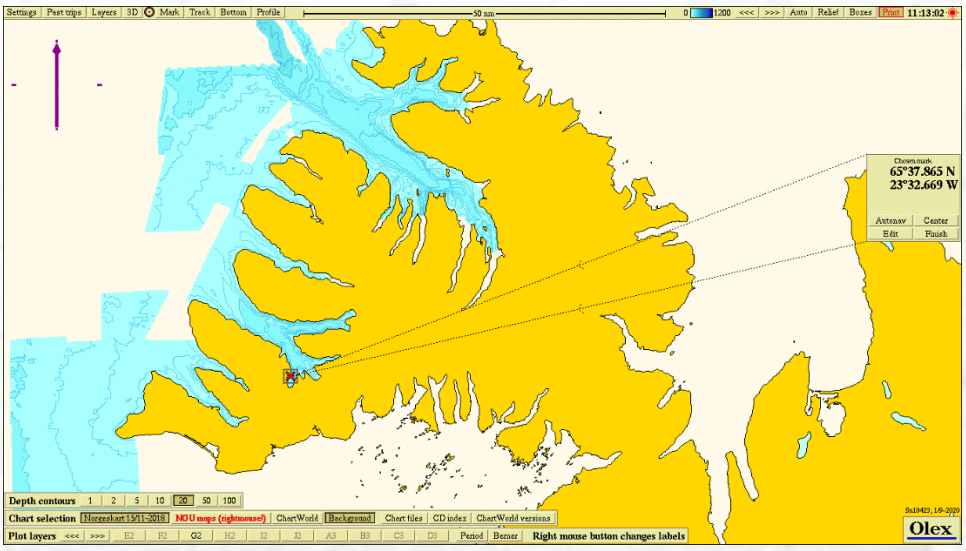
Akvaplan niva

Rapport Report

Arnarlax hf

C-survey (fallow period)

Fossfjordur, 2020.



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Summary / Sammendrag

The results from the monitoring at the farming site Fossfjordur in June 2020 showed that the sediment had slightly elevated levels of organic carbon and the copper concentration at C1 (49.1 mg/kg) was within reported natural levels for bottom sediment around Iceland (Egilsson *et al*., 1999). No load effect was recorded in the fauna and faunal index nEQR showed relatively good conditions and no impact at the stations (≥ 0.6). The diversity index H ' was below 3 at C1 and C4 and above 3 at the other stations and ranged from 2.57 (C4) to 4.66 (C2). NS 9410:2016-assessment of the community in the local impact zone (C1) showed environmental condition 1 (Very good). No pollution indicators were recorded among the top-10 species on any of the stations. The redox measurements (pH/Eh) gave point 0 acc. Appendix D in NS 9410:2016 for all the sampling stations. The oxygen saturation in June was good in the whole water column with 95 % in the bottom water.

Project manager / Prosjektleder

Snorri Gunnarsson

Quality control / Kvalitetskontroll

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Contents

Foreword

Akvaplan-niva completed an environmental C-survey C at the Fossfjordur site. The C-survey is carried out in accordance with NS 9410:2016. The survey includes pH/redox measurements (Eh), hydrography, geochemical analyses and analyses of the bottom fauna at the fish farming site. Results from four stations are included in the pre-survey. This survey is done upon request from Arnarlax hf 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.
Thomas Hansen	Akvaplan-niva	Identification of bottom fauna (Mollusca).
Andrey Sikorsky	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 Silja Baldvinsdóttir, Arnarlax hf for good cooperation.

Accreditation information:

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

NORSK AKKREDITERING TEST 079	Akvaplan-niva AS er akkreditert av Norsk Akkreditering for feltinnsamlinger av sediment og fauna, analyser av TOC, TOM, TN, kornstørrelse, makrofauna og faglig vurderinger og fortolkninger, akkrediteringsnr. TEST 079. Akkrediteringen er i hht. NS-EN ISO/IEC 17025.
Czech Accreditation Institute (Lab nr 1163)	ALS Laboratory Group er akkreditert av Czech Accreditation Institute (Lab nr 1163) for analyser av kobber.

Kópavogur, 01.09 2020

Project leader

1 Summary of C-results

Information client			
Title :	C-survey (fallow period) Fossfjordur, 2020.		
Report nr.	62252.01	Site:	Fossfjordur
Site nr.		Map coordinates (construction):	65°37,865 N 23°32,669 W
		Municipality:	Vesturbyggð
MTB-permission:	2.733	Operations manager:	Rolf Orjan Nordli
Client:	Arnarlax hf		

Biomass/production status at time of survey 11.06.2020			
Fish group:	Salmon	Biomass on examination:	0
Feed input:	0	Produced amount of fish:	0
Type/time of survey			
Maximum biomass:		Follow up study:	
Fallow (resting period):	X	New location:	X

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)	0.610	Fauna C1 (closest to farm)	2.83
Fauna C2	0.732	Fauna C2	4.66
Fauna C3	0.649	Fauna C3	3.32
Fauna C4 (deep area)	0.599	Fauna C4 (deep are)	2.57
Date fieldwork:	11.06.2020	**Date of report:**	01.09 2020
Notes to other results (sediment, pH/Eh, oxygen)			nTOC from 22.3 to 26.5 mg/g TS. Copper 49.1 at C1 Eh positive at all stations O_2-conditions were good throughout the water column.
Responsible for field work:	Snorri Gunnarsson	Signature:	

2 Introduction

2.1 Background and aim of study

Akvaplan-niva on behalf of Arnarlax hf completed bottom survey (type C) for a fish farming site Fossfjordur in Arnarfjörður, Iceland (Figure 1). The survey fulfils the requirements from the Icelandic authorities regarding bottom surveys referring to the standard ISO 12878 and the requirements for environmental bottom surveys (according to Vöktunaráætlun). An environmental study was simultaneously undertaken, with reference to chapter 5.0 in NS 9410:2016 which follows the methodology for C- study. A type C-survey is aimed at studying the environmental conditions of the bottom sediments along a transect sector from the fish farm that extends from the local, to the intermediate and to the regional impact zones. The 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.

