UNIVERSITY OF GOTHENBURG

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Adventures of Group 3
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Abstract

Climate change and increased anthropogenic impacts are making the impacts of hypoxia, the lack of dissolved oxygen, more prominent each year. Hypoxia creates conditions that are profitable for N_2-fixing cyanobacteria blooms, that in result increase eutrophication which leads to more hypoxia. This cycle affects the fishing industry, tourism, water quality in coastal areas and the monetary value of land or properties along the coast (Conley et al. 2009).

Our group's cruise aims were to transfer taught skills, new sampling methods and project planning abilities into practice. Sampling took place in the Byfjord and the Havstensfjord, north of Gothenburg. Stations were chosen to collect max depth, surface and intermediate/sill-level water quality data using CDT sampling equipment and methods. This data was then analyzed and compared in various parameters to visualize the current impacts caused by hypoxia and how it changes by location and depth between the two fjords.

The result showed the salinity increase by depth in both the Byfjord and the Havstensfjord from 22 to 32 PSU from surface to basin water. The increase was higher by depth in the Byfjord compared to Havstensfjord, where the salinity level of the basin water is more stagnant. This is mainly due to the inflow of water to Havstensfjord from Skagerrak.

The temperature decreased from 16 ℃ in the surface water to 8 ℃ in the basin water in the Byfjord and from 16 ℃ in the surface water to 6 ℃ in the basin water in the Havstensfjord. There was a significant difference in between the fjords, where the Byfjord is being much more stagnant with a slow exchange of the basin water.

The concentration of oxygen ranges from 6 mL/L in the surface water to 0 mL/L in the basin water. The higher concentration is due to the influx of the atmospheric oxygen supply and the lower to water stagnation at depth. A strong stagnation occurs in the Byfjord. Conversely, the Havstensfjord with its inflow from Skagerrak has higher oxygen concentrations in deeper water compared to the Byfjord.

Regarding chlorophyll fluorescence, there is a more complex picture and local variations within the surface and bottom water in Havstensfjord and at 20-30 m depth in Byfjord.

Impacts of hypoxia causes an enhancement in the phosphate (P) released from sediments and increased nitrogen (N) loss. N_2-fixing cyanobacteria blooms thrive under these conditions. It increases the available nutrients, leading to even more eutrophication and hypoxia. The nitrate and phosphate concentration profiles with regard to the samples from our nine stations showed this correlation, which will be investigated and analysed further in our individual reports.

Keywords

Deepwater oxygenation. Dead Zones. Baltic Sea. Fjord Dynamics. Anthropogenic. Hypoxia. Anoxia. Phosphorous. Nitrogen. Cyanobacteria. Depth Gradient. CTD.

Organization

University of Gothenburg, Department of Marine Sciences

Acknowledgements

The following crew members and scientific leaders were involved in the execution of the BOX project in September 2021: Joakim, captain of Skagerak; Anders and Christian maneuvering the CTD and box corer; Liz and Marcel providing the introductions to the sample handling and measurements. We thank all the crew members and scientific instructors for their efforts.

Our ship group was divided into three subgroups. Group 1 was in charge of the CTD in the CTD control room. They were responsible for firing the water sampling bottles at predefined depths, communicating the station's coordinates with the captain and working together with the CTD crew members. Group 2 obtained the water samples for nutrient and oxygen concentration analysis. The third group prepared the CTD Niskin water bottles for the next station by emptying the sampling bottles and restoring the release mechanism to its original position.

Scientific Objectives

The project's aim is to compare the Byfjord and Havstenfjord and to investigate the differences between them. By comparing the nutrient composition, salinity and oxygen content at different depths for both fjords we can observe variety and correlations between the two areas.

Fjords are formed by glaciers that have carved oceanic intrusions into land. The characteristics of fjords is that they are narrow and deep with a sill in the mouth. Due to the local water supply from local freshwater and neighboring seas, fjords tend to have strong stratification in the water column. The sill restricts the water flow trapping the denser basin water behind it. Surface water is not restricted by the sill therefore can be exchanged quickly especially if the mouth is wide.

