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Riverine and glacier influence on infaunal benthic communities in Isfjorden, Svalbard.

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ABSTRACT

Fjords are the interface between land and ocean, and processes happening on land have implication for the coastal areas. In addition, differences in fjord characteristics, such as morphology, sedimentation and water circulation, can drive differences in fjord ecology, including benthic community composition (Syvitsky *et al*. 1986). Soft-bottom macro-fauna was collected in August 2018 using a Van-Veen grab along inner to outer fjord transects in Billefjord, Tempelfjord and Adventfjord, as well as several nearshore river estuaries, nearshore glacier sites and shallow control stations. Samples were collected from 30 stations, and community composition was analyzed in relation to environmental factors, including temperature, redox potential (Eh), grain size, total organic matter, salinity bottom water and sediment chlorophyll *a,* and phaeopigment. Results from this study suggest that overarching fjord-based differences are overwhelmed by small-scale drivers with more local impacts, in terms of benthic community structure. Different environmental characteristics were observed between sampled habitats, with regards to chlorophyll a, phaeopigments, sediment porosity and temperature. Eight significant clusters were identified according to community data, and the majority of these clusters clustered according to habitat type. Species richness increase towards less disturbed environment, as well as difference in dominating taxa varied between clusters. Indicating that shallow areas are more temporally unstable, whilst the deeper areas are more stable. Benthic communities contribute to several key biogeochemical processes in sediments, re-mineralization of nutrients, as well as act as a food source for higher tropical levels. Therefore, the purpose with this study was to highlight these coastal areas and investigate how the different benthic communities differs between habitats and how different environmental drivers influence the benthic community structure.

Key words: Benthic community, Coastal environment, Fjord system, Glacier, Isfjord, Nearshore, River Estuary, Terrestrial input

LIST OF FIGURES:

LIST OF TABLES:

Table of Contents

1. INTRODUCTION

1.1 The Arctic environment

The Arctic Ocean (AO) is surrounded by continents and has limited connection to the Pacific Ocean through the Bering Strait, and to the Atlantic Ocean through the Fram Strait - making the AO a "Mediterranean Sea" (Stein, 2008). The AO is divided into two main areas, the Amerasian and the Eurasian side (Townsend, 2012), and consists of approximately 50% shelf and 50% basin. Inflow of Atlantic Water into the Barents Sea brings warm and saline water masses as well as nutrients into the Eurasian side of the Arctic (Wassmann *et al.* 2006). Much of the high AO is covered by seasonal and permanent sea ice, and the shelf area are influenced by river runoff, and some areas by glacier input (Stein, 2008). The whole AO catchment account for approximately 10% of the global river runoff (Stein, 2008). Therefore, in addition to the sea ice and inflow of water masses through the straits, the AO functions as a Pacific-Atlantic estuary (Bluhm *et al*. 2015).

The Mediterranean outlay of the AO results in extensive coastal areas profoundly influenced by terrestrial material including sediment, inorganic and organic material (Carmack *et al.* 2015; Kallenborn *et al.* 2012) and freshwater. In the coastal areas of the Arctic, climate warming accelerates the retreat of glaciers, loss of sea ice, and thawing of permafrost (Ch 28: Polar regions, in Larsen *et al.* 2014). This, along with changes in precipitation patterns, will increase the interactions between land and ocean by increasing inputs of freshwater, organic material, nutrients, pollutants, and sediments to the coastal areas (Kallenborn *et al*. 2012). Lack of data on small riverine systems, which are dominating in the Arctic, and exposed coastlines needs investigation. Because it is important for the understanding on how these coastal ecosystems structure and function, and how they could be affected by a warming Arctic.

1.2 Benthic organisms

Benthos are organisms that live in association with the seafloor and are good indicators of their surrounding environmental conditions (Pearson and Rosenberg, 1978), because most benthic organisms are non-migratory, and have low mobility and are therefore constantly exposed to their local environment. Different benthic organism has different tolerances and adaptations to their surroundings, much of which are related to different life strategies. Benthic organisms are divided into different functional groups according to their size, life history traits, reproduction strategy, mobility, feeding strategy and position in the sediment (Gulliksen *et al.* 2009).

The benthic organisms are highly dependent on sinking of organic material from the pelagic, or horizontal movement from other locations, for food. The amount of the phytoplankton bloom that reaches the seafloor is dependent on various factors such as grazing pressure from zooplankton, re-generation by bacteria, particle sinking velocity and advection (Wassmann *et al.* 2006). These processes are important for understanding the ecosystem as a whole because benthic organisms play a crucial role in re-mineralizing organic matter, which is then transported up into the water column by mixing. How tight the benthic-pelagic coupling is, varies in the different regions in the Arctic and depend on where the phytoplankton bloom occurs and by water transport (Wassmann *et al.* 2006).

Benthic communities are important for many different aspects of the ecosystems: they process organic carbon and help regenerate inorganic nutrients which is used by the primary producers (Renaud *et al.* 2008). As well as functional diversity of benthic communities affects important processes like mineralization of organic matter and biogeochemical processes of sediment characteristics (Norling et al. 2007). Benthos is also an important food source for higher trophic levels, for example marine mammals like walruses (Dunton *et al.* 2017), and many commercial fishes like haddock (*Melanogrammus aeglefinus*), Greenland halibut (*Reinhardtius hippglossoides*) and wolf fishes (*Anarchichas* spp.) (Gulliksen *et al*. 2009).

1.3 Fjord systems in the Arctic

Fjords are products of the retreat of glaciers from the last ice age, as a result of this fjords are influenced by either a river or a glacier at the head of the fjord. They are ocean inlets that are found along coastlines at high latitudes in both hemispheres and are often narrow and surrounded by steep mountains (Syvitski *et al.* 1986). Fjords are complex systems and each fjord varies with regard to hydrography, morphology and biological processes (Copeland *et al.* 2012; Townsend, 2012). The hydrographic patterns in fjords is influenced by freshwater input, and additionally tidal and wind forcing. Additionally, the morphology varies in terms of shape, length and width of the fjord, which can influence mixing events including formation of eddies and upwelling (Cottier *et al.* 2010; Farmer and Freeland, 1983), generating many highly heterogeneous habitats within fjord systems. Regions located near glacier and rivers are often areas with high turbidity, sediment instability and high input of terrestrial material, including: freshwater, sediment, nutrients, organic and inorganic material (Włodarska-Kowalczuk *et al.* 2005; Włodarska-Kowalczuk *et al.* 2007), making these areas a physically disturbed environment with large variation in time and space.

Freshwater input from rivers or glaciers can create a strong seasonal stratification in fjords (Cottier *et al.* 2010). With increasing distance from the freshwater inputs, the less saline surface layer mixes with the underlying water masses in the fjord and salinity may increase towards the outer part of the fjord. The presence of a sill in fjords may prevent mixing of water masses from shelf areas, and hence prevent mixing below the sill depth in the basin, which may cause anoxic conditions in the surface sediment. The water column profile in fjords with a shallow sill is often three layered, with a fresher layer at the surface, which varies in both salinity and temperature throughout the season, due to changes in atmospheric air temperature (Azetsu-Scott and Syvitski (1999); Cottier *et al.* 2005; Nilsen *et al.* 2008), as well as melting events. A mixed layer in the middle and a colder and saline bottom water layer, which is less mixed with the upper water masses (Azetus Scott and Syvitski 1999; Cottier *et al.* 2010; Nilsen *et al.* 2008).

About 25% of the world´s fjords are influenced by glaciers, and these fjords are very different from ice-free fjords, since various ice-processes (e.g. melting and formation of sea ice, ice calving and ice scouring) is likely to affect the deposition of sediment (Syvitski, 1989). In addition, input from melting events influence sediment porosity and carbon content (Włodarska-Kowalczuk *et al.* 2005; Włodarska-Kowalczuk *et al.* 2007). Fine sediment is transferred to the coastal areas from glaciers and glacier-feed rivers. Variation in magnitude of

sediment input can change the sediment composition in a matter of a few days (Forwick *et al.* 2010) and can hence transport finer sediments, by advection and tidal forcing, to depositional sites (basins) within the fjord (Forwick *et al.* 2009; Forwick *et al.* 2010). In glacier influenced fjords ice scouring from calving glaciers can disturb the stability of sediment in nearshore areas and transport sediment to other parts of the fjord. Some fjords have seasonal sea ice cover, which may reach all the way to the seafloor in coastal areas and cause physical disturbance. Sea ice formation can furthermore create highly dense, saline cold-water called brine, which sinks to the seafloor, preventing mixing, creating possible anoxic condition (Kvitek *et al.* 1998; Włodarska-Kowalczuk *et al.* 2007). Marine and land terminating glacier influence the water mass circulation in the adjacent fjord in different ways. Where higher productivity is observed in systems with influence of marine-terminating glaciers. Much of which is due to different melting processes, between the different glacier structures. Marine-terminating glaciers have a down-stream of fresh cold water at the edge of the glacier, which pushes up freshwater and nutrients from the seafloor and up to the surface layers (Meire *et al.* 2017). Whilst land-terminating glaciers resemble river estuary systems, where the fresher surface layer create a strong stratification, limiting exchange of nutrients between water masses.

Seasonal variation in terrestrial input of freshwater affects the quality of particulate organic matter, and rate of sediment organic matter that is transported into the fjord (Bridier *et al.* 2019). These processes as well as high turbidity, can limit primary production in these areas due to high attenuation of light (Murray *et al.* 2015; Bridier *et al.* 2019; Włodarska-Kowalczuk *et al.* 2005). Terrestrial carbon transported from riverine and glaciers plays an important role in the carbon cycle, through additional carbon input to the marine system. The carbon from the terrestrial environment has different fates when it reaches the coastal areas, where it can either be degraded, or sink to the seafloor and stored in the sediments (Parmentier *et al.* 2017). Additionally, terrestrial derived material including organic matter and nutrients from land, can act as an energy source for bottom dwelling organisms (Dunton *et al.* 2012; Harris *et al.* 2018; Morata *et al.* 2008) when marine food is limited.

Fjords are the interface between land and ocean, and processes happening on land influence the coastal areas. Differences in fjord characteristics, such as morphology, sedimentation, and water circulation, can drive differences in fjord ecology, including benthic community composition (Syvitski *et al*. 1986).

1.4 Benthic communities in Arctic fjords

In Arctic fjord, factors structuring benthic communities are in part determined by the surrounding environment and biological factors, which varies spatially and temporally. Some of the abiotic factors known to structure benthic communities are water currents, substrate type, turbidity, temperature, salinity, food supply and depth (Syvitski, 1989; Kedra *et al.* 2012; Meyer *et al.* 2015; Gulliksen *et al.* 2009). However, biotic factors such as food availability, disease, predation and competition are important factors structuring benthic communities.

Benthic communities typically differ along a fjord axis, and diversity is shown to increase with distance from riverine and glacier input (Zajaczkowski and Włodarska-Kowalczuk, 2007; Pearson and Rosenberg, 1978). Much of this is due to processes mention in the last paragraph, including high sedimentation which can be devastating for benthic organisms, by clogging filter feeders, burying adult and larvae, and preventing organisms from achieving their optimal position in the sediment (Meyer *et al.* 2015; Włodarska-Kowalczuk *et al.* 2012). Another consequence of high particulate load is dilution of organic matter, which influence the food availability for benthic communities. In contrast, the outer part of a fjord, limited mixing of bottom water, as well as food availability and gravity flow of sediments may structure the community (Włodarska-Kowalczuk *et al.* 2007).

Food supply for benthos is often linked to pelagic- benthic coupling, and in areas with river or glacier input this relationship is in addition highly influenced by terrestrial inputs. The distance to the seafloor has been observed as a structuring benthic community, and much of this is related to the physical factors that follows with depth and food supply (Holte *et al*. 2004). Variation in input of both phytoplankton and terrestrial material to the benthic communities, have been shown to vary with season (Morata *et al.* 2008). Fresh organic matter is provided to the benthic communities during spring/summer due to the overlying primary production, but areas close to rivers are also highly influenced by terrestrial material due to increased river runoff during the melting season (Morata *et al*. 2008). This tells us that the overlying production is essential for the benthic community, but that terrestrial material also plays a crucial part in fueling the benthic community in times when food is limited. The degree to which benthic organisms are able to utilize terrestrial energy sources is relatively unknown, but there is increasing evidence that they can (Dunton *et al.* 2012; Morata *et al.* 2008). The nearshore benthic community gets carbon input as detritus from various sources, like terrestrial input, salt marshes, seagrass, and from marine littoral habitats (Dunton and Schell, 1987). Much of these comes in forms of small

particles, as a result of erosion, and are transported to the seafloor by advection and vertical movement. The high seasonality in the Arctic with a pulse of energy for the benthic community during spring/summer, and from terrestrial organic material is important for the benthic community, because they are dependent on the energy supply for growth and reproduction (Gulliksen *et al.* 2009).

Typical feeding and motility strategies in these shallow disturbed environments are deposit feeding, and motile organisms, because they can avoid adverse conditions, by moving away from unfavored environmental conditions. While at deeper habitats, more sessile, filter/suspension feeding, and tube dwelling organisms are present, due to more stable sediment and less suspended sedimentation (Włodarska-Kowalczuk and Pearson, 2004; Kokarev *et al.* 2017). Benthic organisms' response to environmental drivers, can help understand how the effect of climate change will influence the coastal ecosystem.

1.5 Climate change: effect on benthic community

The climate in the Arctic is changing, and the changes at high latitudes are predicted to be much greater than at lower latitude (Larsen *et al.* 2014). Some of the physical changes that is predicted in the Arctic includes: increased sea surface and air temperature, loss of sea ice, melting of glaciers, increased river input, thawing of permafrost, ocean acidification, increased input of Atlantic Water and changes in the atmospheric circulation (Wassmann *et al.* 2006). These changes have implications for the Arctic ecosystem, with shift in species composition, occurrence of invasive species (Berge *et al.* 2005) and change in important events like timing of the spring bloom (Wassmann *et al.* 2006).

In the coastal areas, consequences of melting glacier, increased river input and precipitation, thawing of permafrost and erosion, will impact the coastal areas both in the physical environmental and the water chemistry. As a result of higher air temperature, more sediment is expected to be delivered to the coastal areas, both due to melting of glaciers and thawing of permafrost. Marine terminating glaciers is important for different fjord processes, like water circulation. In the past decades many of the glaciers on Svalbard has retreated and are now land based. As a result, from retreat of glacier to land, the glacier input will change towards a surface drainage and the water mass circulation is suggested to become similar to river systems and land terminating glaciers (Adakudlu *et al*. 2019).

