Baseline monitoring of coastal areas in Ísafjarðardjúp

Grunnvöktun fjöru Ísafjarðardjúps

Cristian Gallo

Umhverfissjóðs sjókvíaeldis

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Náttúrustofa Vestfjarða
Aðalstræti 12
415 Bolungarvík

Sími: 456-7005

Kennitala:610397-2209
Netfang: nave@nave.is
Heimasíða: http://www.nave.is

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Abstract: Aquaculture activities in the marine environment (i.e. mariculture) are sources of dissolved Phosphorus (P) and Nitrogen (N) in the water column. This input increases nutrient availability for the macroalgal and epifaunal community in the tidal zones. With this research we aim to obtain a detailed picture of the biodiversity found in the tidal zones of two littoral areas in Ísafjarðardjúp fjord system prior to the implementation of proposed mariculture in the area. Results of this study will allow for the evaluation of the impact that such mariculture activities may have on organisms in the tidal zones of Icelandic fjords.

Company details:
Náttúrustofa Vestfjarða
Aðalstræti 12, 415 Bolungarvík, Iceland.
Telephone number: +354 456 7005
Mail address: *nave@nave.is*
Web: *http://www.nave.is*

Project manager: Cristian Gallo

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INTRODUCTION

The intertidal and subtidal zones are defined as the littoral areas where sea and land come together. The heterogeneous nature of the topography in these tidal areas, combined with consistent tidal shifts allows for the evolution of biologically diverse ecosystems wherever such habitats are found. It has been shown that these tidal ecosystems are often negatively affected by anthropogenic activities such as agriculture, industrial development and urban sprawl. Aquaculture activities in the marine environment (i.e. mariculture) often take place in and around such tidal habitats, yet little is known as to what effect industrial sized mariculture operations may have on these biodiverse environments, especially with regard to large nutrient fluxes. With this research we aim to obtain detailed information on natural biodiversity of the macroalgal and epifaunal community in the intertidal zone of two littoral areas in the Westfjords of Iceland prior to the implementation of mariculture in the Ísafjarðardjúp fjord system. A detailed understanding of this ecosystem prior to the implementation of mariculture will allow for a more in-depth analysis of the effects that such activities may have on organisms in the tidal zones of Icelandic fjords.

Aquaculture is a fast-growing food production industry and fin fish farming in open sea cages (mariculture) is a fast-growing sector in Iceland. The mariculture industry in Iceland is mainly dominated by salmonid farming, with Atlantic Salmon (*Salmo salar*) and Rainbow Trout (*Oncorhynchus mykiss*) dominating the market. A typical mariculture site comprises of several floating cages (6-10) where the fish is stocked as smolt (150-200 grams) and subsequently grows for a period of 1.5 -2 years before being slaughtered. During this growing period farmed fish is fed with manufactured fish feed.

Licensed farmed fish biomass varies but a usual production site needs to accommodate around 3-5 thousand tons of fish at peak biomass. This high biological concentration is a potential source of change in the surrounding ecosystem and therefore may impact the natural environment. The impacts of mariculture activities are various and can differ between species. One of the main impacts is the alteration of the surrounding ecosystem. This alteration is mainly due to the deposition of organic matter (faeces and unused feed) and due to the increase of dissolved Phosphorus (P) and Nitrogen (N) in the water column.

Deposition of organic matter mainly affects benthic organisms on the sea bottom, with the impact usually being more intense in close proximity to the farming site and weakening with increasing distance from the source (Pearson & Rosemberg 1978, Karakassis et al. 1998, Tomassetti et al. 2009). Dissolved P and N could potentially alter the trophic structure in the water basin and the nearby intertidal zone. Another undesirable impact of mariculture comes from the release of trace metals such as Copper and Zinc, mainly from antifouling agents which are applied to nets used in fish farming. Such pollutants are known to affect coastal animal communities, reduce the diversity of native species and increase the presence of more resistant ones (Chou et al. 2002, Lojen et al. 2005, Squadrone et al. 2016).

N and P are naturally present in the marine environment as nutrients which become assimilated by phytoplankton (primary producers) and macroalgae. Mariculture, as with other anthropogenic sources of N and P (i.e. agriculture & wastewater), can lead to increased levels of nutrients in the water column (i.e. eutrophication) (Hall et al. 1992, Bonsdorff et al. 1996). Recent studies suggest that about 60-70% of N and 80% of P supplied as feed in salmon farming is released into the environment (Bergheim & Braaten 2007, Wang et al. 2012). According to Bergheim & Braaten (2007) 41 kg of N and 8 kg of P are released into the environment for each ton of farmed salmon. Thus, a typical aquaculture site with 4000 tons of salmon biomass will release 164 ton of N and 32 ton of P in the environment.

The supply of feed increases with time as the fish grow, however this does not occur in a linear fashion due to reduced feeding efficiency during the winter. Typically feeding is performed daily, however in instances where feeding is done manually, it may occur a minimum of 3 times a week during summer and 2 times a week during the winter. Thus the release of nutrients into the environment follows the seasonal feeding pattern, the amount of nutrients released is therefore higher in the summer/autumn, decreases during winter, increases again in the second farming summer before eventually decreasing again in the second winter and/or around the beginning of slaughter. It can thus be said that nutrient release is continuous but not consistent in intensity throughout the year.

This nutrient input has been shown to alter the natural availability of nutrients in both the water column and in the intertidal zone (La Rosa et al. 2002, Bergheim & Braaten 2007, Oh et al. 2015). In the water column, availability of nutrients affects pelagic primary production (phytoplankton). Since phytoplankton occurrence is temperature depended, during cold periods the extra nutrient input (not naturally present) often leads to an increase in nutrient dependant species of bacteria such as toxic Cyanobacteria, which typically do not bloom excessively in times of low nutrient presence. In times of higher sea temperatures but shorter day length, high nutrient availability may lead to higher than average primary productivity. If uneaten by grazer (zooplankton) these primary producers may eventually fall to the sea floor, leading to oxygen depletion and anoxic conditions on the surrounding sea floor (Smoot et al. 1998, Dalsgaard & Krause-Jensen 2006).

In the intertidal zone, increased nutrient availability may affect the macroalgae community. This may lead to changes in macroalgal population dynamics as well as species diversity. Eutrophication decreases water transparency and therefore affects photosynthetic processes (i.e. algae growth) (Bonsdorff et al. 1997). Fast growing species exploit the nutrients available at the expense of slow growing ones bringing changes to the trophic system (Worm & Lotze 2006, Husa et al. 2014).

Eutrophication may increase the propagation of green and red algae (Husa et al. 2014). Eutrophication also boosts the growth of epiphytic algae on perennial species such as kelp and fucoids, affecting their growth as well as the ecosystem which they support (Hemmi et al. 2005, Oh et al. 2015). Altering macroalgal growth may also lead to alterations in resource allocation for herbivorous isopods and gastropods (Taylor et al. 2003, Hemmi et al. 2005). Moreover, eutrophication may also have a negative effect on the survival of seagrass *Posidonia oceanica* (Rountos et al. 2012).

The effects of eutrophication are much clearer in closed water basins (i.e. Baltic sea), where poor water circulation brings high or stable concentrations in a limited area (Bonsdorff et al. 1997). Most fjords can be looked at as semi-open water systems with variable water circulation due sea currents and bathymetric features. In the case of glacially formed fjords, the presence of a sill (threshold) could lead to stratification of water and little mixing (Syvitski et al. 1987). Since mariculture companies usually prefer to place their operations in semi-closed water basins, the impact of nutrient release on the intertidal zone could be underestimated, especially in case of multiple farming sites on the large scale.

This study assumed that the farming site will function as a source which will have a higher impact on the coastal environment which is closer to the source (fish cages). This also takes into consideration the slower but more prolonged release of N and P from the highly rich sediments created by the deposition of organic matter under the cages used in the fish farm. This assumption was based on similar research which showed that primary production was stimulated by nutrients released from aquaculture activities up to 150 m downstream from pens (Dalsgaard & Krause-Jensen 2006, Jiang et al. 2013).

Mariculture impact assessment studies are conducted by sampling and measuring different factors in the environment. These factors include, but are not limited to benthic community assemblage, redox potential, total organic carbon, oxygen level and P concentration. Monitoring is usually done according to an established standard which defines the sampling methodology. Acceptable levels for monitored environmental factors mentioned above are usually set up by the regulator (governmental institutions) and are usually based on local environmental conditions. Due to deposition and dilution processes, this monitoring usually focuses on the marine environment near the farming site, such as benthic sediments and the water column. Reference stations are usually sampled for comparison between years but the impact on the large scale and the impact on intertidal zone is usually does not require monitoring.

In order to effectively assess the effects that mariculture activities may have on marine life in the intertidal zone it is important to first have a detailed picture of the local ecosystem prior to the implementation of mariculture activities. Thus, the main aim of this study is to obtain a greater understanding of the macroalgal and epifaunal community in the intertidal zone of several fjords prior to the implementation of mariculture in the Ísafjarðardjúp fjord system. Here we catalogue the macroalgal and epifaunal community composition in the intertidal zone in proximity to two proposed mariculture sites in the Ísafjarðardjúp.

STUDY AREA

Ísafjarðardjúp ("deep ice fjord") is a glacial fjord system in the Westfjords, the north western most region of Iceland. It opens to the Denmark Strait which connects the Greenland Sea, an extension of the Arctic Ocean, to the Irminger Sea, a part of the Atlantic Ocean. Ísafjarðardjúp covers an area which is roughly 786 km^2, with an average depth of 50-100 m and maximum depth of 130 m. It is around 75 km long and broadest at the mouth (~20 km). At the opening of Ísafjarðardjúp are Jokulfirdir, a group of fjords which extend to the northeast. Ísafjarðardjúp curves south-east and splits in its south side into 7 smaller fjords. On its north side the Drangajokull glacier retreats from Ísafjarðardjúp trough a lagoon shaped fjord named Kaldalon (Hafrannsóknastofnun 2019) (fig.1).

Sea current were measured in Ísafjarðardjúp in different occasions (Jónsson et al. 2011, Valdimarsson et al. 2014, Noomas 2016a, Noomas 2016b, Ólafsdóttir et al. 2017). Results of these measurements indicate the presence of a counter clockwise current as well asa strong (5 cm/sec) current on the north outer part of Ísafjarðardjúp (Hafrannsóknastofnun 2017) (fig. 1).

