CRUISE REPORT - BOX PROJECT 3.0:

A Comparison of the Physiochemical Properties between Byfjorden and Havstensfjorden

Figure 1. Cruise ship R/V Skagerak.

Authors:
O. Gustavsson, D. Hagman, V. Holgersson, M. Islam, J. Larsson, H. Lindgren, A. Olejnik, R. Pedersen, J. Phillipson, M. Potapo, A. Sjösten, H. Stevenson, A. Sundestrand, O. Widman

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Executive summary

The purpose of this cruise was to understand the differences in hydrography and stratification in the water column between Byfjorden and Havstensfjorden, and to figure out if this was related to the bathymetry of the fjords. This was accomplished by CTD (Conductivity, Temperature & Depth) testing and nutrient sampling taken at various sites in both fjords. Furthermore, this cruise measured the anoxic conditions in Byfjorden and compared them to the conditions in Havstensfjorden through the use of a Box Corer and dissolved oxygen measurements.

Course: MAR440, MARINE PROJECT FROM IDEA TO REALIZATION
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Cruise personnel

Oscar Gustavsson	
David Hagman	
Vanessa Holgersson	
Mahibul Islam	
Johan Larsson	
Hanna Lindgren	
Agata Olejnik	
Rasmus Pedersen	
Jody Phillipson	
Marta Potapo	
Amelie Sjösten	
Hope Stevenson	
Alexander Sundestrand	
Olivia Widman	
Sebastiaan Swart	Assoc. Professor
Louise Biddle	Post doc. Researcher

Scientific objectives

The original BOX project in 2009 aimed to test the hypothesis that bottom water oxygenation causes the excess phosphate to be contained in the sediment. This test was carried out in Byfjorden, a small sill fjord on the Swedish west coast, where surface water was pumped down below the sill depth, causing instability of the water column. The original BOX project stopped 2012 and the new BOX-project 3.0 follow-up (2019) will instead focus on a comparison of Byfjorden with Havstensfjorden and the relationship between them. The main questions to be investigated for this project are:

1) How does the water column hydrography and nutrients differ between the two fjords, and is there any evidence of water exchange over the sill?
2) Can a difference be observed in the vertical stratification between the two fjords, and does the stratification influence the water mass exchange between the surface and deep waters as well as nutrients?
3) What is the distribution of dissolved oxygen (DO) and nutrients in depth and space between the two fjords; can a connection be made between DO and fjord health (e.g. hypoxia)?

Cruise overview

Presented in *Table 1* is the chosen station name, what was sampled at each station and the maximum depth at each station. Longitude and latitude are presented at each station in decimal degrees (Coordinate system: WGS-84). The sampling layout was set to one straight transect of the Byfjord (ByX) and two stations in the Havstensfjord (HavX), this can be seen in *Figure 2.* Two extra CTD casts were collected on either side of the sill, between stations Hav2 and By3 (Hav2.5), and By3 and By4 (By3.5). These stations were chosen based on the bathymetry of the fjord and were collected to enhance the resolution of the data.

Table 1. A brief overview of the cruise plan including stations and transect details.

Station	Sampling	Longitude	Latitude	Depth [m]
Hav1	Nutrients; CTD; O_2; Box	11.90308	58.342659	30
Hav2	Nutrients; CTD	11.87493	58.333603	38
Hav2.5	CTD	11.81068	58.31928	30
By3	Nutrients; CTD	11.84446	58.325627	12.5
By3.5	CTD	11.86372	58.32975	47
By4	Nutrients; CTD; O_2; Box	11.772881	58.313637	44
By5	Nutrients; CTD	11.79785	58.291674	25.1

Diary cruise narrative

The weather on the day of the cruise was overcast with light wind coming from West-Southwest and with speeds of 4 m/s and gusts at 8 m/s. The temperature was around 13°C.

The students were subdivided into three groups, which rotated between the following tasks: CTD operations, sampling of oxygen and nutrients, and data recording. An additional activity of box-core sampling was added at two stations (Hav1 and By4).

At approximately 10 A.M., the ship departed from Uddevalla harbour traveling to the furthest station east of Stora Hasselön.

At the first station the deployment of the CTD was delayed; there was no plan for what depth the Niskin bottles would be closed at before reaching the stations. The depth at which the Niskin bottles were closed at depended on the varying depth on each station. Once the bottom depth was determined, the bottles were closed at regular intervals. It was determined that Niskin bottle five was faulty and misfired. The faulty bottle could not be fixed for the remainder of the cruise and was overcome by firing two bottles (five and six) at the same depth to ensure a sample was collected. This was repeated at every subsequent station. There was leakage of Niskin bottles one

and seven which were required for dissolved oxygen sampling, which may influence the final result.

