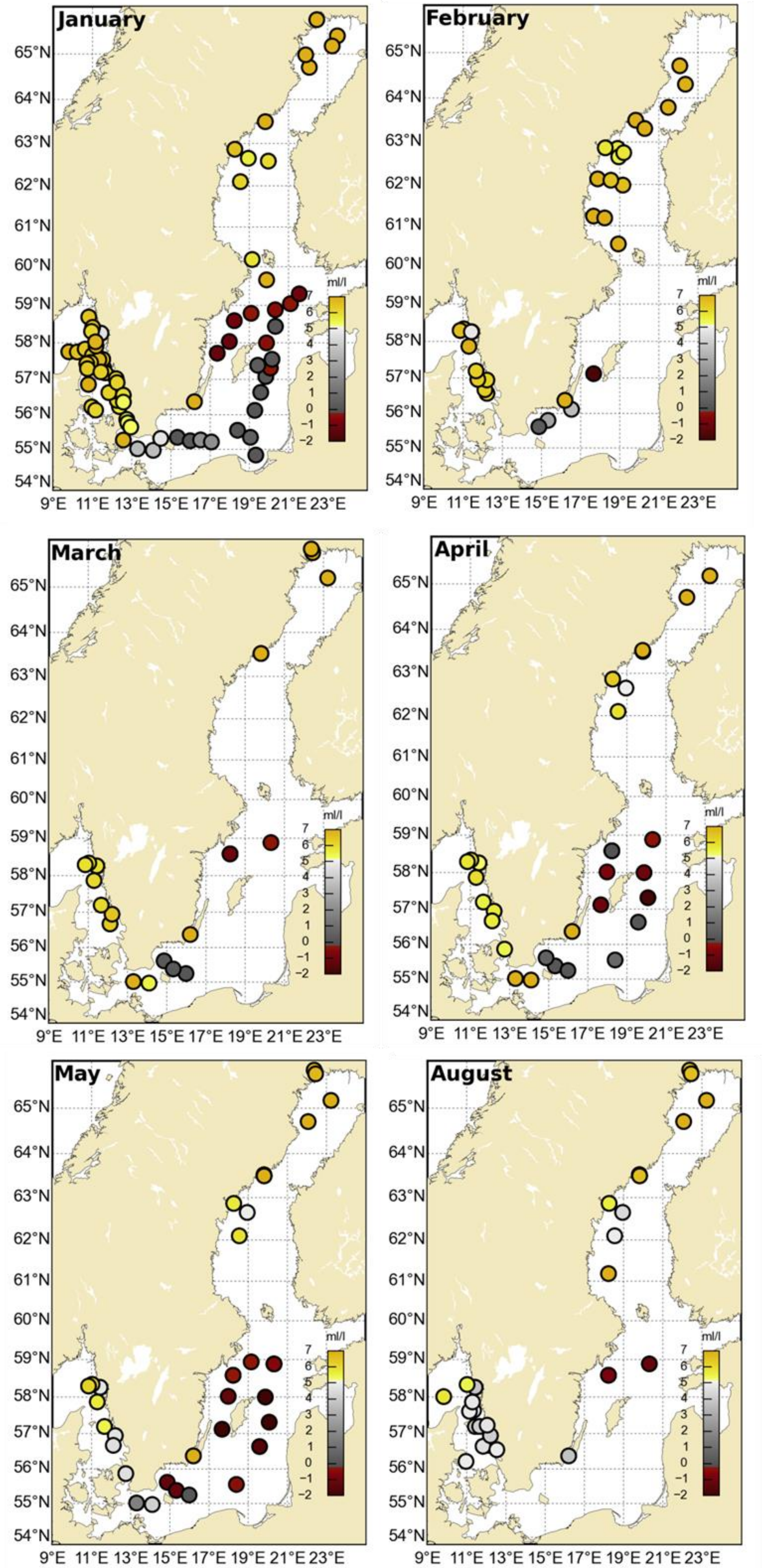


Figure 17 Profiles of Temperature (blue), salinity (red) and oxygen (black, the red line indicates zero oxygen) from stations BY5 in the Bornholm Basin in the beginning of September (top) and mid-October (bottom). Between the two occasions there was an inflow of warm saline water from the Kattegat the oxygenated the bottom water.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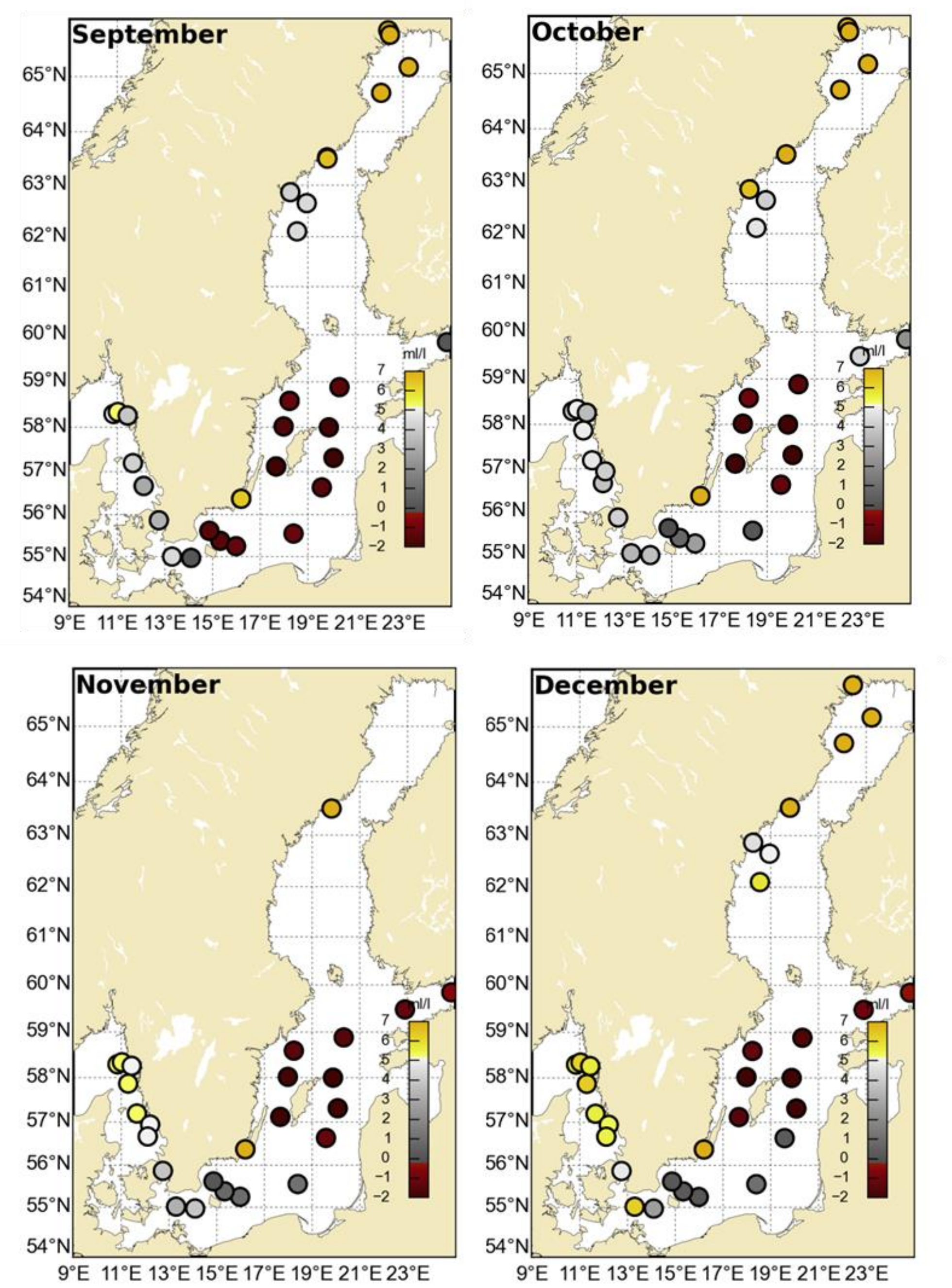


Figure 18 The bottom concentration of oxygen (ml/l) in the Skagerrak, the Kattegat and the Baltic Sea from the monitoring in 2018 for different months. Red colour indicates the presence of hydrogen sulphide.

3.3 Bothnian Bay and Bothnian Sea

3.3.1 Temperature & Salinity

Despite the unusually warm summer and high surface temperatures elsewhere around Sweden, the surface water in the open parts of Bothnian Bay and the Bothnian Sea did not exceed normal temperatures (Figure 19). The lowest temperature was noted in February in the Bothnian Bay; -0.13 °C. A thermocline near the surface began to develop in June and the highest surface temperature was noted in August at station MS4/C14 in the Bothnian Sea with 16.5 °C. The cooling of the surface water had begun in October and continued for the rest of the year. The seasonal variation in the surface temperature was mainly normal throughout the year. The seasonal variation in the surface salinity was 2.3-2.9 in the Bothnian Bay and 4.7-5.5 in the Bothnian Sea. The surface salinity in the Bothnian Bay was lower than normal for most of the year.

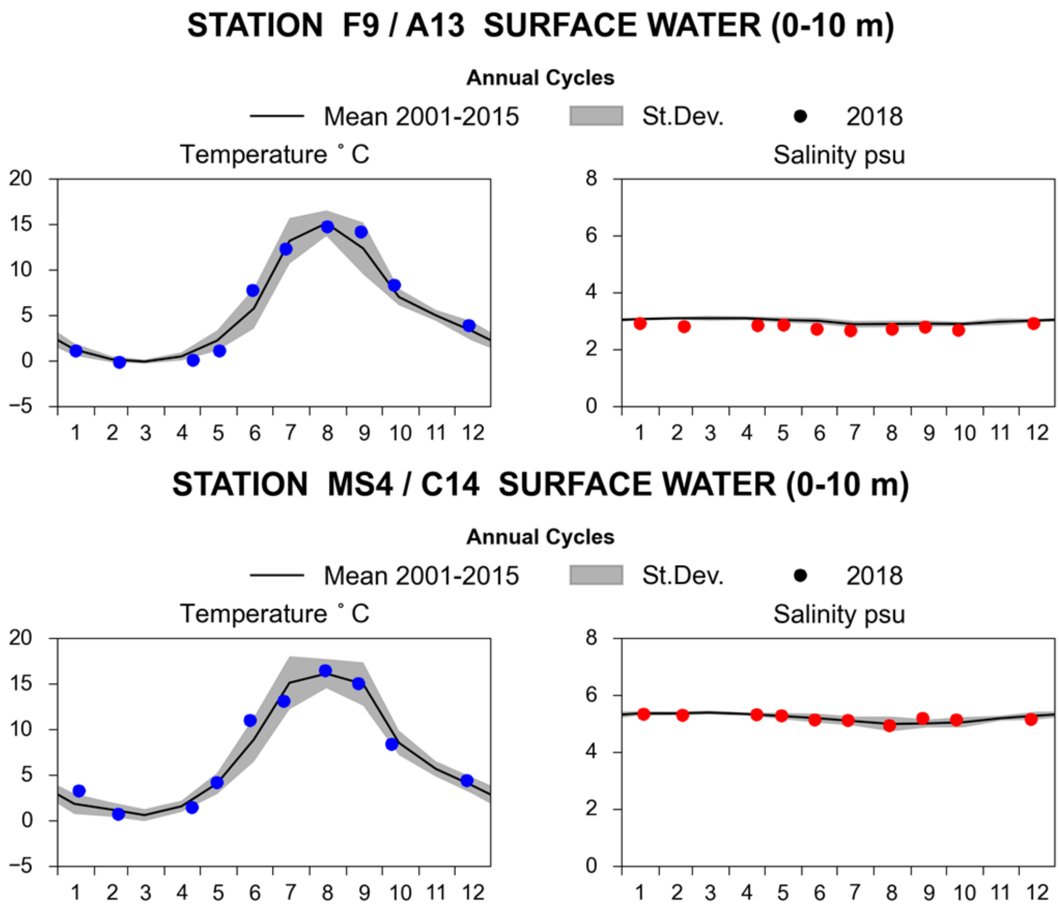


Figure 19 Surface temperature (blue) and salinity (red) at station F9/A13 in the Bothnian Bay and MS4/C14 in the Bothnian Sea.

During winter, the water column in the northernmost part of the Bothnian Bay (station F3/A5) was well mixed down to the bottom at 80 meters. At the other open sea stations the water column was stratified around 60 meters. The stratification was a bit stronger in the Bothnian Sea compared with the Bothnian Bay.

At the coastal station GAVIK-1 in the Bothnian Sea the surface temperature had dropped and salinity together with nutrients had increased at the visit the 13th of August. This might be related to the storm Johanne that passed a few days earlier on the 10th of August and the strong winds have probably caused an upwelling event.

3.3.2 Nutrients

The pool of winter nutrients in the surface layer was mapped by Umeå Marine Sciences Centre in January and February.

In the monitoring programme nutrients are only sampled during the winter months (January, February and December) in the open parts of the Bothnian Bay and Bothnian Sea. In the beginning of the year, the surface concentration of DIP was above normal and around 0.4 µmol/l in the Bothnian Sea and 0.1µmol/l in the Bothnian Bay. Even though the DIP in the Bothnian Bay exceeded normal values it is low compared to other sea areas around Sweden. This is because DIP binds with iron, which is supplied via rivers, and forms complex in the sediment, a process that only works in oxic condition.

The surface concentration of silicate was also above normal in both basins; approximately 41 µmol/l in the Bothnian Bay and approximately 24 µmol/l in the Bothnian Sea. DIN in the surface water was normal to lower than normal and varied between 3.8 µmol/l in the Bothnian Sea to 6.8 µmol/l in the Bothnian Bay.

When the water column was stratified all nutrients were higher below the stratification.

3.3.3 Phytoplankton

The result of any phytoplankton analysis from the Gulf of Bothnia is not presented in this report. However, there were some reports of algae blooms from the coastal Bothnian Sea and at some areas the concentrations of chlorophyll continued to be high well into the autumn, which is unusual.

3.3.4 Oxygen condition in the bottom water

The bottom water in the Bothnian Bay was well oxygenated and there was no oxygen deficiency. This is normal and is because of the weak stratification and hence the good ventilation between the surface and the bottom layer. At some stations the surface concentration of oxygen during summer was actually lower than in the bottom water since warm water dissolves less oxygen than cold water.

In the Bothnian Sea the bottom water is less ventilated because of the stronger stratification and oxygen decreased below the pycnocline. The concentration of oxygen in the bottom water varied from about 6 ml/l in winter to the lowest value of 4.2 ml/l in October, which was lower than normal. Even though there is no oxygen deficit in the bottom water of the Bothnian Sea there is a decreasing trend (see Ahlgren et al 2017[9]), which indicates an environmental change.

3.4 Winter mapping

Each winter the spatial distribution and availability of the nutrients are surveyed (Figure 20, Figure 21 and Figure 22). 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.

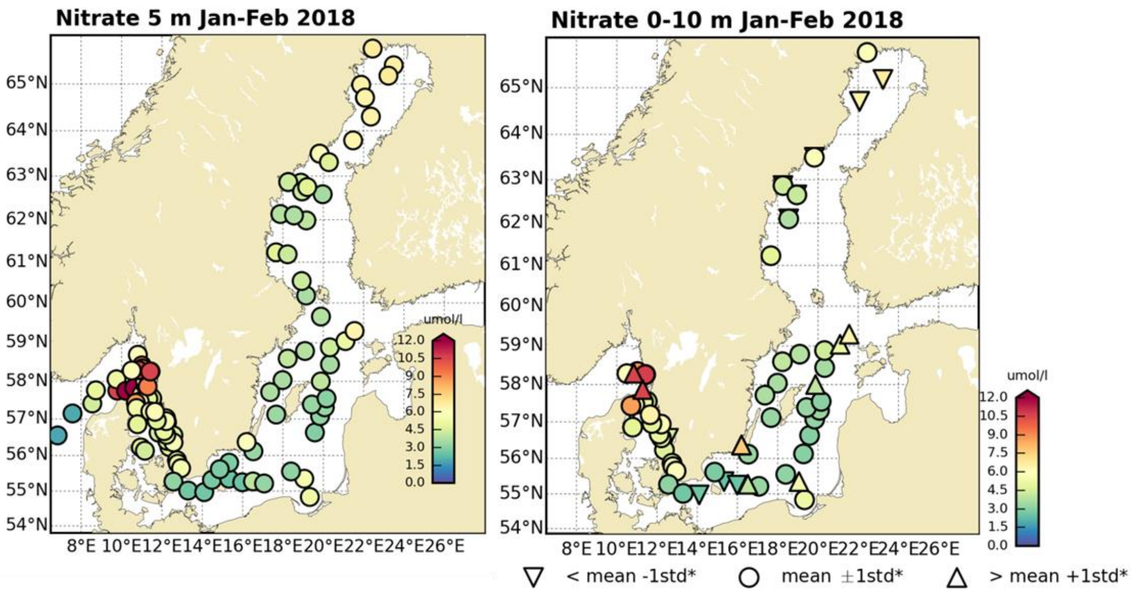


Figure 20 Result from the winter surveys of nitrate during January and February 2018. To the left is all stations presented and to the right only those stations that have standard positions and hence where it is possible to compare the data with statistics. Mean is based on the monitoring 2001-2015 for the respective month and station.

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

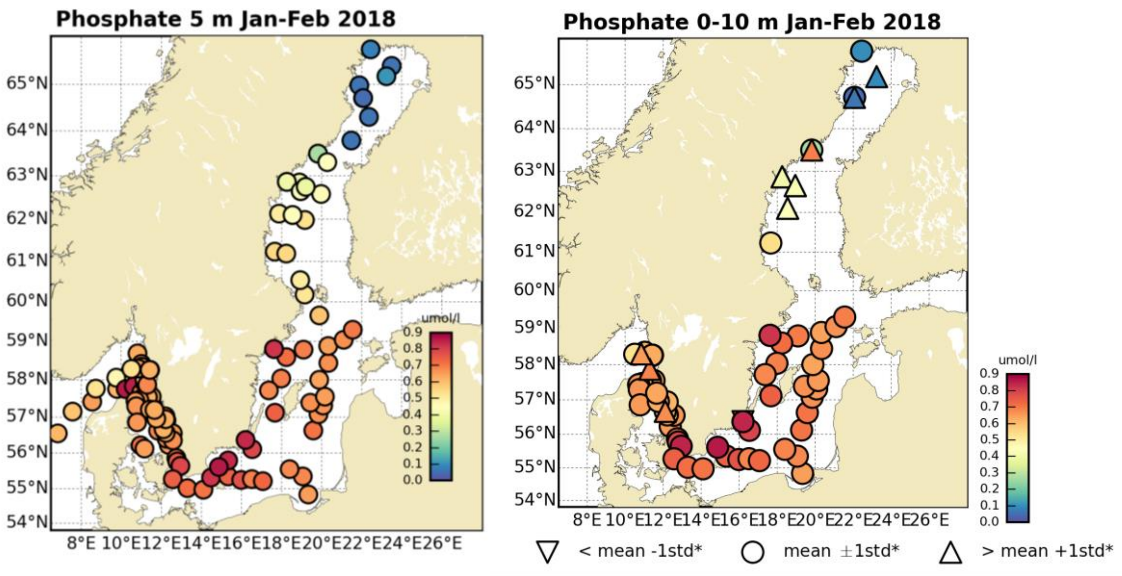


Figure 21 Result from the winter surveys of DIP during January and February 2018. To the left is all stations presented and to the right only those stations that have standard positions and hence where it is possible to compare the data with statistics. Mean is based on the monitoring 2001-2015 for the respective month and station.

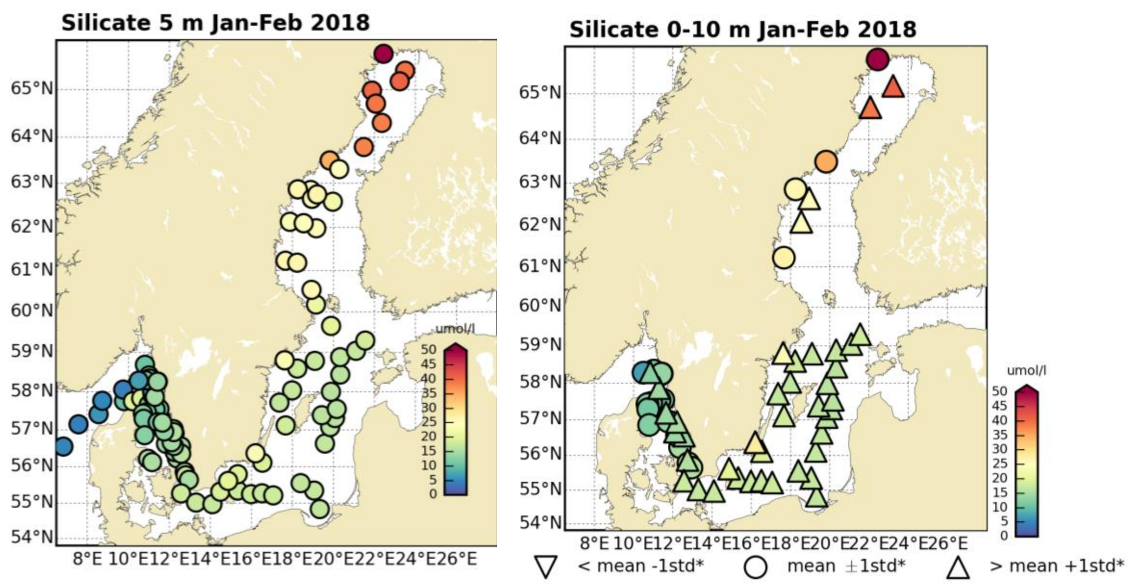


Figure 22 Result from the winter surveys of silicate during January and February 2018. To the left is all stations presented and to the right only those stations that have standard positions and hence where it is possible to compare the data with statistics. Mean is based on the monitoring 2001-2015 for the respective month and station.

3.5 Long time series

Although the main focus of this report is the results from 2018, we also present data in the form of longer time series of two kinds. In Appendix II time series from 1960-2018 from all the stations currently included in the monthly sampling programme are shown. No statistical trend analysis has been done, but the figures give an overview of the development of the monitoring programme as well as providing a quick way to observe the main changes in nutrients, oxygen, temperature and salinity over time in each of the basins.

In Appendix III the content of nutrients in each basin was calculated from the same data set that was used for the time series presented in Appendix II. The resulting time series of nutrient content shows large scale changes of the nutrient pools as well as differences between the basins. Starting in the south with the Arkona and Bornholm basins, a sudden increase in the content of both inorganic and total phosphorus is seen between 2004 and 2005 (Figure 23). 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.

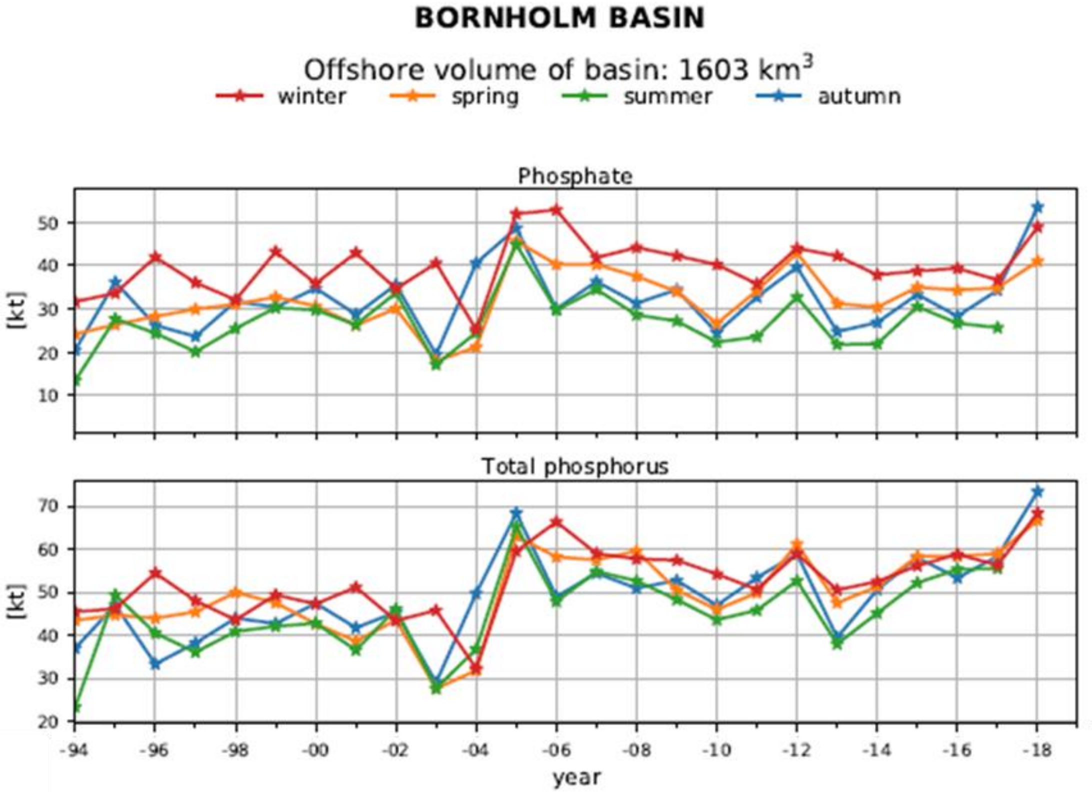


Figure 23 Phosphate (DIP) and total phosphorus content in the Bornholm Basin from 1994 to 2018. The colours show content for winter (red), spring (orange), summer (green) and autumn (blue) each year. The content increases after 2004 in both DIP and total phosphorus, possibly as a result of the major Baltic inflow in the winter 2004-2005. For total phosphorus however the increase coincides with a change of analytical method at the SMHI laboratory which could have caused a part of the increase.

In the rest of the Baltic Proper the phosphorus content increased from 1994 until around 2000 when it starts to level out. The last 3 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 (Figure 24). The nitrogen content trend is opposite, with a decrease in content from 1994 to the beginning of the 21st century (Figure 24). The drop in DIN is most drastic in the Western Gotland Basin for the sub-basins around stations BY31 and BY32. 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 DIP from sediments and decreased burial capacity of phosphorus in anoxic sediments[10]. With continued efforts to keep phosphorus loading lower than during the end of the 20th century phosphorus content could also decrease with time.

[10] Viktorsson L., Ekeroth N., Nilsson M., Kononets M., Hall POJ. *Phosphorus recycling in sediments of the central Baltic Sea.* 2013. Biogeosciences 10 (6), 3901-3916.

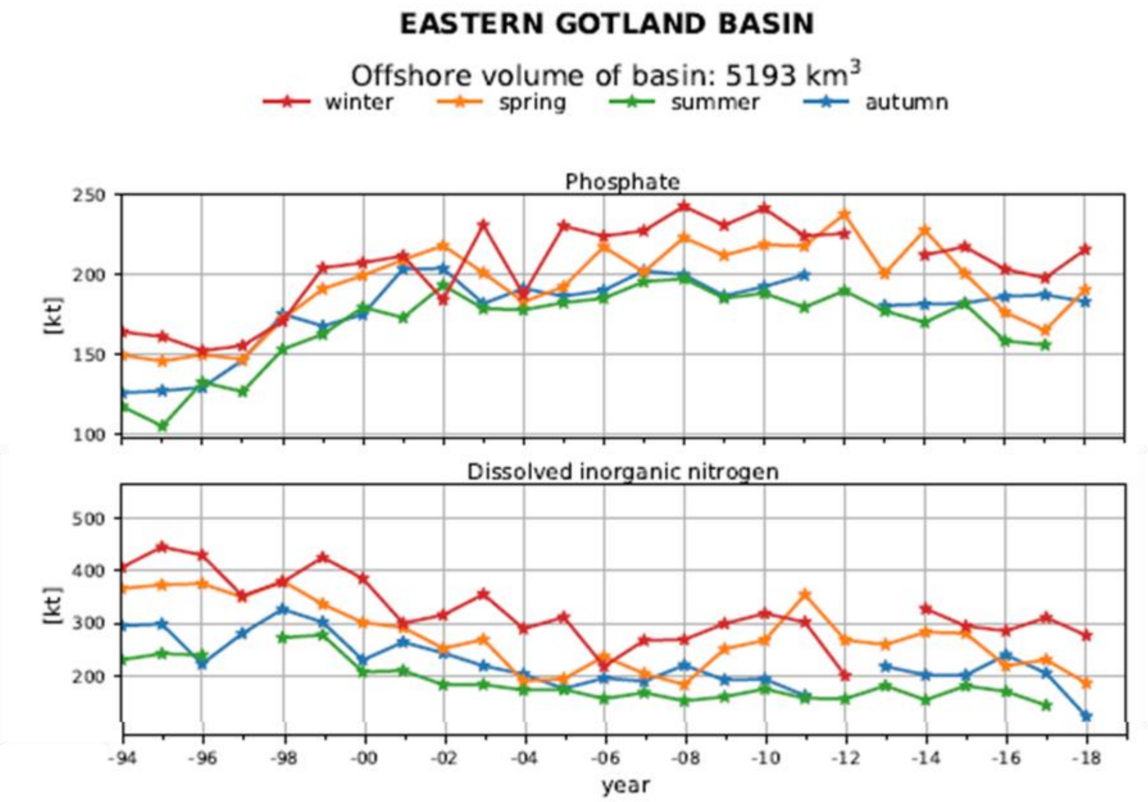


Figure 24 Content of phosphate (DIP) and DIN in the Eastern Gotland Basin from 1994-2018. The colours show content for winter (red), spring (orange), summer (green) and autumn (blue) each year. DIP increases from 1994 to the mid-2000 and there is a tendency toward a decrease the last 3 years. DIN is steadily decreasing since 1994.

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. We speculate that it could be connected to the increase in area of anoxic bottoms since dissolved silica also adsorb to iron oxides in oxic sediments and thus has less adsorption sites under anoxic conditions. Another reason for the increase in dissolved silica could be changes in the phytoplankton community, less species that form silica shells would cause a lower uptake and consequential burial of silica. However, none of these hypotheses are fully investigated and we hope that more in depth studies of the cause for the increase in dissolved silica will be made.

In the Gulf of Bothnia there is less data for this analysis. In the Bothnian Sea there is an increase in winter DIP as well as an increase in total phosphorus over all seasons. Also there is an indication of increasing content of dissolved silica in the Bothnian Sea.

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

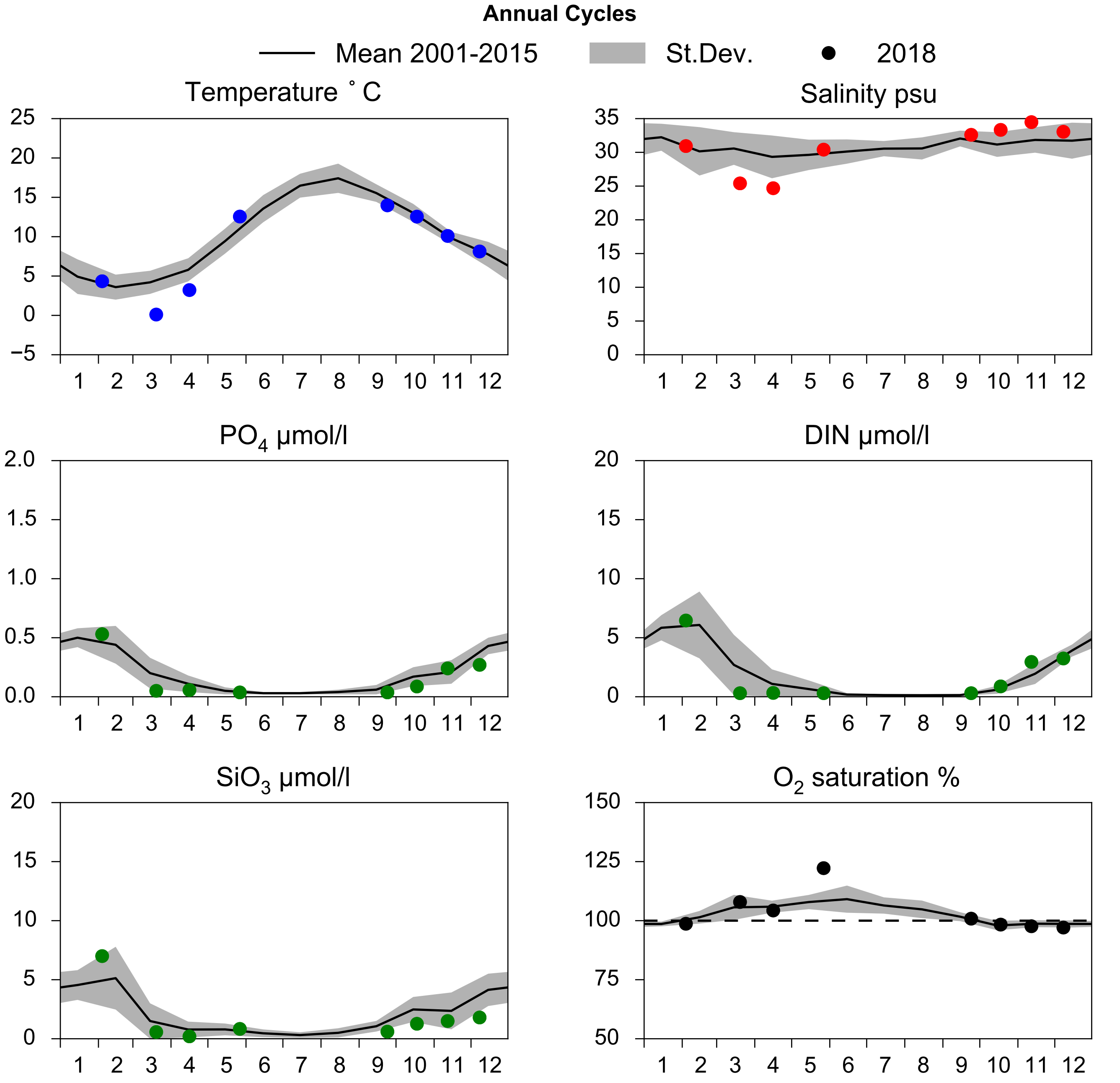
Appendix I

Seasonal cycles from monthly and high frequency stations sampled 2018.

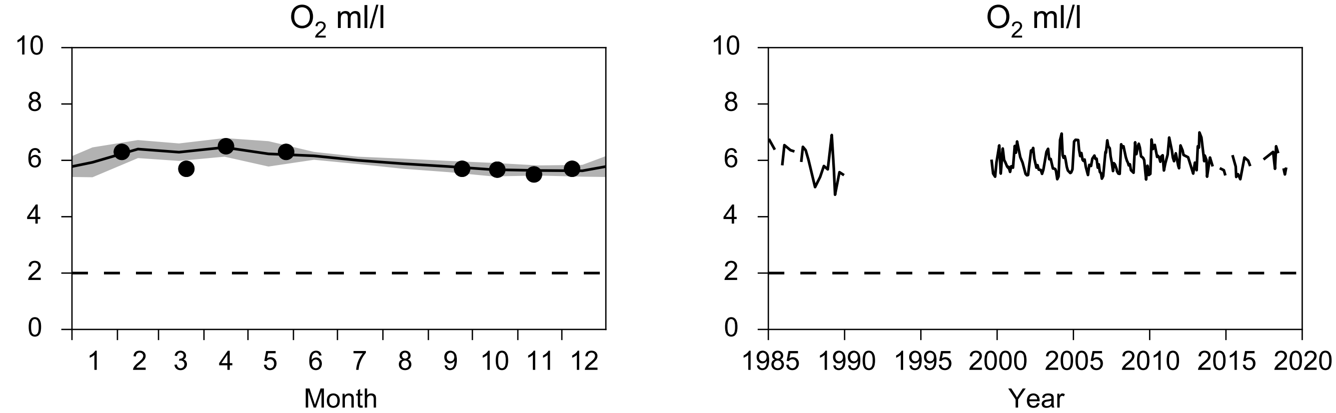
Surface water (0-10 m): including comparison to the mean and standard deviation for the period 2001-2015 at each station. Included parameters are salinity, temperature, dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN; sum of ammonium, nitrate and nitrite), dissolved silica and oxygen saturation. Dissolved oxygen (including hydrogen sulphide expressed as negative oxygen) is presented for the bottom water.

Data of salinity, temperature and oxygen is primarily from the water sampling, but if data is missing, values from the CTD-cast are presented instead. Data in the time series for bottom oxygen is only from water samples.

STATION Å17 SURFACE WATER (0-10 m)

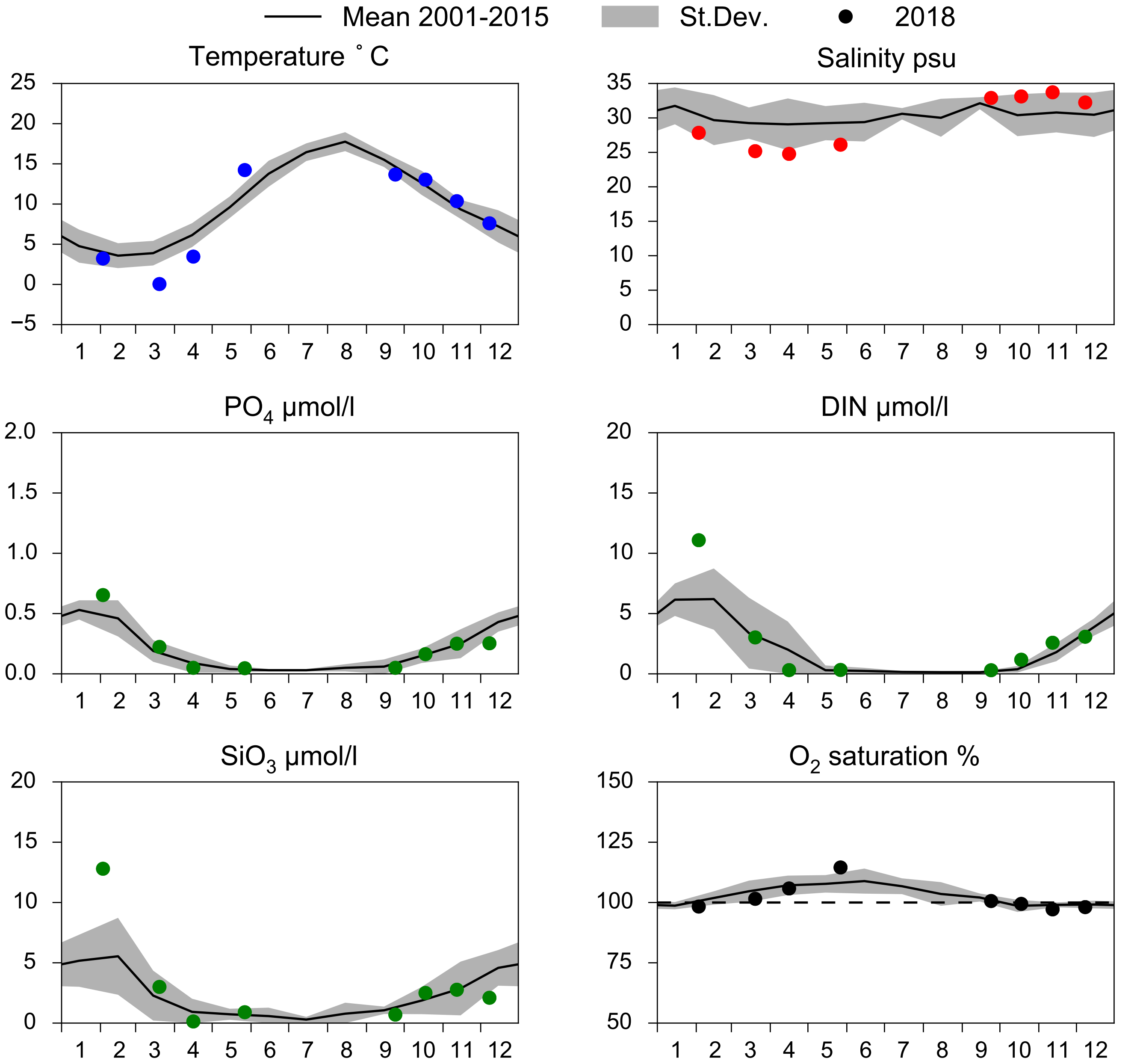


OXYGEN IN BOTTOM WATER (depth >= 300 m)

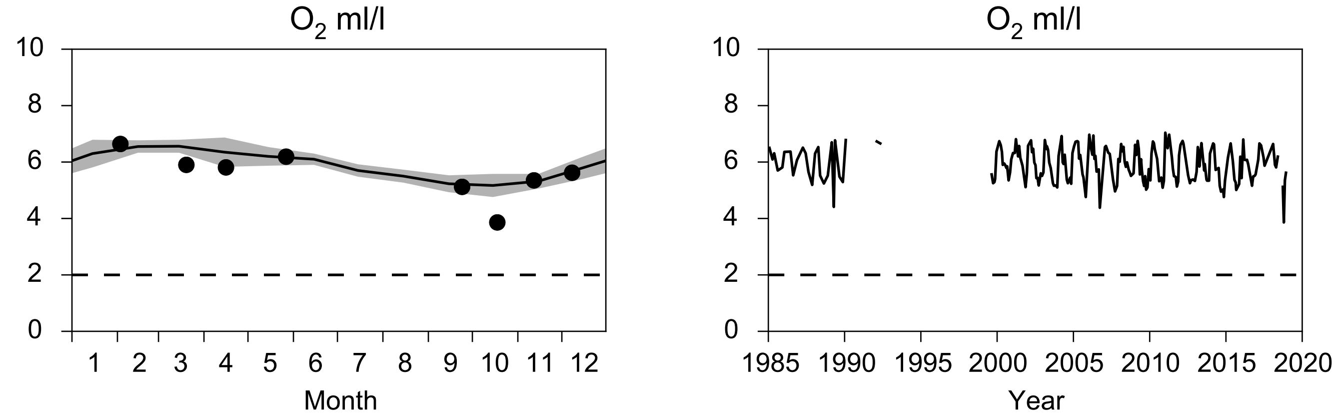


STATION Å15 SURFACE WATER (0-10 m)

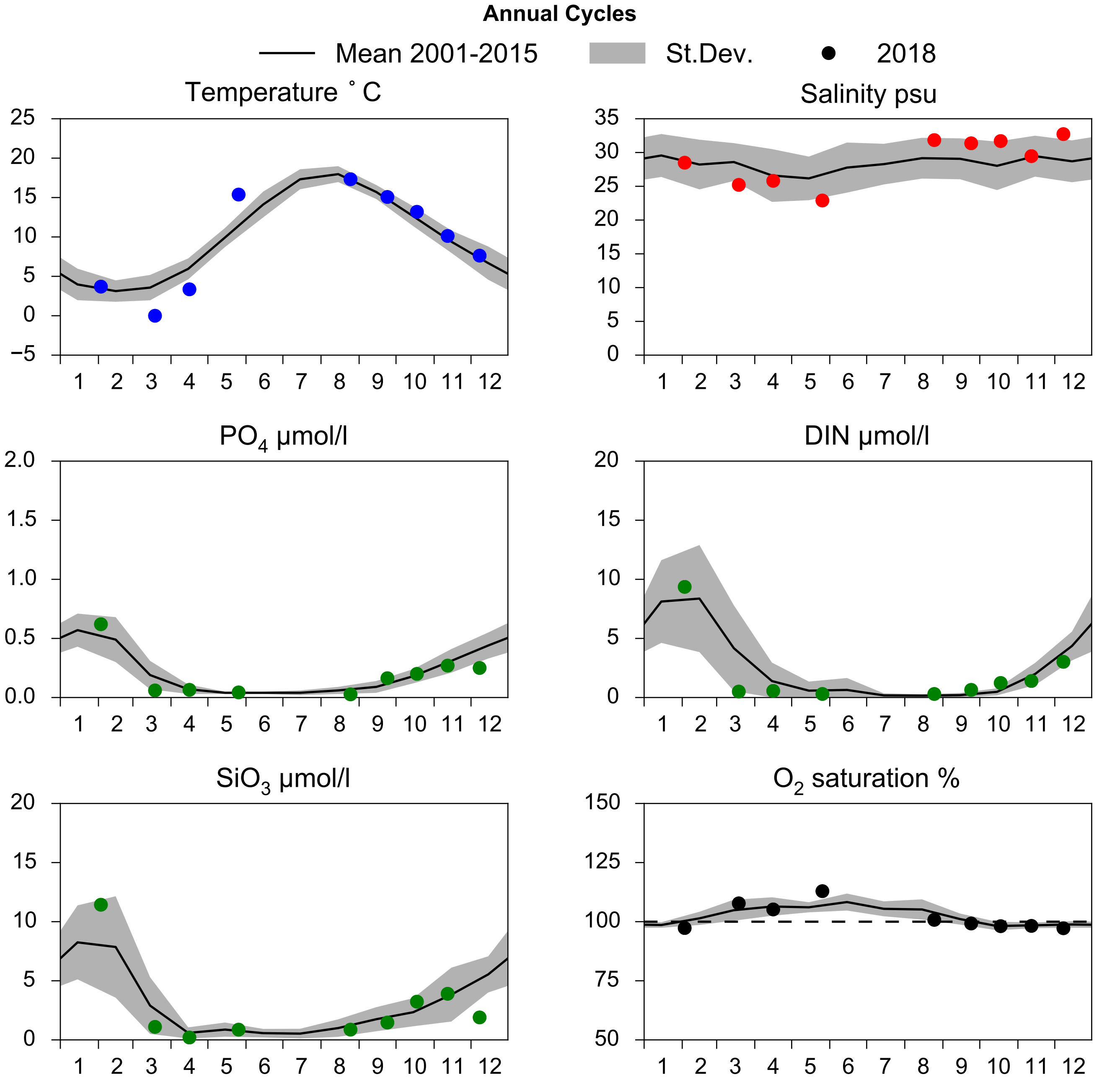
Annual Cycles



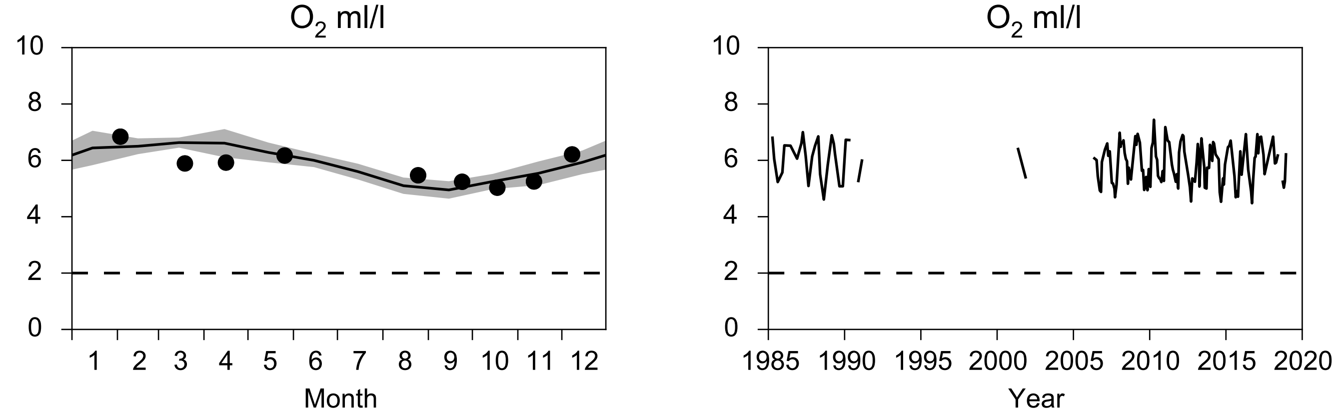
OXYGEN IN BOTTOM WATER (depth >= 125 m)



STATION Å13 SURFACE WATER (0-10 m)

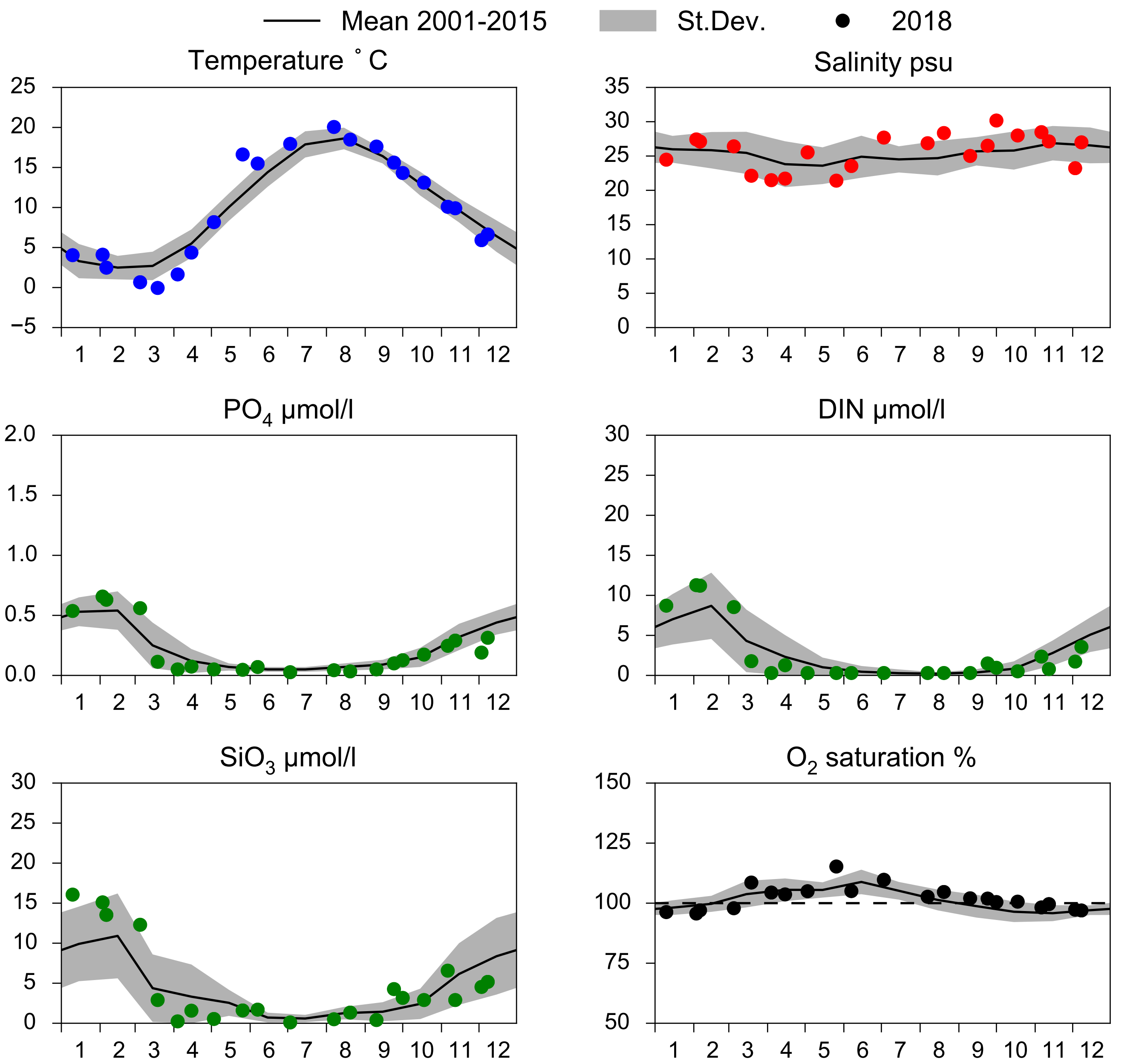


OXYGEN IN BOTTOM WATER (depth >= 80 m)

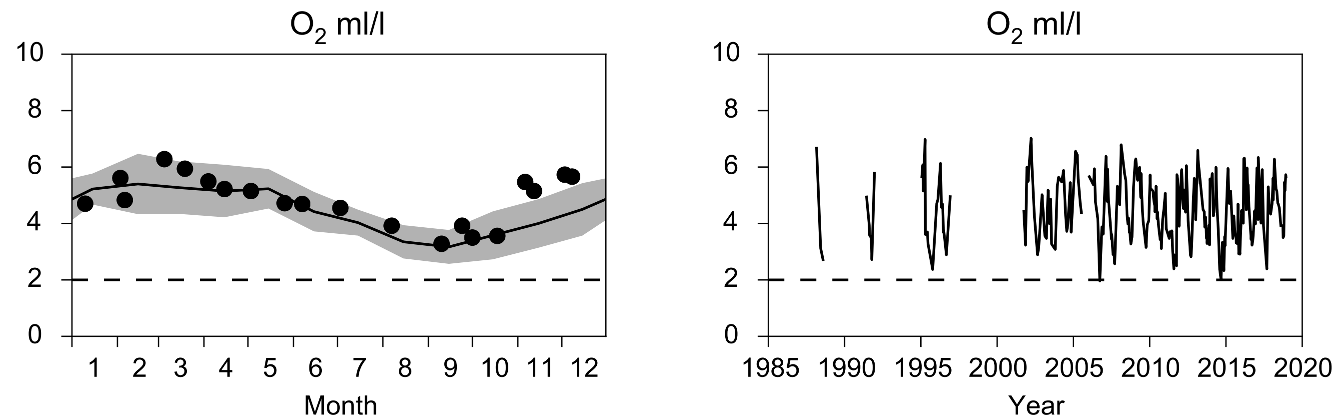


STATION SLÄGGÖ SURFACE WATER (0-10 m)