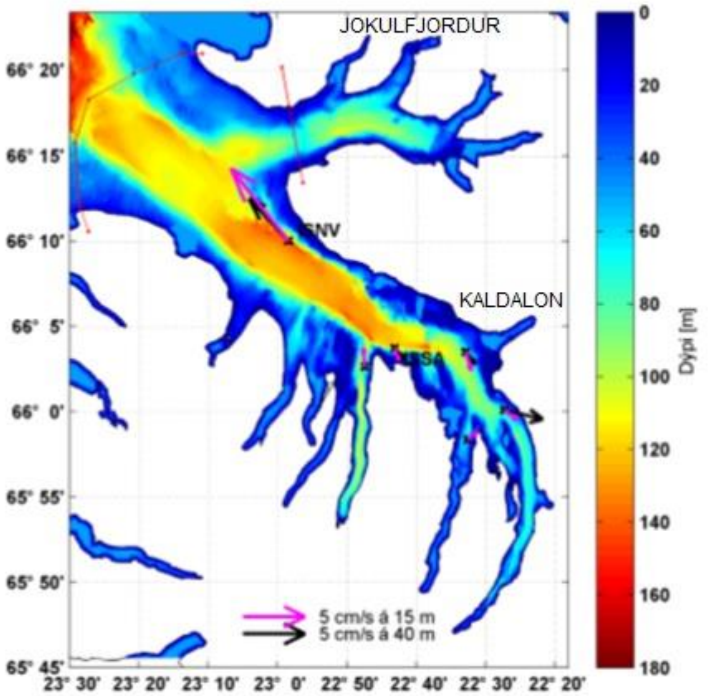

Figure 1. Ísafjarðardjúp, bottom depth and sea current (Hafrannsóknastofnun 2017, modified Cristian Gallo).

Oxygen, temperature and salinity were also measured on different occasions and recently summarized by the Marine Research Institute of Iceland (Hafrannsóknastofnun 2017). Measurements point out that water exchange, temperature and oxygen levels in the fjord are not affected by the sill at the mouth of the fjord. The temperature is the lowest in March (1°C), increases until the middle of November and the mixing seems to arrive down to the deep layer. The oxygen value in the bottom layer is the highest in March and goes down to the lowest value at the end of September. Salinity values show that inflowing of saltier sea water from ocean occurs over the summertime and signs of renovation of the water at bottom layer. Good water circulation are also seen in the oxygen level found at the deeper layer (Hafrannsóknastofnun 2017).

Chemical analysis of nitrates (NO3), phosphates (PO4) og silicon dioxides (SiO2) in sea water was carried out in Ísafjarðardjúp by Hafrannsóknastofnun in 2016 and 2019. Nitrate was found to be between 12,2 and 13,1 µmol/l during mid-winter. Nitrate: Phosphate ratio values were found to be like other shallow bodies of water around Iceland (Ólafsdóttir 2006). Hafrannsóknastofnum categorizes the water basin in Ísafjarðardjúp according to European water Framework Directive 2000/60/EB with nr. 101-1390-C and code CN2152 (Eydal et al. 2014, Ólafsdóttir et al. 2019).

Research on phytoplankton (Guðmundsson and Eydal 1998), zooplankton (Astthorsson and Jonsson 1988, Ástþórsson and Gíslason 1992, Gíslason et al. 2012), sea urchins (Bragason and Jóhannesson 1987, 1988), *Clamys islandica* (Eiríksson H. 1986), *Pandalus borealis* (Skúladóttir et al. 1989) and benthos (Eiríksson et al. 2010) were done in Ísafjarðardjup.

Commercial fishing (cod, halibut, lumpfish, shrimp, scallop) and recreational fishing (halibut, scallop) was done in Ísafjarðardjúp in the past and in different level still active. Evidence seems to support the idea that fjord work as nursery for juvenile Atlantic cod (Jónsdóttir et al. 2019).

The intertidal zone in Ísafjarðardjúp was recently surveyed and defined as "Littoral rocky shore with moderate energy" (Eunis code A 1.2) and further categorised into "Algae shore" (þangfjörur) coded as F1.3 (Ottósson et al. 2016).

Research related to brown seaweed was also carried out between 2015 and 2018 in Ísafjarðardjúp (Jónsson et al. 2015, Helgason et al. 2019). The feasibility of harvesting brown seaweed in the area was investigated and the amount which could be harvested was estimated to be around 30 thousand tons (Jónsson et al. 2015). Regrowth of *Ascophyllum nodosum, Fucus vesiculosus, F. spiralis* and *F. disthicus* was investigated and estimated to be around 2 years (Helgason et al. 2019).

Ísafjarðardjúp has 3 main islands: Æðey, Vigur and Borgarey (fig.2). Æðey likely has the largest Eider duck colony in Iceland as well as a relatively large arctic tern colony (Jónsson 2001). Vigur on the other hand is home to a large Puffin colony as well as smaller populations of Black Guillemot, Arctic Tern and Eider duck.

Aquaculture in Ísafjarðardjúp started in 2002 in Skutulsfjörður and Álftafjörður with farming of cod (*Gadus morhua*) which was fished as smolt and then set in cages to grow. These were small aquaculture enterprises which went on for a decade. In year 2015-2016 the company Hraðfrystihúsið-Gunnvör hf. started farming trout in Álftafjörður and around the same time a former company Álfsfell started to also farm trout in Skutulsfjörður. Due to increased interest in salmon farming in the area the carry capacity of Ísafjarðardjúp was investigated and set by Hafrannsóknastofnun at 30 thousand ton of farmed fish in 2017 (Hafrannsóknastofnun 2017). Háfell (sister company of Hraðfrystihúsið-Gunnvör hf.) set forward an application for Salmon farming in 2016 and the sites selected for this study are between those considered by Háfell (Gunnarsson and Jóakimsson 2015). Salmon farming is still an issue in Ísafjarðardjup but eventually trout farming will start on the study sites in the upcoming years.

This study was conducted on two sites in two different parts of Ísafjarðardjup. Site 1 was on the shore on the east side of Kambsnes at the entrance of Seyðisfjörður and site 2 in shore of Skarðshlíð in Ísafjarðardjúp at the entrance of Skötufjörður (fig.2).

Figure 2. Ísafjarðardjúp and the study sites, black square 1 and 2.

Site 1 is in the mariculture area known as “Norðan við Eyri” with an average depth of 40 meters and size (blue box) of 600 x 1200 m (Gunnarsson and Jóakimsson 2015) (fig.3).

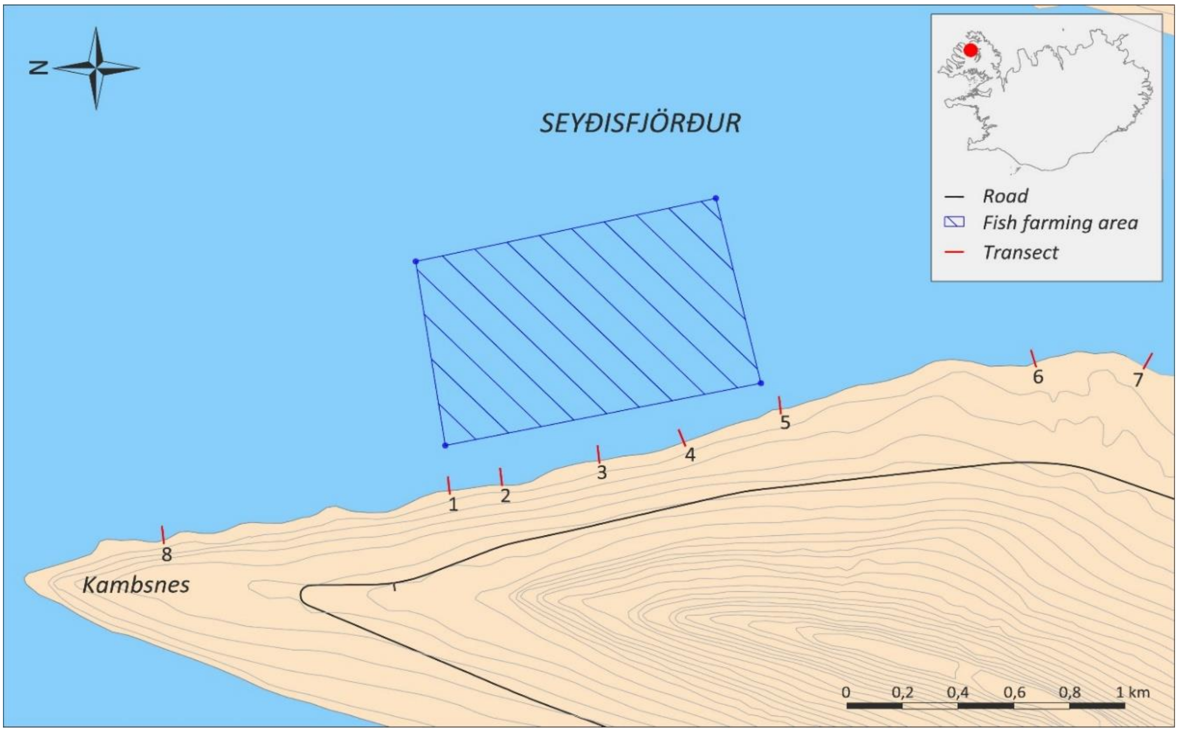

Figure 3. Site 1 at Kambsnes with locations of the sampled transects.

Site 2 is in the area known as Skarðshlíð, with depth of 80-90 meters and a size of 1000 x 700 meters (Gunnarsson and Jóakimsson 2015) (fig.4).

