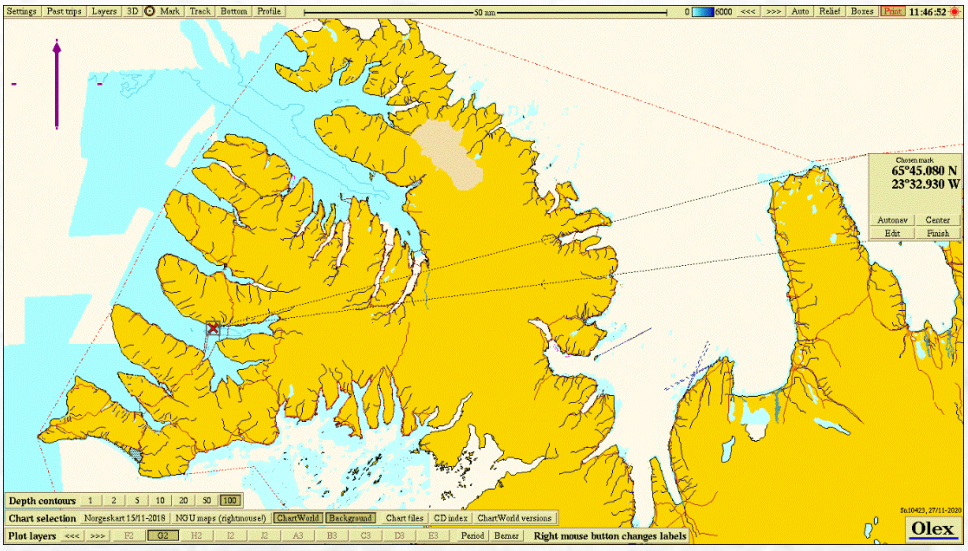
Akvaplan niva

Rapport Report

Arnarlax hf

ASC- and C-survey

Tjaldanes, 2020



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Summary / Sammendrag
The results from the monitoring at the farming site Tjaldanes in October 2020 showed that the fauna might be considered as moderately disturbed at all stations with nEQR between 0.4 and 0.6. The pollution indicator specie *Capitella capitata* (polychaete) was the second most dominant at C1, and not registered among the top-10 species at the other stations. The sediment had somewhat high levels of organic carbon at the stations (nTOC 22.7 – 29,2 mg/kg). The copper level at C1 was 47.7 mg/kg, which is within natural levels reported for bottom sediment around Iceland (Egilsson *et al*., 1999). The redox measurements (pH/Eh) gave points 0 acc. Appendix D in NS 9410:2016 for all the sampling stations. The oxygen saturation in October was low with 36 % in the bottom water.

Project manager / Prosjektleder
Snorri Gunnarsson

Quality control / Kvalitetskontroll
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Contents

Foreword

Akvaplan-niva has carried out an environmental survey of the type ASC and C at the site Tjaldanes. The survey was carried out during max biomass period. The survey includes pH/redox measurements (Eh), hydrography, geochemical analyses and analyses of the bottom fauna at the fish farming site. Results from all stations are included in the ASC survey. This survey has been done upon request from Arnarlax Hf.

The following personnel have contributed in this work:

Snorri Gunnarsson	Akvaplan-niva	Field work, report, project leader.
Hans-Petter Mannvik	Akvaplan-niva	Identification of bottom fauna (Echinodermata). Report, professional assessments and interpretations.
Roger Velvin	Akvaplan-niva	Identification of bottom fauna (Various taxa). QA report, professional assessments and interpretations.
Rune Palerud	Akvaplan-niva	Identification of bottom fauna (Crustaceans). Statistics.
Jesper Hansen	Akvaplan-niva	Identification of bottom fauna (Mollusca).
Thomas Hansen	Akvaplan-niva	Identification of bottom fauna (Polychaeta).
Stine Hermansen	Akvaplan-niva	Hydrographical vertical profiles.
Kristine H Sperre	Akvaplan-niva	Coordination of sorting of bottom fauna.
Ingar H. Wasbotten	Akvaplan-niva	Coordination of geo-chemical analyses.

Akvaplan-niva would like to thank Arnarlax hf, Silja Baldvinsdóttir, for good cooperation.

Accreditation information:

The survey was done by Akvaplan-niva AS with ALS Laboratory Group (Czech Republic) as a sub-contractor.

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Akvaplan-niva AS is accredited under NS-EN ISO/IEC 17025 by Norwegian Accreditation for field sampling of sediments and fauna, analyses of TOC, TOM, TN, particle size and macrofauna, and for professional evaluations and interpretations. Our Accreditation number is TEST 079.

Czech Accreditation Institute (Lab nr 1163)

ALS Laboratory Group is accredited by the Czech Accreditation Institute (Lab nr 1163) for copper analyses.

Non-accredited services: Hydrographical measurements and mapping of bottom topography (Olex). Analyses of emamectin benzoate, carried out by NIVA (Norwegian Institute of Water research).

Kópavogur, 30.11 2020

Snorri Gunnarsson

Project leader

1 Summary

1.1 Summary of the ASC results

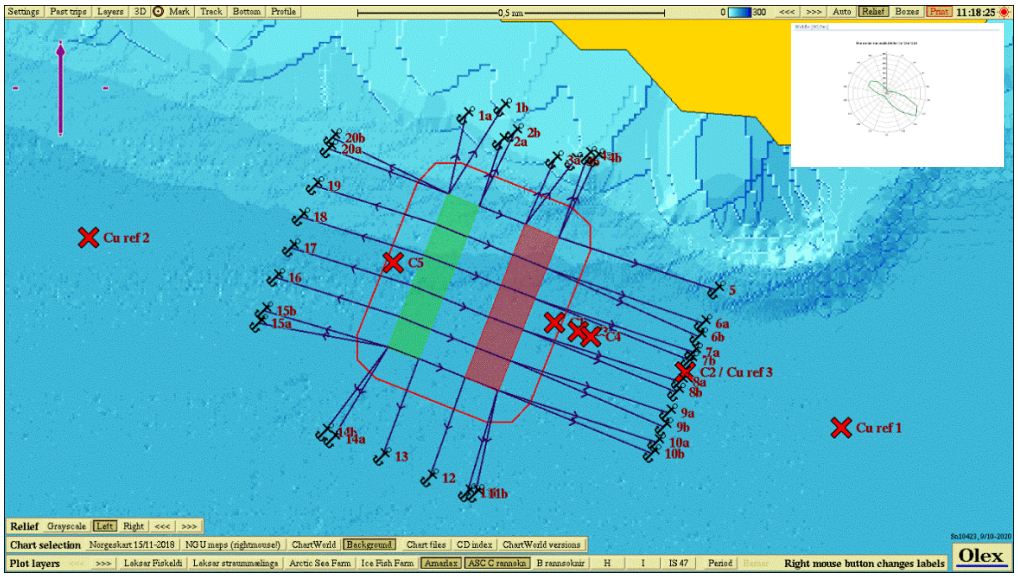
Indicator in ASC	ASC demand	Results							Remarks of the sampling
		C 1 (inside AZE)	C 2/ Cu ref3 (outside AZE)	C 3 (outside AZE)	C 4 (outside AZE)	C 5 (inside AZE)	Cu ref1	Cu ref2	
2.1.1	Redox >0 mV or sulphide level < 1500 microMol/L	280	297	269	245	241	322	292	
2.1.2 2.1.3	«Faunal index score» outside AZE indicates good to very good ecological status Shannon-Wiener > 3 Infaunal Trophic Index ITI ≥ 25	1.97 15	1.46 57	1.52 58	1.71 56	3.11 40			
2.1.3	>= 2 macro faunal taxa within AZE which are not pollution indicators, with more than 100 ind/m^2 present	1	-	-	-	10			
4.7.4	Copper level < 34 mg/kg dry sediment	47.7/ -	34.0/ 49.6	51.1/ 52.9	47.0/ 46.1	-	46.6/ 31.6	44.5/ 45.5	
2.1.4	Location specific AZE	See chapter 3.2.							

*

Conclusions:

The level of copper varied from 31.6 to 52.9 mg/kg in the sediments. The redox potential (Eh) was positive in all sediments. The faunal diversity was low at station C1, C2 C3 and C4 with the diversity index H' < 3, and high at C5. The ITI value was below 25 at C1 and above at the other stations. An evaluation of the faunal community within the AZE (stations C1 and C5) in accordance to the ASC standard, showed that there were one (C1) and ten species (C5), which were not pollution indicator species, present with 100 or more individuals/m^2.

An overview of the location of the stations and the AZE zone (red line) is shown in the figure below.



1.2 Summary of C-results

Information client			
Title :	C-survey Tjaldanes, 2020.		
Report nr.	62333.01	Site:	Tjaldanes
Site nr.		Map coordinates (construction):	65°45,080 N 23°32,930 V
		Municipal:	
MTB-permission:	Site MTB	Operations manager:	Rolf Ørjan Nordli
Client:	Arnarlax hf		

Biomass/production status at time of survey 08.10.2020			
Fish group:	Salmon	Biomass on examination:	5.807
Feed input:	6.703	Produced amount of fish:	
Type/time of survey			
Maximum biomass:	X (08.10 2020)	Follow up study:	
Fallow (resting period):		New locationi:	

Results from the C study /NS 9410 (2016) – Main results from soft bottom fauna			
Faunal index nEQR (Veileder 02:2018)		**Diversity index H' (Shannon-Wiener)**	
Fauna C1 (closest to farm)	0.430	Fauna C1 (closest to farm)	1.97
Fauna C2	0.480	Fauna C2	1.46
Fauna C3	0.573	Fauna C3	1.52
Fauna C4	0.488	Fauna C4	1.71
Fauna C5	0.580	Fauna C5	3.11
Date fieldwork:	08.10.2020	**Date of report:**	27.11 2020
Notes to other results (sediment, pH/Eh, oxygen)			nTOC from 22.7 to 29.2 mg/kg Copper 47.7 mg/kg at C1 Eh positive at all stations O_2-saturation low in the bottom water.
Responsible for field work:	Snorri Gunnarsson	Signature:	

2 Introduction

2.1 Background and aim of study

Akvaplan-niva has on behalf of Arnarlax hf done an ASC-survey for the site Tjaldanes in Anarfjörður, Iceland (Figure 1). The study was conducted based on the Arnarlax hf intention to have the Tjaldanes site certified according by the Aquaculture Stewardship Council (ASC-standard). It is simultaneously undertaken an environmental study with reference to chapter 5.0 in NS 9410:2016, which follows the methodology for C- study described in NS 9410:2016. The survey also fulfils the requirements from Icelandic authorities regarding bottom surveys referring to the standard ISO 12878 and demand for environmental bottom surveys (according to Vöktunaráætlun).

