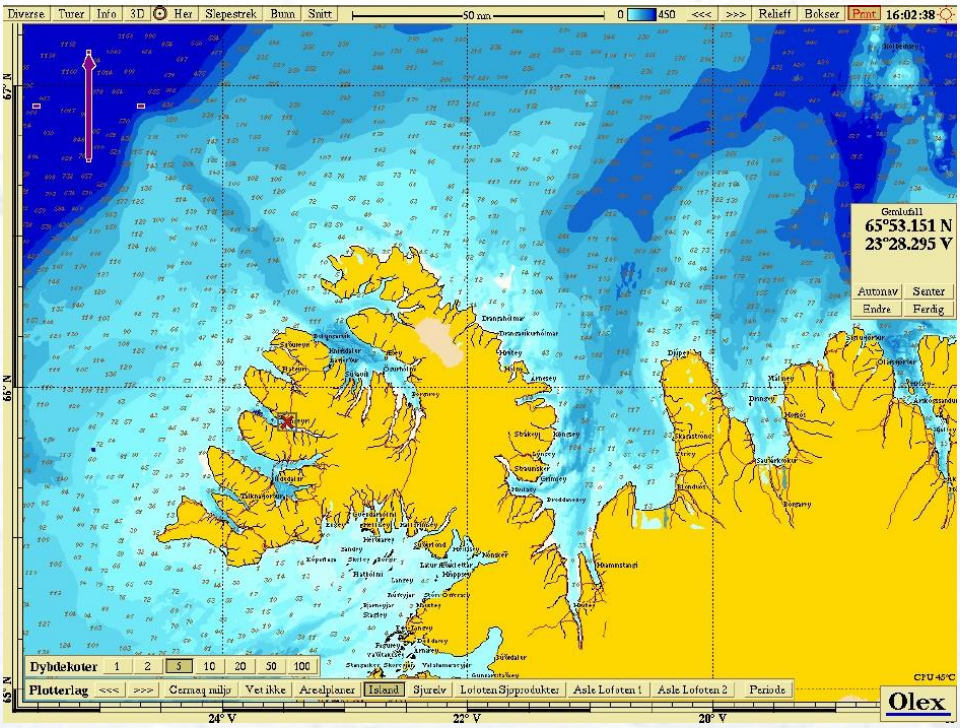
Akvaplan niva

Rapport Report

Arctic Sea Farm hf

C survey

Gemlufall, 2020.



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Summary / Sammendrag
The results from the monitoring at the farming site Gemlufall in May 2020 showed that the sediment was somewhat loaded with organic carbon and the copper concentrations were somewhat above the reported natural levels for bottom sediment around Iceland (Egilsson *et al*., 1999). The faunal index nEQR showed values around 0.6 and the diversity index H ' was around 3 at all stations. 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 May was good in the whole water column with 114 % in the bottom water.

Project manager / Prosjektleder

Arnþór Gústavsson

Arnþór Gústavsson

Quality control / Kvalitetskontroll

Roger Velvin

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Contents

Foreword

Akvaplan-niva completed an environmental C-survey at the Gemlufall 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 survey. This survey is done upon request from Arctic Sea Farm hf hf.

The following personnel have contributed in this work:

Arnþór Gústavsson	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).
Kamila Sztybor	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 Steinunn Guðný Einarsdóttir and the crew of Hafnarnes, Arctic Sea Farm 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, 31.08 2020

Arnþór Gústavsson

Arnþór Gústavson

Project manager

1 Summary of C-results

Information client			
Title :	C-survey Gemlufall, 2020.		
Report nr.	62175.01	Site:	Gemlufall
Site nr.		Map coordinates (construction):	65°53,151 N 023°28,295 W
		Municipal:	Ísafjarðarbær
MTB-permission:	3.500	Operations manager: rett navn	Stein Ove Tveiten
Client:	Arctic Sea Farm hf		

Biomass/production status at time of survey 20.05.2020			
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 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)	0.617	Fauna C1 (closest to farm)	2.85
Fauna C2	0.595	Fauna C2	2.74
Fauna C3	0.608	Fauna C3	2.84
Fauna C4 (deep area)	0.608	Fauna C4 (deep are)	3.01
Date fieldwork:	20.05.2020	**Date of report:**	31.08 2020
Notes to other results (sediment, pH/Eh, oxygen)			nTOC from 23.0 to 26.3 mg/g TS. Copper varied from 63.9 to 77.8 mg/kg Eh positive at all stations O_2-conditions were good throughout the water column.
Responsible for field work:	Arnþór Gústavsson	Signature:	Arnþór Gústavsson

2 Introduction

2.1 Background and aim of study

Akvaplan-niva on behalf of Arctic Sea Farm hf completed a C-survey for the fish farming site Gemlufall in Dýrafjörður, Iceland (Figure 1) after a fallow period. 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. 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.