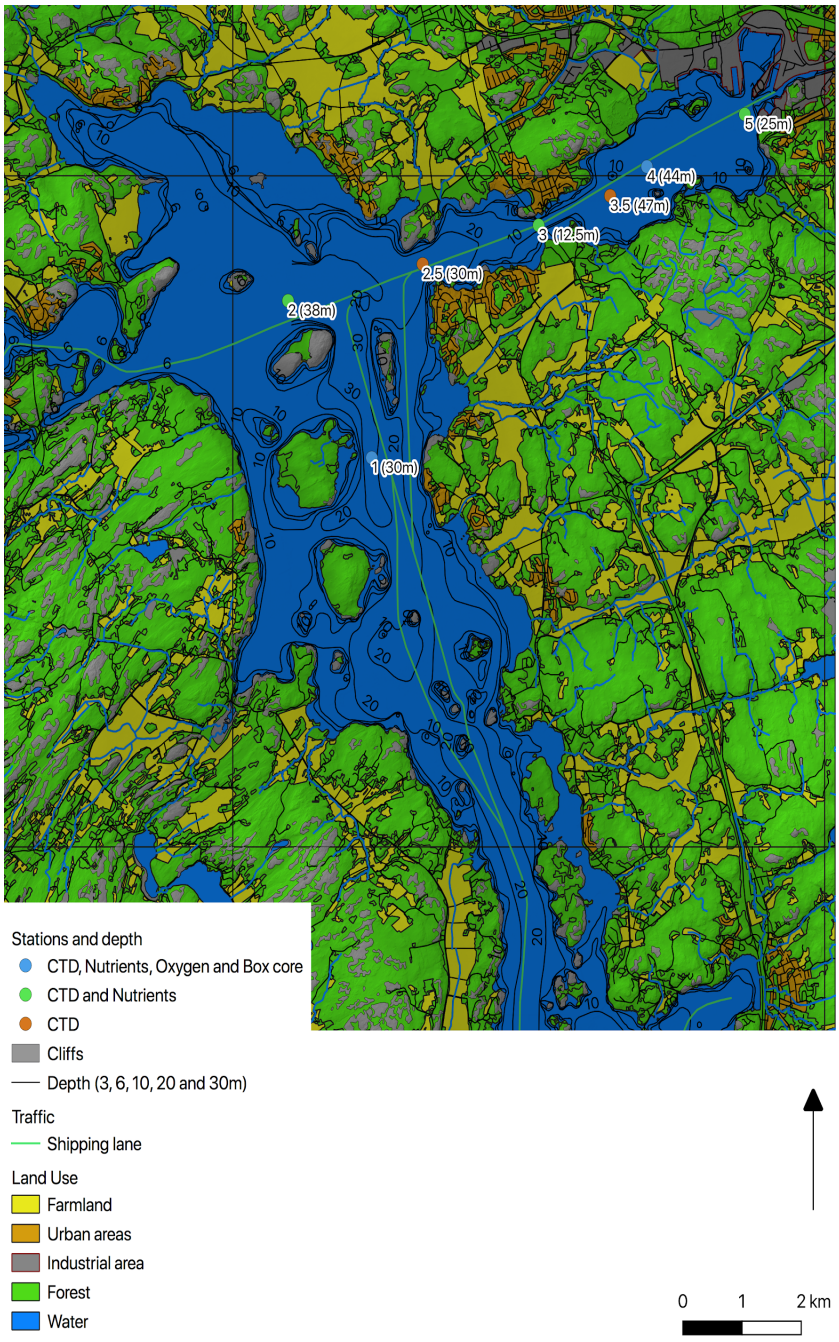


Figure 2. Map over the research area with land data from Lantmäteriet and the available bathymetry data from Sjöfartsverket. The isolines should be read as shallower than but does not say anything about the depth below the isolines. For example, Byfjorden is over 40m deep, but there are no isolines for 20m or 30m.

Sampling was completed by approximately 2 P.M.; with additional time, the collective decision was made to return to the sill to collect additional samples (Hav2.5 and By3.5).

Station/activities log

There was a total of seven sampling occasions, one at each station. CTD measurements were taken at all stations, nutrient samples at five stations, dissolved oxygen samples and box cores at two stations. The activity log in ***Appendix 1*** shows detailed information on all of the above.

Operations

At the five main stations, eight water samples were taken using a rosette sampler with twelve niskin bottles. CTD cast measurements were taken at the five main stations together with two additional stations. Four dissolved oxygen (DO) samples were taken at two of the main stations, for later use in CTD-data calibration. The oxygen calibration was designed to account for temporal drift, temperature, pressure, large oxygen intervals and a combination of any of these factors. The stations were chosen to achieve maximum spread of these factors.