The methodology applied follows the guidelines described for environmental surveillance in ISO 16665:2014, ISO 5667-19:2004 and ASC Salmon Standard. This report is presented in manners to fulfil the demands from the Aquaculture Stewardship Council (ASC). The sampling stations were chosen based on results from earlier ocean current measurements (spread current) and bottom topography at the site (Olex).

A classification or threshold values for this type of survey have not been developed Icelandic officials so it is not possible to apply the classification based on Norwegian threshold values to Icelandic conditions. We do however report the results with these same indexes with reference to Norwegian threshold values but it should be emphasized that some of these (such as NSI) are developed according to Norwegian conditions. For further descriptions of these indexes see details in Appendix 1 and Miljødirektoratets Veileder 02:2018.

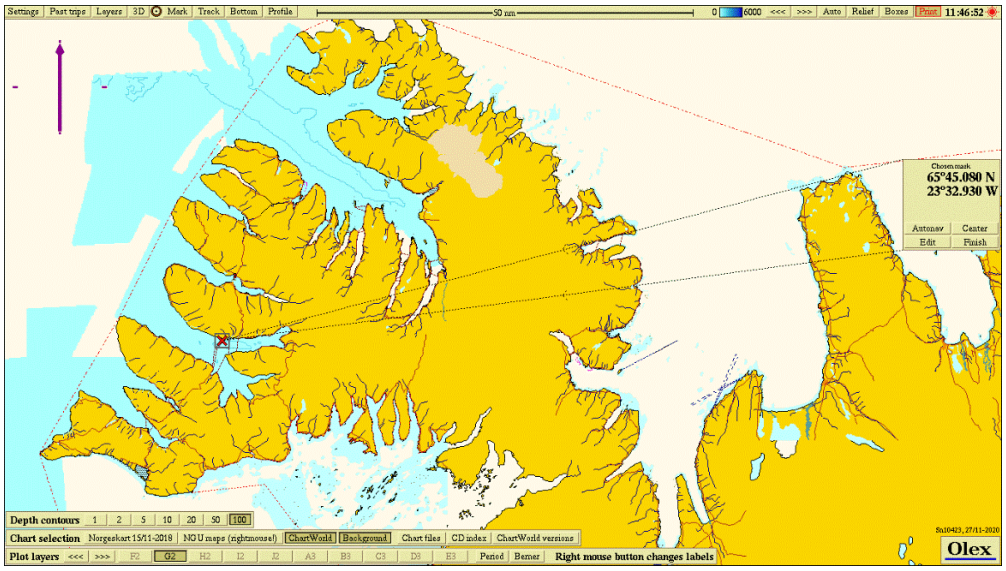


Figure 1. Overview of Arnarfjörður with the farming site Tjaldanes (red cross). The map coordinates for the midpoint of the farming site is given at right site of the picture.

2.2 Site operation and feed use

This is the second generation farmed fish at the Tjaldanes site. The plant is a frame mooring with a total of ten 160 meters circumference cages in a 2 x 5 comfiguration. First production cycle was in the period from June 2015 – May 2017. The placement of the farm area has changed slightly since then as the farm was moved slightly futher out into the fjord. The current sampling took place coherent with period of maximum biomass. The standing biomass the date of sampling was 5.807 ton. The production for the current and previous generation at Tjaldanes is shown in Table 1.

Table 1. Production at Tjaldanes.

Time fish in sea	Production of salmon (ton, round weight).	Feed use (ton)
Summer 2019 - Present generation	5.807	6.703
Previous generation (2015-2017)	3.119	4.089

2.3 Previous surveys

Akvaplan-niva AS has done one previous environmental surveys of the type C (NS 9410) at the site Tjaldanes during fallow period (Mannvik og Gunnarsson, 2019). and the present study is the second C-survey at the site. The results from the fallow study at Tjaldanes in 2019 indicated that the sediment was somewhat loaded with organic carbon and the copper concentrations were slightly elevated at C1. No load effect was recorded in fauna and fauna index nEQR showed moderate impact for all stations (< 0.6). The Diversity index H ' was just over 3 on C5 and under 3 at the other stations where it ranged from 1.4 to 2.1. NS 9410:2016-assessment of the fauna community in the local impact zone (C1) was rated with environmental condition 2 (good). No pollution indicators were recorded among the top-10 on any of the stations. The redox measurements (pH/Eh) gave points 0 acc. Appendix D in NS 9410:2016 for all the sampling stations. The oxygen saturation in March was good in the whole water column with 100% in the bottom water.

For previous generation at the old Tjaldanes site there was an environmental survey done by Náttúrustofa Vestfjarða, at peak biomass which followed guidelines in ISO 12878:2012 (Gallo and Thorsteinsson, 2017). The bottom was hard and sampling with grab proved difficult and samples were collected and analysed for only 4 stations out of 15. These were 0, 0, 55 and 55 m from the cages. The stations closest to the farm had strong smell and negative redox values. At stations in 55 m distance from the farm there was little or none sign of organic accumulation. The Shannon-Wiener index was reported for three stations as 2.27 (0 m), 2.29.

3 Materials and methods

3.1 Professional program

Choice of study parameters, placement of sampling stations and other criteria for the study is based on descriptions in the ASC-standard and the NS 9410 (C-surveys). An overview of the planned professional program is given in Table 2.

For performing the study and analysis, current standards and quality control systems are applied (see Appendix 1 and 2).

Table 2: The planned professional program for the ASC- and C-survey at Tjaldanes, 2020. TOC = total organic carbon. Korn = grain size in sediment. TOM = total organic material. TN = total nitrogen. Cu = Copper. pH/Eh = acidity and redox potential. EMB = emamectin benzoate. C1, C2, C3, C4 and C5 are also part of the C-survey.

Station	Type analyses/parameters
C1 (local impact zone, inside AZE)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. Cu. pH/Eh.
C2 (reference station C survey and ASC, outside AZE)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. 2 x Cu. pH/Eh.
C3 (transect zone, outside AZE)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. 2 x Cu. pH/Eh. EMB.
C4 (transect zone, deep area, outside AZE)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. 2 x Cu. Hydrography/O_2. pH/Eh.
C5 (local impact zone, inside AZE)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. pH/Eh.
Cu ref1 (reference station ASC)	2 x Cu.
Cu ref2 (reference station ASC)	2 x Cu.
Cu ref3 (reference station ASC)	2 x Cu.

The field work was carried out 08.10.2020.

3.2 Placement of ASC-stations and AZE

ASC-standard allows that a site specific AZE zone can be defined deviating from the 30 m from the fish farm (site-specific AZE, see pkt. 2.1.4. in «audit manual»). Based on measured current at the site, an AZE zone of 100 m from the frame of the fish farm has been calculated. Procedure for calculating the AZE zone is given in Appendix 2.

With background in sampling system described in point 2.1 in ASC «Audit manual» («Request to allow for sampling at different locations and/or changes in total number of samples»), samples from five biological stations were collected. The placement of the stations is based on results from measured oceanic current measured at 60 m depth (distribution current) at the site (Helgeland Havbruk, 2013).

Coordinates, depth and distance of stations from frame of fish farm is given in Table 3 and Figure 2.

Table 3. Distance between the nearest frame of the fish farm and sampling stations. Coordinates for stations, depth, ASC-stations at Tjaldanes, 2020. C1, C2, C3, C4 and C5 are also part of the C-survey.

Station	Depth, m	Distance from frame, m	Position N	E
C1	99	80	65º45.033	23º32.600
C2/Cu ref3	103	500	65º44.953	23º32.081
C3	102	155	65º45.019	23º32.507
C4	103	195	65º45.011	23º32.457
C5	87	80	65º45.131	23º33.240
Cu ref1	103	1000	65º44.863	23º31.461
Cu ref2	91	1000	65º45.172	23º34.448

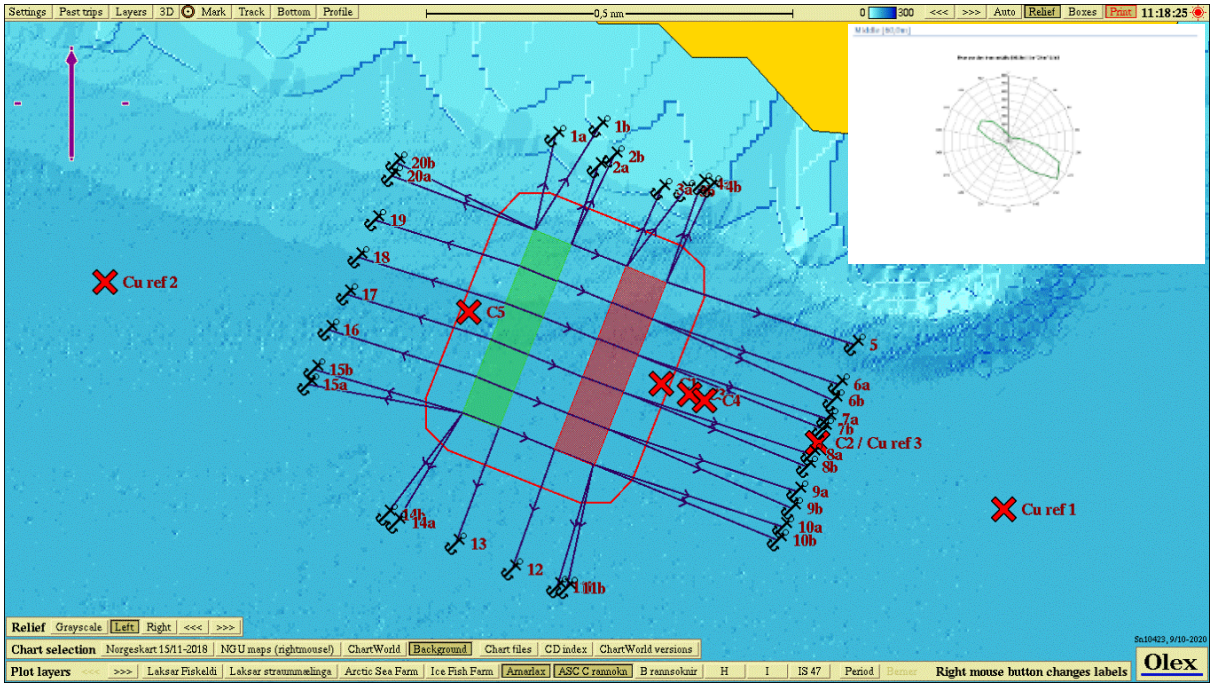


Figure 2. Sampling stations, ASC Tjaldanes, 2020. The site specific AZE is indicated with a red line with distance of 100 m from the frame of the fish farm. The spread current at the site is measured at 60 m depth.

4 ASC-survey Tjaldanes

4.1 Results

4.1.1 Bottom sediment and redox measurements (Eh)

Table 4 shows the description of bottom sediment and results from redox measurements at the sampling stations. Eh had positive values at all stations.

Table 4. Description of bottom sediment and redox measurements (Eh). ASC-stations Tjaldanes, 2020.