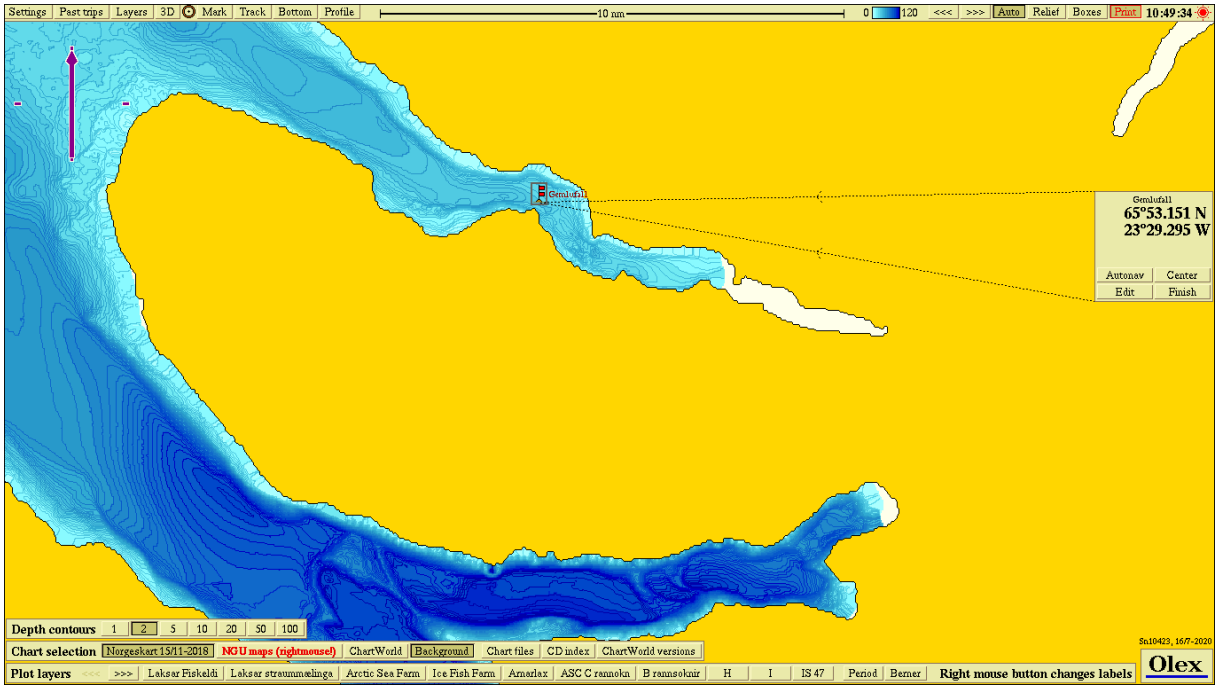

Figure 1. Overview of Dýrafjörður with the farming site Gemlufall (red flag). The map coordinates for the midpoint of the farming site are given at right site of the picture.

2.2 Site operation and feed use

Gemlufall has been in operation for some years but has undergone some changes in setup and cages have been re-located from the time the site was established. Last production cycle was finished in October 2019 and current study is a post-fallow study. The farm is a frame mooring with a total of ten 160 meters circumference cages in a single rig 2 x 5 configuration.

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 3500 tonnes, used as MTB here (Einarsdóttir, pers. reference).

2.3 Previous surveys

Akvaplan-niva AS has not done any previous environmental surveys of the type B/C (NS 9410) at the Gemlufall site, previous studies were carried out by Náttúrustofa Vestfjarða (NAVE). Additionally there are some other investigations that have been conducted in Dýrafjörður related to fish farming activities.

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.
- M-608/2016. Grenseverdier for klassifisering av vann, sediment og biota. Miljødirektoratet, 2016.