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.

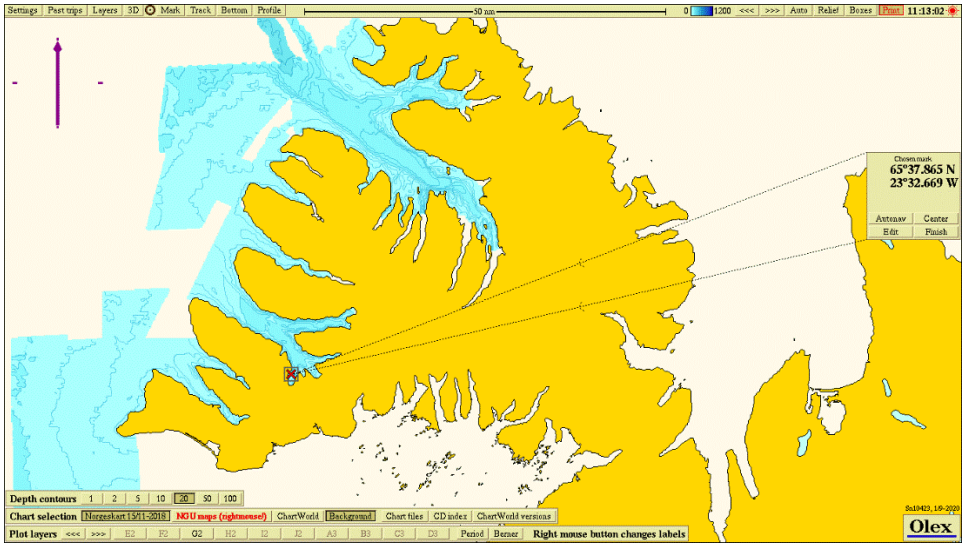

Figure 1. Overview of Arnarfjörður with the farming site Fossfjörður (red cross). The map coordinates for the midpoint of the farming site are given at right site of the picture.

2.2 Site operation and feed use

The Fossfjörður site is located in Arnarfjörður Iceland about 6.5 km southeast from Bíldudalur. At the date of sampling there were no cages installed at the site but the sampling was done at the planned area for installation of frame and cages. The planned installation of cages is 700 – 1000 m north of the previous farming site in Fossafjörður. The depth under cages ranges from about 61 m closer to land on the western part of the farming area up to about 77 m further into the fjord.

The previous Fossfjörður site is has been in fallow state since October 2016 or for about 3 years and 8 months at the date of sampling. Previously there has been farmed two generations of fish at the site.The planned fish farm at the site has a 2 x 3 mooring system with a possibility total

of 6 cages, each with 120 m circumference. The planned timing for putting smolts into sea is summer/fall 2020.

In Iceland, the MTB (maximum allowed biomass) limit is not given a site level as in Norway. The MTB limit determines how much live fish the holder of the permit can have standing in the sea at any time. In Iceland the allowed production is regulated at two levels, site level and company level. For this site the estimated maximal standing biomass for the next generation is 2.733 tonnes, used as MTB here (Baldvinsdóttir, pers reference).

2.3 Previous surveys

In relation to farming of the two previous generations salmon at Fossfjöður in 2011-2013 and 2014-2016 there were done benthic surveys prior to putting fish into sea (Þórisson *et al.* 2010), at max biomass (Þórisson *et al.* 2015 and Gallo 2016) and at fallow period after the first generation. The placement of the cages for these two generations was about 700-1000 m south of the planned fish farming site for the next generation at Fossfjörður. The previous benthic surveys described substantial and long lasting effects from the fish farming activity at Fossfjörður site mainly in close proximity to the cages. Main reason for these negative impacts is suggested to be overfeeding the fish (Þórisson *et al.* 2015).

3 Materials and methods

3.1 Professional program

The choice of study parameters, placement of sampling stations and other criteria for the study is based on descriptions in NS 9410 (C-surveys). An overview of the planned professional program is given in Table 1.

Akvaplan-niva is accredited for field work, analyses of samples and professional evaluation of results in accordance with applicable standards and guidelines (Veiledere). For implementation and follow through, the following standards and quality assurance systems were used:

- ISO 5667-19:2004: *Guidance on sampling of marine sediments.*
- ISO 16665:2014. *Water quality – Guidelines for quantitative sampling and sample processing of marine soft-bottom macro fauna.*
- NS 9410:2016. *Miljøovervåking av bunnpåvirkning fra marine oppdrettsanlegg.*
- Internal procedures. *Kvalitetshåndbok for Akvaplan-niva.*
- Veileder 02:2018. *Klassifisering av miljøtilstand i vann*. Norsk klassifiseringssystem for vann i henhold til Vannforskriften. Veileder fra Direktoratgruppen.

Table 1. The planned professional program for the C-survey at Fossfjordur, 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.

Station	Type analyses/parameters
C1 (local impact zone)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. Cu. pH/Eh.
C2 (transect zone)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. pH/Eh.
C3 (transect zone)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. pH/Eh.
C4 (transect zone, deep area)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. Hydrography/O_2. pH/Eh.

Field work was completed on 11.06.2020.

3.2 Placement of stations and local conditions

The number of stations was calculated with reference to the sites estimated maximal standing biomass for the first generation which is 2.733 tonnes (used as MTB here). According to the standard four sampling stations should be examined. Depth and position of the stations are given in Table 2 and shown in Figure 2. The stations were placed in accordance to the direction of the main oceanic current direction at 15 m depth (Hermansen, 2020).

Table 2. Depth, distance between the nearest frame of the fish farm and sampling stations and coordinates for C-stations at Fossfjordur, 2020.