Annual Cycles

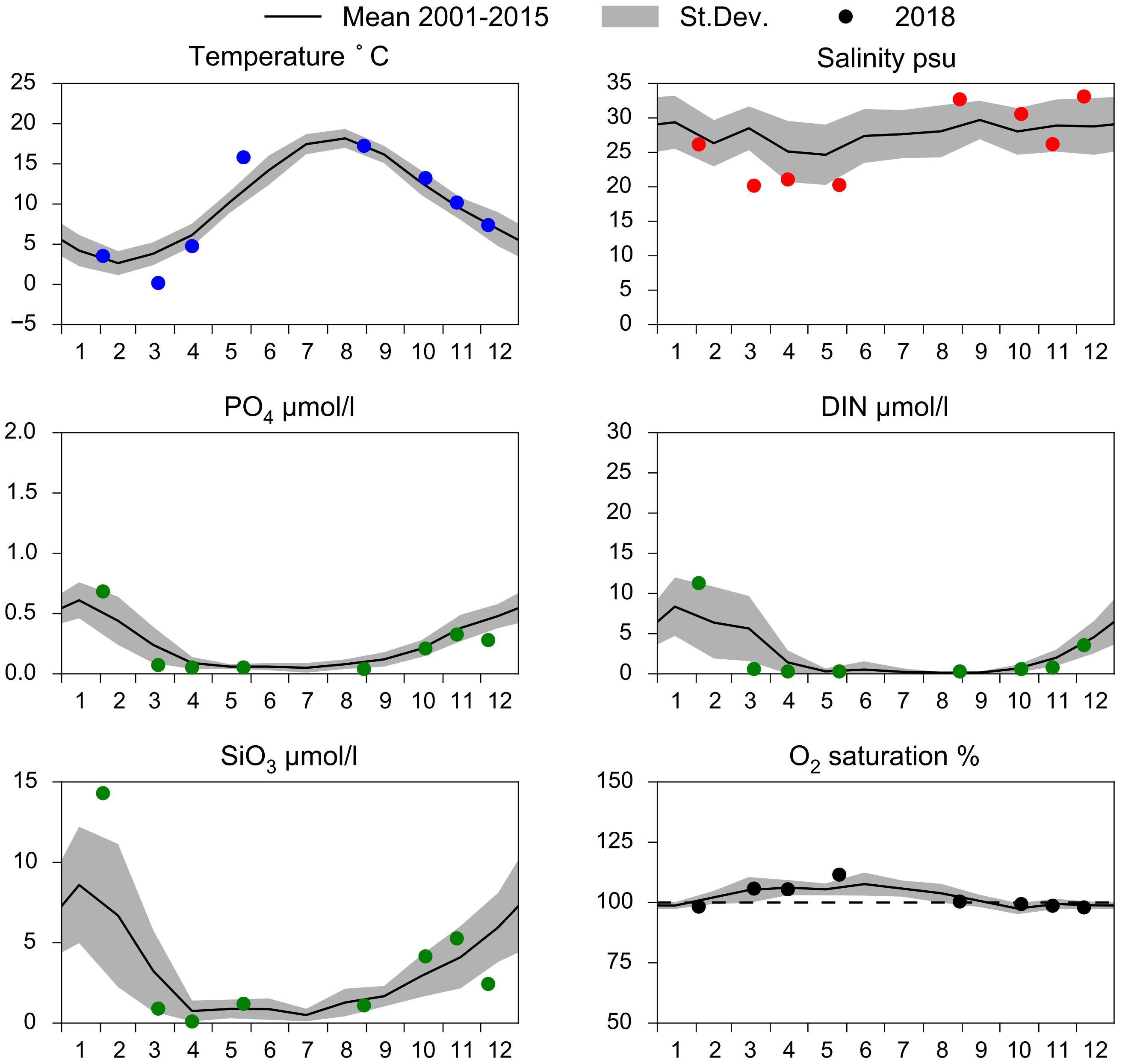


OXYGEN IN BOTTOM WATER (depth >= 64 m)

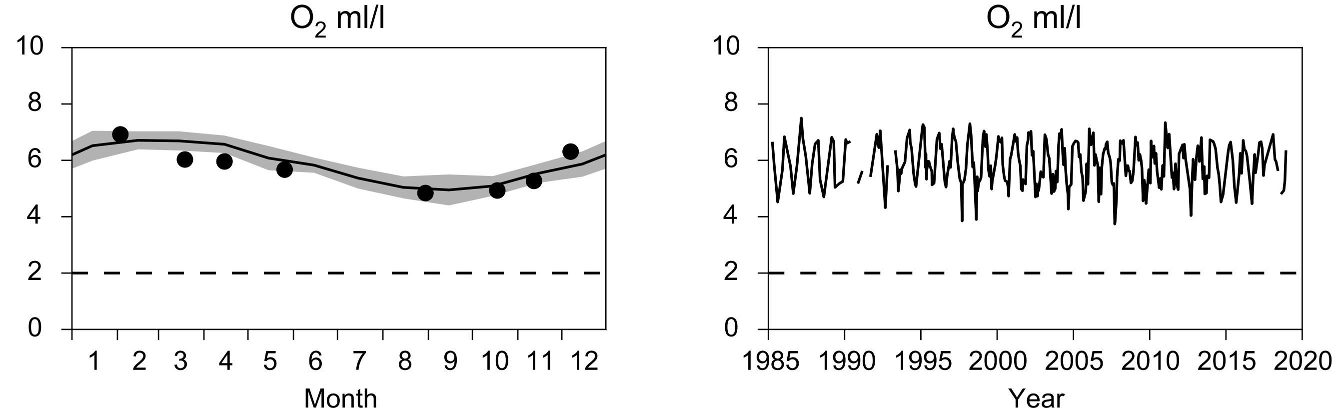


STATION P2 SURFACE WATER (0-10 m)

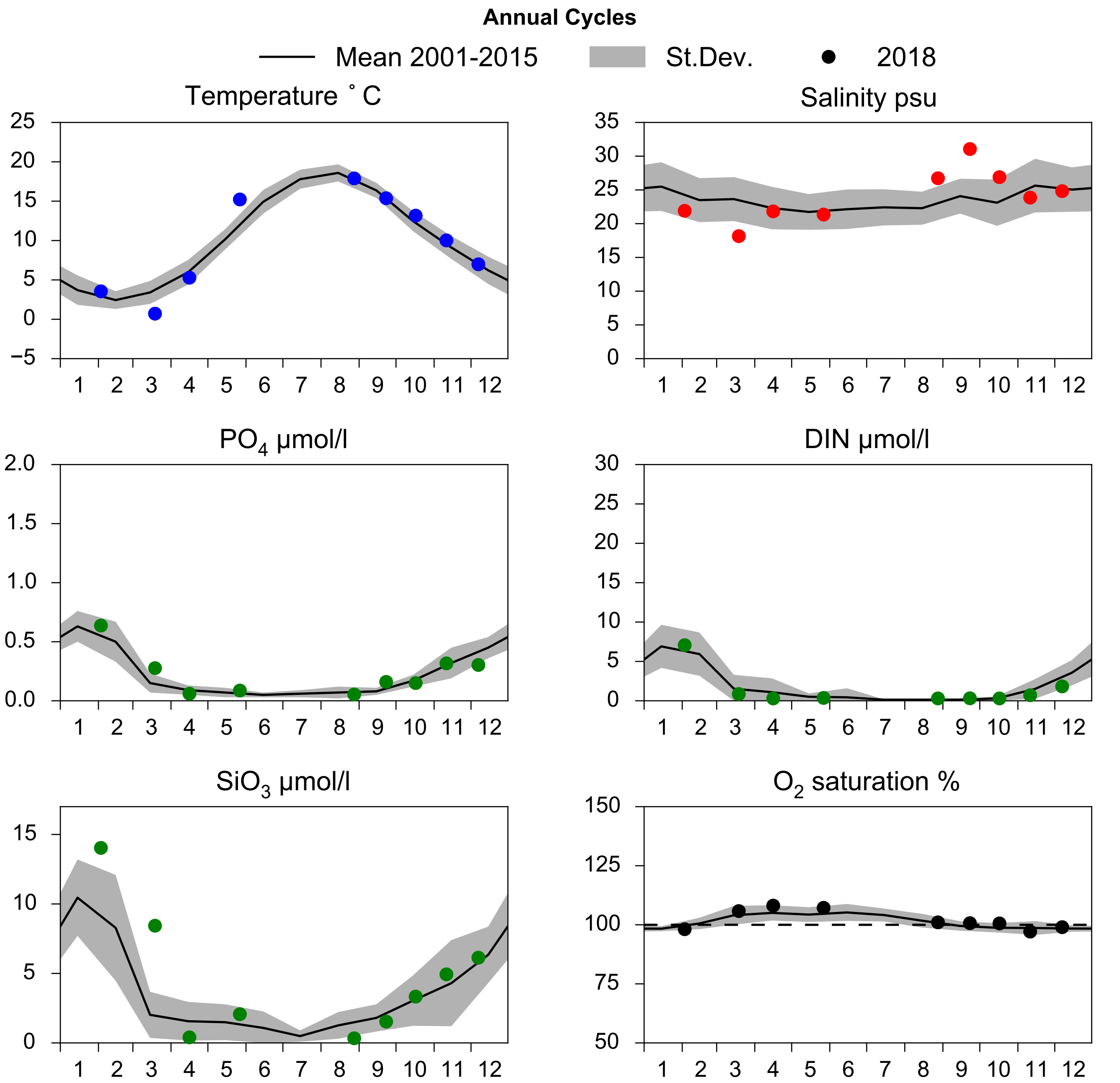
Annual Cycles



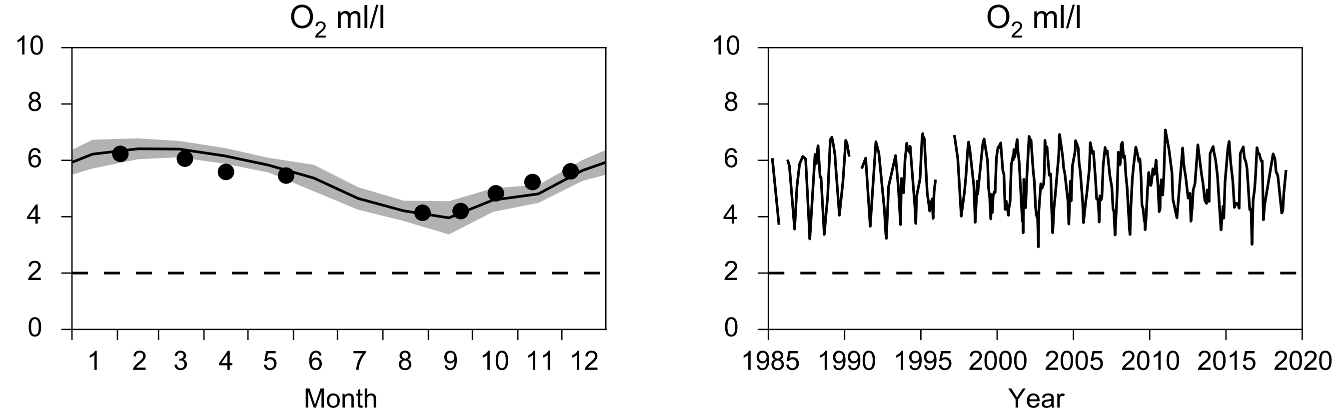
OXYGEN IN BOTTOM WATER (depth >= 75 m)



STATION FLADEN SURFACE WATER (0-10 m)

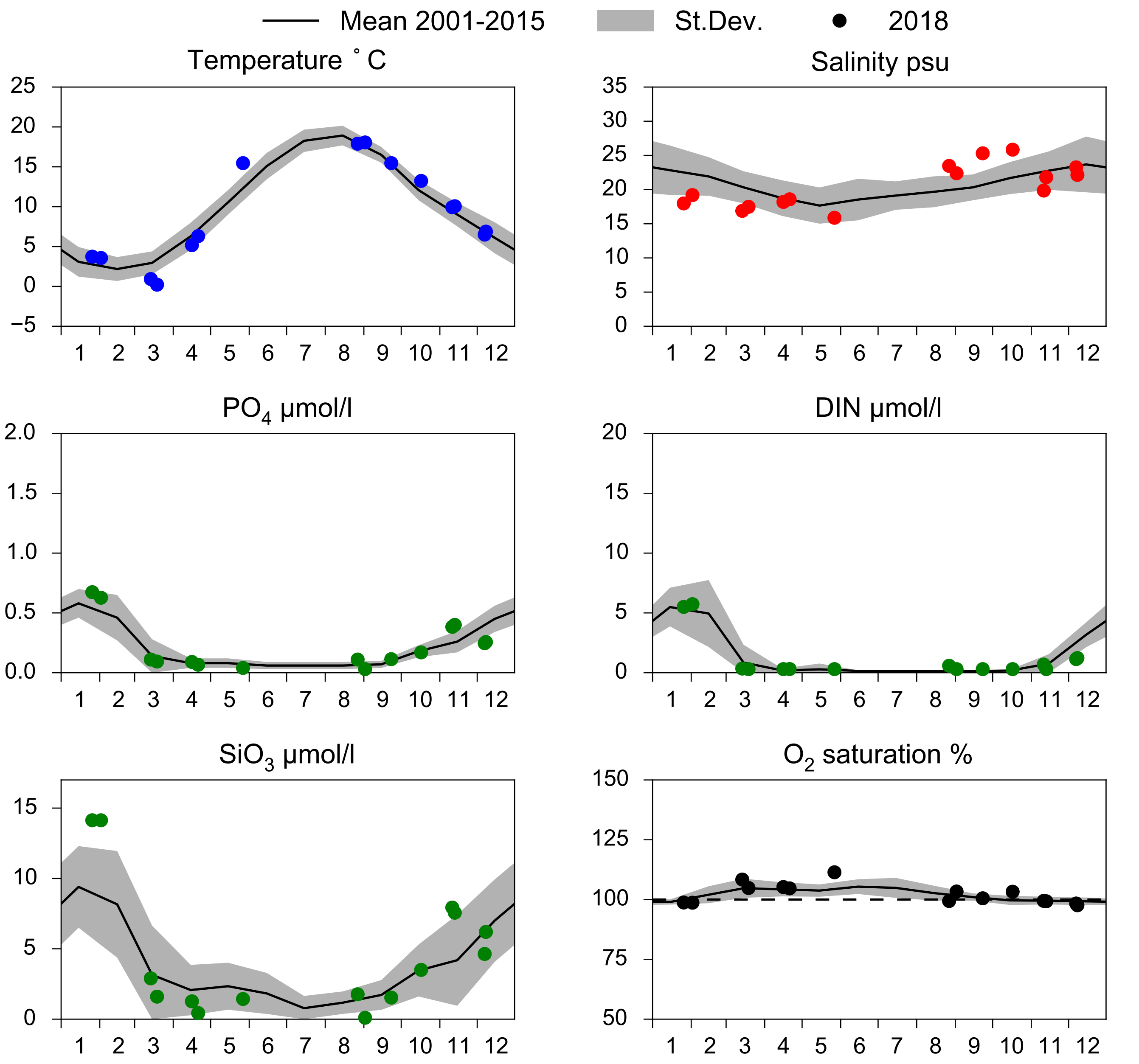


OXYGEN IN BOTTOM WATER (depth >= 74 m)

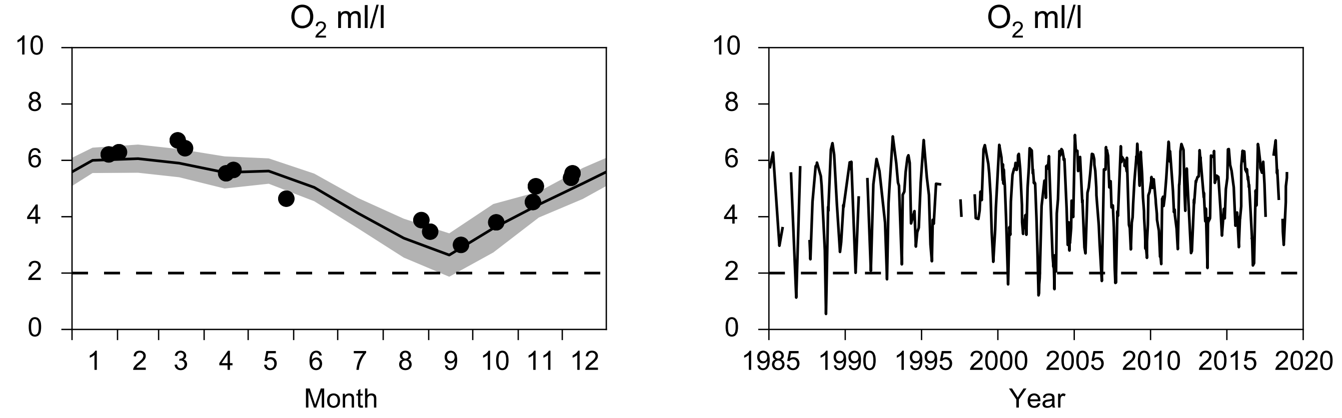


STATION ANHOLT E SURFACE WATER (0-10 m)

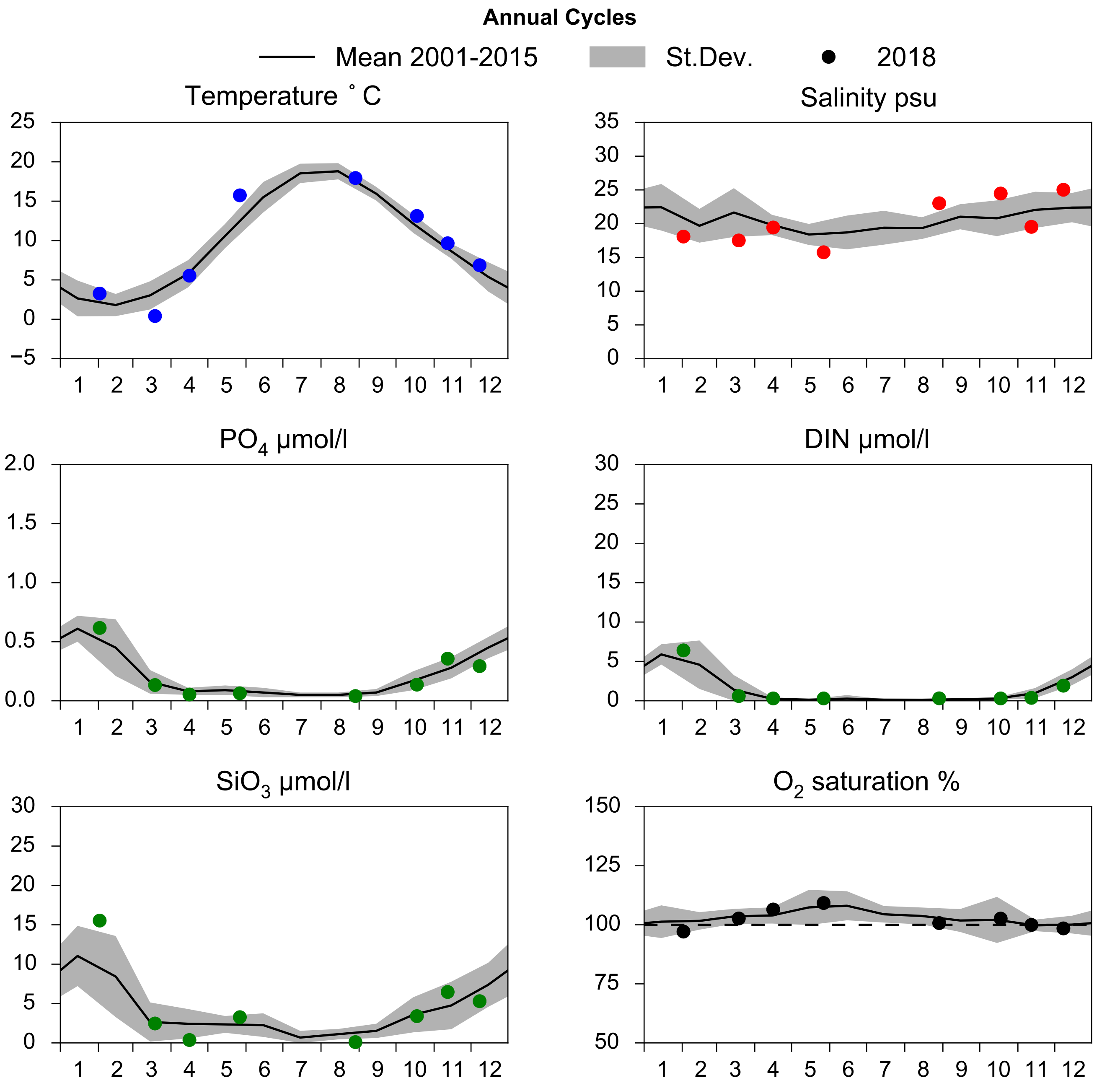
Annual Cycles



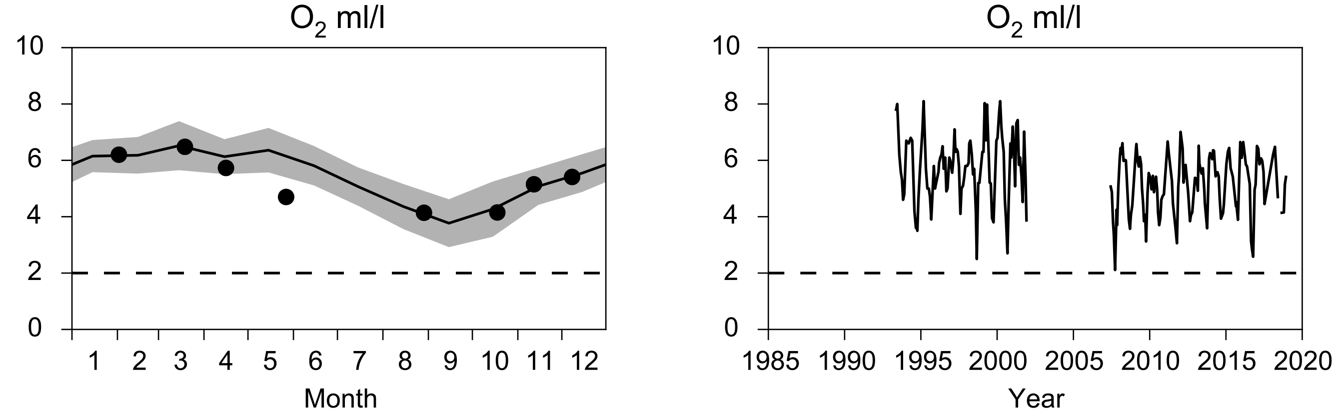
OXYGEN IN BOTTOM WATER (depth >= 52 m)



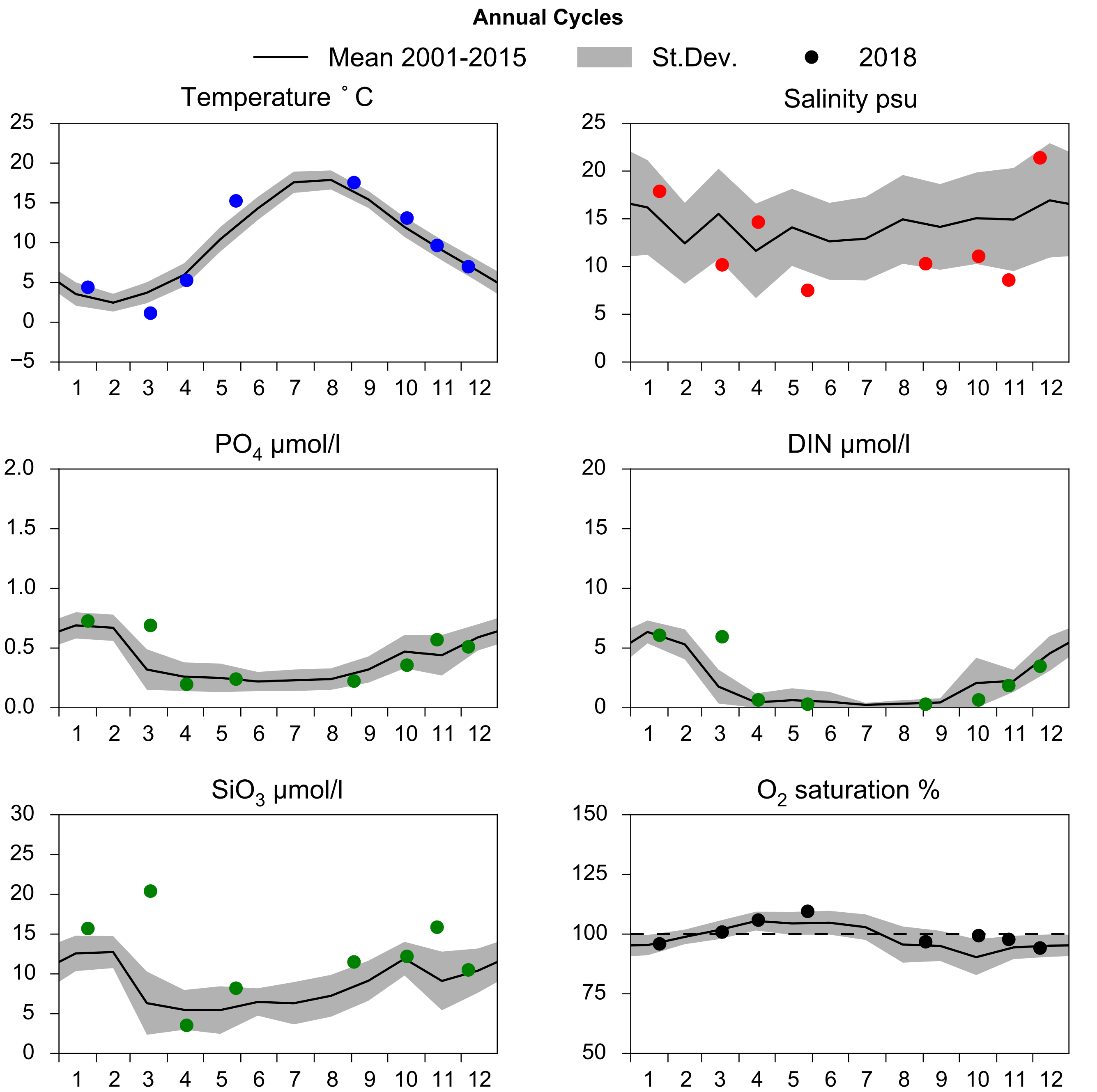
STATION N14 FALKENBERG SURFACE WATER (0-10 m)



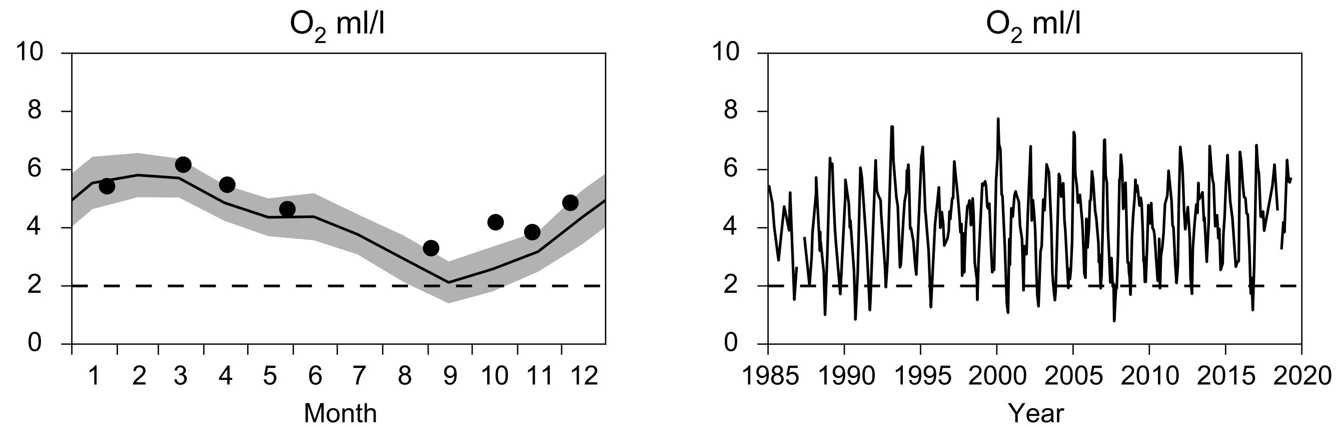
OXYGEN IN BOTTOM WATER (depth >= 25 m)



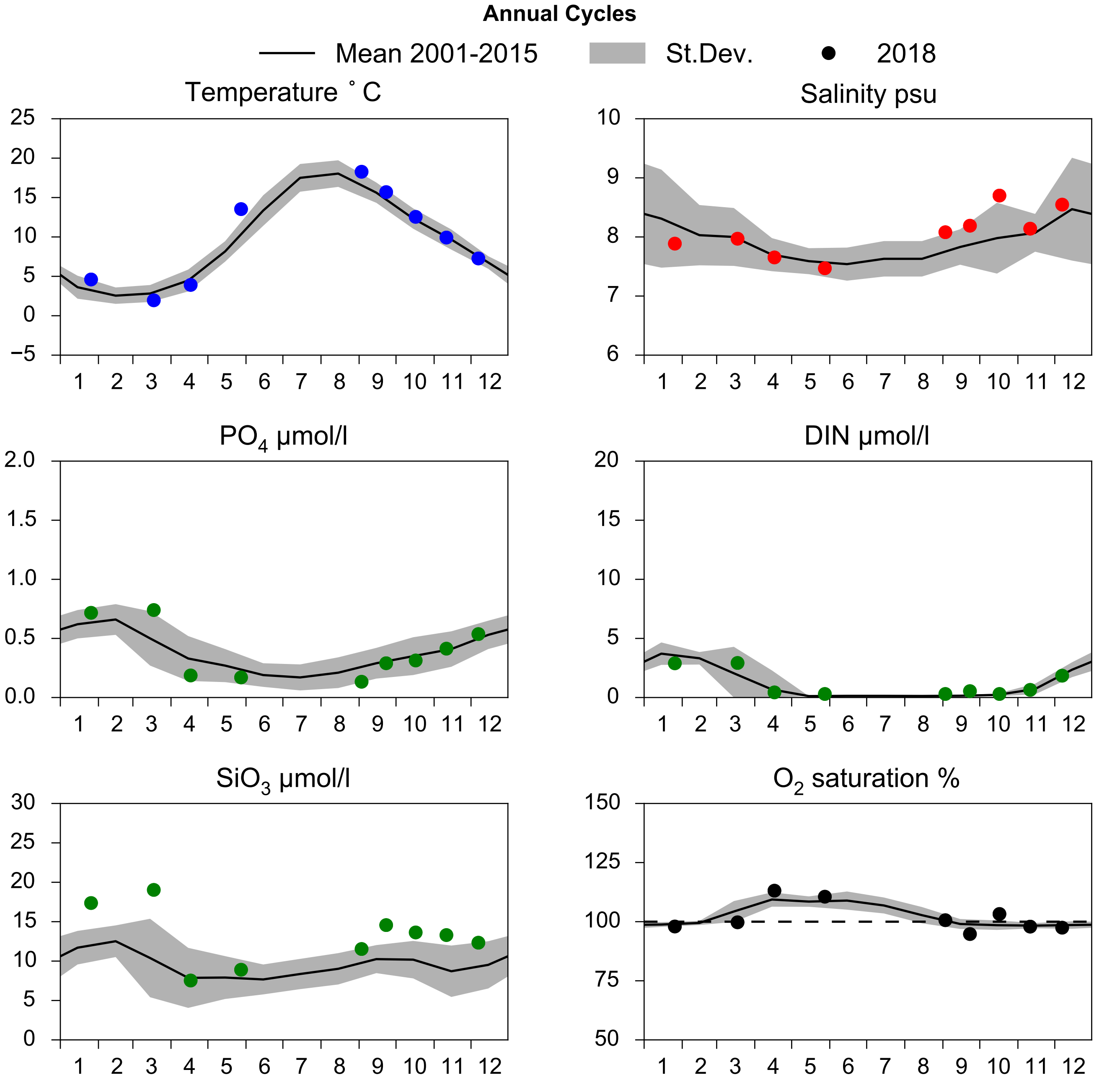
STATION W LANDSKRONA SURFACE WATER (0-10 m)



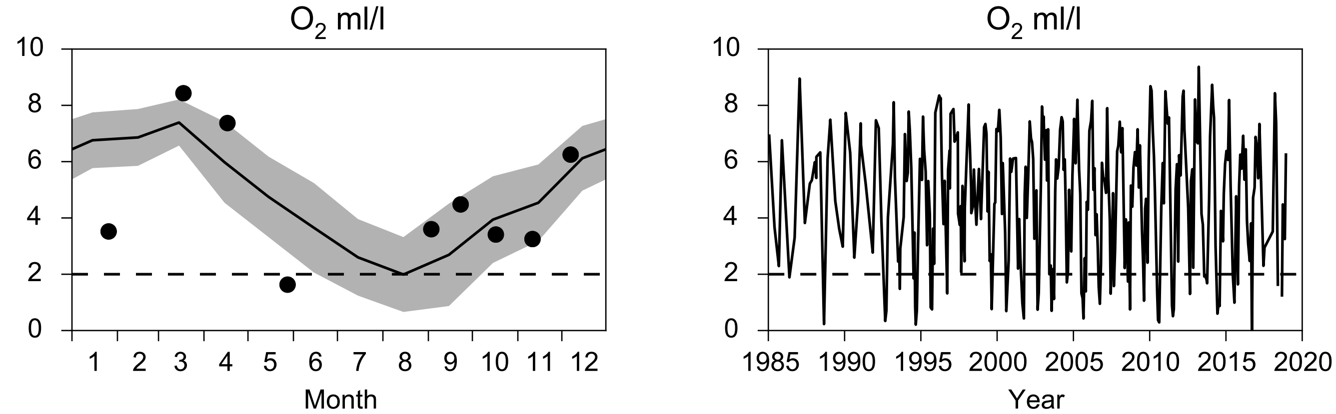
OXYGEN IN BOTTOM WATER (depth >= 40 m)



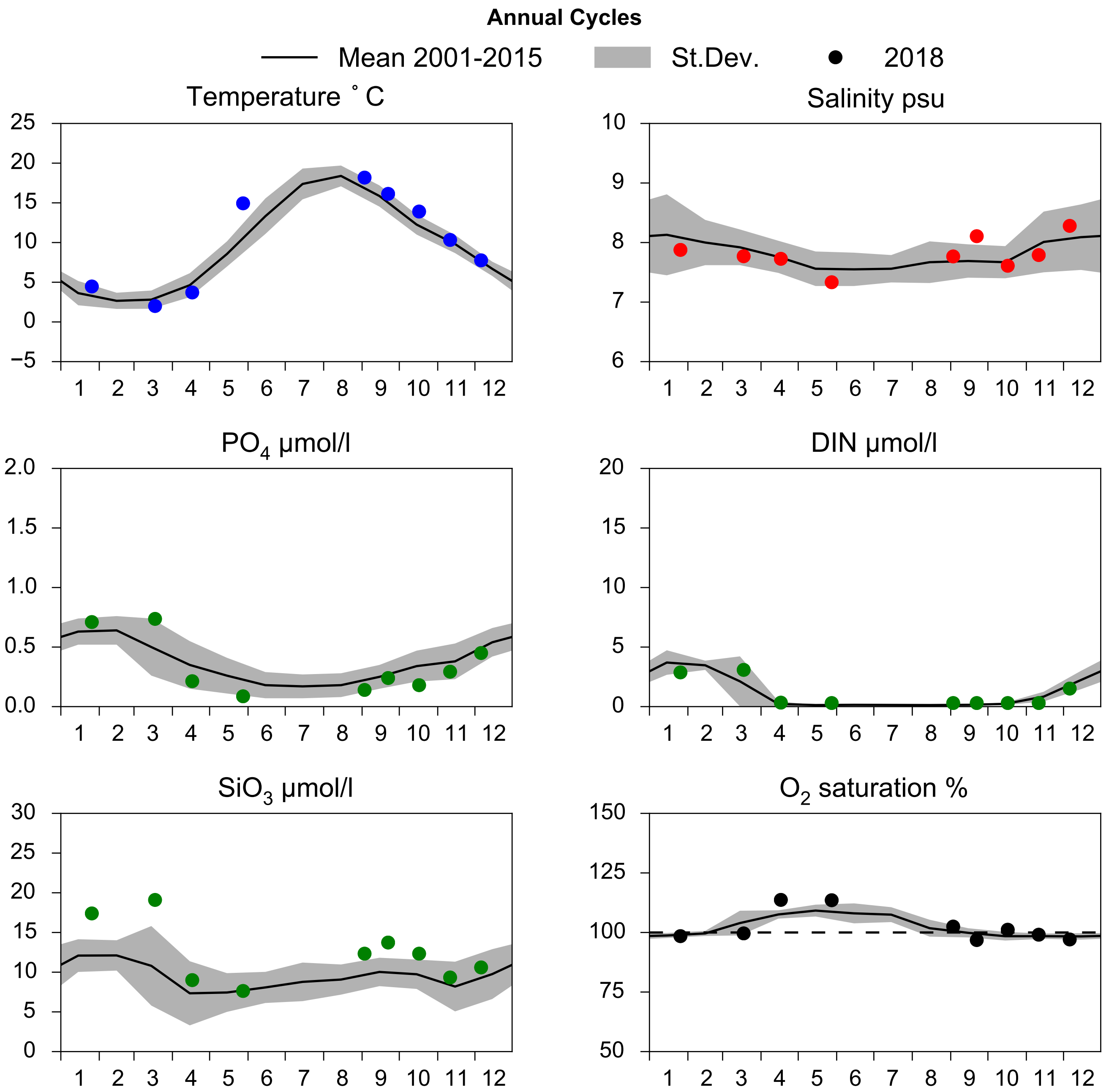
STATION BY1 SURFACE WATER (0-10 m)



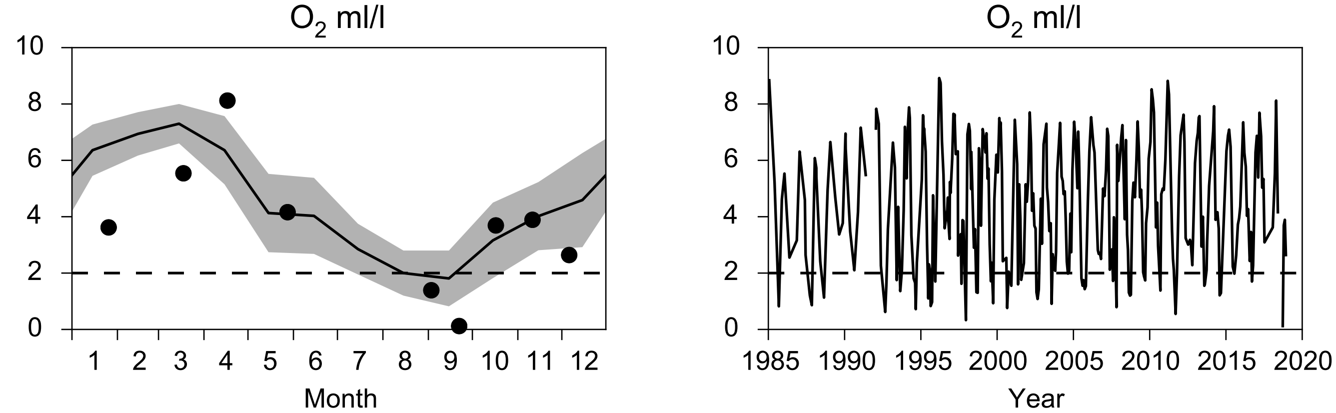
OXYGEN IN BOTTOM WATER (depth >= 40 m)



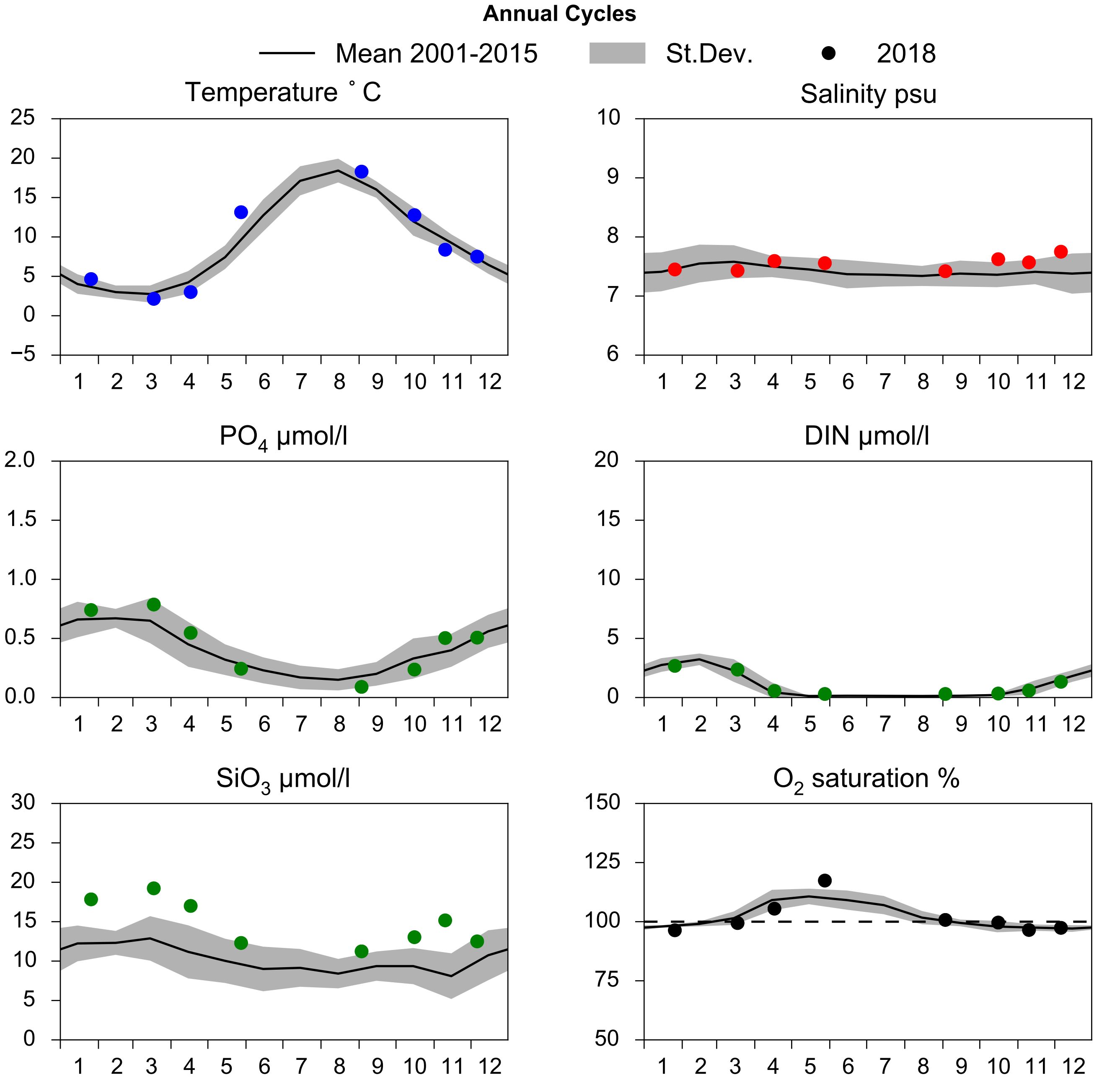
STATION BY2 ARKONA SURFACE WATER (0-10 m)



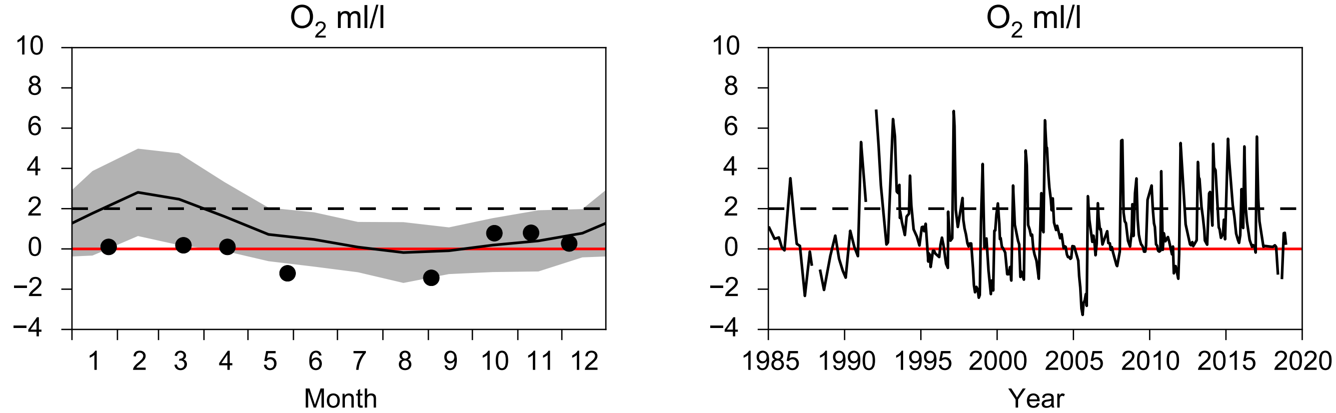
OXYGEN IN BOTTOM WATER (depth >= 40 m)



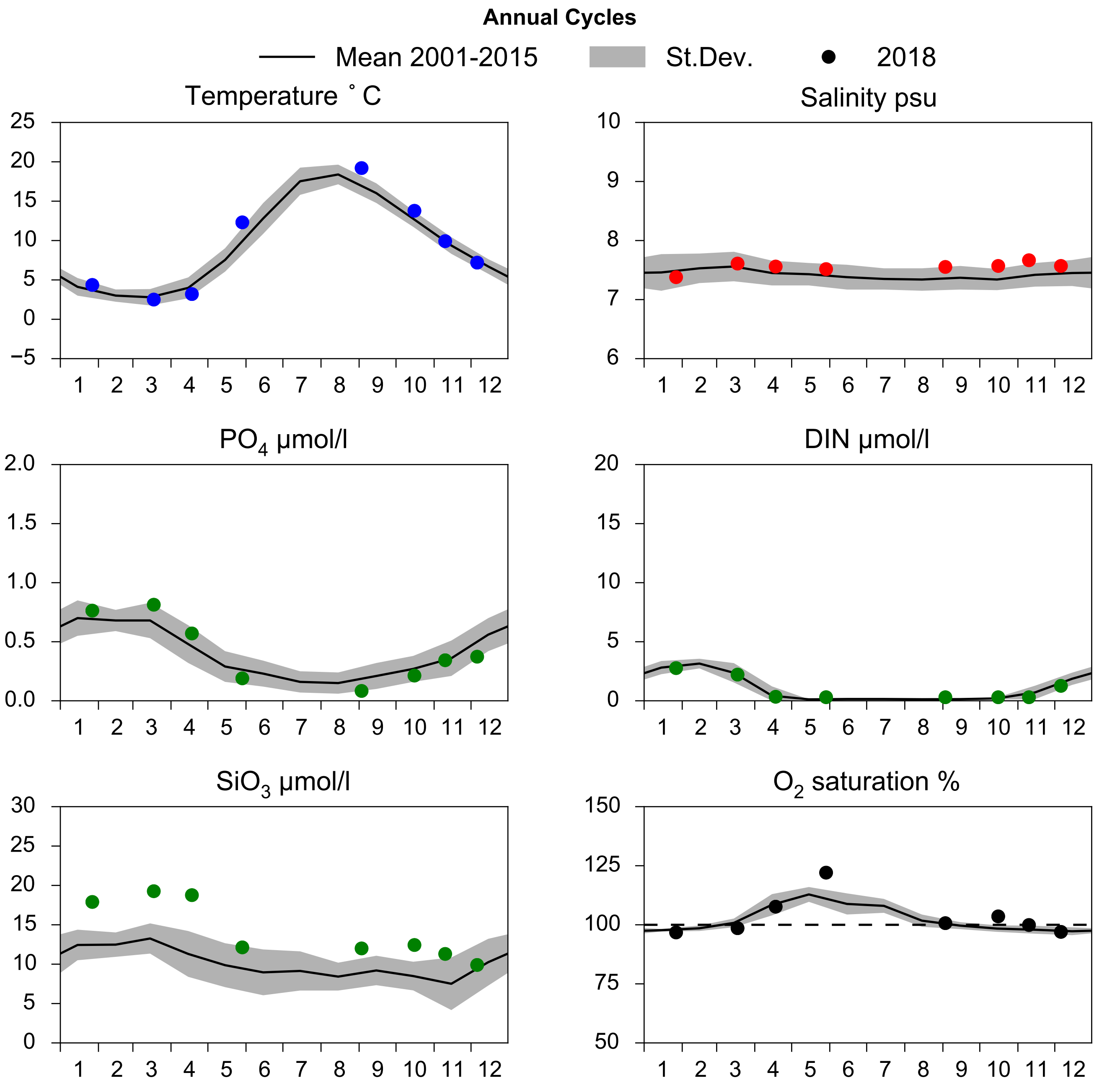
STATION BY4 CHRISTIANSÖ SURFACE WATER (0-10 m)



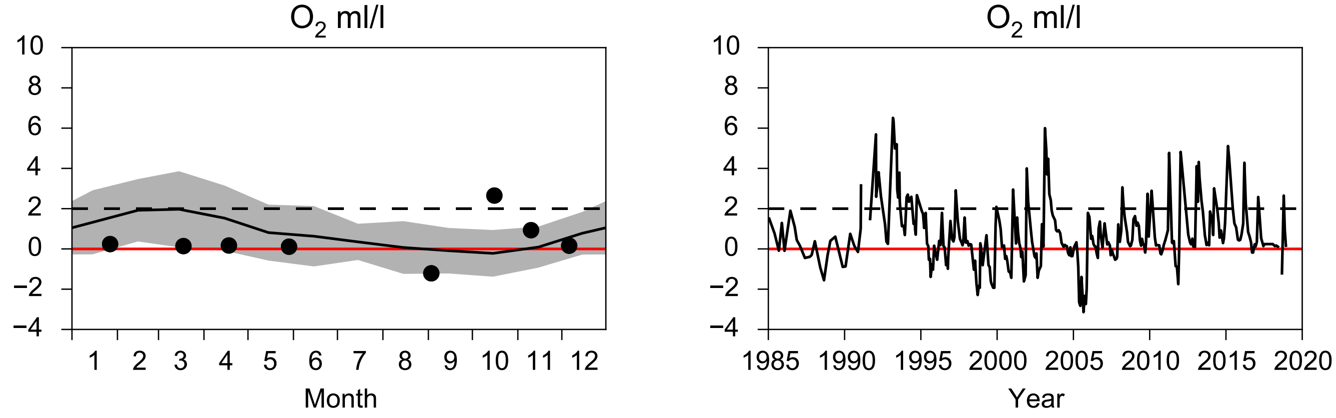
OXYGEN IN BOTTOM WATER (depth >= 80 m)



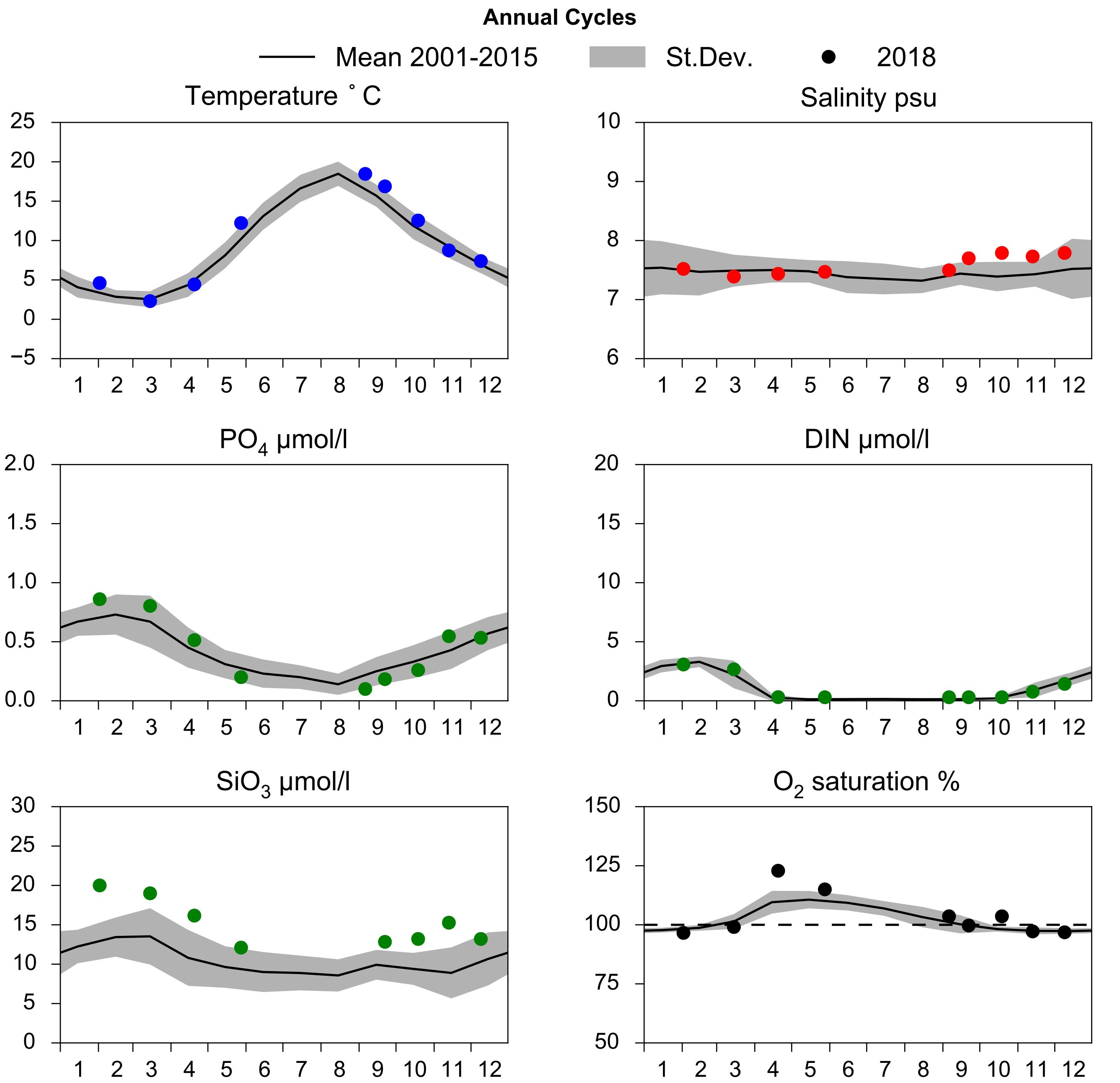
STATION BY5 BORNHOLMSDJ SURFACE WATER (0-10 m)