St.	Description of bottom sediment	Eh
C 1	Muddy, grey olive green	280
C 2/Cu ref3	Muddy, grey olive green	297
C 3	Muddy, grey olive green	269
C 4	Muddy, grey olive green	245
C 5	Muddy with some sand, grey olive green	241
Cu ref1	Muddy, grey olive green	322
Cu ref2	Muddy, grey olive green	292

4.1.2 Copper in sediments

The level of copper in the bottom sediments at all stations are shown in Table 5. The level of copper varied from 31.6 to 52.9 mg/kg.

Table 5. Copper (Cu), mg/kg TS. ASC Tjaldanes, 2020.

St.	Cu repl. 1	Cu repl. 2
C1	47.7	-
C2/Cu ref 3	34.0	49.6
C3	51.1	52.9
C4	47.0	46.1
C5	-	-
Cu ref1	46.6	31.6
Cu ref2	44.5	45.5

4.1.3 Lice treatment substances

At station C3, analyses of the amount of emamectin benzoate and deltametrine in the sediment were carried out. The results are shown in Table 6.

The amount of emamectin benzoate was 2.2 ng/kg and below detection limit for deltametrine.

Table 6: Emamectin benzoate and deltametrine (ng/kg) in sediment at C3, Tjaldanes 2020.

St.	Emamectin benzoate	Deltametrine
C3	2.2	-

4.1.4 Quantitative analyses of bottom fauna

4.1.4.1 Number of species – Shannon Wiener diversity index (H´).

The Shannon-Wiener diversity index (H´) for bottom fauna comunities are presented in Table 7. Here are also presented number of species and individuals for each of the sampling stations. Other fauna indexes according to Veileder 02:2018 are given in Appendix 3.

Number of individuals varied from 127 (C1) to 1928 (C5) and number of species from 14 (C2) to 50 (C5). Diversity index H' was above 3 at C5 and below at the other stations. The ITI value was below 25 at C1 and above at the other stations.

Table 7. Number of species and individuals pr. 0,2 m2. H´ = Shannon-Wieners diversity index. ITI =Infaunal Trophic Index. ASC-stations at Tjaldanes, 2020.

St.	Number individuals	Number species	H´	ITI
C1	127	15	1,97	15
C2	260	14	1,46	57
C3	254	16	1,52	58
C4	330	17	1,71	56
C5	1928	50	3,11	40

4.1.4.2 ASC evaluation of the bottom fauna communities at stations C1 and C5

Below there is a review of to what extent the soft bottom fauna communities at the two sampling stations inside the AZE zone (stations C1 and C5) fulfil the criteria given in the ASC- standard:

"2 highly abundant taxa that are not pollution indicator species"*

> **Highly abundant: Greater than 100 organisms per square meter (or equally high to reference site (S) if abundance is lower than this level)*

In Rygg and Norling (2013) the species are categorized into ecological groups based on the values of the sensitivity indexes. The pollution indicators (pollution indicator species) are categorized into ecological group V. The results are presented in Table 8.

At C1 a total of one species had more than 100 individuals/m^2 and this was not a pollution indicator species. At C5 a total of ten species had more than 100 individuals/m^2 and none of these were pollution indicator species.

Table 8. The dominating taxa with number of individuals per m2 at C1 and C5, Tjaldanes, 2020.

Station	Taxa	Number per 0,2 m^2	Number per m^2	NSI Ecological group *
C1	Ophryotrocha lobifera	79	395	IV
C5	Chaetozone setosa	696	3480	IV
	Thyasira sarsii	426	2130	IV
	Prionospio steenstrupi	258	1290	II
	Galathowenia oculata	104	520	III
	Ophryotrocha lobifera	90	450	IV
	Mediomastus fragilis	51	255	IV
	Ampharete finmarchica	40	200	II
	Abra nitida	35	175	III
	Ampharete petersenae	22	110	Ik
	Ennucula tenuis	22	110	II

*Ecological group: I = sensitive species. II = neutral species. III = tolerant species. IV = oppertunistic species. V = Pollution indicator species. From Rygg and Norling, 2013. Ik = ecological group not none.

5 C-survey Tjaldanes

5.1 Introduction

C-survey is aimed at studying the environmental condition of the bottom sediment in a transect sector from the fish farm that extends from the local, to the intermediate and to the regional impact zone. Main emphasis is on the study of the soft bottom fauna which is conducted according to standards ISO 5567-19:2004 and ISO 16665:2014. The obligatory parameters that are included in the survey are described in NS 9410:2016.

Fauna index is given in Appendix 1.

There have not been developed a classification or threshold values for this type of survey by Icelandic officials so it is not possible to apply the classification based on Norwegian threshold values to Icelandic conditions. However we report the results with these same indexes as with reference to Norwegian threshold values but it should be emphasized that some of these (such as NSI) are developed according to Norwegian conditions. For further descriptions of these indexes see details in Appendix 1 and Miljødirektoratets Veileder 02:2018.

5.2 Professional program and placement of sampling stations

The profession program follows the descriptions and guidance given in NS 9410:2016 for C-surveys (Table 9). The number of stations was assigned with reference to the sites estimated maximal standing biomass for the current generation which is 5.000 ton (used as MTB here). According to the standard five sampling stations were included. Depth and position of the stations are given in Table 10 and shown in

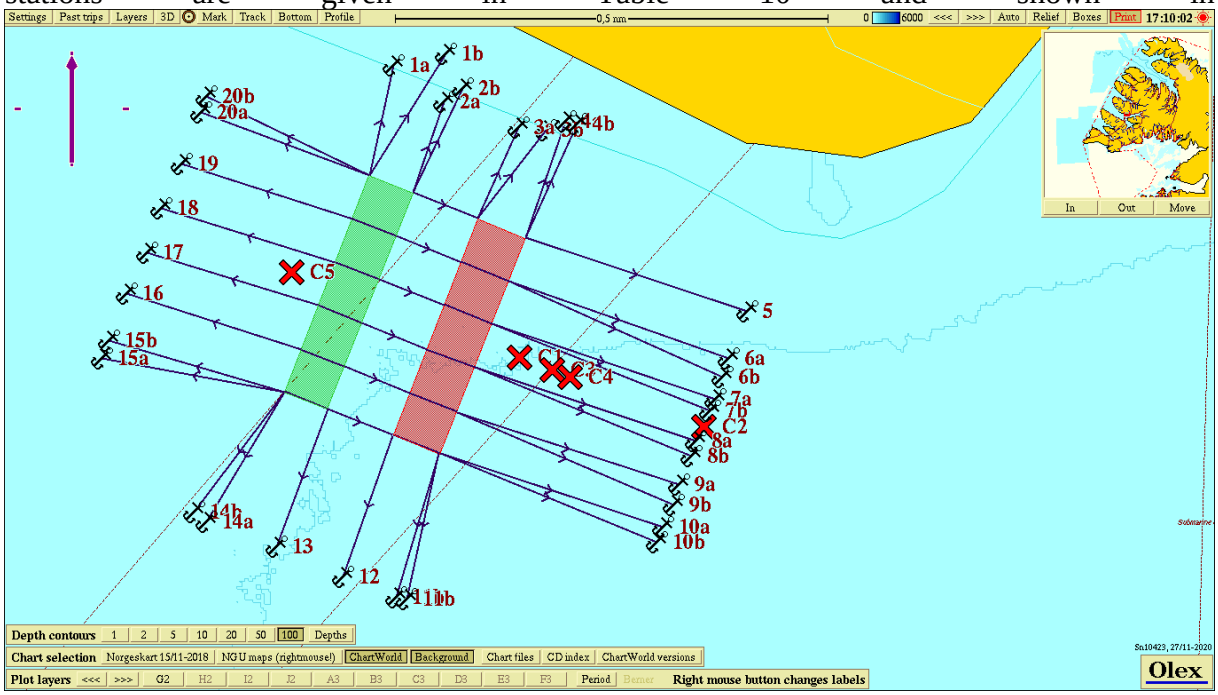


Figure 3. The stations are placed according to the direction of the main oceanic current direction at 60 m (Helgeland Havbruk, 2013) which is assigned current for spread of particles under the fish farm.

Table 9. The planned professional program for the C-survey at Tjaldanes, 2020. TOC = total organic carbon. Korn = grain size distribution in sediment. TOM = total organic material. TN = total nitrogen. Cu = copper. pH/Eh = acidity and redox potential.

Station	Type analyses
C1	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. Cu. pH/Eh.
C2	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. pH/Eh.

C3	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. pH/Eh..
C4	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. pH/Eh. Hydrography/O_2
C5	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. pH/Eh.

Table 10. Depth, distance between the nearest frame of the fish farm and sampling stations and coordinates for C-stations at Tjaldanes, 2020.

Station	Depth, m	Distance from frame, m	Position N	E
C1	99	80	65º45.033	23º32.600
C2	103	500	65º44.953	23º32.081
C3	102	155	65º45.019	23º32.507
C4	103	195	65º45.011	23º32.457
C5	87	80	65º45.131	23º33.240

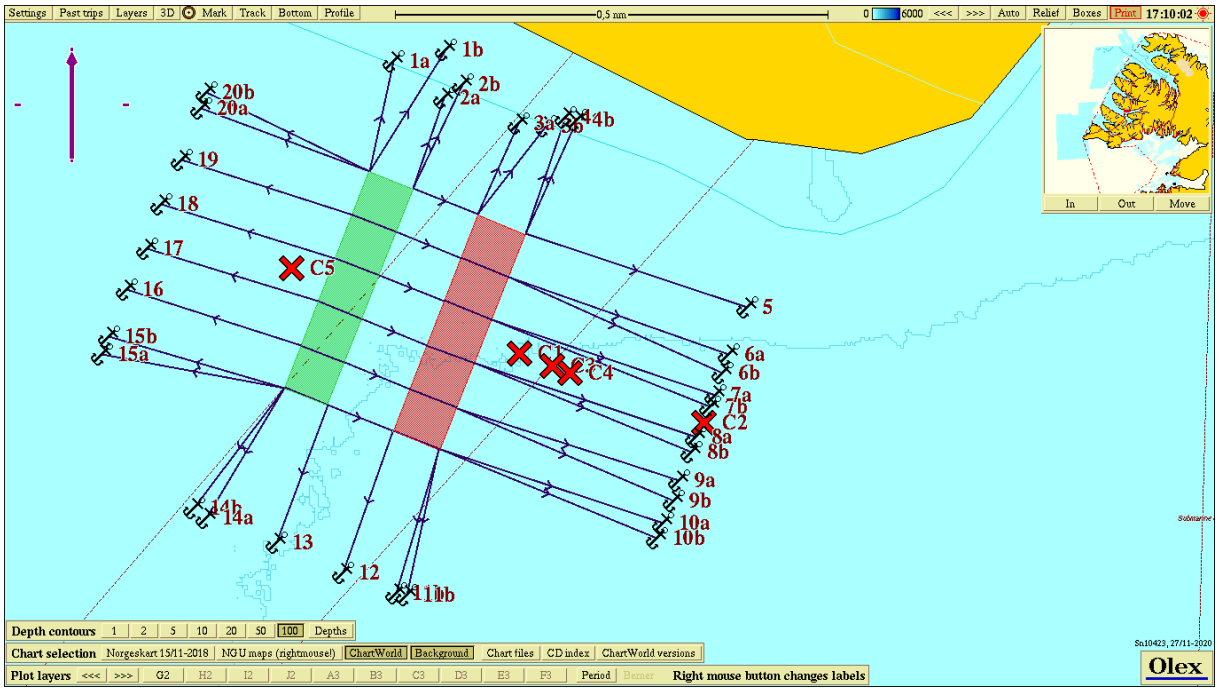


Figure 3. Map showing the sampling stations for the C-survey at Tjaldanes, 2020. Current for spread of particles is measured at 60 m depth.