The four kilometer-long Byfjord is located in Uddevalla forming the northeast-part of the fjord-system around Tjörn and Orust. The Byfjord has a maximum depth of ~ 50 m and a water volume of 0.14 km^3 (Gomes, 2014). Moreover, the fjord is characterized by a sill (Sunninge sund) located at 12 m of depth which disturbs the saltwater exchange from the Havstensfjord, and results in the basin water being trapped below the sill with a slow exchange time of 2-5 years period (David Börjesson, 2013; Gomes, 2014). Furthermore, the fjord is supplied with fresh water from various streams (i.e. Bäveån, Kärraån and Bodeleån).

This affects the salinity of the surface water, resulting in a stratification of the water column and a halocline at a depth of 15 m (Gomes, 2014; Lars-Olof Axelsson, 2021).

Looking into the different physico-chemical parameters of the Byfjord (i.e. salinity, temperature, and oxygen), the salinity of the surface water varies between ~ 5-25 PSU depending on the freshwater supply, while the salinity of basin water is more stagnant with a value of ~ 30 PSU (SMHI, 2004). When it comes to the overall temperature of the Byfjord, deep water stabilizes between 4 and 8 ℃, confirming the water stagnation and the slow exchange of the basin water (SMHI, 2004). However, the surface water is characterised by temperatures between 0-24 °C (SMHI, 2004). Furthermore, the oxygen content also differs between surface and basin water. Surface water has a high concentration of oxygen due to the atmospheric oxygen supply, while the basin water typically has low concentrations of oxygen and high concentration of hydrogen sulfide for several-year periods due to the water stagnation (SMHI, 2004). However, the oxygen concentrations increase when the basin water is exchanged with new saltwater from the Havstenfjord (SMHI, 2004).

The Havstensfjord has its inflow from Skagerrak which is restricted by a sill at 20 meters (Gustafsson and Nordberg, 2000). Havstenfjord has a maximum depth of approximately 42 meters and has a stratified water column. The more saline depth water and more brackish surface water are separated by a pyrrocline at about 15 m depth (Gustafsson and Nordberg, 2002). The salinity of the Havstensfjord varies with depth but reaches a maximum of 31-33‰ /PSU at the bottom. The deeper part of the Havstensfjord is seasonally oxygen deficient, characteristically during autumn and winter (Gustafsson and Nordberg, 2002).

Cruise Overview

We started sampling in the Byfjord close to the harbor where the freshwater input from the river Bäveån is high (Station A). Afterwards we went on to station B where the Byfjord shows the biggest depth. To get a higher resolution of the connection of the two fjords, we decided to sample at three stations close to the sill. The first station was chosen in the Byfjord, another one right on top of the sill (below the bridge), and a third station was chosen after the sill in the Havstensfjord. Furthermore, we chose two stations in the Havstensfjord. Station F provided us with a profile and water samples in the mouth of the Havstensfjord. Moreover, we sampled in the middle of the Havstensfjord where depths extend down to 38.2 m at station G. Additionally, two optional sampling stations were defined in each fjord in case we would have enough time to sample there as well. These stations were chosen to improve the spatial resolution of the nutrient and physico-chemical parameters samples. This ends up being nine stations located in a straight line through the Byfjord and through the Havstensfjord. In summary, the stations were chosen both for unique properties, such as a great depth or around the sill, but also so that the resolution of the data would be high so that we could get a good view of the fjords as a whole. The transect has a total length (from station A to G) of ~ 8.3 km. Fig. 1 indicates the nine different sampling stations in both fjords.

Figure 1. *Overview map of the sampling transect. Stations A to I are indicated on the map. The transect extends over 8.3 km through the Byfjord (Stations A, B, C, and I) and Havstensfjord (Stations E, F, G, and H). Station D is located exactly on top of the sill.*

We planned on doing CTD measurements and taking water samples on each station and for two of the stations we also wanted to take samples with a box corer, to look at the sediment at those stations. The box corer was used on the stations marked B and G on the map above.