There is expected to be an increase in diversity in the coastal benthic community due to advection, bringing more boreal species to the coast of Svalbard and into the Barents Sea (Węsławski *et al.* 2011). However, the fjord-systems in the Arctic may show a different trend. Biodiversity is predicted to increase in the outermost part of the fjord, whilst the inner part, due to changes including increased river-runoff, melting glacier and sea ice loss, biodiversity is expected to decrease. Much of which is because of reduction in the euphotic layer, as a consequence of warmer temperature (Węsławski *et al*. 2011). The effect of terrestrial inputs on benthic communities in Arctic fjord systems are understudied, and the consequences of a warming Arctic on their structure and function need investigation.

2. OBJECTIVES

Aim:

This master thesis investigated community structure of soft bottom macro-benthos in three side-fjords in Isfjorden, Svalbard. The sampled fjords are different in morphological and physical characteristics, as well as differences in terrestrial influence with regards to river and glacier inputs, suggesting that the benthic communities will differ among fjords. In addition, it is known that the local environmental have a huge impact on benthic community structure and linking the environmental drivers to the community might help assess how the systems structure and function, and how this could change in a changing Arctic.

Therefore, three research questions arose for this study, in terms of **1)** investigating the possibility for among fjord differences, in relation to how benthic communities are influenced by large scale factors from physically and morphologically different fjords. Second, **2)** to look at benthic community structure at a more local scale and see if different sources of terrestrial inputs from rivers or glacier, have implication for benthic community structure compared to communities in habitats that are less influenced by terrestrial input. Finally, **3)** linking the sampled environmental factors to the benthic community structure, to asses which environmental variables explains most of the variability, and hence driving the community structure.

3. MATERIALS AND METHODS

3.1 Study area:

Isfjorden (78.15 ºN, 14.40 ºE) is the second longest fjord in Svalbard and is located on the western side of the Svalbard archipelago (Figure 1a). It is one of the largest fjord systems in Spitsbergen and has thirteen side-fjords in addition to the main fjord. The maximum depth of Isfjorden is approximately 425 meters. The fjord has no significant sill at the fjord mouth and therefore exchange of water masses from the continental shelf and slope can mix with the coastal and Arctic waters in the fjord (Figure 1b). The influence of the Western Spitsbergen Current (WSC) makes the climate mild on the west side of the Svalbard archipelago (Nilsen *et al.* 2008). This has implications for the physical, biological and chemical properties of the environment. The WSC penetrates into the fjord, bringing heat and nutrients into the system (Nilsen *et al.* 2008). The side-fjords in Isfjorden are less affected by the WSC, since the current does not usually penetrate into the side-fjords. Therefore, seasonal sea-ice can be produced inside some of these side fjords. Formation of sea-ice in fjords on the western side of Spitsbergen usually happens in November and ice starts to break up in April, though local variation may occur (Forwick *et al.* 2010).

Approximately half of the land area on Svalbard is covered with glaciers; acting as one of the main sources of freshwater to the coastal areas (Sund, 2008). Other freshwater sources on Svalbard include precipitation, rivers and groundwater run-off and temporary sources like melting of sea-ice (Nilsen *et al.* 2008; Prowse *et al.* 2006). The fjord substrate in Isfjorden varies from rocky habitats at the opening of the fjord to soft bottom substrate in side-fjords influenced by riverine and glacial sediment (Sakshaug *et al.* 2009).

a) b)
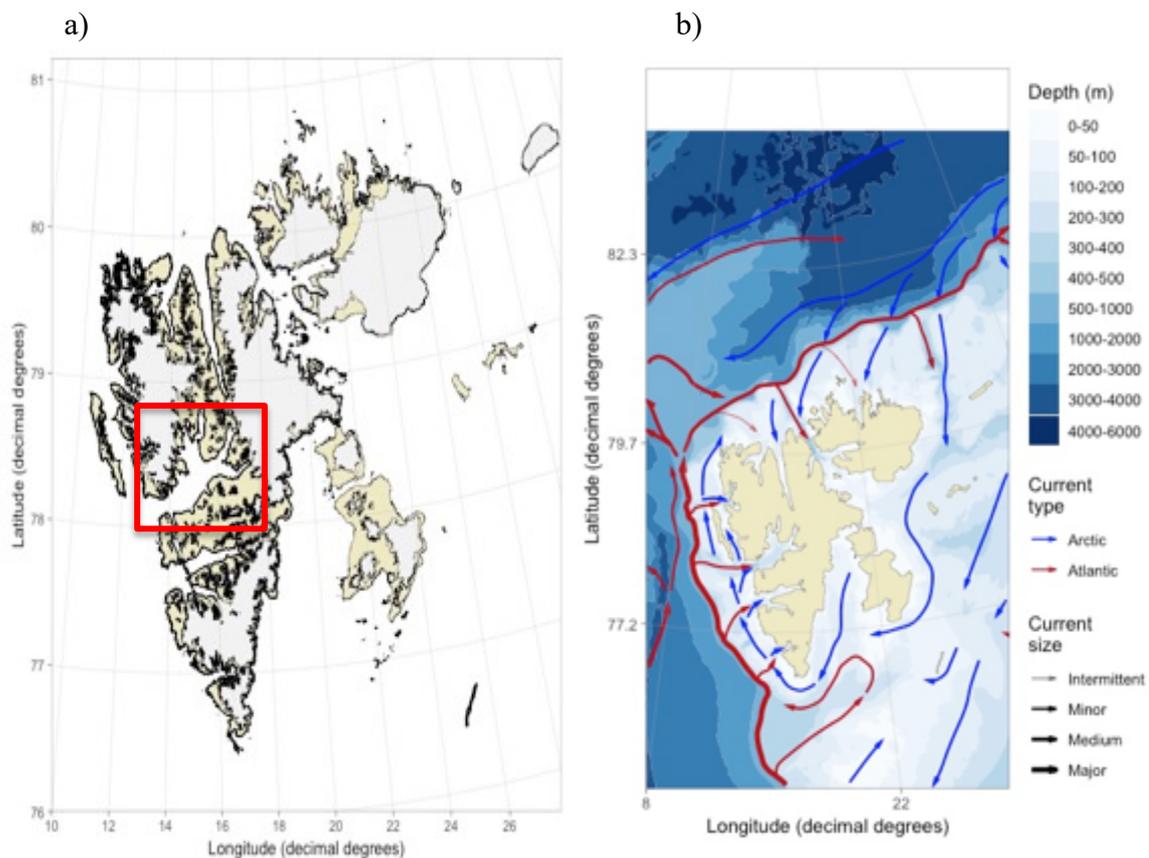
Figure 1: a) Glacier coverage on Svalbard, red box shows Isfjorden, b) WSC and local water currents. Maps was made by using Plot Svalbard (Vihtakari, 2019).

3.1.1 Sampled side- fjords: Adventfjord, Tempelfjord and Billefjord

The three-side fjords are located on the north-eastern side of Isfjorden and differ from each other, with regards to variation in morphological and hydrographical characteristics, Table 1.

Adventfjord is a relatively distinct fjord, with two major river input in the head of the fjord. The connecting rivers are on their part influenced by drained land-terminating glaciers located several kilometres from the fjord. Adventfjord is one of the smallest side-fjords (7 km long and 3-5 km wide) in Isfjorden, and is the fjord where Longyearbyen, the largest settlement on Svalbard is located.

Tempelfjord is located on the north-east side from Adventfjord and is divided into two regions. The inner part mostly influenced by land- terminating glaciers, and the outer part (Sassenfjord), which is mostly influenced by main rivers mentioned in Table 1 (Forwick *et al.* 2010). Tempelfjord is 14 km long, and about 5 km wide, and Sassenfjord is 13 km long and approximately 12 km wide.

Billefjord is located north from Adventfjord, and it is the only fjord in this study with a shallow sill, creating a strong barrier between Billefjord and the main axis of Isfjord. The inner part of the Billefjord is divided into two bays (i.e. Petuniabukta and Adolfbukta) which are different in physical-chemical-geological properties. Petuniabukta is supplied by freshwater and sediments from a braided river, merging into a tidal flat. Whilst Adolfbukta is heavily influenced by Nordenskiöldbreen, a large marine-terminating glacier (Li *et al.* 2012).

Adventfjord and Tempelfjord lack, in contrast to Billefjord, a significant sill and exchange of water masses from Isfjorden is possible. Tempelfjord and Billefjord are in contrast to Adventfjord influenced by large glaciers at the head of the fjord, Table 1. All fjords have considerable river input, which discharges large amount of sediment and particulate organic matter into the system (Forwick *et al.* 2009; Forwick *et al.* 2010; Węsławski *et al.* 1990; Zajaczkowski and Włodarska-Kowalczuk, 2007). The different river systems running into these fjords are different in terms of catchment geology and degree of glaciation, which impacts the particle load and carbon source. Ebbaelva and Gipselva are the rivers which have highest glaciation influence, compared to Adventelva which have a intermediate influence. Sassenelva and DeGeerelva have the lowest glaciation influence. These different morphologies, and terrestrial influence of the fjords may have implications for the physical-chemical properties, as well as have implication for benthic community structure.

Table 1: General features from the three side-fjords sampled.

Fjord features:	Adventfjord	Tempelfjord	Billefjord
Max depth	80 m	150 m	226 m
Presence of shallow sill	No	No	Yes
Sill depth	None	None	70 m
Major rivers	Adventelva and Longyearelva	DeGeerelva, Sassenelva and Gipselva.	Ebbaelva
Major glaciers	None	Bogebreen (land-terminating), Tunabreen (land-terminating) and Von Postbreen (land- terminating)	Nordenskiöldbreen (marine - terminating)

3.2 Sampling:

Sampling in Isfjorden and associated side-fjords took place from 18.08.2018-04.09.2018, using three different boats: a small boat, the UNIS polarcircle *Kolga,* for collecting nearshore stations (outside rivers) and river estuary stations, the RV Helmer Hanssen (the four outer stations), and the MS FARM for the remaining stations (Table 2). Three side-fjords were examined: Tempelfjord, Adventfjord and Billefjord (Figure 2). In total, 30 stations were sampled, including stations from the inner, middle and outer part of each fjord, as well as marine endpoint stations located at the main axis of Isfjorden, nearshore stations and river estuary stations. At each site, a CTD Model SD208, was used to collect physical and biological parameters (e.g. salinity, fluorescence, density and temperature) from the water column. One replicate of community sample was collected at each station using a Van Veen grab of 0.1 m^2 (all sites except small boat sites) or 0.025 m^2 surface area (small boat sites) (Table 2). Different sizes of Van Veen grabs were used due to limitations of using a small boat, with regards to size of equipment and space onboard. Grab samples were sieved over a 1mm sieve and fixed in 10% formalin buffered with 10% borax.

Samples for sediment chemistry were taken from the upper 2 cm of each grab and measurements of pH, temperature (°C), and redox potential (Eh) were taken from the surface layer (upper 2 cm). Temperature was taken immediately with a temperature probe, whilst pH and redox potential were measured using a YSI Pro1020. Redox potential is usually measured in water, and in this study Eh was measured in the sediment, therefore 200 mV was added to the ORP value to get the correct measurement of Eh in the sediment, this was in accordance with producers of using YSI measurements from the YSI.com webpage and their document: "Measuring ORP on YSI 6-Series Sondes: Tips, Caution and Limitations". Additionally, 2 mL of sediments were collected from the Van Veen grabs from the upper 2 cm and placed in plastic containers before being frozen for grain size, total organic matter and pigments. All sediment chemistry samples were kept in tin foil, to prevent light pollution, and kept in a cooler with ice onboard, before being transferred to a freezer at -20 °C.
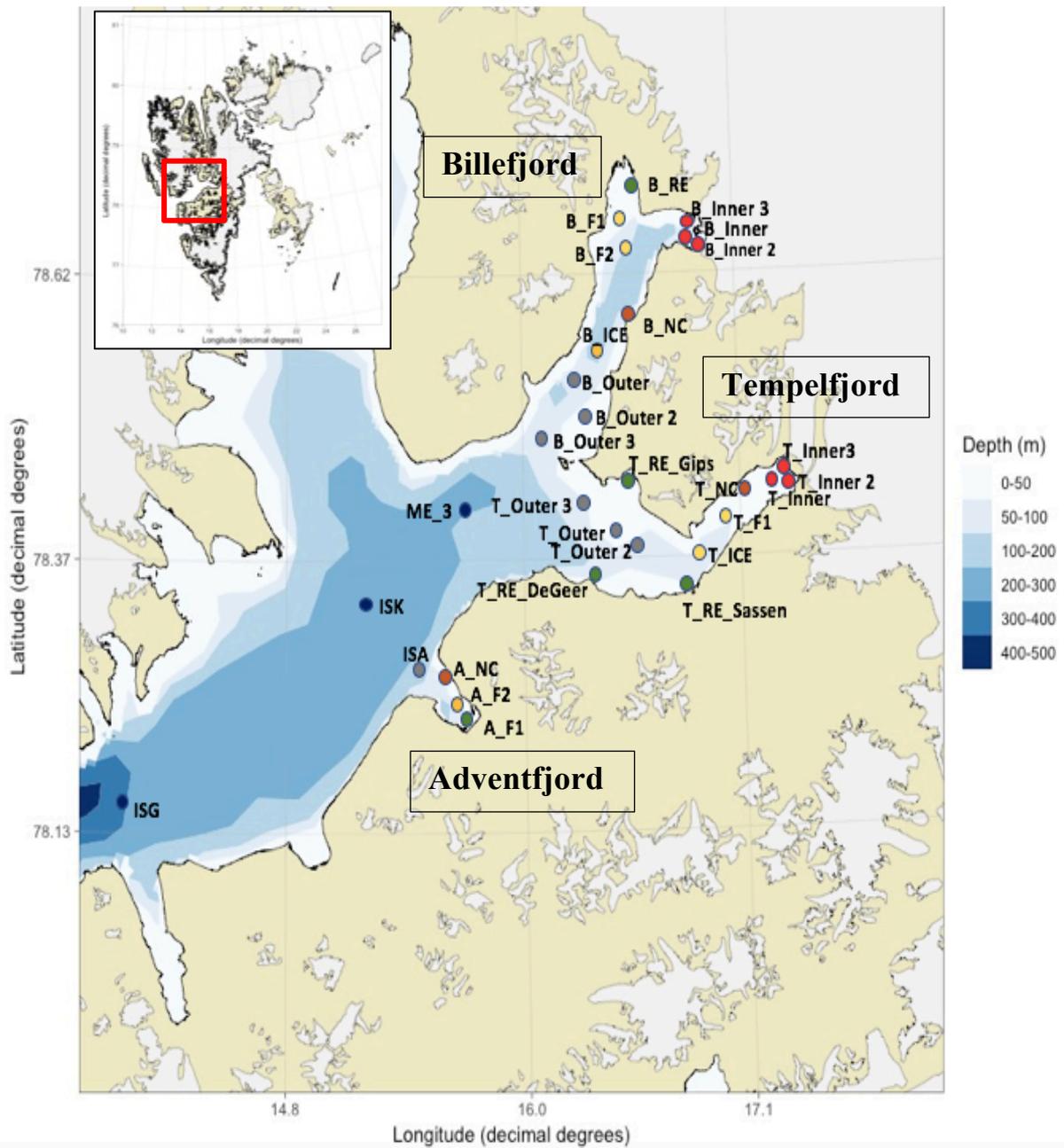
Figure 2: Station map for benthic sampling. Dark blue dots: marine endpoints, grey dots: outer stations, orange/brown dots: nearshore control, green dots: river estuary, yellow dots: fjord transect and red dots: inner stations. Map created by using Plot Svalbard (Vihtakari, 2019).