5.3 Results

5.3.1 Hydrography

At station C4, hydrographic measurements, salinity, temperature, density and oxygen saturation, were carried out for vertical profiles for from surface to bottom. These were carried out using a Sensordata CTDO 204 probe. The hydrographical profile in March 2020 is presented in Figure 4.

The temperature was 8 °C from the surface to appr. 50 m depth and the dropped to 4 C at the bottom. The oxygen was between 80 and 86 % in the upper layer and dropped to 36 % saturation in the bottom water.

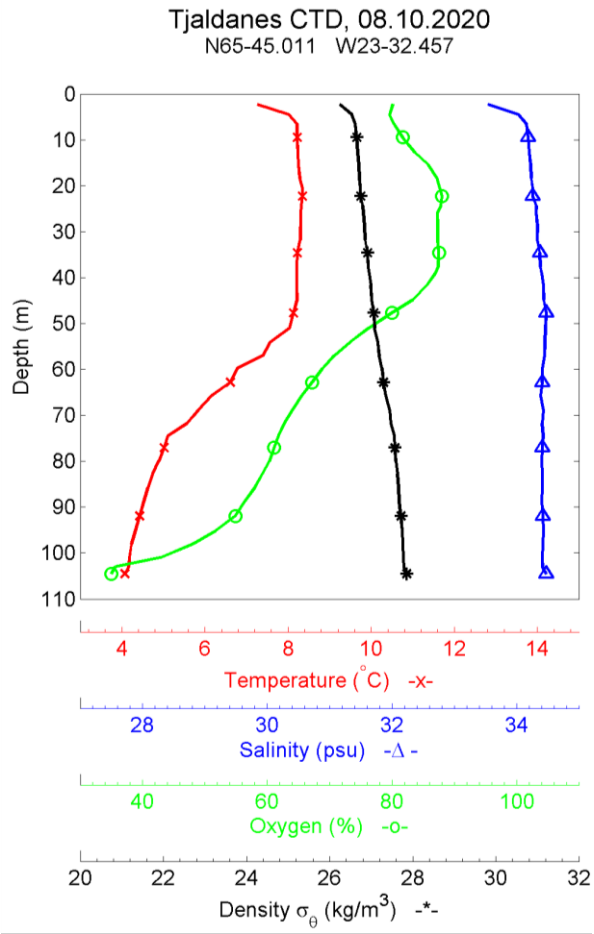


Figure 4. Vertical profiles. Temperature, salinity, density and oxygen at C4 at Tjaldanes, 2020.

5.3.2 TOC, TOM, TN, C/N, grain size and pH/Eh

The level of total organic material (TOM), total organic carbon (TN), C/N-relationship, grain size distribution in sediment (amount of pelite) and pH/Eh in the sediment is presented in Table 11.

TOM-levels varied from 5.9 to 14.3 %. TN-levels were low (2.5 – 5.4 mg/g) as were the C/N-ratios at all stations. TOC were somewhat high and nTOC varied from 22.7 to 29.2 mg/g TS (highest at C2). The bottom sediments were moderately coarse to very fine with pelite amount between 37 to 92 %.

Redox measurements (pH/Eh) gave point 0 at all stations according to Appendix D in NS 9410:2016.

Table 11. Sediment description, TOM (%), TOC (mg/g), TN (mg/g), C/N, grain size distribution (pelite ratio % <0,063 mm) and pH/Eh. Tjaldanes, 2020.

St.	Sediment description	TOM	TOC	nTOC	TN	C/N	Pelite	pH/Eh
C1	Muddy, grey olive green	11.5	25	28.3	4.3	5.7	80	7.6/ 280
C2	Muddy, grey olive green	14.3	28	29.2	4.2	6.7	92	7.8/ 297
C3	Muddy, grey olive green	13.0	26	28.2	5.4	4.8	87	7.7/ 269
C4	Muddy, grey olive green	13.7	26	27.9	5.3	5.0	92	7.6/ 245
C5	Muddy with some sand, grey olive green	5.9	12	22.7	2.5	4.6	37	7.3/ 241

5.3.3 Copper in sediment

The level of copper at station C1 (station closest to the farm) is presented in Table 12. The concentration was 47.7 mg/kg.

Table 12. Sediment analyses. Copper (Cu) in mg/kg TS. C 1 at Tjaldanes, 2020.

St.	Cu
C1	47.7

5.3.4 Soft bottom fauna

5.3.4.1 Fauna indexes and ecological classification

Results from the quantitative soft bottom fauna analyses at the C-stations are presented in Table 13. Faunal index nEQR in the table is presented without the density index (DI) in accordance to recommendations from the Norwegian Environment Agency (Miljødirektoratet).

Number of individuals varied from 127 (C1) to 1928 (C5) and number of species from 14 (C2) to 50 (C5). Diversity index H' varied from 1.46 to 3.11. The overall faunal index nEQR varied between 0.430 and 0.580.

J (Pielous evenness index) is a measure of how equally individuals are divided between species, and will vary between 0 and 1. A station with low-value has a "crooked" individual distribution between the species, indicating a disturbed bottom fauna community. The index was below 0.5 at C2, C3 and C4, showing a somewhat uneven distribution. The index was above 0.5 at C1 and C5.

Table 13. Number of species and individuals pr. 0,2 m2. H´ = Shannon-Wieners diversity index. ES100 = Hurlberts diversity index. NQI1 = overall index (diversity and sensitivity). ISI2012 = sensitivity index. NSI = sensitivity index. J = Pielous evenness index. AMBI = AZTI marine biotic index (part of NQI1). nEQR = normalized EQR). C-stations at Tjaldanes, 2020.

St.	No. ind.	No. species	H´	ES_{100}	NQI1	ISI_{2012}	NSI	nEQR	AMBI	J
C1	127	15	1.97	11.50	0.481	7.17	13.90	0.430	4.40	0.56
C2	260	14	1.46	9.67	0.466	7.94	22.12	0.480	4.19	0.43
C3	254	16	1.52	35.12	0.473	8.16	22.11	0.573	4.16	0.45
C4	330	17	1.71	10.38	0.483	7.56	21.75	0.488	4.18	0.46
C5	1928	50	3.11	16.97	0.590	8.22	16.97	0.580	3.65	0.59

5.3.4.2 NS 9410 Evaluation of the bottom fauna at station C1 (local impact zone).

According to NS 9410 can the classification of the environmental status in the local impact zone also be evaluated baseed on the number of species in relation to their dominance within the bottom fauna community (see chapter 8.6.2 in NS 9410:2016).

The soft bottom communities were classified to environmental condition 2 "Good". The criteria for condition 1 is a prescens of at least 20 species/0,2 m^2 and that none of these comrise more than 65 % of the individuals. At this station the most dominant species comprised 62 % of the individuals (Table 14). The data for number of species and dominating taxa at station C1 is collected from Table 13 and Table 15.

Table 14. Classification of the environmental status of the soft bottom fauna at station C1 at the Tjaldanes site 2020.

Station	Site name	Num. species	Dominating taxa	Environmental condition-NS 9410
C1	Tjaldanes	15	Ophryotrocha lobifera – 62 %	2 - Good

5.3.4.3 Geometric classes

Figure 5 shows the number of species plotted against the number of individuals, where the number of individuals is divided into geometric classes. For an explanation of the concept of geometric classes it is referred to Appendix 3.

The curves at C1, C2, C3 and C4 started low (< 10 species with one individual) and stretched out to varying degrees towards higher classes. At C5 the curve started higher and stretched longest out towards higher classes. The curves did not give any clear indications of the faunal conditions.

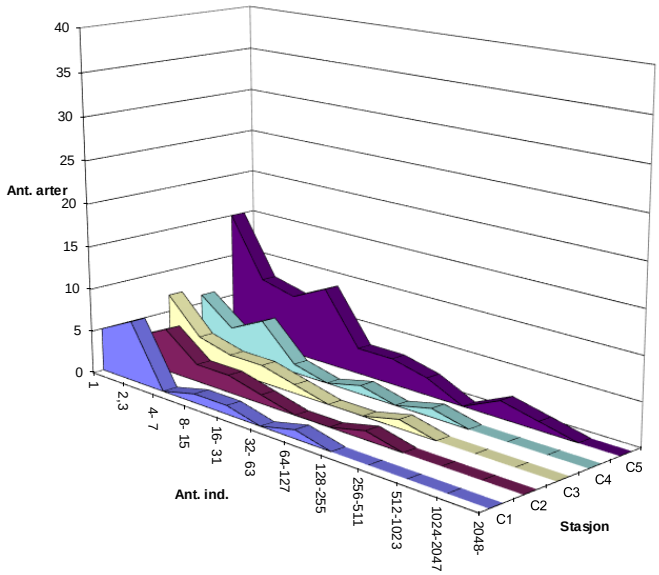


Figure 5. The soft bottom fauna shown as number of species against number of individual's pr. species in geometric classes. Tjaldanes, 2020.

5.3.4.4 Cluster analyses

To investigate the similarity of the fauna composition between the sampling stations, the multivariate technique cluster analysis was used. The results of this are presented in dendrogram in Figure 6.

The similarity between station C2, C3 and C4 was more than 65 %, C1 was 44 % similar to these stations and C5 was 37 % similar to the other stations.