Diary Cruise Narrative

Heavy rains were expected throughout the day, however only light rain occurred during the morning with approximately 9.6 mm precipitation (SMHIa). The wind conditions in the open ocean were taken from the station Måseskär (closest station available for data). A mean wind speed of 14 m/s was measured during the time period the research vessel was out from 10 AM to 3 PM (SMHIb). The mean air temperature was 13.1 °C.

Only one major issue occurred during the day. After the fourth station (D) we were faced with engine problems which forced an hour-long break between measurements.

For sampling we used three different types of data measurement tools: CTD with 24 8L Niskin bottles, oxygen and fluorescence sensors, and a box corer. The CTD sampled conductivity, temperature, depth as well as fluorescence and oxygen at each station. Water samples were taken at each station using the Niskin bottles at different depths for nutrient analysis (Table 1). Oxygen samples were taken from the same Niskin bottles and processed using the Winkler method for redundancy and to confirm the data from the oxygen sensors of the CTD. The box corer was only used at the deepest station of the two fjords, Byfjorden (50m) and Havstensfjorden (38m) for visual analysis and to compare the benthic fauna and flora as well as the sediment top layer.

Station/activities log

Table 1: *The table shows the different station names, the respective coordinates for each station, start time of the CTD, which types of samples were collected, short description of the event and why we chose that station, as well as miscellaneous comments. All samples were collected 23/9/2021.*

Sta.	Coordinates (long/lat)	Start time	Activity identifier	Event description	Comments
A	58º20’461"N 11º53’969"E	10:23:55	4 Nutrient, Oxygen and CTD sampling.	Station closest to freshwater input.	A surface sample was collected at the depth of 1 m.
B	58º20’008"N 11º52’541"E	10:43:01	5 Nutrient, Oxygen, CTD and Box Corer-sampling.	Deepest station within the Byfjord.	Box corer showed anoxic sediment. No macrofauna found.
C	58º19’699"N 11º51’367"E	11:07:03	3 Nutrient, Oxygen and CTD sampling.	The Byfjords closest located station to the sill.	A surface sample was collected at the depth of 1 m.
D	58°19'32.9"N 11°50'41.6"E	11:22:14	2 Nutrient, Oxygen and CTD sampling.	Station located on the sill.	
E	58º19’402”N 11º49’972’’E	12:10:38	2 Nutrient, Oxygen and CTD sampling.	The Havstensfjords closest station to the sill.	The research vessel experienced some mechanical issues between station D and E.
F	58º18’947”N 11º48’234’’E	12:37:54	3 Nutrient, Oxygen and CTD sampling.	Station in the mouth of the Havstensfjord leading up to the sill.	A surface sample was collected at the depth of 1 m.
G	58º18'47.5"N 11º46'2.7"E	12:57:44	4 Nutrient, Oxygen, CTD and Box corer-sampling.	Deepest station in the Havstensfjord.	The Niskin bottle failed to fire at a depth of 13 m, and had to descend back to 13 m after having gone up to 7 m. The box corer showed slightly oxidized sediments with a few polychaete worms.
H	58º19’260”N 11º49’420”E	13:26:47	3 Nutrient, Oxygen and CTD sampling	Station between the sill and the mouth of the Havstensfjord.	
I	52º20’260”N 11º63’292”E	13:50:14	4 Nutrient, Oxygen and CTD sampling	Sample the median depth in the Byfjord.	

Preliminary Results

The following section presents different vertical profiles of the Byfjord and the Havstensfjord toghether measuring how the salinity, temperature, oxygen and fluorescence are spatially distributed along the depth of the two fjords. (Fig. 2-5). The salinity profile is plotted against the temperature (Fig. 6). Furthermore, depth profiles of how the nutrient-levels of nitrate and phosphate changes with depth are shown in Figure 8.

Detailed discussion and analysis of these results can be found in the individual reports.