Table 1. The planned professional program for the C-survey at Gemlufall, 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. 2 x Cu. pH/Eh.
C3 (transect zone)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. 2 x Cu. pH/Eh.
C4 (transect zone, deep area)	Quantitative analyses of bottom fauna. TOC. Korn. TOM. TN. 2 x Cu. Hydrography/O_2. pH/Eh.

Field work was completed on 20.05.2020.

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 coming generation which is 3.500 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 29 m depth (Gustavsson, 2019).

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

Station	Depth, m	Distance from frame, m	Position N	Position W
C1	30	25	65°53.242	23°28.900
C2	29	500	65°53.113	23°28.367
C3	30	100	65°53.223	23°28.820
C4	29	200	65°53.196	23°28.707

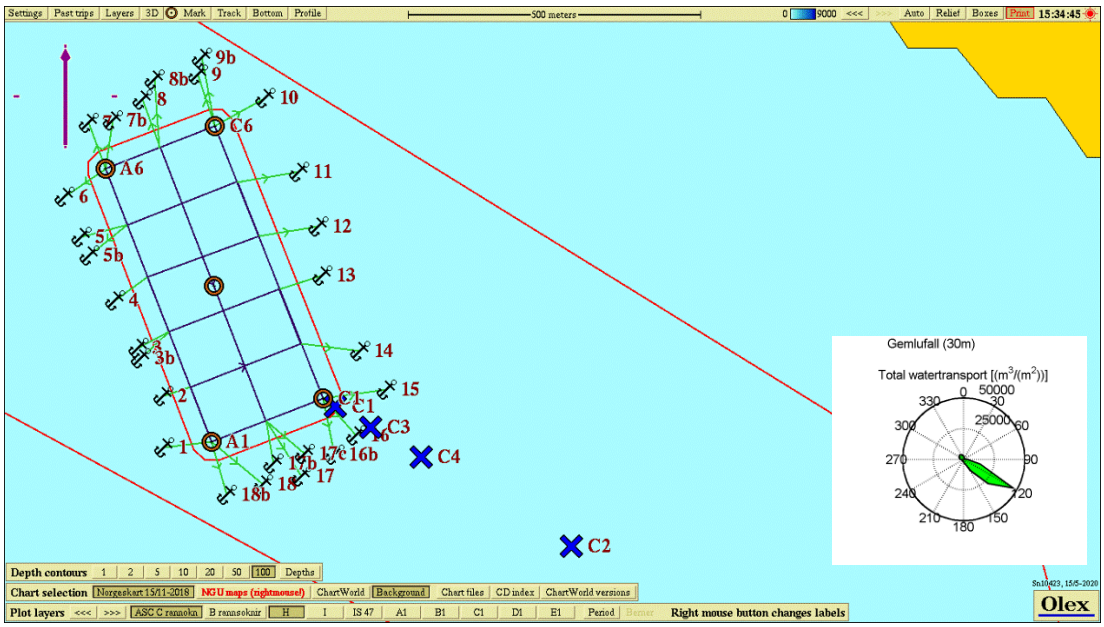

Figure 2. Map showing the sampling stations for the C-survey at Gemlufall, 2020. Current measurements used were from 29 m depth (Gustavsson, 2019).

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, TOM, TN and Cu were taken off from the top 1 cm layer of the sediment and for 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 was 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.

Classification of the environmental condition with respect to Cu is based on reference to the Norwegian Environmental Directorate's veileder M-608/2016.

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 May 2020 is presented in Figure 3.

The temperature dropped from 5.5 ºC in the surface layer to 3.5 at the bottom, and oxygen saturation was above 100 % in the whole water coloumn with 114 % in the bottom layer.