Table 2: Station overview including station type, depth (m) of stations and size of Van Veen Grab and sampling boat used.

Station name:	Station type:	Depth (m):	Van Veen Grab size (m²):	Boat
A_F1	River Estuary	6,5	0.025*	UNIS polarcirkle *Kolga*
A_F2	Mid fjord transect	43	0.025*	UNIS polarcirkle *Kolga*
A_NC	Nearshore control	24	0.025*	UNIS polarcirkle *Kolga*
B_RE	River Estuary	11,0	0.025*	UNIS polarcirkle *Kolga*
B_Inner	Glacier Influenced	46.3	0.1	MS FARM
B_Inner 2	Glacier Influenced	26.6	0.1	MS FARM
B_Inner 3	Glacier Influenced	31.5	0.1	MS FARM
B_F1	Mid fjord transect	65.6	0.1	MS FARM
B_F2	Mid fjord transect	137	0.1	RV Helmer Hanssen
B_Outer	Fjord mouth	103.6	0.1	MS FARM
B_Outer 2	Fjord mouth	39.7	0.1	MS FARM
B_Outer 3	Fjord mouth	87.5	0.1	MS FARM
B_ICE	Mid fjord transect	86.3	0.1	MS FARM
B_NC	Nearshore control	9	0.025*	UNIS polarcircle *Kolga*
T_RE_Sassen	River Estuary	10	0.025*	UNIS polarcircle *Kolga*
T_RE_DeGeer	River Estuary	23	0.025*	UNIS polarcircle *Kolga*
T_RE_Gips	River Estuary	8.50	0.025*	UNIS polarcircle *Kolga*
T_Inner	Glacier Influenced	41.50	0.1	MS FARM
T_Inner 2	Glacier Influenced	30.2	0.1	MS FARM
T_Inner 3	Glacier Influenced	36.1	0.1	MS FARM
T_Outer	Fjord mouth	42.7	0.1	MS FARM
T_Outer 2	Fjord mouth	89	0.1	MS FARM
T_Outer 3	Fjord mouth	43.7	0.1	MS FARM
T_F1	Mid fjord transect	83.5	0.1	MS FARM
T_ICE	Mid fjord transect	98	0.1	MS FARM
T_NC	Nearshore control	16	0.025*	UNIS polarcircle *Kolga*
ME_3	Marine endpoint	214	0.1	MS FARM
ISG	Marine endpoint	274	0.1	RV Helmer Hanssen
ISK	Marine endpoint	250	0.1	RV Helmer Hanssen
ISA	Fjord mouth	120	0.1	RV Helmer Hanssen

* 4 replicates were taken for every station sampled with Van Veen grab size 0.025 m² to get the same total volume as the stations taken with the larger Van Veen grab (0.1 m²).

3.3 Sample processing:

3.3.1 Community samples:

Community samples were soaked in freshwater under a fume hood overnight after removing the formalin. The next day, samples were rinsed again with running water for 30-60 min. All animals were sorted into main taxonomical groups (e.g. Polychaeta, Bivalvia, Gastropoda, Crustacea/Amphipoda, Asteroidea/Ophiuroidea, Caudofoveata, Echinodermata etc.) and stored in 80% ethanol in separate jars. Specimens were then identified to lowest possible taxonomic level using a stereo microscope (40x) and stored in glass jars with 80% ethanol and counted to determine abundance. Bryozoans and other colonial organisms were not included in this study because they cannot be enumerated. Amphipod identification was confirmed by Professor Jørgen Berge (UiT The Arctic University of Norway, Tromsø).

Species richness was noted as the number of species in a given sample and Shannon-Weiner Diversity Index (H') and Pielou´s Evenness (J), using natural logarithm-transformed data, were calculated by using the following equations:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Shannon diversity index =

Evenness = $J = H/\ln(S)$

Where p_i = proportion of species richness, and S = species richness.

3.3.2 Environmental samples:

Grain size

Grain size analysis were performed at the Geology department at the Arctic University of Norway, using the protocol made by Dr John Evens "Acid treatment (HCl) and oxidation with hydrogen peroxide (H_2O_2)- procedure of preparation for marine sediments", UiT, Tromsø, Norway. 2 mL of sediment were pre-treated with 20% HCl and 20% H_2O_2, covering the whole sample, to remove calcium carbonate and organic material, respectively. The treated sediments were then analyzed using a Beckman Coulter Particle Size Analyzer LS 13320. To get the total variation of grain size in one sample, three sub-samples were analyzed for grain size. The three sub-samples were then summarized, and the mean was calculated. The categorical size fraction of grain size from (López, 2016), Table 3, was used to determine sediment grain size and how much they accounted of the total volume.

Table 3: Size fraction used to describe the sediments collected from the seafloor.

Sediment fraction	Size (mm)
Clay	<0.004
Silt	0.004-0.06
Sand	0.06-2

Sediment pigments: Chlorophyll a and Phaeopigments

Sediment pigments were analyzed as described by Holm-Hansen *et al.* (1965). Briefly, 2 mL of sediment was taken, and pigments were extracted in 10 ml 90% acetone, overnight at -20 °C. All samples were kept in the dark and packed in tinfoil to prevent light pollution. The samples were allowed to return to room temperature, before they were centrifuged using an AIC Centrifugette 4206 centrifuge at 1000 rpm for 10 minutes. Four ml of the supernatant was transferred to a fluorometer tube and analyzed using a Turner Design 10-AU Fluorometer, after which 2-3 drops of 10% HCl acid was added, and the sample was vortexed again before recording the fluorescence again in order to determine phaeopigment content. Where chlorophyll a concentration was too high to get a reading, samples were diluted with 90% acetone, and the dilution factor was noted.

Pigments concentration was calculated by using a calibration factor of a known and pure chlorophyll a concentration and was the calibration of the instrument used. Equations for calculating Phaeopigments and Chlorophyll a (μg/L) concentrations is shown below:

Phaeopigments= Fd*Tau*((Rb/Ra*(Ra*Dilution Factor))- (Rb*Dilution Factor))* Volume acetone/ Volume extracted sediment

Chlorophyll a= Fd*Tau*((Rb*Dilution Factor)- (Ra*Dilution Factor))*Volume acetone/ Volume extracted sediment extracted sediment

Fd and Tau is the calibration factor from the instrument (Parsons *et al.* 1984). Rb is the total pigment concentration before adding the acid, and Ra is the fluorescence after adding the acid (phaeopigments).

Total Organic Matter

Loss on ignition (LOI) was determined to get an estimate of total organic matter (TOM) of the sediments. LOI is a widely used method, but there are many procedural variations on the methods of getting results on total organic matter. Some have argued that LOI is not an accurate method, and many different factors may influence the results, including sample size, grain size, exposure time, temperature and position in the oven (e.g. Heriri *et al.* 2001). Interpretation of the results should therefore be done with caution. Sediments were freeze-dried prior to the analysis. Then 30 crucibles were dried in an oven at 60 °C, over a course of 2 days. Each crucible was weighed, before adding approximately 1 gram of freeze-dried sediment, and put back in the oven at 60 °C overnight, before being weighed again. Then the 30 samples were put in a muffle oven at 520 °C for about 5-6 h (Heriri *et al.* 2001). The temperature was set to 520 °C and not 550 °C as in many other methods, to prevent loss of inorganic carbon (Frangipane *et al.* 2009). After the combustion cycle was complete, the samples were weighed again.

Then total organic matter from the sediments was calculated using the equations:

Dry Weight = Dried sediment in crucible- Crucible weight empty

LOI= Dried sediment in crucible- Burned sediment in crucible

%TOM= LOI*100/Dry Weight

3.4 Statistical analysis:

All statistical analysis was conducted by using the R version 3.3.4 (R Core Team 2018) and PRIMER version 7.0.13

The data collected include infaunal community data (abundance), environmental data (depth, salinity, temperature, chlorophyll a, phaeopigments, total organic matter, redox potential (Eh) and grain size (%clay, %silt and %sand), as well as biological diversity indices (Shannon-Wiener diversity index, Pieluo´s evenness, species richness) and total abundance.

3.4.1 Community data

The shallow stations were sampled with a smaller van Veen grab than the deeper stations. The 4 replicates taken at each of these shallow stations were summed together to achieve the same volume as at stations sampled with the 0.1 m^2 Van Veen grab. The community data were explored by using different kinds of transformations: non-transformed, square root, presence-absence and fourth-root transformation, to evaluate the effect of transformation on the results. In the final analysis, fourth root transformation was chosen to even out the power of dominating species (Clarke and Warwick, 2001). Bray Curtis dissimilarity was used to look at differences among samples at different locations, and is commonly used by ecologist as it is appropriate for count (abundance) data (Clarke and Warwick, 2001; Legendre and Legendre, 2012).

To analyze how the stations clustered together according to community data, a cluster analysis was performed in R using the function *hclust*. A cluster dendrogram was made for each type of transformations mentioned and these can be found in the appendix. Average linkage was chosen, measuring the distance from one point to the mean value of another sub-cluster (Clarke and Warwick, 2001). Other linkage methods (e.g. complete linkage, single-linkage) were tested to observe how robust the identified clusters were to clustering methodology. The function *simprof* in library (*clustsig*) in R, was used to see which of the cluster groups were significantly different from each other, using 4th root transformation and Bray Curtis dissimilarity and values at α=0.05. To support these significant clusters an ANOSIM pairwise test was done in PRIMER version 7. Some clusters had very few stations, which limits the ability of ANOSIM to detect differences reliably. Therefore, these groups were not included in the ANOSIM analysis. An additional ANOSIM was performed to address research question (1) regarding fjord differences. A non-metric Multidimensional scaling (nMDS) analysis was done using library

(*vegan*, Oksanen *et al.* 2010) and function *metaMDS* was used to assess how the stations clustered in ordination space, using 4th root transformed data and Bray Curtis dissimilarity.

A species accumulation curve was made using the *speccum* function and method "rarefaction" in library (*vegan*) in R, to estimate whether the curve plateaus. Rarefaction is a method for comparing species richness for different sampling efforts (Heck *et al.* 1975).

3.4.2 Environmental data:

To assess how the stations grouped together according to environmental variables, a Principle Component Analysis (PCA) was carried, using library (vegan) and function *rda*. The environmental data were scaled and centered prior to the analysis. Standardizing the environmental variables was done due to differences in scale/range among the environmental variables. A PCA is an ordination method used to get a graphical picture that reflects similarity between stations by measuring Euclidean distance according to dissimilarities between stations (Clarke and Warwick, 2001). This is a commonly used distance measurment for environmental data, because it measures linear distance between two points (Clarke and Warwick, 2001). A correlation matrix was made to investigate correlation of environmental variables, using library (*Hmisc*) and function *cor*.

3.4.3 Testing environmental variables on community data

To assess how much of the variation in community structure was explained by the environmental variables, a Permutational Multivariate Analysis of Variance using the function *adnois* in the library(*vegan*) was conducted. Using community data as factor and with all environmental variable as individual response variables. This was done to check how much the environmental variables explained the community structure.

Multivariate analysis of community data using ordination methods, specifically Canonical Correspondence Analysis (CCA) and Redundancy Analysis (RDA) in library(*vegan*), was carried out to see to what extent the environmental variables explained the community structure, output from these analyzes are found in the appendix. In addition, environmental variables and biological indices were added to the nMDS analysis as passive correlations using the function *envfit* function in library (*vegan*) in R to more easily interpret the stations clustering.

All maps in this study were made by using the Plot Svalbard package in R. (Vihtakari 2019).