Hydrography

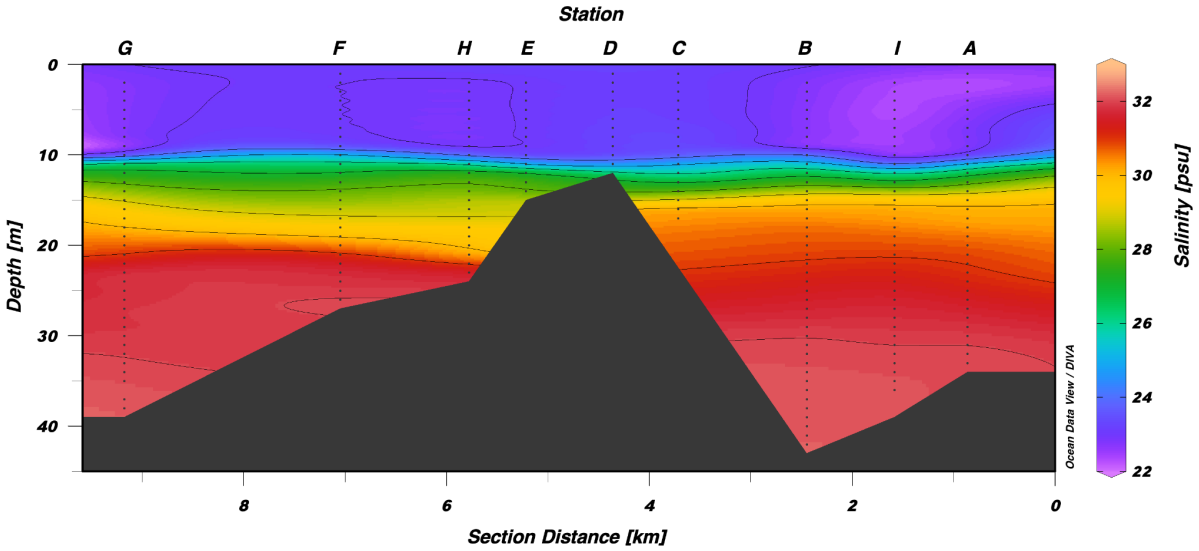

Figure 2. *Vertical section of salinity along the Byfjord (0-4 km) and the inside of the Havstensfjord (4-10 km). Colorbar demonstrates salinity in Practical salinity units (gkg^{-1}), where yellow - red colour denote higher salinities and blue-purple shows lower ones. Black dots indicate sample positions, each one defined with the station name. Spaces between dots are interpolated using DIVA gridding. Contours are highlighted with thin black lines. The section plot is generated using Ocean Data View software (Schlitzer 2021).*