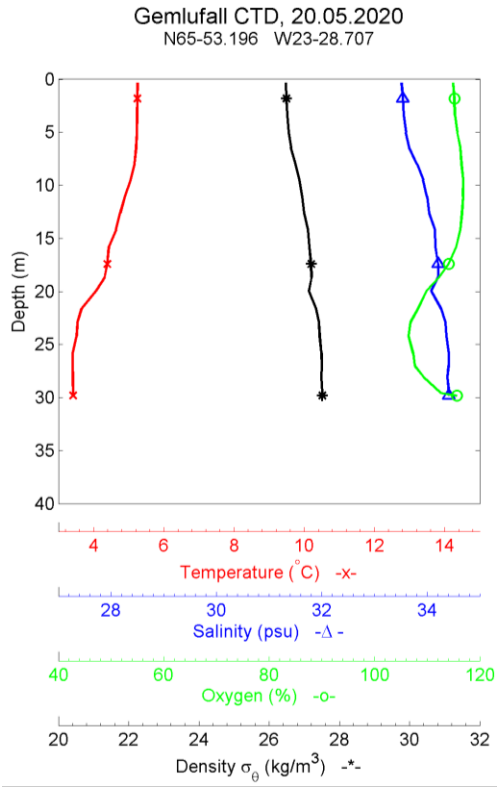

Figure 3. Vertical profiles. Temperature, salinity, density and oxygen at C4 at Gemlufall, 2020.

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 7.9 to 9.3 %. TN-levels were low (3.6 – 4.4 mg/g) as was the C/N-ratio. TOC was somewhat high at all stations and nTOC varied from 23.0 to 26.3 mg/g TS. The bottom sediments grain size were fine with pelite ratio between 72.1 and 87.5 %.

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. Gemlufall, 2020.

St.	Sediment description	TOM	TOC	nTOC*	TN	C/N	Pelitt	pH/Eh
C1	Clay and silt	9.3	22	24.5	4.4	5.0	87.5	7.9/ 344
C2	Clay and silt	7.9	19	23.0	3.9	4.8	76.8	7.8/ 281
C3	Clay and silt	8.7	19	23.9	3.6	5.3	72.1	7.7/ 230
C4	Clay and silt	8.4	22	26.3	4.1	5.5	77.3	7.7/ 212

4.3 Copper

The level of copper in the bottom sediments are shown in Table 4. The level of copper varied from 63.9 to 77.8 mg/kg.

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

St.	Cu repl. 1	Cu repl. 2
C1	67.6	-
C2	63.9	65.4
C3	69.4	65.1
C4	77.8	68.6

4.4 Soft bottom fauna

4.4.1 Faunal indexes and ecological classification

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 737 (C3) to 1994 (C2) and number of species from 29 (C1 and C3) to 32 (C4). The diversity H' varied from 2,74 to 3.01. At all stations, the overall index of nEQR was close to 0.6.

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 0,60 to 0,65 which indicates a somewhat uneven distribution.

Table 5. 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 (excl. DI). C-stations at Gemlufall, 2020.

St.	Numb. ind.	Numb. species	H´	ES_{100}	NQI1	ISI_{2012}	NSI	nEQR	AMBI	J
C1	739	29	2.85	14.45	0.675	8.20	21.80	0.617	2.06	0.63
C2	1994	30	2.74	11.40	0.680	7.75	22.73	0.595	1.73	0.60
C3	737	29	2.84	15.04	0.681	7.51	21.69	0.608	1.98	0.64
C4	798	32	3.01	14.85	0.671	7.49	21.45	0.608	2.18	0.65

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 Gemlufall site 2020.

Station	Site name	Num. species	Dominating taxa	Environmental condition-NS 9410
C1	Gemlufall	29	Ennucula tenuis – 40 %	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 (≤ 10 species) and stretched out somewhat out towards higher classes. These did not give any clear indications of fauna condition.

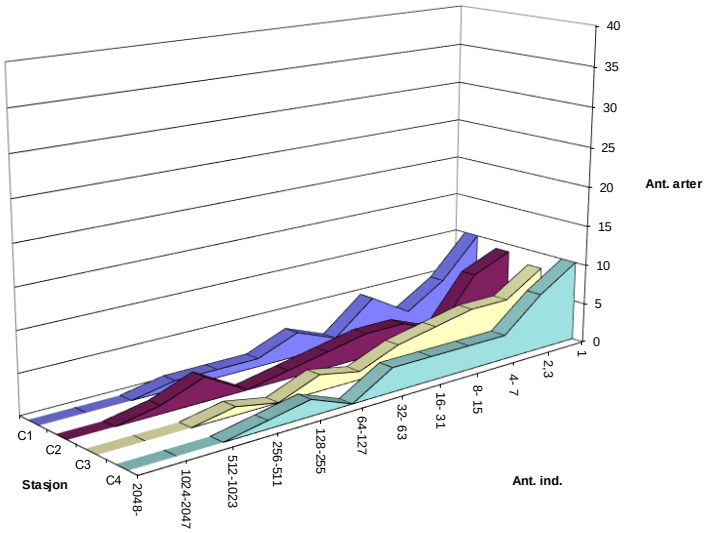

Figure 4. The soft bottom fauna shown as number of species against number of individuals pr. species in geometric classes. Gemlufall, 2020.