Station	Depth, m	Distance from frame, m	Position	
			N	W
C1	61	25	65º37.888	23º32.779
C2	28	400	65º37.906	23º33.265
C3	53	110	65º37.888	23º32.892
C4	81	90	65º37.922	23º32.403

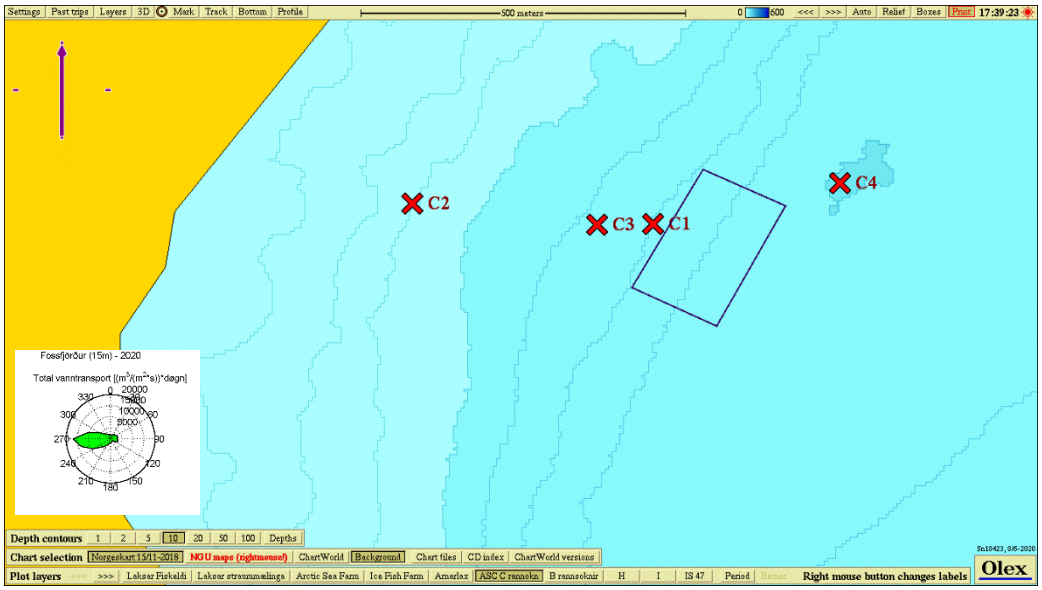

Figure 2. Map showing the sampling stations for the C-survey at Fossfjordur, 2020. Current measurements used were from 15 m depth (Hermansen, 2020).

3.3 Hydrography and oxygen

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.

3.4 Soft bottom sampling and analyses

3.4.1 Fieldwork

The samples were collected with a 0.1 m^2 bottom grab (van Veen). The sample material was collected through inspection openings. Samples for TOC, TN and Cu were taken off from the top 1 cm layer of the sediment and for TOM and grain size analyses from the top 5 cm using a hollow pipe. Only samples with an undisturbed surface were approved. The samples were frozen for further processing in the laboratory.

3.4.2 Total organic material (TOM)

The amount of TOM in sediment was determined by weight loss after combustion at 495 °C. The percent weight loss was calculated. The reproducibility of the TOM analyses is checked during the analyses by using a standard household sediment that contains TOM with a known level. Standard calcium carbonate was burned together with the samples as a control of the amount of carbonate that was not burned in the analyses process.

3.4.3 Total nitrogen (TN)

After drying the samples at 40°C, the amount of total nitrogen (TN) was quantified by electrochemical determination. The internal method is based on NS-EN 12260:2003 (Vannundersøkelse – Bestemmelse av bundet nitrogen (TNb) etter oksidasjon til nitrogenoksider).

3.4.4 Total organic carbon (TOC) and grain size

The proportion of fine material, the fraction less than 63 µm, was determined gravimetrically after wet-sieving of the samples. The results are presented as proportion of fine material on a dry weight basis.

After drying the samples at 40 °C, the content of total organic carbon (TOC) was determined by NDIR-detection in accordance with DIN19539:2016 (Investigation of solids – Temperature-

dependent differentiation of total carbon (TOC_{400}, ROC, TIC_{900})). In order to classify the environmental conditions based on the content of TOC, the measured concentrations are normalized for proportion of fine substance (nTOC) using the equation: nTOC = TOC + 18 (1 – F), where TOC and F represent a measured TOC value and the proportion of fine substance (%) in the sample (Aure *et al.*, 1993).

The classification of the environment conditions for the sediment is based on normalized TOC, and in Norway carried out according to "Veileder" 02:2018.

Classification of condition for organic content in the marine sediment.

nTOC, mg/g	< 20 I Very good	20 - 27 II Good	27 - 34 III Average	34 - 41 IV Bad	> 41 V Very bad

3.4.5 Metal analysis - copper (Cu)

The samples for metal analysis were freeze-dried before being placed in a microwave oven in a sealed Teflon container with concentrated ultrapure nitric acid and hydrogen peroxide. The concentration of copper (Cu) was determined by means of ICP-SFMS.

In Norway classification of the environmental condition with respect to Cu is based on reference to "Veileder" 02:2018.

Classification for copper in the marine sediment.

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

3.4.6 Redox- and pH measurements

At all the stations, a quantitative chemical examination of the sediment was carried out. Acidity (pH) and redox potential (Eh) were measured using electrodes and the YSI Professional Plus instrument. In accordance to the manual of the instrument, 200 mV was added to the measured ORP (the Oxydation Reduction Potential) value.

3.5 Soft bottom fauna investigation

3.5.1 About effect of organic material on bottom fauna

The emission of organic material from fish farms can contribute to the deterioration of conditions for many of the organisms living in the bottom sediment. Negative effects in the bottom fauna can best be assessed through quantitative bottom fauna analyses. Many soft bottom species have low mobility, the fauna composition will largely reflect the local environmental conditions. Changes in the bottom fauna communities are a good indication of unwanted organic loads. Under natural conditions, the communities typically consist of many species. High number of species (diversity) is, amongst other things, dependent on favorable conditions for the fauna. However, moderate increases in organic load can stimulate the fauna and result in an increased number of species found. Larger organic loads can result in less favourable conditions where opportunistic species increase their individual numbers, while the species not suited are knocked out resulting in a reduced diversity of species. Changes in species diversity near emission points of feed and fecal matter can, to a large degree, be attributed to changes in organic content (from the feed and fecal matter) in the sediment.