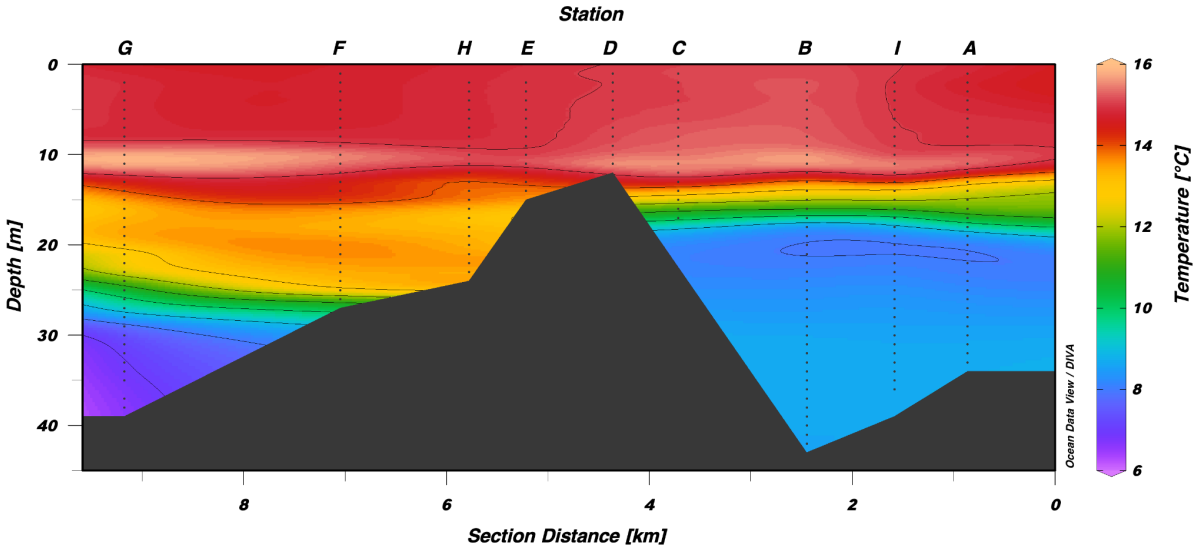

Figure 3. *Vertical section of temperature along the Byfjord (0-4km) and the inside of the*

Havstensfjord (4-10km). Colorbar demonstrates temperature in Celsius degrees, where yellow - red colour denote higher temperatures and blue-purple show lower temperatures. Black dots indicate sample positions, each one defined with the station name. Spaces between dots are interpolated using DIVA gridding. Contours are highlighted with thin black lines. The section plot is generated using Ocean Data View software (Schlitzer 2021).

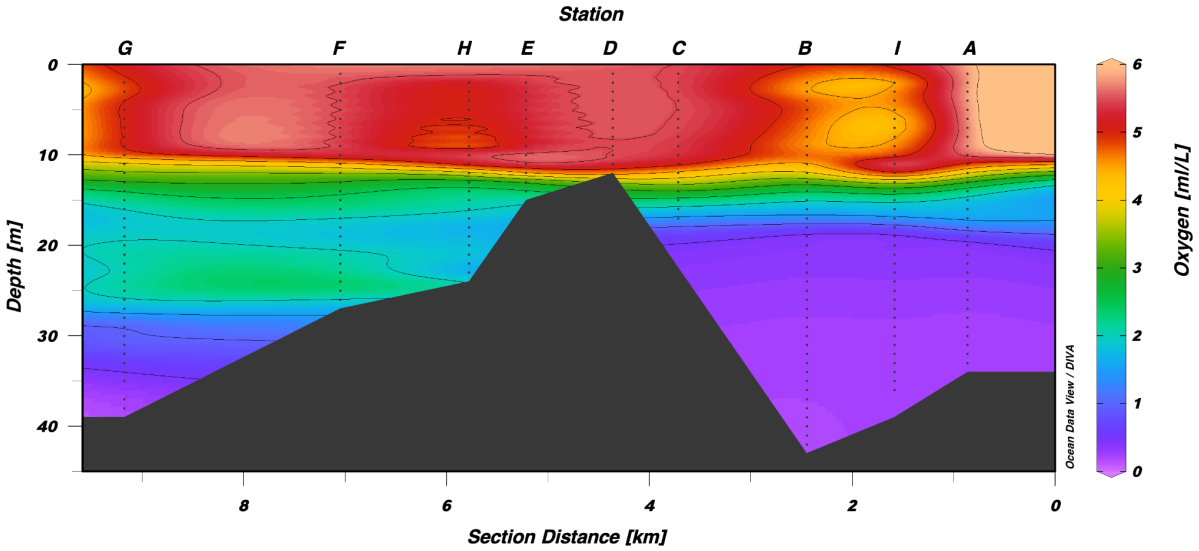

Figure 4. *Vertical section of oxygen content along the Byfjord (0-4km) and the inside of the Havstensfjord (4-10km). Colorbar demonstrates oxygen in milliliter per liter, where yellow - red – green colour shows oxygenated areas, blue shows hypoxic waters and purple anoxic waters. Black dots indicate sample positions, each one defined with the station name. Spaces between dots are interpolated using DIVA gridding. Contours are highlighted with thin black lines. The section plot is generated using Ocean Data View software (Schlitzer 2021).*