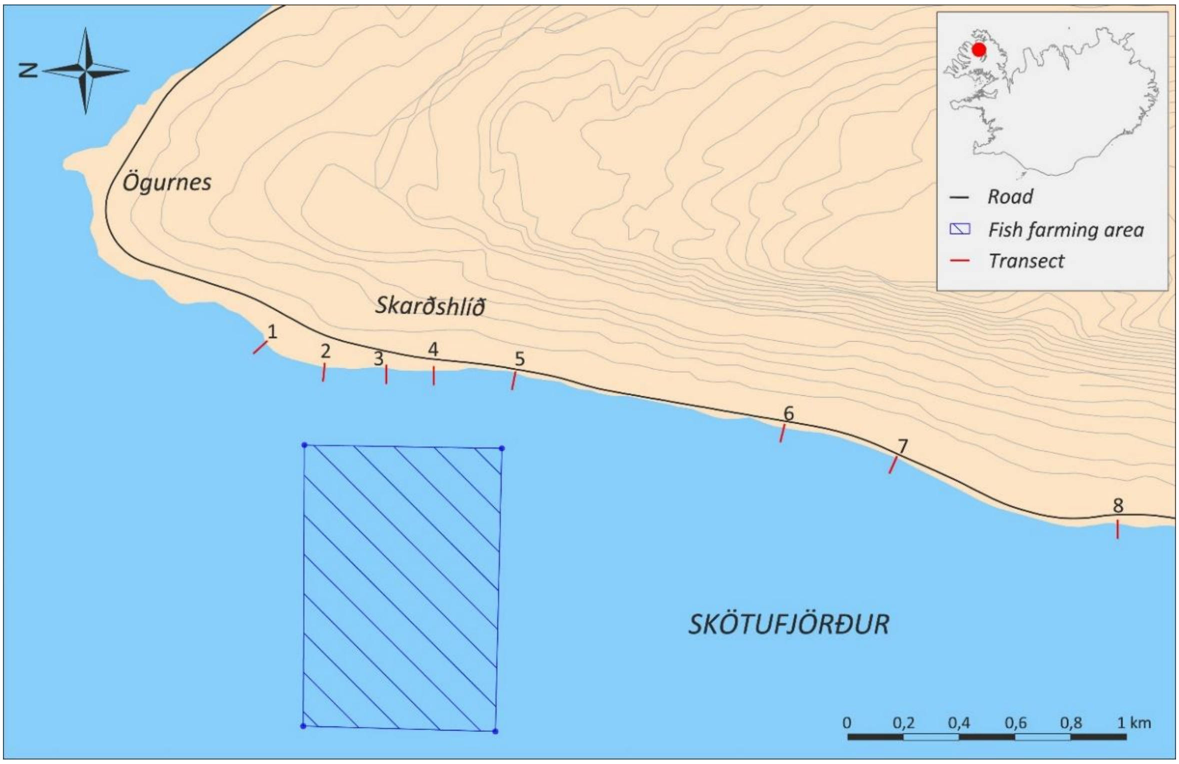

Figure 4. Site 2 Skarðshlíð with locations of the sampled transects.

METHODOLOGY

In order to determine the best field methodology a preliminary survey was conducted at both study sites. Sites were surveyed at low tide (spring tide). Site 2 (Skarðshlíð) was visited April 30th 2018 while site 1 (Kambsnes) was visited Mai 5th 2018. Preliminary surveys of both sites indicate that the intertidal zone is rocky, relatively exposed to waves and has a relatively short exposed shore during low tide. The rocky shores in these sites are characterized by bedrocks and medium to large boulders (0,5 to 1 meter in diameter). Few sparse tide pools remain submerged during low tide. The intertidal zone constitutes of 4 distinct zones which are each characterized by distinct trophic communities (fig.5 and 6).

Figure 5. Shore at Kambsnes (site1). Visible are the 3 zones A, B and C but kelps (zoneD) are emerging from water. Picture taken 5 Mai 2018 (Cristian Gallo).

Zone A was demarcated by the level of the high tide and acts as the interface between the terrestrial and marine ecosystem. This zone was characterized by little to no algae and almost exclusively by the presence of rough periwinkle (*Littorina saxatilis*). Zone B was characterized by the presence of algae such as *Ascophyllum nodosum* and *Fucus vesiculosus*, with Ascophyllum almost always predominant. This zone was always relatively long (around 10 meters) and was always, at least in part, exposed during regular low tide. Zone C was characterized by a smaller type of macroalgae and by the presence of *Fucus disticus* growing on the biggest boulders. Zone C was a short zone (less than 5 meters) usually submerged during regular low tide (fig. 7 and 8). Zone D was located at the lowest part of the shore, was always submerged, and was mainly composed of kelp (*Laminaria digitata*).

Figure 6. Shore at Skarðshlíð (site 2). Visible are 3 zones A, B and C and kelps (zone D) are emerging from water. Picture taken 11 July 2018 (Cristian Gallo).

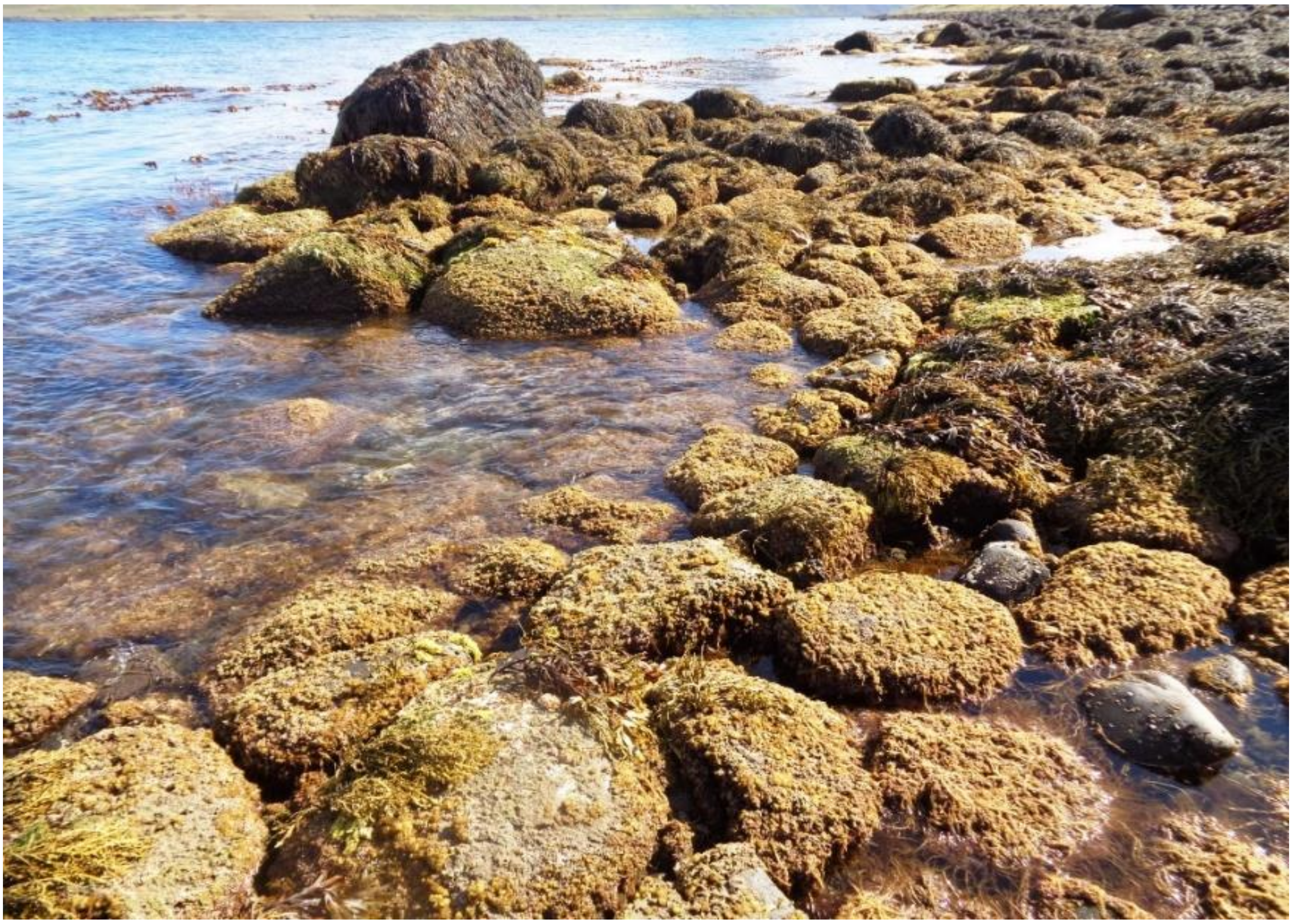

Figure 7. Zone C at Kambsnes (site 1). Picture taken 13 August 2018 (Cristian Gallo).

Figure 8. Zone C at Skarðshlíð (site 2). Picture taken 13 June 2018 (Cristian Gallo).

The methodology developed for this study assumed that the aquaculture site worked as source of organic nutrients, with the majority of the impact of this nutrient load being felt around and next to the aquaculture area itself and decreasing together with nutrient concentrations as one moves further away from the aquaculture area itself. Based on the above assumption and on the fact that the intertidal zone was relatively uniform, a total of 8 transects were taken at each study site: 5 on the intertidal zone directly in front of the aquaculture area and 3 at least 1 km away from the aquaculture area (Fig. 3 and 4). The 3 transects which were stationed at least 1 km away from the aquaculture sites served as controls because of the effects of aquaculture activity is believed to be minimal at such distances (Dalsgaard & Krause-Jensen 2006, Jiang et al. 2013). The position of transects were chosen in advance. Coordinates are in Appendix 1.

Sampling was always conducted during low spring tide in zone A, B and C but in high tide for zone D. Sampling was carried out on June 13th as well as July 11th,12th, and 26th 2018 in Skarðshlíð (Site 2) and August 10th, 13th, 14th as well as September 10th 2018 in Kambsnes (Site1). Zone D was sampled November 6th 2019 in Kambsnes and November 14th 2019 in Skarðshlíð.

Sampling was performed using a 1m^2 and 20 cm^2 frame. Starting with zone A, 3 frames (1 m^2) were set down parallel to each other with a meter in between. By convention frame 1 was the frame to the left looking at the sea (fig. 9). Two lines were digitally drawn on a portable GIS device from the external sides of the frames at zone

A, perpendicular to the shoreline down into the sea. This helped to lay down the frames in zone B and C but especially helped for the sampling at zone D. A transect was therefore identified as a strip perpendicular to the shore, 5 meters wide from the higher level of the tide to the sharp shelf which is typical of glacial fjords (fig. 10).

Figure 9. Sampling at zone A. 3 (1m^2) frames laid down beside each other. Picture taken 12July 2018 at Skarðshlíð (Cristian Gallo).