4. RESULTS

4.1 Community data

4.1.1 Spatial patterns of community

Cluster analysis of community data indicated eight significant station clusters (Figure 3a). This output, illustrated in Figure 4, showed that stations did not cluster according to fjord, but rather by habitat. This was supported by the ANOSIM done to check for among fjord differences (ranging from R= -0.1 to 0.77, p>0.05), with one exception (Adventfjord) which was significantly different from Isfjorden (R=0.77, p<0.05). Instead, the cluster analysis and the nMDS (Figure 3 a and b) revealed that the stations clustered primarily according to habitat; which again was supported by ANOSIM (ranging from R: 0.59-0.93, p<0.05), except one group(T_In/B_Out2/T_NC) which was not significantly different from the T_Inner cluster group. The Marine Endpoint and River Estuary stations clustered together in a distinct group each, with the exception of River Estuary station (T_RE_DeGeer). The mid fjord axis stations and the outer fjord stations, clustered together in one cluster group, named Outer Fjord. This cluster also included one inner station (B_Inner 3) and excluded two outer stations (B_Outer 2 and T_Outer 3 station). The stations influenced by glaciers clustered together in two distinct groups by fjord. Specifically, the two inner stations in Tempelfjord as well as fjord axis station T_F1 clustered together (T_Inner). The remaining stations did not cluster according to habitat type (Figure 3).
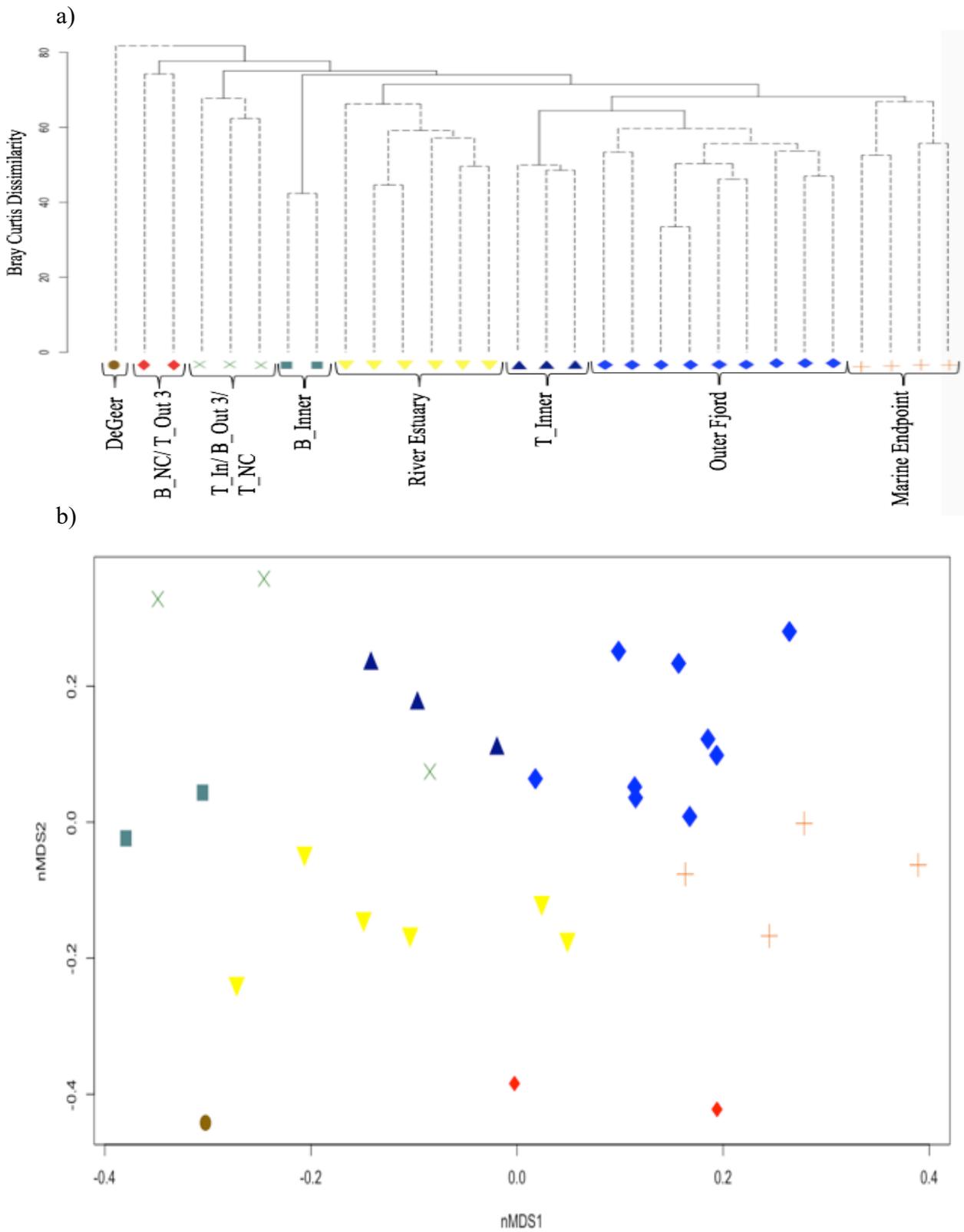
Figure 3: a) Show the significant clusters from the hierarchical cluster analysis, using 4th root transformation, Bray Curtis Dissimilarity and Average linkage, b) Show a nMDS analysis with community data using the groupings (groupings shown in figure b), 2D stress: 0.22.
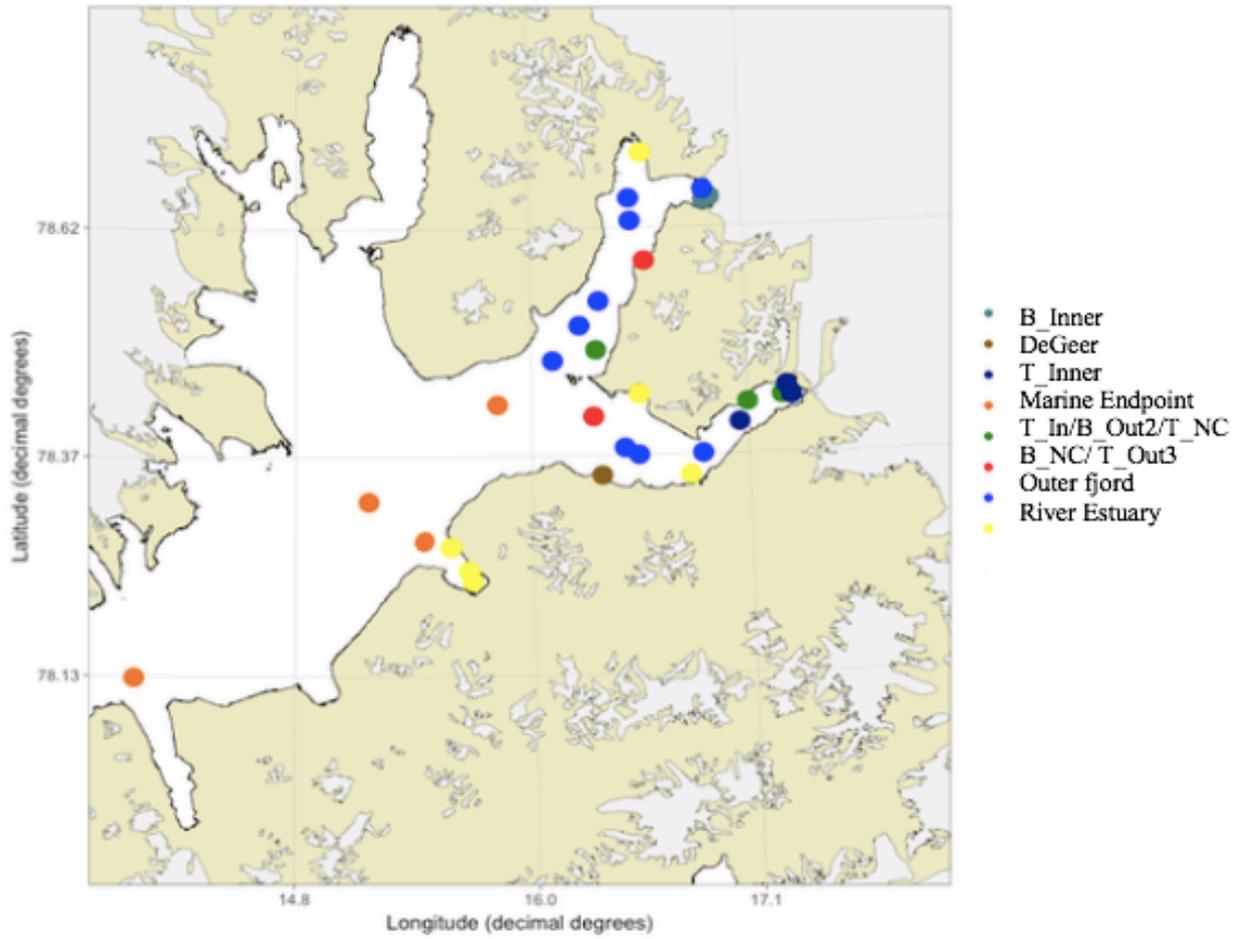
Figure 4: Map of study area with clustered grouped stations, from Figure 3a, and the distribution of the cluster groupings.

4.1.2 Diversity indices

The fjord axis stations had higher species richness, compared to the glacier influenced sites and the B_NC/T_Out3 and T_In/B_Out2/T_NC cluster groups (Table 4). The River Estuary cluster group had species richness comparable to the Marine Endpoint cluster. In the River Estuary group, three stations had relatively high species richness T_RE_Gips (S: 43), A_NC (S: 39) and B_RE (S: 34) compared to the other stations within this cluster, which ranged from (15 to 25 taxa). Lowest species richness was found in the DeGeer and B_Inner clusters. Shannon Diversity Index H' was highest in the B_NC/T_Out3 cluster, and lowest in the B_Inner cluster (Table 4). Evenness (Table 4) was highest at the T_In/B_Out2/T_NC, followed by the B_NC/T_Out3, Outer Fjord and T_Inner clusters. The lowest evenness was found in the B_Inner cluster.

Table 4: Biological indices (Species richness (S), Abundance, Shannon- Wiener Diversity Index (H´) and Evenness (J´)), with the mean values from each cluster group, and ± standard deviation. Cluster groups are arranged according to species richness, highest to lowest.

Cluster group:	S	Abundance	H´	J´
Outer Fjord	34.6 ± 8.2	277.1 ± 77.05	2.637 ± 0.25	0.748 ± 0.03
Marine Endpoint	29.7 ± 13.4	344.2 ± 273.8	2.192 ± 0.27	0.674 ± 0.11
River Estuary	29.3 ± 11.07	480.2 ± 182.5	2.182 ± 0.43	0.653 ± 0.06
B_NC/T_Out3	28 ± 5.6	135 ± 16.9	2.642 ± 0.18	0.798 ± 0.01
T_Inner	18.6 ± 1.5	90.7 ± 24.6	2.329 ± 0.11	0.796 ± 0.01
T_In/B_Out2/T_NC	16 ± 6.08	59 ± 30.5	2.319 ± 0.19	0.844 ± 0.04
B_Inner	11.5 ± 2.1	492 ± 427	1.226 ± 0.12	0.507 ± 0.08
DeGeer	9	178	1.529	0.664

Species accumulation curves did not differ significantly between stations sampled with the large grab (n=21 stations) and those sampled with the small grab (n=9 stations) (Figure 5). A species accumulation curve (Figure 5) showed that stations taken with a small grab and stations taken with a larger grab are not significantly different (overlapping of the 95% confidence intervals). Fewer stations were taken with the smaller grab (4*0.0025 m^2), compared to the large grab (0.1 m^2). When combining all the stations an asymptote was not reached, indicating that amount of samples did not capture the full species richness (Figure 5).
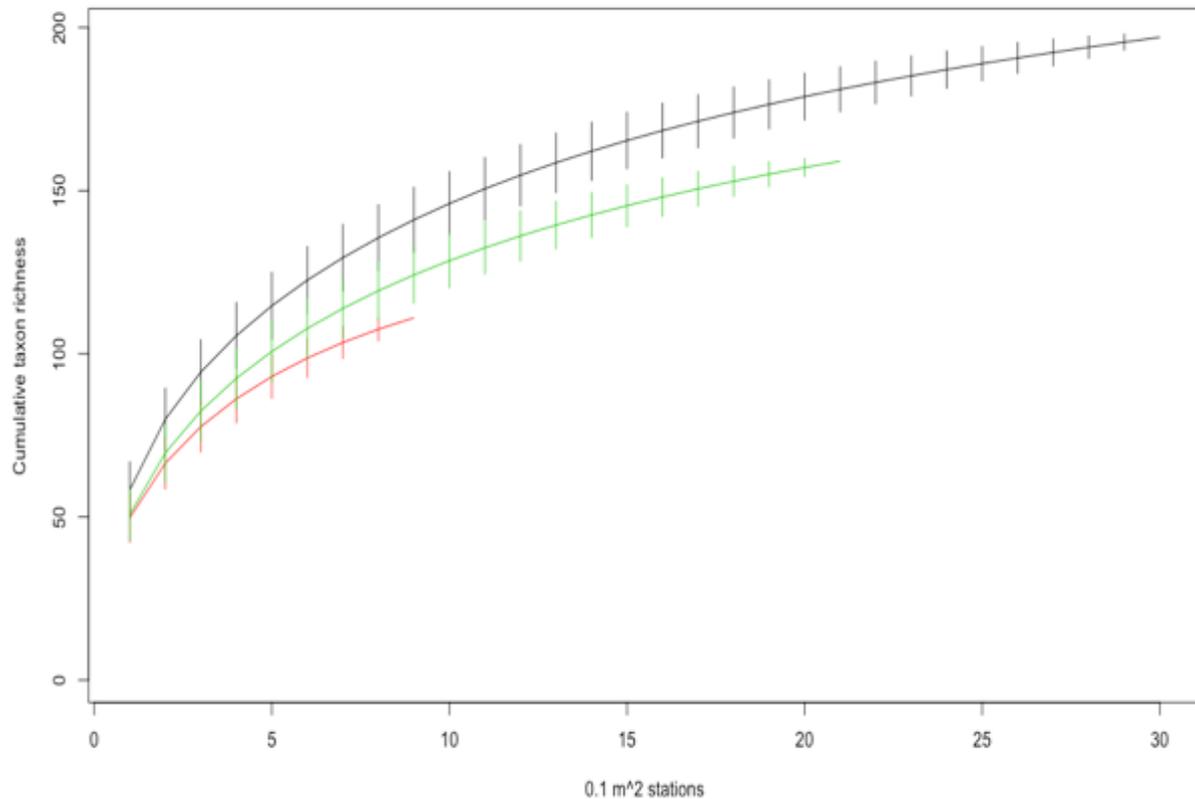
Figure 5: Species accumulation curve with 95% confidence intervals. Black line: all stations, green: stations taken with the large grab, red stations taken with the small grab. X- axis show total number of 0.1 m^2 stations, and y-axis: cumulative taxon richness.

4.1.3 Abundance and composition of benthic community

A total of 8633 individuals were counted, representing 197 taxa. Polychaeta and Mollusca dominated at all stations contributing on average 63% and 31% of the total abundance, respectively (Appendix Figure A6). Other taxa contributed less to the total abundance: Crustacea 2.5%, Echinodermata 0.6%, Cnidaria 0.2%, Priapula 0.2% and Sipuncula 0.1%. The highest abundance was found in B_Inner 2 (794 individuals (0.1m^2)) in Billefjord and was due to the high abundance of polychaeta *Chaetozone* sp. at that station. Lowest abundance was found at T_NC (46 individuals (0.1m^2)) in Tempelfjord.