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 composition was more than 66 % similar for all stations in the survey.

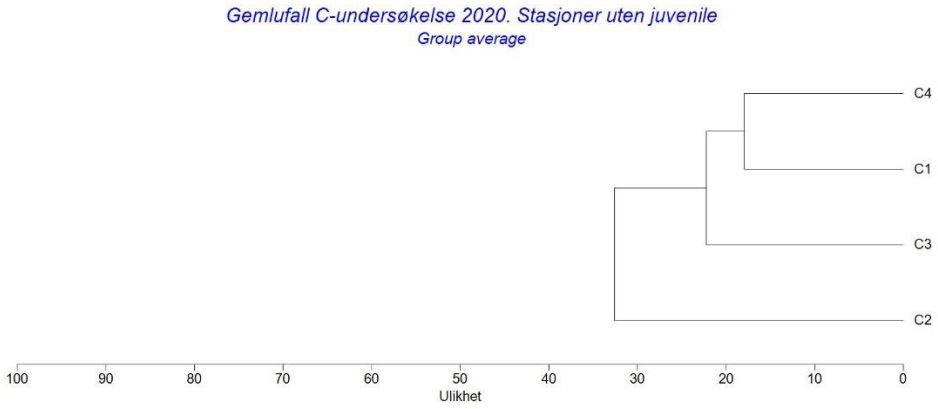

Figure 5. Cluster diagram for the soft bottom fauna at the C- sampling stations at Gemlufall, 2020.

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 fauna at all stations were dominated by the neutral bivalve *Ennucula tenuis* with between 30 and 46 % of the individuals. The other most dominant species at the stations were a mixture of 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. Gemlufall, 2020.*

C1	Numb.	Cum.	EG	C2	Numb.	Cum.	EG
Ennucula tenuis	299	40 %	II	Ennucula tenuis	595	30 %	II
Abra nitida	149	60 %	III	Owenia sp.	413	50 %	II
Galathowenia oculata	83	71 %	III	Abra nitida	374	69 %	III
Macoma calcarea	42	77 %	IV	Galathowenia oculata	336	86 %	III
Thyasira gouldi	35	82 %	IV	Nuculana pernula	71	89 %	II
Thyasira sarsii	32	86 %	IV	Sternaspis scutata	46	91 %	Ik
Sternaspis scutata	16	88 %	Ik	Myriochele malmgreni/olgae	34	93 %	Ik
Levinsenia gracilis	14	90 %	II	Thyasira gouldi	27	94 %	IV
Nephtys ciliata	11	91 %	III	Thyasira sarsii	19	95 %	IV
Nuculana pernula	11	93 %	II	Axinopsida orbiculata	16	96 %	Ik
C3	**Numb.**	**Cum.**	**EG**	**C4**	**Numb.**	**Cum.**	**EG**
Ennucula tenuis	344	46 %	II	Ennucula tenuis	259	32 %	II
Galathowenia oculata	104	60 %	III	Abra nitida	161	52 %	III
Abra nitida	95	73 %	III	Galathowenia oculata	128	68 %	III
Macoma calcarea	41	78 %	IV	Macoma calcarea	56	75 %	IV
Owenia sp.	23	82 %	II	Thyasira gouldi	39	80 %	IV
Thyasira gouldi	20	84 %	IV	Thyasira sarsii	34	84 %	IV
Thyasira sarsii	20	87 %	IV	Levinsenia gracilis	19	86 %	II
Nuculana pernula	15	89 %	II	Sternaspis scutata	17	88 %	Ik
Sternaspis scutata	13	91 %	Ik	Axinopsida orbiculata	16	90 %	Ik
Axinopsida orbiculata	9	92 %	Ik	Nuculana pernula	9	91 %	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.