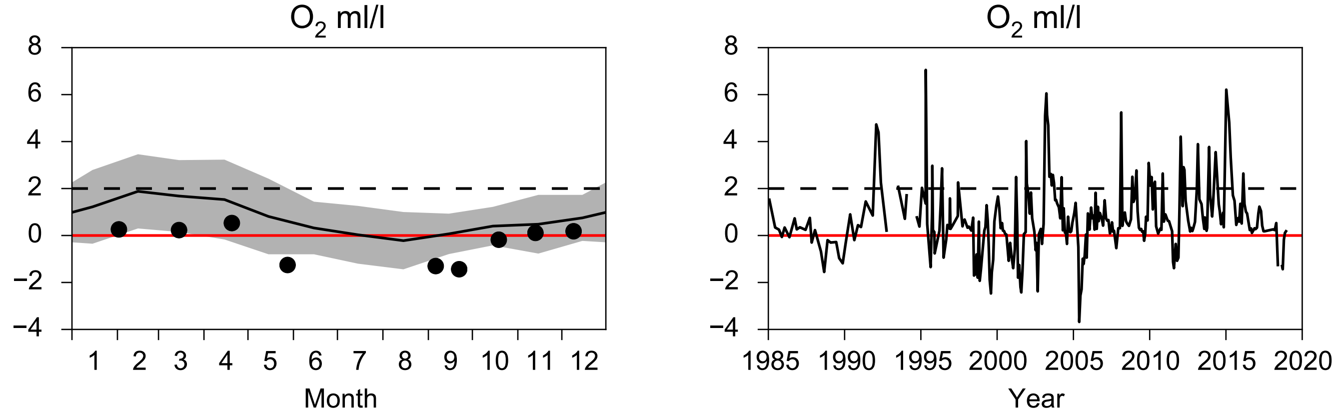
OXYGEN IN BOTTOM WATER (depth >= 80 m)



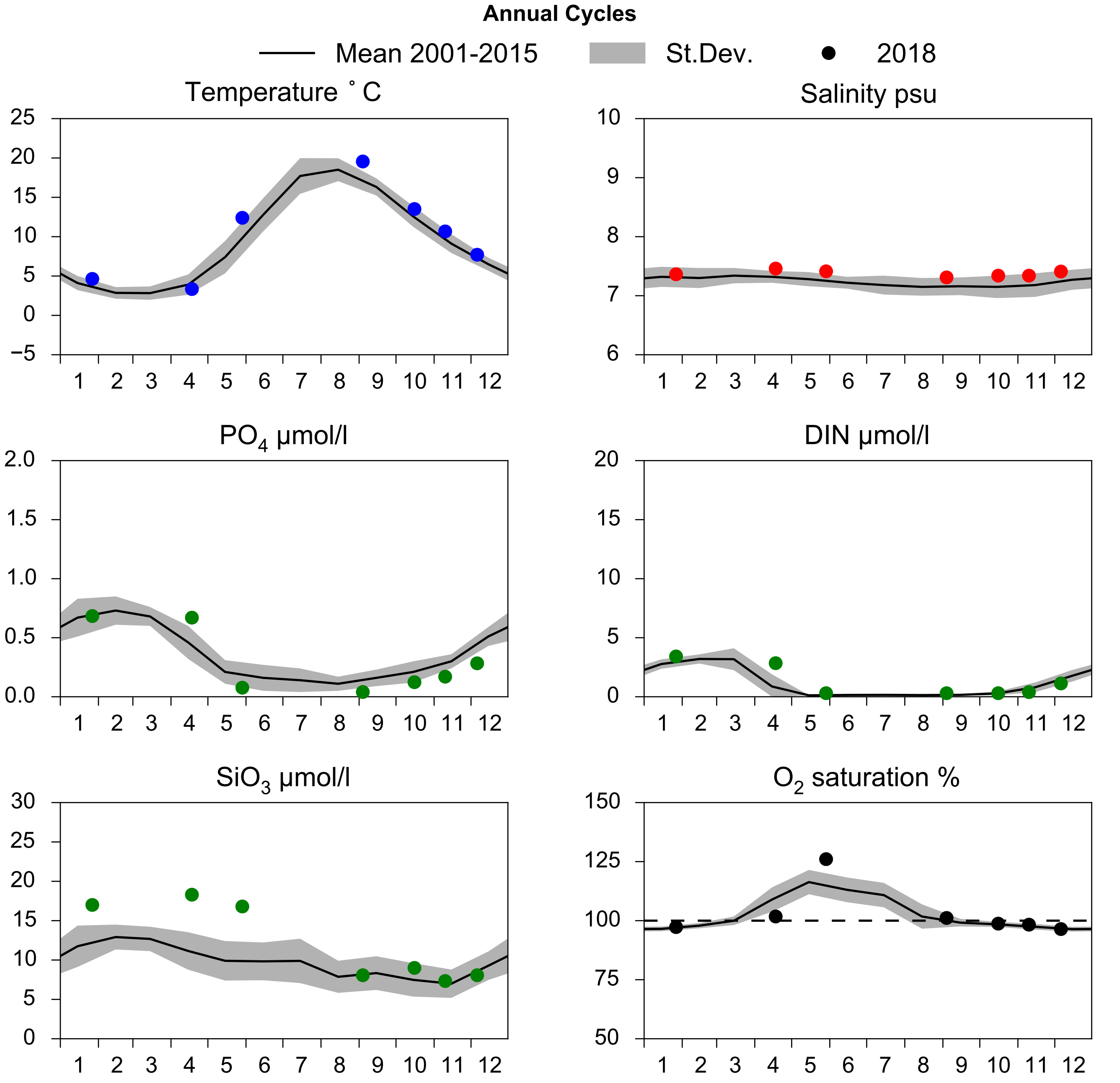
STATION HANÖBUKTEN SURFACE WATER (0-10 m)



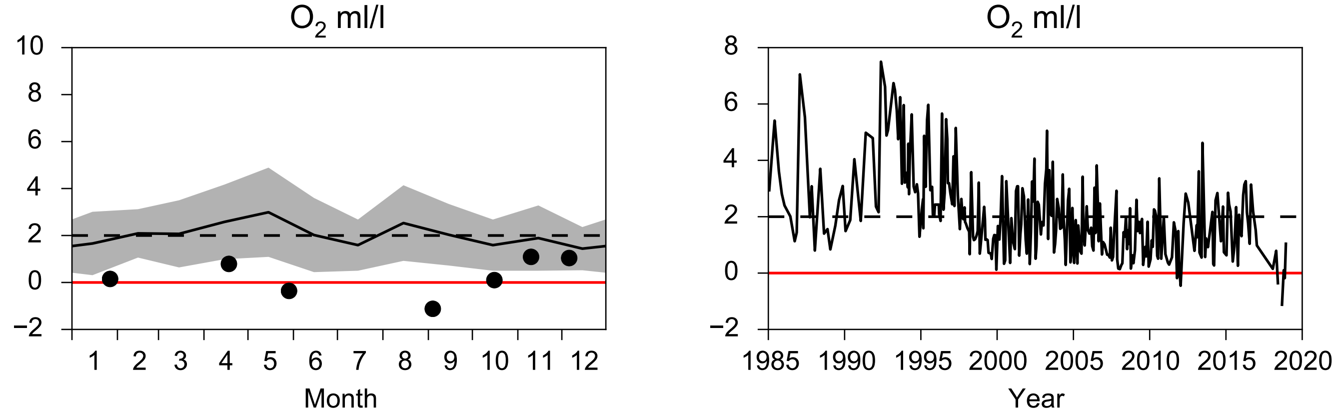
OXYGEN IN BOTTOM WATER (depth >= 70 m)



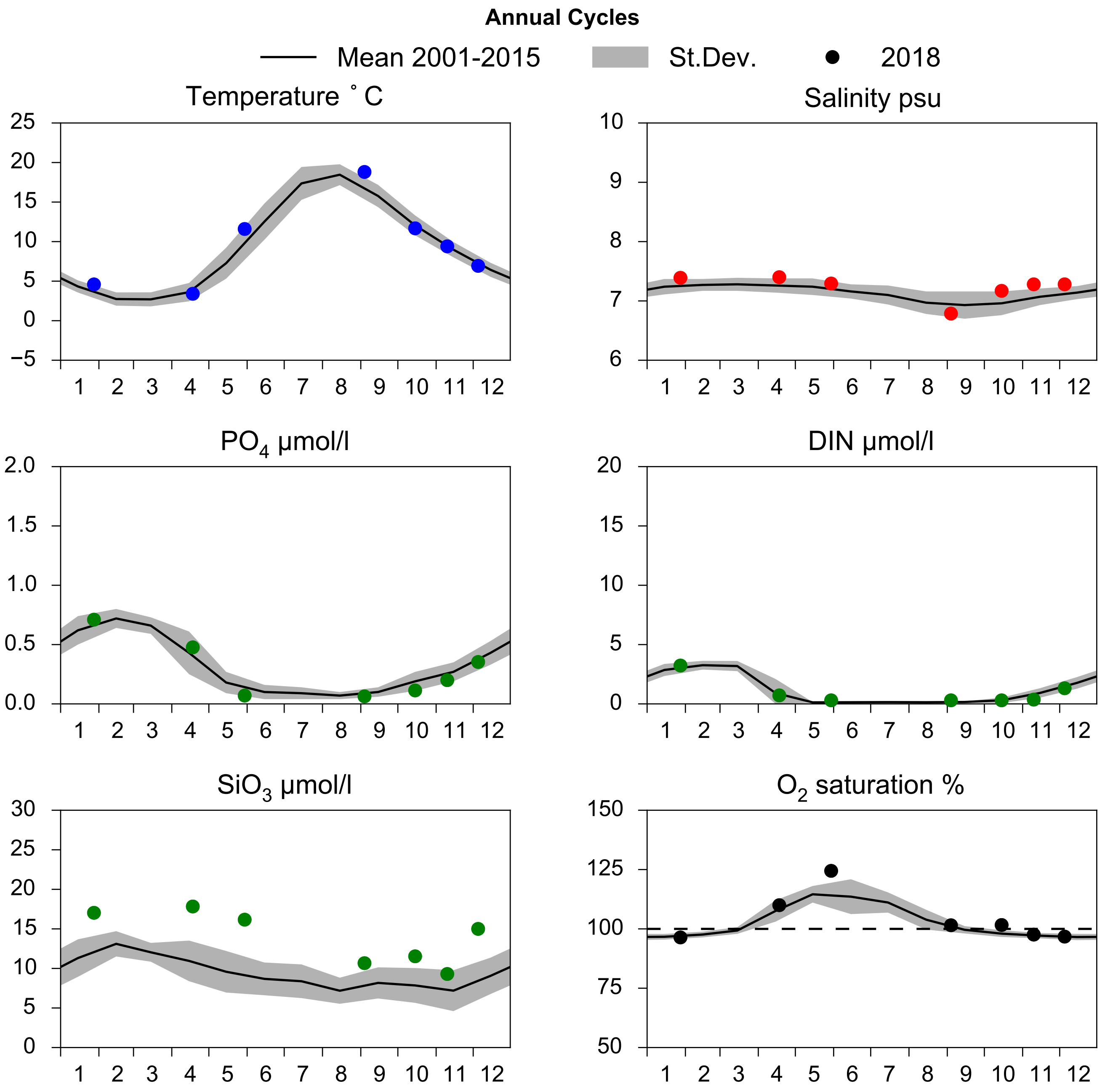
STATION BCS III-10 SURFACE WATER (0-10 m)



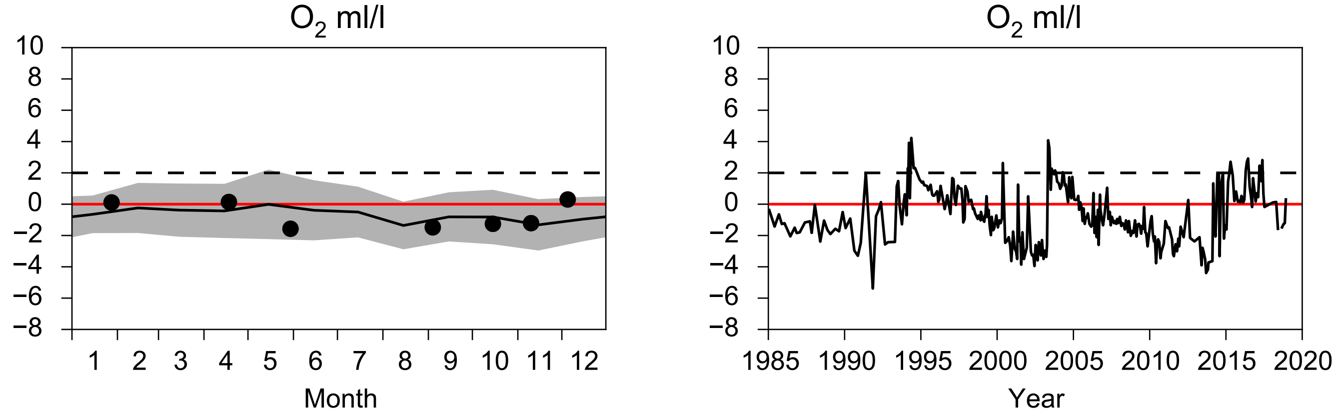
OXYGEN IN BOTTOM WATER (depth >= 80 m)



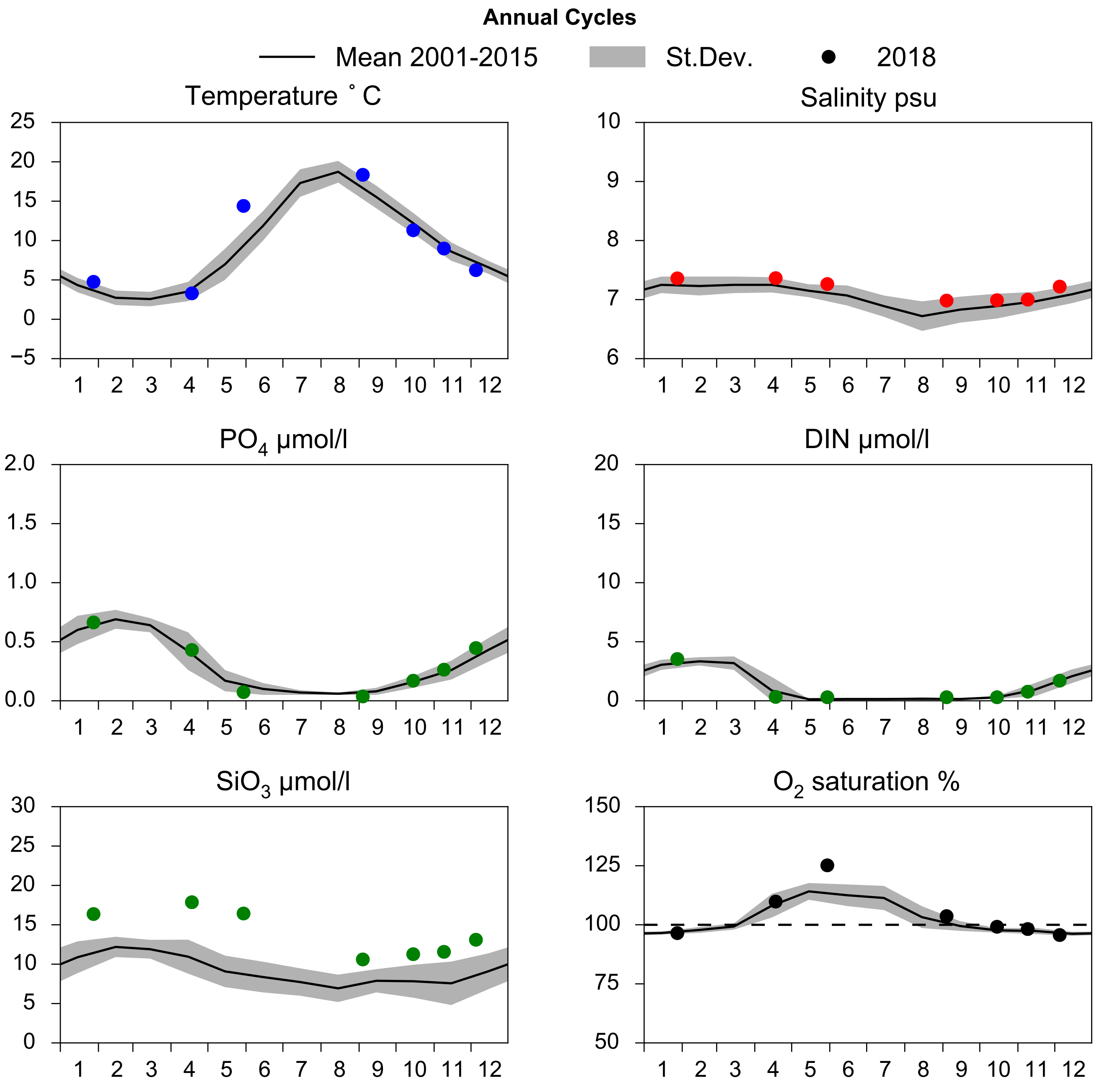
STATION BY10 SURFACE WATER (0-10 m)



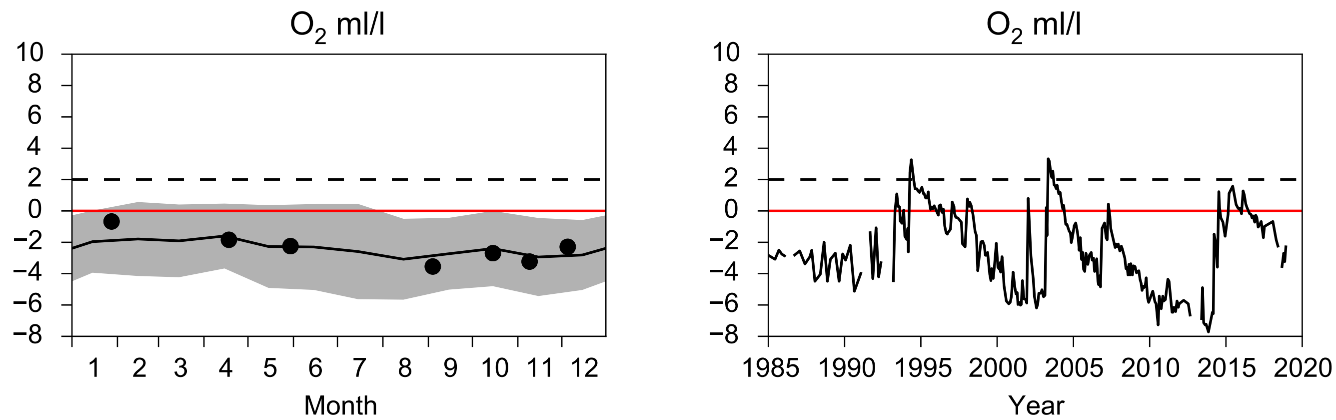
OXYGEN IN BOTTOM WATER (depth >= 125 m)



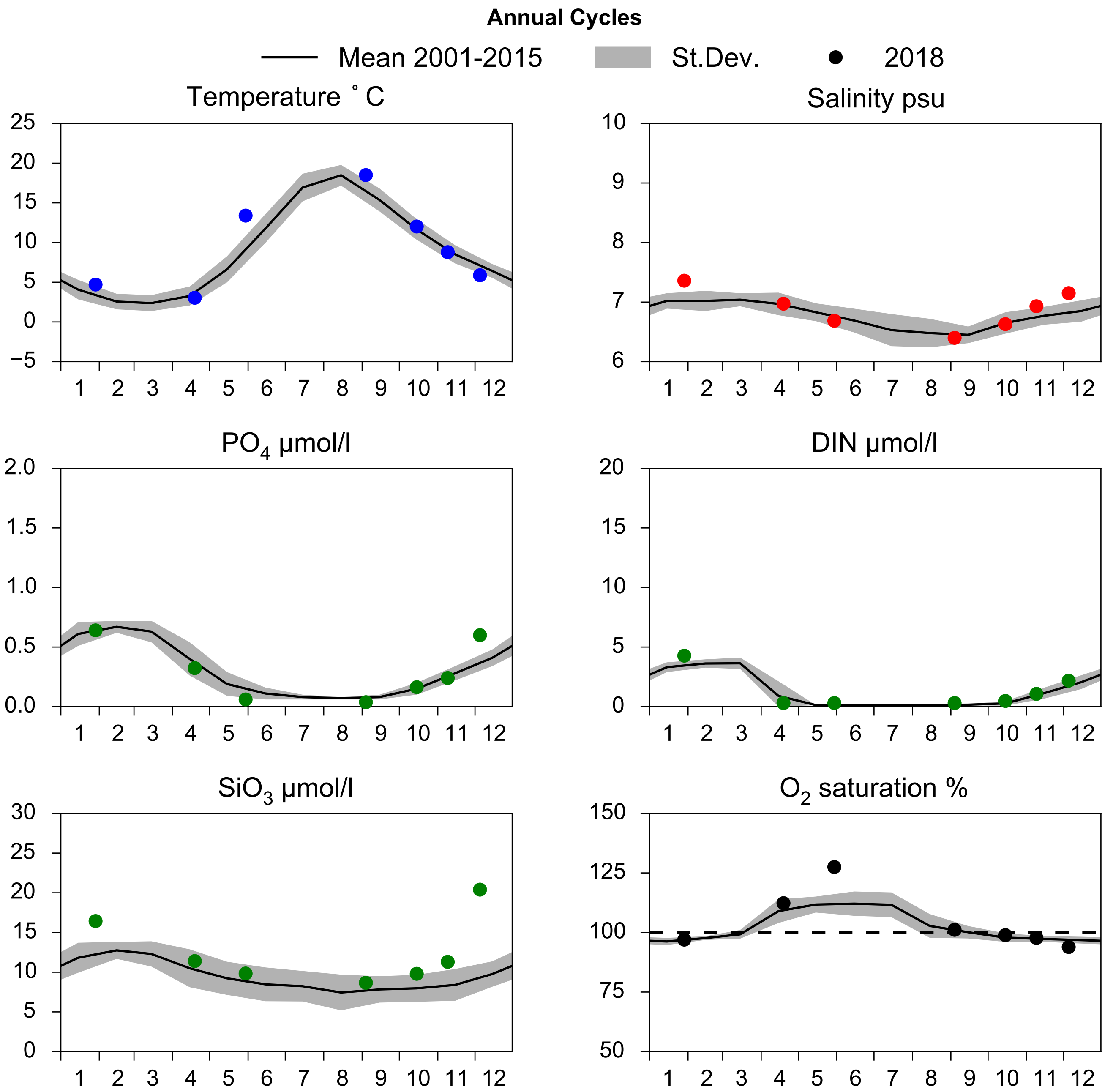
STATION BY15 GOTLANDSDJ SURFACE WATER (0-10 m)



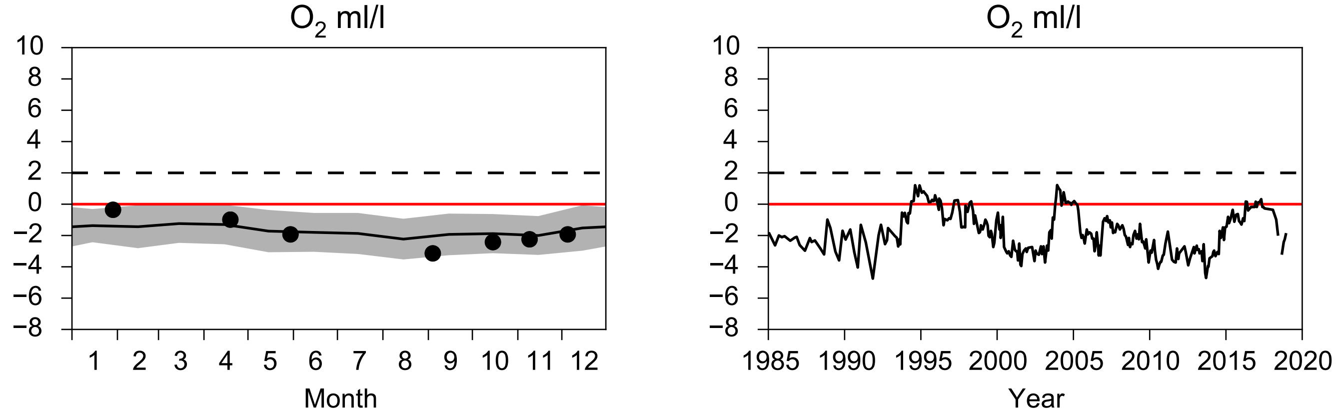
OXYGEN IN BOTTOM WATER (depth >= 225 m)



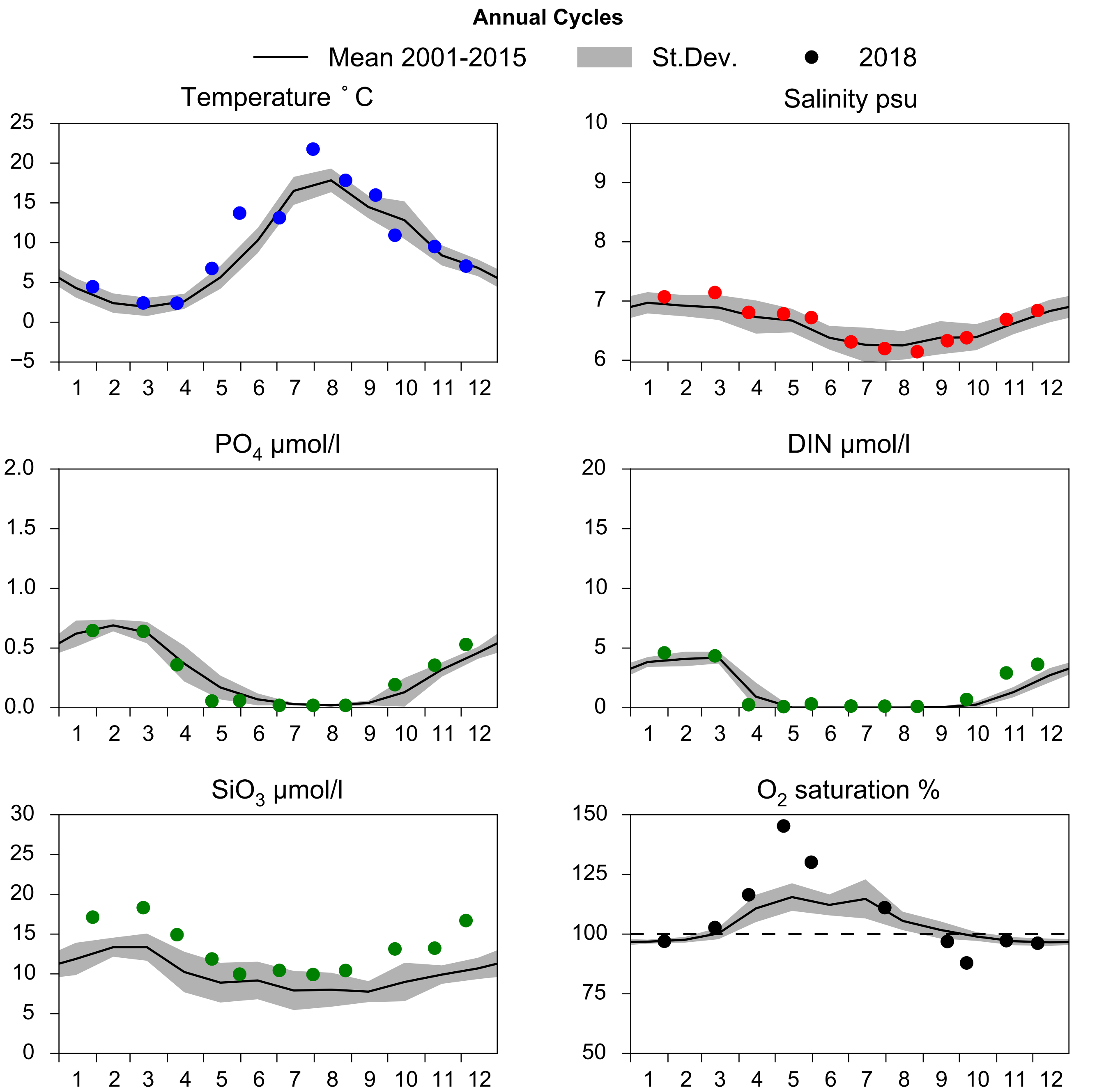
STATION BY20 FÅRÖDJ SURFACE WATER (0-10 m)



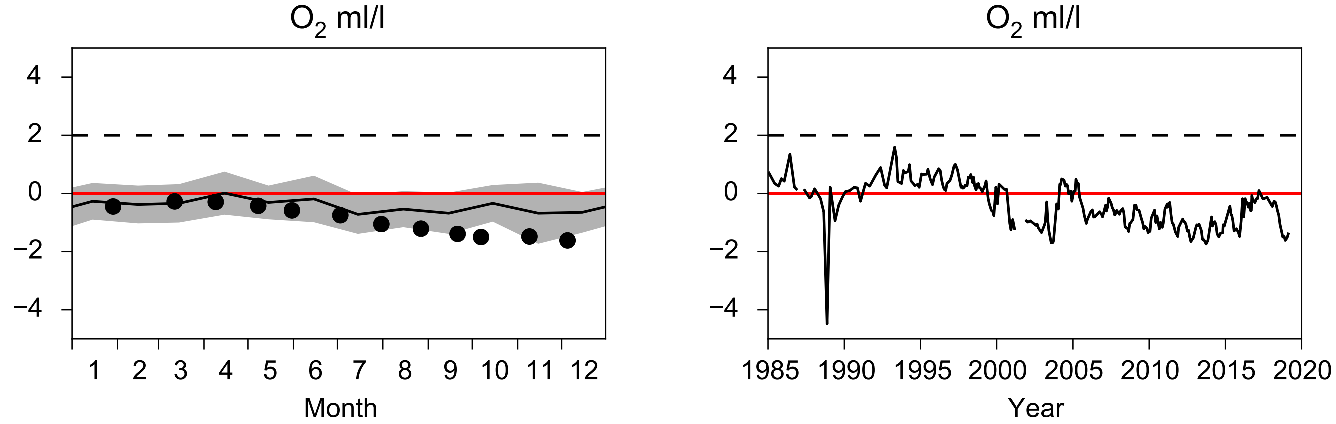
OXYGEN IN BOTTOM WATER (depth >= 175 m)



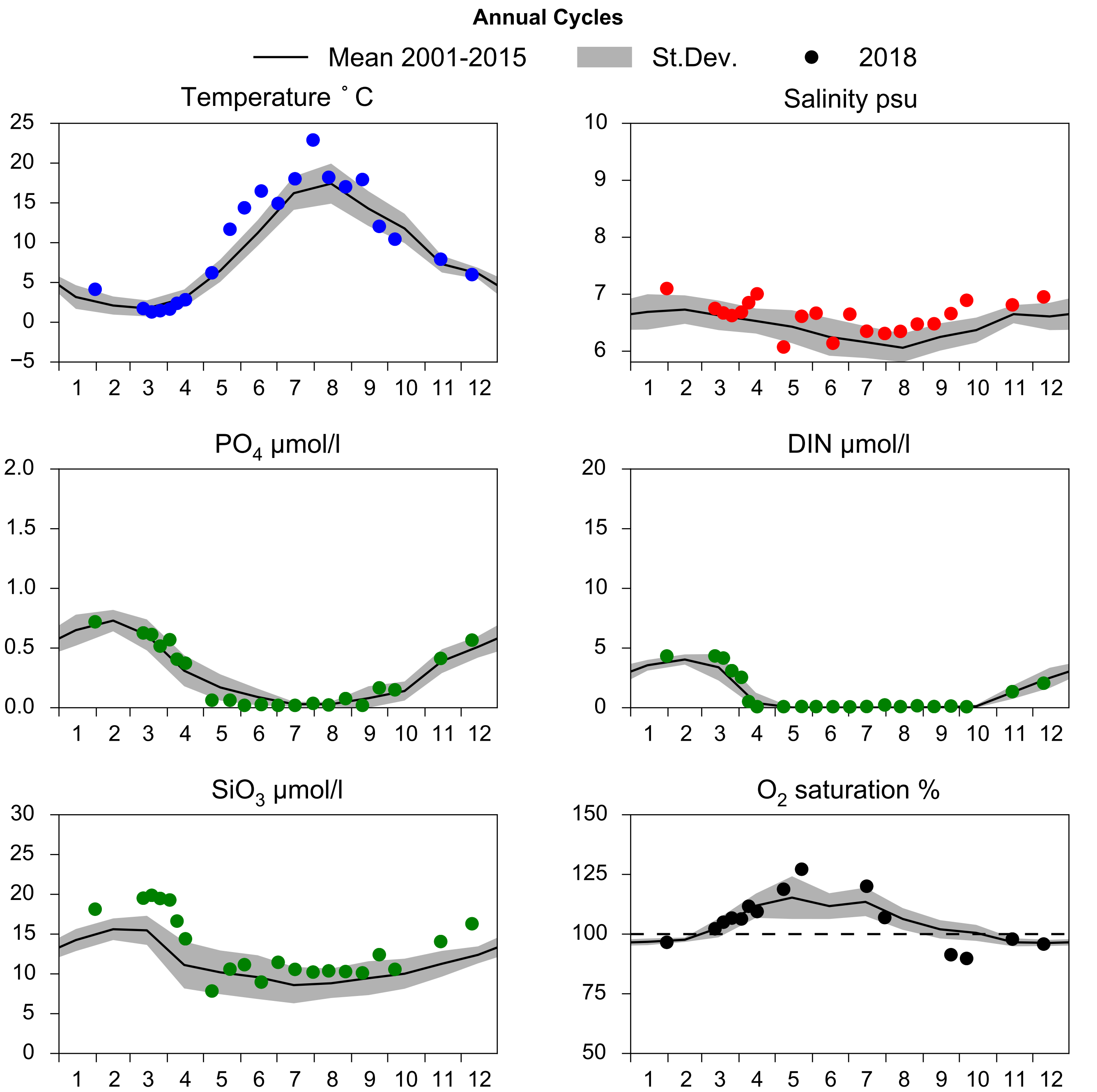
STATION BY29 / LL19 SURFACE WATER (0-10 m)



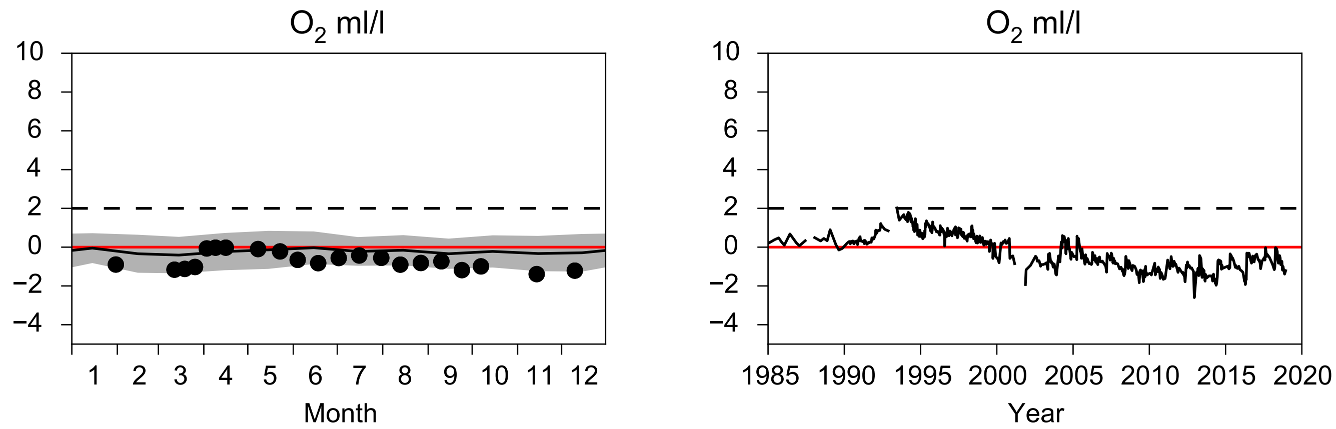
OXYGEN IN BOTTOM WATER (depth >= 150 m)



STATION BY31 LANDSORTSDJ SURFACE WATER (0-10 m)

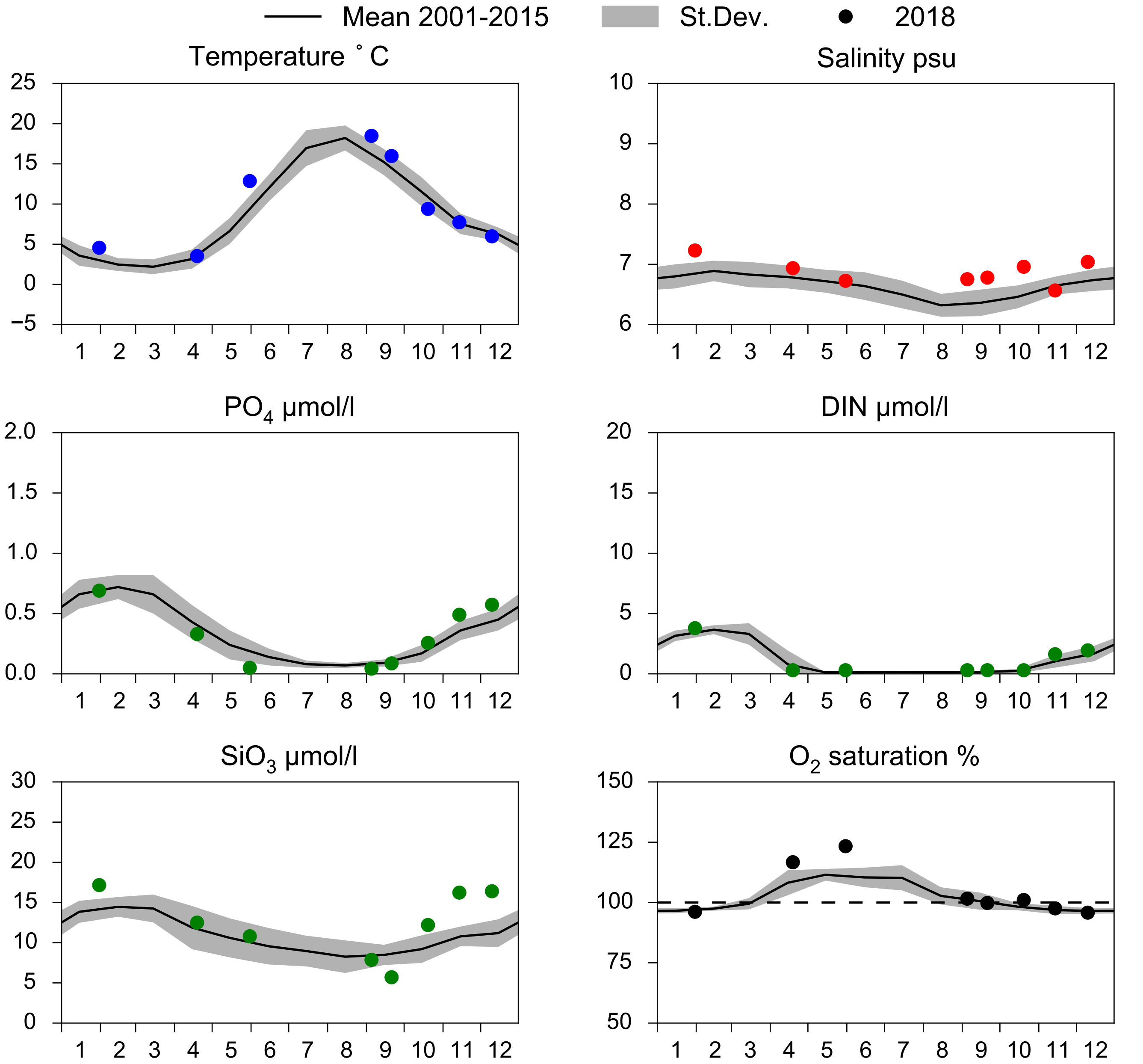


OXYGEN IN BOTTOM WATER (depth >= 425 m)

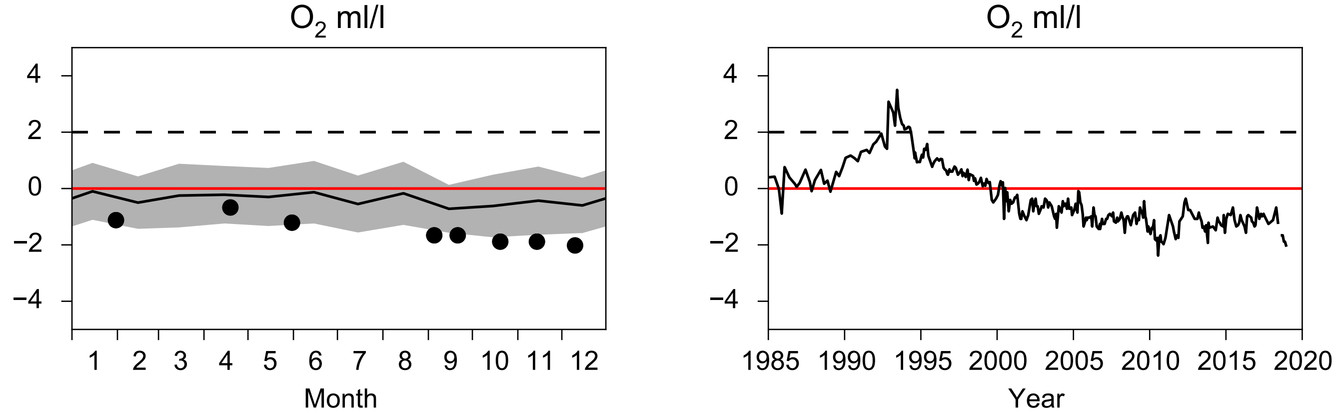


STATION BY32 NORRKÖPINGSDJ SURFACE WATER (0-10 m)

Annual Cycles

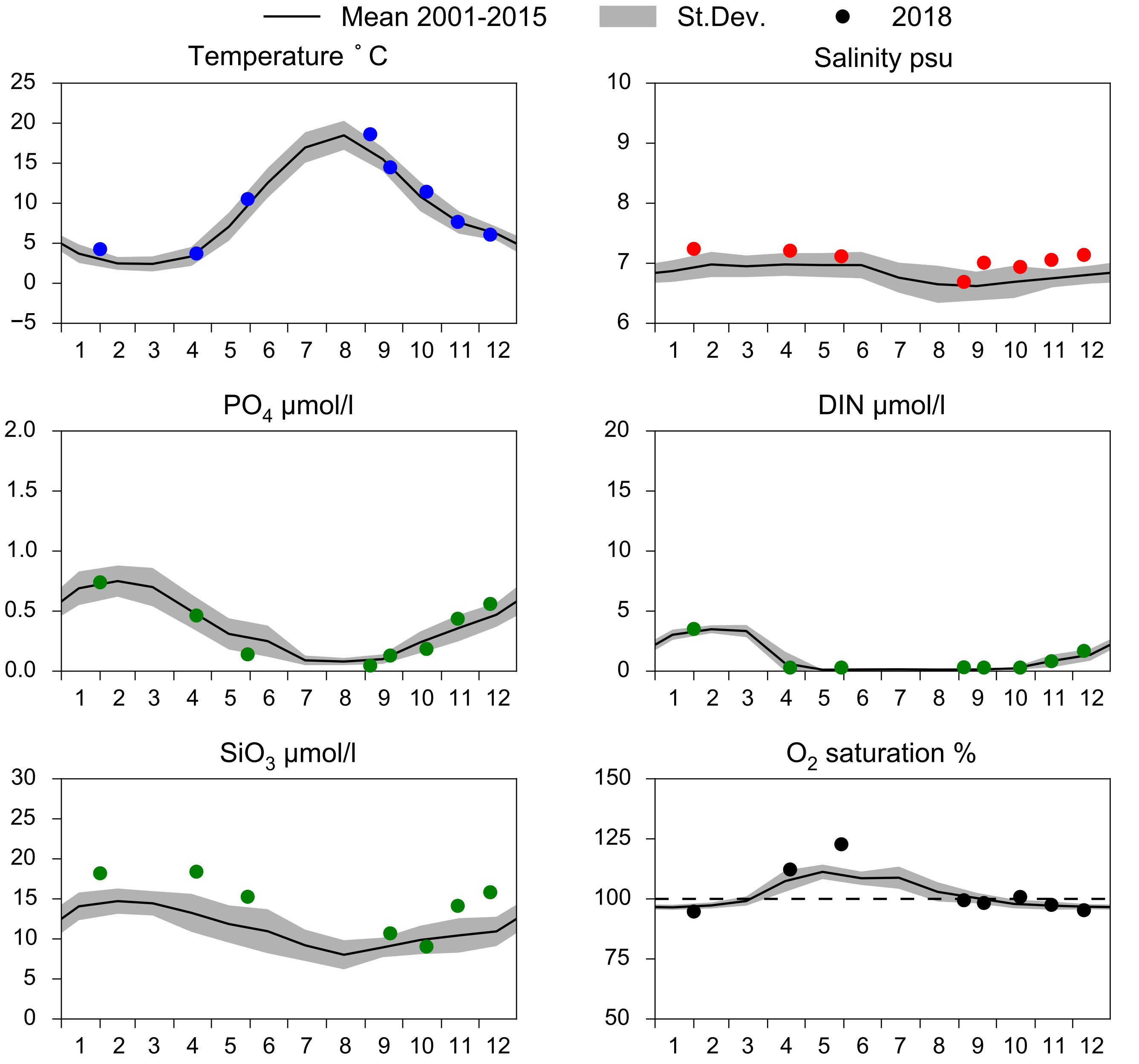


OXYGEN IN BOTTOM WATER (depth >= 175 m)

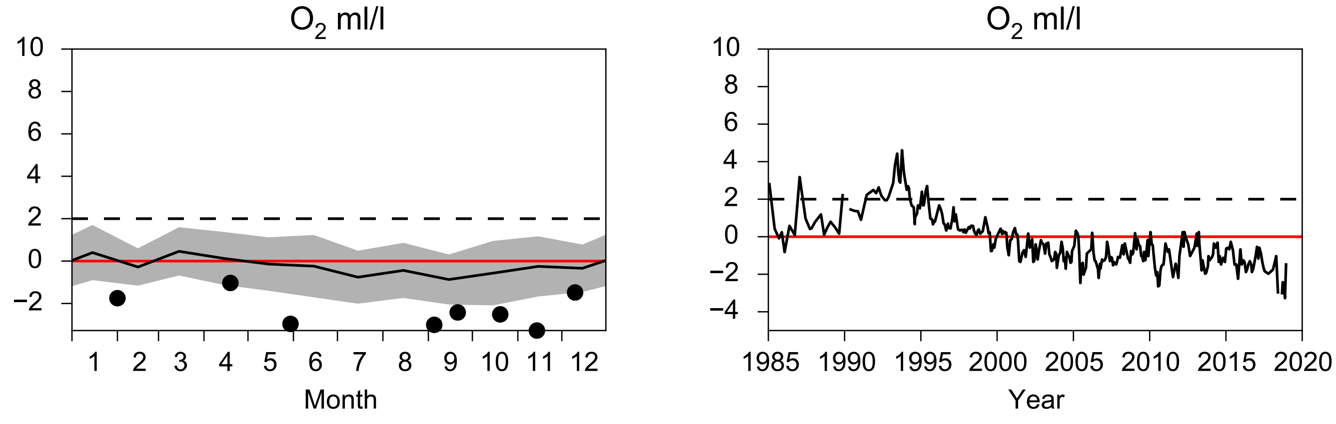


STATION BY38 KARLSÖDJ SURFACE WATER (0-10 m)

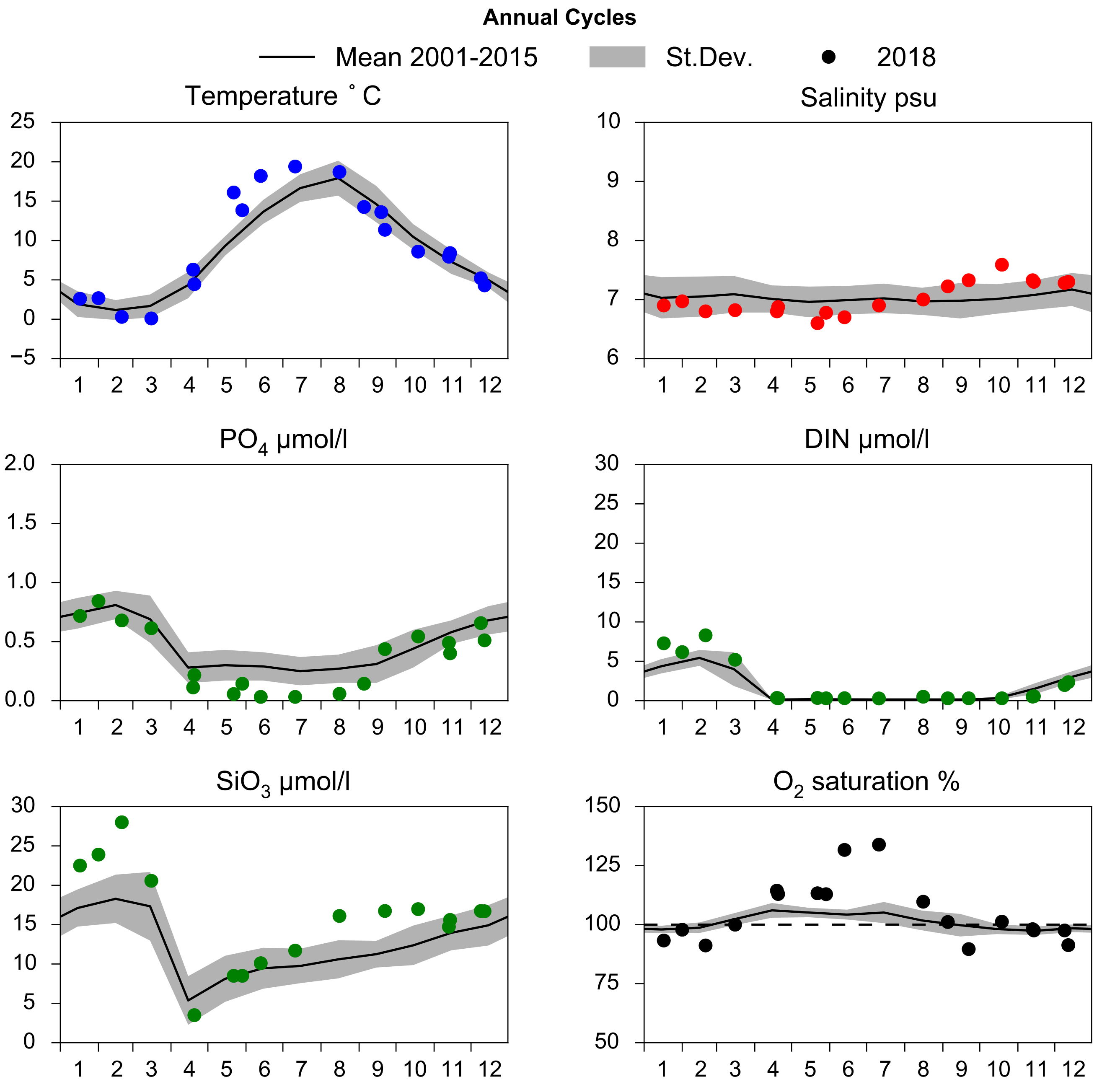
Annual Cycles



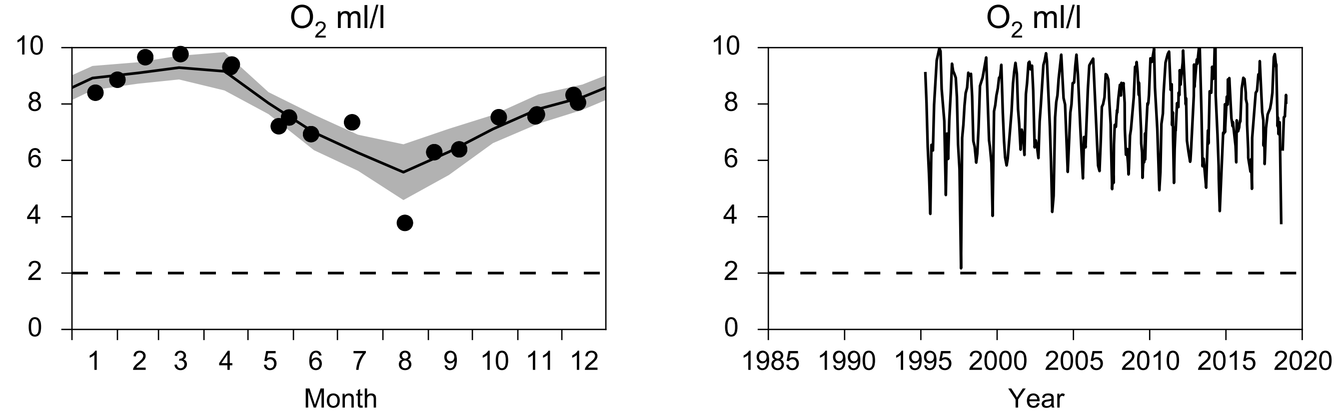
OXYGEN IN BOTTOM WATER (depth >= 100 m)