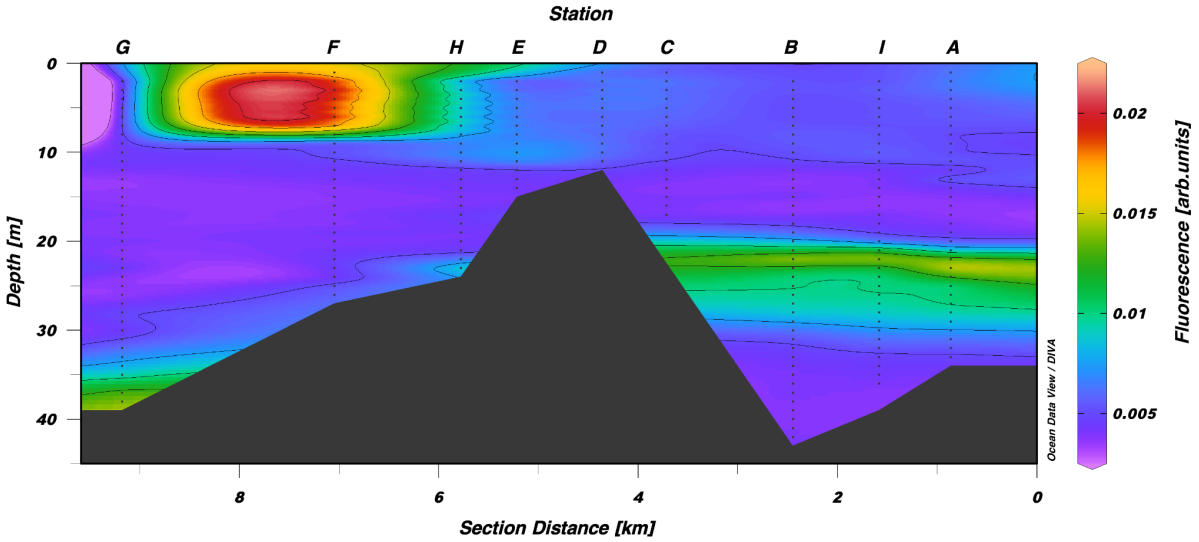

Figure 5. *Vertical section of chlorophyll fluorescence along the Byfjord (0-4km) and the inside of the Havstensfjord (4-10km). Colorbar demonstrates fluorescence in arbitrary units, where yellow - red colour shows high intensity and blue-purple shows low. Black dots indicate sample positions, each one defined with the station name. Spaces between dots are interpolated using DIVA gridding. Contours are highlighted with thin black lines. The section*

plot is generated using Ocean Data View software (Schlitzer 2021).