4.5 Summary and conclusions – C-survey

4.5.1 Summary

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

- The hydrography measurements showed good oxygen conditions throughout the water column with 114 % saturation in the bottom layer in May 2020.
- The number of individuals varied from 737 to 1994 and number of species from 29 to 32. The diversity H' varied from 2,74 to 3.01. At all stations, the overall index of nEQR was close to 0.6.
- TOC was rather high at all stations and nTOC varied from 23.0 to 26.3 mg/g TS. TOM-levels varied from 7.9 to 9.3 %. TN-levels were low (3.6 – 4.4 mg/g) as was the C/N-ratio. The copper level in sediments were high (63.9 to 77.8 mg/kg) according to Norwegian standards, and somewhat above the reported natural levels in Icelandic coastal areas (Egilsson *et al*. 1999). The sediments were fine with pelite ratio between 72.1 and 87.5 %. 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 Gemlufall in May 2020 showed that the sediment was somewhat loaded with organic carbon and the copper concentrations were somewhat above the reported natural levels for bottom sediment around Iceland (Egilsson *et al*., 1999). The faunal index nEQR showed values around 0.6 and the diversity index H ' was around 3 at all stations. 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 May was good in the whole water column with 114 % in the bottom water.

4.5.3 Environmental trend

A similar C-survey (fallow) was carried out in July 2017 by NAVE (Gallo, 2018). The sampling position are different between the two surveys and, therefore, only a general comparison of the results can be carried out.

TOC and copper levels were not measured in the previous study which excludes comparison. Number of species in current study are slightly higher than in previous study, along with eveness index (J) while Shannon-Wiener index was slightly lower values in current study.

5 References

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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 macrofauna.

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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.

Pers. reference: Steinunn Guðný Einarsdóttir, Arctic Sea Farm hf

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

Referanser:

Bray, R.T. & J.T. Curtis, 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.*, 27:325-349.

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Shannon, C.E. & W. Weaver, 1949. The Mathematical Theory of Communication. *Univ Illinois Press*, Urbana 117 s.

Statistikk resultater Gemlufall, 2020:

Antall arter og individer per stasjon

st.nr.	tot.	C1	C2	C3	C4
no. ind.	4268	739	1994	737	798
no. spe.	51	29	30	29	32

Bunndyrindekser per replikat

st.nr.	tot.	C1_01	C1_02	C2_01	C2_02	C3_01	C3_02	C4_01	C4_02
no. ind.	4268	400	339	1103	891	187	550	361	437
no. spe.	51	24	22	22	26	22	22	26	23
Shannon-Wiener:		2,8	2,9	2,7	2,7	3,3	2,4	3,0	3,1
Pielou		0,60	0,66	0,61	0,58	0,74	0,53	0,63	0,67
ES100		15	14	11	12	18	12	15	14
SN		1,78	1,75	1,59	1,70	1,87	1,68	1,84	1,74
ISI-2012		7,54	8,85	7,29	8,22	7,39	7,64	7,44	7,54
AMBI		1,984	2,143	1,771	1,685	2,079	1,88	2,254	2,098
NQI1		0,68	0,67	0,67	0,69	0,69	0,67	0,67	0,67
NSI		22,1	21,5	22,7	22,8	20,8	22,6	21,3	21,6

Bunndyrindekser, gjennomsnitt per stasjon

st.nr.		C1	C2	C3	C4
Shannon-Wiener:		2,85	2,74	2,84	3,01
Pielou		0,63	0,60	0,64	0,65
ES100		14,4	11,4	15,0	14,8
SN		1,76	1,64	1,77	1,79
ISI-2012		8,20	7,75	7,51	7,49
AMBI		2,064	1,728	1,980	2,176
NQI1		0,67	0,68	0,68	0,67
NSI		21,80	22,73	21,69	21,45
Tilstandsklasse nEQR		0,617	0,595	0,608	0,608

Geometriske klasser

int.	C1	C2	C3	C4
1	10	9	8	10
2,3	5	7	5	7
4- 7	2	1	5	3
8- 15	5	3	4	3
16- 31	1	3	3	3
32- 63	3	2	1	3
64-127	1	1	2	0
128-255	1	0	0	2
256-511	1	3	1	1
512-1023	0	1	0	0
1024-2047	0	0	0	0
2048-	0	0	0	0