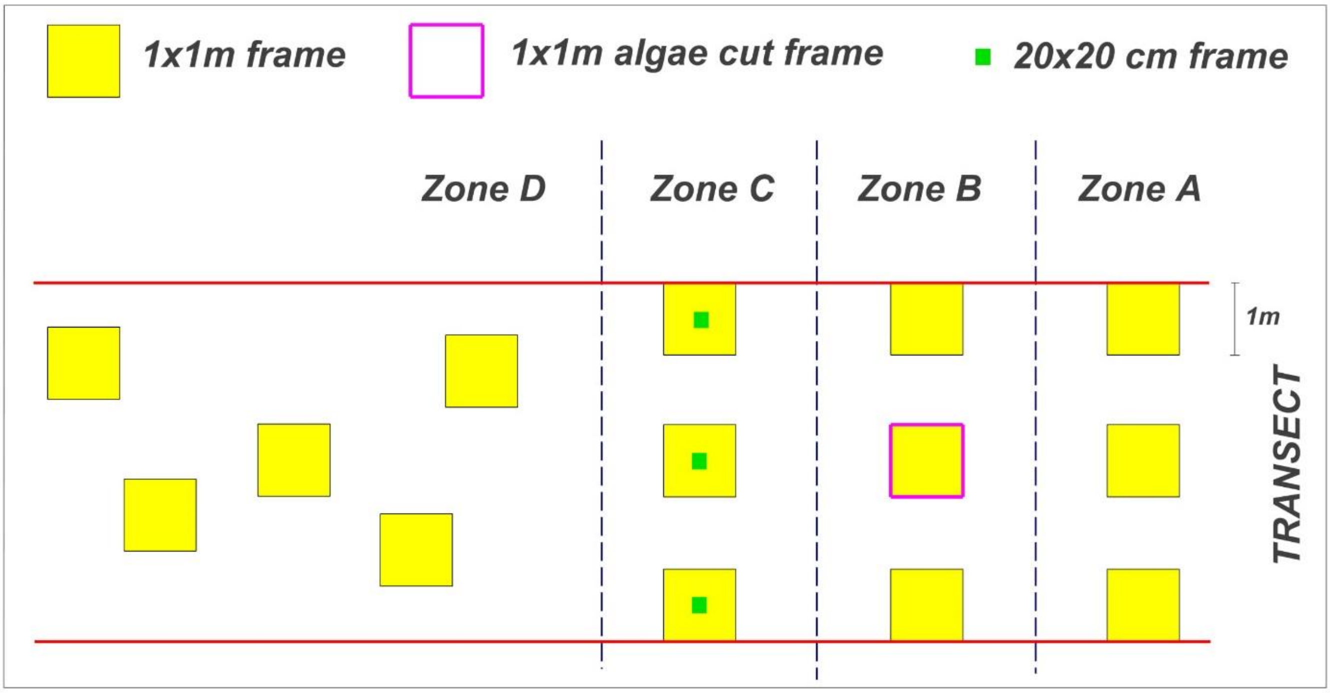

Figure 10. Sampling scheme used in this intertidal zone assessment. Positions of the frame at zone D could be different. (Cristian Gallo).

Due to the consistent variability in the trophic community composition among the 4 zones, a different methodology was consistently used to sample in each zone. Zones A, B and C were measured on land with use of a meter tape, while zone D was measured from sea by measuring the total length of transect with a range finder. Pictures were taken and descriptions made of all frames in zones A, B and C (not submerged) during sampling. The density of algae was estimated as percent cover and each species present were assigned a value of 1% as convention. Apart for this, individual zones were treated as follows.

Zone A (fig. 11): algae cover was estimated in the frames and the number of *Littorina saxatilis* as well as other invertebrates were counted directly. A qualitative method (x= present, xx= abundant, xxx= very abundant) was used to estimate the number of individuals for species which counting was not feasible due to small size or high numbers (fig. 12). 30 *Littorina saxatilis* were collected and set in a container.

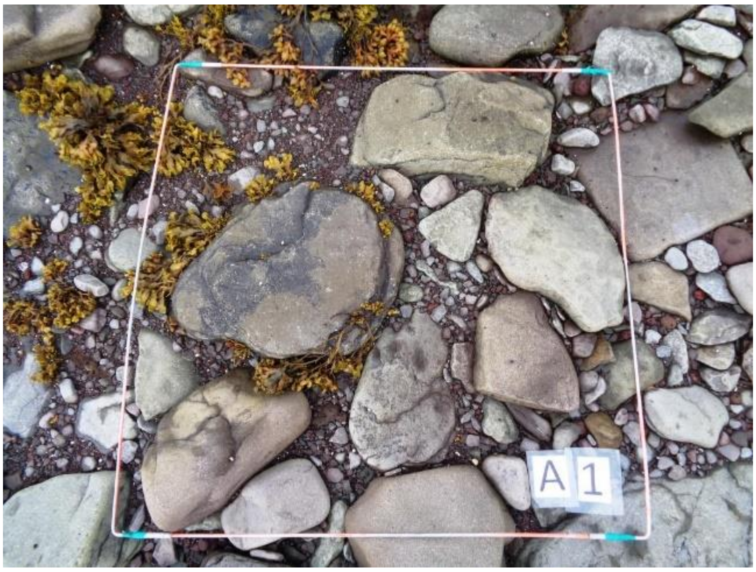

Figure 11. Typical frame at zone A, Skarðshlíð. Picture taken 12 July 2018 (Cristian Gallo).

Figure 12. Number of gasteropodes were counted but counting of barnacles was only qualitative estimated. Skarðshlíð. Picture taken 12 July 2018 (Cristian Gallo).

Zone B (fig. 13): all 3 frames were described in terms of algae cover and the presence of fauna was estimated using a quantitative method (x= present, xx= abundant, xxx= very abundant). Algae, *Ascophyllum nodosum* or *Fucus vesiculosus,* were cut down to 10 cm in frame 2 and weighed separately (wet weight). After the cut, algae present in this under layer were identified (fig. 14 and 15), estimate cover and count all fauna except for those species for which counting was not feasible due to small size or high numbers (fig. 12), in which case the same qualitative method as described above was used. 30 *Littorina obtusata* and 30 *Idotea granulosa* were collected if possible and placed in separated containers.

Figure 13. Sampling at zone B, Kambsnes. Picture taken 10 August 2018 (Cristian Gallo).

Figure 14. Zone B, frame 2 before cutting of Ascophyllum nodosum and Fucus vesiculosus. Picture taken 11 July 2018 (Cristian Gallo).

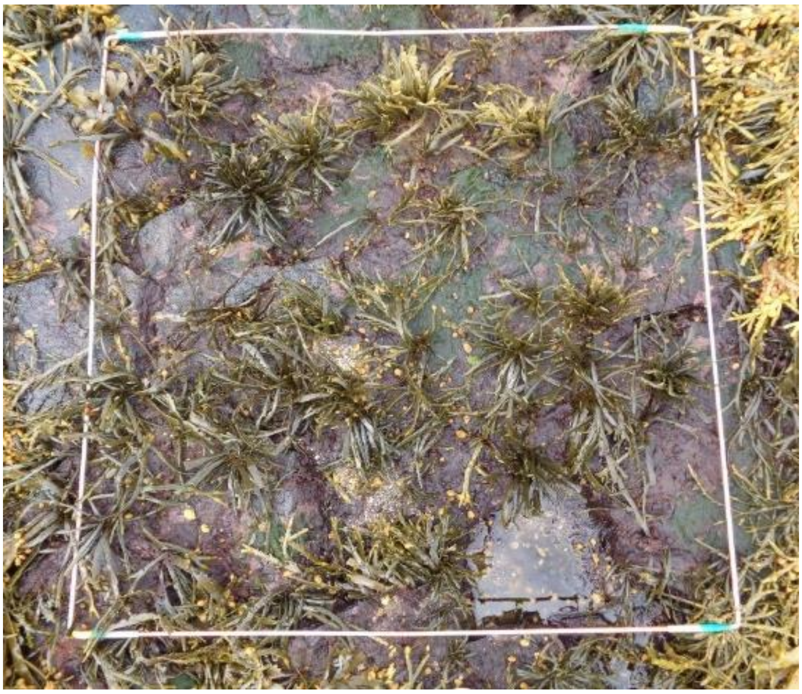

Figure 15. Zone B, frame 2 after cutting of Ascophyllum nodosum and Fucus vesiculosus. Picture taken 12 July 2018 (Cristian Gallo).

Zone C (fig.16): all 3 frames were described in terms of algae cover and the presence of fauna was counted or estimated using a quantitative method (x= present, xx= abundant, xxx= very abundant). A smaller frame (20x 20 cm) was set in the middle of the big frame and photographed. Everything within the frame (20x20 cm) was collected and placed into a plastic container for faunal analysis. At least 30 individuals of *Semibalanus balanoides* and *Idotea granulosa* were collected if present and placed into a plastic container.

Figure 16. Sampling at zone C, Kambsnes. Picture taken 13 August 2018 (Cristian Gallo).

Figure 17. Zone C, overview of frames, Kambsnes. Picture taken 10 Agust 2018 (Cristian Gallo).

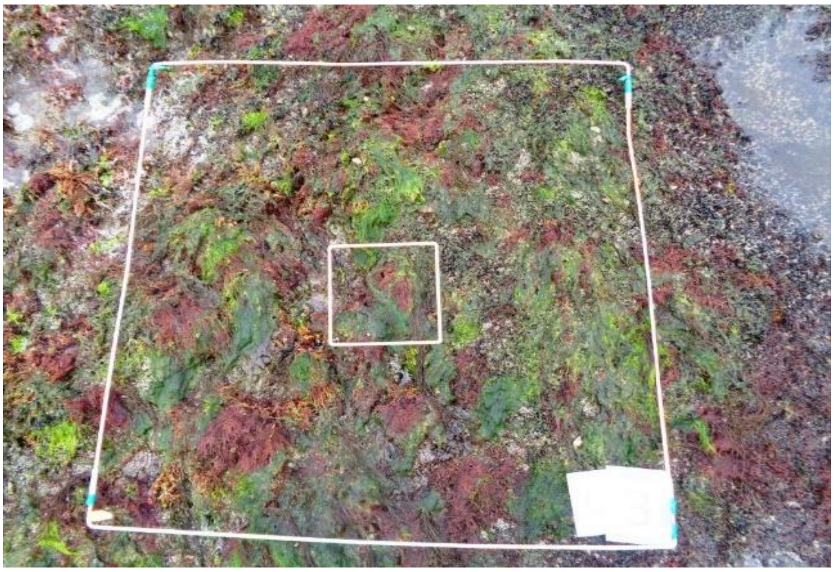

Figure 18. Zone C, overview of frames, Kambsnes. Picture taken 10 September 2018 (Cristian Gallo).