3.5.2 Sampling and fixation

All the bottom fauna samples were taken with a 0.1 m^2 van Veen grab. Only grab samples where the grab was completely closed and the surface undisturbed were approved. After approval, the contents were washed through a 1 mm seive and the remaining material fixed with

4 % formalin with Bengal Rose dye added and neutralized with borax. In the laboratory, the animals were sorted from the remaining sediment.

3.5.3 Quantitative bottom fauna analysis

At all stations, two samples (replicates) were collected in accordance with guidelines in NS 9410 (2016). After sorting the sample material was processed quantitatively. The bottom fauna was identified to the lowest level possible, and quantified by specialists (taxonomists). The quantitative lists of species were analyzed statistically. See Appendix 1 for description of analysis methods. The following statistical methods were used to describe community structure and to assess the similarity between different communities:

- Shannon-Wiener diversity index (H')
- Hurlberts diversity index (ES_{100}) – expected number of species pr. 100 individuals
- Pielou's evenness index (J)
- Sensitivities index (Ømfintlighet) (ISI_{2012}), unsuitable at low individual/species number
- Sensitivity index (NSI)
- Composite index for diversity of species and sensitivity (NQI1)
- Sensitivities index which is included in NQI1 (AMBI)
- Normalized EQR (nEQR)
- Number of species plotted against the number of individuals in geometric arts classes
- Clusteranalyes
- The ten most dominant taxa per station (top-ten)

4 Results

4.1 Hydrography

The hydrographical profile for the deep station C4 in June 2020 is presented in Figure 3.

Temperature was around 6 ºC in the surface and dropped to 2 ºC at the bottom, and oxygen saturation 120 % in the upper layer and 95 % in the bottom layer.

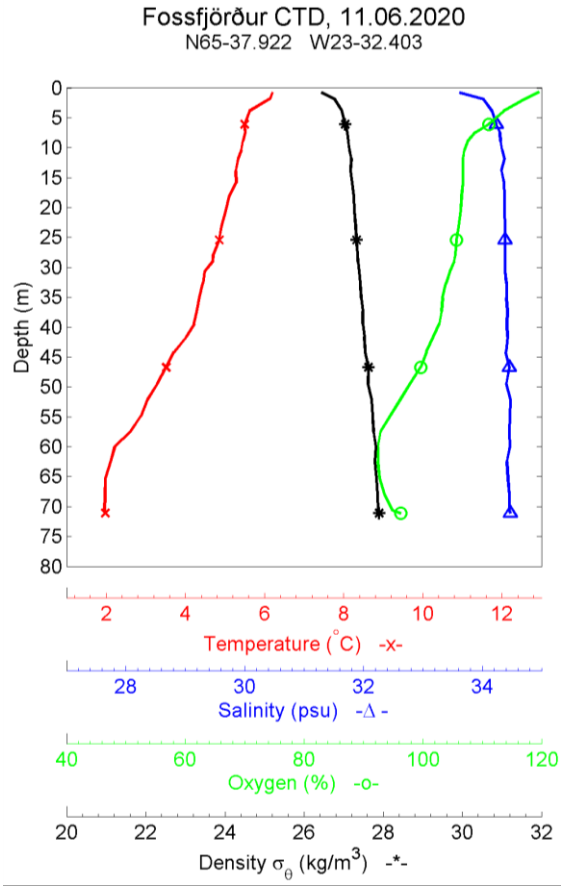

Figure 3. Vertical profiles. Temperature, salinity, density and oxygen at C4 at Fossfjordur, 2020.

4.2 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 (Pelitt) and pH/Eh in the sediment is presented in Table 3.

TOM-levels varied from 8,2 to 12,4 %. TN-levels were low (3,2 – 4,9 mg/g) as was the C/N-ratio. TOC was slightly elevated at all stations and nTOC varied from 22,7 to 26,5 mg/g TS. The bottom sediments grain size were moderately fine with pelite ratio between 61 and 89 %.

Redox measurements (pH/Eh) gave a point of 0 for all the sampling stations according to Appendix D in NS 9410:2016.

Table 3. Sediment description, TOM (%), TOC (mg/g), TN (mg/g), C/N, grain size distribution (pelitt ratio % <0,063 mm) and pH/Eh. Fossfjordur, 2020.

St.	Sediment description	TOM	TOC	nTOC*	TN	C/N	Pelitt	pH/Eh
C1	Muddy, olive green, no smell	10.0	20	25.6	3.3	6.0	68	7.6/ 305
C2	Muddy, olive green, no smell (Lithothamnion)	11.0	18	22.3	3.6	5.1	78	7.6/ 392
C3	Muddy/gravel, olive green, no smell	8.2	16	22.7	3.2	4.8	61	7.7/ 320
C4	Muddy, olive green, no smell	12.4	24	26.5	4.9	4.9	89	7.8/ 334

4.3 Copper

The level of copper in the bottom sediment at C1 is shown in Table 4. The level was 49,1 mg/kg.

Table 4. Copper (Cu), mg/kg TS. C Fossfjordur, 2020.

St.	Cu repl. 1
C1	49.1

4.4 Soft bottom fauna

4.4.1 Faunal indexes

Results from the quantitative soft bottom faunal analyses at the C-stations are presented in Table 5. Faunal index nEQR is presented without the density index (DI) in accordance with recommendations from the Norwegian Environment Agency (Miljødirektoratet).

The number of individuals varied from 255 (C4) to 861 (C2) and number of species from 24 (C4) to 72 (C2). The diversity H' varied from 2,57 to 4,66. At stations C1, C2 and C3, the overall index of nEQR was higher than 0.6 while it was just below at C4 (0,599). The nEQR values indicate relatively good conditions and no disturbance of the communities.