Sampling of dissolved oxygen

Dissolved oxygen (DO) samples were taken at Hav1 and By4 in order to calibrate the CTD-data. By4 was chosen instead of By5 due to By4 having a greater depth and assumed colder bottom water and oxygen depletion. By taking samples evenly distributed from the bottom to the surface at Hav1 and By4, the calibration achieved maximum spread of oxygen concentration, temperature and pressure, and close to maximum temporal spread.

For dissolved oxygen sampling, water samples were taken from Niskin bottles in the order of highest to lowest depth, and before nutrient sampling to prevent contamination. Further contamination was prevented by allowing water to overflow the Biological Oxygen Demand (BOD) bottles three times, ensuring that no bubbles were present to influence the results. Two reagents, Manganese (II) chloride ($MnCl_2$) and Potassium Hydroxide (NaOH/NaI) respectively,

were added to the BOD bottle to chemically bind the oxygen as a precipitate. These samples were used for oxygen calibration.

Analysis of dissolved oxygen

The dissolved oxygen samples were analysed approximately 24 hours later in the lab at the Botanical building of Gothenburg University. Sulfuric acid (H_2SO_4) was added to the samples and titrated, using Winkler titration, with Sodium Thiosulfate ($Na_2S_2O_3$) until end point, indicated by a colour change.

The titration measurements were used for the oxygen calibration calculation shown in *Equation 1*. Variable M represents the concentration in mol/l of sodium thiosulphate. Variable b equals the number of ml of sodium thiosulphate used in titration and V is the volume of the sample BOD bottle.

Equation 1.

$$c(O_2) = \frac{b \times M}{V-2} \frac{22.4 \times 1000}{4} ml/L$$

The results of the oxygen calibration are presented in *Figure 3,* showing a line of best fit generating an R^2 value of 0.837.

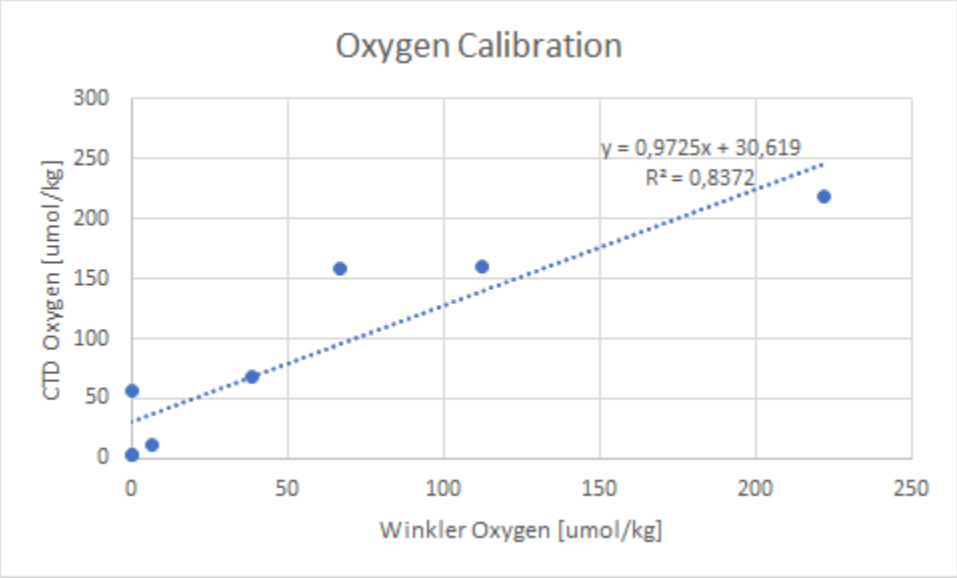


Figure 3. A calibration plot that describes the D.O. concentration (µmol/kg) from the Niskin bottles (x-axis) and the CTD measurements (y-axis) from the same depths. The y-value provides the linear regression and the R-Value the goodness of fit.

Sampling of Nutrients

To get the nutrient samples, a syringe with an attached Filtropur S 0.45 µm was used for the removal of larger undissolved particles. The filtered water was poured into labeled test tubes and analyzed by research engineer Hans Olsson at Kristineberg Marine Research Station with QuAAtro, XY-3 Sampler, Seal Analytical 2015. In total, 40 samples were taken, eight at each station, and were tested for phosphates (PO_4) , silicates (SiO_2), and nitrogen compounds (NO_2 , NO_3 , NH_4), The results are shown in *Figures 3 to 7* below. All nutrient data is provided in ***Appendix 2***.

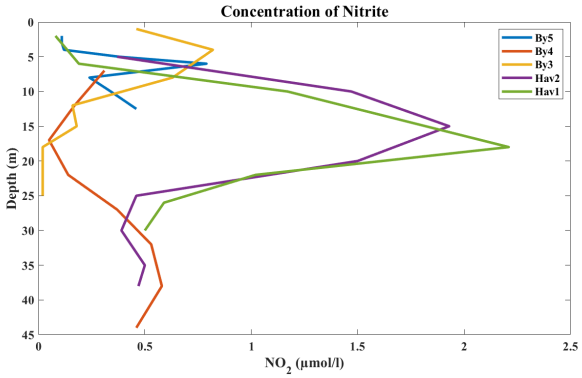


Figure 4. Concentration of Nitrite, station comparison.