Zone D: sampling was conducted from a boat using the same $1m^2$ frame. The boat was anchored at the highest part of the zone and a rope released until the end of the zone. The $1m^2$ sampling frame was lowered to the sea floor inside the 5 m wide transect (fig. 19 and 20). Five samples were taken randomly along the zone from highest to lowest points. Using an Aqua-scope (fig. 21) and focusing within the submerged $1m^2$ frame, kelp plants and sea urchins were counted, % coverage of *Lithothamnium glaciale* (mærl) was estimated and other algae present were noted. The length of the zone was indirectly measured with a rangefinder by measuring the total length of the all transect starting from zone A and subtracting the length of other zones previously measured on land.

Figure 19. Frame (1m2) on the sea bottom at zone D. Picture taken 14 November 2019 (Cristian Gallo).

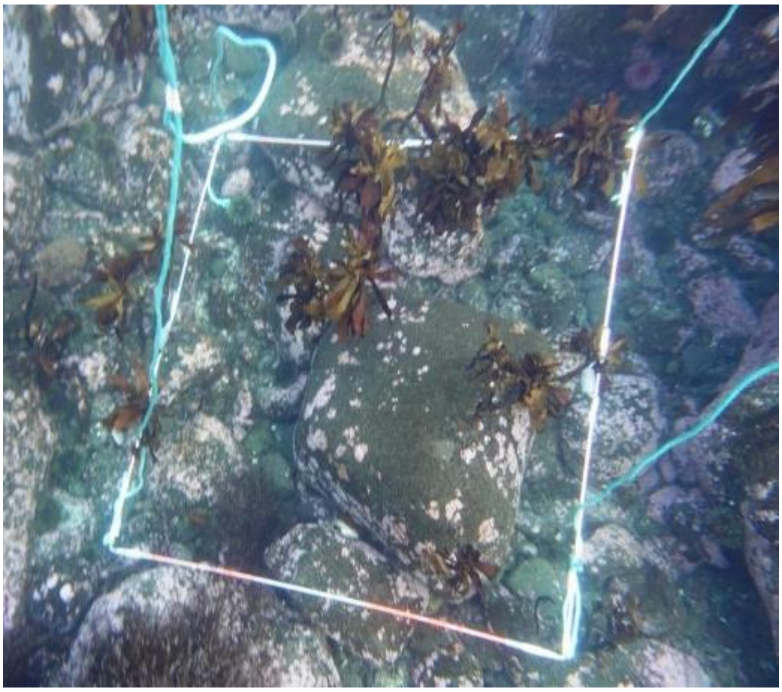

Figure 20. Frame (1m2) on the sea bottom at Zone D. Pictures taken 14 November 2019 (Cristian Gallo).

Figure 21. Acqua-scope used for submergerd algae density estimation, Skarðshlíð. Picture taken 14 November 2019.

Littorinas, Idoteas and barnacles were collected separately for isotopes analysis, labelled, and placed in a freezer at Náttúrustofa Vestfjarða in Bolungarvík. Animal samples from zone C were placed in a formaldehyde solution with sea water (8%) and after 5-6 days the formaldehyde was replaced with 90% EtOH. All animals in the samples were later identified and counted using a stereo microscope at Náttúrustofa Vestfjarða´s laboratory in Bolungarvík. To confirm identification of algae, sub-samples were sent to Karl Gunnarson at the Icelandic Marine Research Institute (Hafrannsóknastofnun).

Datasets were averaged in case of 3 or 5 replicates. Shannon-Wiener biodiversity index and Simple matching similarity test was calculated using Primer 6 (CiTE).

RESULTS

Site 1. Kambsnes

Table 1. Kambsnes. Zones length (meter). Transect 7 was not considered for the calculation of the average standard transect size (Av. Tr.).

Zone	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
A	5	3	3	3	3	2	4	2	3,0
A-B	4	6	5	0	2	5	13	0	3,1
B	6	9	13	16	15	13	10	23	13,6
C	2	3	5	6	4	3	-	5	4,0
D	23	14	24	15	12	18	-	21	18,1

Table2. Fauna at Kambsnes, zone A. Averaged from 3 frames (1m²).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Littorina saxatilis	56,0	142,3	11,7	11,0	11,0	65,3	53,7	153,7	63,1
Nucella lapillus		1,7						0,7	0,3
Littorina obtusata						5,0			0,6
*Semibalanus balanoides**	xx		x			xx			
*Spirorbis spp.**						x			

*x = present, xx =abundant, xxx= very abundant

Table 3. Flora at Kambsnes, zone B, frame 2. Algae wet weight (kg) after cut (1m²).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Acophyllum nodosum	13	12	9	5	4	30	30	9	14
Fucus vesiculosus		1		6	3			6	2

Table 4. Flora and fauna at Kambsnes, zone B. Coverage (%) averaged from 3 frames (1m²), animals estimated quantitatively (see methodology).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Acophyllum nodosum	75,0	91,7	8,0	78,3	75,0	95,0	86,7	36,7	77,29
Fucus vesiculosus	13,3	6,7	3,3	21,7	23,3	5,0	13,3	38,3	15,63
Bedrock/ sand	3,3	1,7	15,0		1,7			11,7	4,17
Fucus spiralis	8,7							1,7	1,29
Polysiphonia lanosa	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Pylaiella littoralis								5,0	0,63
Chondrus crispus								3,3	0,42
Cystoclonium purpureum			2,0						0,25
Elachista fucicola	0,7			0,3	0,3		0,3	0,3	0,23
Fucus linearis								1,7	0,21
Monostroma grevillei CF								1,7	0,21
Plumaria plumosa			0,7						0,10
Ceramium sp.								0,3	0,10
Chorda filum								0,3	0,10
Chordaria flagelliformis								0,3	0,10
Cladophora rupestris			0,3						0,10
Corallina officinalis								0,3	0,10
Devaleraea ramentacea								0,3	0,10
Lithothamnion glaciale					0,3				0,10
Palmaria palmata	0,3								0,10
Spongonema tomentosum				0,3					0,10
Braun unknown	0,3								0,10
Red unknown								0,3	0,10
Littorina obtusata	x	x	x	xx	xx	x	x	x	
Semibalanus balanoides	xxx	xx	x		xxx			xx	
Mytilus edulis	xxx								
Nucella lapillus	x	x	x	x	x	x		x	
Littorina saxatilis								x	
Dynamena pumila	x	x	x	x		x	x	x	

*x = present, xx =abundant, xxx= very abundant

Table 5. Flora and fauna at Kambsnes, zone B, frame 2. Coverage (%) and animals counted or estimated (1m^2) after removal of covering of *Ascophyllum nodosum* and *Fucus vesiculosus*.

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Bedrock/sand	5,0	1,0	3,0	15,0	3,0	75,0	5,0	65,0	21,5
Acophyllum nodosum	4,0	4,0	25,0	2,0	2,0	25,0	2,0	5,0	8,6
Fucus vesiculosus	1,0		5,0	25,0	2,0			25,0	7,3
Lithothamnion glaciale	1,0	5,0	1,0	1,0	5,0	1,0	25,0		4,9
Plumaria plumosa		25,0	5,0	1,0	5,0				4,5
Cystoclonium purpureum	1,0	5,0	15,0	1,0					2,8
Ceramium cf virgatum	5,0			5,0	5,0				1,9
Cladophora rupestris		1,0	1,0	1,0	5,0			5,0	1,6
Corallina officinalis	1,0	5,0	5,0						1,4
Palmaria palmata	1,0		1,0	1,0	5,0				1,0
Halichondria panicea cf	1,0						5,0		0,8
Spongonema tomentosum					5,0			1,0	0,8
Red unknown	1,0	1,0			1,0			1,0	0,5
Chordaria flagelliformis			1,0					1,0	0,3
Green unknown	1,0	1,0							0,3
Monostroma grevillei cf			1,0		1,0				0,3
Chondrus crispus				1,0					0,1
Dictyosiphon foeniculaceus		1,0							0,1
Dumontia contorta				1,0					0,1
Elachista fucicola	1,0								0,1
Pylaiella littoralis			1,0						0,1
Polysiphonia lanosa								1,0	0,1
Rhodomela lycopodioides					1,0				0,1
Braun unknown	1,0								0,1
Semibalanus balanoides	xxx	xx	x		xxx			xx	
Mytilus edulis	xxx								
Littorina obtusata	19,0	15,0	26,0	15,0	98,0	35,0	62,0	22,0	36,5
Nucella lapillus	2,0	6,0	3,0	4,0	2,0	3,0		3,0	2,9
Littorina saxatilis								9,0	1,1
Testudinalia testudinalis		1,0	1,0		1,0	1,0			0,5
Idotea granulosa			2,0	1,0					0,4
Buccinum undatum			1,0	1,0					0,3

*x = present, xx =abundant, xxx= very abundant

Table 6. Flora and fauna at Kambsnes, zone C. Percent cover averaged from 3 frames (1m^2). Transect 7 excluded from average (Av. Tr.).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Acrosiphonia arcta	8,3	31,7	5,0	5,3	28,3	3,3		28,3	15,8
Corallina officinalis		13,3	23,3	8,3	15,0			21,7	11,7
Fucus distichus f. Typica	16,7	5,3	1	13,3	1	16,7	7,0	5,3	8,5
Leathesia difformis	1,0	11,7	16,7	8,7	8,3	0,7		8,3	7,9
Cystoclonium purpureum	23,3	8,7	5,0	1,0	0,7	6,7		5,3	7,2
Acophyllum nodosum	0,3	8,3	11,7	8,3	3,3	8,3	0,7	7,0	6,8
Bedrock/sand		6,7	13,3	2	11,7	8,3	93,3	1,7	6,2
Chondrus crispus	8,7	2,3	0,3	3,7	1	1,7		8,3	3,7
Eudesme virescens		5,3	1	6,7	5,3			5,0	3,3
Lithothamnion glaciale	0,3	5,0	3,7	6,7	2,3			5,3	3,3
Mytilus edulis						25,0			3,1
Chordaria flagelliformis	0,7	0,3	2,0	8,3	2,0	3,3		3,7	2,9
Cladophora rupestris	8,3		1,7	0,3		1,0		3,7	2,1
Palmaria palmata	11,7			1,7		0,3			2,0
Rhodomela lycopodioides	3,7		0,3	3,7	2,0				1,4
Ceramium cf virgatum	0,3					8,3			1,2
Spongonema tomentosum	3,7			0,7	1,0	1,7		0,3	1,0
Dumontia contorta		0,3		3,3	0,3	0,3		2,0	0,9
Enteromorpha prolifera	0,3	2,3				3,3			0,9
Pylaiella littoralis	5,0		0,3		0,7				0,9
Ralfsia fungiformis cf				0,7	3,7				0,6
Monostroma grevillei cf		0,3		1,0	1,0	0,7			0,4
Braun unknown	0,3		0,7	1,0	0,3	0,3		0,3	0,4
Ahnfeltia plicata			0,3	2,0					0,3
Scytosiphon lomentarius	2,0								0,3
Devaleraea ramentacea	1,7								0,2
Polysiphonia lanosa				0,7	0,3		0,3	0,3	0,2
Dictyosiphon foeniculaceus			0,3	0,3	0,3				0,1
Elachista fucicola	0,3								0,1
Plumaria plumosa	0,3					0,3			0,1
Red unknown	0,3								0,1