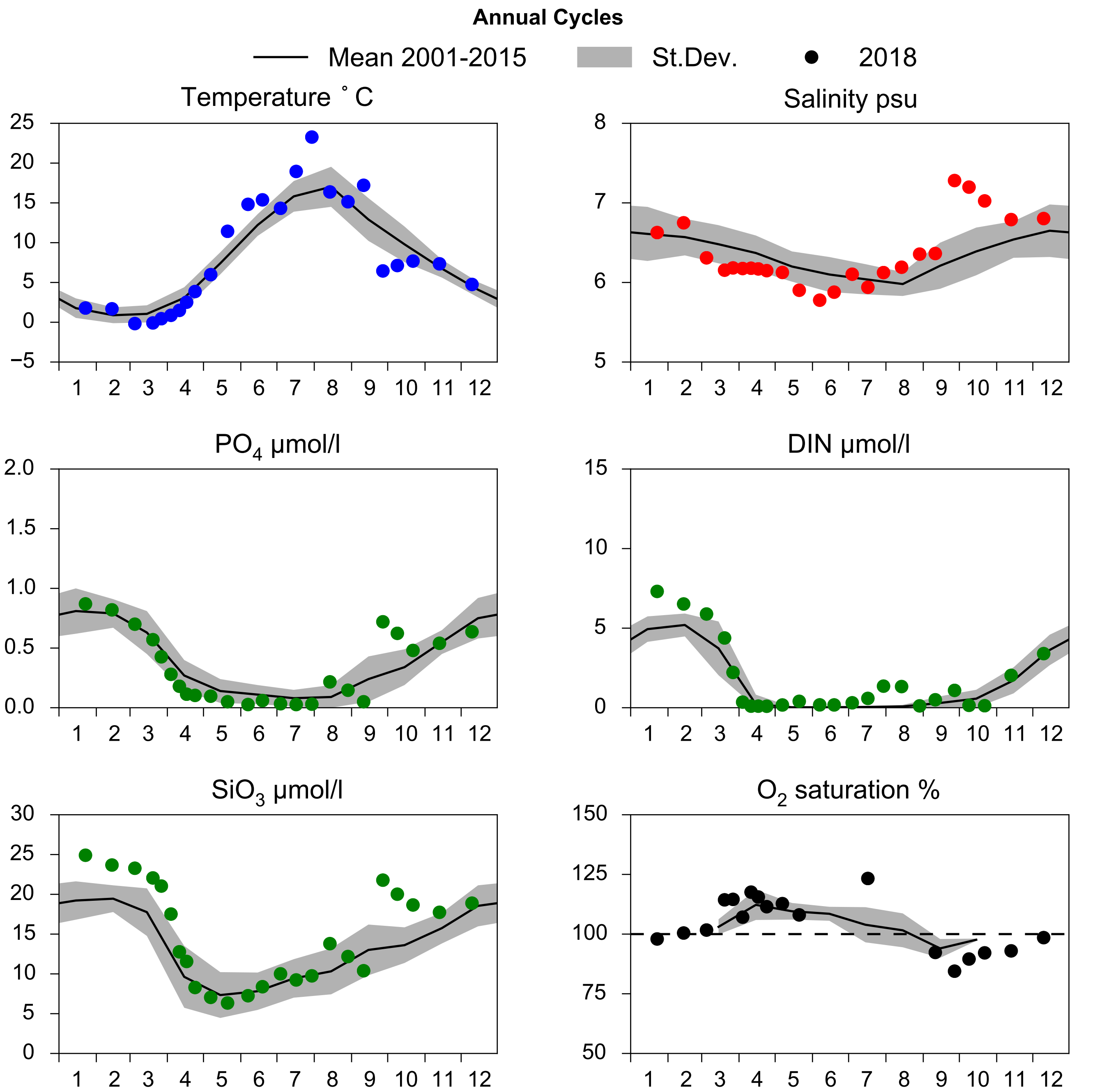
STATION REF M1V1 SURFACE WATER (0-10 m)



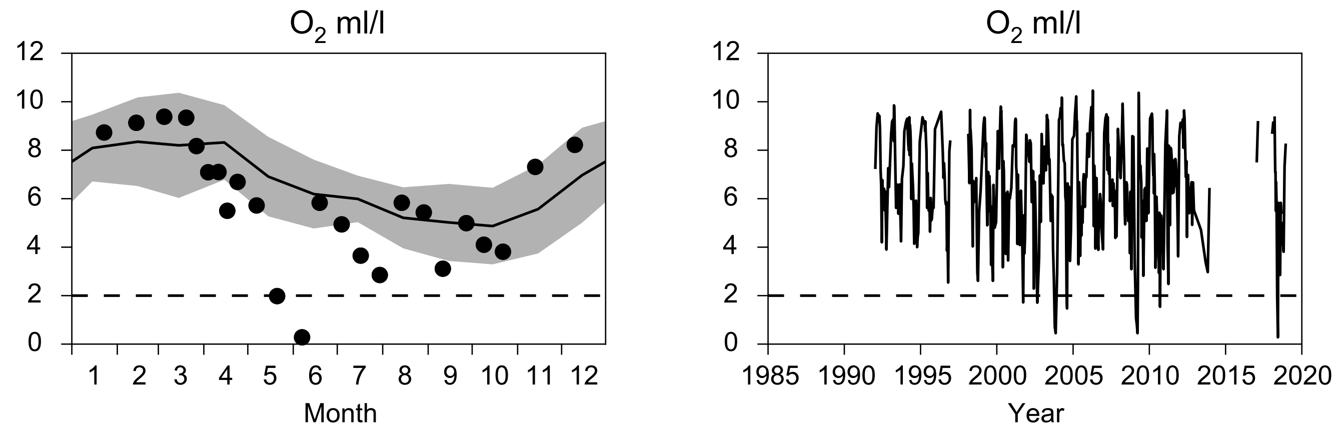
OXYGEN IN BOTTOM WATER (depth >= 17 m)



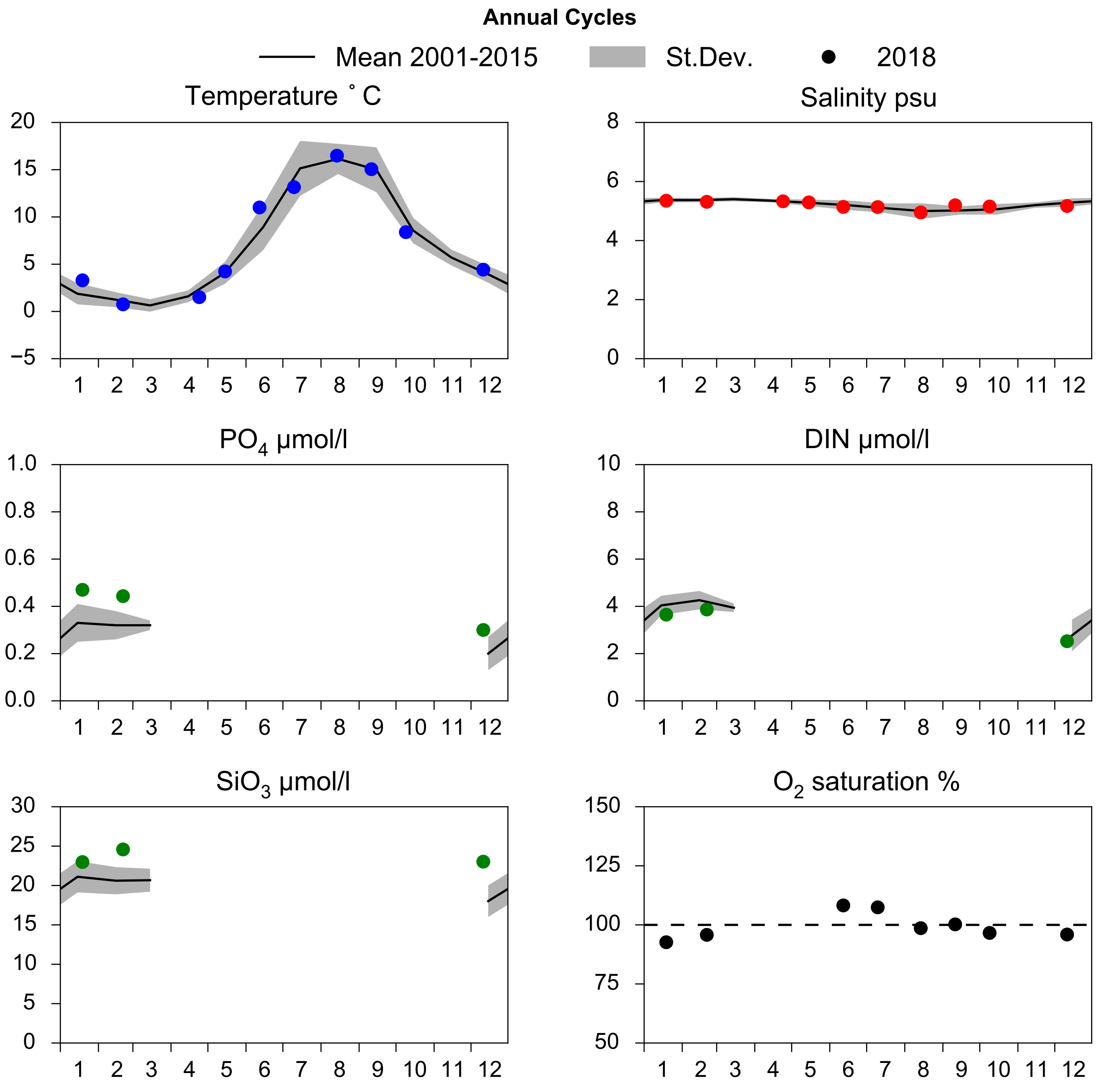
STATION B1 SURFACE WATER (0-10 m)



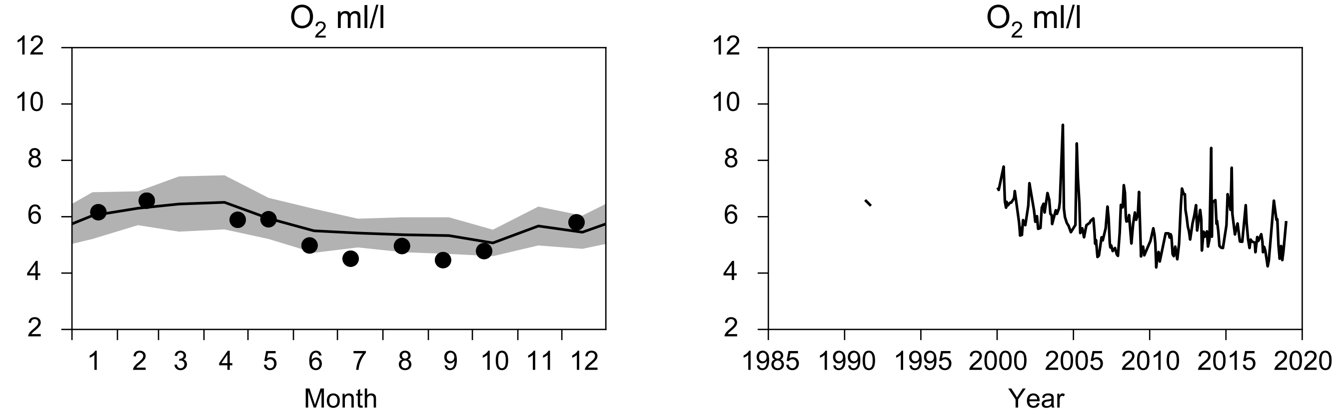
OXYGEN IN BOTTOM WATER (depth >= 40 m)



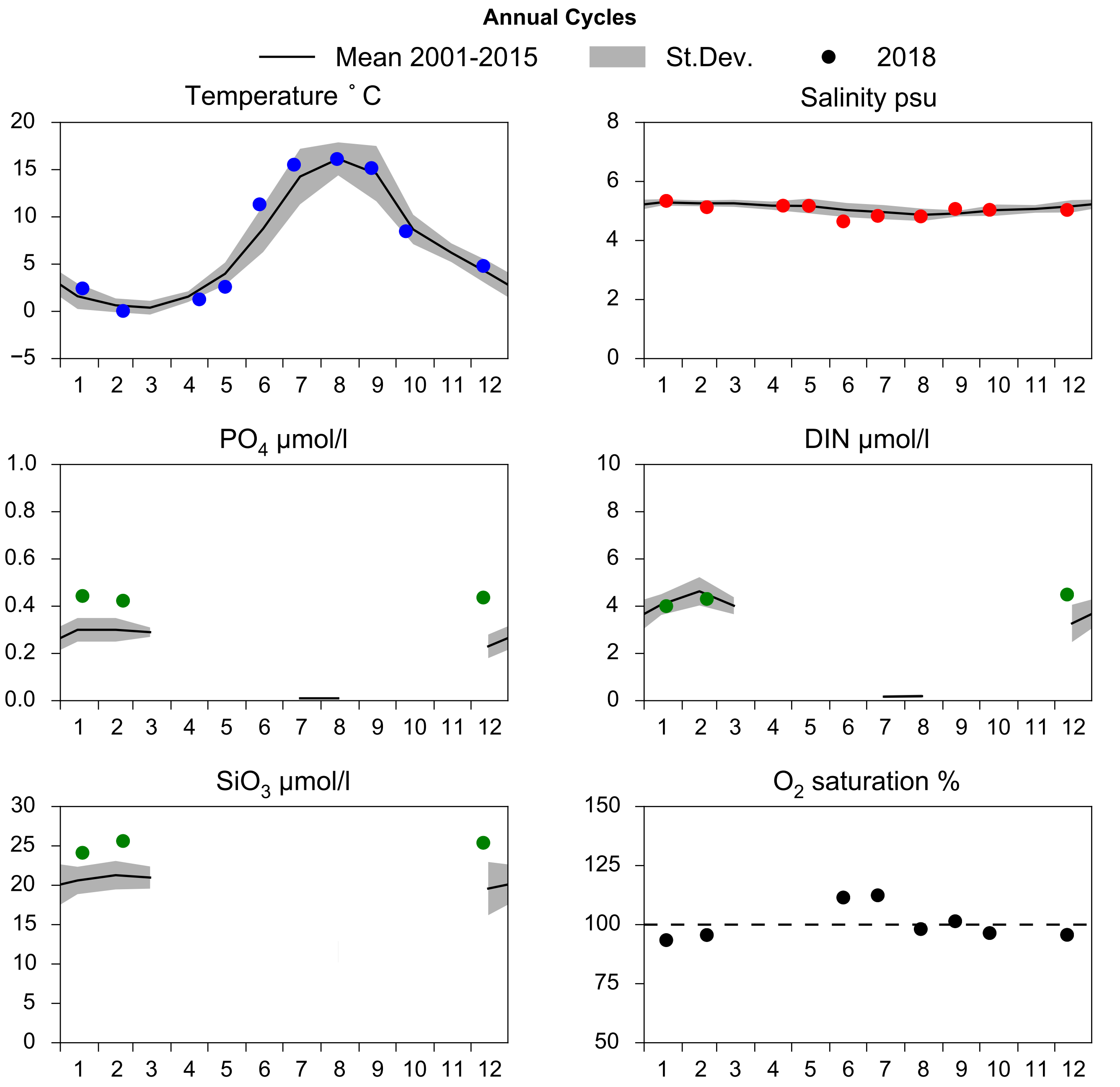
STATION MS4 / C14 SURFACE WATER (0-10 m)



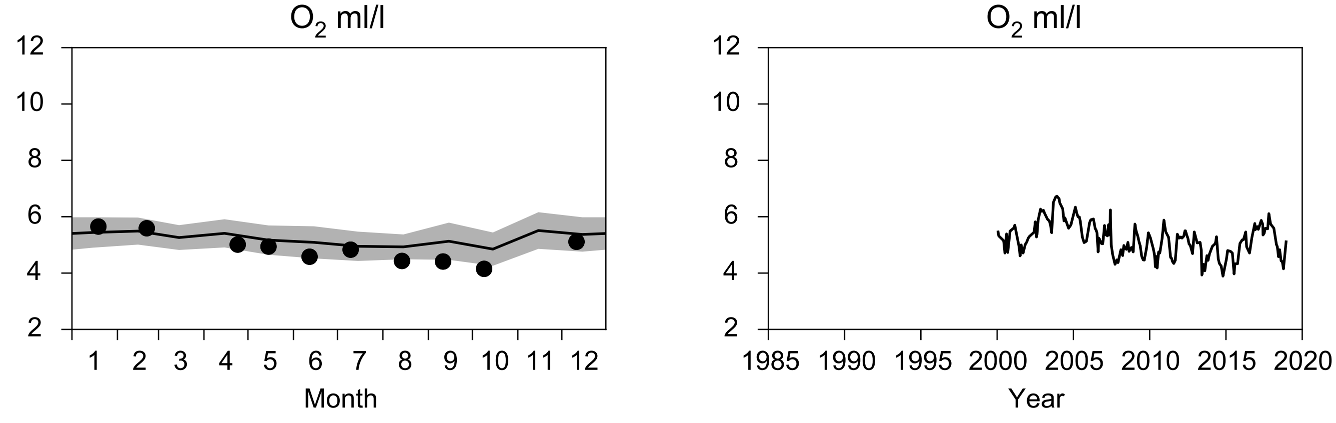
OXYGEN IN BOTTOM WATER (depth >= 80 m)



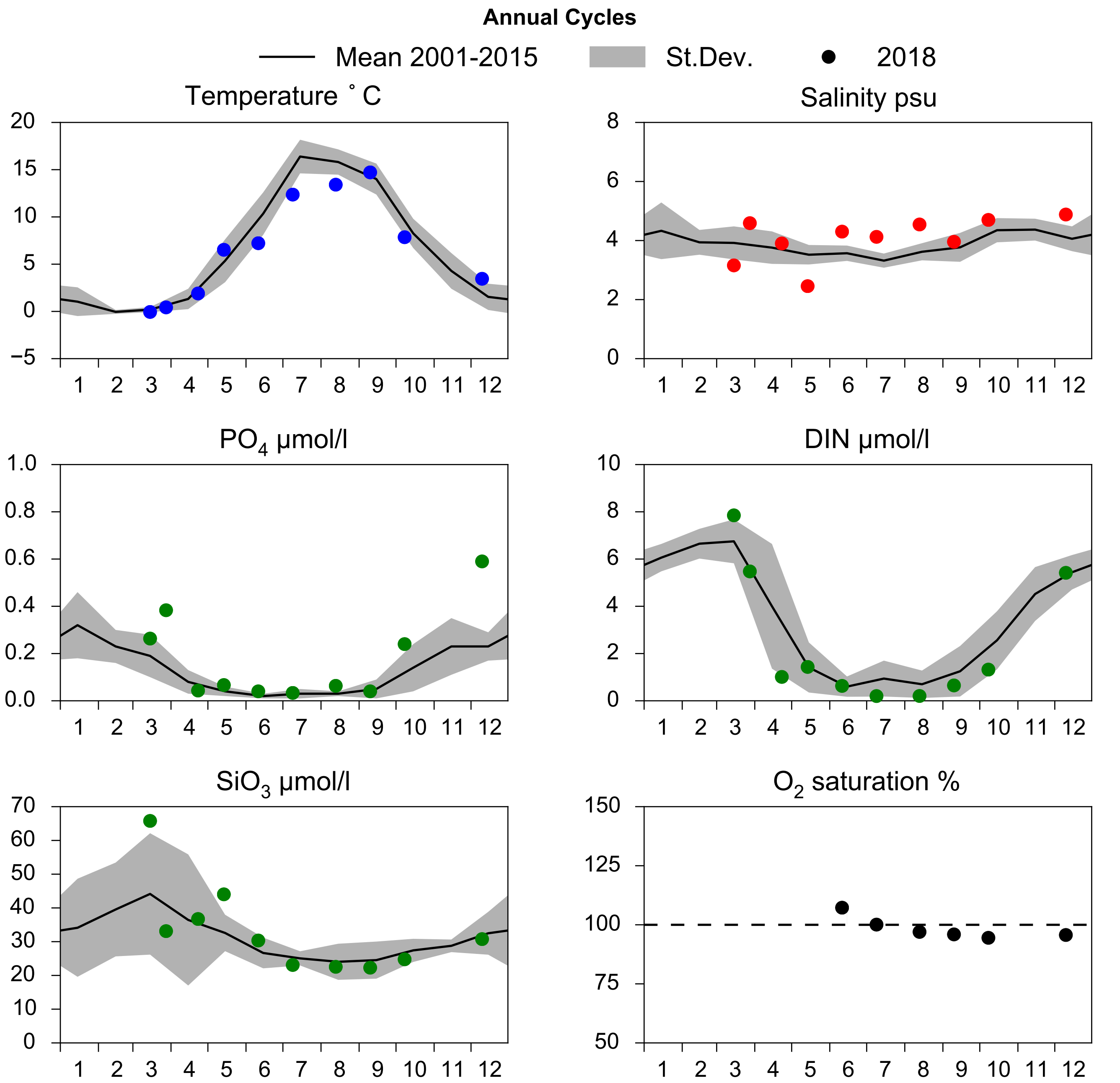
STATION C3 SURFACE WATER (0-10 m)



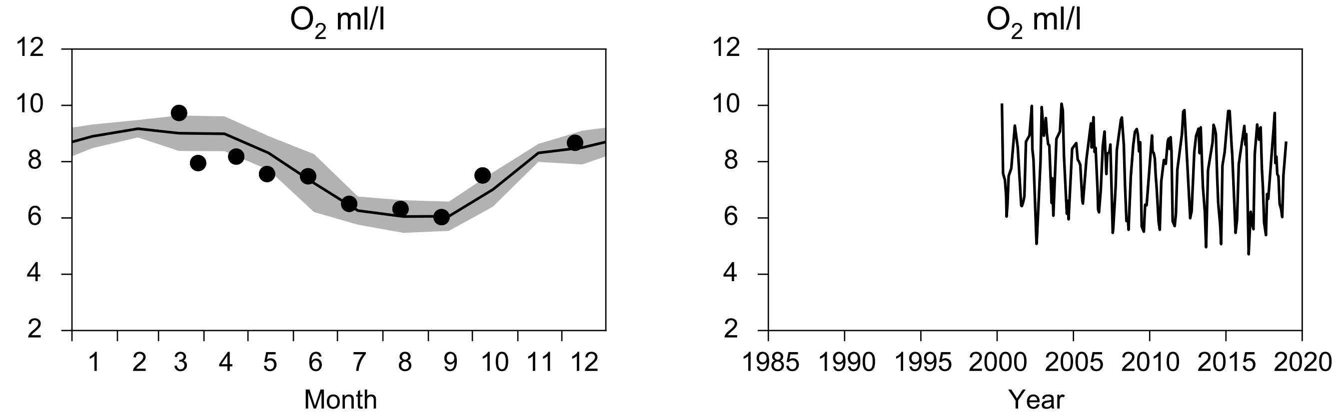
OXYGEN IN BOTTOM WATER (depth >= 184 m)



STATION B7 SURFACE WATER (0-10 m)

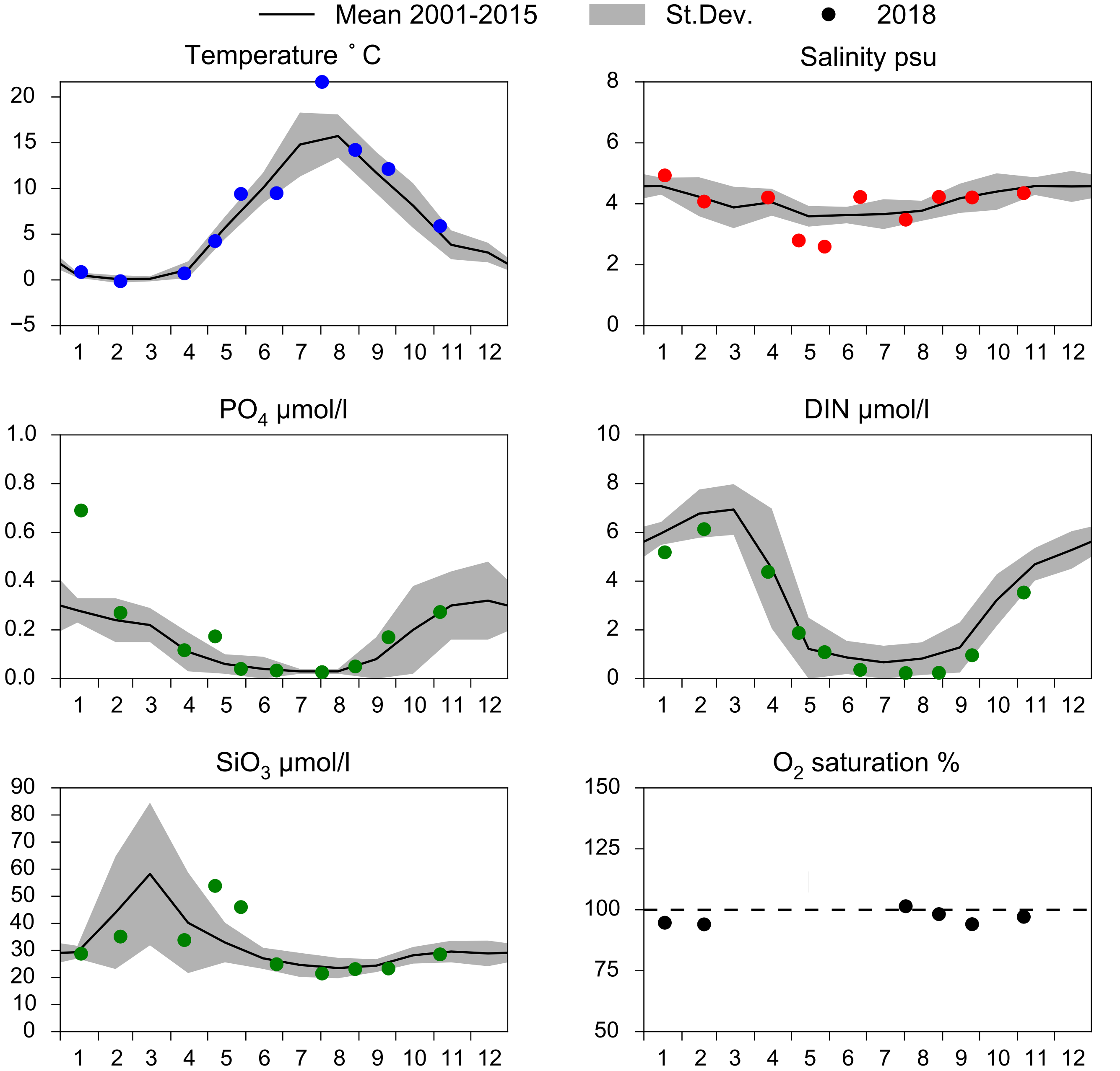


OXYGEN IN BOTTOM WATER (depth >= 20 m)

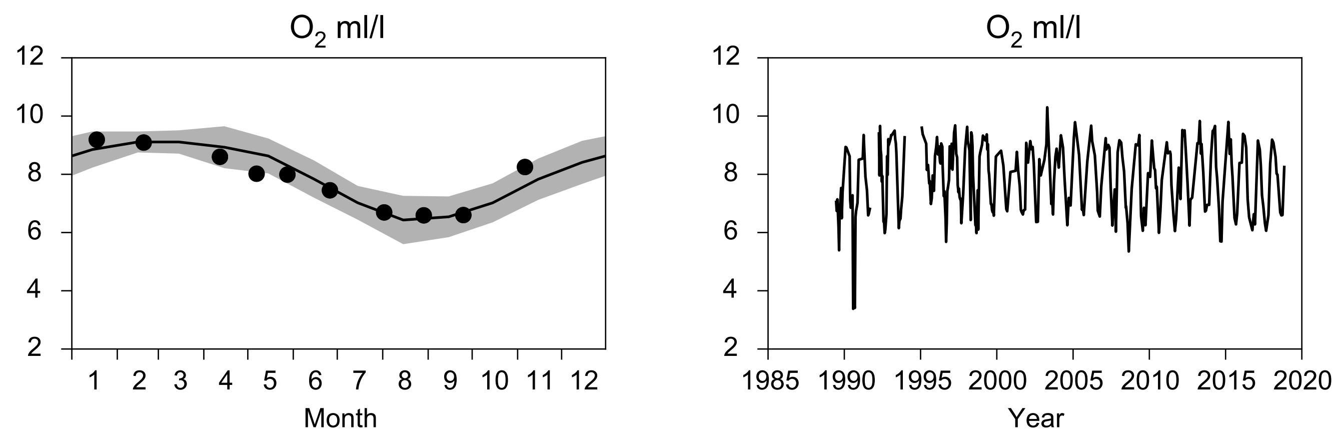


STATION NB1 / B3 SURFACE WATER (0-10 m)

Annual Cycles

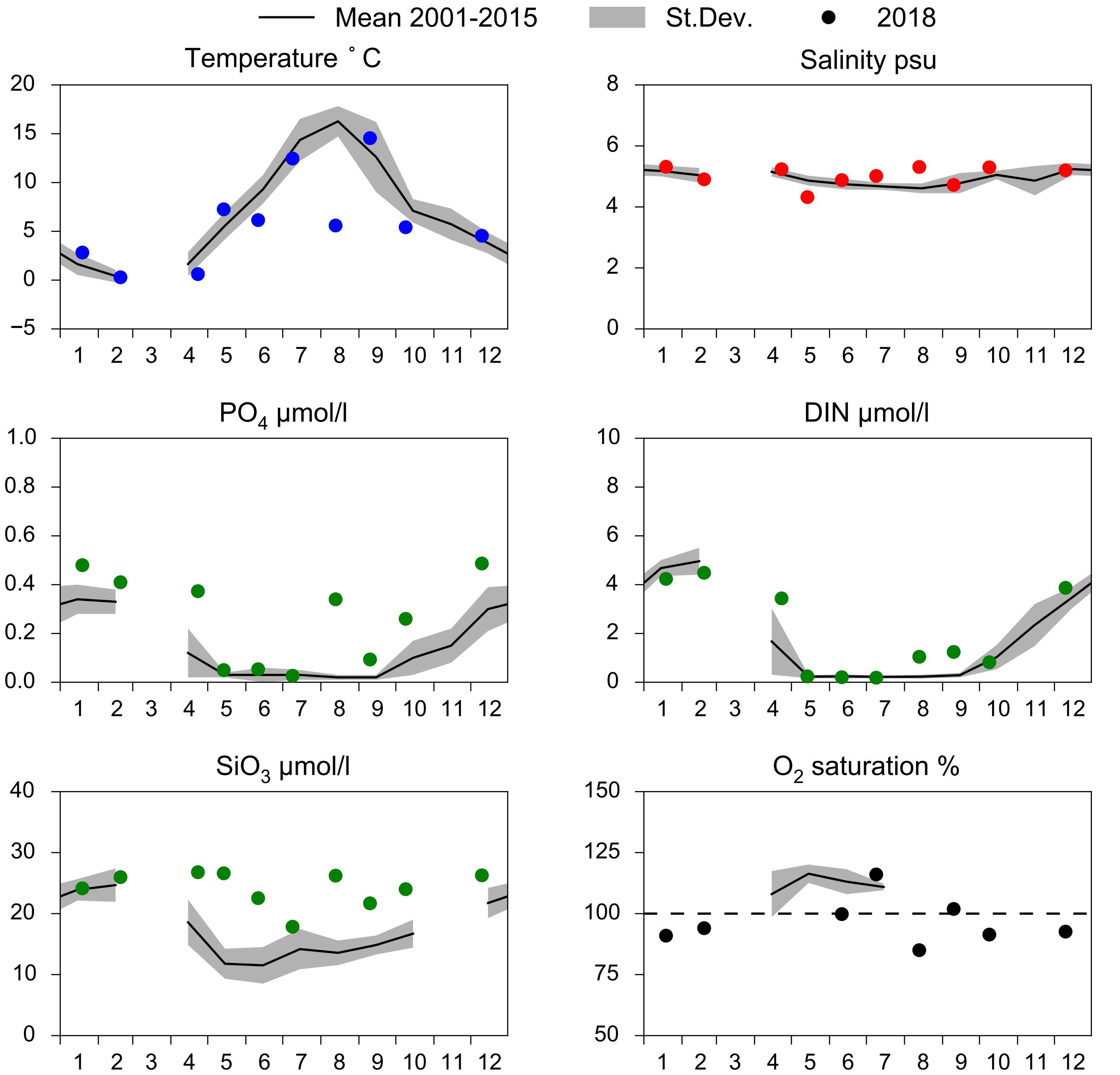


OXYGEN IN BOTTOM WATER (depth >= 20 m)

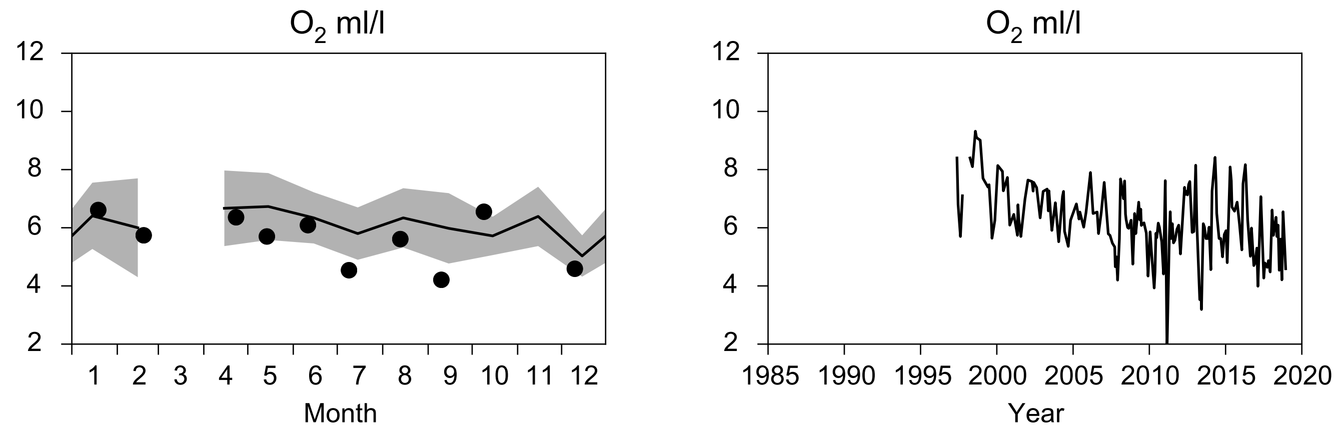


STATION GAVIK-1 SURFACE WATER (0-10 m)

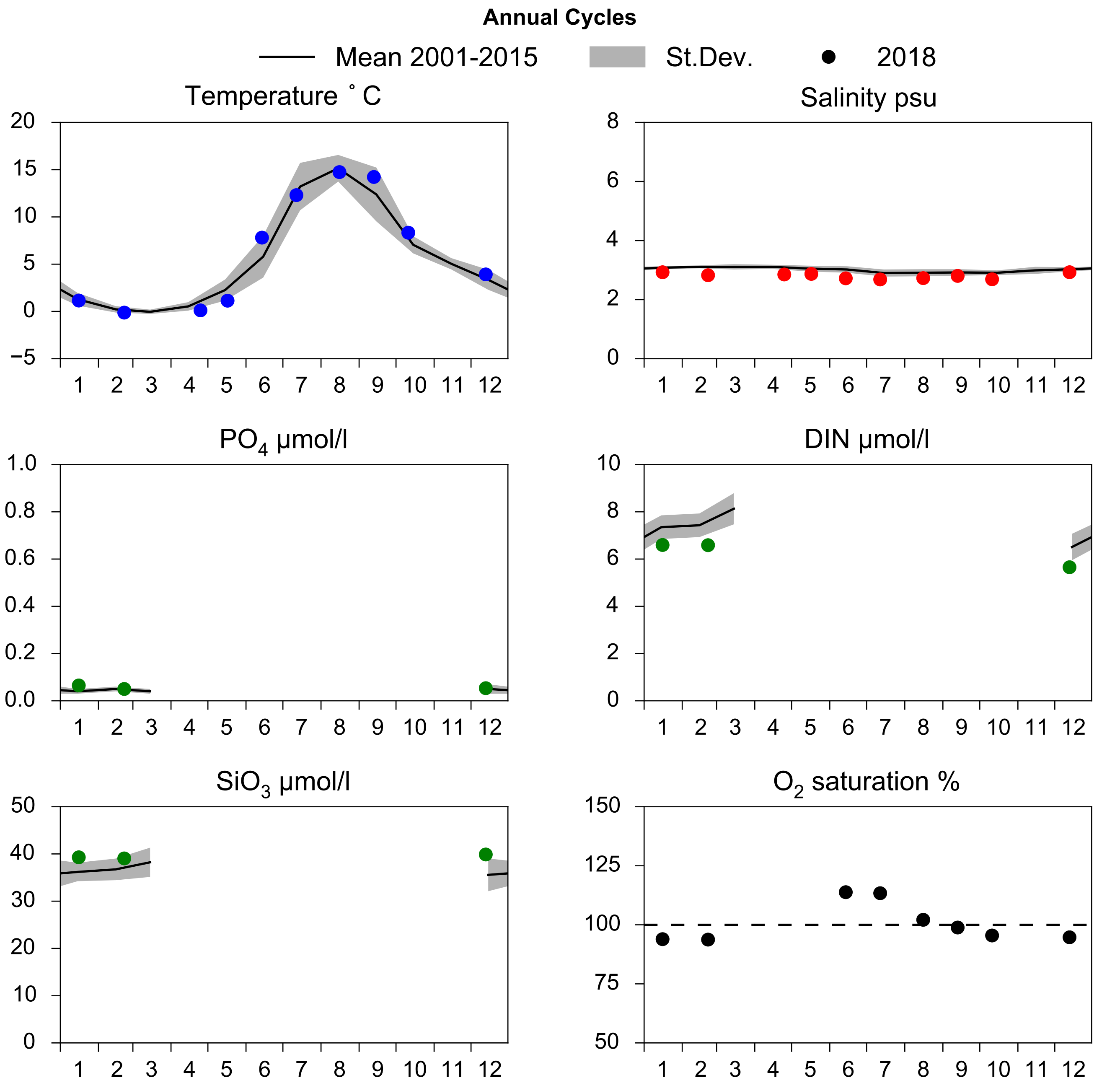
Annual Cycles



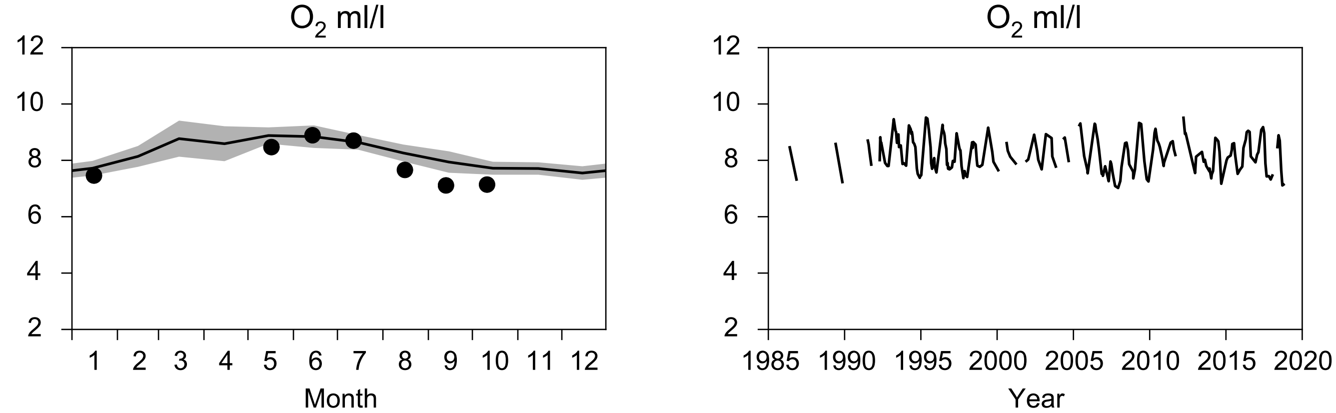
OXYGEN IN BOTTOM WATER (depth >= 75 m)



STATION F9 / A13 SURFACE WATER (0-10 m)

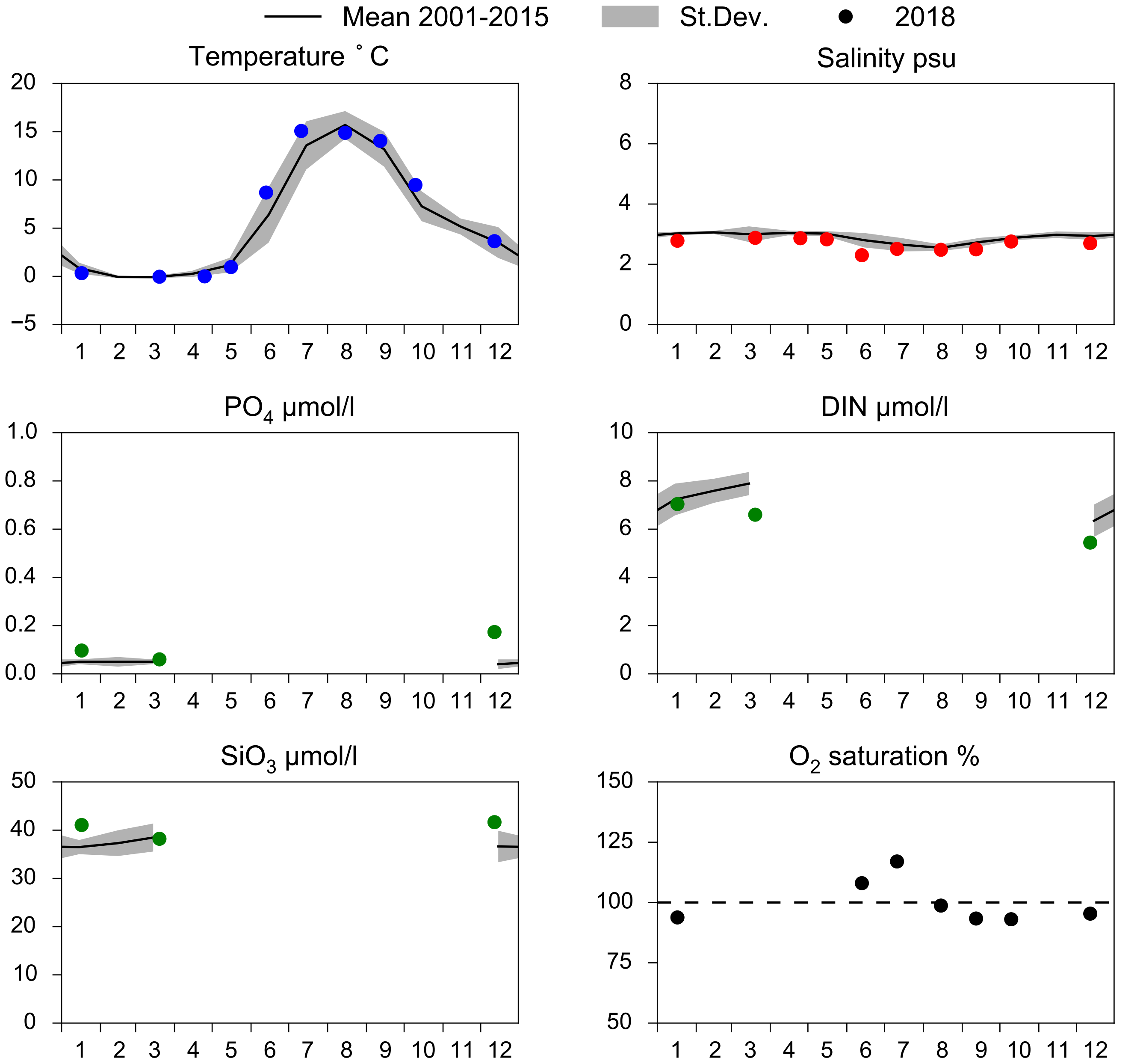


OXYGEN IN BOTTOM WATER (depth >= 120 m)

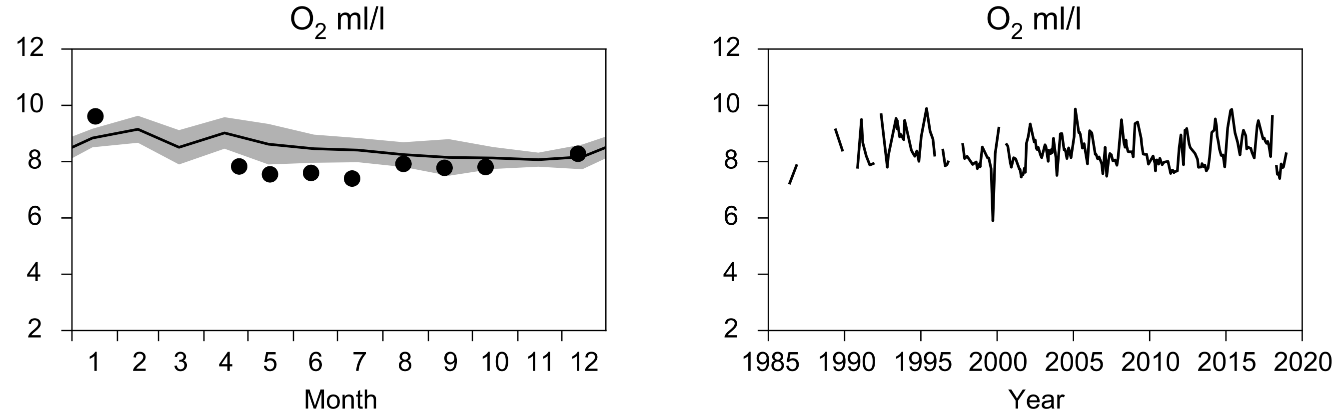


STATION F3 / A5 SURFACE WATER (0-10 m)

Annual Cycles

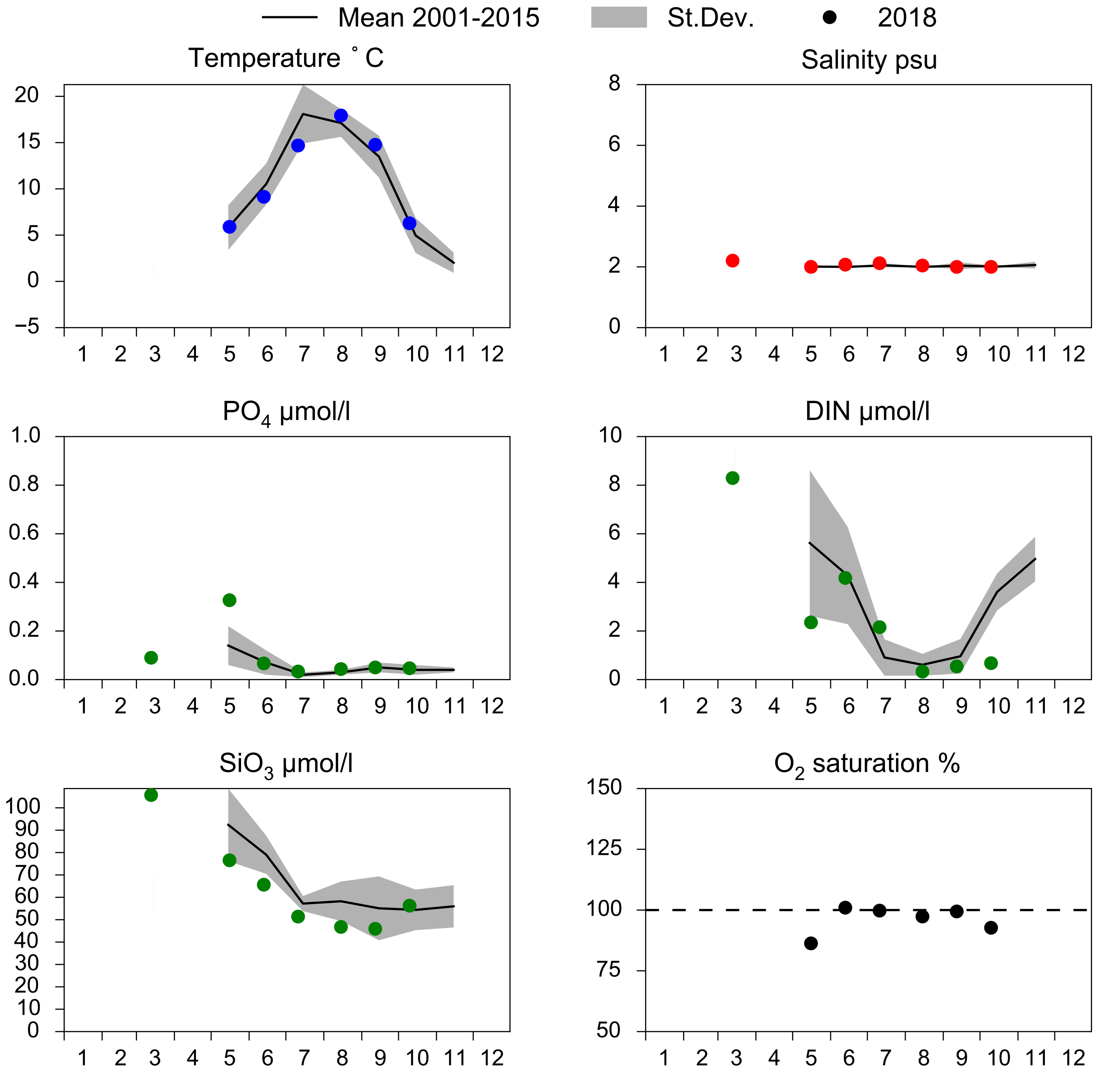


OXYGEN IN BOTTOM WATER (depth >= 80 m)

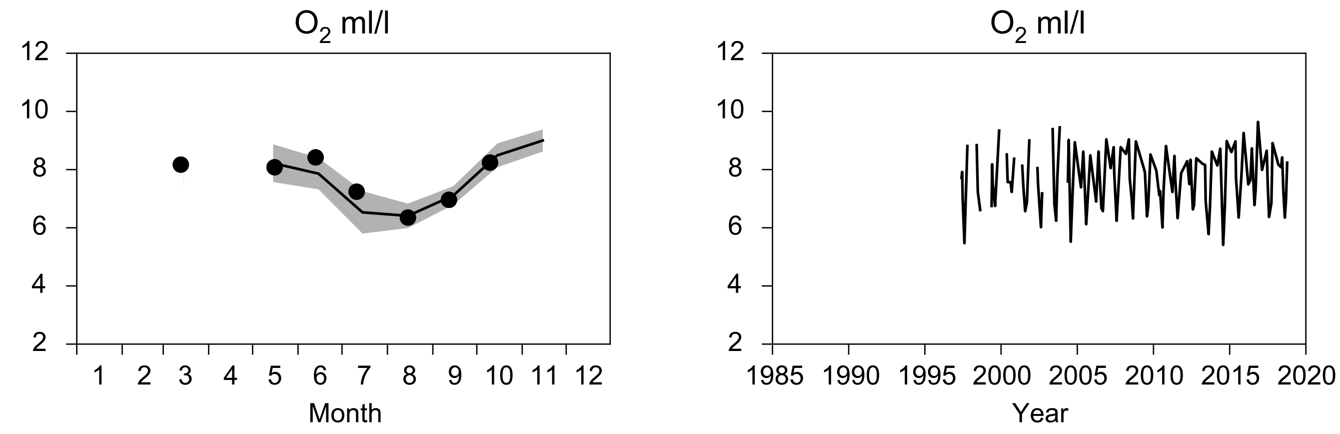


STATION RÅNEÅ-1 SURFACE WATER (0-10 m)

Annual Cycles

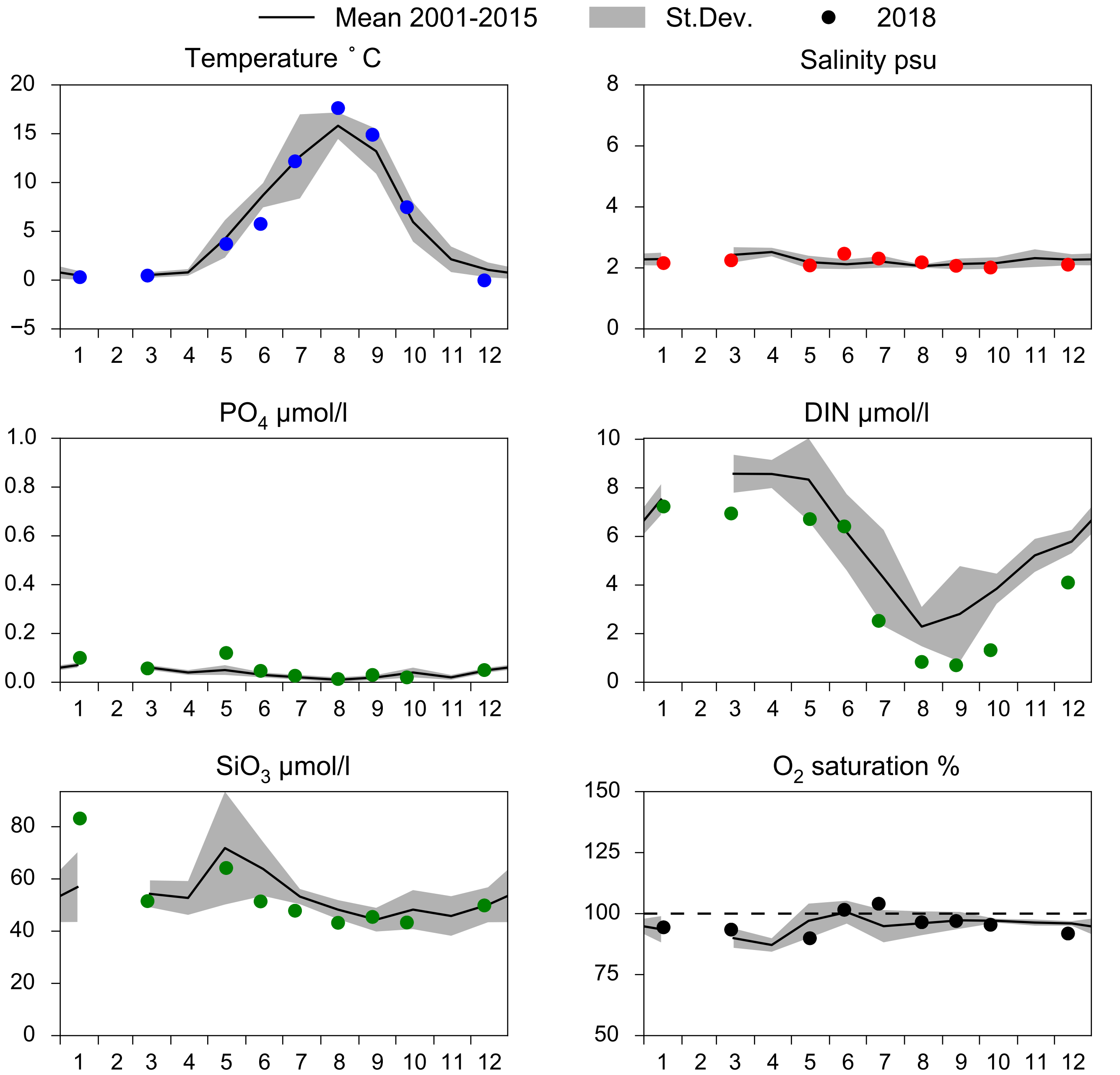


OXYGEN IN BOTTOM WATER (depth >= 5 m)