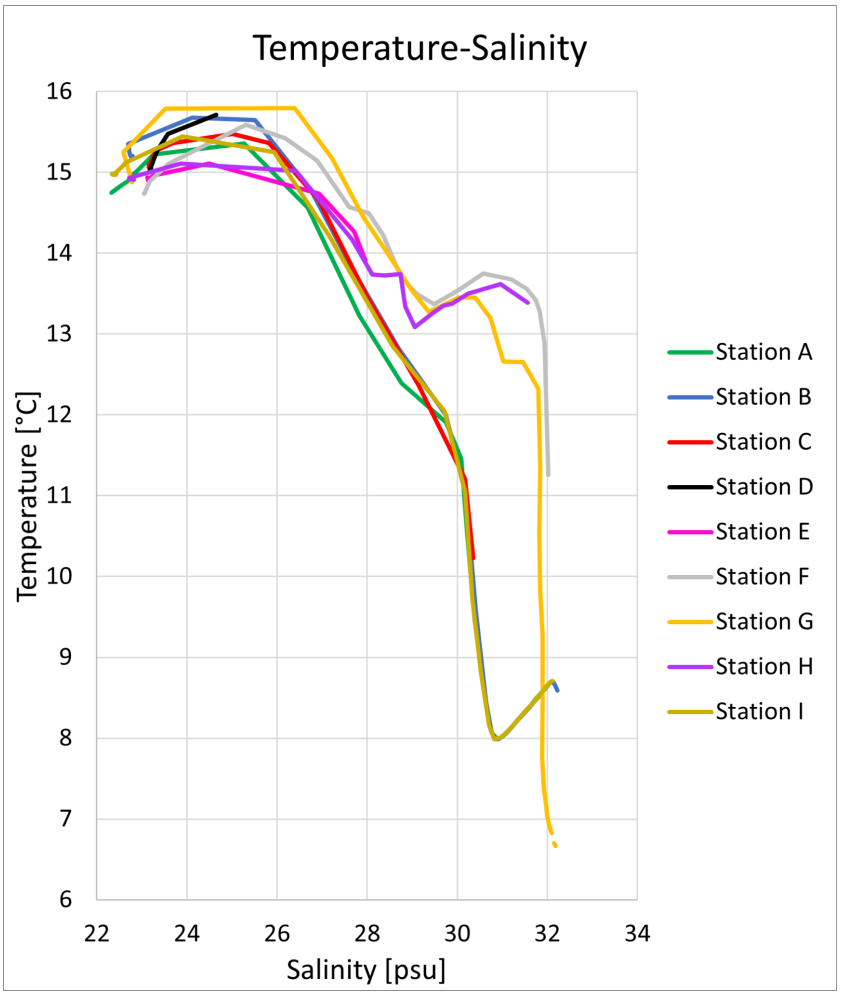

Figure 6: *Temperature plotted against salinity for all nine stations separated by color. The temperatures range from 6.5 °C to 16 °C on the y-axis and salinity, reaching from 22 to 32 PSU on the x-axis.*