Table 7. Fauna at Kambsnes, zone C. Average abundance in 3 smaller frames (400 cm²) expressed here in individuals on 1m². Transect 7 excluded from the calculation of the average transect (AV. Tr.).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Arthropoda									
Acarina	227	17		13	2			13	38,9
Crustacea									
Amphipoda	12	43	593	5		27		155	119,3
Amphithoe rubricata	17	578	513	193	475	95		28	271,4
Corophium bonelli			67						9,5
Gammarus spp.		2			7				1,2
Hyale prevosti	24			13				7	6,3
Isopoda									
Idotea granulosa	577	73	298	32	128	22		393	217,7
Jaera spp.	43	27	17	47	33			93	37,1
Copepoda			17	2					2,7
Decapoda									
Carcinus maenas			2						0,2
Cirripedia									
Semibalanus balanoides	73		2						10,7
Insecta									
Chironomidae larvae	3	27	37	123	97	327	3	13	89,5
Mollusca									
Bivalvia									
Hiatella arctica		247	138	3				5	56,1
Heteranomia squamula cf		3	2						0,7
Musculus discors		1						2	0,4
Mytilus edulis	15147	264	167	14	113	977		353	2433,5
Turtonia minuta	93	1276	1457	713	157	83		955	676,3

Table continue in the next page.

Taxa	**Transect**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Av. Tr.**
Gasteropoda									
Lacuna vincta	33	747	2127	13667	123	37		1327	2580,0
Littorina obtusata	113			2	12	3			18,6
Margarites helicinus		12	26	27	1	33			14,1
Nucella lapillus	27	36	177	47	52	47		95	68,5
Onoba aculeus	37	1193	3313	28	8	593		767	848,5
Skeneopsis planorbis	1853	2452	98	63	2293	48		853	1094,5
Testudinalia testudinalis								3	0,5
Tonicella marmorea		3	2						0,7
Annelida Oligochaeta	733	19	1682	12	23	68	47	735	467,4
Annelida Polychaeta									
Cirratulus cirratus	3	3	7						1,9
Eteone sp.		13							1,9
Fabricia stellaris			5	13	277				42,1
Malacoceros fuliginosus							7		*
Naineris quadricuspida				2		63			9,3
Nereis pelagica		5	35	3		2		17	8,8
Lepidonotus squamatus		17	7						3,3
Phyllodoce sp.		2		25				1	4,0
Polynoidae		23	7	2					4,5
Scoloplos armiger			7	93		18			16,9
Spio sp.							43		*
Spirorbis spp.		67	746	5	33	1333			312,0
Nematoda	857	2177	2667	3825	2273	44	38	3928	2253,0
Nemertea		3			7	83	17	13	15,2
Turbellaria						7			1,0

*transect 7 excluded from calculations of Av. Tr.

Table 8. Zone C, Kambsnes. Number of species (S), total individuals (N), Margalef species richness (d), Pielou´s evenness (J´) and Shannon-Wiener (H´log $_e$) results.

Transect	S	N	d	J'	H'(loge)
1	18	29223	1.65	0.41	1.18
2	28	55518	2.47	0.47	1.57
3	28	22132	2.70	0.64	2.13
4	26	23778	2.48	0.49	1.60
5	19	10227	1.95	0.68	2.02
6	20	14350	1.99	0.45	1.34
7	6	425	0.83	0.52	0.94
8	21	28730	1.95	0.58	1.75

Table 9. Zone C, Kambsnes. Simple Matching Similarity Test between transects.

Transect	1	2	3	4	5	6	7
2	61						
3	61	71					
4	71	66	71				
5	78	68	59	73			
6	71	61	61	76	78		
7	56	37	32	37	59	56	
8	78	73	54	73	71	68	54

Table 10. Flora and fauna at Kambsnes, zone D. Average abundance from 5 frames (1m^2), transect 7 not sampled. Laminaria plants and sea urchins counted, *Lithothamnion glaciale* coverage (%).

Taxa	Transect						
	1	2	3	4	5	6	8	Av. Tr.
Laminaria digitata	9,3	10,3	11,6	7	13,5	8,5	8,5	9,8
Laminaria saccharina	0,8	1,0	2,4		0,6			0,7
Lithothamnion glaciale %	57	52	49	28	58	42	66	50 %
Sea urchins	1,6	1,4	1,6	2,2	1,6	1,8	2,4	1,8

Site2. Skarðshlíð

Table 11. Skarðshlíð. Zones length (meter).

Zone	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
A	5	6	6	5	4	4	4	4	4,7
B	8	7	6	9	6	6	3	16	7,6
C	3	5	5	7	6	6	11	3	5,7
D	12	10	10	8	8	10	10	9	9,6

Table 12. Fauna at Skarðshlíð, zone A. Average from 3 frames (1m^2).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Littorina saxatilis	156,7	103,3	26,0	36,0	86,7	101,3	65,3	36,0	76,4
Littorina obtusata					11,7			5,7	2,2
Nucella lapillus		2,7		0,3	7,0		1,0	5,0	2,0
Semibalanus balanoides					xxx		xxx		

*x = present, xx =abundant, xxx= very abundant

Table 13. Flora at Skarðshlíð, zone B, frame 2. Algae wet weight (kg) after cut (1m^2).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Acophyllum nodosum	18	15		14	10	13	3	14	11
Fucus vesiculosus		1	10		4	6	14		4

Table 14. Flora and fauna at Skarðshlíð, Zone B. Coverage (%) average from 3 frames (1m²) and animals estimated.

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Acophyllum nodosum	100	46,7	16,7	80	58,3	35	10	70	52,1
Fucus vesiculosus		38,3	58,3	20	23,3	38,3	68,3	22	33,6
Bedrock		5	16,7		18,3	13,3	18,3	8,3	10,0
Cladophora rupestris		6,7	0,3		0,3	1,7			1,1
Braun unknown			5,3		1,7		0,3		0,9
Fucus linearis						6,7			0,8
Fucus spiralis			3,3				3,3		0,8
Fucus distichus f. Typica						5			0,6
Green unknown			2,3		0,3	0,7			0,4
Polysiphonia lanosa	0,7	0,7						0,7	0,3
Acrosiphonia arcta			1,7		0,3				0,3
Elachista fucicola	0,3		0,3		0,3	0,3	0,3	0,3	0,2
Plumaria plumosa		1,7							0,2
Monostroma grevillei cf			0,3		0,3				0,1
Devaleraea ramentacea			0,3						0,1
Chordaria flagelliformis					0,3				0,1
Semibalanus balanoides			xxx		xxx	xxx	xxx		
Mytilus edulis			xx		xx	x	x		
Littorina obtusata	xx	xx	xx	xx	x	xx	xx	xx	

*x = present, xx =abundant, xxx= very abundant

Table 15. Flora and fauna at Skarðshlíð, Zone B, frame 2. Percent cover and animals counted or estimated after removal of *Ascophyllum nodosum* and *Fucus vesiculosus* (1m^2).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Bedrock	5		35	10	45	40	20	60	26,9
Acophyllum nodosum	25	15	25	15	25	40	5	25	21,9
Fucus vesiculosus		15	15	1	10	20	70		16,4
Plumaria plumosa	45	30	5	40				5	15,6
Cladophora rupestris	20	35	5	25	10	1	1		12,1
Corallina officinalis	5	1	5					5	2,0
Lithothamnion glaciale	1	5		10					2,0
Chordaria flagelliformis			5		10				1,9
Red unknown	1	1	5	1			1	1	1,2
Acrosiphonia arcta							5		0,6
Braun unknown		1	1				1	1	0,5
Palmaria palmata							1	1	0,3
Fucus spiralis								1	0,1
Halichondria panicea								1	0,1
Monostroma grevillei cf								1	0,1
Polysiphonia lanosa								1	0,1
Semibalanus balanoides			xxx		xxx	xxx	xxx		
Mytilus edulis			xx		xx	x	x		
Littorina obtusata	13	152	53	65	25	89	35	112	68,0
Nucella lapillus	2	3		4	6	5	5		3,1
Testudinalia testudinalis	3							1	0,5
Idotea granulosa		2							0,3
Patella pellucida							1		0,1

*x = present, xx =abundant, xxx= very abundant

Table 16. Flora at Skarðshlíð, zone C. Coverage (%) average from 3 frames (1m²).