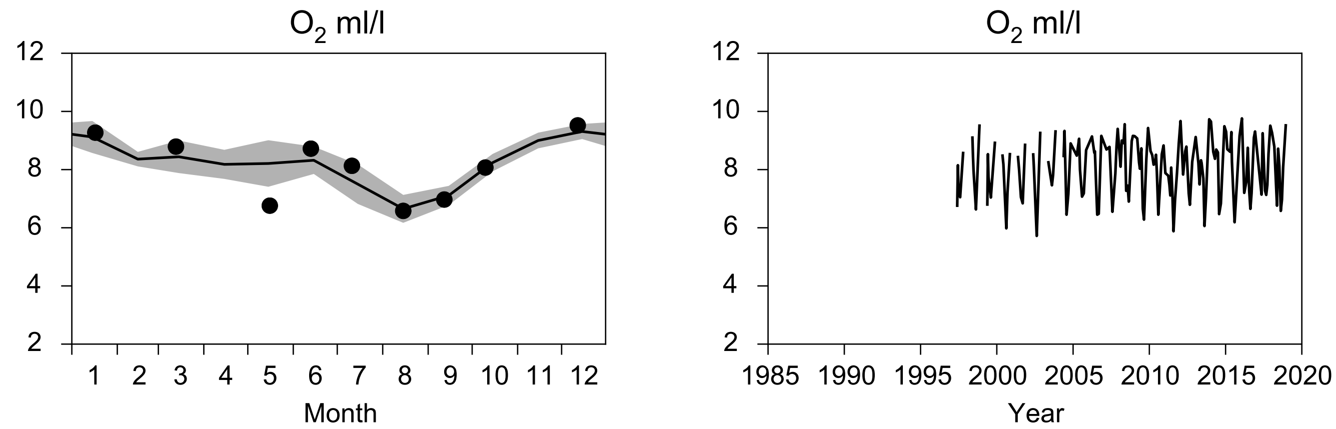


STATION RÅNEÅ-2 SURFACE WATER (0-10 m)

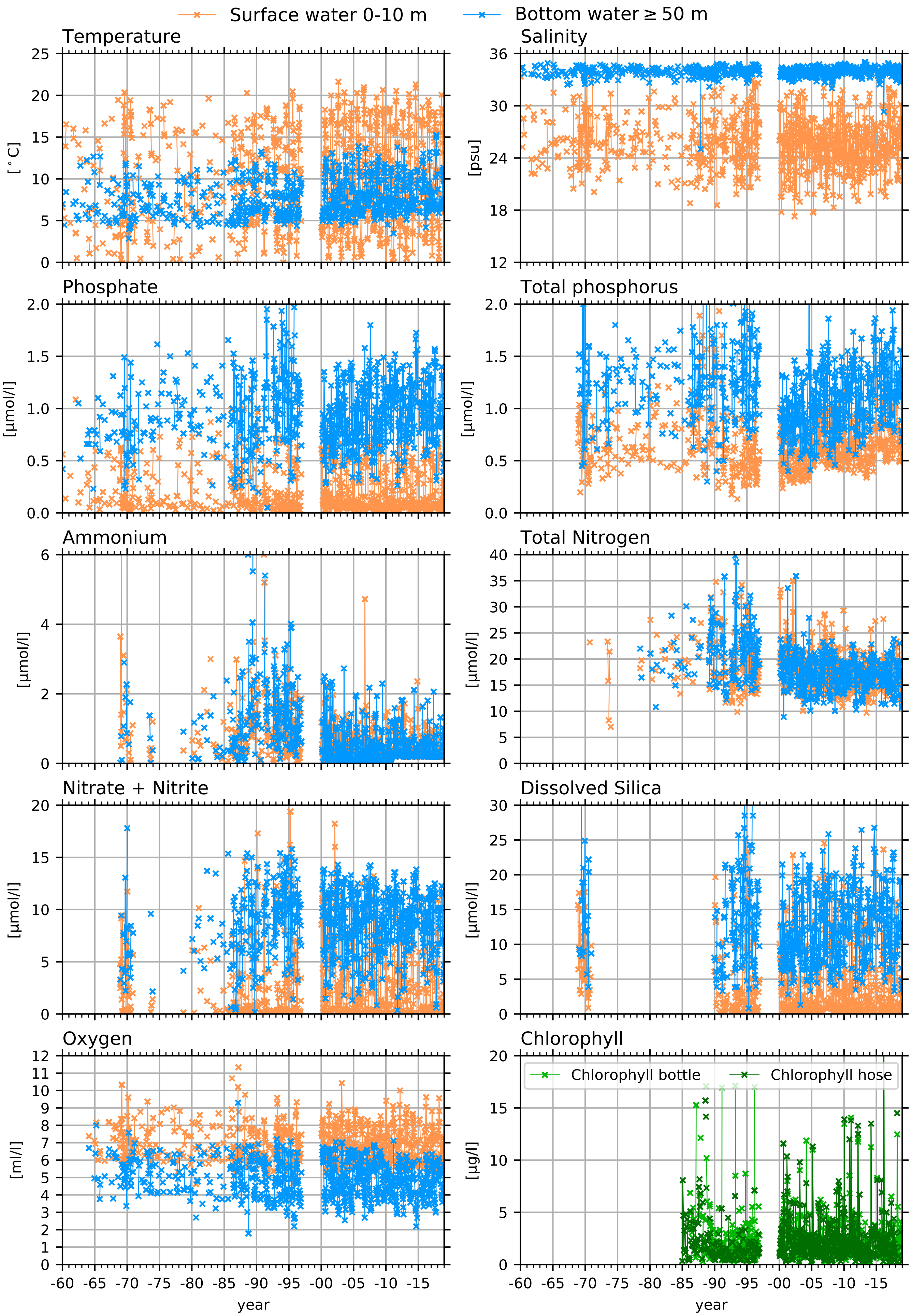
Annual Cycles



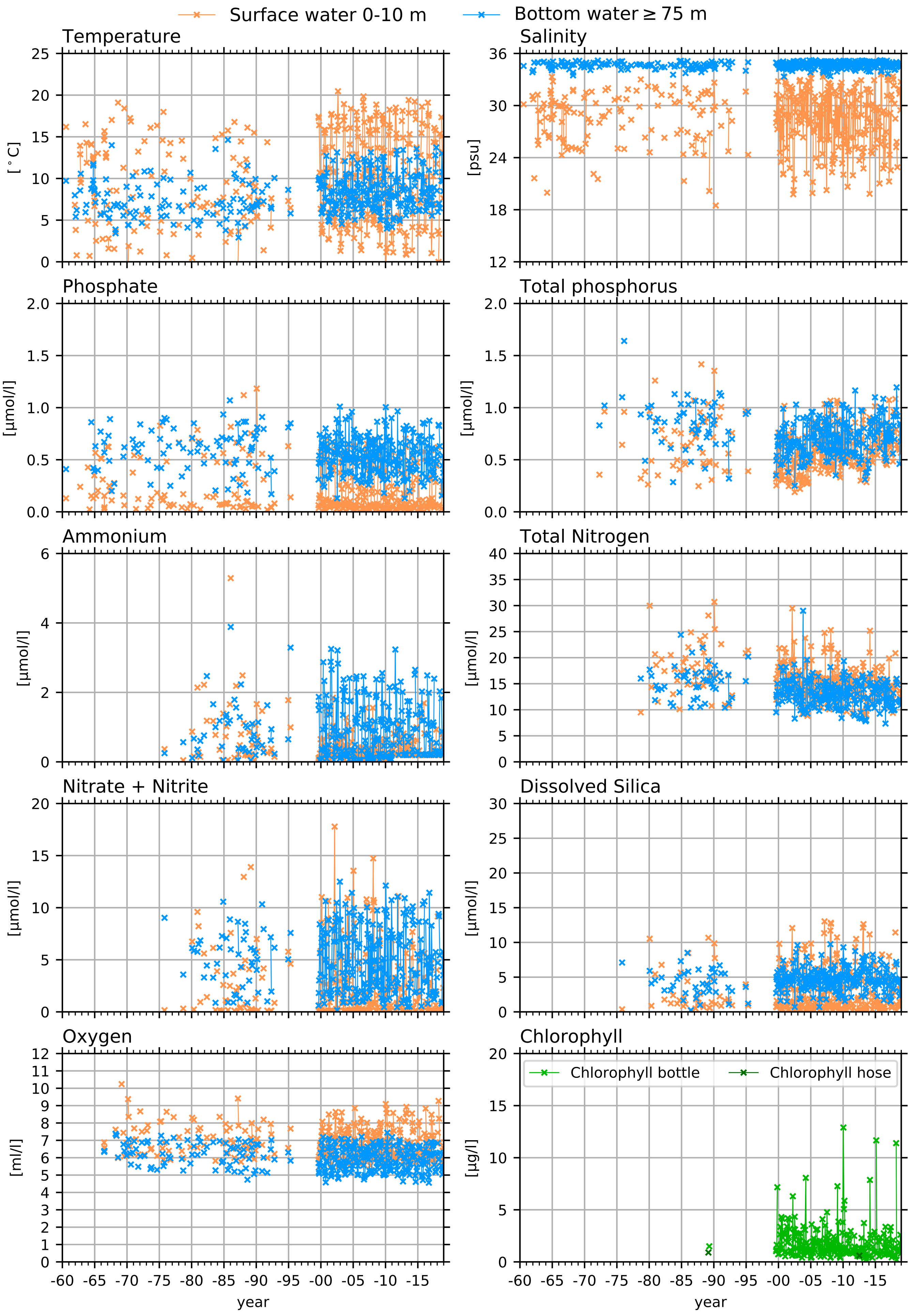
OXYGEN IN BOTTOM WATER (depth >= 9 m)



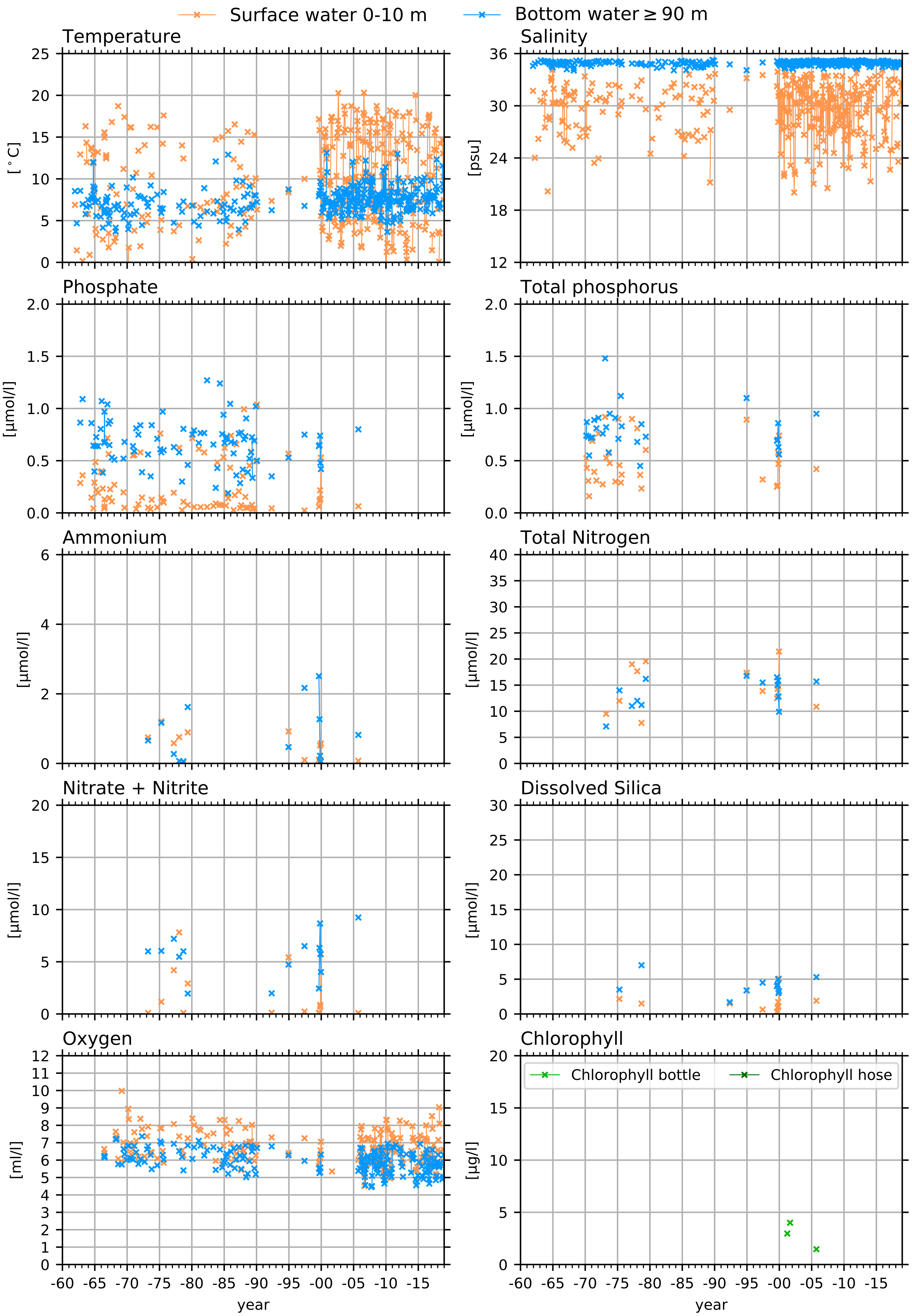
SLÄGGÖ, SKAGERACK



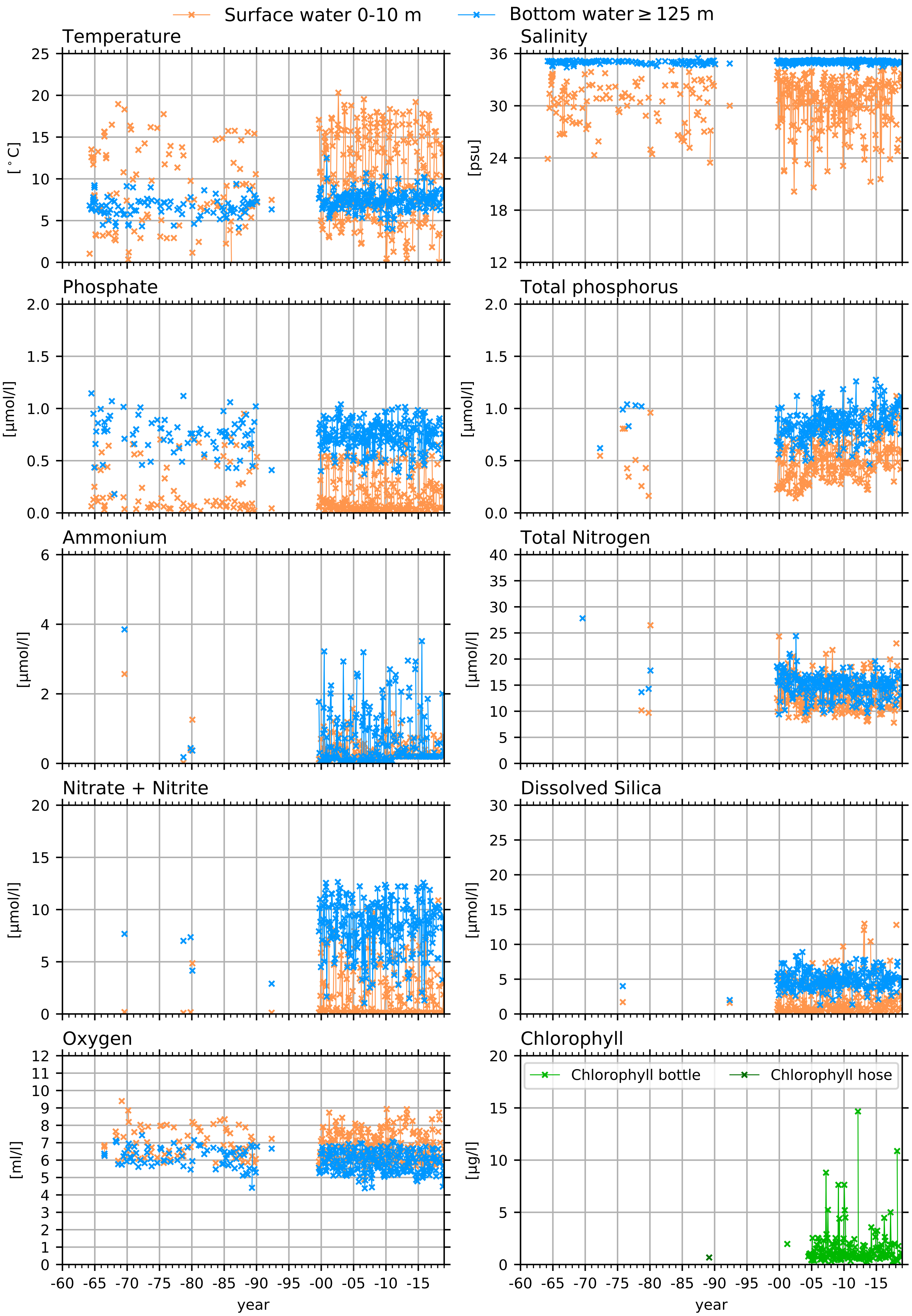
Å13, SKAGERACK



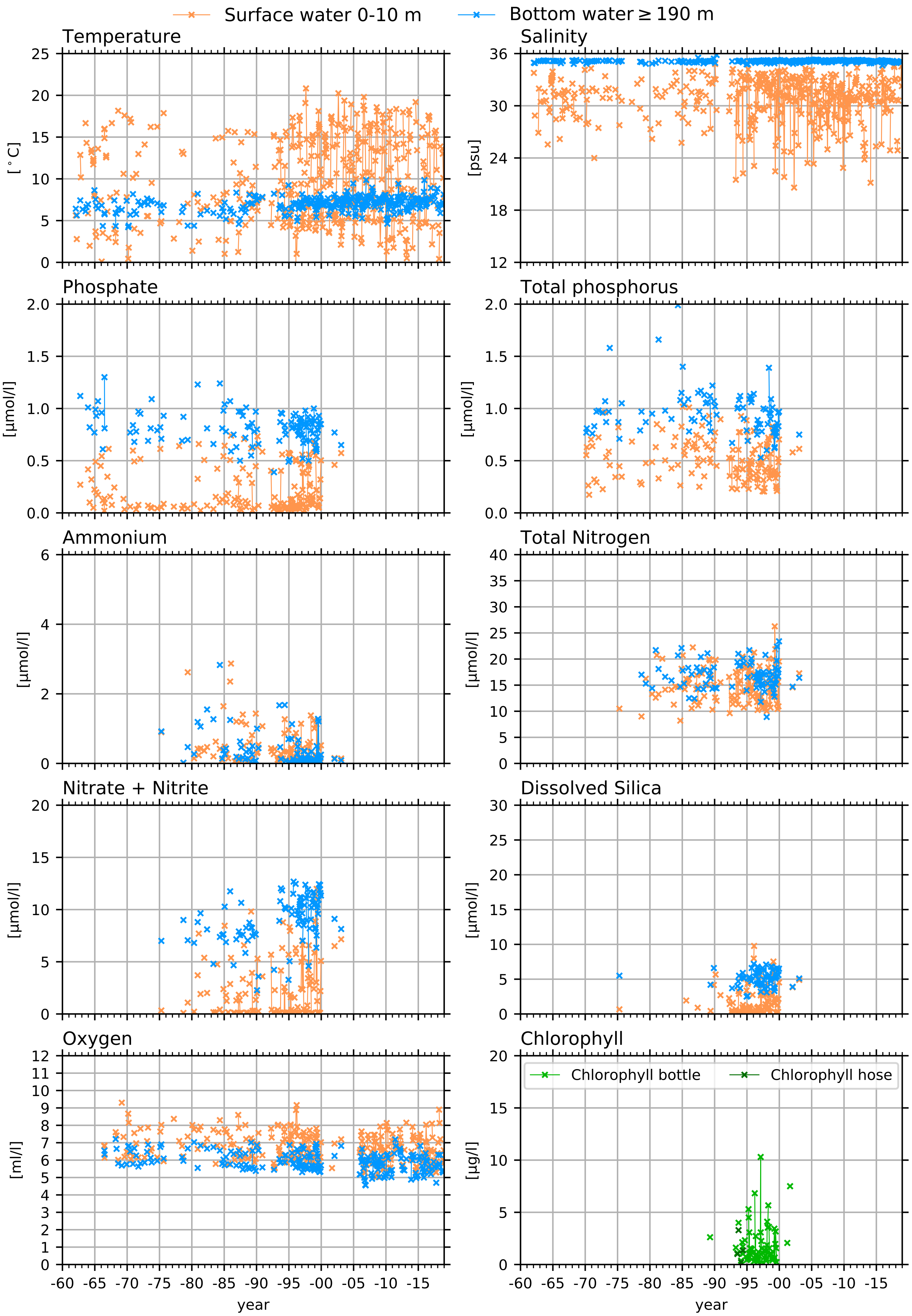
Å14, SKAGERACK



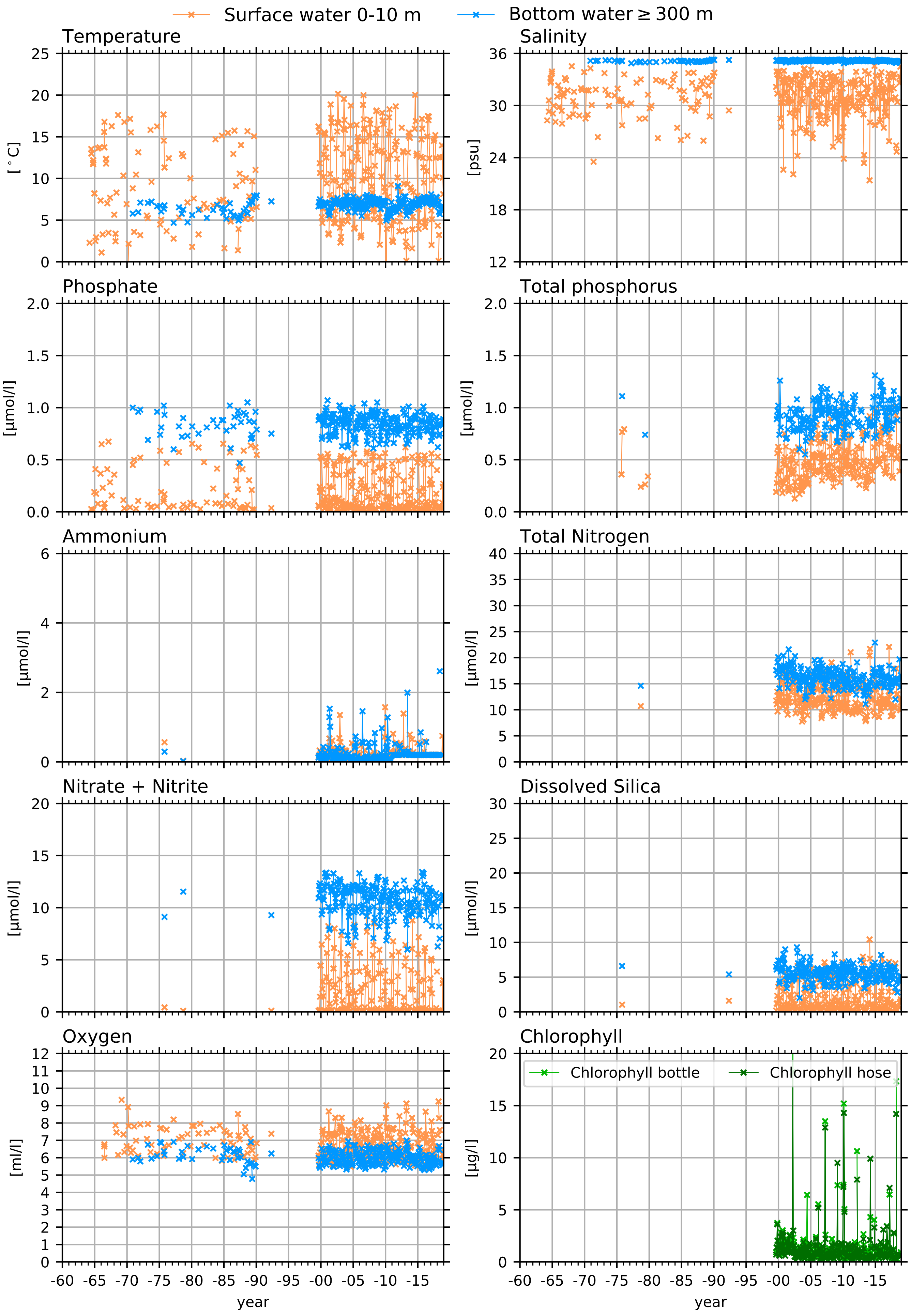
Å15, SKAGERACK



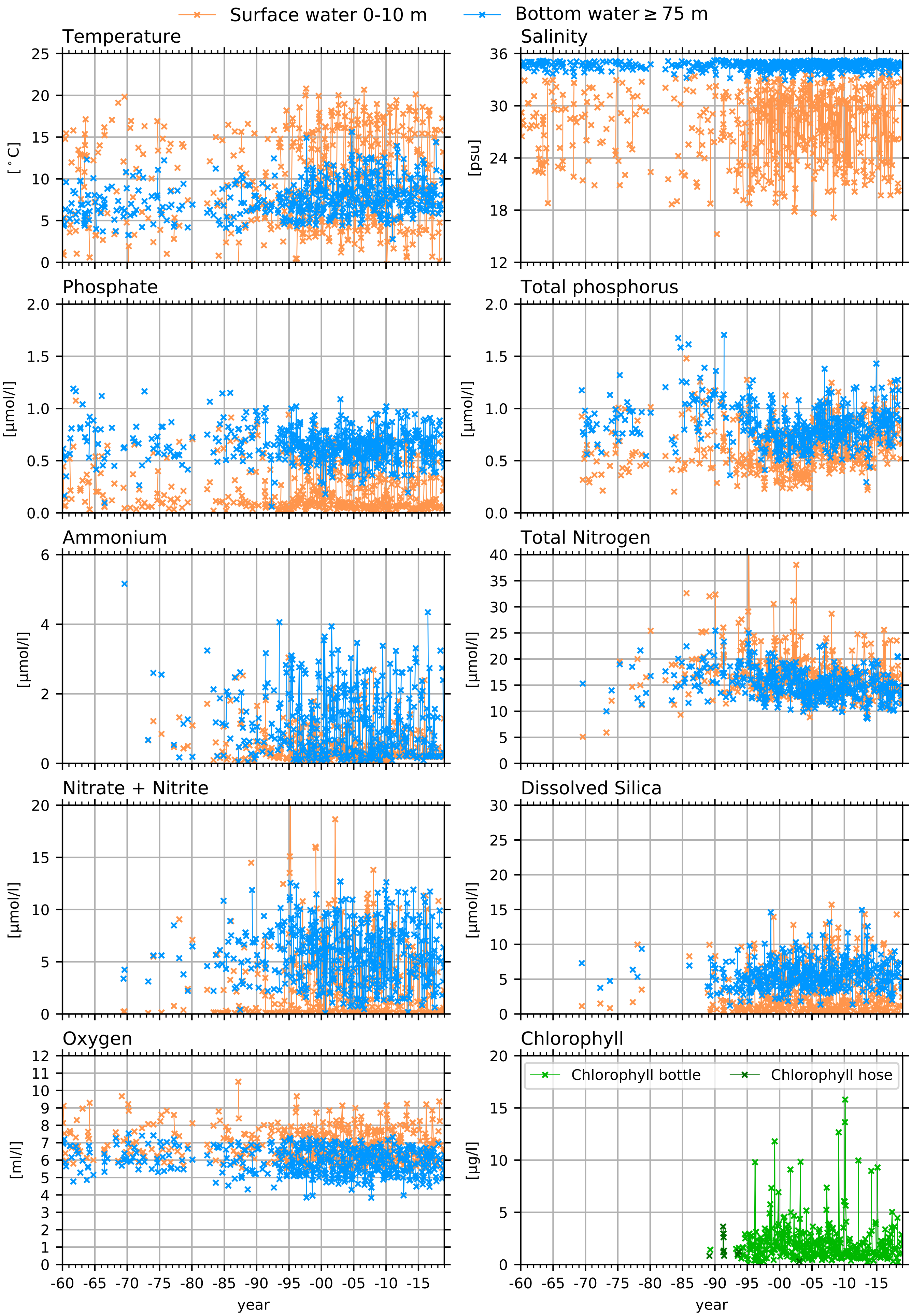
Å16, SKAGERACK



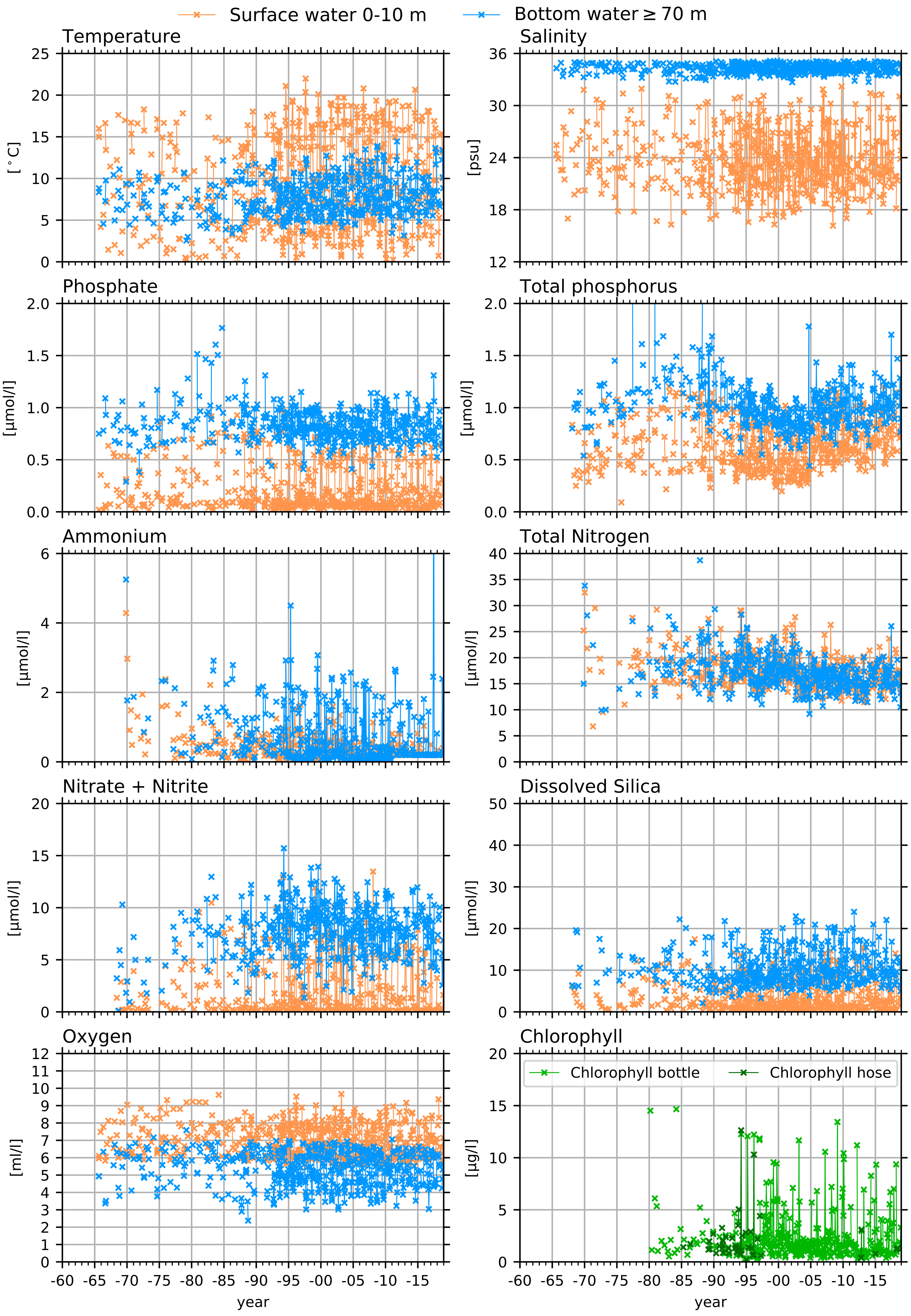
Å17, SKAGERACK



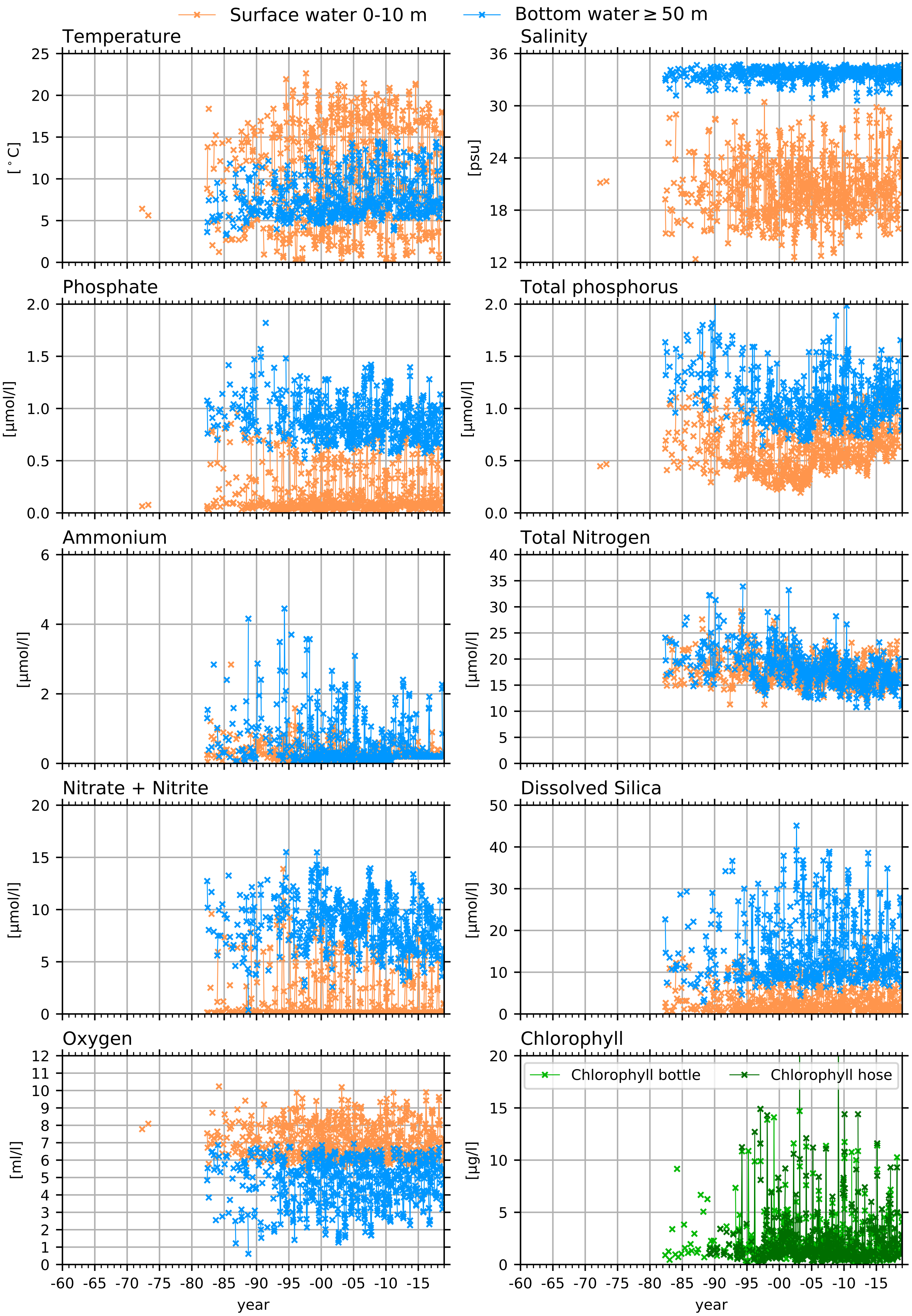
P2, SKAGERACK



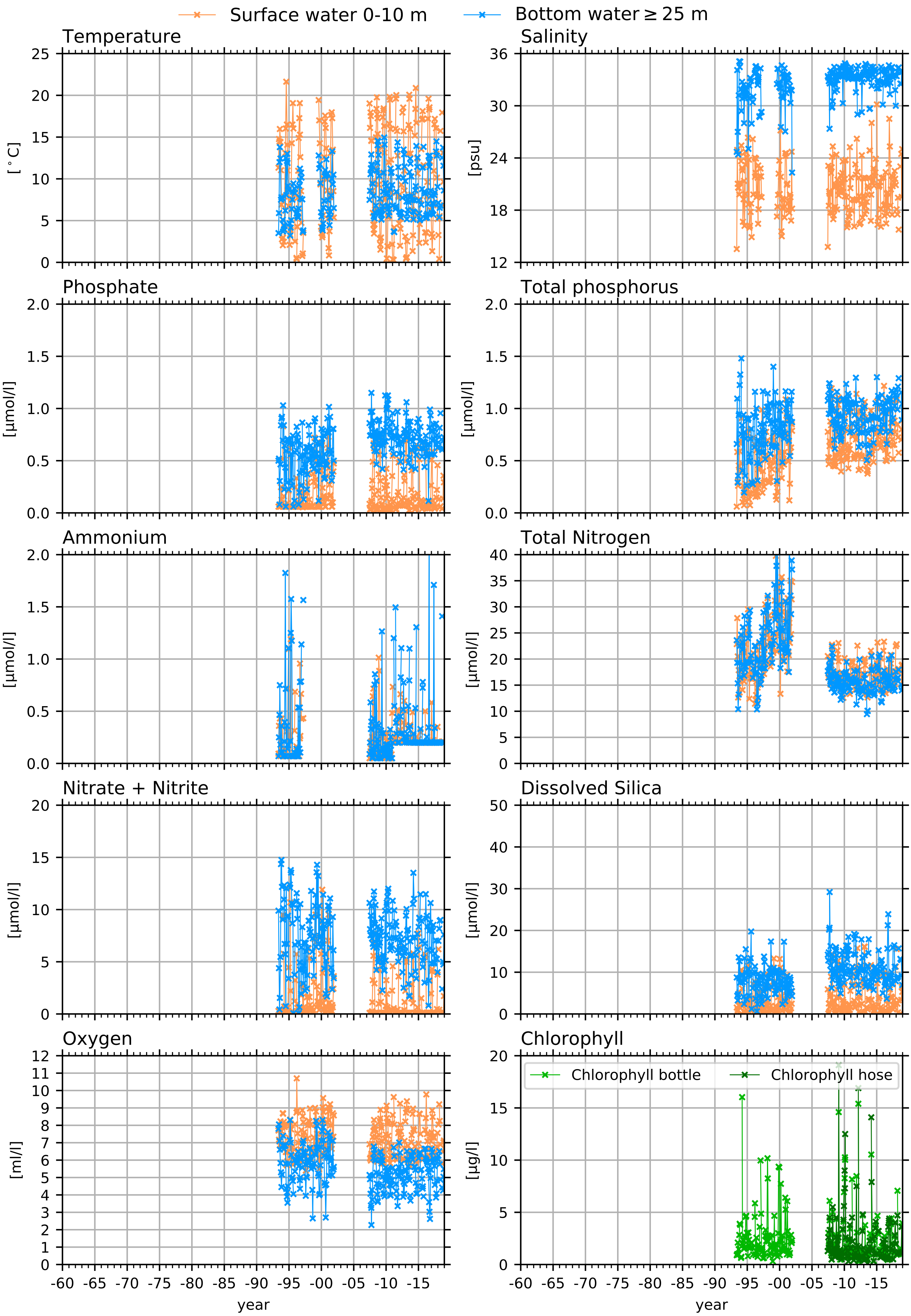
FLADEN, KATTEGAT



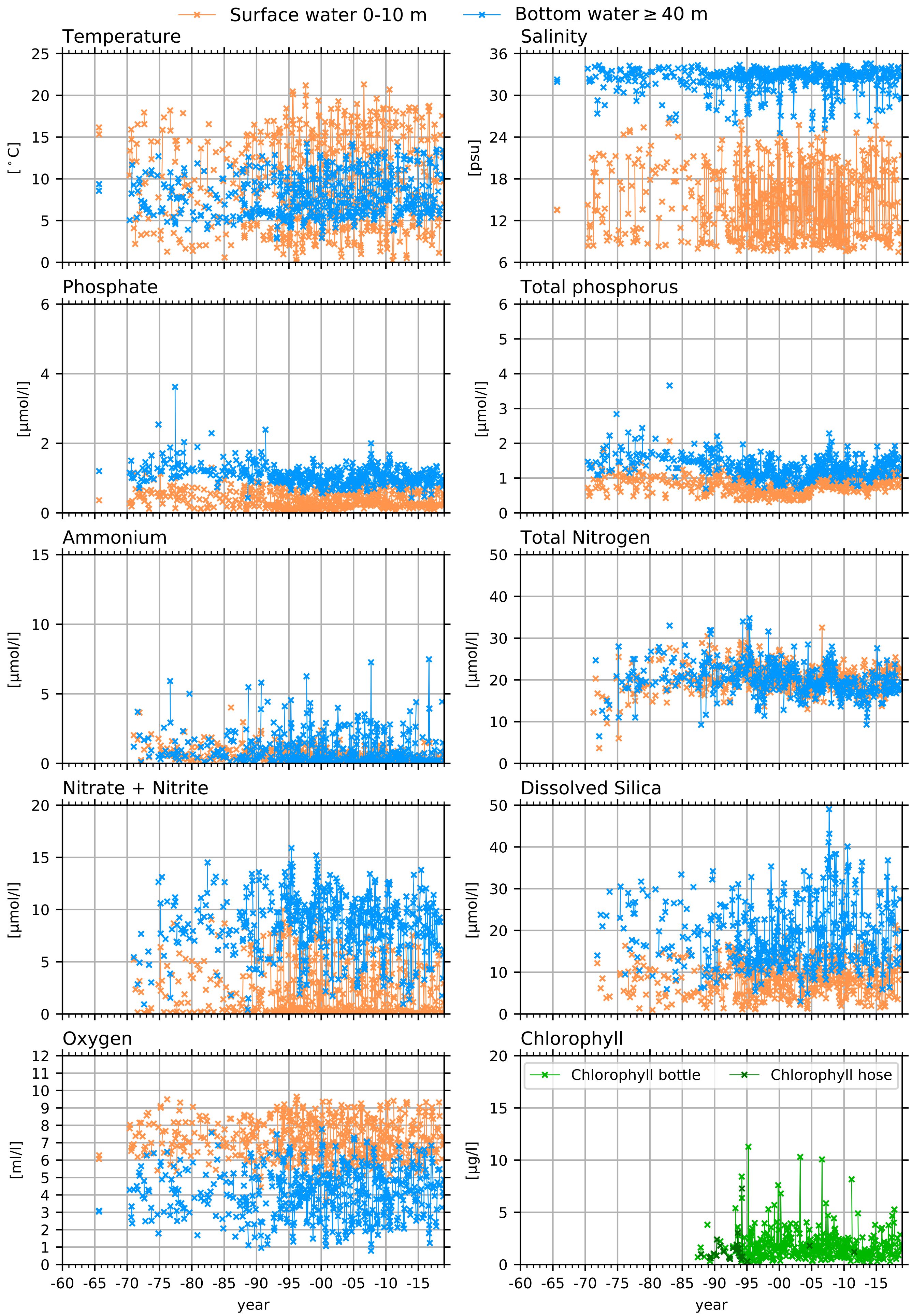
ANHOLT E, KATTEGAT



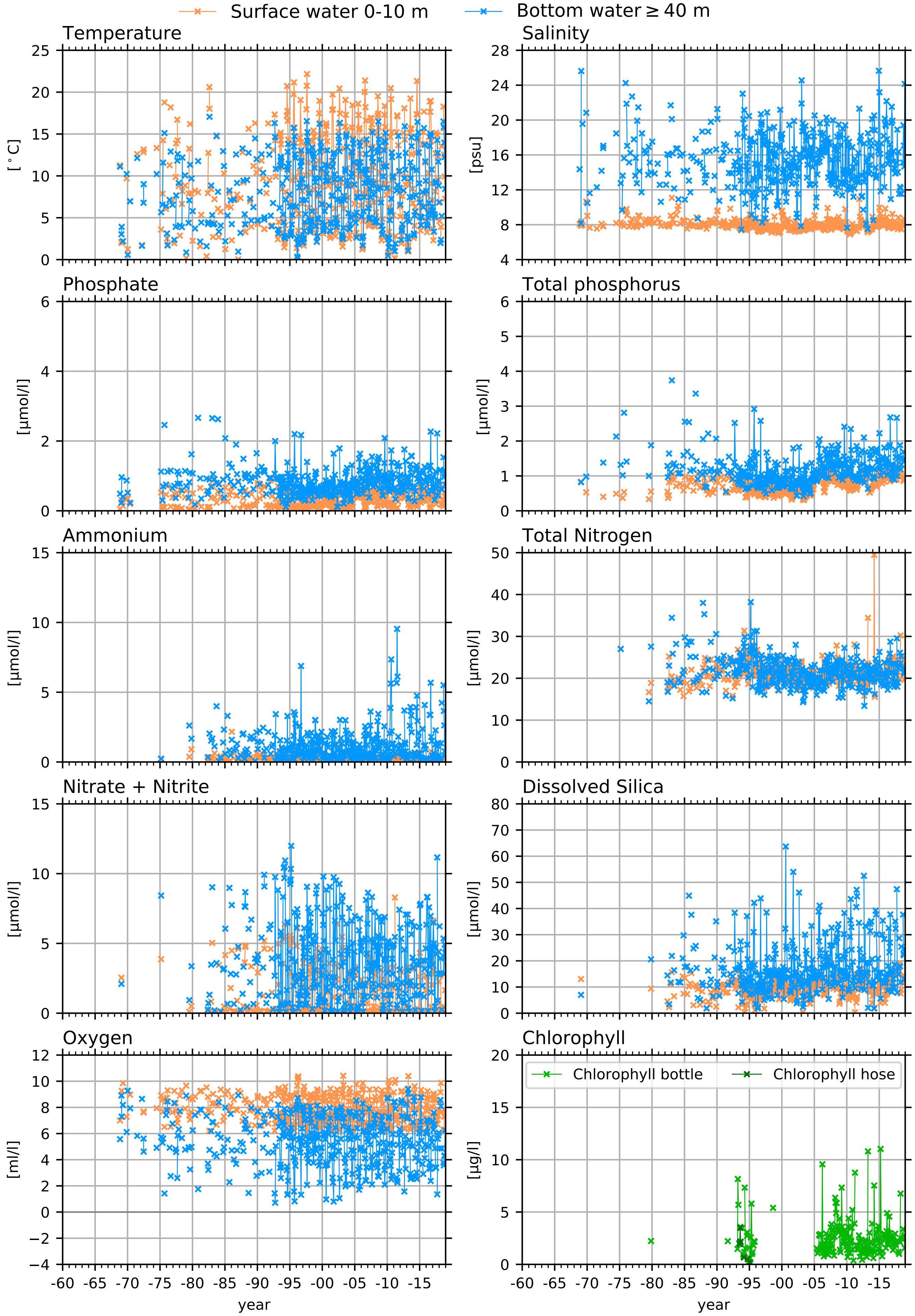
N14 FALKENBERG, KATTEGATT



W LANDSKRONA, THE SOUND

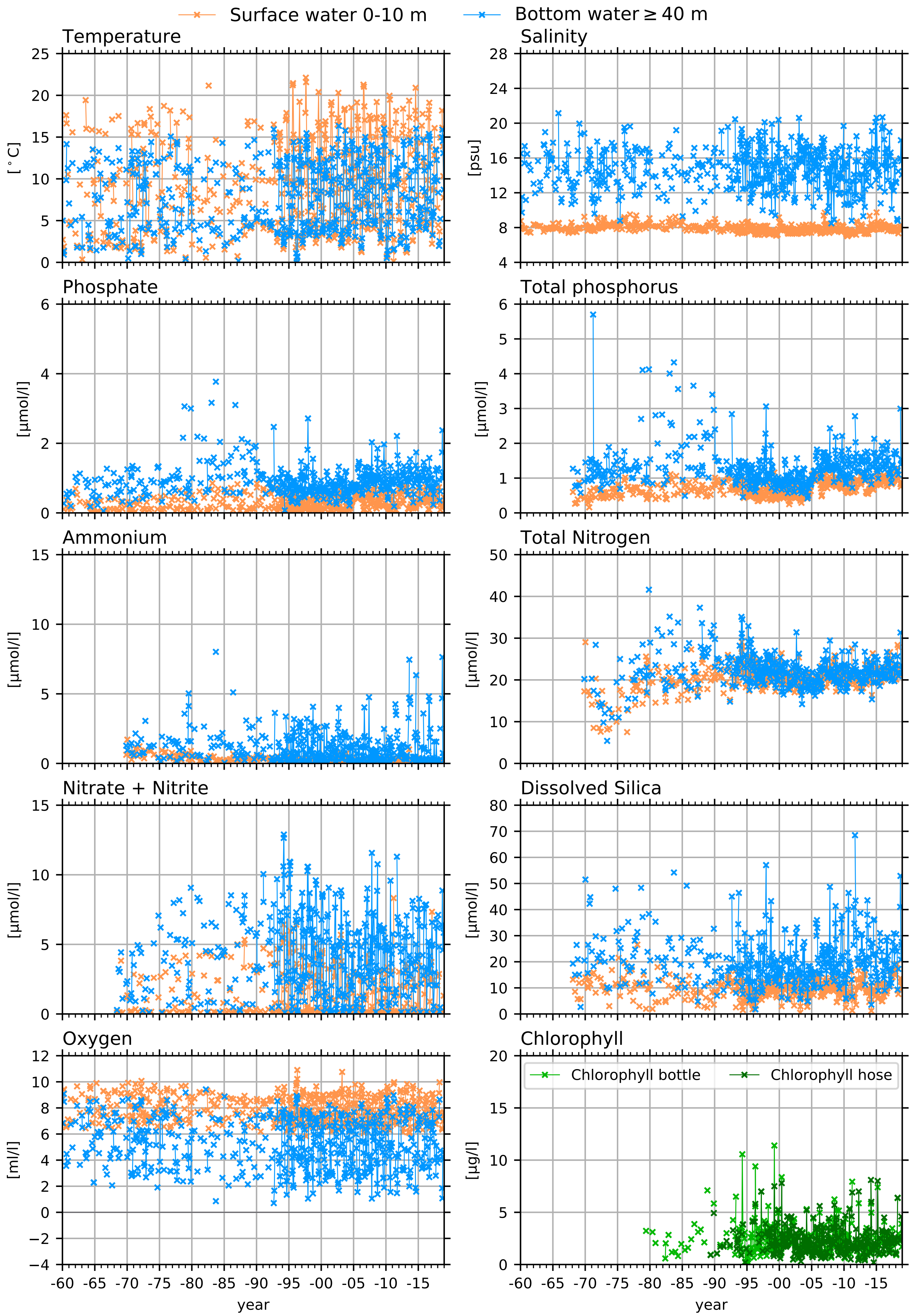


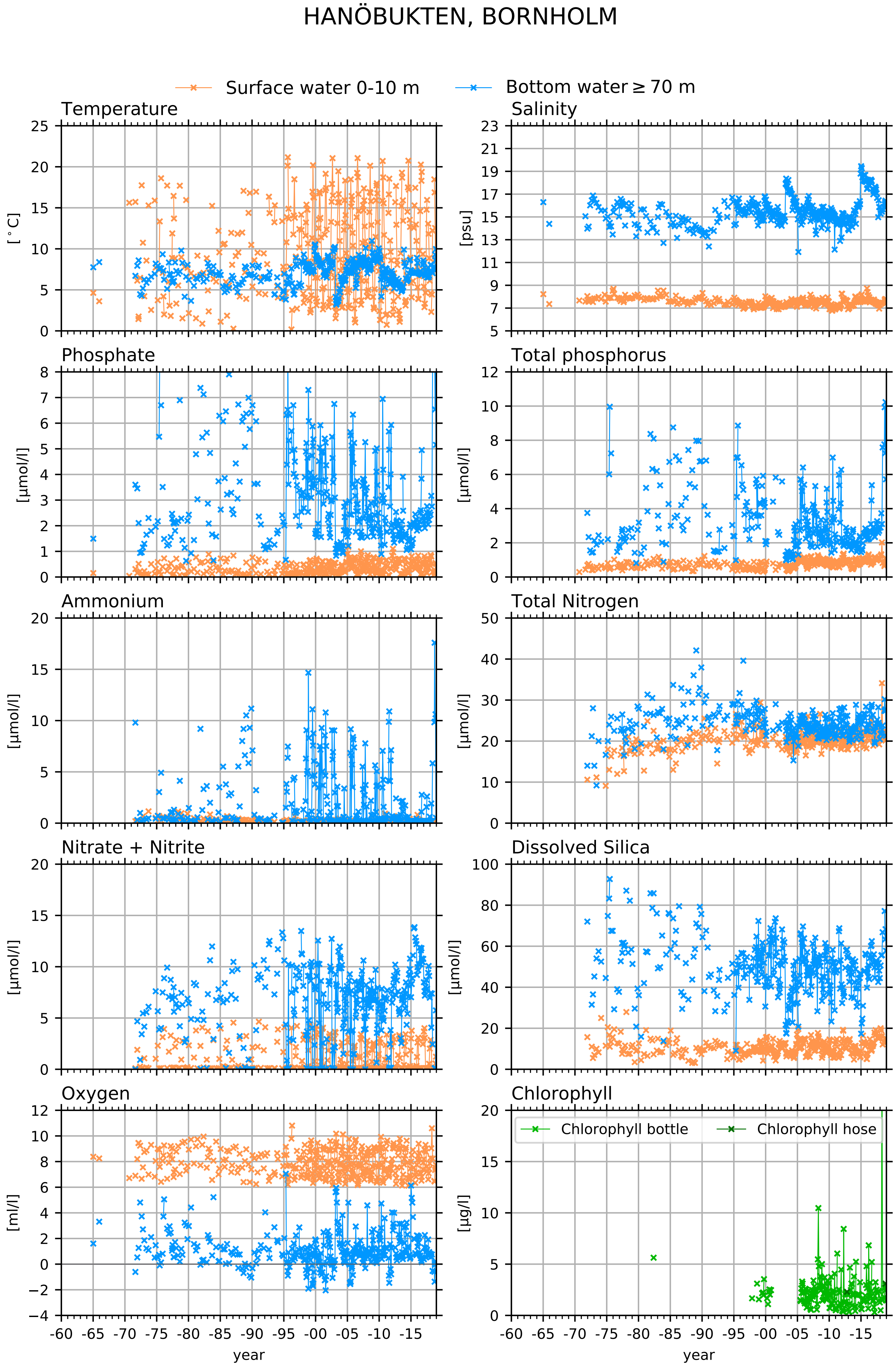
BY1, ARKONA



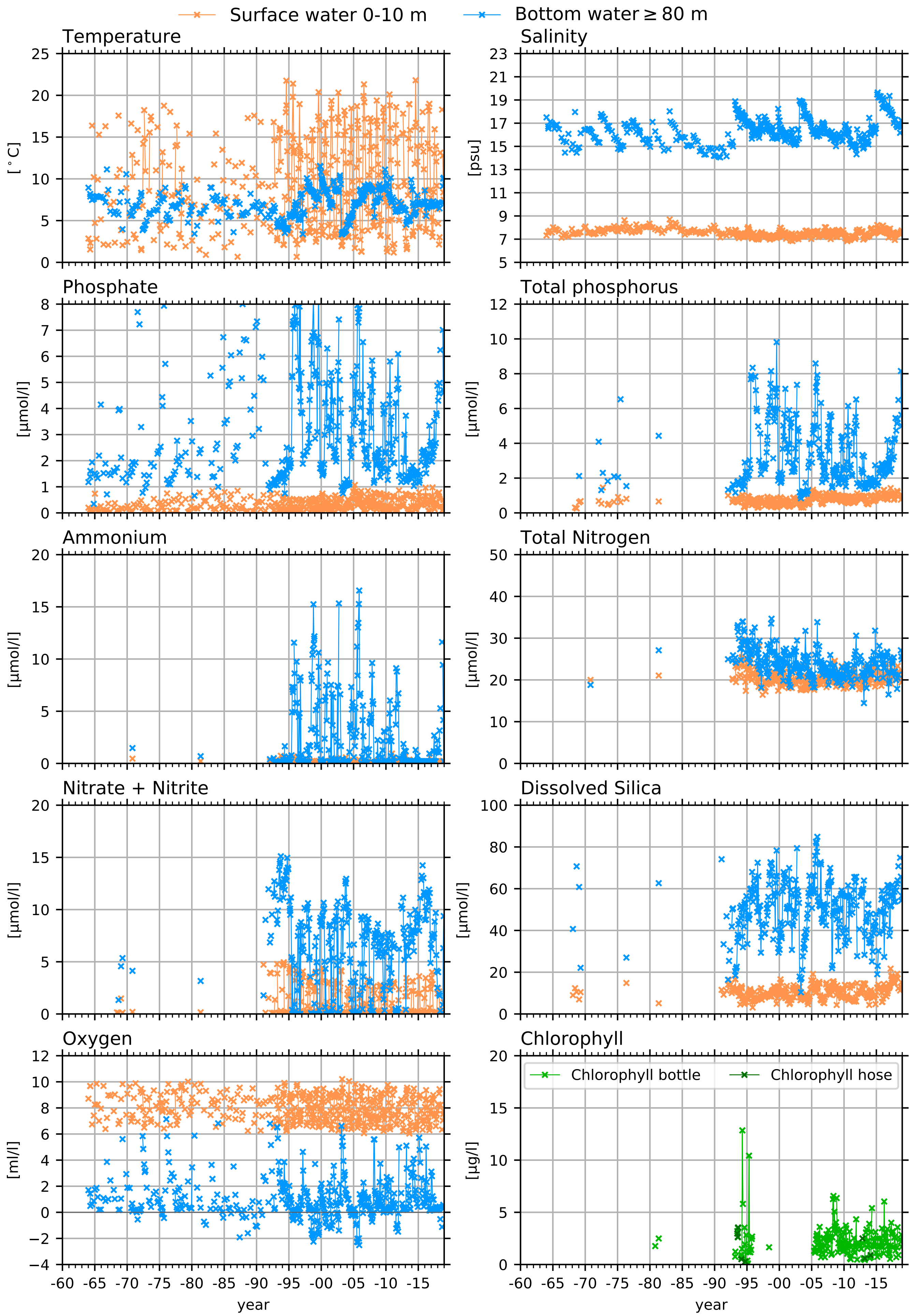
Surface water 0-10 m
Bottom water ≥ 40 m
Temperature
[°C]
Salinity
[psu]
Phosphate
[µmol/l]
Total phosphorus
[µmol/l]
Ammonium
[µmol/l]
Total Nitrogen
[µmol/l]
Nitrate + Nitrite
[µmol/l]
Dissolved Silica
[µmol/l]
Oxygen
[ml/l]
Chlorophyll
Chlorophyll bottle
Chlorophyll hose
[µg/l]
-60 -65 -70 -75 -80 -85 -90 -95 -00 -05 -10 -15
year