Artsliste

Gemlufall C-undersøkelse 2020

Rekke	Klasse	Art/Taxa	01	02	Sum
Stasjonsnr.: C1					
ANNELIDA					
	Polychaeta				
		Chaetozone sp.	1	1	2
		Cistenides hyperborea	1		1
		Eteone flava/longa	1		1
		Galathowenia oculata	45	38	83
		Lagis koreni	1	1	2
		Levinsenia gracilis	6	8	14
		Mediomastus fragilis		1	1
		Melinna cristata		1	1
		Nephtys ciliata	5	6	11
		Owenia sp.	4	1	5
		Pholoe baltica	1		1
		Praxillella praetermissa	6	3	9
		Prionospio cirrifera	3		3
		Scoloplos armiger	1		1
		Spio limicola	1		1
		Sternaspis scutata	12	4	16
		Syllis cornuta	1	3	4
CRUSTACEA					
	Malacostraca				
		Eudorella sp.		1	1
		Leucon sp.	1		1
MOLLUSCA					
	Bivalvia				
		Abra nitida	66	83	149
		Abra prismatica		1	1
		Axinopsida orbiculata	3	5	8
		Ennucula tenuis	185	114	299
		Macoma calcarea	16	26	42
		Nuculana pernula	6	5	11
		Thyasira gouldi	21	14	35
		Thyasira sarsii	12	20	32
		Yoldia hyperborea	1	1	2
ECHINODERMATA					
	Ophiuroidea				
		Ophiocten affinis		2	2
		Ophiuroidea indet. juv.	2	5	7
		Maks:	185	114	299
		Antall:	25	23	30
		Sum:			746
Stasjonsnr.: C2					
NEMERTINI					
		Nemertea indet.		1	1
ANNELIDA					
	Polychaeta				
		Galathowenia fragilis		1	1
		Galathowenia oculata	190	146	336
		Lagis koreni	1	2	3
		Leitoscoloplos mammosus		2	2
		Levinsenia gracilis		2	2

Rekke	Klasse	Art/Taxa	01	02	Sum
		Maldane sarsi	7	2	9
		Melinna cristata	1	2	3
		Myriochele malmgreni/olgae	25	9	34
		Nephtys ciliata	2	2	4
		Owenia sp.	215	198	413
		Praxillella praetermissa	9	6	15
		Prionospio cirrifera		1	1
		Proclea graffii		1	1
		Scoloplos armiger	1		1
		Sternaspis scutata	26	20	46
CRUSTACEA					
	Malacostraca				
		Campylaspis sp.	1		1
		Lysianassidae indet.	1		1
		Oedicerotidae indet.	1	1	2
		Crustacea indet. juv.		1	1
MOLLUSCA					
	Opistobranchia				
		Retusa obtusa		1	1
	Bivalvia				
		Abra nitida	228	146	374
		Axinopsida orbiculata	7	9	16
		Ciliatocardium ciliatum		1	1
		Ennucula tenuis	316	279	595
		Macoma calcarea	5	3	8
		Nuculana pernula	44	27	71
		Thyasira gouldi	10	17	27
		Thyasira sarsii	8	11	19
		Yoldia hyperborea	3		3
ECHINODERMATA					
	Ophiuroidea				
		Ophiocten affinis	2	1	3
		Ophiuroidea indet. juv.	7	6	13
		Maks:	316	279	595
		Antall:	23	28	32
		Sum:			2008

Stasjonsnr.: C3

ANNELIDA					
	Polychaeta				
		Ampharete finmarchica		1	1
		Galathowenia oculata	20	84	104
		Gattyana cirrhosa	5		5
		Lagis koreni	3	1	4
		Levinsenia gracilis		8	8
		Melinna cristata		1	1
		Nephtys ciliata	3	3	6
		Owenia sp.		23	23
		Pholoe baltica	2		2
		Praxillella praetermissa	2	1	3
		Prionospio cirrifera		3	3
		Proclea graffii	1		1
		Scoloplos armiger		1	1
		Spio limicola	1		1
		Sternaspis scutata	1	12	13