Nutrients

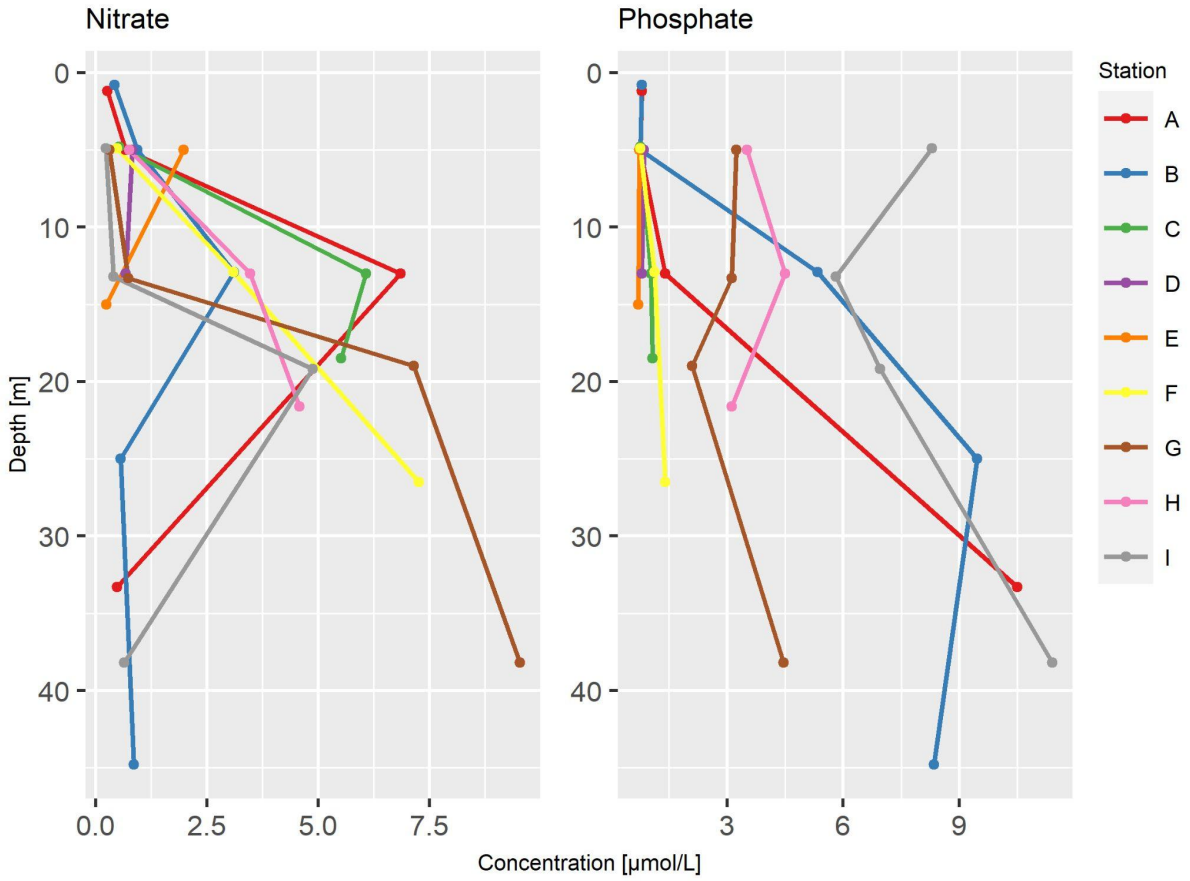

Figure 7*: Nitrate and phosphate concentration profiles for all nine stations plotted against the depth ranging between 0-45 m. The concentration range differs slightly with the range for nitrate being between 0.0-10.0 µmol/L and the range for phosphate being between 0.0-12 µmol/L.*

References

Conley, D. J., Bonsdroff, E., Carstensen, J., Destouni, G., Gustafsson, B. G., Hansson, L.-A., Rabalais, N. N., Voss, M., & Zillen, L. (n.d.). 2009. Tackling hypoxia in the Baltic sea: Is engineering a solution? Environ. Sci. Technol. Viewpoint ed. 43, pg. 3407–3411.

David Börjesson, A. W. (2013). Marinbiologisk inventering av Bållevik-Kastet, Uddevalla kommun. M. M. AB. https://www.uddevalla.se/download/18.71ecc6ce1584bf4184a71e/1479365620069/Marinbiologisk%20inventering.pdf

Gomes, W. d. S. (2014). Byfjorden: metallbelastning under årtionden och miljöstatusbedömning [Degree of Bachelor of Science, University of Gothenburg]. https://nanopdf.com/download/byfjorden-metallbelastning-under-rtionden-och_pdf

Gustafsson, M., Nordberg, K., 2002. The impact of climate and shore-level displacement on the environmental development of Havstens Fjord and Koljö Fjord, Swedish west coast. The Holocene 12, 325–338. https://doi.org/10.1 191/0959683602hl547rp

Gustafsson, M., Nordberg, K., 2000. Living (Stained) Benthic Foraminifera and their Response to the Seasonal Hydrographic Cycle, Periodic Hypoxia and to Primary Production in Havstens Fjord on the Swedish West Coast. Estuar. Coast. Shelf Sci. 51, 743–761. https://doi.org/10.1006/ecss.2000.0695

Lars-Olof Axelsson, A. S. (2021). How large is the cod consumption by cormorants in the By fjord, Sweden? Journal of Water Management and Research. https://www.tidskriftenvatten.se/wp-content/uploads/2021/06/VATTEN_21_2_105-114.pdf

SMHI(a). 2021. [online] Available at: <https://www.smhi.se/vader/observationer/observationer#ws=wpt-a,proxy=wpt-a,tab=all,stationid=81210,type=weather> [Accessed 27 September 2021].

SMHI(b). 2021. [online] Available at: <https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/#param=wind,stations=all,stationid=81050> [Accessed 27 September 2021].

SMHI, E. M., Håkan Olsson, Helma Lindow, Jonny Svensson. (2004). Integrerat Kustzonssystem för Bohusläns skärgård. SMHI. http://smhi.diva-portal.org/smash/get/diva2:947592/FULLTEXT01.pdf

Schlitzer, R. 2021. Ocean data view [Computer software]. Retrived from https://odv.awi.de/