BY2 ARKONA, ARKONA

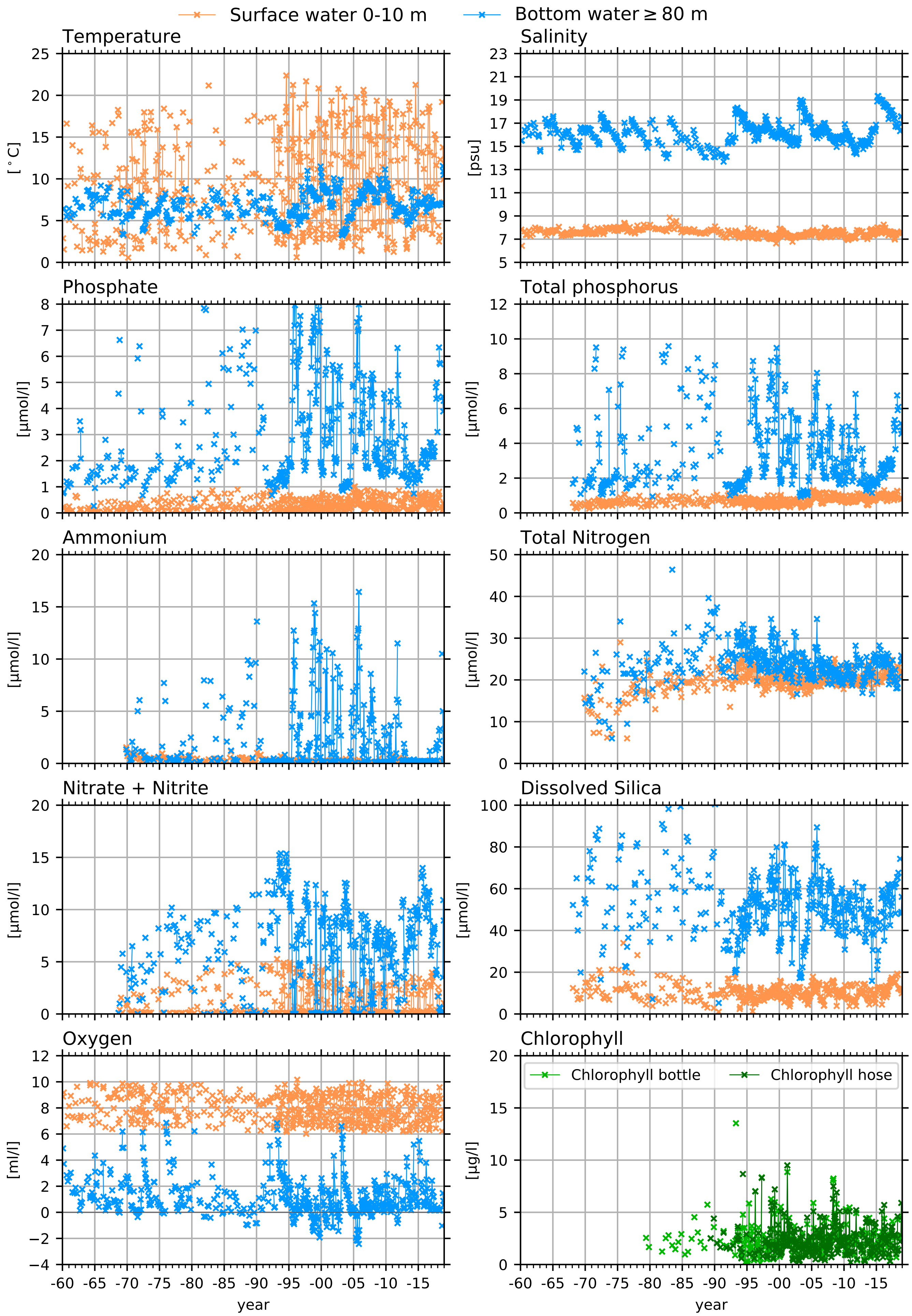



HANÖBUKTEN, BORNHOLM
Surface water 0-10 m
Bottom water ≥ 70 m
Temperature
[°C]
Salinity
[psu]
Phosphate
[µmol/l]
Total phosphorus
[µmol/l]
Ammonium
[µmol/l]
Total Nitrogen
[µmol/l]
Nitrate + Nitrite
[µmol/l]
Dissolved Silica
[µmol/l]
Oxygen
[ml/l]
Chlorophyll
Chlorophyll bottle
Chlorophyll hose
[µg/l]
year
-60 -65 -70 -75 -80 -85 -90 -95 -00 -05 -10 -15

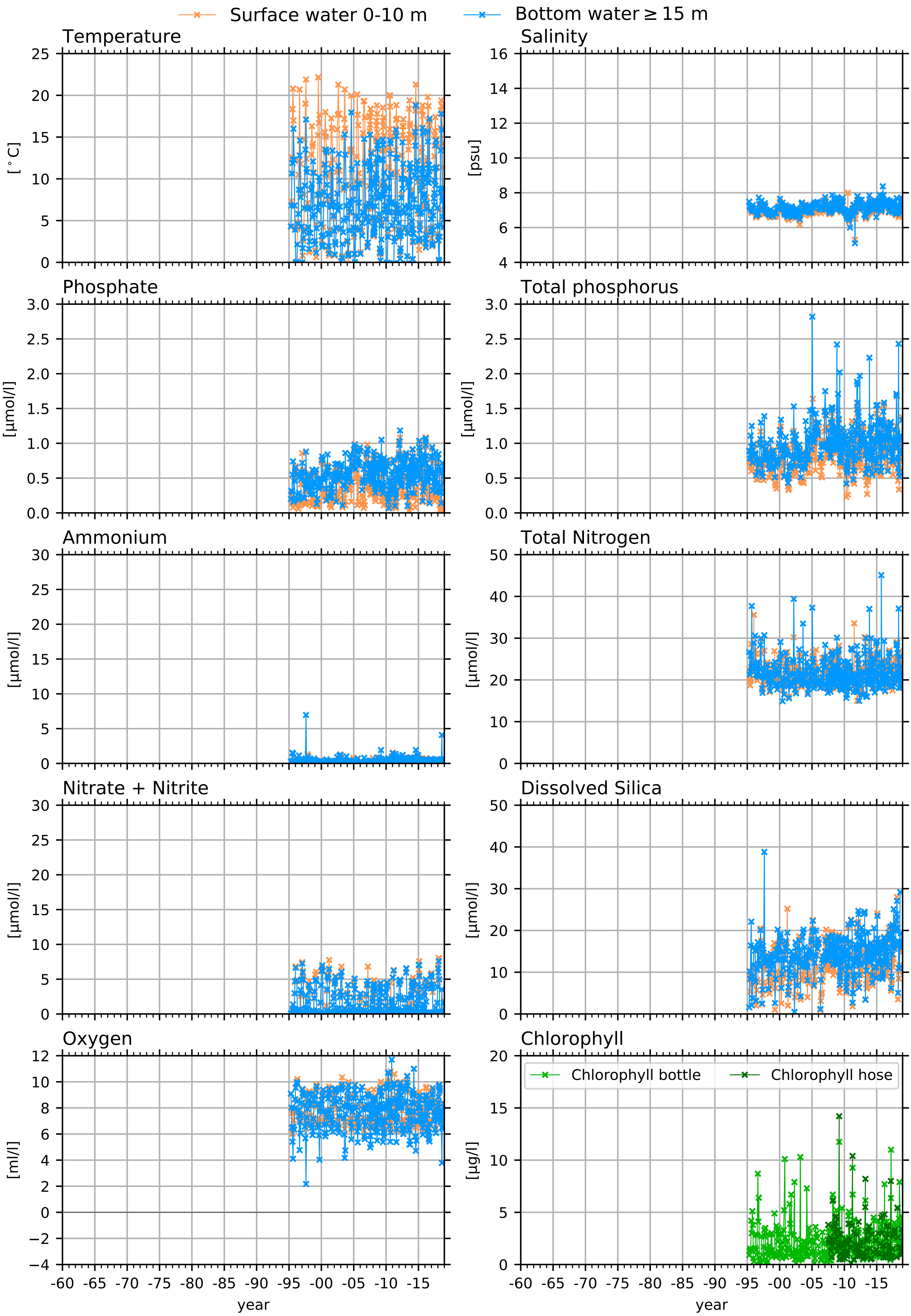
BY4 CHRISTIANSÖ, BORNHOLM



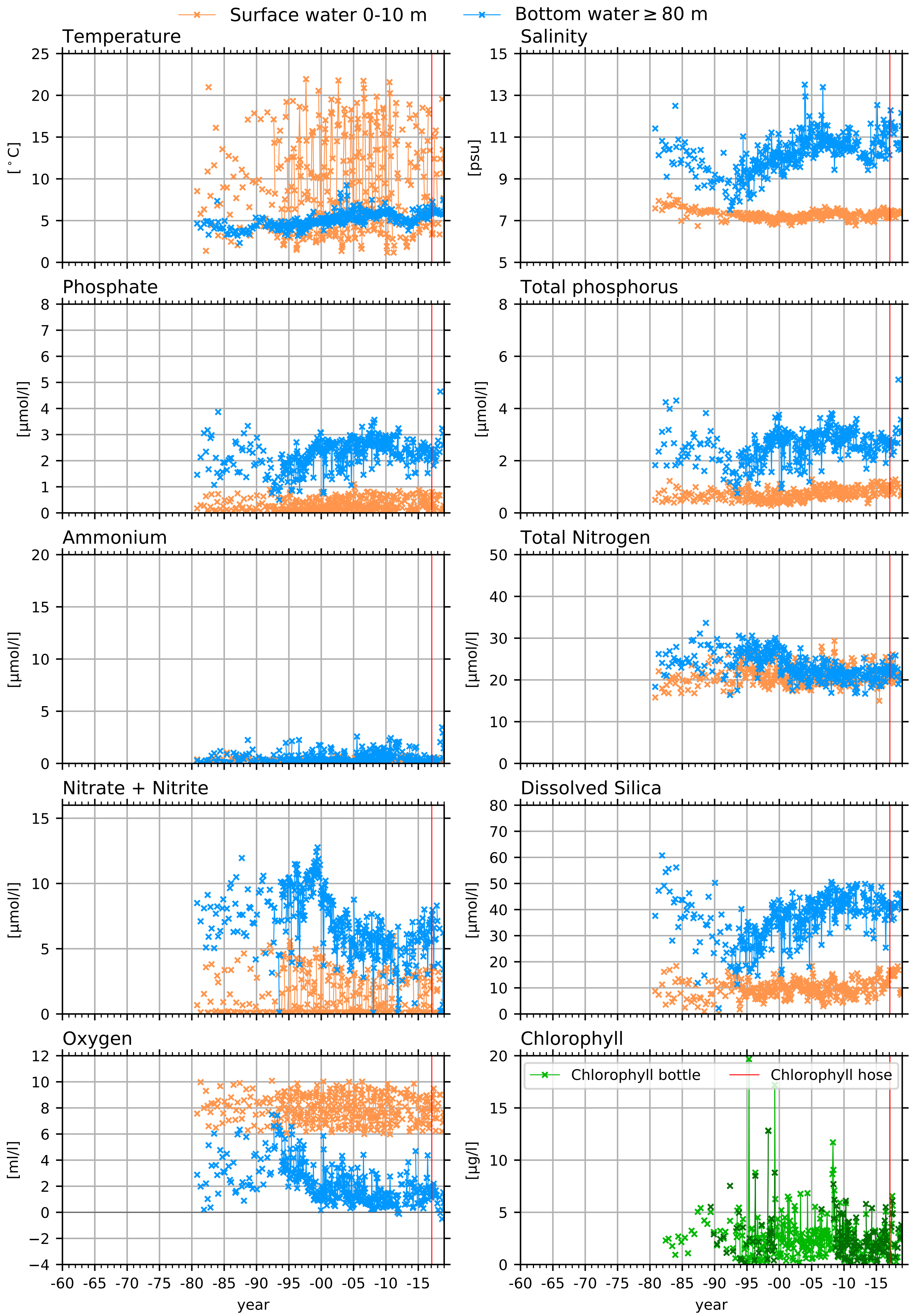
BY5 BORNHOLM DEEP, BORNHOLM



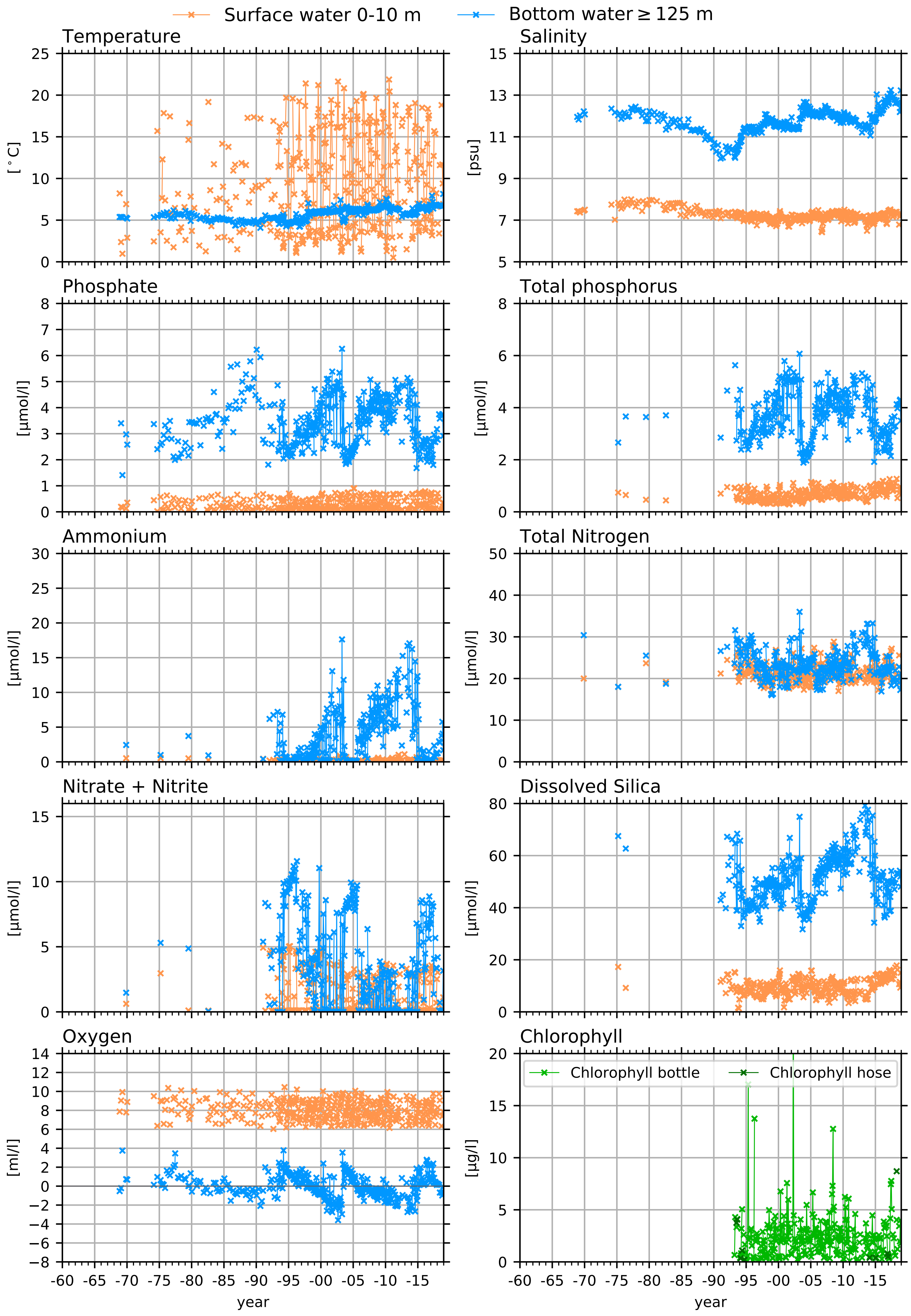
REF M1V1, BORNHOLM

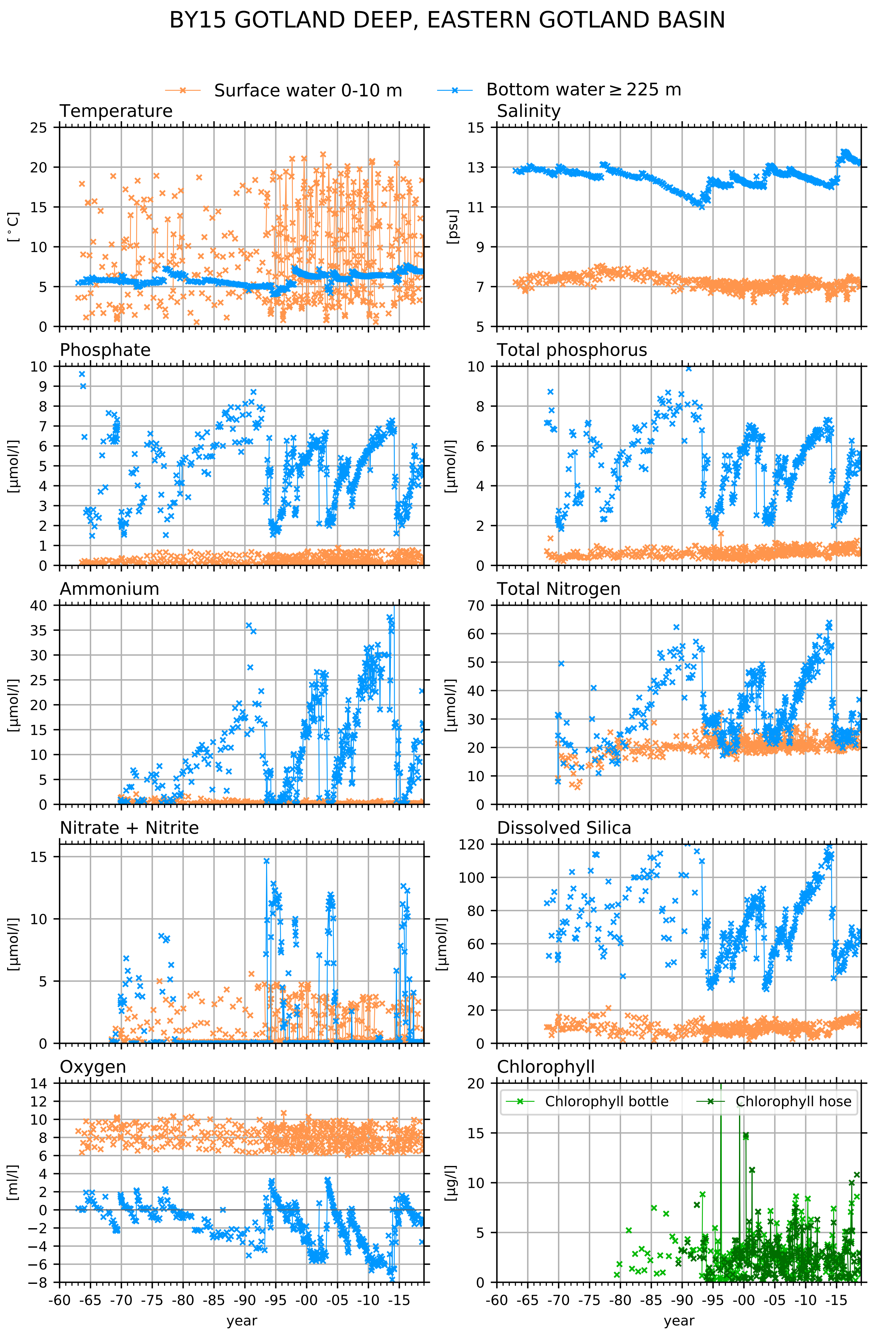


BCS III-10, EASTERN GOTLAND BASIN



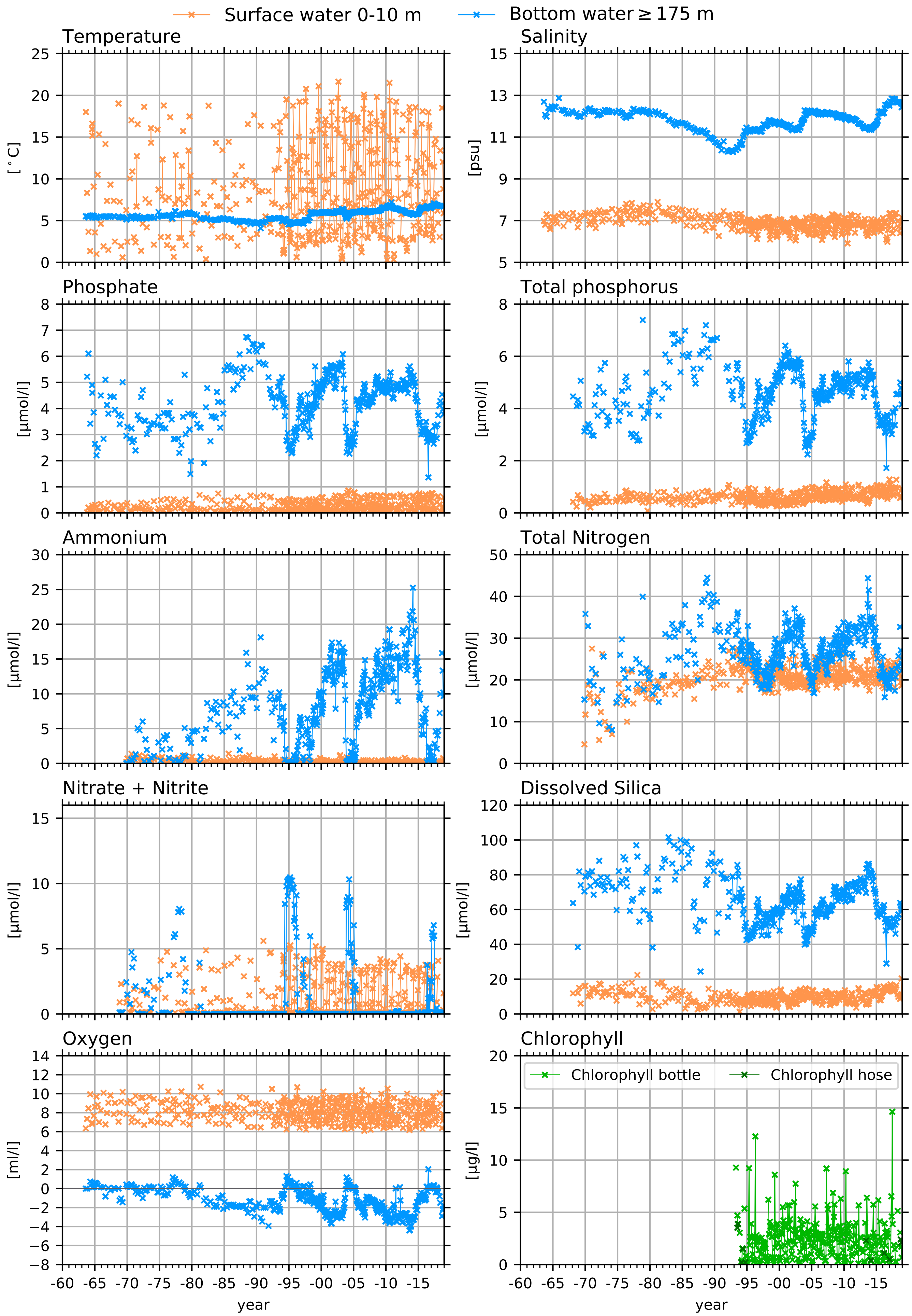
BY10, EASTERN GOTLAND BASIN



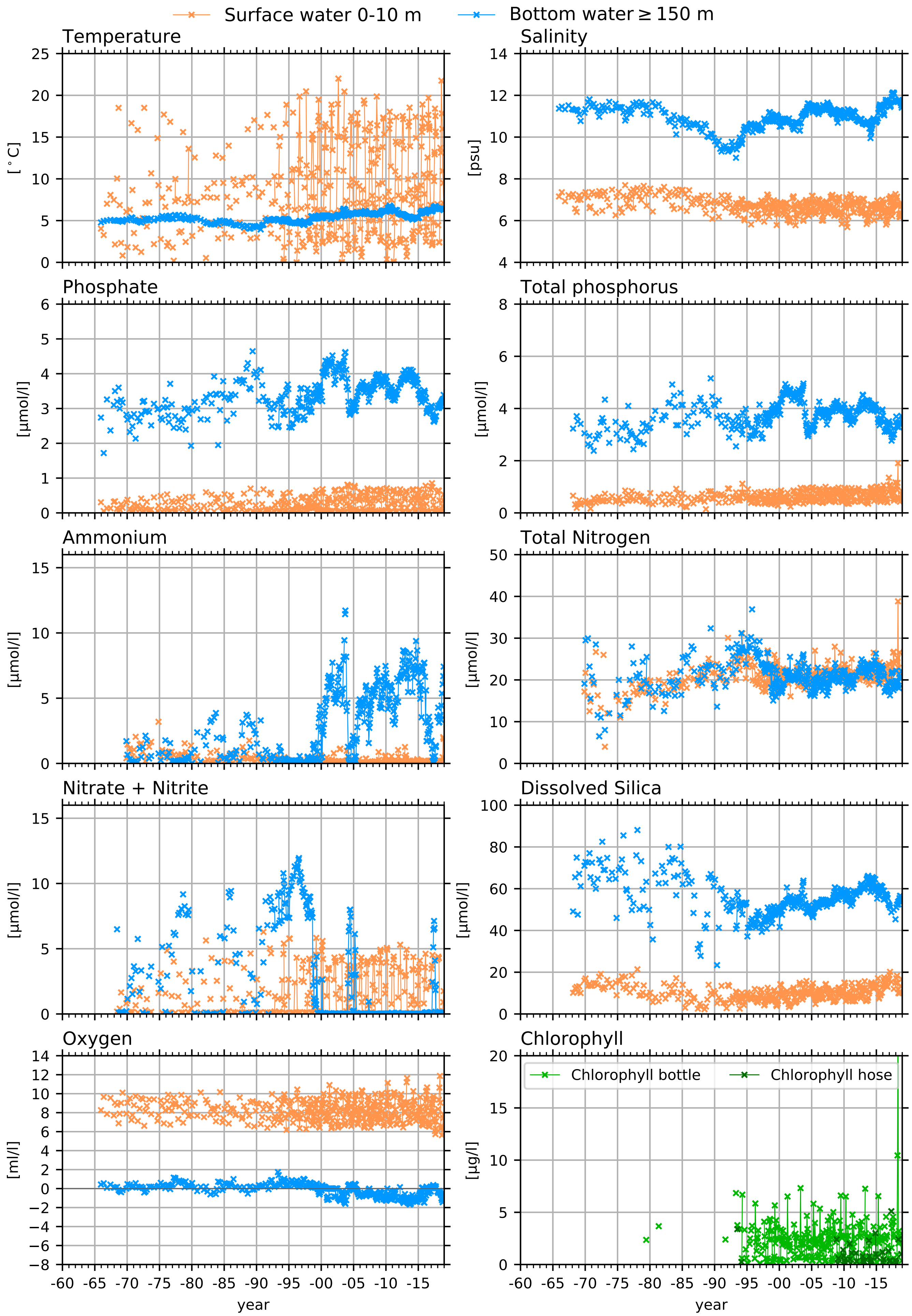


BY15 GOTLAND DEEP, EASTERN GOTLAND BASIN
Surface water 0-10 m
Bottom water ≥ 225 m
Temperature
[° C]
Salinity
[psu]
Phosphate
[µmol/l]
Total phosphorus
[µmol/l]
Ammonium
[µmol/l]
Total Nitrogen
[µmol/l]
Nitrate + Nitrite
[µmol/l]
Dissolved Silica
[µmol/l]
Oxygen
[ml/l]
Chlorophyll
Chlorophyll bottle
Chlorophyll hose
[µg/l]
year

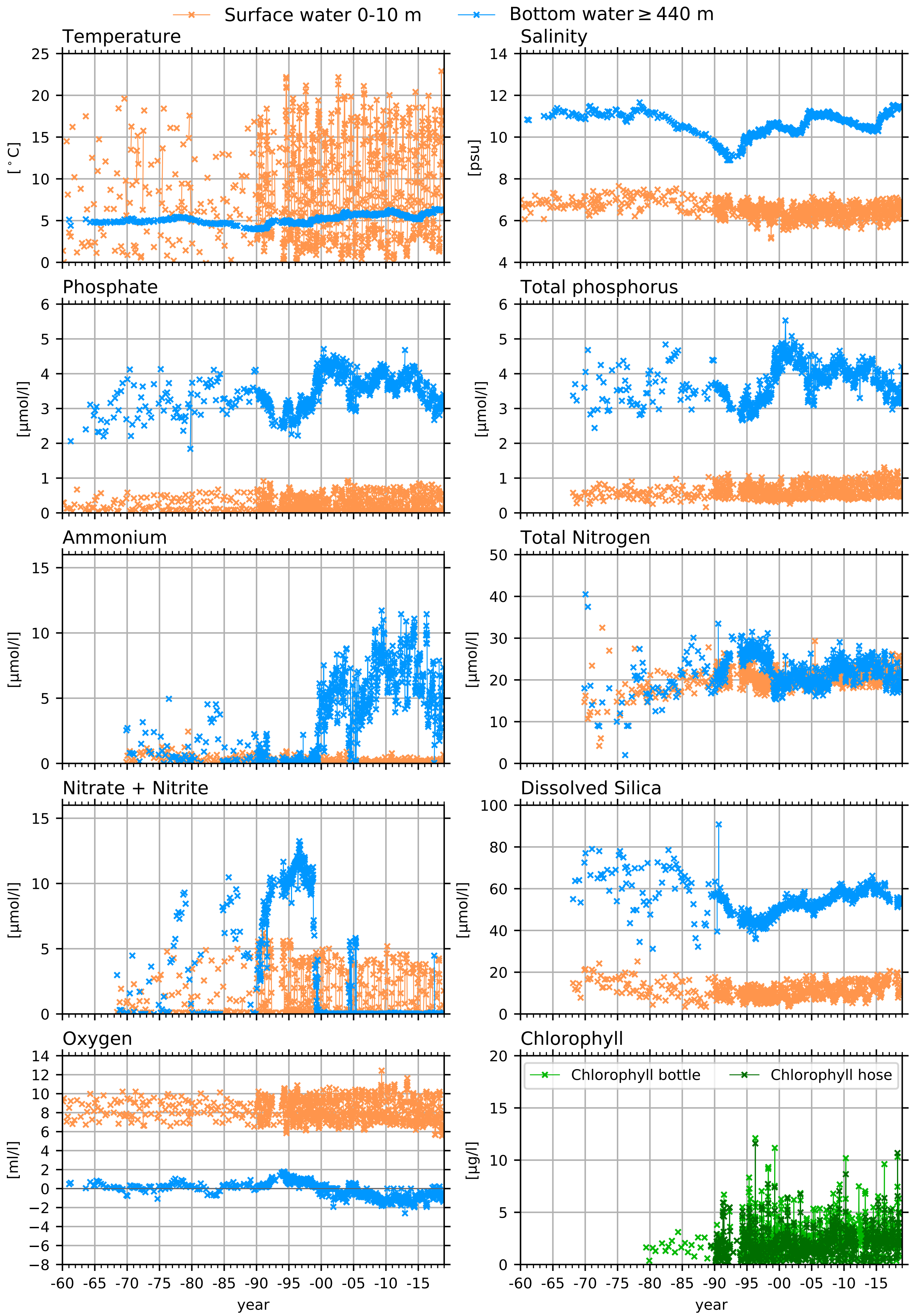
BY20 FÅRÖ DEEP, EASTERN GOTLAND BASIN



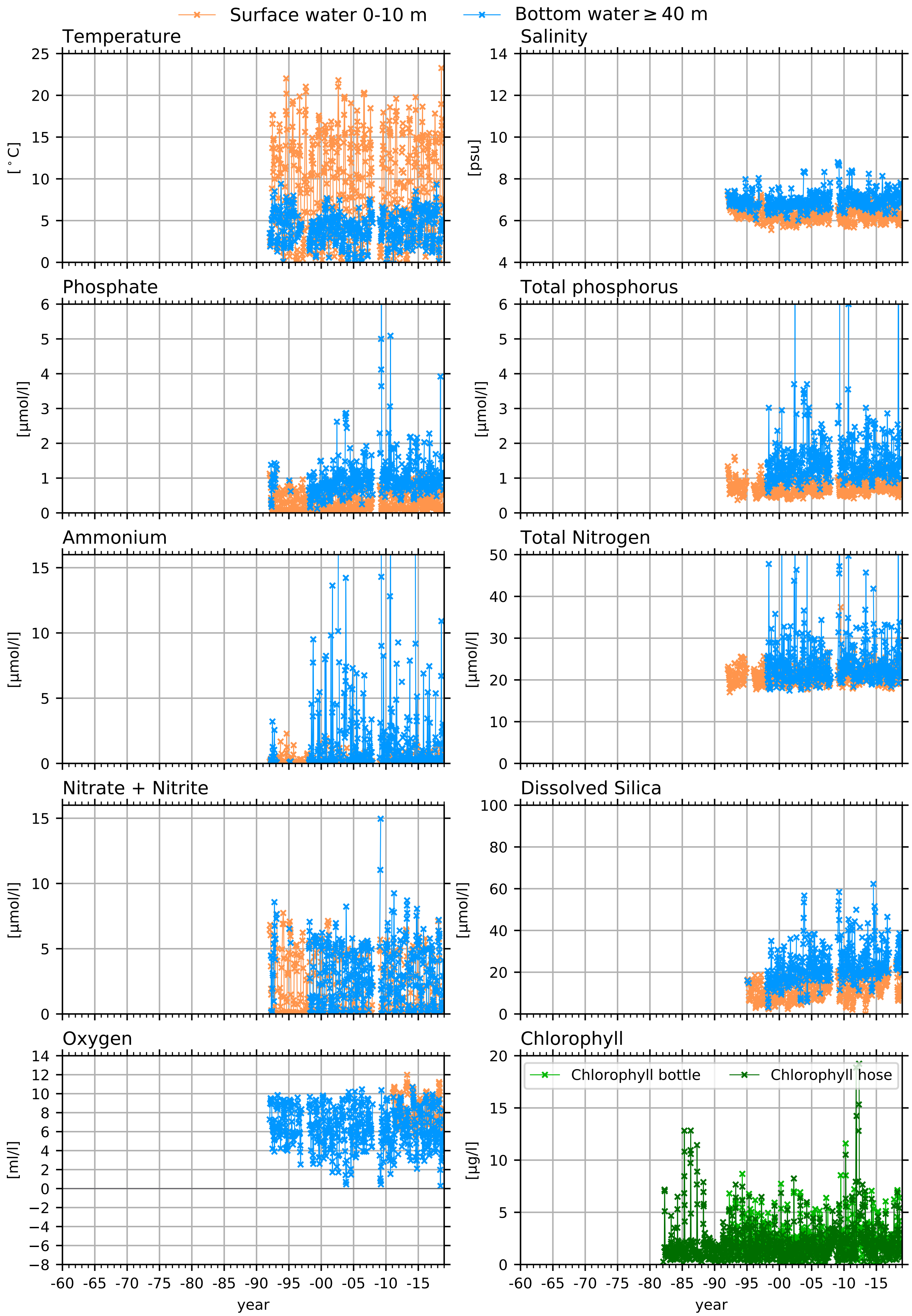
BY29 / LL19, NORTHERN BALTIC PROPER



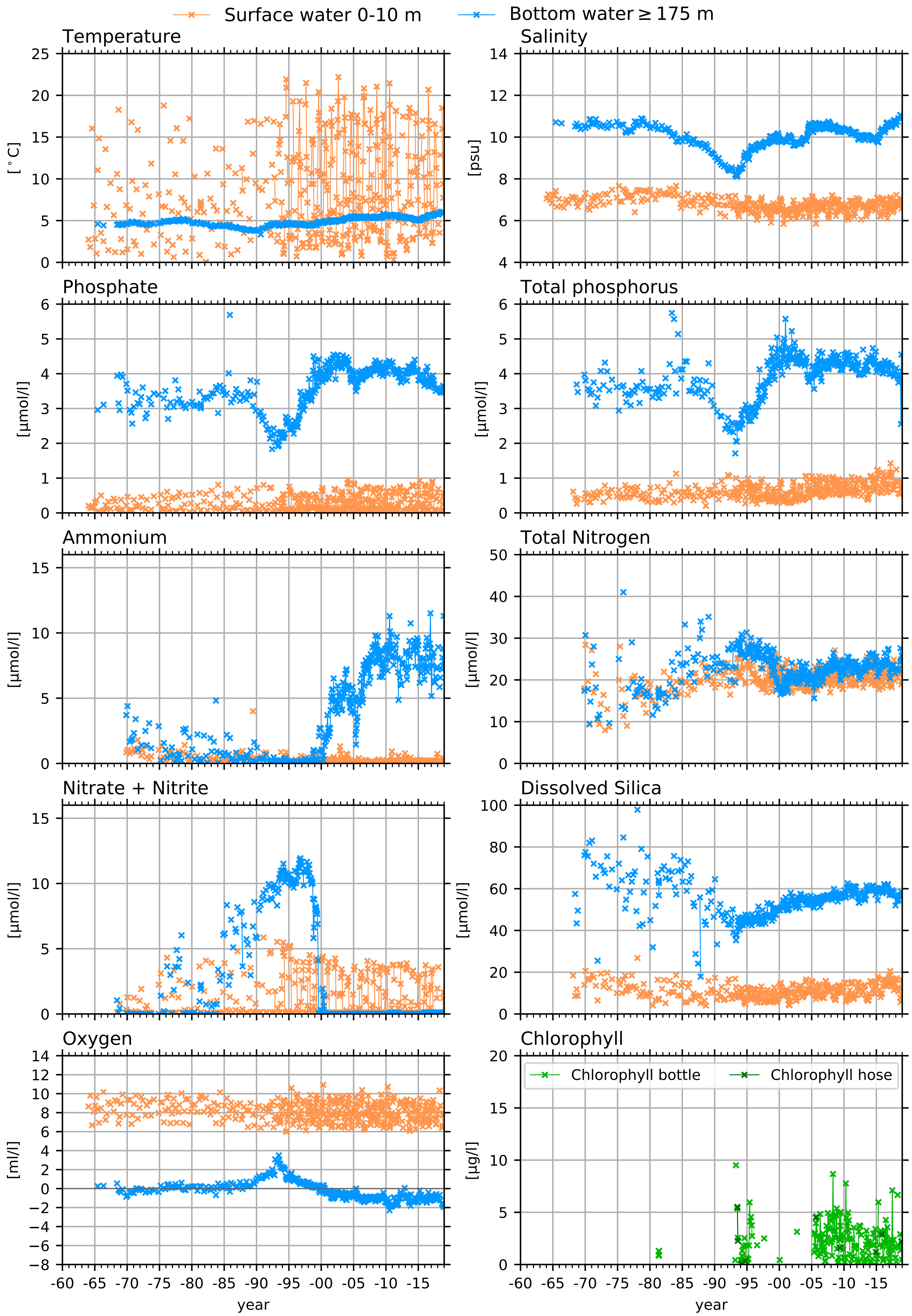
BY31 LANDSORT DEEP, BALTIC PROPER



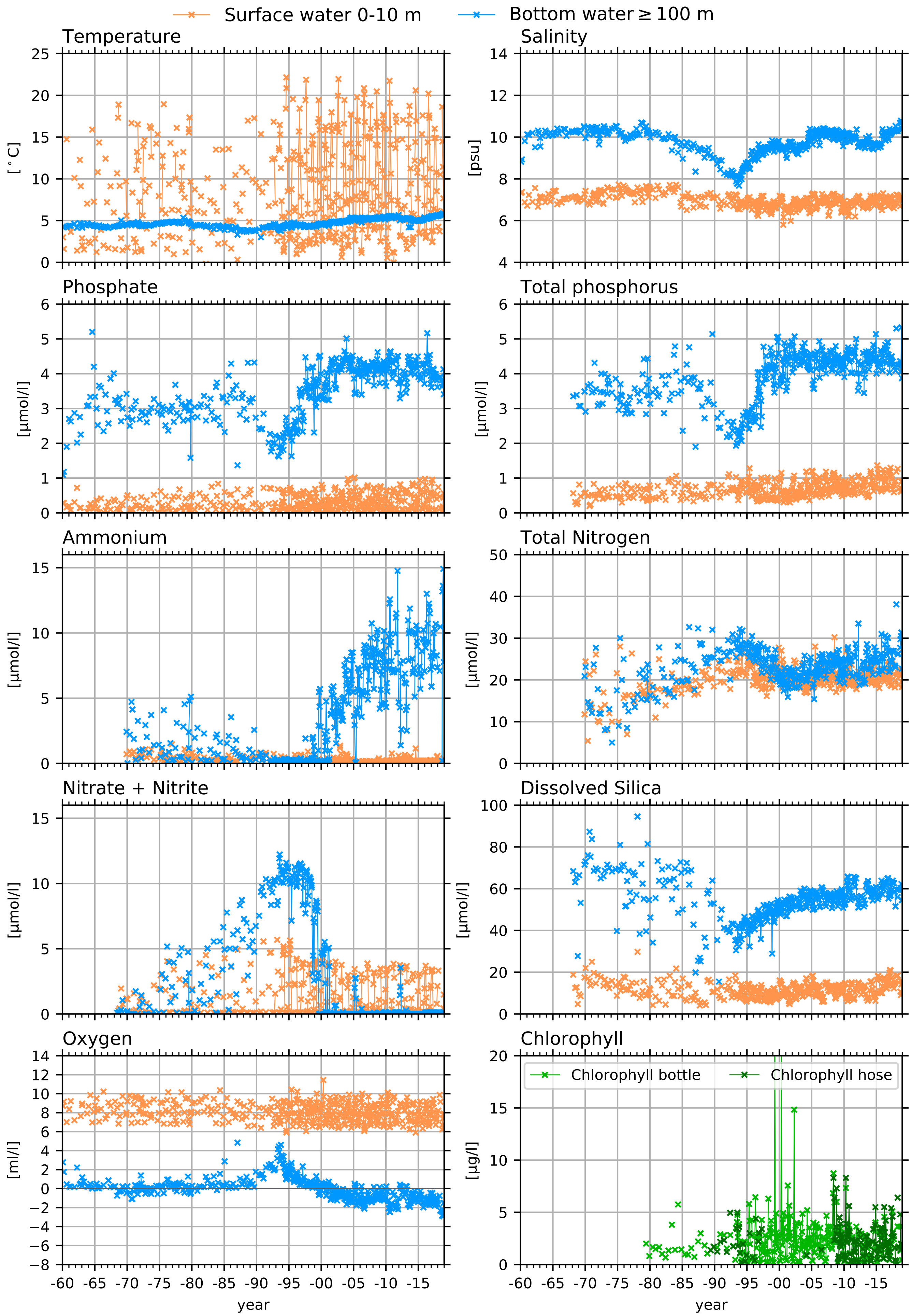
B1 (ASKÖ), WESTERN GOTLAND BASIN



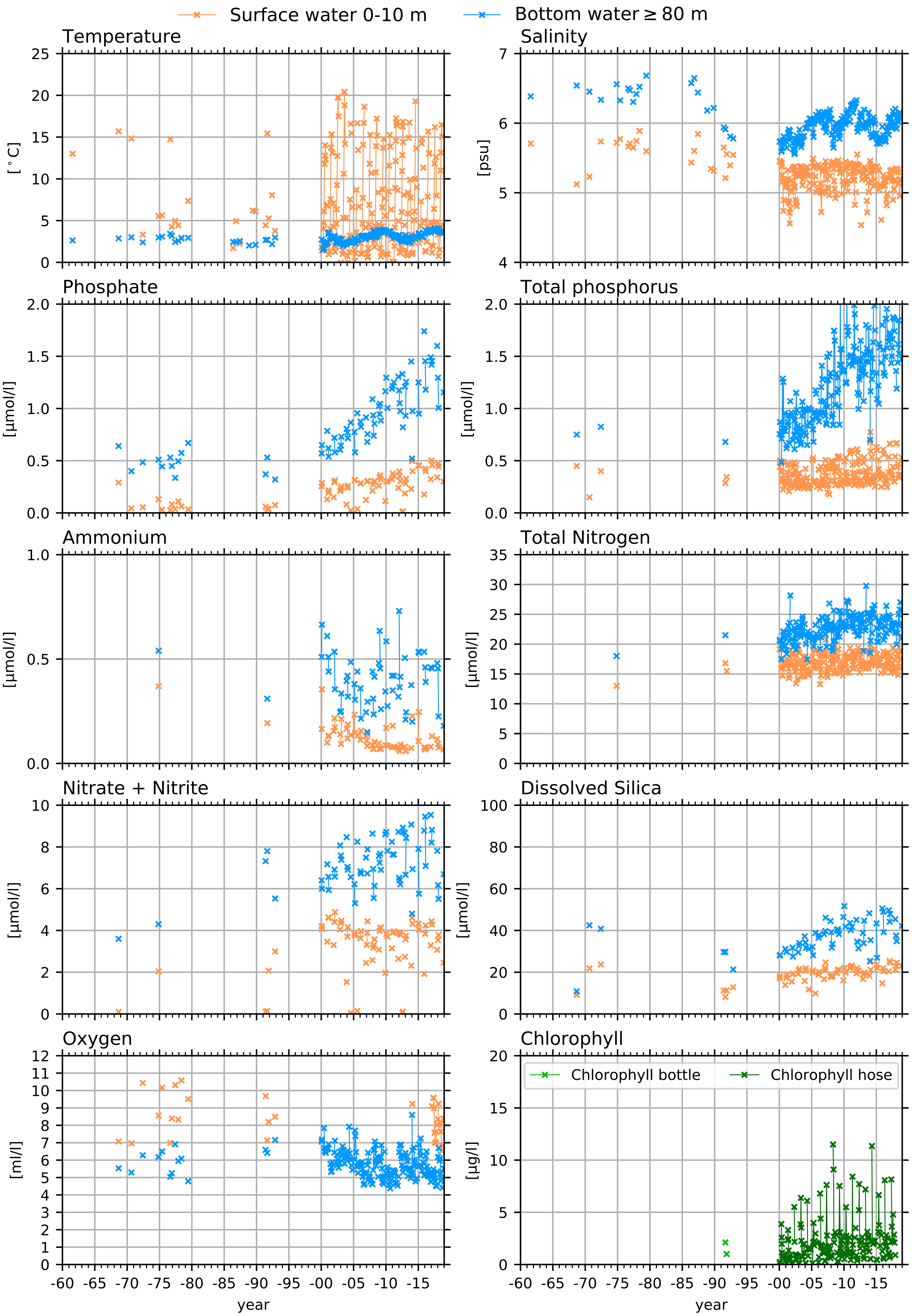
BY32 NORRKÖPING DEEP, WESTERN GOTLAND BASIN