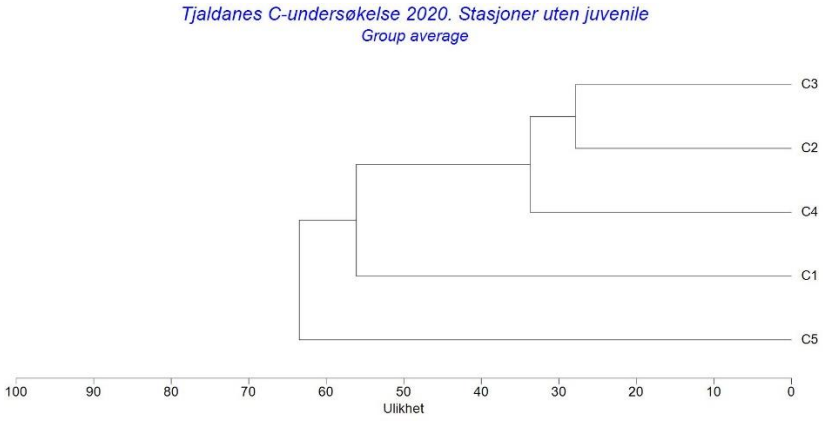


Figure 6. Clusterplott for the soft bottom fauna at the C- sampling stations at Tjaldanes, 2020.

5.3.4.5 Species composition

The main features of the species composition are shown in the form of a top ten species list from each station in Table 15.

In Rygg and Norling (2013) the species are divided into five ecological groups (EG) based on the value of the sensitivity index. These groups run from sensitive species (group I) to pollution indicators (group V).

The fauna at station C1 was dominated by the opportunistic species *Ophryotrocha lobifera* (polychaete) with 62 % of the individuals. The other most dominant species at this station were a mixture of neutral, tolerant and opportunistic species together with the pollution indicator species *Capitella capitata* (polychaete).

At C2, C3 and C4 the neutral polychaete *Prionospio steenstrupi* dominated with 73, 75 and 69 % of the individuals, respectively. The other most dominant species at this station were a mixture of neutral, tolerant and opportunistic species.

At C5 the opportunistic polychaete *Chaetozone setosa* dominated with 36 % of the individuals. The other most dominant species at this station were a mixture of neutral, tolerant and opportunistic species.

None pollution indiciator species were registered among the top-10 at C2, C3, C4 and C5.

Table 15. Number of individuals, cumulative percentage and ecological group for the ten most dominant species on the C stations. Tjaldanes, 2020.*

C1	Numb.	Cum.	EG	C2	Numb.	Cum.	EG
Ophryotrocha lobifera	79	62 %	IV	Prionospio steenstrupi	192	73 %	II
Capitella capitata	18	76 %	V	Chaetozone setosa	27	84 %	IV
Thyasira sarsii	8	82 %	IV	Thyasira sarsii	10	87 %	IV
Chaetozone sp.	3	84 %	III	Mediomastus fragilis	8	90 %	IV
Ennucula tenuis	3	87 %	II	Ampharete finmarchica	6	93 %	II
Mediomastus fragilis	3	89 %	IV	Parougia eliasoni	4	94 %	Ik
Ampharete borealis	2	91 %	III	Ennucula tenuis	2	95 %	II
Melinna cristata	2	92 %	II	Melinna cristata	2	96 %	II
Mytilus edulis	2	94 %	IV	Nemertea indet.	2	97 %	III
Prionospio steenstrupi	2	95 %	II	Nuculana sp. juv.	2	97 %	Ik
C3	**Numb.**	**Cum.**	**EG**	**C4**	**Numb.**	**Cum.**	**EG**
Prionospio steenstrupi	191	75 %	II	Prionospio steenstrupi	228	69 %	II
Chaetozone setosa	21	83 %	IV	Chaetozone setosa	46	83 %	IV
Thyasira sarsii	10	87 %	IV	Mediomastus fragilis	13	87 %	IV
Mediomastus fragilis	8	90 %	IV	Ampharete borealis	7	89 %	III
Ampharete borealis	5	92 %	III	Ophelina acuminata	7	91 %	II
Melinna cristata	5	94 %	II	Thyasira sarsii	6	93 %	IV
Ampharete finmarchica	3	95 %	II	Melinna cristata	5	94 %	II
Bylgides sarsi	2	96 %	III	Cossura pygodactylata	4	95 %	Ik
Parougia eliasoni	2	97 %	Ik	Ennucula tenuis	3	96 %	II
Asteroidea indet. juv.	1	97 %	III	Nemertea indet.	3	97 %	III

C5	Numb.	Cum.	EG
Chaetozone setosa	696	36 %	IV
Thyasira sarsii	426	58 %	IV
Prionospio steenstrupi	258	71 %	II
Galathowenia oculata	104	77 %	III
Ophryotrocha lobifera	90	81 %	IV
Mediomastus fragilis	51	84 %	IV
Ampharete finmarchica	40	86 %	II
Abra nitida	35	88 %	III
Ampharete petersenae	22	89 %	Ik
Ennucula tenuis	22	90 %	II

*Ecological groups: EG I = sensitive species. EG II = neutral species. EG III = tolerant species. EG IV = opportunistic species. EG V = pollution indicator species. From Rygg and Norling, 2013. Ik = unidentified group.

5.4 Summary and conclusions – C-survey

5.4.1 Summary

The results from the environmental survey (type C) at Tjaldanes in October 2020, can be summarized as follows:

- The hydrography measurement showed low oxygen saturation with 36 % oxygen in the the bottom water.
- Number of individuals varied from 127 (C1) to 1928 (C5) and number of species from 14 (C2) to 50 (C5). Diversity index H' varied from 1.46 to 3.11. At all stations, the nEQR was between 0.4 and 0.6, which indicates moderate disturbed fauna. The pollution indicator specie *Capitella capitata* (polychaete) was the second most dominant at C1, and not registered among the top-10 species at the other stations.
- TOC was somewhat high at most of the stations and lower at C5 and nTOC varied from 22.7 to 29.2 mg/g TS (highest at C2). TN-levels were low (2.5 – 5,4 mg/g) as was the C/N-ratio. The copper level in the sediment at C1 was 47.7 mg/kg, but well within reported natural levels in Icelandic coastal areas (Egilsson *et al*. 1999). The bottom sediments were moderately coarse to very fine with pelite amount between 37 to 92 %. The redox measurements (pH/Eh) gave points 0 acc. Appendix D in NS 9410:2016 for all the stations.

5.4.2 Conclusion

The results from the monitoring at the farming site Tjaldanes in October 2020 showed that the fauna might be considered as moderately disturbed at all stations with nEQR between 0.4 and 0.6. The pollution indicator species *Capitella capitata* (polychaete) was the second most dominant at C1, and not registered among the top-10 species at the other stations. The sediment had somewhat high levels of organic carbon at the stations (nTOC 22.7 – 29,2 mg/kg). The copper level at C1 was 47.7 mg/kg, which is within natural levels reported for bottom sediment around Iceland (Egilsson *et al*., 1999). The redox measurements (pH/Eh) gave points 0 acc. Appendix D in NS 9410:2016 for all the sampling stations. The oxygen saturation in October was low with 36 % in the bottom water.

5.4.3 Environmental trend since the last C- survey

A C-survey was carried out at the location in 2019 (Mannvik & Gunnarsson, 2019) at fallow period prior to putting current generation fish into sea. The conclusion was: *"The results from the monitoring at the farming site Tjaldaneseyrar in 2019 showed that the sediment was somewhat loaded with organic carbon and the copper concentration was slightly elevated at C1 (48.0 mg/kg) but within natural levels reported for bottom sediment around Iceland (Egilsson et al., 1999). No load effect was recorded in fauna and fauna index nEQR showed moderate impact for all stations (< 0.6). The Diversity index H ' was just over 3 on C5 and under 3 at the other stations where it ranged from 1.4 to 2.1. NS 9410:2016-assessment of the community in the local impact zone (C1) showed environmental condition 2 (Good). No pollution indicators were recorded among the top-10 species on any of the stations. The redox measurements (pH/Eh) gave points 0 acc. Appendix D in NS 9410:2016 for all the sampling stations. The oxygen saturation in March was good in the whole water column with 100% in the bottom water."*

The diversity index H' and the faunal index nEQR are at the same levels at the stations in the two surveys. The same is the case with the nTOC- and Cu-values.

6 References

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Rygg, B. & K. Norling, 2013. Norwegian Sensitive Index (NSI) for marine macro invertebrates, and an update of Indicator Species Index (ISI). NIVA report SNO 6475-2013. 48 p.

Appendix 1. Metodebeskrivelser og klassifiseringssystemer (in norwegian)

Hydrografi og oksygen

I henhold til NS 9410 ble det gjennomført hydrografiske registreringer for vertikalprofilen med hensyn til saltholdighet, temperatur, tetthet og oksygenmetning fra overflate til bunn på den dypeste stasjonen. Målingene ble gjennomført ved hjelp av en Sensordata CTDO 202 sonde.

Geokjemiske analyser

Feltinnsamlinger

Prøvene ble hentet med en 0,1 m^2 grabb (van Veen). Prøvematerialet ble tatt ut gjennom inspeksjonsluker etter at sedimentoverflaten var godkjent. Prøver for TOC, TOM, TN og Cu ble tatt av fra øverste 1 cm av sedimentet, og for kornfordelingsanalyser fra de øverste 5 cm ved hjelp av rør. Kun prøver med uforstyrret overflate ble godkjent og prøvematerialet ble frosset for videre bearbeidelse i laboratorium.

Total organisk materiale (TOM)

Mengden av TOM i sediment ble bestemt ved vekttap etter forbrenning ved 495 °C. Vekttapet i prosent etter forbrenning ble beregnet. Reproduserbarheten av TOM-analysene er sjekket i opparbeidingsperioden ved å bruke et husstandardsediment som inneholder TOM med kjent nivå. Standard kalsiumkarbonat ble brent sammen med prøvene som kontroll på at karbonat ikke ble forbrent i prosessen

Total nitrogen (TN)

Etter tørking av prøvene ved 40 °C ble innhold av total nitrogen (TN) kvantifisert ved elektrokjemisk bestemmelse. Den interne metoden er basert på NS-EN 12260:2003 (Vannundersøkelse – Bestemmelse av bundet nitrogen (TNb) etter oksidasjon til nitrogenoksider).

Totalt organisk karbon (TOC) og kornfordeling

Andelen finstoff, dvs. fraksjonen mindre enn 63 µm, ble bestemt gravimetrisk etter våtsikting av prøvene. Resultatene er angitt som andel finstoff på tørrvektsbasis.

Etter tørking av prøvene ved 40 °C ble innhold av total organisk karbon (TOC) bestemt ved NDIR-deteksjon i henhold til DIN19539:2016 (Investigation of solids – Temperature-dependent differentiation of total carbon (TOC_{400}, ROC, TIC_{900})). For å kunne klassifisere miljøtilstanden basert på innhold av TOC, er de målte konsentrasjonene normalisert for andel finstoff (nTOC) ved bruk av ligningen: nTOC = TOC + 18(1 – F), hvor TOC og F står for henholdsvis målt TOC verdi og andel finstoff (%) i prøven (Aure *m.fl.*, 1993).

Klassifisering av miljøtilstanden for sedimentene er basert på normalisert TOC, og ble gjennomført i henhold til Veileder 02:2018.