Rekke	Klasse	Art/Taxa	01	02	Sum
		Syllis cornuta	1		1
CRUSTACEA					
	Malacostraca				
		Pleurogonium spinosissimum	1		1
MOLLUSCA					
	Bivalvia				
		Abra nitida	29	66	95
		Arctica islandica		2	2
		Axinopsida orbiculata	6	3	9
		Ennucula tenuis	47	297	344
		Macoma calcarea	37	4	41
		Mya sp. juv.	1	1	2
		Nuculana pernula	5	10	15
		Thyasira gouldi	2	18	20
		Thyasira sarsii	13	7	20
		Thyasiridae indet.	2	1	3
		Yoldia hyperborea	2	2	4
ECHINODERMATA					
	Ophiuroidea				
		Ophiocten affinis	3	2	5
		Ophiura albida	1		1
		Ophiuroidea indet. juv.	2	3	5
		Maks:	47	297	344
		Antall:	24	24	31
		Sum:			744

Stasjonsnr.: C4

ANNELIDA					
	Polychaeta				
		Chaetozone sp.	5	1	6
		Galathowenia oculata	46	82	128
		Lagis koreni	2		2
		Leitoscoloplos mammosus	3		3
		Levinsenia gracilis	3	16	19
		Mediomastus fragilis	5	1	6
		Melinna cristata		2	2
		Nephtys ciliata	4	4	8
		Nephtys paradoxa	1		1
		Owenia sp.	1	8	9
		Paramphinome jeffreysii	1		1
		Pholoe baltica	1		1
		Praxillella praetermissa	1	2	3
		Prionospio cirrifera		1	1
		Scoloplos armiger		3	3
		Spio limicola		1	1
		Sternaspis scutata	1	16	17
		Terebellides sp.	1		1
CRUSTACEA					
	Malacostraca				
		Leucon sp.	1		1
		Oedicerotidae indet.		1	1
MOLLUSCA					
	Bivalvia				
		Abra nitida	95	66	161
		Axinopsida orbiculata	10	6	16
		Bivalvia indet.		1	1
		Ennucula tenuis	114	145	259

Rekke	Klasse	Art/Taxa	01	02	Sum
		Macoma calcarea	34	22	56
		Nuculana pernula	3	6	9
		Parvicardium pinnulatum	1		1
		Thyasira gouldi	8	31	39
		Thyasira sarsii	14	20	34
		Thyasiridae indet.	3	1	4
		Yoldia hyperborea	1	1	2
ECHINODERMATA					
	Ophiuroidea				
		Ophiocten affinis	2		2
		Ophiuroidea indet. juv.	7	2	9
		Maks:	114	145	259
		Antall:	27	24	33
		Sum:			807
				TOTAL:	***Maks:*** 595
					Sum: 4305

Appendix 2. Analyserapport – Geokjemiske analyser (in norwegian)

Framsenteret
Postboks 6606 Langnes, 9296 Tromsø
Foretaksnr.: NO 937 375 158 MVA
Tel: 77 75 03 00
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ANALYSERAPPORT
Sedimentprøver

Kunde:	**Arctic Sea Farm hf.**
Kunde referanse:	**Gemlufall C/B undersøkelse Q2 2020**
Kontaktperson kunde:	
e-post:	
Kontaktperson Akvaplan-niva:	**Arnþór Gústavsson**
Dato:	09.06.2020
Rapport nr.:	**62175**
Analyseparameter(e):	Korn, TOM, TOC, TN og Cu
Kontaktperson:	Oda Sofie B. Wilhelmsen
Analyseansvarlig:	Ingar H. Wasbotten (sign.)
Underskriftsberettiget:	Lisa Torske Digitally signed by Lisa Torske Date: 2020.06.09 15:29:17 +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:

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
62175/C1	C1	Sediment	26.05.2020	Korn, TOM, TOC, TN, Cu	27.05.20 -04.06.20
62175/C2	C2	Sediment	26.05.2020	Korn, TOM, TOC, TN, 2xCu	27.05.20 -04.06.20
62175/C3	C3	Sediment	26.05.2020	Korn, TOM, TOC, TN, 2xCu	27.05.20 -04.06.20
62175/C4	C4	Sediment	26.05.2020	Korn, TOM, TOC, TN, 2xCu	27.05.20 -04.06.20

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*	Cu*	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	22	4,4	9,3	87,5	12,5	67,6	ia	24,5	5,0
C2	19	3,9	7,9	76,8	23,2	63,9	65,4	23,0	4,8
C3	19	3,6	8,7	72,1	27,9	69,4	65,1	23,9	5,3
C4	22	4,1	8,4	77,3	22,7	77,8	68,6	26,3	5,5

* 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