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 varied from 0,62 to 0,82 which indicates a relatively evenly distribution.

Table 5. Number of species and individuals pr. 0,2 m^2. 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 (excl. DI). C-stations at Fossfjordur, 2020.

St.	Numb. ind.	Numb. species	H´	ES_{100}	NQI1	ISI_{2012}	NSI	nEQR	AMBI	J
C1	383	26	2.83	15.58	0.606	8.28	22.03	0.610	3.09	0.65
C2	861	72	4.66	30.96	0.770	8.60	21.51	0.732	1.81	0.82
C3	610	32	3.32	17.87	0.649	8.60	21.88	0.649	2.57	0.73
C4	255	24	2.57	16.26	0.567	8.53	22.20	0.599	3.63	0.62

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

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

The soft bottom communities were classified to environmental condition 1 "Very good". The criteria for condition 1 is that there are at least 20 species/0,2 m^2 and that none of these are in

numbers exceeding 65 % of the individuals (Table 6). The data for number of species and dominating taxa at station C1 is given in Table 5 and Table 7.

Table 6. Classification of the environmental status of the soft bottom fauna at station C1 at the Fossfjordur site 2020.

Station	Site name	Num. species	Dominating taxa	Environmental condition-NS 9410
C1	Fossfjordur	26	Prionospio steenstrupi – 43 %	1 – Very good

4.4.3 Geometric classes

Figure 4 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 is given in Appendix 1.

All curves started relatively low (< 20 species) and stretched out in varying degrees towards higher classes. These did not give any clear indications of fauna condition.

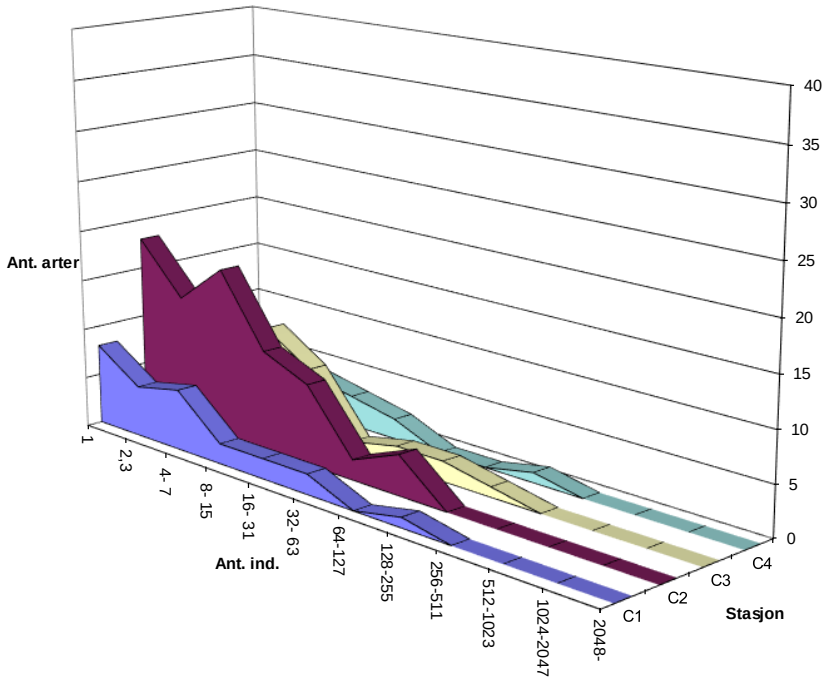

Figure 4. The soft bottom fauna shown as number of species against number of individuals pr. species in geometric classes. Fossfjordur, 2020.

4.4.4 Cluster analyses

To investigate the similarity of the faunal composition between the sampling stations, the multivariate technique cluster analysis was used. The results of this are presented in dendrogram in Figure 5.

The fauna at C1 and C3 were 64 % similar, C4 was 52 % similar to these stations and C2 33 % similar to the other stations.

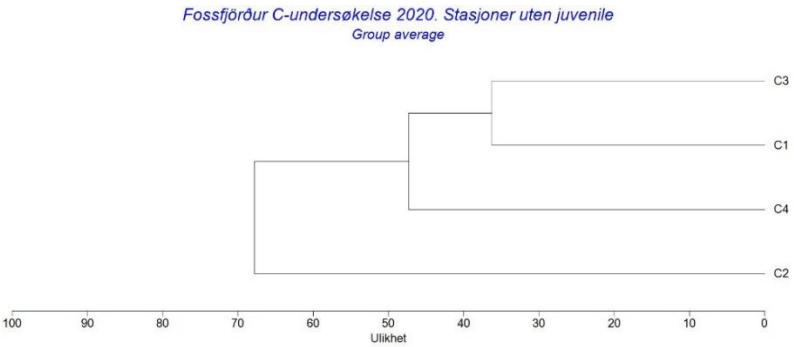

Figure 5. Cluster diagram for the soft bottom fauna at the C-stations at Fossfjordur, 2020.

4.4.5 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 7.

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 neutral polychaete *Prionospio steenstrupi* was most dominant at C1, C3 and C4 with 31 to 55 % of the individuals. The other dominants at these stations were a mixture of sensitive, neutral, tolerant and opportunistic species.

The opportunistic polychaete *Maldane sarsi* was most dominant at C2 with 11 % of the individuals. The other dominants at this station were a mixture of sensitive, neutral, tolerant and opportunistic species.

No pollution indicator species were recorded among the top-10 at any of the stations.