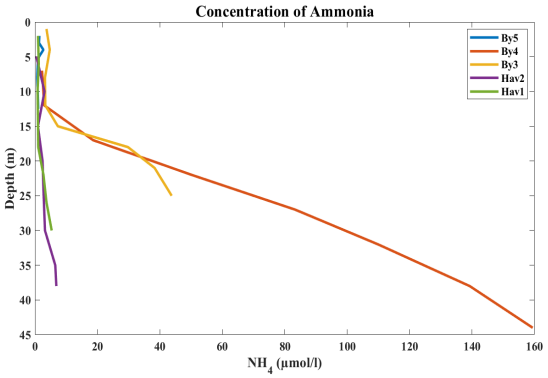


Figure 6. Concentration of Ammonia, station comparison.

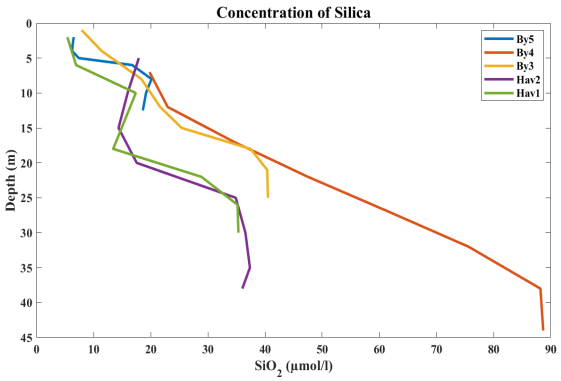


Figure 5. Concentration of Silica, station comparison.

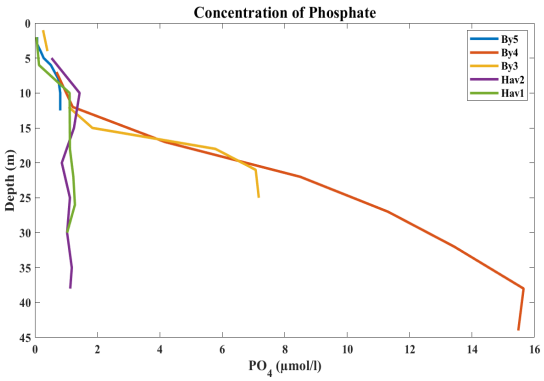


Figure 7. Concentration of Phosphate, station comparison.

Sampling of box core

Box core samples were taken at Hav1 and By4 *(Figure 8);* these were chosen to compare the deep basin in Byfjorden with and an area of relative depth in Havstenfjorden. The box cores

were taken to further confirm the level of oxygen depletion at the bottom of the fjords. The top 10 cm of the sediment in the box cores were analysed for color, sediment type, bioturbation, macrofauna and apparent oxygen conditions. Based off the smell of the sample, the presence of methane and hydrogen sulphide was identified, indicating prolonged anoxia. To investigate the presence of macrofauna, a litre of sediment was sieved. If bioturbation was evident, sediment would have lamination and evidence of life. Sediment type was determined based on dominant grain size, and the colour was noted.

Figure 8. Box sample from station By4.

CTD

CTD data was processed in Sea-Bird's SBE. Data processing acquired the bin average of requested variables every half metre and the upcast of the CTD was excluded. The upcast was ignored due to higher velocities which can lead to data lag. It was exported in ascii-format for easier management. The requested CTD output was oxygen, fluorescence, time, coordinates and density (salinity and temperature), presented in *Figures 9 to 14* below. All CTD data is available in ***Appendix 3***.

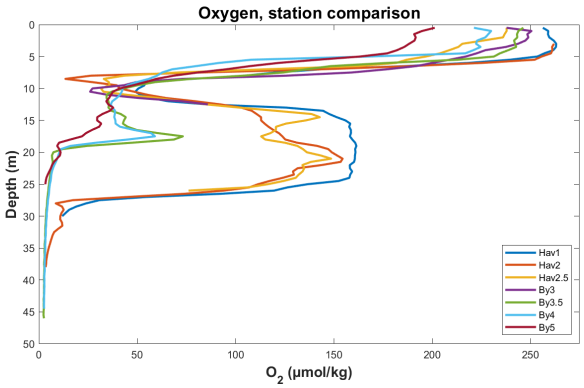


Figure 9. CTD Oxygen concentration values, station comparison.