Total abundance varied between cluster, with the highest abundance in the River Estuary group, followed by the Outer Fjord and Marine Endpoint cluster. The polychaeta (*Chaetozone* sp.) was present in all clusters but occurred in different abundances. The highest abundance of

Chaetozone sp., was found in the B_Inner cluster (Figure 6). The majority of these cluster groups was dominated by Polychaeta, though the Outer Fjord and River Estuary also had a relatively high abundance of Mollusca, compared to the other cluster groups. In the River Estuary cluster group had the highest average abundance of all the groupings, but not highest species richness. The dominating feeding guild in all groups consisted of either surface deposit feeders and sub-surface deposit feeders, Table 5.
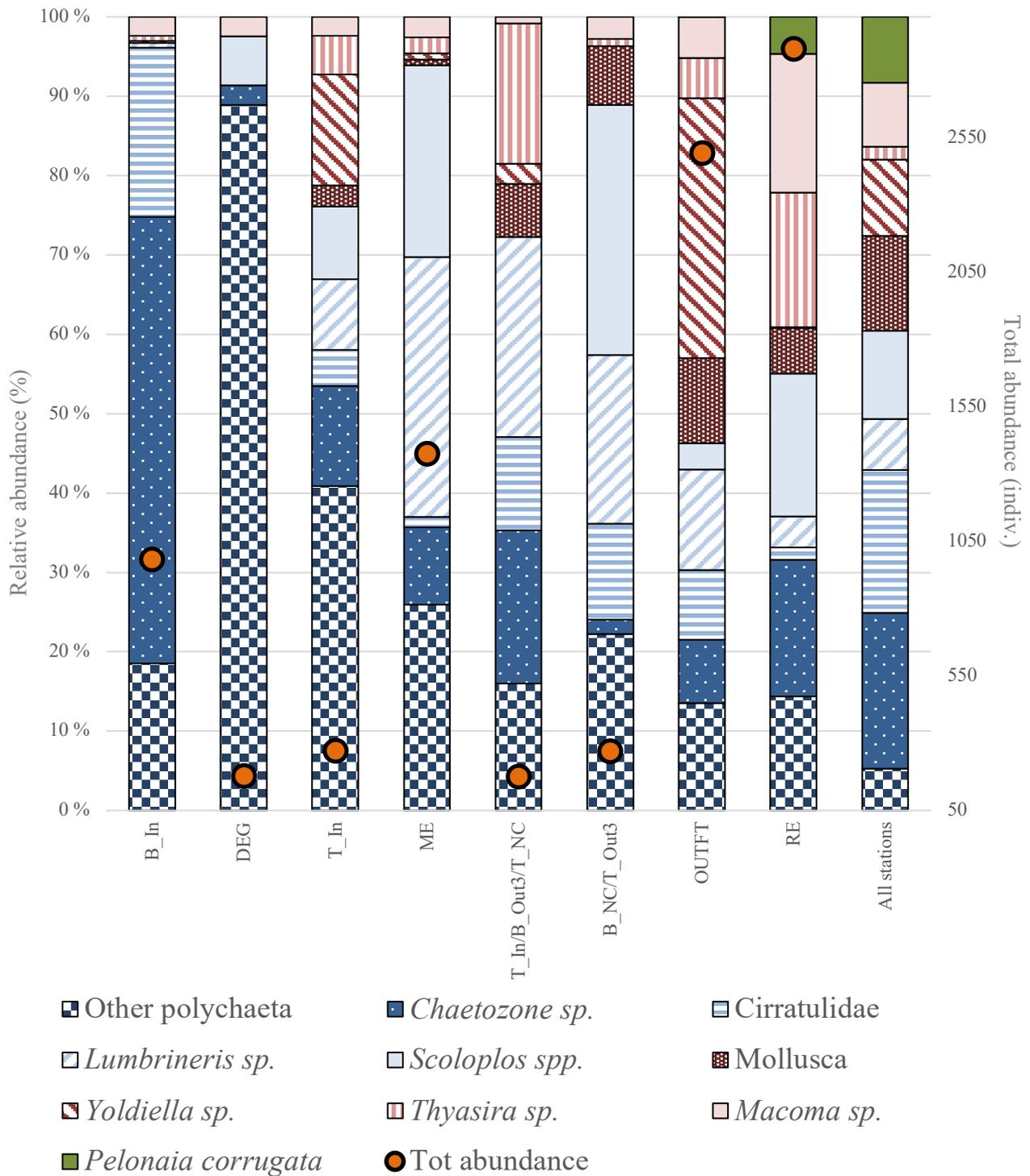
Figure 6: Relative abundance of the top dominating species/taxa, abundance over 50 (n>50), within each cluster group, and the mean abundance for each taxon was calculated within each cluster group. Second y-axis (Orange circles) show total abundance within each cluster group. Red pattern: Mollusca, Green: Ascidiacea and Blue pattern: Polychaeta.

Riverine and glacier influenced cluster group

The B_Inner cluster group, had the highest abundance of all the cluster groups, Table 4. This cluster group had high abundances of polychaetas: *Chaetozone* sp., *Cossura longocirrata* and *Caulleriella* sp, Table 5. Overall, the taxa Mollusca appeared in relatively small numbers in this cluster group, Figure 6, while the dominating taxa in this cluster group were Polychaeta. In the T_Inner glacier influenced cluster group, species like the bivalve *Yoldiella* sp., and the polychaetas *Chaetozone* sp. and *Lumbrineris* sp., dominated.

The bivalve genera *Macoma* sp. and *Thyasira* spp., had high abundance in the River Estuary cluster group. All stations in Adventfjord were clustered in this group. A_F1 had a high abundance of the class: Ascidiacea: *Pelonaia corrugate,* compared to other stations. In the DeGeer cluster group the abundance was relatively high (179 indv. ($0.1m^2$)), compared to species richness (9 taxa). In this station the polycaheta *Capitella* sp. was most dominant, and this genus was highest in this station compared to other sites.

Outer fjord and Marine endpoint station

The Outer fjord cluster group had the highest abundance of *Yoldiella* sp., Table 5. One of the inner stations in Billefjord (B_Inner 3) clustered within this cluster group, high abundance of Mollusca was observed in this station. This cluster group also had a high abundance of the polychaetas *Lumbrineris* sp., *Chaetozone* sp. and *Terebellides stroemii*.

The Marine Endpoint stations were taken in the main axis of Isfjord and was mostly dominated by Polychaeta, Figure 6. This group had the highest abundance of *Lumbrineris* sp. Interestingly these stations had lower abundance that the River Estuaries and Outer Fjord cluster groups, Figure 6. These grabs also consisted of more tube dwelling organisms (e.g. Maldanidae, Oweniidae and Ampharitidae) than the other stations.

Other cluster groups

In the T_In/B_Out2/T_NC cluster group species found in other cluster groups as well dominated: *Chaetozone* sp., *Thyasira* sp. and *Lumbrineris* sp., though these stations had very low abundances, Table 5. The B_NC/T_Out 3 cluster group had the highest abundance of polychaeta *Scoloplos* spp., Figure 6, but was also dominated by other polychaeta species like *Marenziella wierni* and *Hormothoe imbricata*, Table 5.

Table 5: Species/taxa contributing more than 5% of total abundance in each individual cluster group. Feeding guild: SDF: Surface deposit feeder, SSDF: Sub-surface deposit feeder, P: Predator, S: Scavenger, O: Opportunistic, FF: Filter feeder, SF: Suspension feeder. All feeding guild is supported by: https://www.univie.ac.at/arctictraits/ and (Fauchald *et al.* 1979) for *Caulleriella* sp.

Cluster group	Species/taxa	Relative abundance (%)	Feeding guild
B_Inner	*Chateozone* sp.	54.9	SDF/SF
	Caulleriella sp.	20.8	SDF
	Cossura longocirrata	17.8	SSDF
DeGeer	*Capitella* sp.	46.6	SDF/SSDF/P
	Spionidae	28.1	SDF/SF
	Capitellidae	6.1	SDF/SSDF
	Eteone sp.	6.1	SDF/P
	Scoloplos spp.	5.6	SDF/SSDF
T_Inner	*Yoldiella* spp.	19.1	SDF/SSDF
	Chaetozone sp.	15.8	SDF/SF
	Lumbrineris sp.	12.1	O/S/P
	Scoloplos spp.	8.8	SDF/SSDF
	Thyasira sp.	6.6	FF/SF
	Polycirrus sp.	6.2	SDF/SF/FF
T_In/B_Out2/T_NC	*Lumbrineris* sp.	16.9	O/S/P
	Chaetozone sp.	12.9	SDF/SF
	Thyasira sp.	11.8	FF/SF
	Terebellides stroemii	10.1	SDF
	Cirratulidae	7.9	SDF/SSDF
	Edwarsiidae	5.08	
B_NC/T_Out3	*Marenzelleria wireni*	13.7	SDF/SF/FF
	Harmothoe imbricata	12.6	O/S/P
	Scoloplos spp.	12.6	SDF/SSDF
	Lumbrineris sp.	8.5	O/S/P
	Terebellides stroemii	7.04	SDF
River Estuary	*Scoloplos* spp.	15.6	SDF/SSDF
	Macoma sp.	15.09	SDF
	Chaetozone sp.	14.9	SDF/SF
	Thyasira sp.	14.7	FF/SF
	Terebellides streomii	8.1	SDF
Outer Fjord	*Yoldiella* spp.	25.4	SDF/SSDF
	Lumbrineris sp.	9.8	O/S/P
	Chaetozone sp.	6.2	SDF/SF
	Terebellides stroemii	5.6	SDF
Marine Endpoint	*Lumbrineris* sp.	27.4	O/S/P
	Scoloplos spp.	20.3	SDF/SSDF
	Maldane sarsi	13.6	SDF/SSDF
	Chaetozone sp.	8.1	SDF/SF

4.2 Physical environment

Different physical environment was observed among the different stations, Figure 7, covered a range in depth, temperature, sediment grain size and %TOM, as well as chlorophyll a and phaeopigment concentrations. The deep-water stations along the Isfjorden axis differ from the other stations within each side fjord in that these stations are deeper and had higher chlorophyll *a* and phaeopigment concentrations, as well as lower clay and %TOM content. From the PCA plot, Figure 7, the outer fjord group are associated with colder sediment temperatures, whilst some of the River Estuaries are stations with warmer temperature. Some of the River Estuary cluster group and, stations influenced by glacier input (T_Inner and B_Inner) have higher content of clay and organic material (%TOM). Redox potential (Eh) appear to be lower in the Outer Fjord cluster groupings, and higher in some River Estuary stations, as well as the DeGeer cluster group. Overall, the River Estuary stations, the B_NC/T_Out3 and T_Inner cluster group stations are more variable with regards to the environmental variables presented, than the Outer Fjord and Marine Endpoint cluster group.
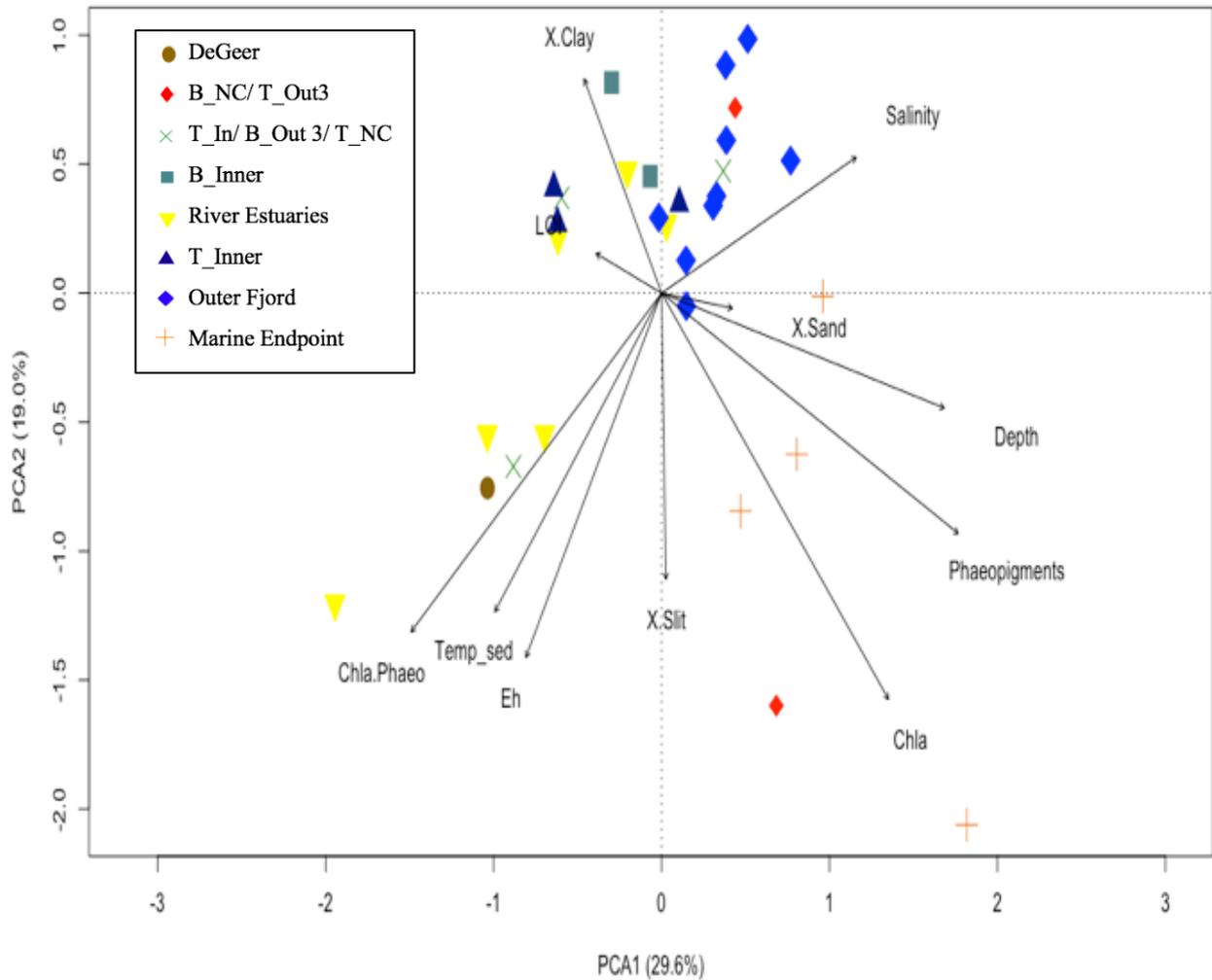
Figure 7: Principle component analysis of scaled and centered environmental data. The ordination (the two axis) explains 45.7% of the variance among stations. Color and shape of symbols indicate the cluster that each station belongs to, according to the community data.