Table 7. Number of individuals, cumulative percentage and ecological group for the ten most dominant species on the C stations. Fossfjordur, 2020.*

C1	Numb.	Cum.	EG	C2	Numb.	Cum.	EG
Prionospio steenstrupi	167	43 %	II	Maldane sarsi	94	11 %	IV
Ennucula tenuis	55	58 %	II	Levinsenia gracilis	91	21 %	II
Euchone papillosa	36	67 %	III	Macoma calcarea	82	30 %	IV
Ampharete borealis	30	75 %	III	Thyasira gouldi	79	39 %	IV
Thyasira sarsii	28	82 %	IV	Scoloplos sp.	57	45 %	Ik
Thyasira gouldi	10	85 %	IV	Heteromastus filiformis	41	50 %	IV
Euclymeninae indet.	9	87 %	I	Astarte montagui	31	53 %	I
Galathowenia oculata	7	89 %	III	Spio limicola	28	56 %	Ik
Axinopsida orbiculata	5	90 %	Ik	Parvicardium pinnulatum	24	59 %	Ik
Chaetozone setosa	5	91 %	IV	Euclymeninae indet.	23	62 %	I
C3	**Numb.**	**Cum.**	**EG**	**C4**	**Numb.**	**Cum.**	**EG**
Prionospio steenstrupi	190	31 %	II	Prionospio steenstrupi	141	55 %	II
Ennucula tenuis	96	46 %	II	Chaetozone sp.	19	63 %	III
Euchone papillosa	73	58 %	III	Thyasira sarsii	16	69 %	IV
Ampharete borealis	61	68 %	III	Ophelina acuminata	15	75 %	II
Thyasira gouldi	42	75 %	IV	Ampharete borealis	13	80 %	III
Thyasira sarsii	21	78 %	IV	Ennucula tenuis	11	84 %	II
Euclymeninae indet.	14	80 %	I	Chaetozone setosa	7	87 %	IV
Melinna cristata	10	82 %	II	Ampharete finmarchica	6	89 %	II
Scoloplos sp.	9	83 %	Ik	Leucon sp.	4	91 %	Ik
Sternaspis scutata	9	85 %	Ik	Scoletoma sp.	4	93 %	Ik

*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.

4.5 Summary and conclusions – C-survey

4.5.1 Summary

The results from the environmental monitoring (type C) at Fossfjordur, 2020, can be summarized as follows:

- The hydrography measurements showed good oxygen conditions throughout the water column with 95 % saturation in the bottom layer in June 2020.
- The number of individuals varied from 255 (C4) to 861 (C2) and number of species from 24 (C4) to 72 (C2). The diversity H' varied from 2.57 to 4.66. At stations C1, C2 and C3, the overall index of nEQR was higher than 0.6 while it was just below at C4 (0.599). The nEQR values indicate relatively good conditions and no disturbance of the communities.
- TOC was slightly elevated at all stations and nTOC varied from 22.7 to 26.5 mg/g TS. TOM-levels varied from 8.2 to 12.4 %. TN-levels were low (3.2 – 4.9 mg/g) as was the C/N-ratio. The copper level in the sediment at C1 was elavated (49.1 mg/kg) according to Norwegian standards, but within reported natural levels of 55 mg/kg in Icelandic coastal areas (Egilsson *et al*. 1999). The sediment was moderately fine grained with a pelite share between 61 and 89 %. The redox measurements (pH/Eh) gave point 0 acc. Appendix D in NS 9410:2016 for all the stations.

4.5.2 Conclusion

The results from the monitoring at the farming site Fossfjordur in June 2020 showed that the sediment had slightly elevated levels of organic carbon and the copper concentration at C1 (49.1 mg/kg) was within reported natural levels of 55 mg/kg for bottom sediment around Iceland (Egilsson *et al*., 1999). No load effect was recorded in the fauna and faunal index nEQR showed relatively good conditions and no impact at the stations (≤ 0.6). The diversity index H ' was below 3 at C1 and C4 and above 3 at the other stations and ranged from 2.57 (C4) to 4.66 (C2). NS 9410:2016-assessment of the community in the local impact zone (C1) showed environmental condition 1 (Very good). No pollution indicators were recorded among the top-10 species on any of the stations. The redox measurements (pH/Eh) gave point 0 acc. Appendix D in NS 9410:2016 for all the sampling stations. The oxygen saturation in June was good in the whole water column with 95 % in the bottom water.

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Appendix 1. 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

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Statistikk resultater Fossfjordur, 2020:

Antall arter og individer per stasjon

st.nr.	tot.	C1	C2	C3	C4
no. ind.	2109	383	861	610	255
no. spe.	89	26	72	32	24

Bunndyrindekser per replikat

st.nr.	tot.	C1_01	C1_02	C2_01	C2_02	C3_01	C3_02	C4_01	C4_02
no. ind.	2109	209	174	398	463	228	382	117	138
no. spe.	89	17	24	41	63	22	26	17	19
Shannon-Wiener:		2,7	2,9	4,6	4,7	3,2	3,5	2,4	2,7
Pielou		0,67	0,64	0,87	0,78	0,71	0,74	0,59	0,64
ES100		13	19	30	32	16	19	16	17
SN		1,69	1,94	2,08	2,28	1,83	1,83	1,82	1,85
ISI-2012		8,36	8,19	8,51	8,70	9,07	8,14	8,47	8,58
AMBI		2,835	3,347	2,044	1,576	2,525	2,606	3,782	3,478
NQI1		0,60	0,61	0,73	0,81	0,65	0,65	0,55	0,58
NSI		21,7	22,3	21,5	21,5	21,9	21,9	22,0	22,4

Bunndyrindekser, gjennomsnitt per stasjon

st.nr.		C1	C2	C3	C4
Shannon-Wiener:		2,83	4,66	3,32	2,57
Pielou		0,65	0,82	0,73	0,62
ES100		15,6	31,0	17,9	16,3
SN		1,81	2,18	1,83	1,83
ISI-2012		8,28	8,60	8,60	8,53
AMBI		3,091	1,810	2,566	3,630
NQI1		0,61	0,77	0,65	0,57
NSI		22,03	21,51	21,88	22,20
Tilstandsklasse nEQR		0,610	0,732	0,649	0,599