Tilstandsklassifisering for organisk innhold i marine sediment.

nTOC, mg/g	< 20 I Svært god	20 - 27 II God	27 - 34 III Moderat	34 - 41 IV Dårlig	> 41 V Svært dårlig

Kobber (Cu)

Prøven for metallanalyse ble frysetørket før den ble oppsluttet i mikrobølgeovn i lukket teflonbeholder med konsentrert ultraren salpetersyre og hydrogenperoksid. Konsentrasjonene av kobber (Cu) ble bestemt ved hjelp av ICP-SFMS.

Klassifisering av miljøtilstanden med hensyn til Cu ble gjennomført i henhold til Miljødirektoratets veileder M-608/2016.

Tilstandsklassifisering for kobber (Cu) i marine sedimenter.

Cu mg/kg	< 20 Klasse I	20 - 84 Klasse II	20 - 84 Klasse III	84 - 147 Klasse IV	> 147 Klasse V

Redoks- og pH målinger

På alle stasjonene ble det utført en kvantitativ kjemisk undersøkelse av sedimentet. Surhetsgrad (pH) og oksydasjon/redokspotensial (ORP) ble målt ved hjelp av elektroder og instrumentet YSI Professional Plus. I hht. manual for instrumentet, ble 200 mV lagt til den målte ORP-verdien for å få Eh-verdien.

Bunndyr

Om organisk påvirkning av bunndyrssamfunn

Utslipp av organisk materiale (fôrrester/fekalier) fra marine oppdrettsanlegg kan bidra til forringede livsvilkår for mange av de bunnlevende organismene. Negative effekter i bunndyrsamfunnet kan best vurderes gjennom kvantitative bunndyrsanalyser. Fordi de fleste bløtbunnartene er lite mobile, vil faunasammensetningen i stor grad gjenspeile de stedsegnede miljøforholdene. Endringer i bunndyrssamfunnene er god indikasjon på uønskede belastninger. Under naturlige forhold består samfunnene av mange arter. Høyt artsmangfold (diversitet) er blant annet betinget av gunstige forhold for faunaen. Likevel kan eksempelvis moderate økninger i organisk belastning stimulere faunaen og eventuelt øke artsmangfoldet noe. Større belastning gir dårligere forhold der opportunistiske arter øker sine individtall, mens ømfintlige slås ut. Dette betyr redusert artsmangfold. Endringer i artsmangfold under og ved oppdrettsmerder kan i stor grad knyttes til endringer av organisk innhold (fôr og fekalier) i sedimentet.

Innsamling og fiksering

Alle bunndyrprøvene ble tatt med en 0,1 m^2 van Veen grabb. Kun grabbskudd hvor grabben var fullstendig lukket og overflaten uforstyrret ble godkjent. Etter godkjenning ble innholdet vasket i en 1 mm sikt og gjenværende materiale fiksert med 4 % formalin tilsatt fargestoffet bengalrosa og nøytralisert med boraks. På laboratoriet ble dyrene sortert ut fra gjenværende sediment.

Kvantitative bunndyrsanalyser

På alle stasjonene innsamles det to prøver (replikater) iht. retningslinjene i NS 9410 (2007) og ASC standarden. Sortert materiale ble opparbeidet kvantitativt. Bunndyrene ble identifisert til fortrinnsvis artsnivå eller annet hensiktsmessig taksonomisk nivå og kvantifisert av spesialister (taksonomer). De kvantitative artslistene inngikk i statistiske analyser. Se Appendix 2 for beskrivelse av analysemetoder. For å klassifisere miljøtilstanden er Direktoratgruppens veileder 02:2018 benyttet. Følgende statistiske metoder ble benyttet for å beskrive samfunnenes struktur og for å vurdere likheten mellom ulike samfunn:

- Shannon-Wiener diversitetsindeks (H')
- Hurlberts diversitetsindeks (ES_{100}) - forventet antall arter pr. 100 individer
- Pielou's jevnhetsindeks (J)
- Ømfintlighetsindeks (ISI_{2012}), uegnet ved lavt individ/artstall
- Sensitivitetsindeks (NSI)
- Sammensatt indeks for artsmangfold og ømfintlighet (NQI1)
- Ømfintlighetsindeks som inngår i NQI1 (AMBI)
- Normalisert EQR (nEQR)
- Antall arter plottet mot antall individer i geometriske artsklasser
- Clusteranalyser
- De ti mest dominerende taksa pr. stasjon (topp-10)

Indeksene er beregnet som snitt av to replikater.

Økologisk tilstandsklassifisering basert på observert verdi av indeks (fra Veileder 02:2018).

Indeks	I Svært god	II God	III Moderat	IV Dårlig	V Svært dårlig
NQI1	0,9 - 0,82	0,82 - 0,63	0,63 - 0,49	0,49 - 0,31	0,31 - 0
H´	5,7 - 4,8	4,8 - 3,0	3,0 - 1,9	1,9 - 0,9	0,9 - 0
ES_{100}	50 - 34	34 - 17	17 - 10	10 - 5	5 - 0
ISI_{2012}	13 - 9,6	9,6 - 7,5	7,5 - 6,2	6,1 - 4,5	4,5 - 0
NSI	31 - 25	25 - 20	20 - 15	15 - 10	10 - 0
nEQR	1,0 – 0,8	0,8 – 0,6	0,6 – 0,4	0,4 – 0,2	0,2 – 0,0

Bunndyrsamfunnet i anleggssonen ble også vurdert i henhold til NS 9410 klassifisering av miljøtilstand, basert på antallet arter og dominansforhold (C-undersøkelsen). I tillegg ble det gjort en vurdering av hvorvidt bunndyrsamfunnene på anleggssonestasjonen oppfylte følgende krav fra ASC-standarden (ASC-undersøkelsen):

"2 highly abundant taxa that are not pollution indicator species"*

> **Highly abundant: Greater than 100 organisms per square meter (or equally high to reference site (S) if abundance is lower than this level)*

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Appendix 2. Prosedyre for beregning av AZE (in norwegian)

I ASC-undersøkelser skal det fastlegges AZE (Allowable Zone of Effect) rundt oppdrettsanlegg som danner utgangspunkt for valg av prøvestasjonsnett. I standarden, som ble laget for skotske forhold, står det at den skal være 30 meter fra merdkanten. På grunn av store dyp og sterk strøm blir dette ikke riktig avstand for norske forhold.

ASC-standarden tillater at en fastlegger en lokalitetsavhengig AZE (site specific AZE). Det er laget en intern AZE kalkulator til formålet for Akvaplan-niva.

Beregning av "site specific" AZE:

På grunn av påvirkning fra strøm og vind og lange fortøyningsliner er oppdrettsanlegg på svai. En må derfor regne med at fôrpartikler og fiskeavføring vil havne på bunnen i det området der anlegget befinner seg på svai. En AZE må inkludere dette område. Svaien legges til 20 % av dybde, f.eks. for et anlegg med størst dybde på 100 m legges det inn en mulig svai på 20 m i hver retning. Tallet er tidligere brukt av Fiskeridirektoratet ved kontroll av anleggets koordinater. Det stemmer også overens med oppgitt strekk (inntil 10 %) og elastisitet fra fortøyningsliner.

Videre vil enhver lokalitet ha et eget påvirkningsmønster fra fôrpartikler og fiskeavføring som havner på bunnen, ofte kalt lokalitetens fotavtrykk, som bestemmes av dybde, partiklenes synkehastighet og lokalitetens strømforhold. Forventet utstrekning (L) av påvirkningsområdet kan beregnes ved å dele dybde (D) med synkehastighet (V_f) og gange med gjennomsnittlig strømhastighet (V_s) på spredningsstrøm. Synkehastighet er satt til 7,5 cm/s utfra Bannister et al (2016) sin vitenskapelige artikkel der resultatet fra forsøkene var at mellom 60 og 80 % av all feces synker med en hastighet mellom 5 og 10 cm/s.

$L = (V_s) * D/(V_f)$ eksempel 100 m dybde, 7,5 cm/s synkehastighet og 6 cm/s gjennomsnittlig spredningsstrøm

L = 6 cm/s * 10000cm/7,5 cm/s = 80 m.

Med svai på 20% av 100 m = 20 m blir

AZE da L + svai = 80 m + 20 m = 100 m

D og (V_s) hentes fra lokalitetsrapport.

Referanse:

Bannister, R. J., Johnsen, I. A., Hansen, P. K., Kutti, T., & Asplin, L. Near- and far-field dispersal modelling of organic waste from Atlantic salmon aquaculture in fjord systems. – ICES Journal of Marine Science, doi: 10.1093/icesjms/fsw027

Appendix 3. Bunndyrstatistikk og artslister (in norwegian)

Diversitetsmål

Diversitet er et begrep som uttrykker mangfoldet i dyre- og plantesamfunnet på en lokalitet. Det finnes en rekke ulike mål for diversitet. Noen tar mest hensyn til artsrikheten (mål for artsrikheten), andre legger mer vekt på individfordelingen mellom artene (mål for jevnhet og dominans). Ulike mål uttrykker derved forskjellige sider ved dyresamfunnet. Diversitetsmål er "klassiske" i forurensningsundersøkelser fordi miljøforstyrrelser typisk påvirker samfunnets sammensetning. Svakheten ved diversitetsmålene er at de ikke alltid fanger opp endringer i samfunnsstrukturen. Dersom en art blir erstattet med like mange individer av en ny art, vil ikke det gjøre noe utslag på diversitetsindeksene.

Shannon-Wieners indeks (Shannon & Weaver, 1949) er gitt ved formelen:

$$H' = -\sum_{i=1}^{s} \frac{n_i}{N} \log_2 \left(\frac{n_i}{N} \right)$$

der n_i = antall individer av art *i* i prøven
N = total antall individer
s = antall arter

Indeksen tar hensyn både til antall arter og mengdefordelingen mellom artene, men det synes som indeksen er mest følsom for individfordelingen. En lav verdi indikerer et artsfattig samfunn og/eller et samfunn som er dominert av en eller få arter. En høy verdi indikerer et artsrikt samfunn.

Pielous mål for jevnhet (Pielou, 1966)

har følgende formel, der symbolene er som i Shannon-Wieners indeks

$$J = \frac{H'}{\log_2 s}$$

Hurlberts diversitetskurver

Grafisk kan diversiteten uttrykkes i form av antall arter som funksjon av antall individer. Med utgangspunkt i total antall arter og individer i en prøve søker man å beregne hvor mange arter man ville vente å finne i delprøver med færre individer. Diversitetsmålet blir derved uavhengig av prøvestørrelsen og gjør at lokaliteter med ulik individtetthet kan sammenlignes direkte. Hurlbert (1971) har gitt en metode for å beregne slike diversitetskurver basert på sannsynlighetsberegning.