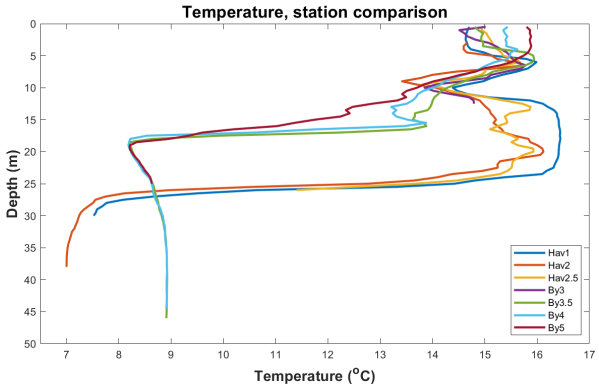


Figure 10. CTD Temperature values, station comparison.

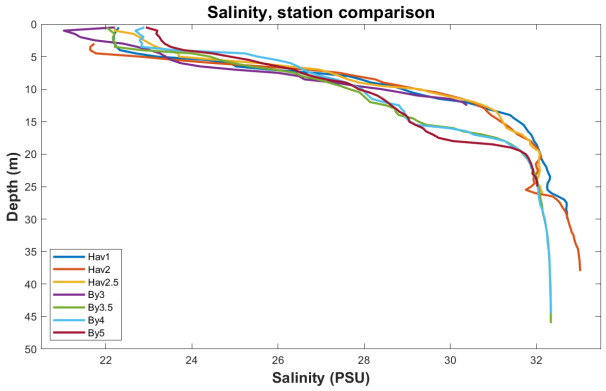


Figure 11. CTD Salinity values, station comparison.

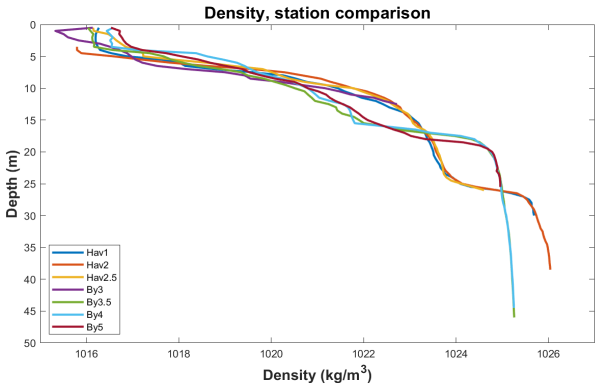


Figure 12. CTD Density values, station comparison.

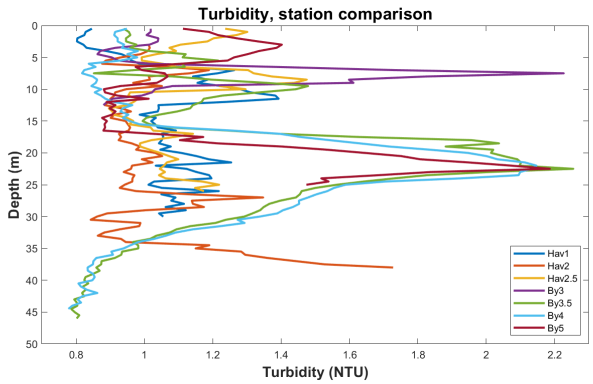


Figure 13. CTD Turbidity values, station comparison.

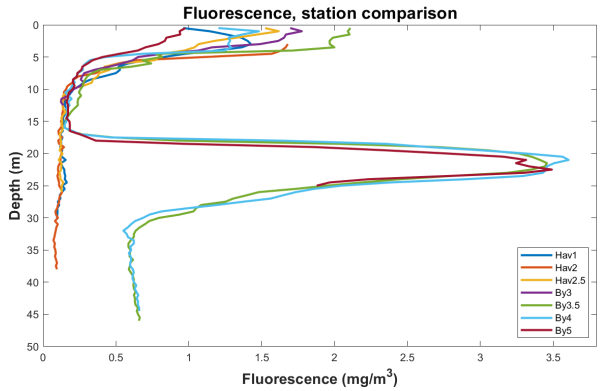


Figure 14. CTD Fluorescence values, station comparison.