Geometriske klasser

int.	C1	C2	C3	C4
1	8	18	7	10
2,3	5	13	2	4
4- 7	6	17	10	4
8- 15	2	10	7	3
16- 31	2	8	1	2
32- 63	2	2	2	0
64-127	0	4	2	0
128-255	1	0	1	1
256-511	0	0	0	0
512-1023	0	0	0	0
1024-2047	0	0	0	0
2048-	0	0	0	0

Artsliste

Fossfjörður C-undersøkelse 2020

Rekke	Klasse	Art/Taxa	01	02	Sum
Stasjonsnr.: C1					
NEMERTINI					
		Nemertea indet.		1	1
ANNELIDA					
	Polychaeta				
		Ampharete borealis	25	5	30
		Chaetozone setosa		5	5
		Euchone papillosa	26	10	36
		Euclymeninae indet.	3	6	9
		Galathowenia oculata	1	6	7
		Heteromastus filiformis	2	2	4
		Laphania boecki	3	1	4
		Lumbrineris sp.		2	2
		Melinna cristata		1	1
		Nephtys ciliata	1	1	2
		Nephtys incisa		1	1
		Ophelina acuminata	1	3	4
		Praxillella gracilis		2	2
		Prionospio steenstrupi	84	83	167
		Scoloplos sp.	1		1
		Sternaspis scutata	1	1	2
CRUSTACEA					
	Malacostraca				
		Gammaridea indet.		1	1
		Leucon sp.	1		1
MOLLUSCA					
	Prosobranchia				
		Lacuna vincta		1	1
	Bivalvia				
		Axinopsida orbiculata	1	4	5
		Ennucula tenuis	31	24	55
		Macoma calcarea	2	1	3
		Nuculana sp. juv.		2	2
		Thyasira gouldi	9	1	10
		Thyasira sarsii	17	11	28
		Thyasiridae indet.		1	1
		Maks:	84	83	167
		Antall:	17	25	27
		Sum:			385
Stasjonsnr.: C2					
NEMERTINI					
		Nemertea indet.	10	2	12
SIPUNCULIDA					
		Phascolion strombus		2	2
ANNELIDA					
	Polychaeta				
		Aricidea hartmani		1	1
		Chaetozone setosa	18	3	21
		Chaetozone sp.		4	4
		Cistenides hyperborea	1	1	2
		Dipolydora sp.		3	3

Rekke	Klasse	Art/Taxa	01	02	Sum
		Eteone flava/longa	11	8	19
		Euchone papillosa		1	1
		Euclymeninae indet.	23		23
		Flabelligera sp.		1	1
		Harmothoe fragilis	4	3	7
		Heteromastus filiformis	21	20	41
		Laonice cirrata		3	3
		Laphania boecki	1	15	16
		Levinsenia gracilis	52	39	91
		Lumbrineris sp.	4	2	6
		Maldane sarsi	25	69	94
		Melinna cristata		1	1
		Myxicola infundibulum		1	1
		Nephtys ciliata	4	1	5
		Nephtys paradoxa	1		1
		Nereimyra punctata		1	1
		Nothria hyperborea		1	1
		Notomastus latericeus		1	1
		Ophelina acuminata	1		1
		Pholoe assimilis	8	1	9
		Pholoe baltica	2	1	3
		Pholoe inornata		3	3
		Praxillella gracilis	8	3	11
		Prionospio steenstrupi	11	2	13
		Pseudopotamilla sp.		3	3
		Rhodine gracilior	5	3	8
		Scalibregma inflatum		2	2
		Scoletoma fragilis	5	1	6
		Scoletoma sp.		4	4
		Scoloplos sp.	22	35	57
		Spio limicola	16	12	28
		Sternaspis scutata	5		5
		Syllis cornuta		4	4
		Tharyx killariensis		4	4
	Oligochaeta				
		Oligochaeta indet.	1	1	2
CRUSTACEA					
	Ostracoda				
		Ostracoda indet.	4	12	16
	Malacostraca				
		Lysianassidae indet.	1		1
		Oedicerotidae indet.	1	5	6
MOLLUSCA					
	Caudofoveata				
		Caudofoveata indet.		2	2
	Polyplacophora				
		Boreochiton ruber		2	2
	Prosobranchia				
		Erginus rubellus		1	1
		Lepeta caeca	6	1	7
		Margarites groenlandicus	4	4	8
		Moelleria costulata	4		4
		Onoba semicostata		1	1
		Steromphala cineraria		1	1
	Bivalvia				
		Abra nitida	4	1	5

Rekke	Klasse	Art/Taxa	01	02	Sum
		Arctica islandica	8	7	15
		Astarte elliptica	4		4
		Astarte montagui	4	27	31
		Axinopsida orbiculata		1	1
		Chlamys islandica		1	1
		Ciliatocardium ciliatum		2	2
		Ennucula tenuis		1	1
		Macoma calcarea	30	52	82
		Mya sp. juv.		2	2
		Nuculana pernula		2	2
		Nuculana sp. juv.	13	1	14
		Parvicardium pinnulatum	8	16	24
		Thracia myopsis	4	5	9
		Thyasira gouldi	42	37	79
		Thyasira sarsii	5	5	10
		Thyasiridae indet.		1	1
ECHINODERMATA					
	Ophiuroidea				
		Amphipholis squamata	4		4
		Ophiopholis aculeata		8	8
		Ophiura albida		6	6
		Ophiuroidea indet. juv.		8	8
	Echinoidea				
		Echinidea indet. juv.	4	2	6
TUNICATA					
	Ascidiacea				
		Ascidiacea indet. (solit)	6		6
		Maks:	52	69	94
		Antall:	43	67	76
		Sum:			891

Stasjonsnr.: C3

NEMERTINI					
		Nemertea indet.		4	4
ANNELIDA					
	Polychaeta				
		Ampharete borealis	23	38	61
		Chaetozone sp.	1	5	6
		Chone sp.	2		2
		Cossura longocirrata		4	4
		Eteone barbata		1	1
		Euchone papillosa	24	49	73
		Euclymeninae indet.	2	12	14
		Galathowenia oculata		6	6
		Heteromastus filiformis		5	5
		Laonice cirrata	1		1
		Levinsenia gracilis	2	1	3
		Lumbrineris mixochaeta	3	5	8
		Melinna cristata	5	5	10
		Nephtys ciliata		4	4
		Ophelina acuminata	2	5	7
		Praxillella praetermissa		4	4
		Prionospio steenstrupi	77	113	190
		Pseudopotamilla reniformis	4		4
		Scoloplos sp.	6	3	9