ES_n er forventet antall arter i en delprøve på n tilfeldig valgte individer fra en prøve som inneholder total N individer og s arter og har følgende formel:

$$ES_n = \sum_{i=1}^{s} \left[1 - \frac{\binom{N-N_i}{n}}{\binom{N}{n}} \right]$$

der N = total antall individ i prøven
N_i = antall individ av art *i*
n = antall individ i en gitt delprøve (av de N)
s = total antall arter i prøven

Plott av antall arter i forhold til antall individer

Artene deles inn i grupper/klasser etter hvor mange individer som er registrert i en prøve. Det vanlige er å sette klasse I = 1 individ pr. art, klasse II = 2-3 individer, klasse III = 4-7 individer, klasse IV = 8-15 individer, osv., slik at de nedre klassegrensene danner en følge av ledd på formen 2^x, x=0,1,2, … En slik følge kalles en geometrisk følge, derfor kalles klassene for geometriske klasser. Hvis antall arter innenfor hver klasse plottes mot klasseverdien på en lineær skala, vil det fremkomme en kurve som uttrykker individfordelingen mellom artene i samfunnet. Det har vist seg at i prøver fra upåvirkede samfunn vil det være mange arter med lavt individantall og få arter med høyt individantall, slik at vi får en entoppet, asymmetrisk kurve med lang "hale" mot høye klasseverdier. Denne kurven vil være godt tilpasset en log-normal fordelingskurve.

Ved moderat forurensing forsvinner en del av de individfattige artene, mens noen som blir begunstiget, øker i antall. Slik flater kurven ut, og strekker seg mot høyere klasser eller den får ekstra topper. Under slike forhold mister kurven enhver likhet med den statistiske log-normalfordelingen. Derfor kan avvik fra log-normalfordelingen tolkes som et resultat av en påvirkning/forurensing. Det har vist seg at denne metoden tidlig gir utslag ved miljøforstyrrelse. Ved sterk forurensning blir det bare noen få, men ofte svært tallrike arter tilbake. Log-

normalfordelingskurven vil da ofte gjenoppstå, men med en lavere topp og spredt over flere klasser enn for uforstyrrede samfunn.

Faunaens fordelingsmønster

Variasjoner i faunaens fordelingsmønster over området beskrives ved å sammenligne tettheten av artene på hver stasjon. Til dette brukes multivariate klassifikasjons- og ordinasjons-analyser (Cluster og MDS).

Analysene i denne undersøkelsen ble utført ved hjelp av programpakken PRIMER v5. Inngangsdata er individantall pr. art, pr. prøve. Prøvene kan være replikater eller stasjoner. Det tas ikke hensyn til hvilke arter som opptrer. Forut for klassifikasjons- og ordinasjonsanalysene ble artslistene dobbelt kvadratrot-transformert. Dette ble gjort for å redusere avviket mellom høye og lave tetthetsverdier og dermed redusere eventuelle effekter av tallmessig dominans hos noen få arter i datasettet.

Clusteranalyse

Analysen undersøker faunalikheten mellom prøver. For å sammenligne to prøver ble Bray-Curtis ulikhetsindeks benyttet (Bray & Curtis, 1957):

$$d_{ij} = \frac{\sum_{k=1}^{n} \left| X_{ki} - X_{kj} \right|}{\sum_{k=1}^{n} (X_{ki} + X_{kj})}$$

der n = antall arter sammenlignet
X_{ki} = antall individ av art k i prøve nr. i
X_{kj} = antall individ av art k i prøve nr. j

Indeksen avtar med økende likhet. Vi får verdien 1 hvis prøvene er helt ulike, dvs. ikke har noen felles arter. Identiske arts- og individtall vil gi verdien 0. Prøver blir gruppert sammen etter graden av likhet ved å bruke "group-average linkage". Forholdsvis like prøver danner en gruppe (cluster). Resultatet presenteres i et trediagram (dendrogram).

Ømfintlighet (AMBI, ISI og NSI)

Ømfintligheten bestemmes ved indeksene ISI og AMBI. Beregning av ISI er beskrevet av Rygg (2002). Sensitivitetsindeksen AMBI (Azti Marin Biotic Index) tilordner en ømfintlighetsklasse (økologisk gruppe, EG): EG-1: sensitive arter, EG-II: indifferente arter, EG-III: tolerante arter, EG-IV: opportunistiske arter, EG-V: forurensningsindikerende arter. Sammensetningen av makroevertebratsamfunnet i form av andelen av økologiske grupper indikerer omfanget av en forurensningspåvirkning.

NSI er en sensitivitetsindeks som ligner AMBI, men er utviklet med basis i norske faunadata og ved bruk av en objektiv statistisk metode. En prøves NSI verdi beregnes ved gjennomsnittet av sensitivitetsverdiene av alle individene i prøven.

Sammensatte indekser (NQI1 og NQI2)

Sammensatte indekser NQI1 og NQI2 bestemmes både ut fra artsmangfold og ømfintlighet. NQI1 er brukt i NEAGIG (den nordøst-atlantiske interkalibreringen). De fleste land bruker nå sammensatte indekser av samme type som NQI1 og NQI2.

NQI1 indeksen er beskrevet ved hjelp av formelen:

NQI1 (Norwegian quality status, version 1) = [0.5* (1-AMBI/7) + 0.5*(SN/2.7)* (N/(N+5)]

Diversitetsindeksen SN = lnS/ln(lnN), hvor S er antall arter og N er antall individer i prøven

Infaunal Trophic Index (ITI)

Infaunal Trophic Index was developed by Word, 1979. The index, a numerical description of the behavior of the groups in the environment, is calculated by the formula:

$$ITI = 100 \sum_{i=1}^{3} \frac{(4-i)}{3} p_i$$

Where p_i is the proportion of species in class i, where

- class 1 are suspension feeders (highest quality);
- class 2 are interface feeders;
- class 3 are surface deposit feeders and
- class 4 are subsurface deposit feeders (lowest quality).

To calculate the ITI an R-script from https://CRAN.R-project.org/package=benthos was used

The accuracy of the ITI depends (among other things) on the number of taxa for which a sensitivity group is available.

Referanser:

Bray, R.T. & J.T. Curtis, 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr*., 27:325-349.
Hurlbert, S.N., 1971. The non-consept of the species diversity: A critique and alternative parameters. *Ecology* 52:577-586.
Pielou, E. C., 1966. Species-diversity and pattern-diversity in the study of ecological succession. *Journal of Theoretical Biology* 10, 370-383.
Rygg, B., 2002. Indicator species index for assessing benthic ecological quality in marine water of Norway. *NIVA report* SNO 4548-2002. 32 p.
Shannon, C.E. & W. Weaver, 1949. The Mathematical Theory of Communication. *Univ Illinois Press*, Urbana 117 s.
Word, J.Q. 1979. The Infaunal Trophic Index. In, Annual Report 1978. Coastal Water Research Project, El Segundo, California, USA, pp. 19–39.

Statistikk resultater Tjaldanes, 2020:

Antall arter og individer per stasjon

st.nr.	tot.	C1	C2	C3	C4	C5
no. ind.	2899	127	260	254	330	1928
no. spe.	58	15	14	16	17	50

Bunndyrindekser per replikat

st.nr.	tot.	C1_01	C1_02	C2_01	C2_02	C3_01	C3_02	C4_01	C4_02	C5_01	C5_02
no. ind.	2899	74	53	101	159	99	155	170	160	1195	733
no. spe.	58	12	11	10	11	8	15	11	15	38	40
Shannon-Wiener:		1,8	2,1	1,3	1,7	1,5	1,6	1,6	1,8	2,8	3,4
Pielou		0,51	0,61	0,38	0,48	0,49	0,40	0,46	0,46	0,53	0,64
ES100		12	11	10	9	58	12	9	12	15	19
SN		1,70	1,74	1,51	1,48	1,36	1,67	1,47	1,67	1,86	1,96
ISI-2012		7,88	6,45	8,43	7,44	7,45	8,87	7,38	7,75	8,36	8,08
AMBI		4,212	4,587	4,248	4,123	4,197	4,127	4,209	4,151	3,724	3,578
NQI1		0,49	0,47	0,46	0,47	0,44	0,51	0,46	0,50	0,58	0,60
NSI		14,8	13,0	22,5	21,7	21,6	22,6	21,4	22,1	16,9	17,0

Bunndyrindekser, gjennomsnitt per stasjon

st.nr.		C1	C2	C3	C4	C5
Shannon-Wiener:		1,97	1,46	1,52	1,71	3,11
Pielou		0,56	0,43	0,45	0,46	0,59
ES100		11,5	9,7	35,1	10,4	17,0
SN		1,72	1,49	1,52	1,57	1,91
ISI-2012		7,17	7,94	8,16	7,56	8,22
AMBI		4,400	4,186	4,162	4,180	3,651
NQI1		0,48	0,47	0,47	0,48	0,59
NSI		13,90	22,12	22,11	21,75	16,97
Tilstandsklasse nEQR		0,430	0,480	0,573	0,488	0,580

Geometriske klasser

int.	C1	C2	C3	C4	C5
1	5	3	7	6	15
2,3	7	5	3	3	8
4- 7	0	2	2	5	7
8- 15	1	2	2	1	9
16- 31	1	1	1	0	3
32- 63	0	0	0	1	3
64-127	1	0	0	0	2
128-255	0	1	1	1	0
256-511	0	0	0	0	2
512-1023	0	0	0	0	1
1024-2047	0	0	0	0	0
2048-	0	0	0	0	0

ITI pr. stasjon

Station_no	ITI	% N ITI	% S ITI
C1	15	27 %	63 %
C2	57	93 %	60 %
C3	58	91 %	71 %
C4	56	91 %	39 %
C5	40	67 %	49 %

Artsliste

Tjaldanes ASC-C-undersøkelse

Rekke	Klasse	Art/Taxa	01	02	Sum
Stasjonsnr.: C1					
ANNELIDA					
	Polychaeta				
		Ampharete borealis	2		2
		Capitella capitata	3	15	18
		Chaetozone setosa		1	1
		Chaetozone sp.	3		3
		Galathowenia oculata	1		1
		Mediomastus fragilis	2	1	3
		Melinna cristata	1	1	2
		Ophryotrocha lobifera	52	27	79
		Prionospio steenstrupi	1	1	2
CRUSTACEA					
	Malacostraca				
		Dulichiidae indet.		1	1
		Paguridae indet.	1		1
MOLLUSCA					
	Bivalvia				
		Ennucula tenuis	1	2	3
		Mytilus edulis	1	1	2
		Nuculana pernula		1	1
		Thyasira sarsii	6	2	8
ECHINODERMATA					
	Asteroidea				
		Asteroidea indet. juv.	1		1
		Maks:	52	27	79
		Antall:	13	11	16
		Sum:			128
Stasjonsnr.: C2					
NEMERTINI					
		Nemertea indet.	1	1	2
ANNELIDA					
	Polychaeta				
		Ampharete finmarchica	1	5	6
		Chaetozone setosa	8	19	27
		Chaetozone sp.	1		1
		Eteone flava/longa		1	1
		Mediomastus fragilis		8	8
		Melinna cristata	2		2
		Parougia eliasoni		4	4
		Praxillella gracilis	1	1	2
		Prionospio steenstrupi	80	112	192
MOLLUSCA					
	Bivalvia				
		Ennucula tenuis	1	1	2
		Nuculana pernula	1		1
		Nuculana sp. juv.	2		2
		Thyasira sarsii	5	5	10
		Yoldia hyperborea		2	2
		Maks:	80	112	192
		Antall:	11	11	15
		Sum:			262