Cruise track charts

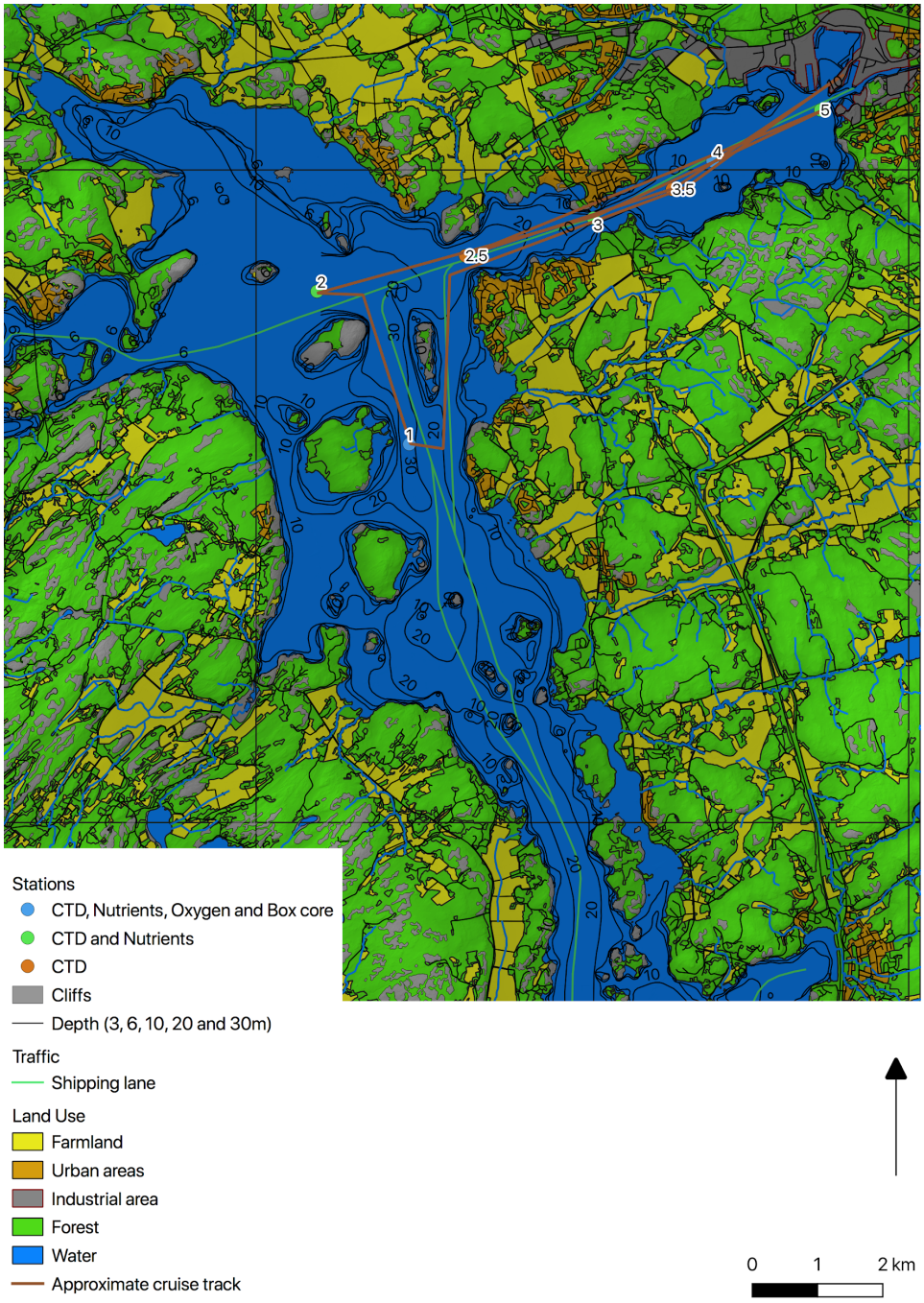


Figure 15. Cruise track. The track started in Uddevalla harbour and went to the stations in the following order: Ha1, Ha2, By3, By4 By5, Ha2.5 and Ha3.5, then back to Uddevalla Harbour.

Acknowledgements

Special acknowledgements goe to the crew of R/V Skagerak and Hans Olsson for the nutrient sample analysis.

Figure 16. CTD sampling equipment and staff. Notice the weather.