Rekke	Klasse	Art/Taxa	01	02	Sum
		Sternaspis scutata	1	8	9
		Terebellides sp.	1		1
CRUSTACEA					
	Malacostraca				
		Stenothoidae indet.	1		1
MOLLUSCA					
	Caudofoveata				
		Caudofoveata indet.		1	1
	Bivalvia				
		Arctica islandica	1		1
		Axinopsida orbiculata		1	1
		Ennucula tenuis	36	60	96
		Macoma calcarea	1	4	5
		Mya sp. juv.		4	4
		Nuculana pernula		8	8
		Nuculana sp. juv.	4		4
		Thyasira gouldi	20	22	42
		Thyasira sarsii	11	10	21
		Thyasiridae indet.	4	4	8
		Maks:	77	113	190
		Antall:	23	27	34
		Sum:			618

Stasjonsnr.: C4

ANNELIDA					
	Polychaeta				
		Ampharete borealis	4	9	13
		Ampharete finmarchica	2	4	6
		Chaetozone setosa	5	2	7
		Chaetozone sp.	7	12	19
		Euchone papillosa		1	1
		Galathowenia oculata		1	1
		Heteromastus filiformis	1	1	2
		Lanassa venusta	1		1
		Lumbrineris mixochaeta	2		2
		Melinna cristata	1	1	2
		Nephtys paradoxa	1		1
		Ophelina acuminata	4	11	15
		Pholoe baltica		1	1
		Praxillella gracilis		1	1
		Prionospio steenstrupi	70	71	141
		Scoletoma sp.	2	2	4
		Sternaspis scutata	1		1
		Terebellides sp.		1	1
CRUSTACEA					
	Malacostraca				
		Leucon sp.	1	3	4
MOLLUSCA					
	Bivalvia				
		Ennucula tenuis	4	7	11
		Nuculana pernula		3	3
		Thyasira gouldi		1	1
		Thyasira sarsii	10	6	16
		Yoldia hyperborea	1		1
		Maks:	70	71	141
		Antall:	17	19	24
		Sum:			255
				TOTAL:	***Maks:*** 190
					Sum: 2149

Appendix 2. Analyserapport – Geokjemiske analyser (in norwegian)

62252 Kjemirapport C-undersøkelse m klassifisering.xlsx_040520

Framsenteret
Postboks 6606 Langnes, 9296 Tromsø
Foretaksnr.: NO 937 375 158 MVA
Tel: 77 75 03 00
E-post: kjemi@akvaplan.niva.no

ANALYSERAPPORT
Sedimentprøver

Kunde:	**Arnarlax hf.**
Kunde referanse:	**Fossfjörður C og B undersøkelse sommer 2020**
Kontaktperson kunde:	
e-post:	
Kontaktperson Akvaplan-niva:	Snorri Gunnarsson
Dato:	15.07.2020

Rapport nr.:	**62252**
Analyseparameter(e):	Korn, TOM, TOC, TN, Cu
Kontaktperson:	Oda S. B. Wilhelmsen
Analyseansvarlig:	(sign.)
Underskriftsberettiget:	Digitally signed by Oda Sofie Bye Wilhelmsen Date: 2020.07.15 13:03:06 +02'00' (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:
Stasjon C2 og C3 inneholder skjellbiter større enn 15 mm som ikke er inkludert i kornanalysen. Skjellene ville utgjøre hhvis 3 vekt% og 12 vekt% av total prøve.

Analysene gjelder bare for de prøver som er testet. De oppgitte analyseresultat omfatter ikke feil som måtte følge av prøvetagningen, inhomogenitet eller andre forhold som kan ha påvirket prøven før den ble mottatt av laboratoriet. Rapporten får kun kopieres i sin helhet og uten noen form for endringer. En eventuell klage skal leveres laboratoriet senest en måned etter mottak av analyseresultat. Nærmere informasjon om analysemetodene (måleusikkerhet, metodeprinsipp etc.) fås ved henvendelse til Akvaplan-Niva AS

Lab-id.	Kundens id.	Materiale	Mottatt lab	Parametere	Analyse-periode
62252/C1	C1	Sediment	19.06.2020	Korn, TOM, TOC, TN, Cu	24.06.20 - 09.07.20
62252/C2	C2	Sediment	19.06.2020	Korn, TOM, TOC, TN	29.06.20 - 09.07.20
62252/C3	C3	Sediment	19.06.2020	Korn, TOM, TOC, TN	29.06.20 - 09.07.20
62252/C4	C4	Sediment	19.06.2020	Korn, TOM, TOC, TN	29.06.20 - 09.07.20

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

	TOC	TN	TOM	Pelitt	> 0,063 mm	Cu*	N TOC	C/N
Kundens id.:	mg/g TS	mg/g TS	% TS	vekt%	vekt%	mg/kg TS	mg/g TS	
C1	20	3,3	10,0	67,8	32,2	49,1	25,6	6,0
C2	18	3,6	11,0	78,1	21,9	ia	22,3	5,1
C3	16	3,2	8,2	60,9	39,1	ia	22,7	4,8
C4	24	4,9	12,4	88,6	11,4	ia	26,5	4,9

* 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

N TOC (Normalisert TOC) = målt TOC mg/g + 18*(1-F), der F=andel finstoff (pelitt) gitt ved %pelitt/100.

ia = ikke analysert

Tilstandsklassifisering for organisk innhold i marine sedimenter ihht. Veileder 02:2018:

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

Tilstandsklassifisering for kobber (Cu) i marine sedimenter (grenseverdier fra M-608/2016):

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