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Fucus distichus f. Typica	3,0	8,3	17,0	17,0	21,7	38,3	41,7	16,7	23,8
Acrosiphonia arcta	18,3	43,3	48,3	16,7	25,0	13,3	8,3	5,3	22,3
Bedrock		8,3	2,0	1,0	3,0	1,0	6,7	3,0	14,4
Pylaiella littoralis	8,3	8,7	7,0	2,0	8,3	5,0	23,3		10,1
Chordaria flagelliformis	5,0	8,7		5,3		11,7	0,7	3,7	4,4
Cystoclonium purpureum		13,6	5,0	6,7	0,7	2,0		0,3	3,5
Cladophora rupestris	11,7	2,0	0,3	1,7		3,3	0,7	2,0	2,7
Acophyllum nodosum	11,7	2,0		0,3		3,3	1,7		2,4
Corallina officinalis	5,0	0,3				0,3		11,7	2,2
Spongonema tomentosum	5,0	0,7	2,0	3,3		7,0	0,7		2,3
Monostroma grevillei cf	3,3	0,7		8,3	0,3	0,3		2,3	1,9
Palmaria palmata		5,3		3,3		3,7	2,3	0,3	1,9
Laminaria saccharina								13,7	1,7
Braun unknown	1,6	0,3	2,0	0,3	5,0	0,3	3,6		1,6
Devaleraea ramentacea		0,7	0,7	1,3		0,3	0,7		1,6
Desmarestia aculeata					1,0			2,0	1,5
Rhodomela lycopodioides		0,7				1,7		5,0	0,9
Lithothamnion glaciale				0,7				5,3	0,8
Laminaria digitata		0,3			0,3	3,3		1,7	0,7
Chondrus crispus								3,3	0,4
Dictyosiphon foeniculaceus		0,3		0,3		1,7	0,7		0,4
Polysiphonia lanosa	0,7						0,3		0,1
Ceramium sp.		0,3						0,7	0,1
Dumontia contorta		0,3			0,3	0,3			0,1
Green unknown			0,3			0,3			0,1
Enteromorpha prolifera							0,3		0,1
Fucus vesiculosus							0,3		0,1
Halichondria panicea cf		0,3							0,1
Red unknown						0,3			0,1

Table 17. Fauna at Skarðshlíð, zone C. Average abundance of 3 smaller frames (400 cm^2) expressed here in individuals on $1m^2$.

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Arthropoda									
Acarina	9	21	12	663	167	242	28		142,8
Crustacea									
Amphipoda						5	17	167	23,6
Amphithoe rubricata	8	7	13	62		13			12,9
Corophium bonelli								14	1,8
Gammarus spp.		12	93	228		2	3		42,3
Hyale prevosti	55	55	8	87					25,6
Isopoda									
Idotea granulosa	27	267	87	165		17	3	12	72,3
Jaera spp.	2	1							0,4
Copepoda		1	62	33	167			23	35,8
Decapoda									
Eupagurus bernhardus								2	0,3
Hyas araneus								2	0,3
Cirripedia									
Semibalanus balanoides	77	1	2					223	37,9
Insecta									
Chironomidae	9	7		33	13	2	7		8,9
Mollusca									
Bivalvia		3							0,4
Hiatella arctica	58	8		2					8,5
Musculus discors	33		3		2			7	5,6
Mytilus edulis	415	227	4773	3147	2118	287	1767		1591,8
Turtonia minuta	7253	167	13	27				163	952,9

Table continue in the next page.

Taxa	**Transect**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Av. Tr.**
Gasteropoda									
Lacuna vincta	3	8	27	8		1	7	138	24,0
Littorina obtusata	45	97	3	23	2	13	18	12	26,6
Margarites groenlandicus		3						2	0,6
Margarites helicinus	14	1	17	12	2	3		33	10,3
Nucella lapillus	38	57	2	47	22	33	13	2	26,8
Onoba aculeus	1297	327	34	575	5	77	73	32	302,5
Skeneopsis planorbis	353	593	12187	11453	3217	2853	3427		4260,4
Tectura virginea	2								0,3
Testudinalia testudinalis	8	2		13		3	3	2	3,9
Annelida Oligochaeta	197	287	5	73	1348	243	692	13	357,3
Annelida Polychaeta									
Harmothoe imbricata								14	1,8
Lepidonotus squamatus								2	0,3
Naineris quadricuspida			3	7				1	1,4
Nereis pelagica						3	2	7	1,5
Phyllodoce maculata	7							28	4,4
Polynoidae				7		5			1,5
Spirorbis spp.								167	20,9
Nematoda	164	8	978	698	2692	342	713	177	721,5
Nemertea						3	13		2,0

Table 18. Zone C, Skarðshlíð. Number of species (S), total individuals (N), Margalef species richness (d), Pielou´s evenness (J´) and Shannon-Wiener (H´log $_e$) results.

Transect	S	N	d	J'	H'(loge)
1	22	18561	2.14	0.56	1.73
2	23	9477	2.40	0.49	1.53
3	19	18871	1.83	0.35	1.04
4	21	17363	2.05	0.39	1.20
5	12	9800	1.20	0.61	1.52
6	19	6037	2.07	0.47	1.38
7	16	7101	1.69	0.52	1.45
8	24	1684	3.10	0.77	2.44

Table 19. Zone C, Skarðshlíð. Simple Matching Similarity Test between transects.

Transect	1	2	3	4	5	6	7
2	81						
3	76	78					
4	76	84	84				
5	68	65	76	70			
6	65	68	68	78	70		
7	62	65	65	70	73	92	
8	46	43	54	43	46	43	46

Table 20. Flora and fauna at Skarðshlíð, zone D. Average abundance from 5 frames (1m^2). Laminaria plants, *Dermarestia aculeata* and sea urchins counted, *Lithothamnion glaciale* estimated by percent cover.

Taxa	Transect								
	1	2	3	4	5	6	7	8	Av. Tr.
Laminaria digitata	14,4	9,8	11,2	11,0	6,0	11,6	11,0	9,0	10,5
Laminaria saccharina				4,0	0,6		4,8	10,2	2,5
Desmarestia aculeata			0,2			0,2	0,2	0,6	0,2
Lithothamnion glaciale	40,0	14,0	16,0	28,0	20,0	21,0	9,0	9,2	19,6 %
Corallina officinalis							x	x	
Sea urchins	6,0	6,0	6,2	9,0	3,8	5,6	7,8	10,3	6,8

x =present

In Kambsnes, the middle zone (AB) is characterized mainly by the presence of *Fucus spiralis* (table 1 and fig. 22), however algae abundance was less when compared with zone B. The average zone length (Av. Tr.) for zones A and C was similar (3 - 4 m.) while zone B was longer (13.6 m. avg.) and particularly extended at transect 8 (23 m). In Kambsnes transect 7 was excluded from these calculations because it was topographically differentiated from the other transects, being less rocky, more level and having a longer shore. Due to its proximity to the peninsula (eyri) the shore at zone C was mainly composed of sand. Zone D was found to be on average around 18 m. In Skarðshlíð (table 11) the shoreline was more homogeneous with no presence of the AB zone (*Fucus spiralis)*, zones A and C were similar (5-6-meter-long), with zone C particularly long at transect 7 (11 meters). Zone B was in average 7.6 meters at this site and zone D was 9.6 m.

Figure 22. Zone AB between zone A (frames) and zone B. Zone AB with Fucus spiralis (more reddish colour) if compare to Ascophyllum nodosum and Fucus vesiculosus in different brown -green colour. Kambsnes. Picture taken September 10th, 2018 (Cristian Gallo).

Figure 23. Overview of all zones from the border between zone C and D, Skarðshíð. Picture taken April 30th 2018 (Cristian Gallo).

Zone A was dominated mainly by *Littorina saxatilis*, with an average of 63 ind./m^2 in Kambsnes and 76 ind./m^2 in Skarðshíð. *Littorina obtusata, Nucella lapillus* and *Semibalanus balanoides* were also present in this zone in low abundance (table 2 and 12).

In general zone B at both locations was mainly dominated by the presence of 2 algal species, *Ascophyllum nodosum* and *Fucus vesiculosus*. In Kambsnes, *Ascophyllum nodosum* showed roughly 77 % cover and had a wet weight of roughly 14 kg per m^2 while *F. vesiculosus* showed roughly 15% cover and had a wet weight of roughly 2 kg per m^2(table 3 and 4). In Kambsnes, *Ascophyllum nodosum* had a wet weight of roughly 30 kg per m^{2}transect 6 and 7. In Skarðshlíð, *Ascophyllum nodosum* showed on average around 52 % cover with full cover at transect 1 and lowest (10%) at transect 7. *Fucus vesiculosus* had 34% cover and was more abundant then *Ascophyllum* at transect 3 and 7. In Skarðshlíð, the wet weight of *A. nodosum and F. vesiculosus* was 11 and 4 kg per m^2 respectively(table 13 and 14).Few other species of algae were present with very low coverage.

After *A. nodosum* and *F. vesiculosus* were removed from inside the frame the algae cover was re-assessed. At this stage in Kambsnes the bedrock became the most abundant with 21 % cover per m^2 on average between 8 frames. *A. nodosum* and *F. vesiculosus*, which were left intentionally at 10 cm length, were covering 9 and 7 % of the m^2 frame respectively. After those the most common species were *Lithothamnion glaciale* (vörtukórall) (~5%), *Plumaria plumosa* (rauðfjöður) (4.5%), *Cystoclonium purpureum* (rauðskúfur) (2.8%), *Ceramium cf virgatum* (brimkló) (1.9%), *Cladophora rupestris* (steinskúfur) (1.6%), *Corallina officinalis* (kóralþang) (1.4 %), *Palmaria palmata* (söl) (1%). Other algae were found but their coverage weas less than 1% per m^2. *Littorina obtusata* (þangdoppa), *Nucella lapillus* (nákuðungur) and *Semibalanus balanoides* (fjöruhrúðurkarl) were the most common animals in the frame with an average of 36 Littorinas and 3 of Nucellas per m^2 (table 5).

In Skarðshlíð, after removal, the bedrock covered around 27% of 1 m^2, *Ascophyllum nodosum* (22%), *Fucus vesiculosus* (16%), *Plumaria plumosa* (16%), *Cladophora rupestris* (12%), *Corallina officinalis,* Lithothamnion *glaciale* and *Chordaria flagelliformis* (2% each). 1,2% of red unknown algae rather broken or unrecognisable, the rest was all under 1% cover. *Littorina obtusata* (68 ind./m^2) and *Semibalanus balanoides* were the most abundant animals (table 15).

Zone C was characterized by smaller algae species. At Kambsnes, *Acrosiphonia arcta* (brimskúfur) was most abundant with 16 % on average cover between 7 transects (transect 7 was excluded because it was very different from the other transects). The next most abundant algae species was *Corallina officinalis*(12%), *Fucus distichus* (belgjaþang) (8.5%), *Leathesia difformis* (fjörupungar) (8%), *Cystoclonium purpureum* (7.2%), *Ascophyllum nodosum* (6.8%), bedrock (6.2%), *Chondrus crispus* (fjörugrös) (3.7%), *Eudesme virescens* (slímbendill) and *Lithothamnion glaciale* (3.3% each). *Cladophora rupestris* (2.1%), *Palmaria palmata* (2.0%), *Rhodomela* *lycopodioides* (surtarjafni) (1.4%), *Ceramium cf virgatum* (1.2%) and *Spongonema tomentosum* (snúðslý) (1%). *Mytilus edulis* (krækilingur) cover was 25 % on average at transect 6. Many other algae species were found but all of them covered less than 1% of the sampling frame (table 6).