Sediment grain size

Grain size composition was generally dominated by clay and silt, but the Outer fjord cluster had higher percentage of sand compared to all other clusters. Of clay and silt, silt dominated in nearly all cluster groupings, and was highest in the Marine Endpoint and DeGeer cluster groups. The highest percentage of clay was found in cluster groupings T_Inner and B_NC/T_Out3, followed by the B_Inner group (Table 6). It should be noted that the B_Outer 2, B_NC and T_Outer 3 stations had a large amount of gravel present in the grab, but this is not evident in the results because gravel was not included in the grain size analysis.

Salinity and temperature

Salinity in bottom water ranged from 30 to 35, see Table 6, with the lowest salinity measurements found in the River Estuary cluster, where the T_RE_Sassen station had the overall lowest salinity (9.2), the other stations in this cluster group ranged from (32.2 to 35.2). The highest salinity was found in the DeGeer cluster, (Table 6).

Temperature in the sediment varied between 1.1 and 4.7 ºC among clusters, though some cold-water (T < 0° C) was detected in the mid fjord Billefjord. Lowest temperatures were found in the Outer Fjord and B_Inner cluster groups. The mean temperatures for the River Estuary and DeGeer were close to 5 degrees, and the T_In/B_Out2/T_NC, T_Inner and Marine Endpoint cluster groups had all temperatures at approximately 2 degrees.

Redox potential (Eh)

Redox potential (Eh) showed negative values in the B_NC/T_Out3 and B_Inner cluster groups, Table 6, indicating less oxidized sediments. The Marine Endpoint and T_Inner cluster groups had a higher Eh, indicating well oxidized sediment.

Sediment Organic matter

%TOM varied from 6.5 to 11.3, Table 6, with the highest percentage of organic matter in B_Inner and the T_In/B_Out2/T_NC cluster group and the lowest values in the B_NC/T_Out3 cluster group. Similar %TOM values were observed in the River Estuary, T_Inner, Outer Fjord and the Marine Endpoint cluster group. The DeGeer cluster group had higher %TOM (9.5) than the cluster group just listed.

Sediment pigments

Sediment chlorophyll a and phaeopigments concentrations range from (707.5 to 6720.7 and 549.2 to 143539.8, respectively). Chlorophyll a concentration was highest in the Marine Endpoint cluster group, followed by the B_NC_T_Out3 cluster group, Table 6. Lowest chlorophyll a concentration was found in the DeGeer cluster group. Phaeopigments had the highest values in the B_NC/T_Out3 cluster group (Table 6), and lowest values in the DeGeer cluster group. The Chla:Phaeo ratio ranged from (0.3-1.1, Table 6), and highest ratio values were in the River Estuary cluster group and lowest ratio value in the Outer fjord cluster group.

Table 6: Overview of environmental variables from each cluster group, where the average value from each group is included, and ± standard deviation.

Cluster grouping:	Depth (m)	Salinity (psu)	Temp sed (C)	Phaeo (ug/L)	Chla (ug/L)	Chla.Phaeo	Eh (ORP)	%Clay	%Silt	%Sand	%LOI
River Estuary	17.2±14.08	30.02±10.3	4.7±0.7	2386.1±1783.03	1384.4±849.3	0.7±0.4	111.5±308.4	37.03±5.8	56.7±3.6	6.3±7.4	7.9±1.2
DeGeer	23	35.6	4.9	549.2	627.5	1.1	391.4	32.6	60.9	6.5	9.5
B_NCT_Out3	26.3±24.5	33.3±1.4	4.3±1.1	14539.8±4198.6	6269.9±5219.5	0.4±0.2	-162.2±364.5	38.3±12.6	58.4±11.4	3.2±1.2	6.5±2.7
T_In/T_NC/B_Out3	32.4±22.1	33.9±14.2	2.88±1.5	4291.5±1.1	2505±4465.1	0.8±1619.8	70.6±0.5	43.9±229.4	53.5±1.1	2.6±1.1	10.5±1.02
B_Inner	36.4±13.9	35.06±1.1	1.7±1.2	1353.4±1128.6	707.5±753.2	0.4±0.2	-78.9±11.4	40.9±3.2	57.3±4.03	1.8±0.8	11.3±0.9
T_Inner	49.9±29.2	32.3±0.005	2.2±1.2	2359.7±3018.6	1055.4±902.5	0.6±0.2	126.8±89.2	43.8±2.7	53.4±1.2	2.7±1.6	7.5±1.4
Outer Fjord	82.3±32.03	33.7±1.3	1.04±1.3	6262.8±2198.1	1515.8±569.9	0.3±0.07	25.1±132.9	35.4±11.9	54.5±8.5	10.04±14.3	7.3±2.6
Marine Endpoint	207±81.8	35±1.1	2.6±1.7	12264.6±6256.3	6720.7±4406.3	0.5±0.1	165.4±260.5	33.6±9.3	59.3±5.7	7.1±7.5	7.9±1.4

Correlation analysis of environmental variables

Correlation analysis revealed 11 significant correlations of environmental variables, Table 7. Depth correlated negatively with temperature and had positive correlations with phaeopigments, chlorophyll a and Chla:Phaeo ratio. Grain size parameters are not independent from one another, since they are compositional data, but correlation analysis revealed a negative correlation between clay and sand (r: -0.77, Table 7), as well as positive correlation between clay and %TOM, and negative correlation between sand and %TOM. Chlorophyll a and phaeopigments were positively correlated. Chlorophyll a did not correlate with Chla:Phaeo ratio, but both Phaeopigments, Salinity, Eh and Temperature positively correlated with Chla:Phaeo ratio (r: -0.34, r: -0.35, r:0.61 and r:0.56, respectively (Table 7).

Table 7: Correlation matrix with environmental variables. Star indicate level of significant correlation (**p=0.05*, p=0.01**, p=0.001*****).

	Depth	Salinity	Temp	Phaeo	Chla	Chla:Phaeo	Eh	Clay	Silt	Sand	LOI
Depth											
Salinity	0.21										
Temp	**- 0.38***	-0.23									
Phaeo	**0.52****	0.18	0.00								
Chla	**0.50****	0.16	0.27	**0.87*****							
Chla:Phaeo	-0.28	**-0.35***	**0.61****	**-0.34***	0.06						
Eh	-0.01	-0.31	0.20	0.09	0.11	**0.56****					
Clay	-0.23	0.00	0.04	-0.1	-0.20	0.01	-0.17				
Silt	0.03	0.03	0.05	0.08	0.19	0.19	0.30	-0.27			
Sand	0.20	-0.03	-0.07	0.04	0.06	-0.14	-0.03	**-0.77*****	-0.4		
LOI	-0.12	0.18	0.12	-0.15	0.02	**0.31***	-0.02	**0.48****	-0.19	**-0.34***	

35

4.3 Environmental variables driving benthic community

Environmental variables sampled had low explanatory power for the community structure (Table 8). Of all environmental parameters measured, sediment temperature explained the most variability in the community, explaining 10% of the variability. Depth, Phaeo and Chla, explained 5%, 6% and 6% of the variance, respectively. Multivariate analysis of CCA and RDA, also revealed low explanatory power of the two axes, these figures are found in the appendix.

Table 8: Permutational Multivariate Analysis of Variance on community data and environmental variables as response variables. **(p=0.05*, p=0.01**, p=0.001***)**. Residuals: 0.55, with all environmental variables. The order of the environmental variables is according to significance. Chla: chlorophyll a, Phaeo: phaeopigments, Eh: Redox potential, TOM: total organic matter.

Parameter	Df	R2	Pr(>F)
Temperature	1	0.102	**0.001*****
Chla	1	0.061	**0.008****
Phaeo	1	0.066	**0.003****
Depth	1	0.056	**0.013***
Silt	1	0.037	0.296
Eh	1	0.029	0.537
Clay	1	0.022	0.889
Salinity	1	0.022	0.785
Sand	1	0.019	0.938
LOI	1	0.03	0.408

The different clusters have different community structure though many of the same species are found throughout the fjord system, different species dominate in the different cluster groups (Table 5, Figure 6). When adding the environmental variables and the biological indices to the nMDS of the community data, Figure 8, output showed that the Marine Endpoint cluster group has higher species richness and that chlorophyll a concentration is higher in this cluster group. The Outer Fjord stations is associated with higher salinity than the other cluster groups, as well as higher evenness. Stations associated with glacier influence (T_Inner and B_Inner clusters) were associated with high clay content and high %TOM (Figure 8), as well as lower species richness. At DeGeer during sampling processing, presence of dark terrestrial material consisting of leaves and branches in the sediments was observed, shown in Figure 9. T_Inner

and B_Outer 2 consisted of gravel, while T_NC had very little material, in the sample after sieving over 1 mm sieve.

The B_NC/T_Out3 cluster group have affinity for silt, and warmer temperatures, Figure 8. Both of these stations contained a considerable amount of gravel and cobbles, which made it difficult to get a full grab, particularly at B_NC. At this station there was also considerable amounts of whole kelp macro algae, that came up with the grab sample.
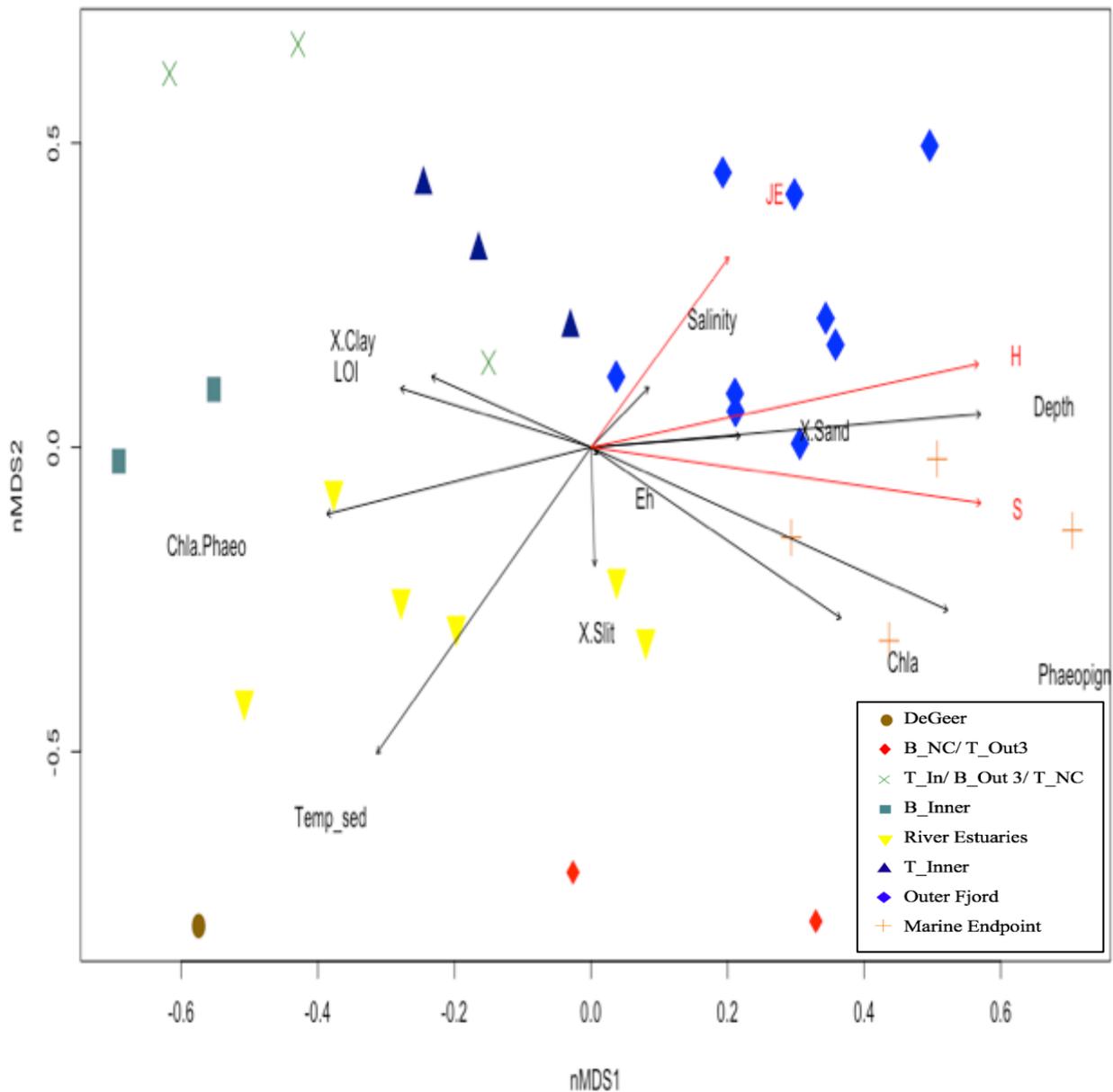
Figure 8: nMDS of community data using cluster groupings, with environmental data (black arrows) and biological indices (S: Species richness, H: Shannon-Weiner Diversity Index, JE: Evenness (red arrows)) added as passive correlations. 2D stress: 0.22.
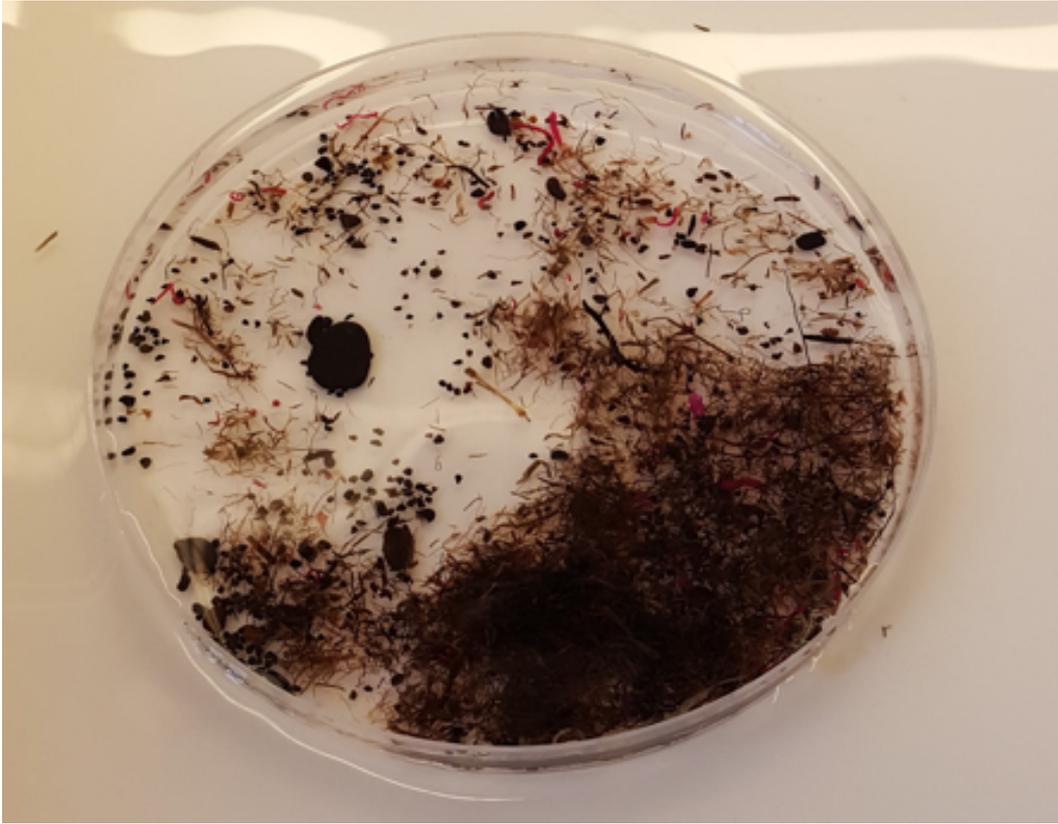
Figure 9: Sub-sample of the T_RE_DeGeer station, after sieving.