Rekke	Klasse	Art/Taxa	01	02	Sum
Stasjonsnr.: C3					
NEMERTINI					
		Nemertea indet.	1		1
ANNELIDA					
	Polychaeta				
		Ampharete borealis	2	3	5
		Ampharete finmarchica		3	3
		Bylgides sarsi	1	1	2
		Chaetozone setosa	11	10	21
		Eteone flava/longa		1	1
		Gattyana amondseni		1	1
		Laphania boecki		1	1
		Lumbrineris mixochaeta		1	1
		Mediomastus fragilis	4	4	8
		Melinna cristata	2	3	5
		Ophelina acuminata		1	1
		Parougia eliasoni		2	2
		Prionospio steenstrupi	72	119	191
MOLLUSCA					
	Bivalvia				
		Ennucula tenuis		1	1
		Thyasira sarsii	6	4	10
ECHINODERMATA					
	Asteroidea				
		Asteroidea indet. juv.		1	1
		Maks:	72	119	191
		Antall:	8	16	17
		Sum:			255
Stasjonsnr.: C4					
NEMERTINI					
		Nemertea indet.	2	1	3
ANNELIDA					
	Polychaeta				
		Ampharete borealis	2	5	7
		Ampharete finmarchica		1	1
		Chaetozone setosa	24	22	46
		Cossura pygodactylata		4	4
		Mediomastus fragilis	10	3	13
		Melinna cristata	4	1	5
		Nephtys ciliata		1	1
		Nephtys paradoxa		1	1
		Ophelina acuminata		7	7
		Ophryotrocha lobifera	1		1
		Prionospio steenstrupi	119	109	228
MOLLUSCA					
	Opistobranchia				
		Dendronotus sp.		1	1
	Bivalvia				
		Ennucula tenuis	1	2	3
		Nuculana pernula	1	1	2
		Nuculana sp. juv.		1	1
		Thyasira sarsii	5	1	6
		Yoldia hyperborea	1		1

Rekke	Klasse	Art/Taxa	01	02	Sum
		Maks:	119	109	228
		Antall:	11	16	18
		Sum:			331

Stasjonsnr.: C5

NEMERTINI					
		Nemertea indet.		3	3
ANNELIDA					
	Polychaeta				
		Ampharete borealis	5	4	9
		Ampharete finmarchica	26	14	40
		Ampharete octocirrata	4	1	5
		Ampharete petersenae	10	12	22
		Aphelochaeta sp.	2		2
		Capitella capitata	2	2	4
		Chaetozone setosa	442	254	696
		Chone sp.	4	3	7
		Eteone flava/longa	16	5	21
		Euchone incolor	1	8	9
		Euchone papillosa	6	5	11
		Euclymene droebachiensis	3	6	9
		Galathowenia oculata	35	69	104
		Goniada maculata	3		3
		Laphania boecki	3	12	15
		Leaena ebranchiata		1	1
		Lumbrineris mixochaeta		1	1
		Mediomastus fragilis	17	34	51
		Melinna cristata	9	5	14
		Nephtys ciliata		3	3
		Ophelina acuminata	1		1
		Ophryotrocha lobifera	39	51	90
		Ophryotrocha sp.	1		1
		Parougia eliasoni	4	1	5
		Pholoe assimilis	3	1	4
		Pholoe baltica	1		1
		Polycirrus sp.		1	1
		Praxillella gracilis		2	2
		Praxillella praetermissa		1	1
		Prionospio steenstrupi	193	65	258
		Proclea graffii	1		1
		Scoloplos armiger	2	1	3
		Spio limicola	1		1
CRUSTACEA					
	Malacostraca				
		Brachyura indet. juv.		1	1
		Caprellidae indet.	1		1
		Diastylis scorpioides		1	1
		Metopa sp.	1	1	2
		Pleurogonium spinosissimum		1	1
MOLLUSCA					
	Opistobranchia				
		Fionoidea indet.		1	1
		Philine denticulata	4	1	5
	Bivalvia				
		Abra nitida	20	15	35

Rekke	Klasse	Art/Taxa	01	02	Sum
		Abra prismatica	2		2
		Axinopsida orbiculata		10	10
		Ennucula tenuis	8	14	22
		Macoma calcarea	3	5	8
		Mytilus edulis		1	1
		Nuculana pernula	1	4	5
		Thyasira sarsii	316	110	426
		Thyasiridae indet.	4	4	8
		Yoldia hyperborea	1		1
ECHINODERMATA					
	Asteroidea				
		Asteroidea indet. juv.	1	1	2
	Ophiuroidea				
		Ophiuroidea indet. juv.		1	1
		Maks:	442	254	696
		Antall:	39	43	53
		Sum:			1932
				TOTAL:	***Maks:*** 696
					Sum: 2908

Appendix 4. Analyserapport – Geokjemiske analyser (in norwegian)

Framsenteret
Postboks 6606 Langnes, 9296 Tromsø
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ANALYSERAPPORT
Sedimentprøver

Kunde:	**Arnarlax Hf**
Kunde referanse:	**Tjaldanes ASC og C max belastning 2020 II**
Kontaktperson kunde:	
e-post:	
Kontaktperson Akvaplan-niva:	Snorri Gunnarsson
Dato:	28.10.2020

Rapport nr.:	**62333.01**
Analyseparameter(e):	Korn, TOM, TOC, TN, Cu, Emamektin benzoat, Deltametrin
Kontaktperson:	Oda S. Bye Wilhelmsen
Analyseansvarlig:	(sign.)
Underskriftsberettiget:	Digitally signed by Oda Sofie Bye Wilhelmsen Date: 2020.10.28 09:40:30 +01'00' (sign.)

Prøvene ble sendt/levert til Akvaplan-Niva AS av oppdragsgiver, og merket som angitt i tabellen på side 2.
Resultater av analysene er gitt fra side 3.

MERKNADER:
Dette er en foreløpig rapport, som ikke inneholder resultater for lusemidlene Emamektin benzoat (EMB) og Deltametrin (DLM).
Sedimentprøvene C1 - C5 inneholdt sedimentagglomerater som ikke ble løst opp under kornfordelingsanalysen.

Lab-id.	Kundens id.	Beskaffenhet ved mottak	Mottatt lab	Parametere	Analyse-periode
62333/C1	C1	Frossen	15.10.2020	Korn, TOM, TOC, TN, Cu	15.10.20 - 24.10.20
62333/C2	C2	Frossen	15.10.2020	Korn, TOM, TOC, TN, 2x Cu	15.10.20 - 24.10.20
62333/C3	C3	Frossen	15.10.2020	Korn, TOM, TOC, TN, 2x Cu, EMB, DLM	15.10.20 - 24.10.20
62333/C4	C4	Frossen	15.10.2020	Korn, TOM, TOC, TN, 2x Cu	15.10.20 - 24.10.20
62333/C5	C5	Frossen	15.10.2020	Korn, TOM, TOC, TN	15.10.20 - 24.10.20
62333/Cu.ref.1	Cu.ref.1	Frossen	15.10.2020	2x Cu	20.10.20 - 21.10.20
62333/Cu.ref.2	Cu.ref.2	Frossen	15.10.2020	2x Cu	20.10.20 - 21.10.20
62333/Cu.ref.3	Cu.ref.3	Frossen	15.10.2020	2x Cu	20.10.20 - 21.10.20

EMB = Emamektin benzoat

DLM = Deltametrin

Følgende analysemetoder er benyttet

Parameter	Metodereferanse
Kornfordeling (splitt i to)	Sikting, basert på Bale, A.J. & Kenny, A.J. 2005. Sediment analysis and seabed characterisation . In: Eleftheriou,A; McIntyre, A.D. "Methods for the study of marine benthos", 3rd ed. Blackwell Science, Oxford, UK. ISBN 0-632-05488-3, pp. 43-86
Totalt organisk materiale-TOM	Intern metode basert på NS 4764:1980
Totalt organisk karbon-TOC	NDIR-deteksjon. Intern metode basert på DIN 19539:2016
Totalt bundet nitrogen - Total-N	Elektrokjemisk deteksjon. Intern metode basert på NS-EN 16168:2012. MERK: ved TOC-verdier større enn ca 60 mg/g TS kan TN-resultater bli underestimert
Kobber-Cu (utført av underlev.)	EPA 200.7, ISO 11885, EPA 6010 og SM 3120

Resultater

Resultater forts.

	TOC	TN	TOM	Pelitt	> 0,063 mm	Cu*	Cu*	EMB**	DLM**	N TOC	C/N
Kundens id.:	mg/g TS	mg/g TS	% TS	vekt%	vekt%	mg/kg TS	mg/kg TS			mg/g TS	
C1	25	4,3	11,5	80,4	19,6	47,7	ia			28,3	5,7
C2	28	4,2	14,3	92,3	7,7	34,0	49,6			29,2	6,7
C3	26	5,4	13,0	87,2	12,8	51,1	52,9			28,2	4,8
C4	26	5,3	13,7	92,0	8,0	47,0	46,1			27,9	5,0
C5	12	2,5	5,9	38,6	61,4	ia	ia			22,7	4,6
Cu.ref.1	ia	ia	ia	ia	ia	46,6	31,6				
Cu.ref.2	ia	ia	ia	ia	ia	44,5	45,5				
Cu.ref.3	ia	ia	ia	ia	ia	45,5	43,2				

* Analysen er utført av ALS Laboratory Group, ALS Czech Republic s.r.o, Na Harfě 9/336, Praha, Tsjekkia

Akkreditering: Czech Accreditation Institute, labnr. 1163

** Ikke-akkreditert analyse utført av Norsk Institutt for Vannforskning - NIVA, Gaustadalléen 21, NO-0349 Oslo.
EMB = emamectin benzoat, DLM = deltametrin

N TOC (Normalisert TOC) = målt TOC mg/g + 18*(1-F), der F=andel finstoff (pelitt) gitt ved %peli

ia = ikke analysert

Tilstandsklassifisering for marine sedimenter ihht. Veileder 02:2018:

Normalisert TOC, mg/g TS	< 20	20-27	27-34	34-41	> 41
	I Svært god	II God	III Moderat	IV Dårlig	V Svært dårlig

Cu, mg/kg TS	< 20	20-84	84 - 147	> 147
	Klasse I	Klasse II/III	Klasse IV	Klasse V