At Skarðshlíð, *Fucus distichus* showed highest coverage (24%), then *Acrosiphonia arcta* (22%), bedrock (14%), *Pylaiella littoralis* (steinslý) (10%), *Chordaria flagelliformis* (4.4%) and lastly *Cystoclonium purpureum* (3.5 %). Other species with less coverage can be viewed in table 16.

Zone C contained a diverse community of organisms, with over 35 species at both locations. In zone C at Kambsnes there were over forty species. The most abundant species in zone C at Kambsnes were *Mytilus edulis, Lacuna vincta* (þarastrútur), *Skeneopsis planorbis* (mærudoppa) and nematodes, all having over 1 thousand ind./m^2. The second most abundant organisms were *Turtonia minuta* (mæruskel), *Onoba aculeus* (baugasnotra), oligochaetes (ánar) and *Spirorbis spp.* (snúðormar), all having between 300 and 1 thousand ind./m^2(fig. 24). It is also worth mentioning that *Amphithoe rubricata* (dílafló) were also present with around 270 ind./m^2, as well as *Idotea granulosa* (þanglús) (218 ind./m^2), *Hiatella arctica* (rataskel) (56 ind./m^2), *Nucella lapillus* (nákuðungur) (68 ind./m^2)(fig. 25) and *Fabricia stellaris* (mottumaðkur) (42 ind./m^2). In total 12 species of polychaetas were found in the samples (table 7). Based on these results the number of species were similar (between 18 and 28) in all transect except for transect 7 (only 6). The Margalef species richeness index (d) (d = (S - 1) / ln N), which shows a measure of diversity in terms of the number of species in a specific site where S is the number of species, and N is the total number of individuals in the sample was also calculated. For transect 7, d was found to be between 1,65 and 2,70, with the lowest diversity being found in transect 7 (0,83). Pielou´s evenness, which show how even is the abundance between species in the sample, was measured between 0,41 and 0,68 with more evenness at transect 5 and lowest at transect 1. Pielou´s index span between 0 and 1 therefore measured values can be considered in between. The Shannon-Wiener diversity index, which measures species diversity, was found to be 0,9-2,1 (log e) for zone C at Kambsnes,with the lowest values being at transect 7 and highest values being found at transect 3 and 5. Shannon-Wiener diversity index values was found between 1 and 2,5 in other intertidal zones in the Westfjords area (Eiríksson et al. 2011, Eiríksson et al. 2015, Gallo and Albertsdóttir 2018). Average diversity (excluding transect 7) was 1,65 (log e) (table 8), which indicate an average diversity for the Westfjords area. A simple match similarity test, which measures how similar are the station between themselves based exclusively on species found, shows values between 59 and 78 between all transects except for transect 7, which was found to be very different from all other transects (similarity values between 32-59) (table 9).

At least 36 species were found in zone C in Skarðshlíð. The most abundant species were: *Skeneopsis planorbis* (in average 4260 ind./m^2), *Mytilus edulis* (>1000 ind./m^2), *Turtonia minuta* (in average 953 ind./m^2). The second most abundant groups were nematodes, oligochaetes and *Onoba aculeus* with anywhere between 300 and 953 ind./m^2. Worth mentioning: *Gammarus spp.* (42 ind./m$^{2)}$ were the most abundant amphipods, *Idotea granulosa* (72 ind./m^2), 9 species of gastropods and at least 7 species of polychaeta were found in the samples (table 17). At Skarðshlíð the number of species were found to be between 12 and 24 with the lowest diversity being found at transect 5 and the highest at transect 8. The Margalef species richeness index was found to be between 1.69 and 3,10. Pielou´s evenness, which show how even is the abundance between species in the sample, measured between 0,35 and 0,77 with more evenness at transect 8 and lowest at transect 4. The Shannon-Wiener diversity index shows values between 1 and 2,4 with the average transect having a value of 1,5 (table 18). A Simple matching similarity test returned values between 62 and 92 between all transect except transect 8. Transect 8 shows a lower similarity compared to others transect with values between 43-54 mainly due to the absence of *Mytilus edulis* and *Skeneopsis spp*. which were instead very abundant in all other transects (table 19).

Figure 24. Polychaeta *Spirorbis spp.* growing on *Fucus distichus*. (Cristian Gallo)

Figure 25. *Nucella lapillus* on green algae.

In Zone D the most common algae species present were *Laminaria digitata* and less of *L. saccharina*. The number of *L. digitata* in a 1m^2 frame varied along the transect. The number was always higher on the first sampled frame which was located higher on the shore. In this location the counting proved hard, with this sampling method, with up to 23 plants counted per 1m^2 (fig. 26).

At Kambsnes the number of plants ranged from 7 at transect 4 to 13.5 at transect 5, with an average of almost 10 plants/m^2. In comparison *L. saccharina* was much scarcer with 0,7 plant/m^2. *Lithothamnion glaciale* coverage went from 28 to 66 % with an average on 7 transect of 50%. Sea urchins counted 1,8 sea urchins every m^2 (table 10).

At Skarðshlíð *Laminaria digitata* density was between 6 to 14,4 plants/m^2 with an average of 10,5 plants/m^2. *L. saccharina* was absents in half of the transect and was found having an average density of 2,5 plants per m^2 mainly due to the high presence in transect 8. *Lithothamniom glaciale* coverage was around 20% at Skarðshlíð, sea urchins 6,8 animals x m^2. Here we also noted presence of *Desmarestia aculeata* and *Corallina officinalis* but in low density (table 20).

Figure 26. Kelp plants in 1m^2 frame. At highest part of zone D counting proved to be hard with this method due to high number of plants in the frame (Cristian Gallo).

DISCUSSION

Mariculture will affect the nutrient availability in the fjord ecosystem and may eventually change the population density of certain algae species as well as the herbivorous community which thrives on them. In order to obtain a baseline understanding, this study catalogued the community composition and population density of organisms found at 2 intertidal areas in Ísafjarðardjup prior to the implementation of proposed mariculture activities in the area. Algae coverage and animal abundance were evaluated on 8 transect for each site.

As mentioned above, these findings will serve as a baseline to determine the effects that proposed mariculture in the area may have on the organisms which reside in the intertidal zone. This study also provided an opportunity to investigate and collect valuable information about the intertidal zone in the Westfjords of Iceland. For example, *Chondrus crispus* (fig. 27) was found in both study sites, this is interesting because this species has not been recorded previously in Ísafjarðardjup (Karl Gunnarson, personal comment).

Figure 27. Chondrus crispus, Kambsnes. Picture taken 13 August 2018. (Cristian Gallo)

This study also provided the opportunity to look at some elements of the shore ecosystem which are not prevalent, and therefore unlikely monitored with regular methodology, but which could eventually provide a better understanding on the impact of mariculture on the intertidal environment. For example, more focus should be given to those species which are believed take advantage of the nutrient increase which is associated with mariculture. This includes green algae of the genus Ulva and Enteromorpha (fig. 28) as well as epiphytic algae (fig. 29). These mentioned algae were found in very low cover due to their small size and localize presence at a few locations as well as in water ponds left by retrieving sea during tides. These organisms could possibly be used as indicator species as an increase in their abundance/presence could be indicative of increased organic nutrient load from mariculture operations in the area. Therefore, a methodology could potentially be created which uses the density/abundance of these organisms as an indicator of potential heavy nutrient load deposition from mariculture operations.

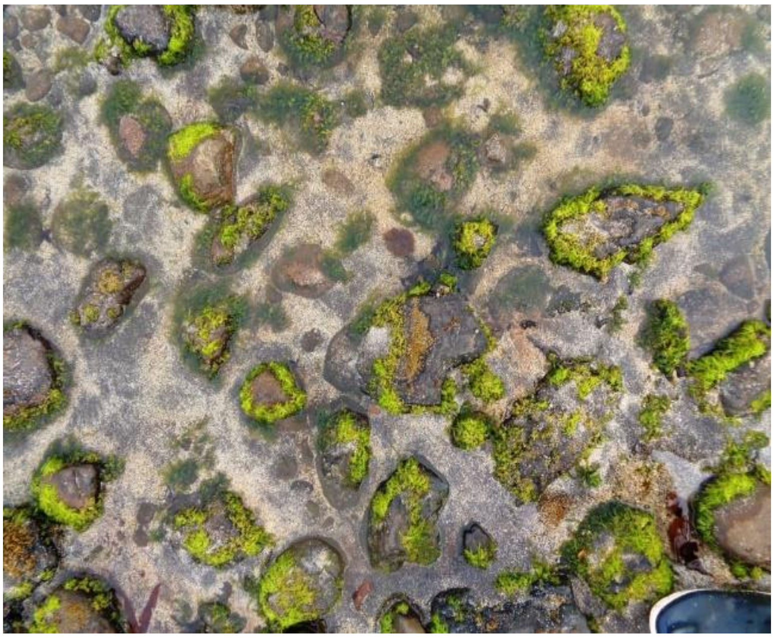

Figure 28. Ulva intestinalis, Kambsnes. Picture taken 10 September 2018 (Cristian Gallo).

Figure 29. *Polysiphonia lanosa* on *Ascophyllum nodosum*, Kambsnes. Picture taken 13 August 2018 (Cristian Gallo).

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APPENDIX 1.

Coordinates of sampled transects in Kambsnes and Skarðshlíð. Gps position correspond to frame 2 in zone B.

Transect	Kambsnes	Skarðshlíð
1	N66.03488° W22.93444°	N66.04933° W22.77133°
2	N66.03270° W22.93271°	N66.04717° W22.77232°
3	N66.03005° W22.93063°	N66.04520° W22.77235°
4	N66.02759° W22.92884°	N66.04307° W22.77207°
5	N66.02463° W22.92536°	N66.04090° W22.77237°
6	N66.01536° W22.92004°	N66.03100° W22.77540°
7	N66.01193° W22.92223°	N66.02208° W22.78103°
8	N66.04286° W22.93880°	N66.01432° W22.78242°