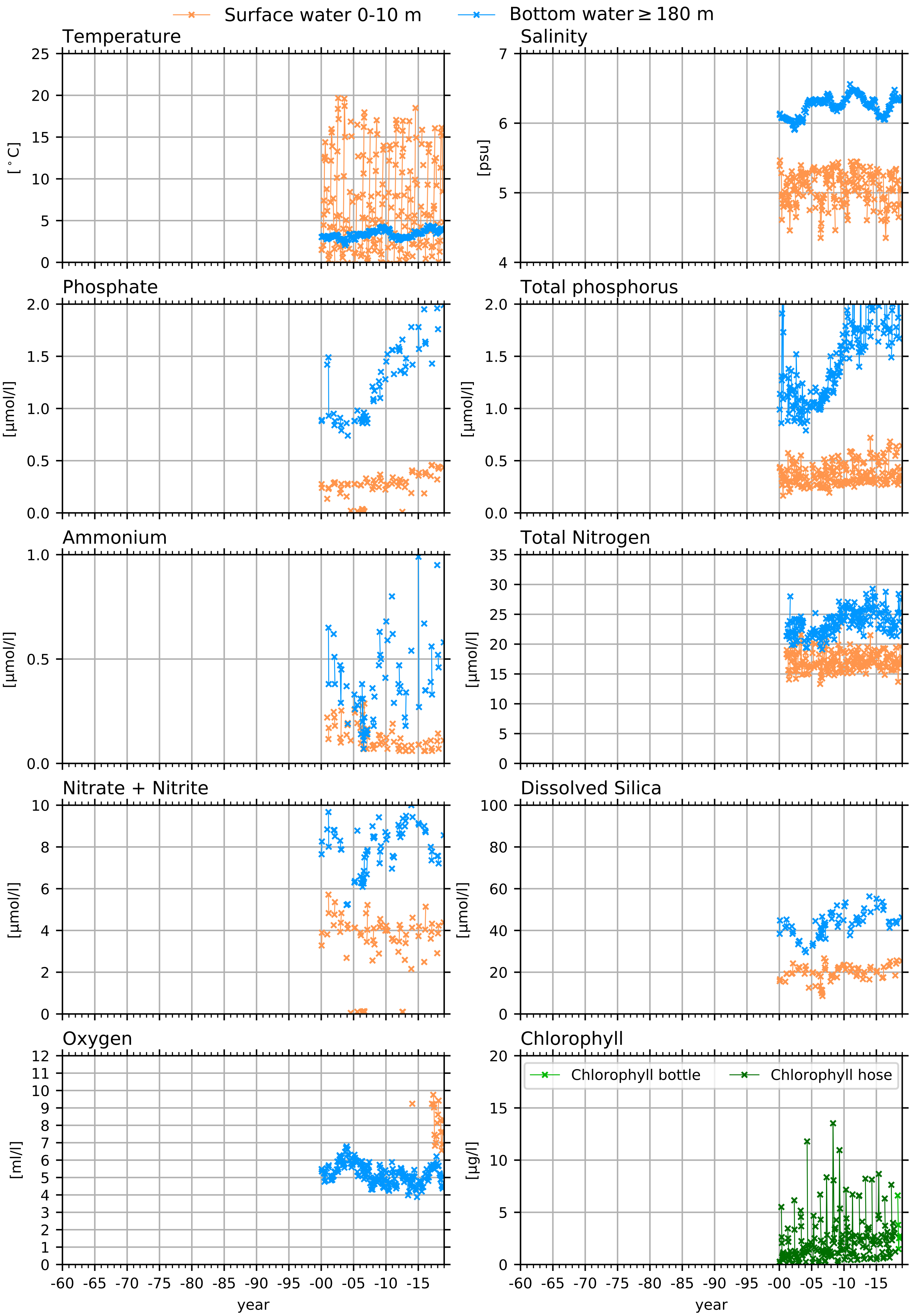
BY38 KARLSÖ DEEP, WESTERN GOTLAND BASIN



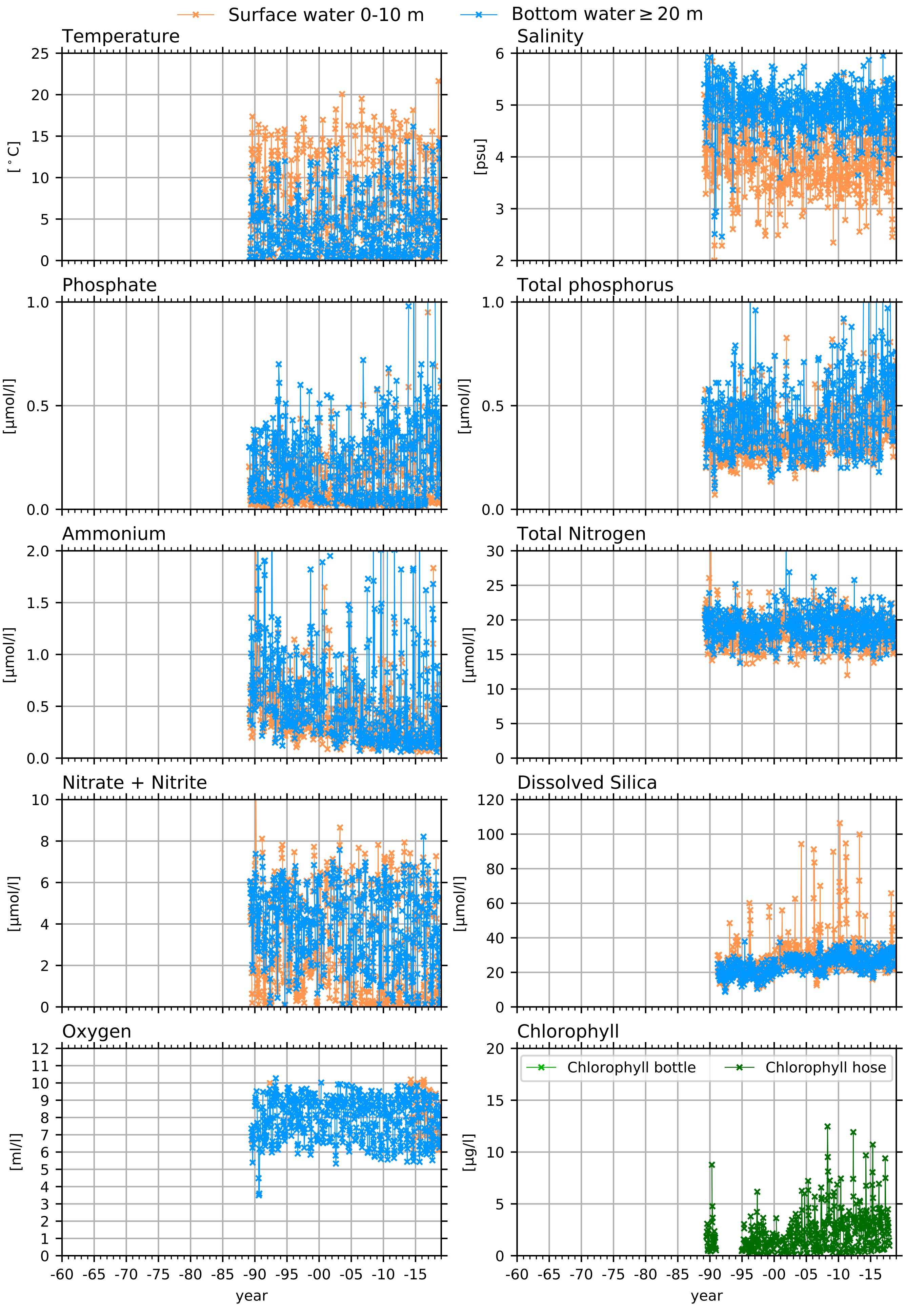
MS4 / C14, BOTHNIAN SEA



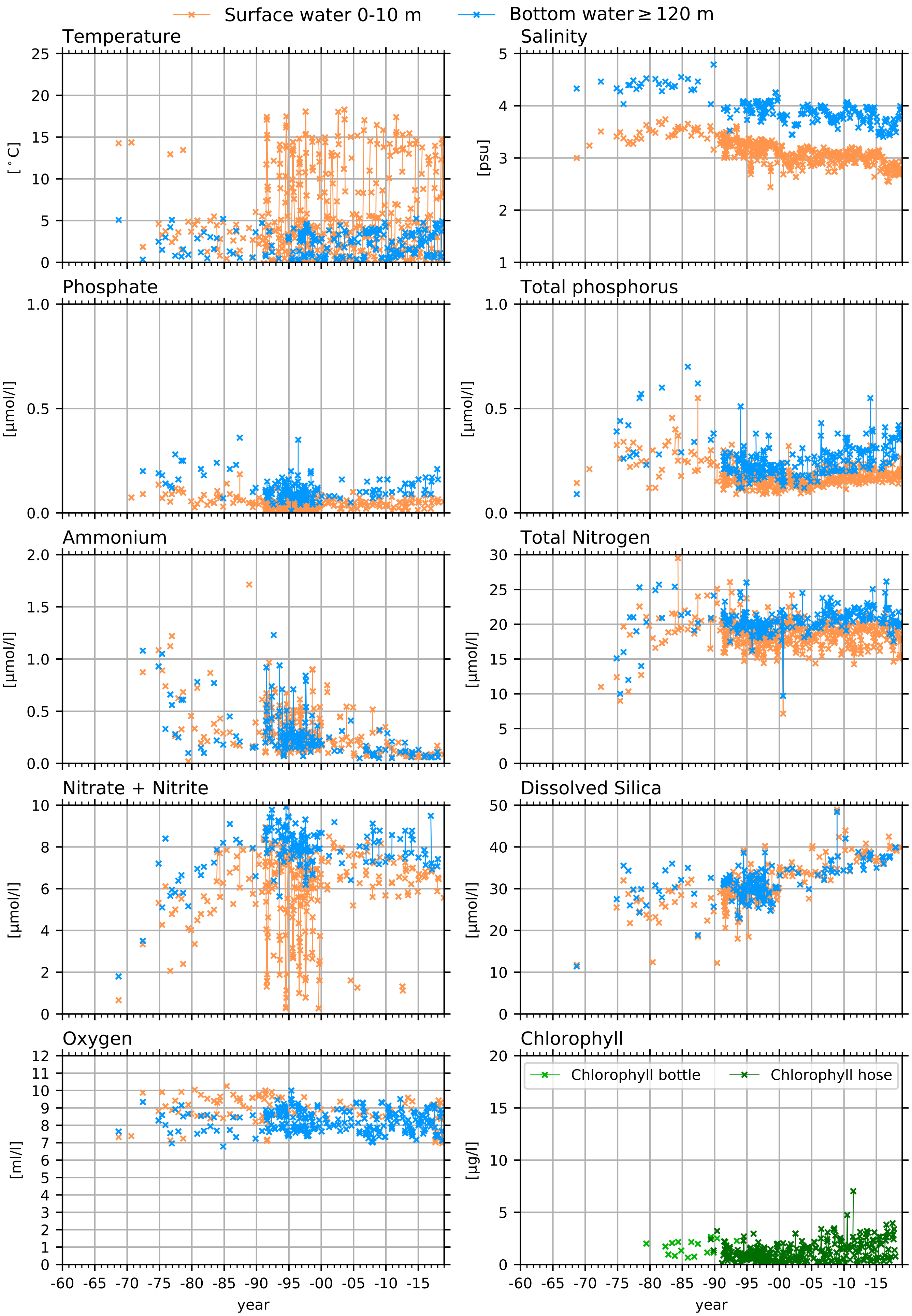
C3, BOTHNIAN SEA



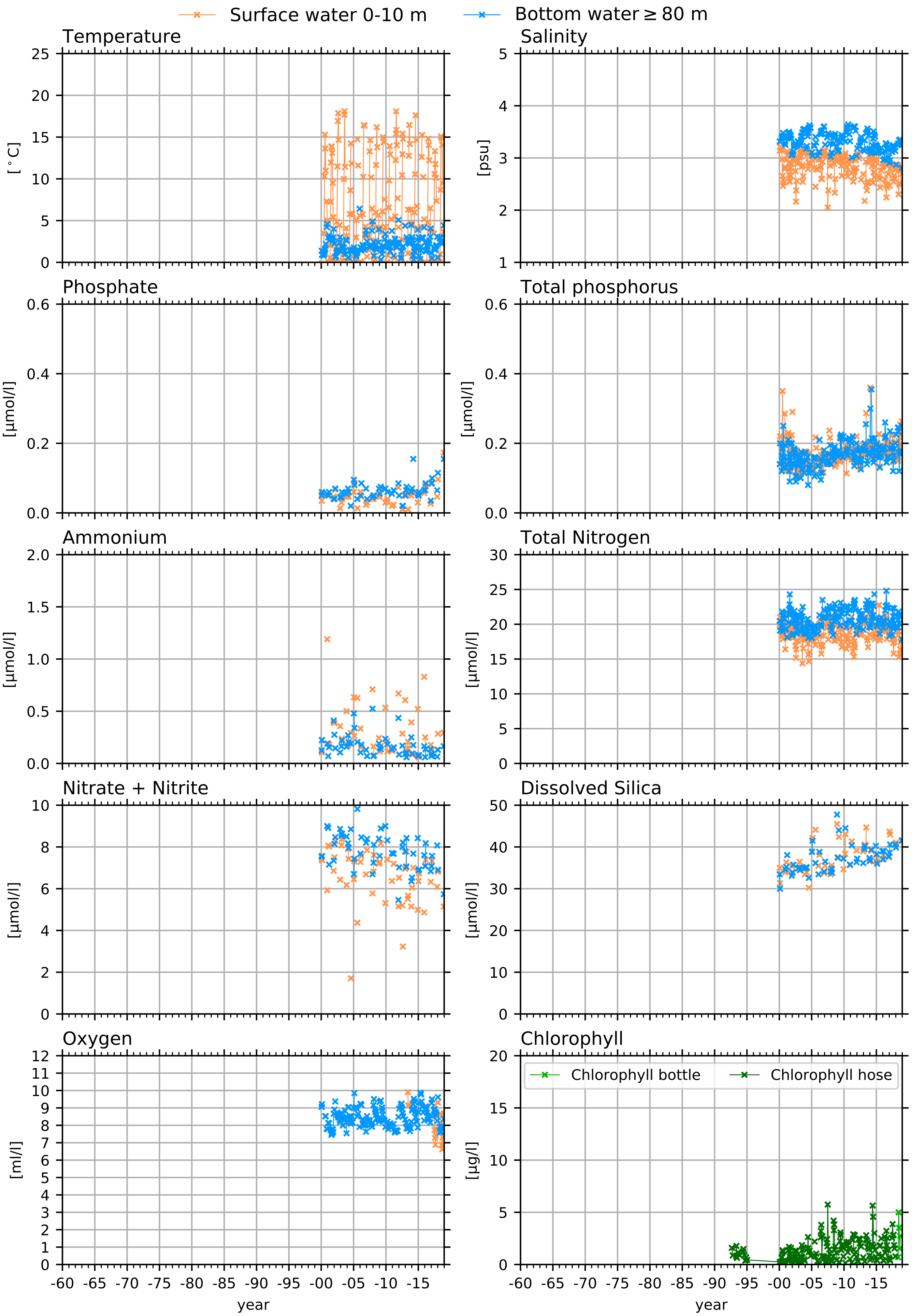
B7 & NB1 / B3, THE QUARK



F9 / A13, BOTHNIAN BAY



F3 / A5, BOTHNIAN BAY



Appendix III

Nutrient content per basin in the Baltic Sea and the Gulf of Bothnia

Method

The basin content of nutrients was calculated from the same data set that was used for the time series presented in Appendix II. Each profile was interpolated (linearly) to retrieve concentrations in 1 m depth resolution from each station. Only complete profiles with data in the surface, intermediary and deep waters are used.

The data is divided into winter, spring, summer and autumn (winter: Dec-Feb, spring: Mar-May, summer: June-Aug, autumn: Sep-Nov). This means that 2018 winter was calculated from data collected in December 2017, January 2018 and February 2018.

For each basin the concentration at each depth is multiplied by the volume of that depth layer, thereby getting the content of each nutrient in that depth layer. All depth layers are then summed to give the content for the whole basin. In Bornholm Basin, Arkona Basin, Bothnian Sea and Bothnian Bay the average concentration of two stations is used for the calculation, assuming little horizontal variations in all depth layers. The Western Gotland Basin and the Eastern Gotland Basin are divided into three and four sub-basins respectively because the horizontal variations, especially in the deep waters, are larger here. The sub-basins are chosen based on bathymetry around the monitoring stations. Calculated content is shown both for the sub-basins and the whole basins.

The winter and summer content is shown for all basins on the last page. Note that the difference in content between the basins depends on their difference in size.

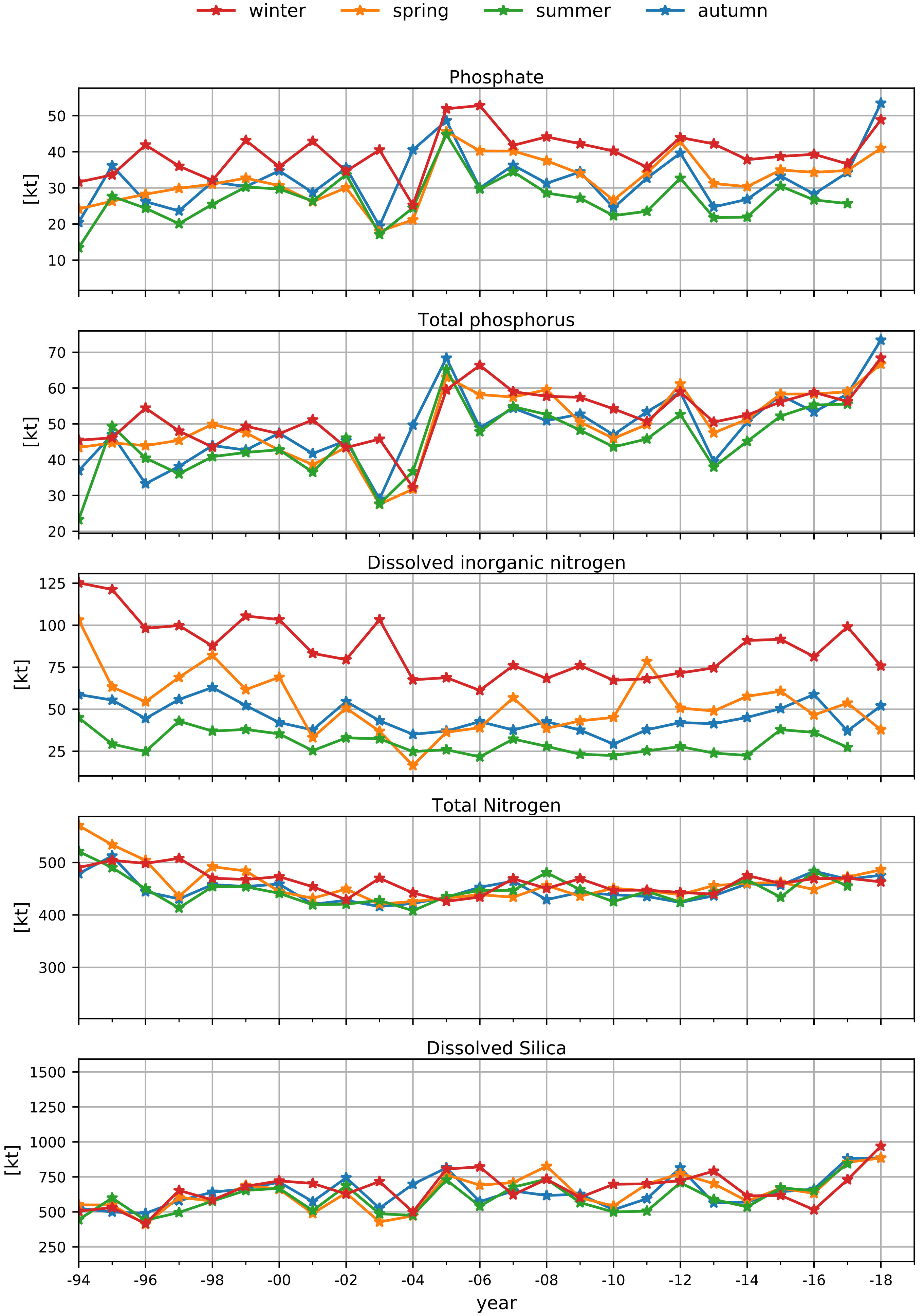
The volume of each depth layer was calculated from the bathymetry dataset iowotopo2 available by IOW at https://www.io-warnemuende.de/topography-of-the-baltic-sea.html and by using the open sea basin subdivision set by HELCOM. The sub-basin divisions where made with GIS-software and lines for these division where drawn with guidance from the bathymetry map. All basin subdivisions used are shown in the first figure of this Appendix (Figure 1).

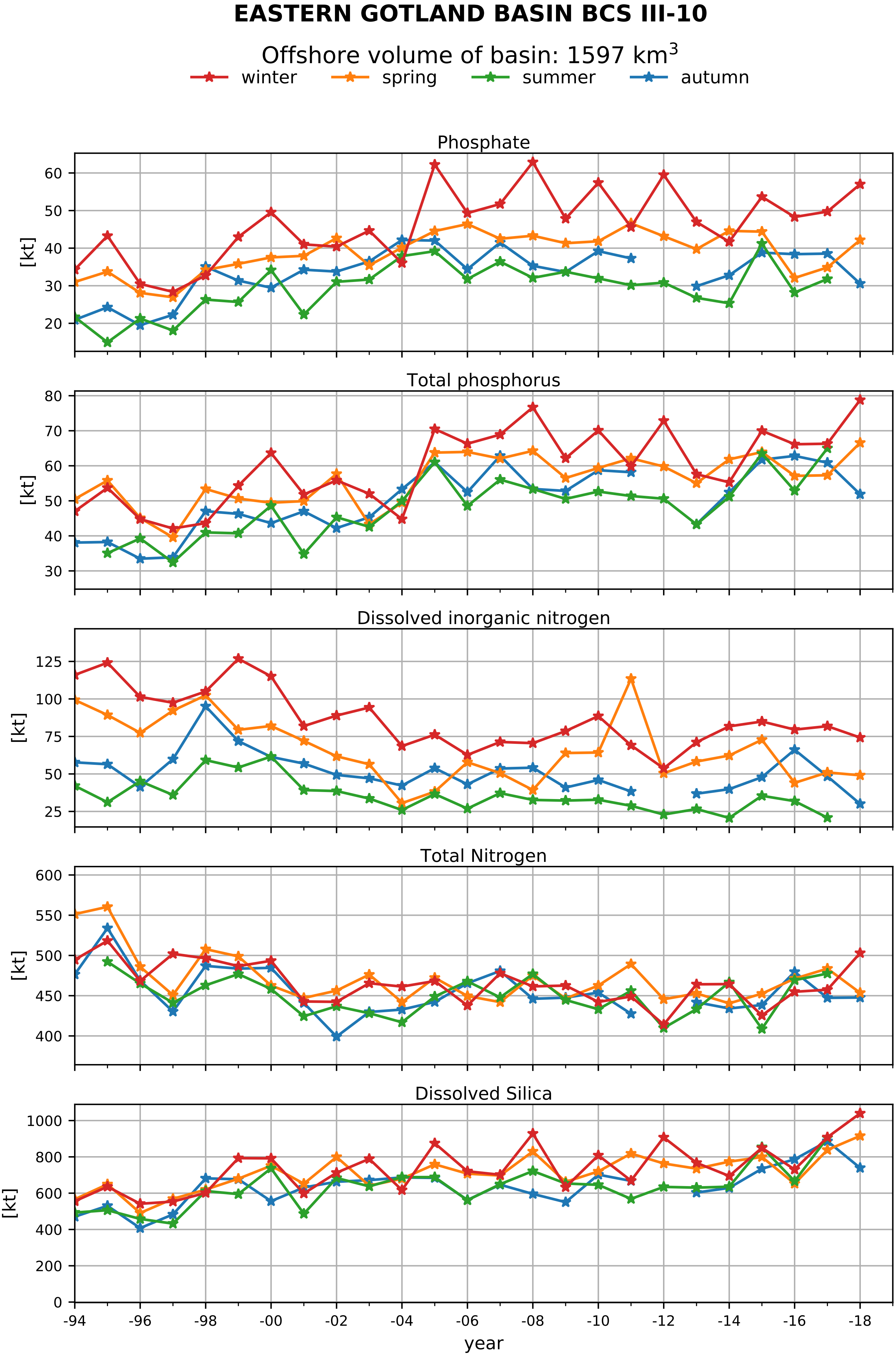
Figure 1 Basin subdivisions used for calculating hypsography and then basin content of sub-basins. The major basins shown in different colours are the HELCOM basin division revised in 2018. The previous basin division placed the station BY31 in the Northern Baltic Proper. The dashed lines showing the sub-basins were drawn to follow the bathymetry to get a smaller basin that the individual monitoring station better represents.


ARKONA BASIN
Offshore volume of basin: 353 km3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18

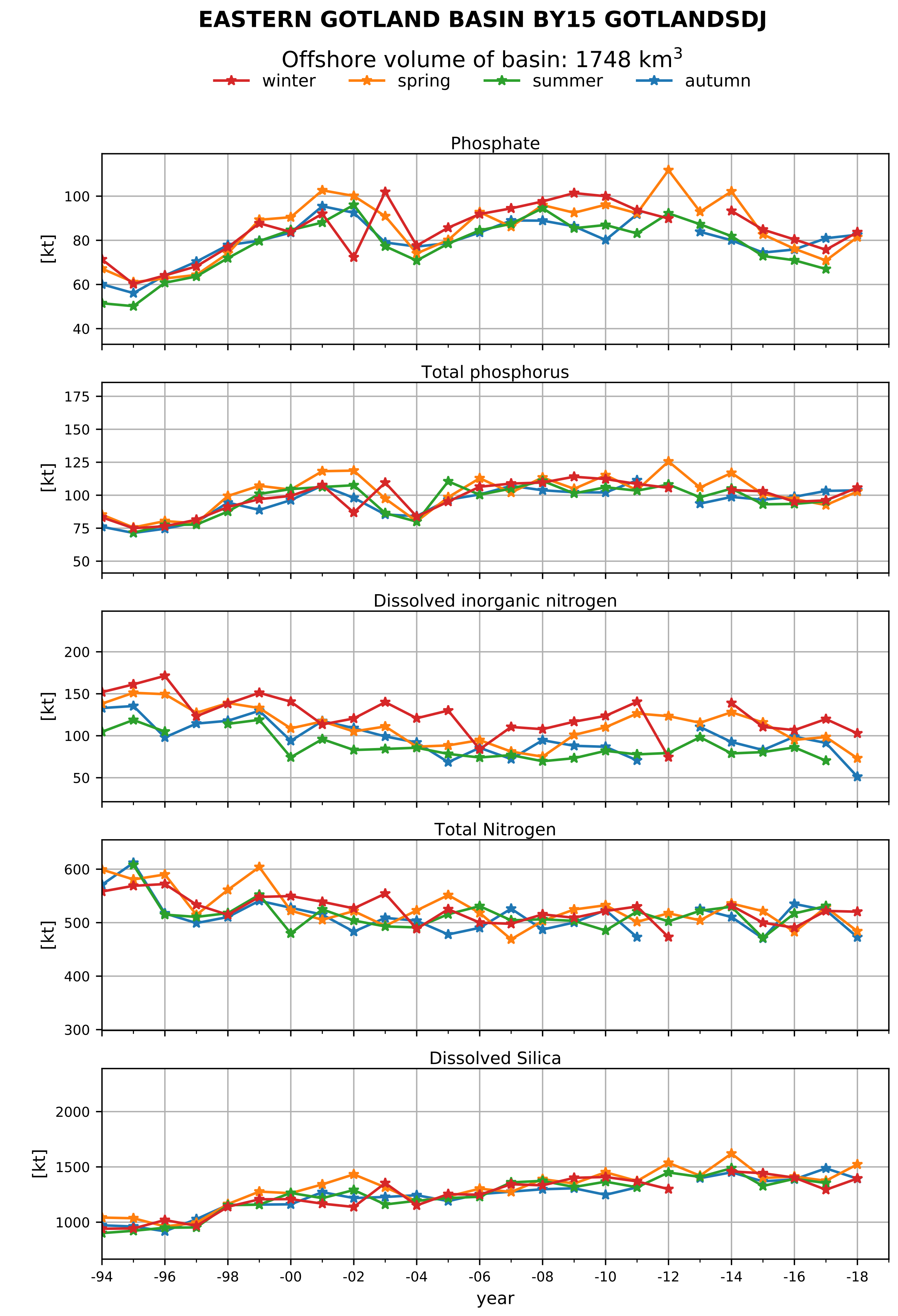
BORNHOLM BASIN

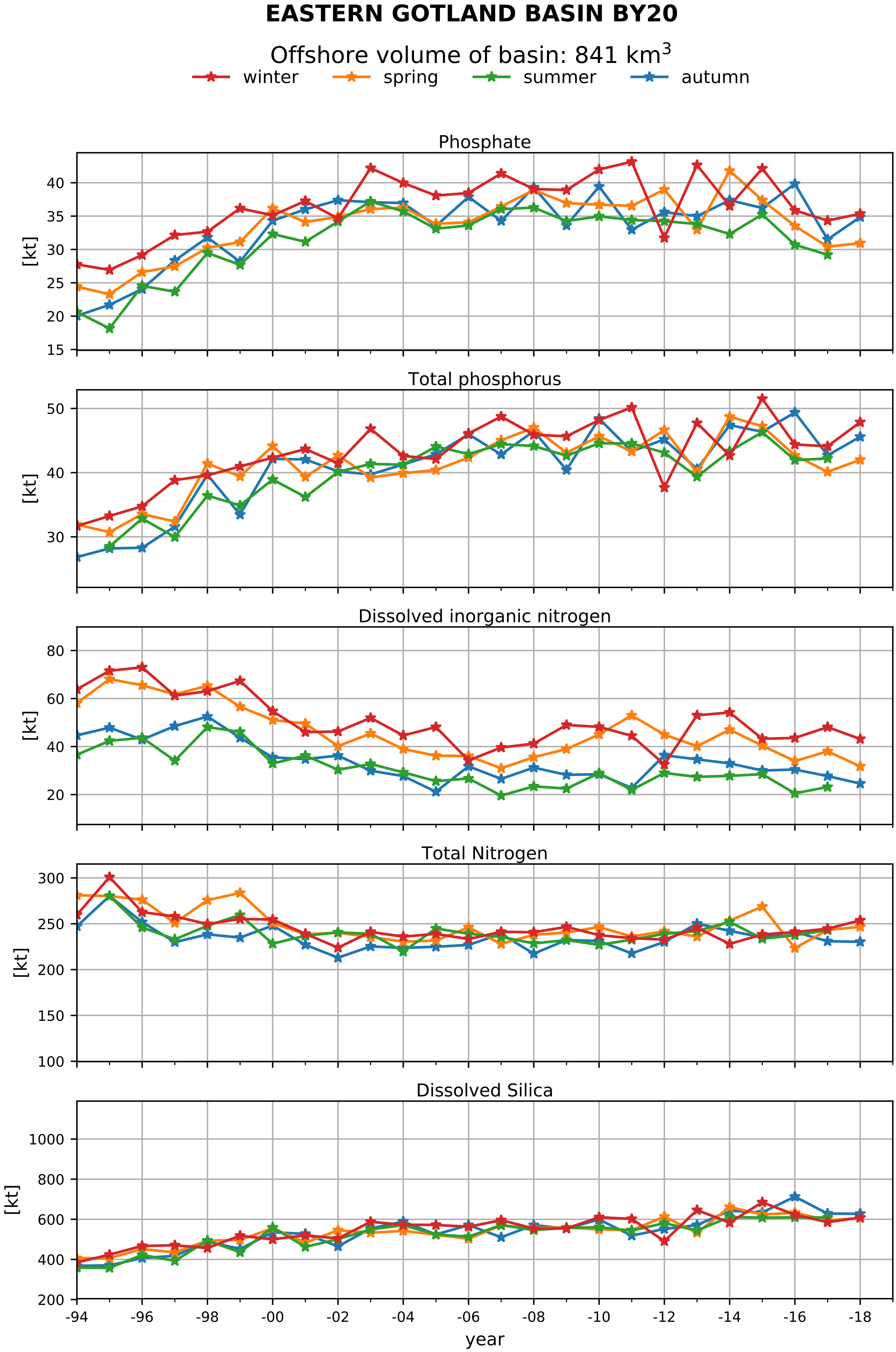
Offshore volume of basin: 1603 km^3




EASTERN GOTLAND BASIN BCS III-10
Offshore volume of basin: 1597 km^3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18
year


EASTERN GOTLAND BASIN BY10
Offshore volume of basin: 1007 km^3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18


EASTERN GOTLAND BASIN BY15 GOTLANDSDJ
Offshore volume of basin: 1748 km³
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18


EASTERN GOTLAND BASIN BY20
Offshore volume of basin: 841 km3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18

EASTERN GOTLAND BASIN

Offshore volume of basin: 5193 km^3

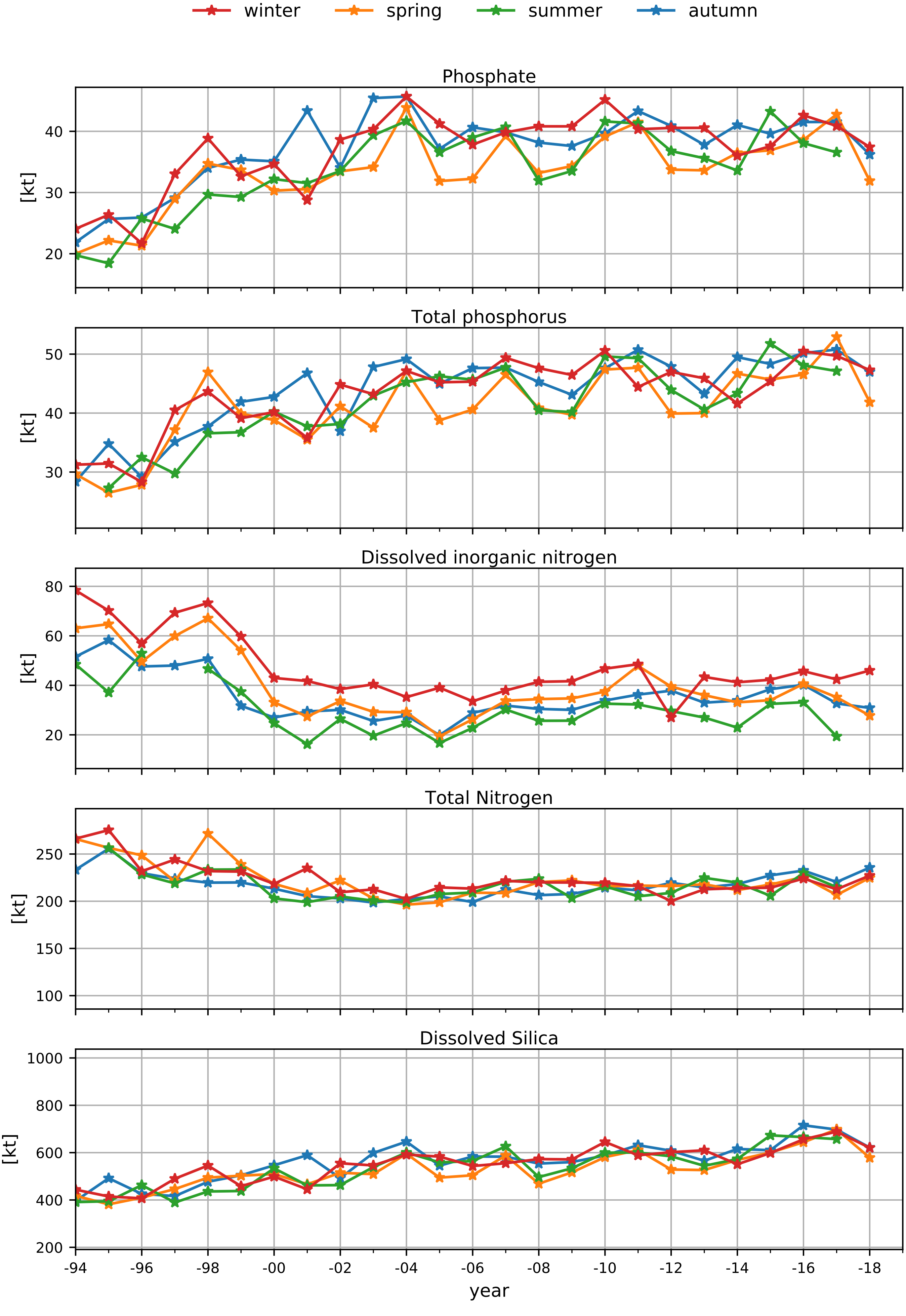
NORTHERN BALTIC PROPER

Offshore volume of basin: 2327 km^3


WESTERN GOTLAND BASIN BY31 LANDSORTSDJ
Offshore volume of basin: 723 km3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18

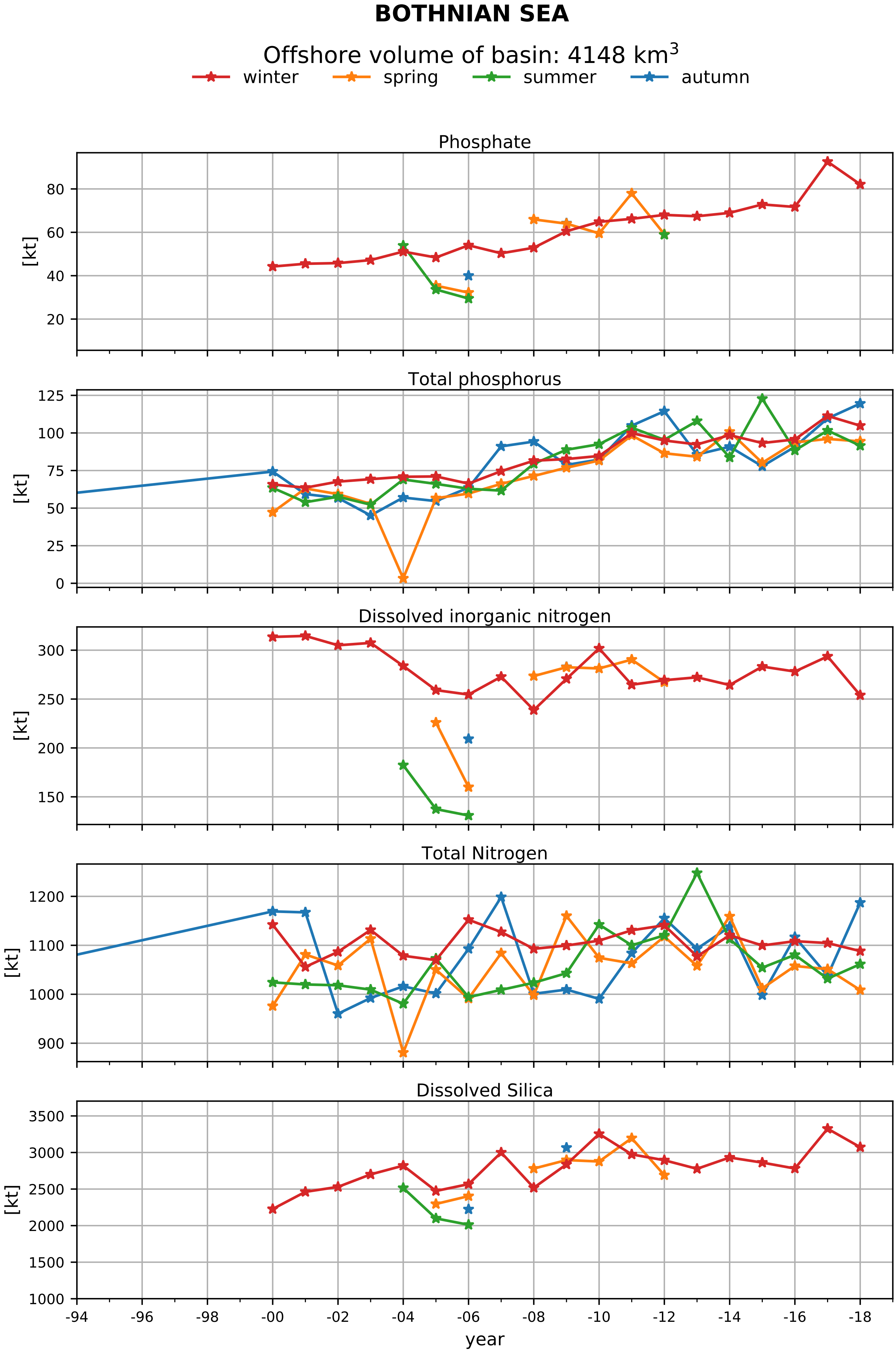
WESTERN GOTLAND BASIN BY32

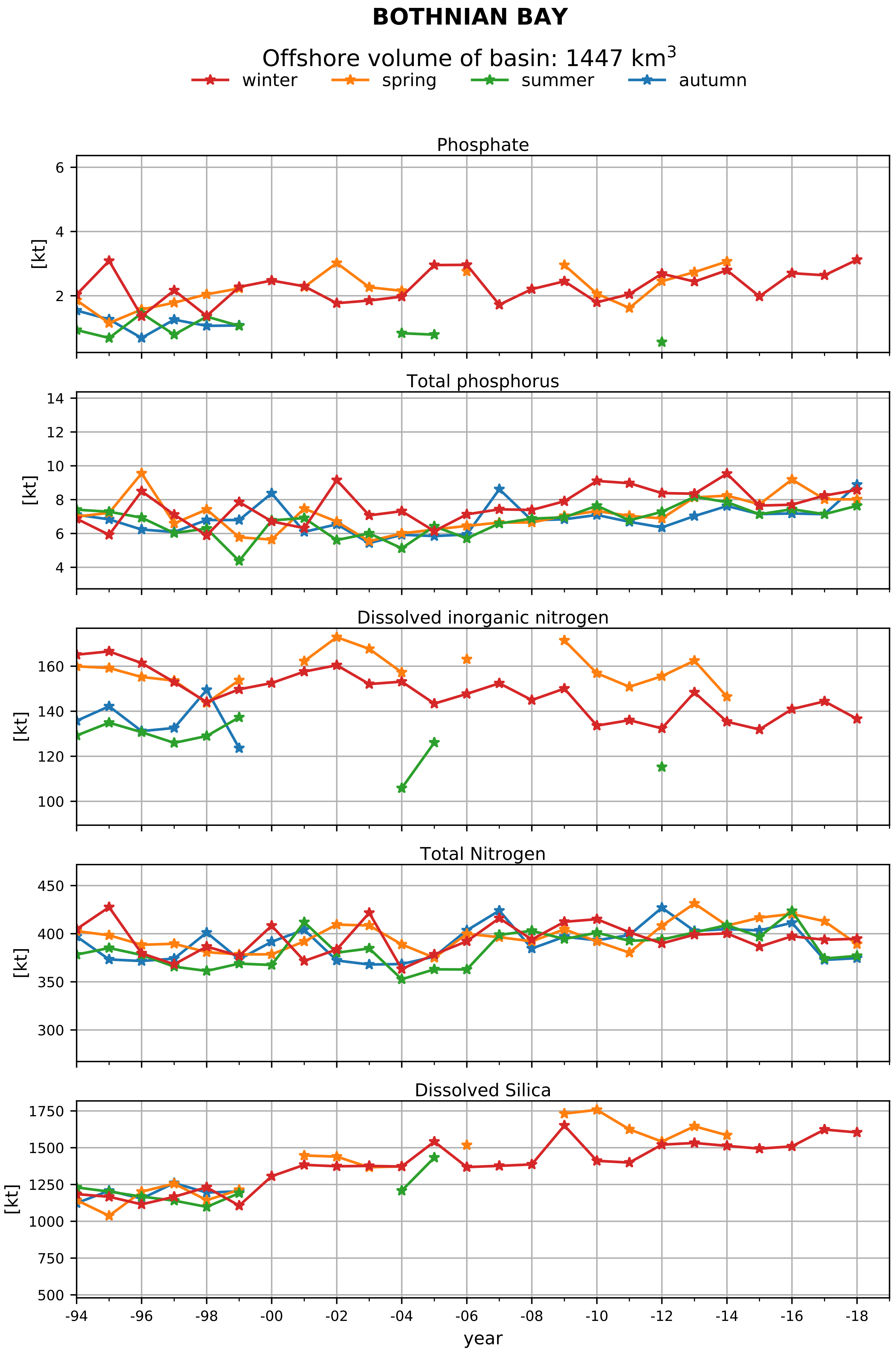
Offshore volume of basin: 767 km^3



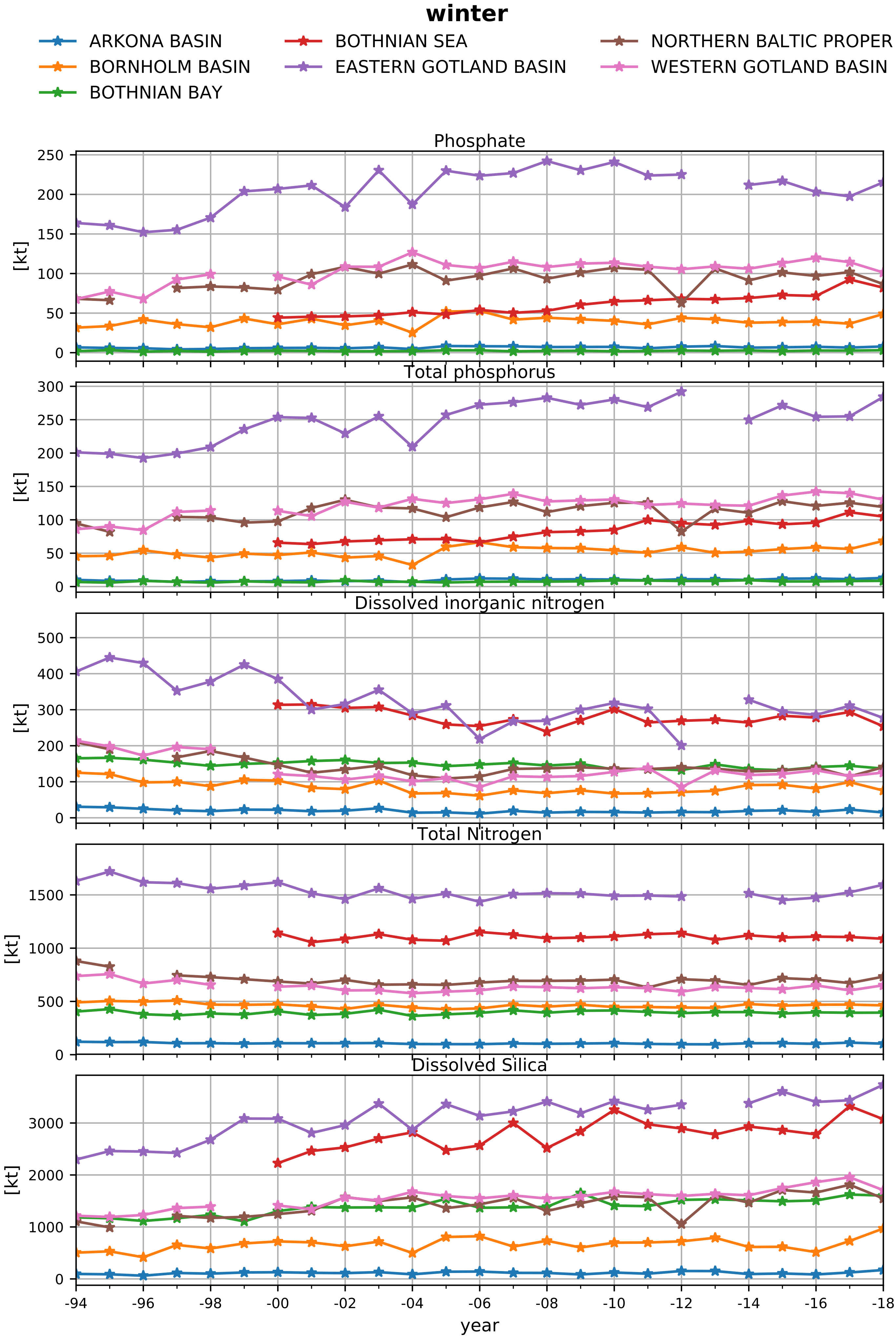

WESTERN GOTLAND BASIN BY38
Offshore volume of basin: 708 km3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18

WESTERN GOTLAND BASIN
Offshore volume of basin: 2198 km3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18


BOTHNIAN SEA
Offshore volume of basin: 4148 km^3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18



BOTHNIAN BAY
Offshore volume of basin: 1447 km3
winter
spring
summer
autumn
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18


winter
ARKONA BASIN
BORNHOLM BASIN
BOTHNIAN BAY
BOTHNIAN SEA
EASTERN GOTLAND BASIN
NORTHERN BALTIC PROPER
WESTERN GOTLAND BASIN
Phosphate
Total phosphorus
Dissolved inorganic nitrogen
Total Nitrogen
Dissolved Silica
[kt]
year
-94
-96
-98
-00
-02
-04
-06
-08
-10
-12
-14
-16
-18

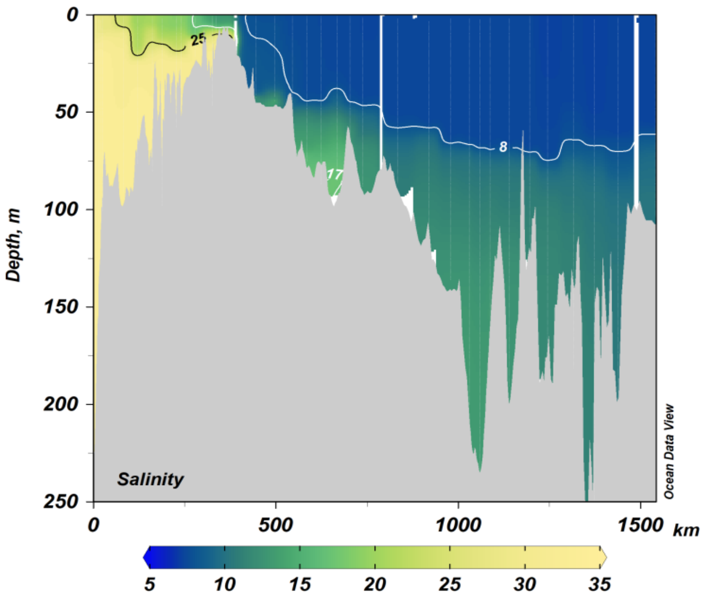
Appendix IV

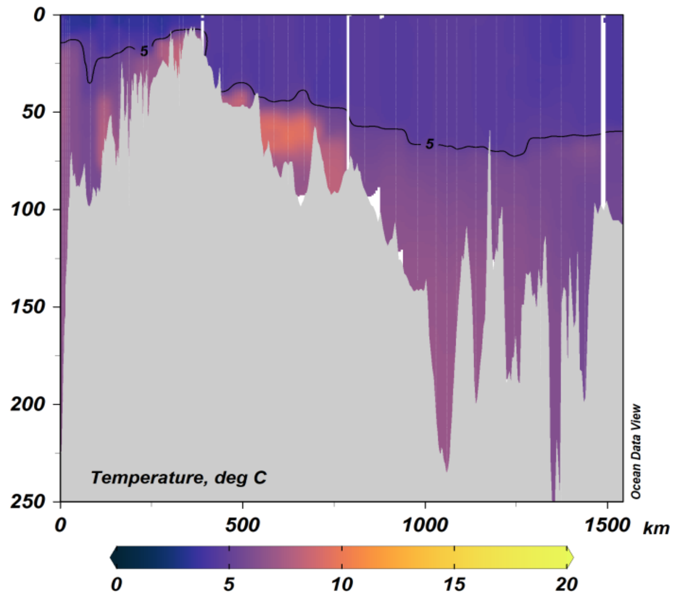
Transects from the Skagerrak to the Western Gotland basin

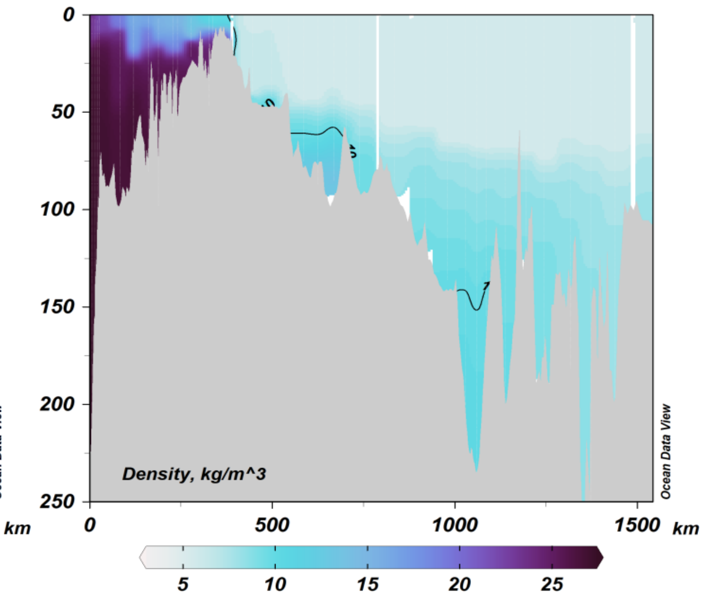
Included parameters are salinity, temperature, density and dissolved oxygen from CTD.