5. DISCUSSION

5.1 Benthic community structure: Fjord versus habitat

The fjords studied vary in many of the major environmental factors thought to influence Arctic benthic communities, including depth, terrestrial influence source, sediment porosity and sedimentation rates (Holte *et al*. 2004; Morata *et al.* 2008; Sejr *et al.* 2000; Włodarska-Kowalczuk and Pearson, 2004). As such, I would have expected a difference in the benthic communities among these fjords. All the studied fjords are located in the Isfjorden system, and one could argue that species composition may not be that different between sub-fjords because the whole system might be influenced similarly by water masses from the adjacent continental shelf to some extent. One study, however, found that environmental characteristics and dominant species of bays in fjords on the western side Spitsbergen were essentially the same and did not show strong fjord-based differences (Włodarska-Kowalczuk *et al.* 1998). This supports my findings from the cluster analysis showing that stations from different fjords, but from the same general habitat within fjords (e.g. river estuary, mid fjord and outer fjord), clustered together. Thus, I suggest that overarching fjord-based differences are overwhelmed by small-scale drivers with more local environmental impacts.

The fjords in Svalbard are subject to a range of environmental conditions, ranging from disturbed inner basins where glacier melt water and/or river-runoff bring freshwater and heavy loads of sediments, to deep saline waters in the open fjord (Włodarska-Kowalczuk *et al.* 2005). The habitat types sampled differ with regards to degree of physical disturbance, in terms source and distance from terrestrial inputs (i.e. rivers or glaciers). This study observed differences in community structure from riverine and glacier influenced sites, compared to fjord transect and Marine Endpoint, with an increase in diversity from disturbed areas towards less disturbed areas. Thus, these results indicate that community structure reflects down-fjord pattern in terms of depth, temperature, sedimentation rate and food availability.

5.2 Shallow water communities versus deep water communities

Shallow areas are very dynamic and complex systems, with regards to large variation in physical factors like influence from land and strong impact of local conditions. These nearshore areas are known to exhibit large seasonal variations in freshwater input, sedimentation rates and temperature (Holte *et al.* 1996; Meyer *et al.* 2015; Kokarev *et al.* 2017; Włodarska-Kowalczuk *et al.* 2012). The deeper parts of the fjords are suggested to be more stable with regards to sedimentation and temperature, and other shallow water disturbances like ice scouring and freshwater input, which may allow for higher diversity.

Species richness and abundance

Areas associated with brackish water and high sedimentation rates are often low in species richness and have species with similar life history traits (Kokarev *et al.* 2017; Włodarska-Kowalczuk *et al.* 2012). I observed an increase in species richness from the disturbed areas associated with river estuaries and glacier influenced sites. Results found that the main feeding guilds were similar among dominant taxa in the different cluster groups (Table 5), which could be explained by not including all taxa present in the cluster groups. The Outer Fjord and Marine Endpoint cluster groups had the highest diversity, though diversity was also relatively high in the River Estuaries. The reasons for this was mainly caused by two stations, which could be explained by sampling methodology. Using different number of replicates and size of Van Veen grab can either increase or decrease species richness. Though, investigation (Węsławski *et al.* 1990) done in Gipsvika (where station T_RE_Gips is located) showed that this area has an atypical benthic community patterns, with many rare species, and few dominant species. This system is found to be relatively productive, with occasionally occurrence of eddies and indirect influence of the WSC, these oceanographic processes mixes nutrient throughout the water column (Węslawski *et al.* 1990) and can enhance production.

Abundance did not show a similar increasing trend from disturbed areas as species richness, and instead the overall abundance was highest in the River Estuary cluster. This pattern has been found in other studies as well (Pearson and Rosenberg, 1978; Włodarska-Kowalczuk *et al.* 2012). The input from rivers and glacier seems to influence which species are present at these sites, and opportunistic species are often found to be very abundant in areas associated with high disturbance. Opportunistic taxa generally have life histories that favor rapid colonization in disturbed areas, leading to high abundance of relatively few taxa (Pearson and

Rosenberg, 1978). Species richness, however, increases with distance from disturbed areas as strong selection toward opportunistic strategies are relaxed and other life-history traits can survive (Zajaczkowski and Włodarska-Kowalczuk, 2007).

Depth

Depth has been shown to be an important factor structuring the benthic community in most benthic studies (e.g. Meyer *et al.* 2015; Kokrav *et al.* 2017; Steffens *et al.* 2006), but it alone does not directly explain why the communities differ. Other parameters that vary with depth may explain the observed correlation (e. g. disturbance, salinity, temperature and food supply). The low explanatory power of depth in this study could be explained by how important environmental parameters (e.g. grain size, temperature and food supply) differ in shallow areas with no direct link to depth per se, and hence make the benthic communities differ, even among shallow areas. Communities may still respond to these parameters, but the lack of the typical covariance with depth leads to results that seemingly contradict general theories of community development, built largely from studies away from shallow habitats.

Differences in river and glacier characteristics

Rivers or glaciers entering fjord systems can create a relatively unstable environment in the nearby area with regard to input of organic matter, high sedimentation, temperature changes, freshwater input and ice scouring. This have implications for which benthic organisms inhabit these areas (Holte, 1998; Meyer *et al.* 2015; Kokarev *et al.* 2017; Włodarska-Kowalczuk *et al.* 2012). The sampled River Estuary stations differs in terms of catchment and glaciation influence, which have implications for input of terrestrial material and sediment grain size (Forwick *et al.* 2010; Prowse *et al.* 2006). Still, the River Estuary station in this study clustered together. My results found that temperature was highest in the River Estuaries. Temperature is usually relatively stable in deeper areas, whilst it may change rapidly in shallower areas throughout the season due to changes in atmospheric temperature and freshwater input from rivers and glaciers. In the River Estuary stations in general, the bivalves *Macoma* sp. and *Thyasira* sp. were most abundant. *Macoma* sp. have been suggested to be an abundant taxon in areas with high terrestrial carbon and freshwater inputs (Roy *et al.* 2014). In one of the River Estuary stations (DeGeer), however, the opportunistic polychaeta *Capitella* sp., a genus that is often considered an indicator species of stressful environments (Holte *et al.* 1996; Pearson and Rosenberg, 1978), dominated. Despite similarities in the physical environment with the other

River Estuary station, difference in benthic community structure were observed. One suggestion for this include fullness of the grab samples: each of the four (small) grabs had a mean fullness was 66% (compared with 84% from the other River Estuary locations), which may have prevented us from capturing the total species richness at this site. Similar community structure among the majority of River Estuaries found in Isfjorden suggest similar source of disturbance, despite differences in glaciation influence between rivers.

River estuaries and land-terminating glaciers have similar terrestrial inputs and physical characteristics (Meire *et al.* 2017), though my findings showed that these habitats did not have similar benthic community structure. In this study the River Estuary sites and the land terminating glacier site (T_Inner, Figure 3a) did not cluster together, but much of this could be due to depth differences. The T_Inner cluster group were taken at depth close to 40 meters whilst the River Estuary were taken at approximately 10 meters depth and may explain why these stations did not cluster together. Differences in depth also resulted in colder temperatures in T_Inner station. In addition, lower species richness was found in T_Inner, compared to the River Estuaries, and the main taxa dominating in these habitats differed. With higher abundance of Polychaetas (i.e. *Scoloplos* spp. and *Lumbrineris* sp.) in T_Inner, compared to higher abundance of Mollusca (i.e. *Macoma* sp. and *Thyasira* sp.) at the River Estuary sites.

Additionally, the two glacier influenced cluster groups (T_Inner and B_Inner) were not similar in benthic community structure. Billefjord is thought to be a marine terminating glacier, suggesting that the communities would differ, though the glacier in Billefjord has retreated substantially for the last decades (Li et al. 2012). The two distinct benthic communities observed near the Nordenskiöldbreen in Billefjord, seem to be affected differently by the glacier. On the one side, the systems seem to be influenced by a marine-terminating glacier, due to clear blue water on the sampling day (pers.obs). Which might explain why the station (B_Inner 3) clustering together with the Outer Fjord stations. In addition, the high abundance of Mollusca compared to Polychaeta at this site resemble the community structure at the Outer Fjord. The two stations sampled on the other side of the glacier, however, was sampled in areas with brown water. The physical conditions at the B_Inner location seems to resemble land-terminating glacier, like in Tempelfjord, and should in theory have similarities with the river estuary inputs. The difference among the stations in the inner part of Billefjord could be explained by higher diversity at the B_Inner 3 station (S:24 taxa). At this station dominating taxa include the bivalves *Ennucula tenuis* and Y*oldiella* spp.. In contrast to the B_Inner cluster group, which was mostly dominated by Polychaeta (i.e. *Chaetozone* sp., *Cossura longocirrata*

and *Caulleriella* sp.). This indicated that the benthic communities change even over a short distance (200 m, even though depth was similar). This finding corresponds with another study, which found that the local-scale environment was the main driver influencing the benthic community composition in shelf areas, rather than large- scale processes (Kokarev *et al.* 2017).

Sedimentation and sediment chemistry

High sedimentation rates may be devastating for benthic organisms by burying organisms, preventing them from achieving their optimal position in the sediment, and clogging feeding structures (Włodarska-Kowalczuk and Pearson, 2004; Kokarev *et al.* 2017). Therefore, differences in benthic community structure were expected among the different habitat sampled, with more highly mobile and tolerant species in the disturbed nearshore areas. This study found high abundance of *Macoma* sp. in the river estuaries, this species is a surface deposit feeder and is known to have high tolerance to input of terrestrial material. In addition, *Thyasira* sp. is a small size bivalve, and is very motile. This helps them because they are able to maintain their optimal position in the sediment (Włodarska-Kowalczuk and Pearson, 2004), despite high sedimentation. Thus, both these bivalves are also often found in glacial bays and other high sedimentation sites (Włodarska-Kowalczuk and Pearson, 2004). Several polychaetes, *Chaetozone* sp., *Cossura longocirrata* and *Caulleriella* sp., were highly abundant in the glacier-influenced areas in Billefjord (B_Inner), and these have also been found to be the dominant species near glaciers in other studies (Holte and Gulliksen, 1998; Włodarska-Kowalczuk and Pearson, 2004; Włodarska-Kowalczuk and Węslawski 1998). In the glacier influenced sites in Tempelfjord, the dominant taxa included *Yoldiella* sp. and again *Chaetozone* sp. All taxa mentioned in the glacier influenced sites have a high tolerance to environmental stressors, such as high sedimentation rates, inorganic and organic material, as well as freshwater input from rivers and glaciers (Włodarska-Kowalczuk *et al.* 1998; Włodarska-Kowalczuk and Pearson, 2004). All mentioned species, except *Thyasira* sp., which is a filter feeder, are deposit feeders (Włodarska-Kowalczuk and Pearson, 2004) which might be favored in areas where burial and clogging may be a consequence of high sedimentation rates.

Grain size and sediment stability are other factors structuring benthic communities (Denisenko *et al.* 2019; Włodarska-Kowalczuk *et al.* 2012). My results showed that grain size had low explanatory power explaining benthic community structure, though a study from a nearby glacier-influenced fjord (Kongsfjord, Svalbard) has shown that the sediment composition here was essentially homogenous. Additionally, that sediment stability and sedimentation processes

are more important factors influencing the distribution and structure of the macro-benthic communities than grain-size per se (Kedra *et al.* 2013). This suggests that high sedimentation rates during melting season in these shallow areas affect benthic communities more than the sediment composition itself. Other studies have found similar patterns suggest that sedimentation and sediment stability might be an important regulator on the diversity in these terrestrial influenced areas (Holte *et al.* 1996; Włodarska-Kowalczuk and Pearson, 2004; Włodarska-Kowalczuk *et al.* 2005). High sedimentation rates also influence the grain size in fjords. Transport of fine sediment into fjords from glaciers and rivers, can change the sediment composition in fjords (Forwick *et al.* 2010). These sediments can be distributed throughout fjord systems due to oceanographic processes including advection and tidal forcing (Zajaczkowski, 2008). My results indicate a higher percentage of clay in the glacier influenced sites compared to the River Estuary sites, which had higher percentage of silt and sand. It is likely this finer sediment is glacially derived and may influence community structure, favoring surface deposit feeders and mobile taxa groups.

Outer fjord and Marine Endpoint

Species richness and functional diversity is often greater in areas with less disturbance of high terrestrial inputs (e.g. sedimentation, inorganic and organic material) (Kokarev *et al.* 2017; Włodarska-Kowalczuk *et al.* 2012; Włodarska-Kowalczuk and Pearson, 2004), as well as variable physical environment. The benthic community in fjord mouths is often dominated by tube-dwelling and mobile organisms. In addition, organisms here are larger and penetrate deeper into the sediment compared to organisms at glacier influenced sites, which are often small sized and do not penetrate deep in the sediment (Kokarev *et al.* 2017; Włodarska-Kowalczuk *et al.* 2012; Włodarska-Kowalczuk and Pearson, 2004). In the Marine Endpoint stations, the polychaete species *Maldane sarsi* and *Galathowenia* sp. were abundant and in the Outer Fjord cluster group the polychaete *Terebellides stroemii* was abundant. These species are tube-dwelling organisms and have lower tolerance to sedimentation and unstable sediment than species found in the shallow areas. These tube-dwelling organisms are important for sediment stability and biogeochemical processes (Kokarev *et al.* 2017). The polychaete *Lumbrineris* sp. was also abundant at these stations, and is a predator found in almost all habitats within fjord and shelf systems (Włodarska-Kowalczuk and Pearson, 2004). Other dominant taxa in communities at Outer Fjord stations included some of the same species as in many of the shallow stations (e.g. *Chaetozone* sp., *Thyasira* sp. and *Macoma* sp.). In the deeper areas, the physical environment is more stable, and limitation is mainly driven by food availability.