Appendix

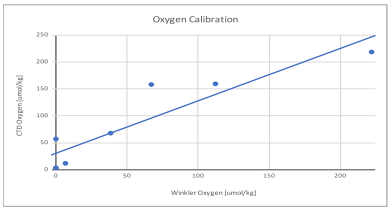
Appendix 1 - Station/activities log

Station	Niskin bottle	Oxygen sample name	Nutrient sample name	Depth	Comments	Latitude	Longitude	Start Julian	End Julian	Date	Start time (GMT+2)	End time (GMT+2)	Box core	Event description
HAV1	1	483	HAV1 NUT1	30		58.29304	11.79839	40,36749	40,37251	25/9/2019	10:35:17	10:50:09	Yes	CTD
HAV1	2		HAV1 NUT2	26		58.29304	11.79839			25/9/2019			Yes	7 nutrient samples
HAV1	3	488	HAV1 NUT3	22		58.29304	11.79839			25/9/2019			Yes	4 oxygen samples
HAV1	4	244	HAV1 NUT4	18		58.29304	11.79839			25/9/2019			Yes	1 box core
HAV1	6		HAV1 NUT6	10		58.29304	11.79839			25/9/2019			Yes	
HAV1	7	481	HAV1 NUT7	6		58.29304	11.79839			25/9/2019			Yes	
HAV1	8		HAV1 NUT8	2		58.29304	11.79839			25/9/2019			Yes	
HAV2	1		HAV2 NUT1	38		58.57821	11.82585	2.8870e-0	40.58547	25/9/2019	11:30:25	11:37:59		CTD
HAV2	2		HAV2 NUT2	35		58.57821	11.82585			25/9/2019				8 nutrient samples
HAV2	3		HAV2 NUT3	30		58.57821	11.82585			25/9/2019				
HAV2	4		HAV2 NUT4	25		58.57821	11.82585			25/9/2019				
HAV2	6		HAV2 NUT6	20		58.57821	11.82585			25/9/2019				
HAV2	7		HAV2 NUT7	15		58.57821	11.82585			25/9/2019				
HAV2	8		HAV2 NUT8	10		58.57821	11.82585			25/9/2019				
HAV2	9		HAV2 NUT9	5		58.57821	11.82585			25/9/2019				
BY 2.5						58.31928	11.81068	40.51513	40.51624	25/9/2019	14:18:24	14:21:15		CTD
BY3	1		BY1 NUT1	12,5	LEAKAGE	58.32516	11.84362	40.42284	40.42548	25/9/2019	12:02:45	12:10:13		CTD
BY3	2		BY1 NUT2	10		58.32516	11.84362			25/9/2019				8 nutrient samples
BY3	3		BY1 NUT3	8		58.32516	11.84362			25/9/2019				
BY3	4		BY1 NUT4	6		58.32516	11.84362			25/9/2019				
BY3	6		BY1 NUT6	5		58.32516	11.84362			25/9/2019				
BY3	7		BY1 NUT7	4		58.32516	11.84362			25/9/2019				
BY3	8		BY1 NUT8	3		58.32516	11.84362			25/9/2019				
BY3	9		BY1 NUT9	2		58.32516	11.84362			25/9/2019				
BY 3.5						58.32975	11.86372	40.52955	40.53090	25/9/2019	14:38:03	14:42:11		CTD
BY4	1	33	BY2 NUT1	44		58.33351	11.87408	40.44371	40.44688	25/9/2019	12:30:00	12:39:43	Yes	CTD
BY4	2		BY2 NUT2	38		58.33351	11.87408			25/9/2019			Yes	8 nutrient samples
BY4	3	116	BY2 NUT3	32		58.33351	11.87408			25/9/2019			Yes	4 oxygen samples
BY4	4		BY2 NUT4	27		58.33351	11.87408			25/9/2019			Yes	1 box core
BY4	6		BY2 NUT6	22		58.33351	11.87408			25/9/2019			Yes	
BY4	7	741	BY2 NUT7	17		58.33351	11.87408			25/9/2019			Yes	
BY4	8		BY2 NUT8	12		58.33351	11.87408			25/9/2019			Yes	
BY4	9	486	BY2 NUT9	7	sulfur smell	58.33351	11.87408			25/9/2019			Yes	
BY5	1		BY3 NUT1	25,1		58.34152	11.90171	40.47471	40.47630	25/9/2019	13:14:12	13:22:31		CTD
BY5	2		BY3 NUT2	21		58.34152	11.90171			25/9/2019				8 nutrient samples
BY5	3		BY3 NUT3	18		58.34152	11.90171			25/9/2019				
BY5	4		BY3 NUT4	15		58.34152	11.90171			25/9/2019				
BY5	6		BY3 NUT6	12		58.34152	11.90171			25/9/2019				
BY5	7		BY3 NUT7	8		58.34152	11.90171			25/9/2019				
BY5	8		BY3 NUT8	4		58.34152	11.90171			25/9/2019				
BY5	9		BY3 NUT9	1		58.34152	11.90171			25/9/2019				

Appendix 2 - Raw data for dissolved oxygen

Oxygen lab		9/26/2019										
Bottle ID	Bottle volume [mL]	Na-tiosulfate [mL]	sample depth	station	O2 [mL/L]	O2 from paper	density [kg/m3]			O2[umol/kg]	O2 CTD [umol/kg]
741	122,42	0	17	By4	0		1024,1	0	0	0	57,115
116	119,89	0	32	By4	0		1025,13	0	0	0	3,527
244	120,9	2,73	18	Hav1	2,571572		1023,44	114,8335812	0,112203	112,2035304	159,442
488	112,97	1,524	22	Hav1	1,538145	0,06825	1023,65	68,68588483	0,067098	67,09899363	158,16
33		0	44	By4	0		1025,25	0	0	0	2,639
486	112,34	0,866	7	BY4	0,879028		1019,68	39,25301577	0,038495	38,49542579	67,858
481	110,04	4,883	6	Hav1	5,061977		1018,11	226,042585	0,222021	222,0217707	218,539
483	127,47	0,173	30	Hav1	0,154427		1025,67	6,895953455	0,006723	6,723364684	11,917