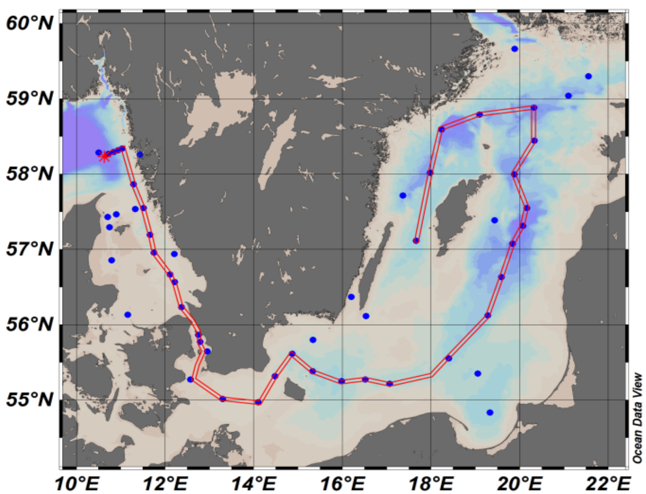
Transects are made with ODV (Schlitzer, R., Ocean Data View, https://odv.awi.de, 2019)

SMHI cruise January-February
20180124 – 20180204
CTD section



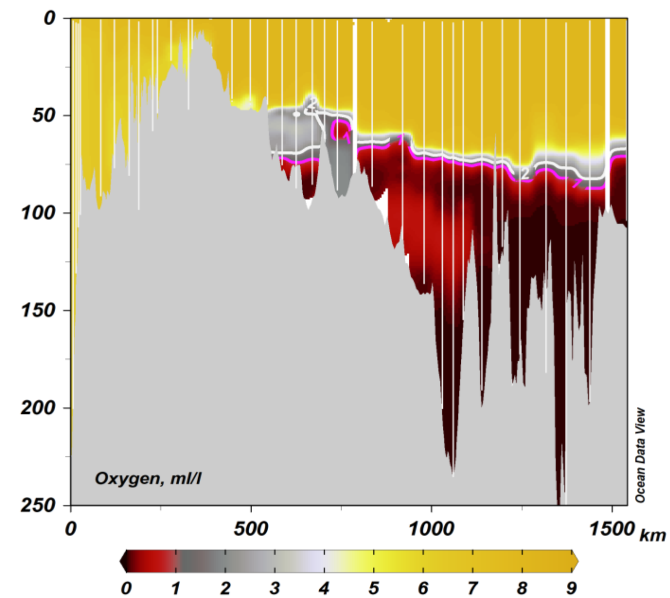




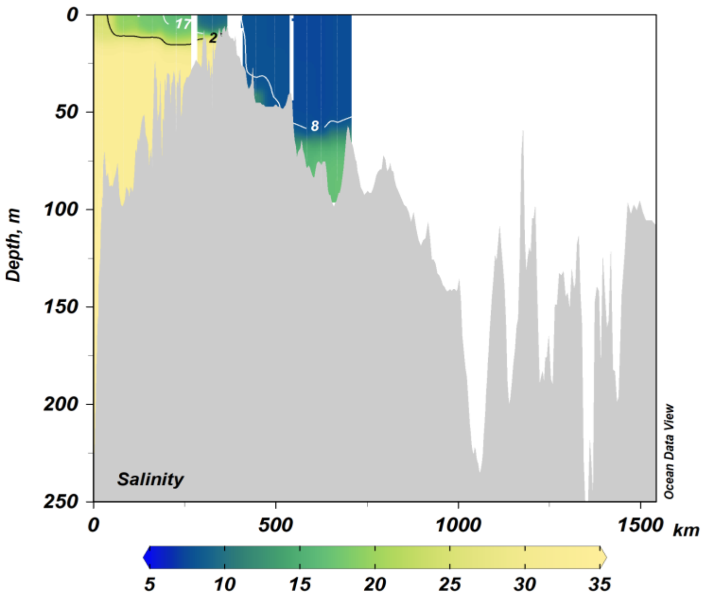


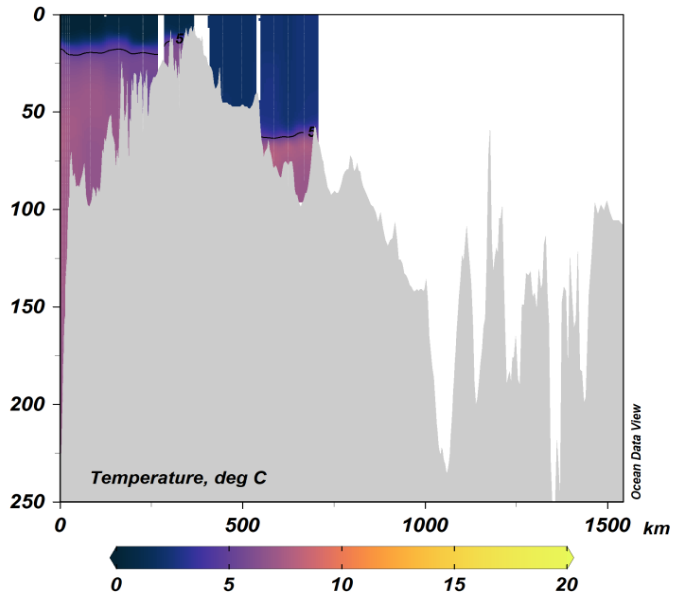
Isolines
Salinity: 6, 8, 17 (white), 25 (black)
Temperature: 5
Oxygen: 1 (pink), 2 (white)
Density: 10

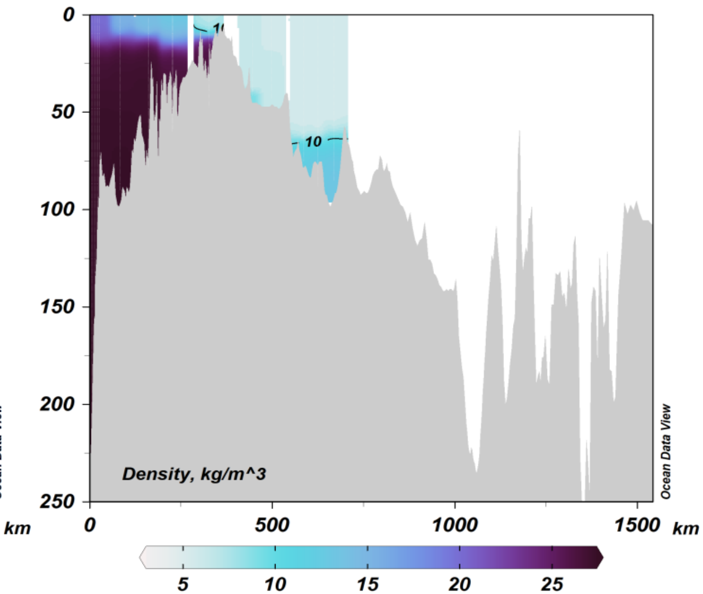
Thin vertical lines are stations

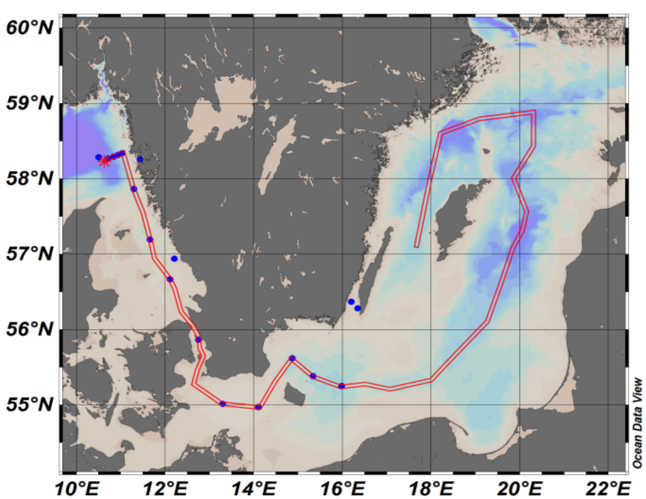


SMHI cruise March 20180314 – 20180320 CTD section



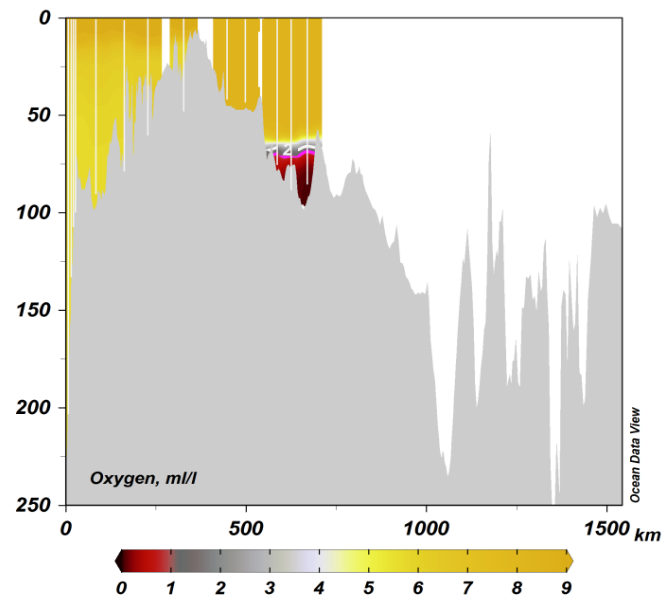




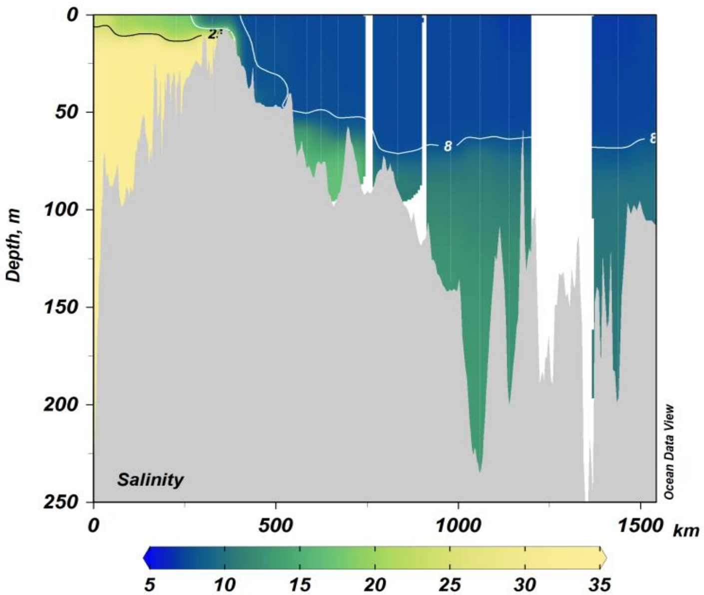


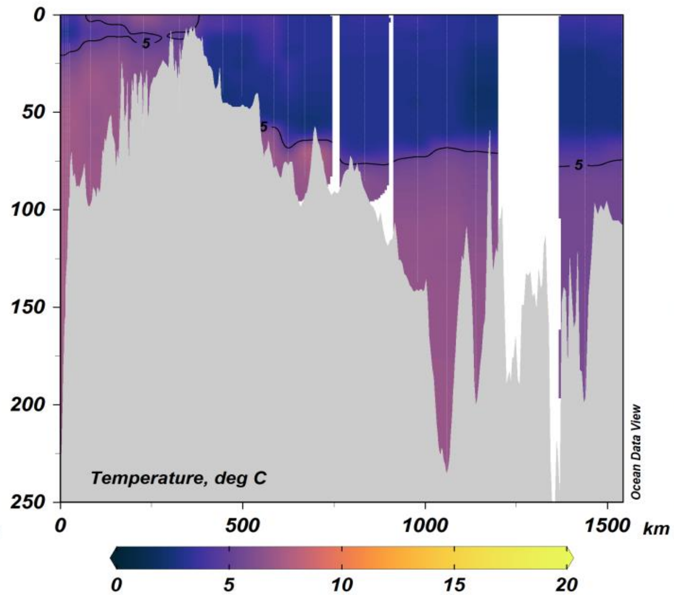
Isolines
Salinity: 6, 8, 17 (white), 25 (black)
Temperature: 5
Oxygen: 1 (pink), 2 (white)
Density: 10

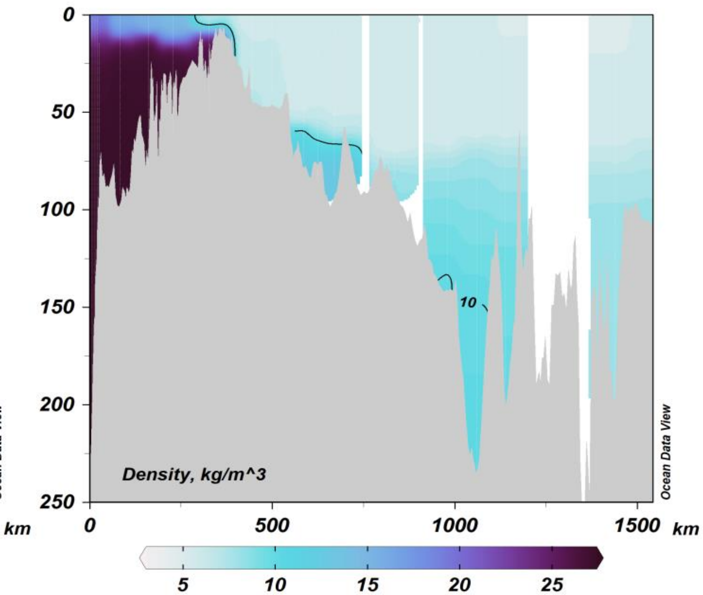
Thin vertical lines are stations

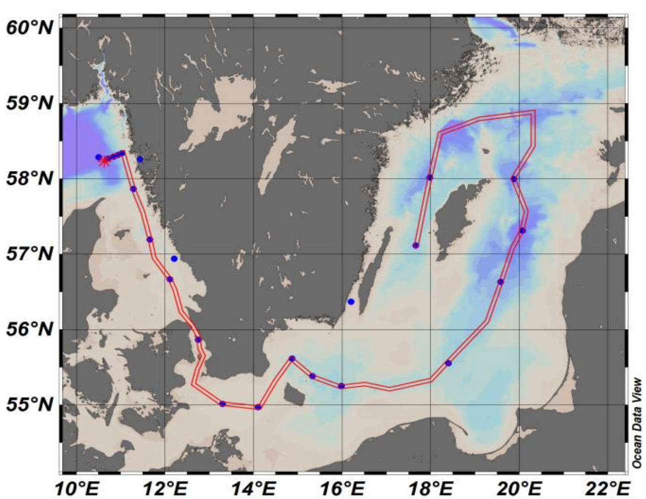


SMHI cruise April
20180415 – 20180421
CTD section



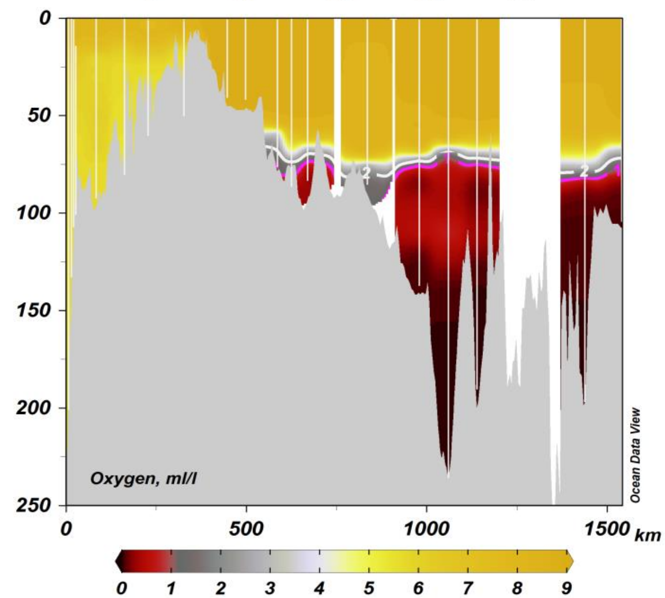




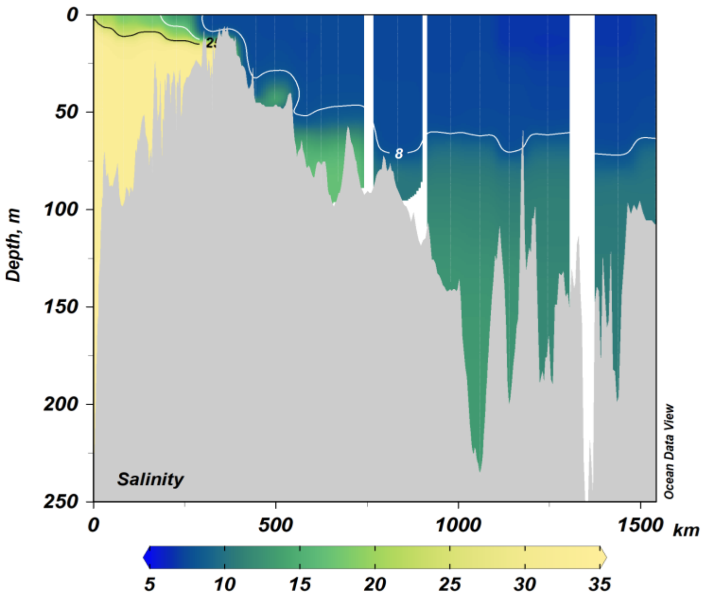


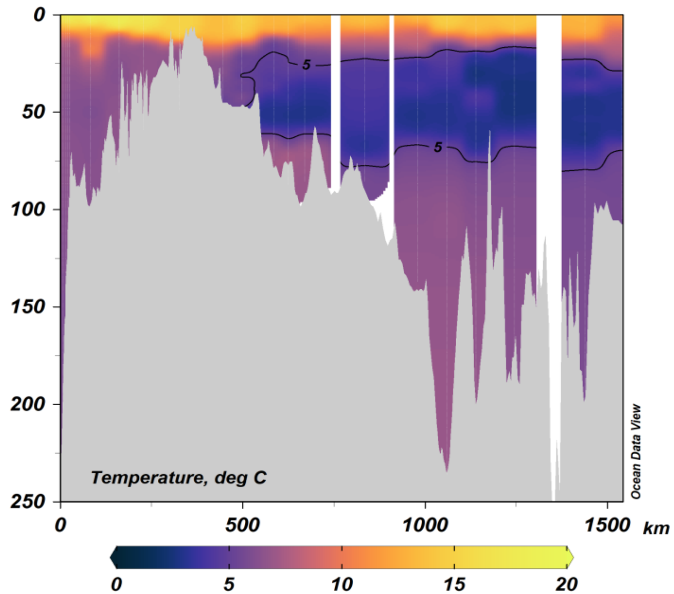
Isolines
Salinity: 6, 8, 17 (white), 25 (black)
Temperature: 5
Oxygen: 1 (pink), 2 (white)
Density: 10

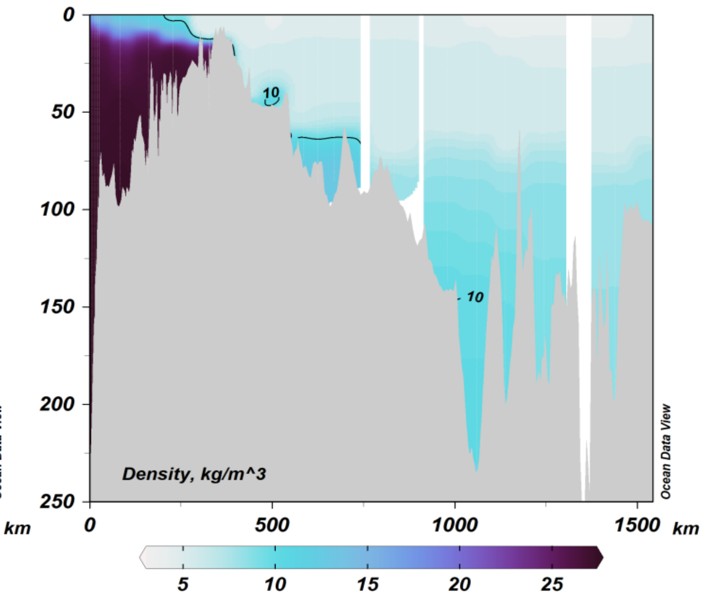
Thin vertical lines are stations

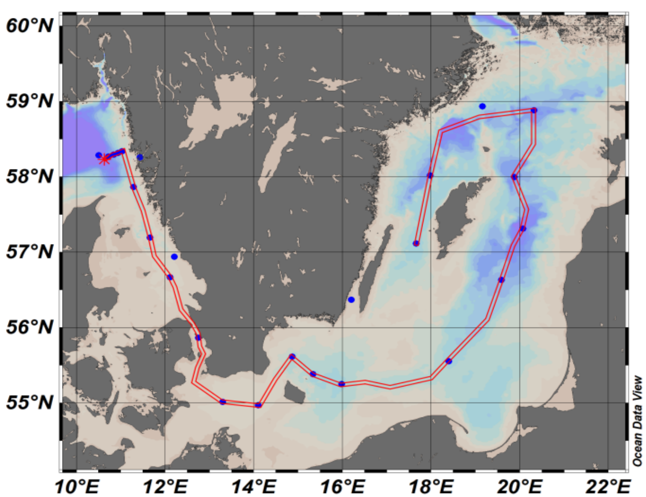


SMHI cruise May
20180526 – 20180601
CTD section



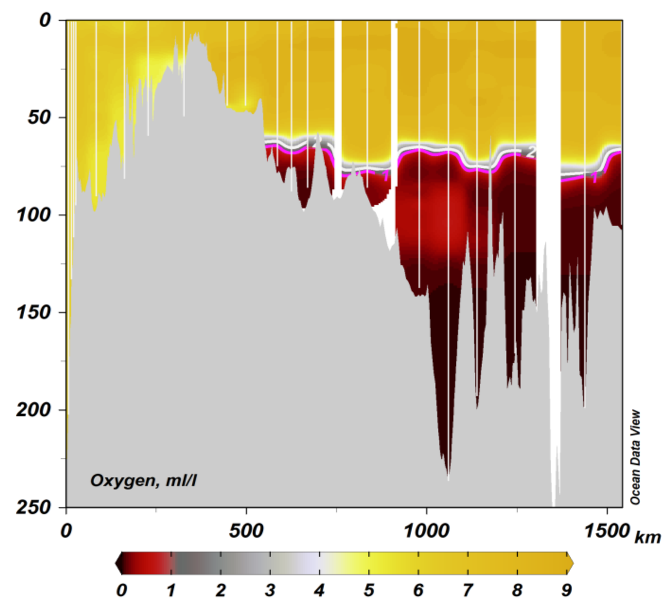




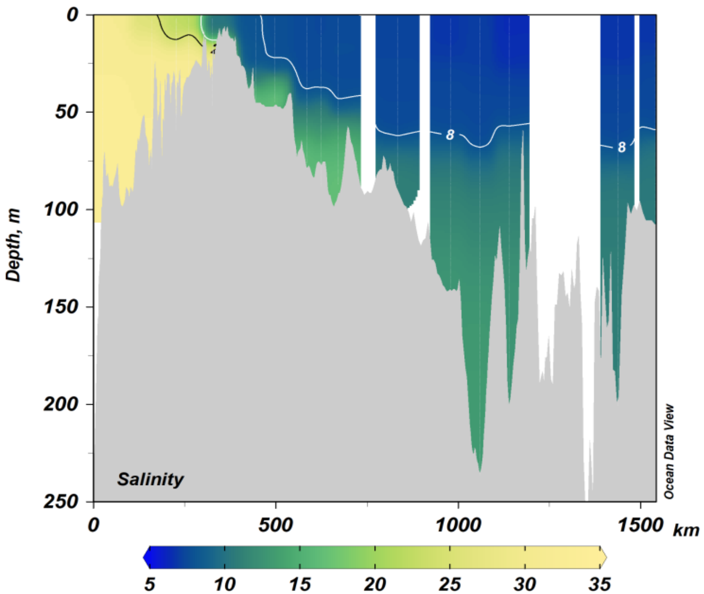


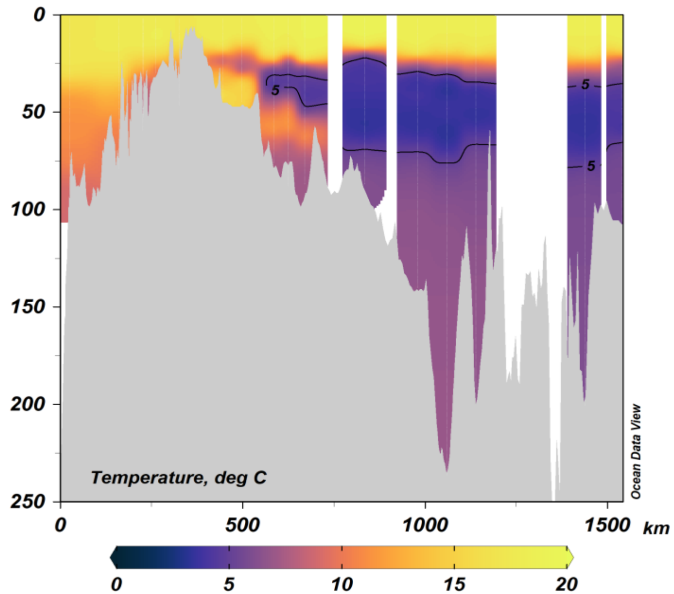
Isolines
Salinity: 6, 8, 17 (white), 25 (black)
Temperature: 5
Oxygen: 1 (pink), 2 (white)
Density: 10

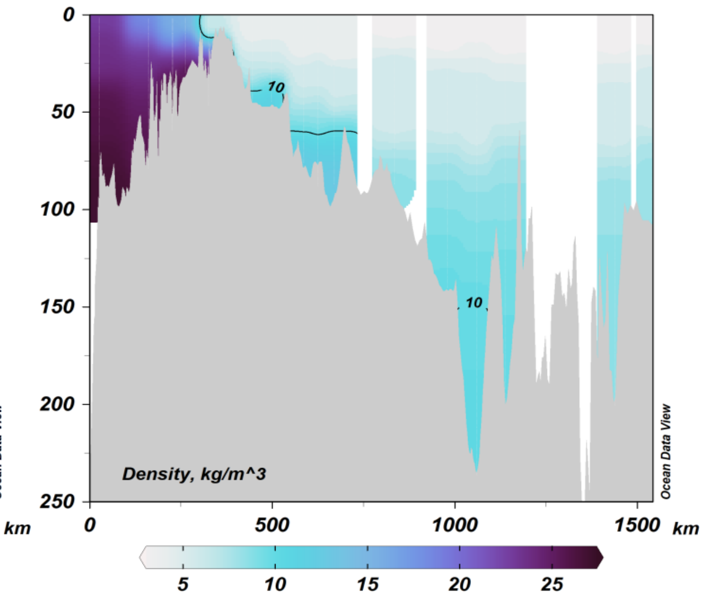
Thin vertical lines are stations

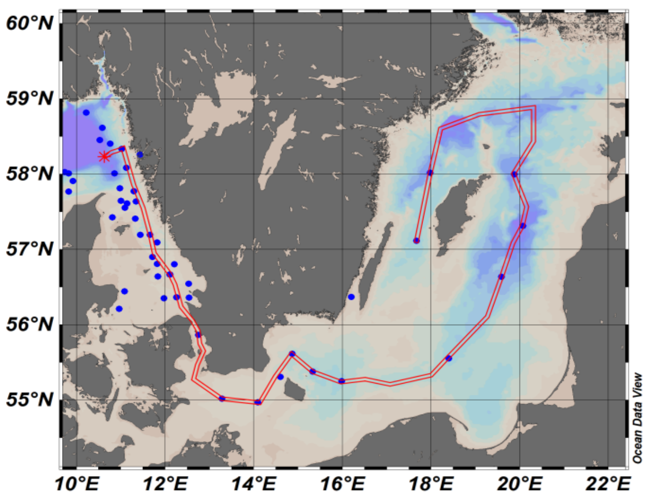


SMHI cruises August-September 20180820-20180931 & 20180902 – 20180907 CTD section









Isolines

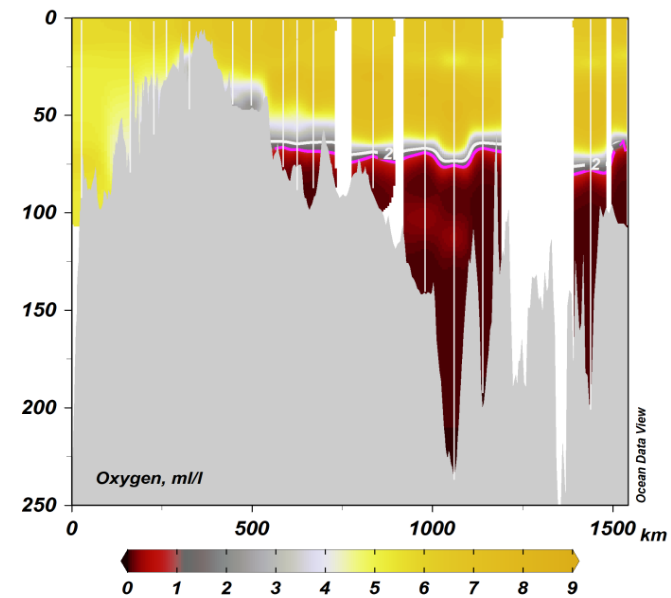
Salinity: 6, 8, 17 (white), 25 (black)

Temperature: 5

Oxygen: 1 (pink), 2 (white)

Density: 10

Thin vertical lines are stations



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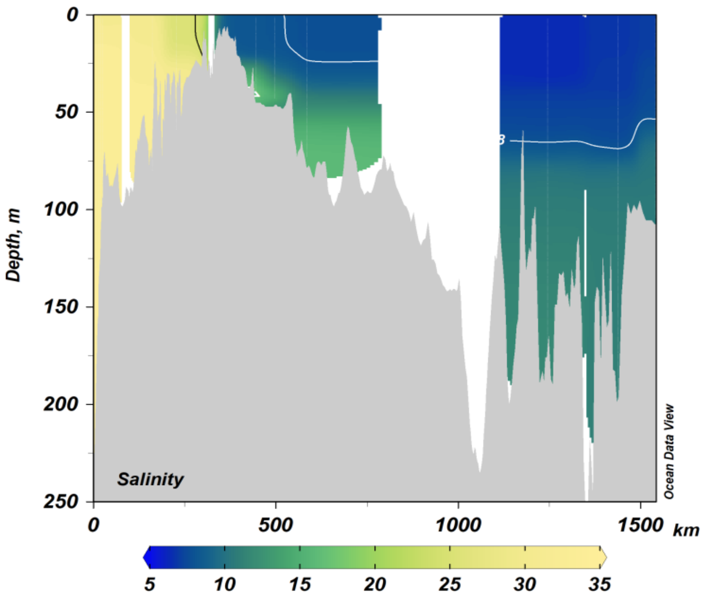
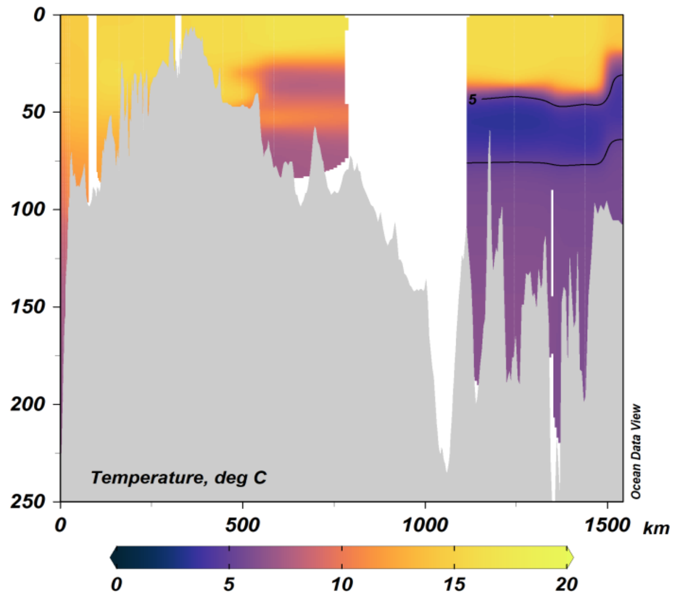
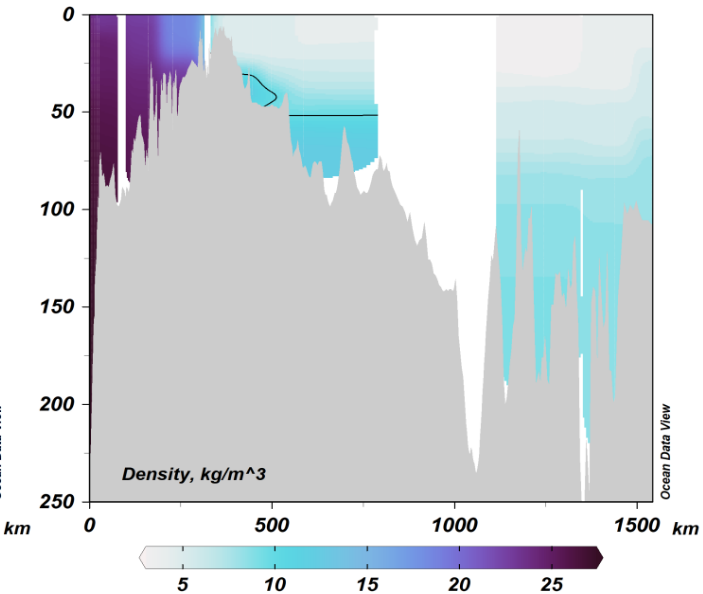
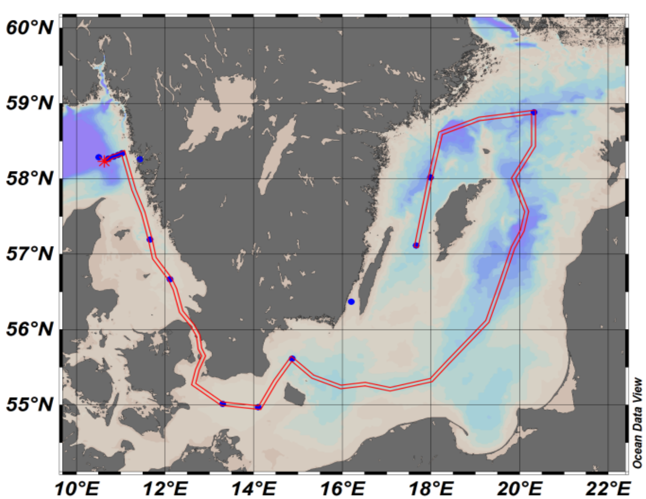








Isolines

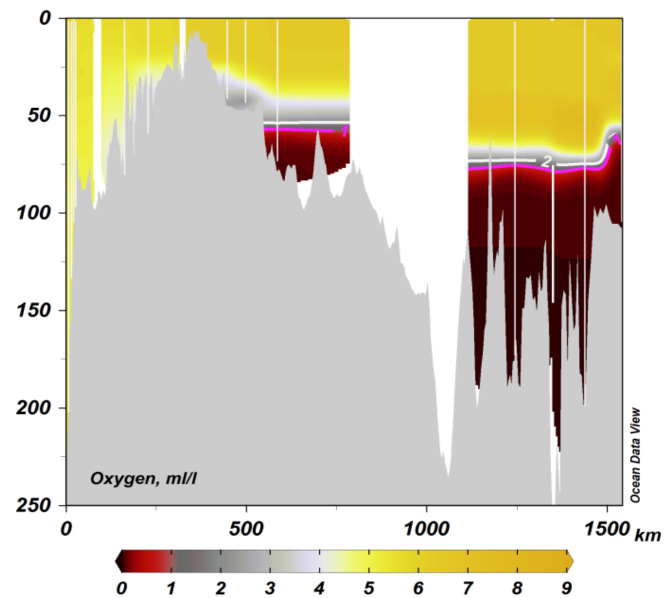
Salinity: 6, 8, 17 (white), 25 (black)

Temperature: 5

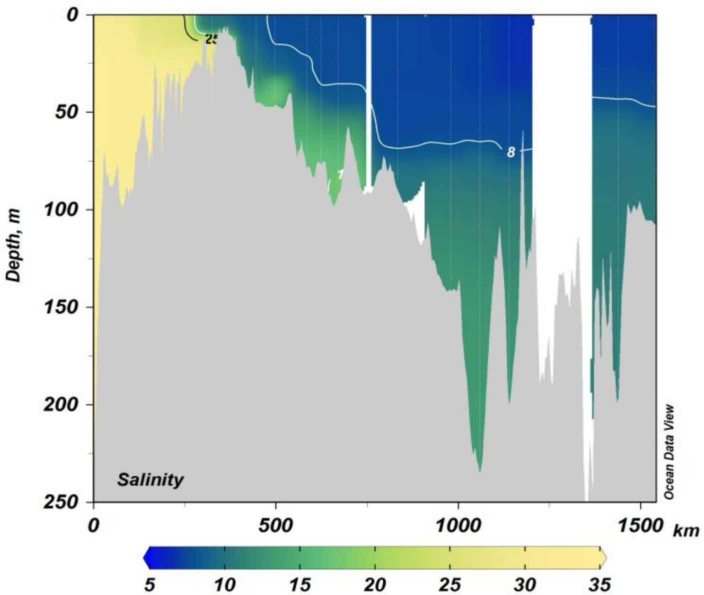
Oxygen: 1 (pink), 2 (white)

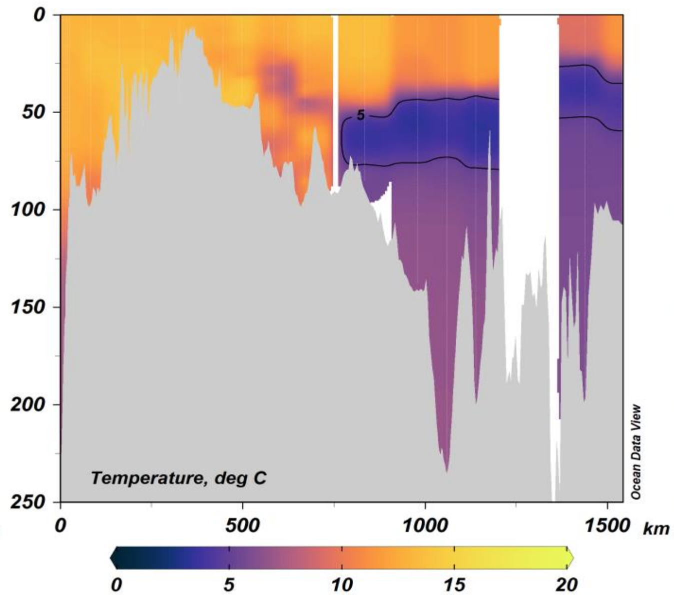
Density: 10

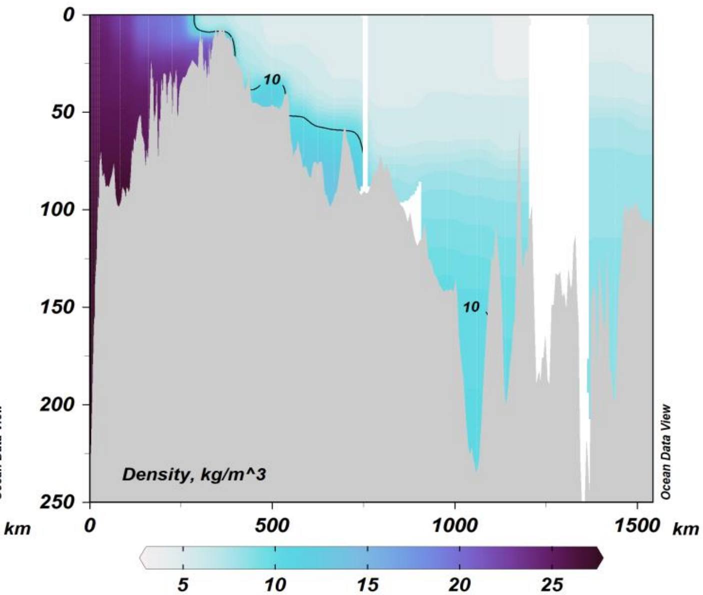
Thin vertical lines are stations

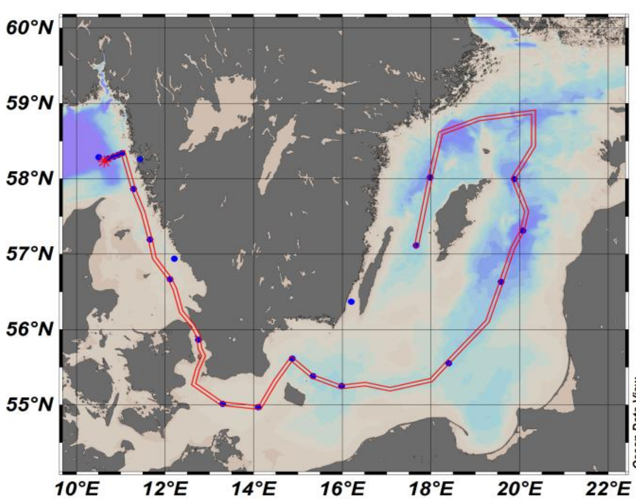


SMHI cruise October
20181014 – 20181021
CTD section









Isolines
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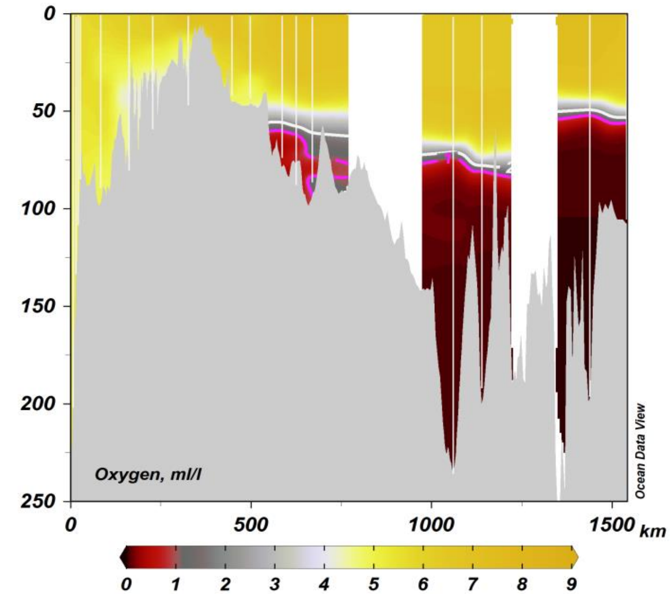
Temperature: 5
Oxygen: 1 (pink), 2 (white)
Density: 10

Thin vertical lines are stations



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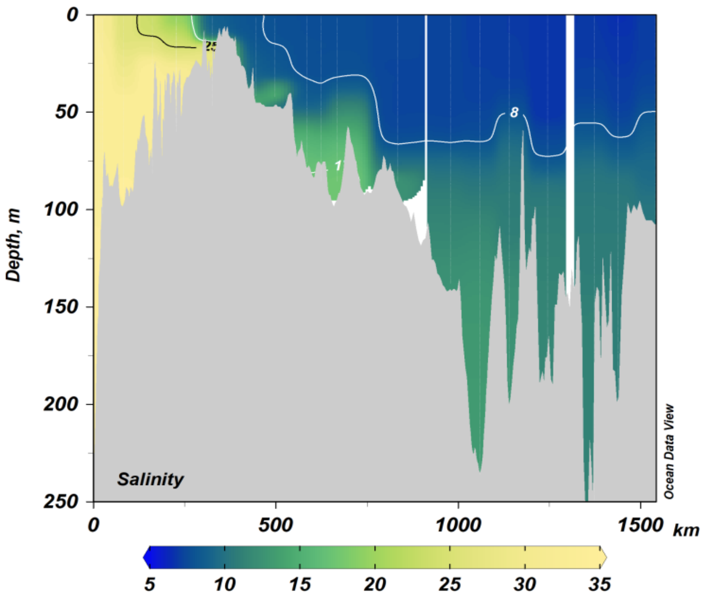

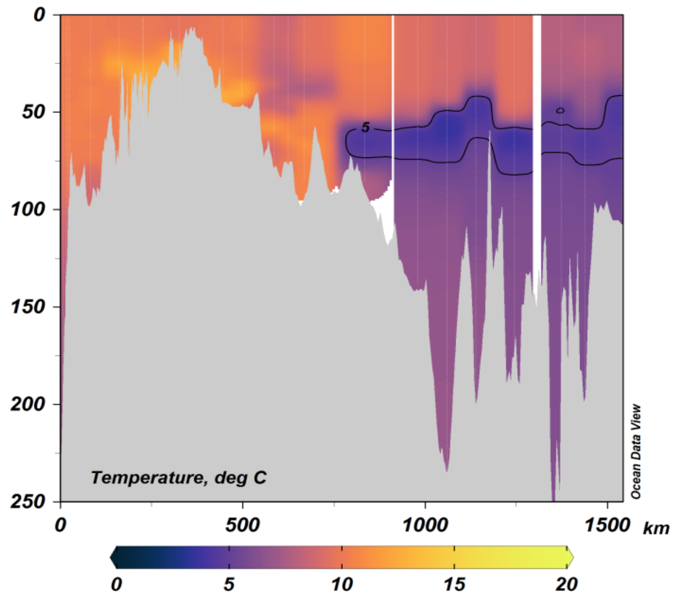

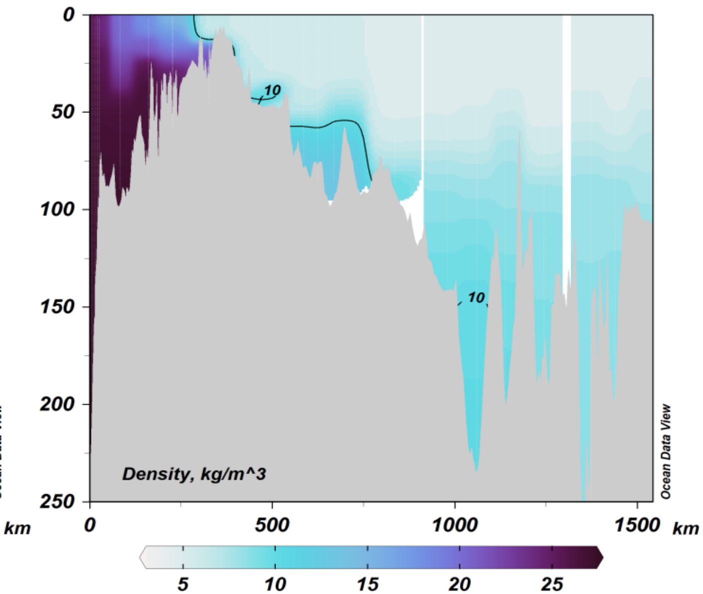

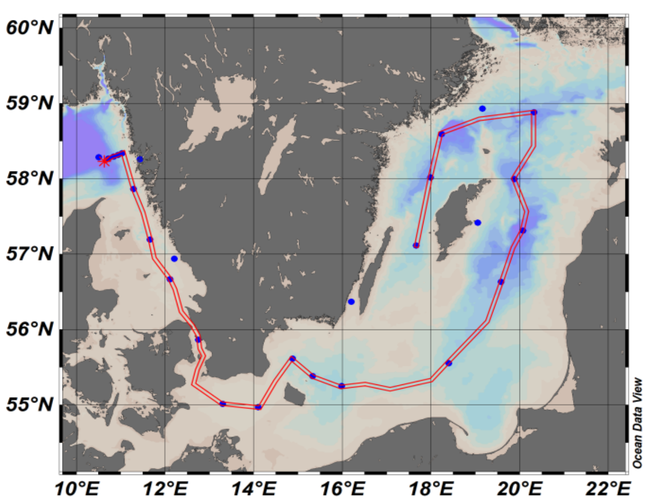

Isolines
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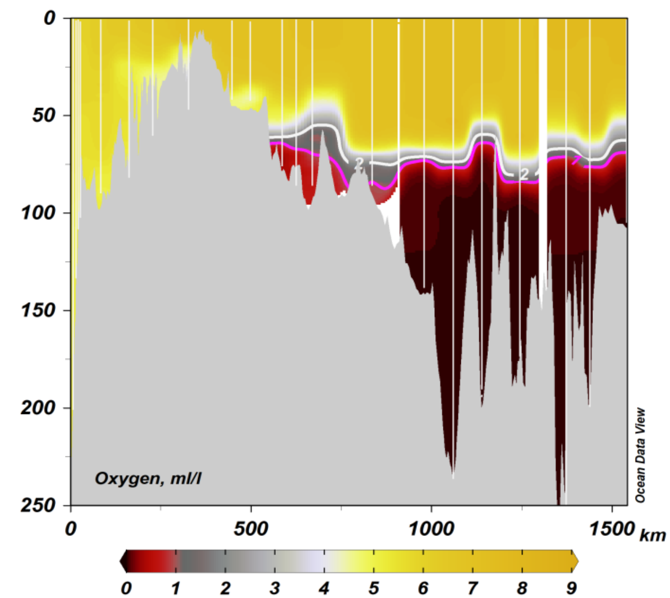
Temperature: 5
Oxygen: 1 (pink), 2 (white)
Density: 10

Thin vertical lines are stations



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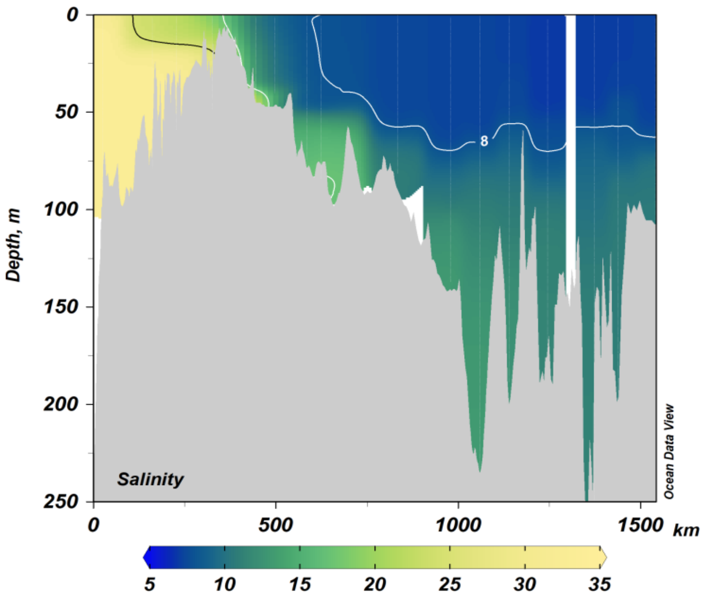
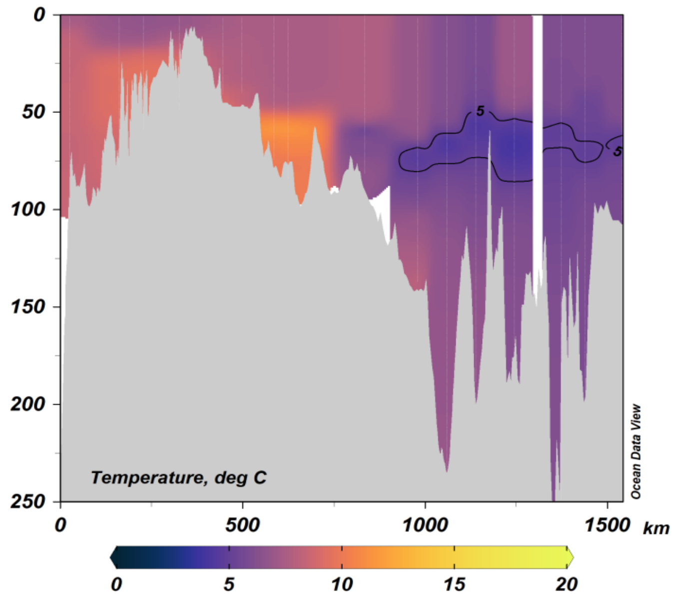
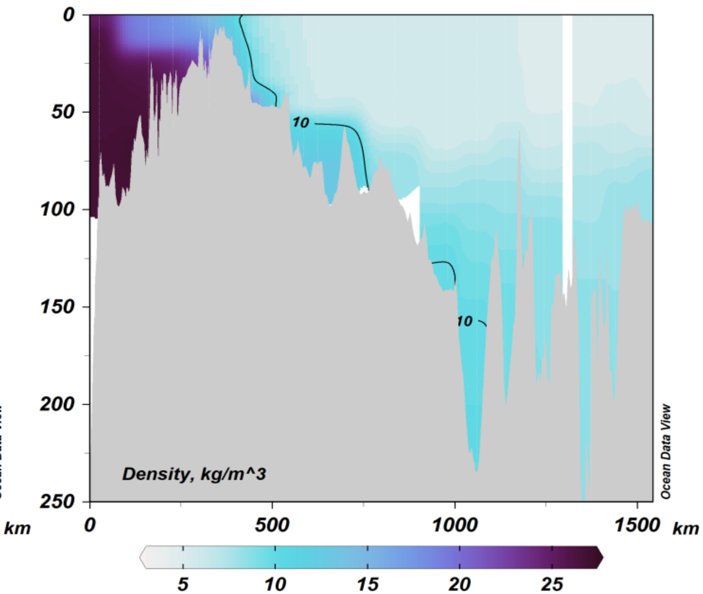
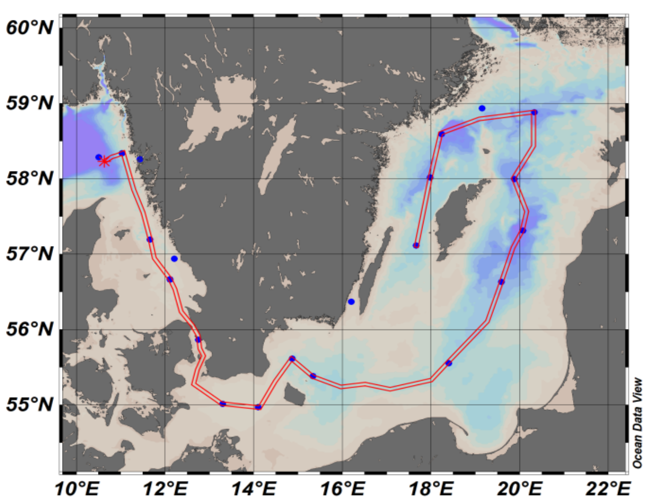


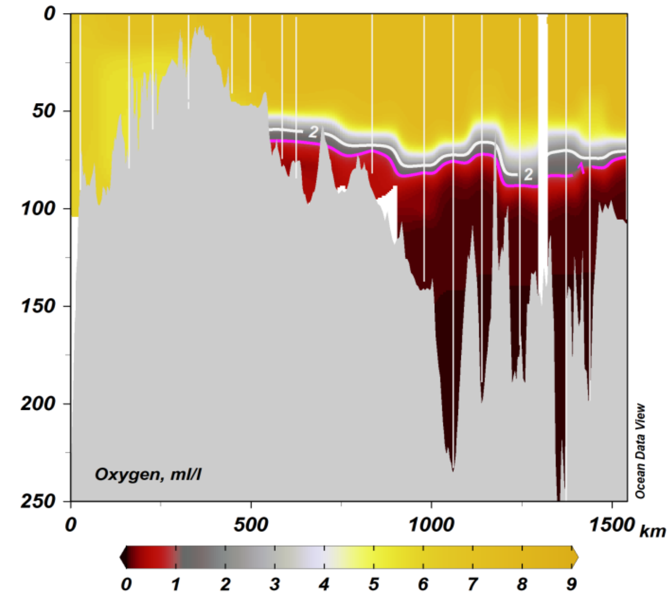






Isolines
Salinity: 6, 8, 17 (white), 25 (black)
Temperature: 5
Oxygen: 1 (pink), 2 (white)
Density: 10

Thin vertical lines are stations



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Sveriges meteorologiska och hydrologiska institut
601 76 NORRKÖPING
Tel 011-495 80 00 Fax 011-495 80 01

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