Na-thiosulfate conc: 0,02 M
[S2O3-]=(bxM)/1000



Appendix 3 - Raw data for nutrients

Sample:	NO2 µmol/l	NO3 µmol/l	NH4 µmol/l	PO4 µmol/l	SiO2 µmol/l	Lat	Lon	Depth (m)
Hav1 Nut1	0,50	16,60	5,36	1,03	35,35	58.29304	11.79839	30
Hav1 Nut2	0,59	16,34	3,71	1,28	35,19	58.29304	11.79839	26
Hav1 Nut3	1,02	13,27	2,73	1,23	28,87	58.29304	11.79839	22
Hav1 Nut4	2,21	4,85	1,04	1,12	13,43	58.29304	11.79839	18
Hav1 Nut6	1,17	6,08	0,84	1,11	17,39	58.29304	11.79839	10
Hav1 Nut7	0,19	0,68	1,23	0,13	6,94	58.29304	11.79839	6
Hav1 Nut8	0,08	0,17	0,96	0,05	5,41	58.29304	11.79839	2
Hav2 Nut1	0,47	13,75	6,85	1,13	36,03	58.57821	11.82585	38
Hav2 Nut2	0,50	14,49	6,51	1,18	37,36	58.57821	11.82585	35
Hav2 Nut3	0,39	17,54	3,21	1,03	36,57	58.57821	11.82585	30
Hav2 Nut4	0,46	16,87	2,79	1,12	34,89	58.57821	11.82585	25
Hav2 Nut6	1,50	8,46	2,43	0,86	17,55	58.57821	11.82585	20
Hav2 Nut7	1,93	6,05	0,96	1,25	14,37	58.57821	11.82585	15
Hav2 Nut8	1,47	7,49	3,06	1,43	15,96	58.57821	11.82585	10
Hav2 Nut9	0,37	3,68	0,48	0,53	17,92	58.57821	11.82585	5
By1 Nut1	0,46	7,65	1,05	0,81	18,62	58.32516	11.84362	12,5
By1 Nut2	0,34	7,60	0,90	0,81	19,18	58.32516	11.84362	10
By1 Nut3	0,24	6,63	0,74	0,75	20,14	58.32516	11.84362	8
By1 Nut4	0,79	3,55	0,92	0,51	16,77	58.32516	11.84362	6
By1 Nut6	0,38	1,50	1,29	0,28	7,41	58.32516	11.84362	5
By1 Nut7	0,12	0,99	2,70	0,18	6,26	58.32516	11.84362	4
By1 Nut8	0,11	0,69	1,29	0,07	6,35	58.32516	11.84362	3
By1 Nut9	0,11	0,75	1,43	0,07	6,53	58.32516	11.84362	2
By2 Nut1	0,46	<0,05	159,42	15,48	88,69	58.33351	11.87408	44
By2 Nut2	0,58	<0,05	139,24	15,65	88,20	58.33351	11.87408	38
By2 Nut3	0,53	<0,05	109,89	13,43	75,61	58.33351	11.87408	32
By2 Nut4	0,37	<0,05	83,32	11,31	61,67	58.33351	11.87408	27
By2 Nut6	0,14	<0,05	50,20	8,50	47,51	58.33351	11.87408	22
By2 Nut7	0,05	0,46	18,61	4,16	34,58	58.33351	11.87408	17
By2 Nut8	0,17	5,72	2,97	1,21	22,97	58.33351	11.87408	12
By2 Nut9	0,31	4,97	2,27	0,69	19,79	58.33351	11.87408	7
By3 Nut1	<0,02	0,47	43,79	7,17	40,52	58.34152	11.90171	25,1
By3 Nut2	<0,02	0,21	38,32	7,07	40,38	58.34152	11.90171	21
By3 Nut3	<0,02	0,17	29,78	5,78	37,47	58.34152	11.90171	18
By3 Nut4	0,18	2,62	7,34	1,84	25,42	58.34152	11.90171	15
By3 Nut6	0,16	5,52	3,32	1,08	21,65	58.34152	11.90171	12
By3 Nut7	0,63	3,85	3,21	1,00	18,37	58.34152	11.90171	8
By3 Nut8	0,82	1,20	4,75	0,40	11,44	58.34152	11.90171	4
By3 Nut9	0,46	0,96	3,69	0,26	7,92	58.34152	11.90171	1

Appendix 4 - Raw data from CTD measurements.
Download link: https://drive.google.com/open?id=1W75cVTmDzVtTsIErVeirYOXlnzsvuoNa