Food availability

The amount of the phytoplankton-derived organic material, often assumed to be the most important food source for benthos, that reaches the seafloor is dependent on various factors such as grazing pressure from zooplankton, re-generation by bacteria, and advection (Wassmann *et al.* 2006). Particulate organic matter can come in many other forms such as dead organisms, fecal pellets or terrestrially-derived organic matter, and kelp detritus (Carroll and Ambrose, 2012). Pelagic-benthic coupling is shown to be tight in shelf areas due to high input from planktonic primary production, ice algae blooms, as well as distance to the seafloor (Carroll and Ambrose, 2012). While this might be true in the mid-fjord and outer part of the fjords studied, other factors influence pelagic-benthic coupling in the shallow areas, including sedimentation from land and advection away from these areas. This study found species richness highest in areas with higher chlorophyll a concentration (Figure 8), indicating that fresh organic matter might be an important factor influencing diversity. This is in agreement with earlier studies which have found that food availability and quality of the food to be important in structuring benthic communities (Persson, 1983; Carroll and Ambrose, 2012). The low chlorophyll concentrations in the shallow areas, including River Estuaries and glacier influenced sites. As well as, low species richness indicate that food supply might be limited, or not as available for the benthic organisms living there. Increase in chlorophyll a concentration moving away from riverine or glacier influenced sites is supported by another study (Krajewska *et al.* 2007) and can be due to high particle load in the shallow areas that prevents light penetration and dilutes nutrients, reducing primary productivity in these areas. The differences in community structure and diversity between terrestrially influenced sites and the Outer Fjord axis and Marine Endpoint groups indicate that food availability might be an important part regulating the diversity at these sites.

During the spring bloom, the coastal benthic community is fueled by fresh (un-grazed and less degraded) phytodetritus from the phytoplankton bloom, and during winter they may feed on low quality detritus from the terrestrial environment (Kedra *et al.* 2012). Whilst the low chlorophyll a concentration in the riverine and glacier influenced sites might be due to disturbances like high turbidity and high sedimentation. Glaciers and rivers provide another source of food to the coastal areas, in form of terrestrial derived organic matter (Kokrav *et al.* 2017; Kedra *et al.* 2012), which might fuel the benthic community in times when marine-derived food is limited (Dunton *et al.* 2012; Harris *et al.* 2018; Kedra *et al.* 2012; Morata *et al.* 2008). The organic matter inputs can be diluted due to high inorganic particles, making them

less available for some organisms. It is also unclear how bio-available (i.e. how readily the benthos can break down the organic matter and turn it into energy) the organic matter is, and this need further investigation (Dunton *et al.* 2012). The lability of terrestrial can be highly seasonal, with more labile matter in spring and more recalcitrant material in summer (Holmes *et al.* 2008). My results showed that the highest TOM content was near the glacier influenced sites in Billefjord, though this does not provide information about origin of the organic matter. The low species richness in this area, might indicate that the food available is not that labile for the organisms. One of the few studies that investigated the variation in community structure throughout seasons, suggested that benthic communities in Kongsfjord, Svalbard are stable and adapted to cope with a variable environment. These authors found that many of the organisms found year-round are omnivorous species, meaning that they can shift diet when the preferred diet is limited (Kedra *et al.* 2012). This strategy indicates that some of the species living in these disturbed environments have good resilience to cope with seasonal changes regarding food availability.

Temporal changes in coastal areas

These shallow dynamic systems exhibit large temporal changes in e.g. salinity, temperature, sedimentation, and organic and inorganic content (Holte *et al.* 1996; Meyer *et al.* 2015; Kokarev *et al.* 2017; Włodarska-Kowalczuk *et al.* 2012). The low diversity in these shallow areas might be related to other nearshore disturbances like ice scouring, or during winter when many of the nearshore areas are covered with sea ice. Winter sea ice and calving glaciers can scrape the seafloor, removing any larger organisms and leaving behind some small and highly mobile taxa that can survive this kind of disturbance (Conlan *et al.* 1998; Conlan and Kvitek, 2005). The mechanism by which benthic organisms are able to recover from these disturbances is of interest because benthic organisms have different life history traits with regards to spawning time, reproductive strategy (direct or by larvae), colonization and competitive abilities (Wildish, 1977).

5.3 Reflections

Seasonal variability affects the physical and biological conditions; the circulation of water masses, turbidity, magnitude of primary production, sedimentation processes and sediment characteristics (Włodarska-Kowalczuk and Pearson, 2004). Variation in sedimentation rates due to melting events from riverine and glacial runoff can change the sediment composition in a matter of a few days (Forwick *et al.* 2010), and from other studies sediment porosity is one of the main factors structuring benthic communities in shallow areas (Denisenko *et al.* 2019; Włodarska-Kowalczuk *et al.* 2012). A single sampling of such dynamic sites only provides a snapshot of what is going on in these shallow areas. Sampling happened in late August and observations of large river and glacier plumes in the sampling area. Therefore, it could be argued that the benthic community might still be recovering from the inputs from rivers and glaciers, as well as from limited food supply.

Shallow areas are difficult to study due to rapid changes throughout the year, compared to deeper systems. The logistical difficulty sampling these areas is getting as close to the influenced sites as possible, preventing use of same equipment for sampling the deeper stations. These challenges have led to a substantial knowledge gap regarding shallow nearshore habitat sampling, and more research is needed to fill this gap on these very dynamic systems. Another difficulty is quantifying the magnitude of terrestrial influence (e. g. sedimentation rate, freshwater input rate, organic material etc.) to determine where the influence stops. I sampled nearshore control stations, but it is hard to determine if these really are real controls, and not influenced by terrestrial input at some level. For further research on nearshore shallow areas I would recommend measuring more unambiguous environmental variables that indicate terrestrial influence, like sedimentation rates and stable C and N isotopes. These could give an indication of the presence and/or degree of terrestrial influence. Another easy to add factor for further investigation, is measuring distance from glaciers and rivers. Distance from a disturbed area have in another study, shown that species composition varied with distance from rivers and glacier in shallow depths (Kedra *et al.* 2011).

The species-accumulation curve indicated that I did not capture all species present with the number of stations sampled, and more stations could have helped with that. But due to time and budgetary constraints, this would not have been possible. Because these shallow areas most likely have high seasonal changes in both physical and biological processes, it may confound a spatial study, which only gives you a snapshot of the ecosystem. Therefore, for further studies

in the same areas, I suggest a temporal study or sampling from same stations as this study to get a timeseries on these different coastal areas in Isfjorden.

Climate change accelerate the retreat of glacier, melting of sea ice and thawing of permafrost. Which increasing the land-ocean interaction, by delivering high amount of terrestrial material to the coastal areas. This will have implications for the benthic communities in these coastal areas, and knowledge on how this will influence the benthic community with regards to species composition needs investigation. Benthic communities contribute to several key biogeochemical processes in sediments, remineralization of nutrients to the water column, as well as act as a food source for higher tropical levels. Therefore, the purpose with this study was to highlight these coastal areas and investigate how the different benthic communities differ and how different environmental drivers influence their structure. Further research is needed in these shallow areas to see how the community is influenced seasonally, so a larger time line on these systems is needed to fully understand the community structure and their function in the system.

6. CONCLUSIONS

Although the three study fjord systems differed in their morphology and source of terrestrial input, there were no major differences among fjords in benthic community structure. Instead, the local environment seemed to be the main driver influencing benthic community structure in different habitats, including source of disturbance as well as food availability. Shallow benthic communities differed from communities along fjord axis transects and marine endpoints, with an increase in species richness towards the less disturbed outer fjord. Differences in community composition were observed among habitats, with more robust species in the shallow areas, where high sedimentation, temperature changes, input of organic matter as well as temporal changes influence the physical environment. Shallow areas are dynamic systems, with high seasonal variability and spatial heterogeneity in environmental conditions. The low diversity at glacier fronts and in river estuaries indicates that these shallow areas are more unstable and temporally variable, while the deeper areas are more stable, supporting higher diversity.

This study provides unique data on relatively understudied shallow benthic communities, including at sites highly influenced by terrestrial inputs. With a changing Arctic, and with substantial changes at the land-ocean interface, there is a need for data on these poorly studied systems, in order to predict how benthic communities might respond to future environmental change.

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APPENDICES

Cluster Dendrogram

as.dist(Non_trans.veg)
hclust (", "average")

Figure A1: Hierarchical cluster analysis, using non-transformed community data (count), Bray Curtis dissimilarity and average linkage.

Cluster Dendrogram

as.dist(sqrt.veg)
hclust (", "average")
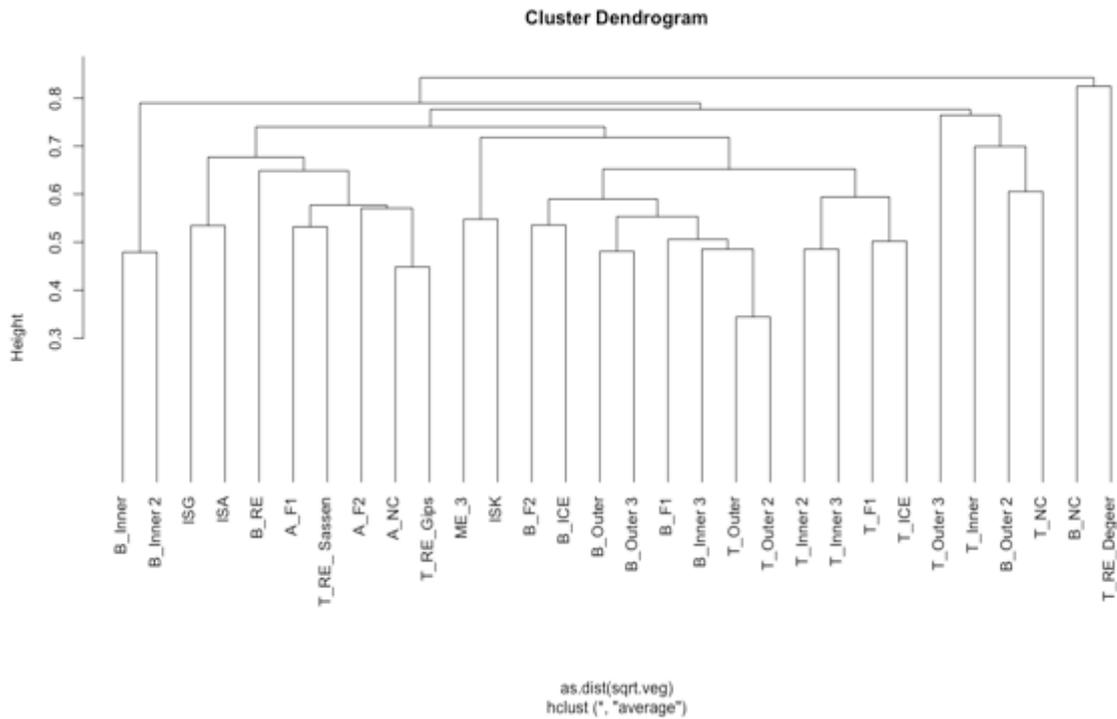
Figure A2: Hierarchical cluster analysis, using squared root transformed community data (count), Bray Curtis dissimilarity and average linkage.
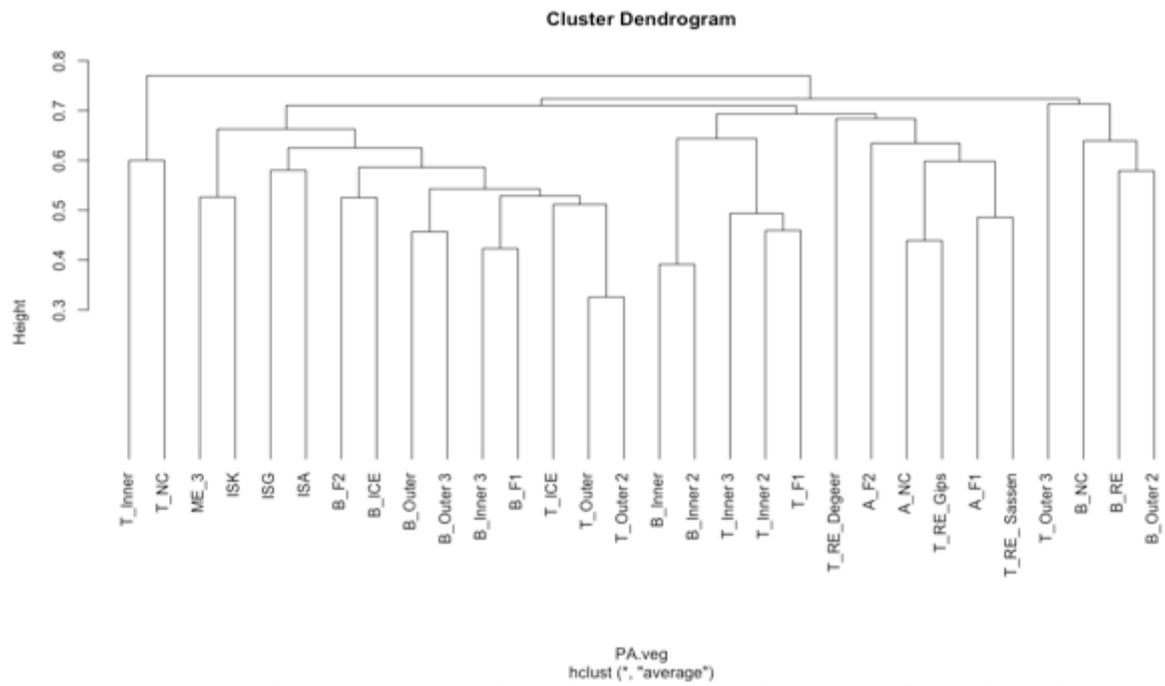
Figure A3: Hierarchical cluster analysis, using presence- absent transformation of community data (count), Bray Curtis dissimilarity and average linkage.
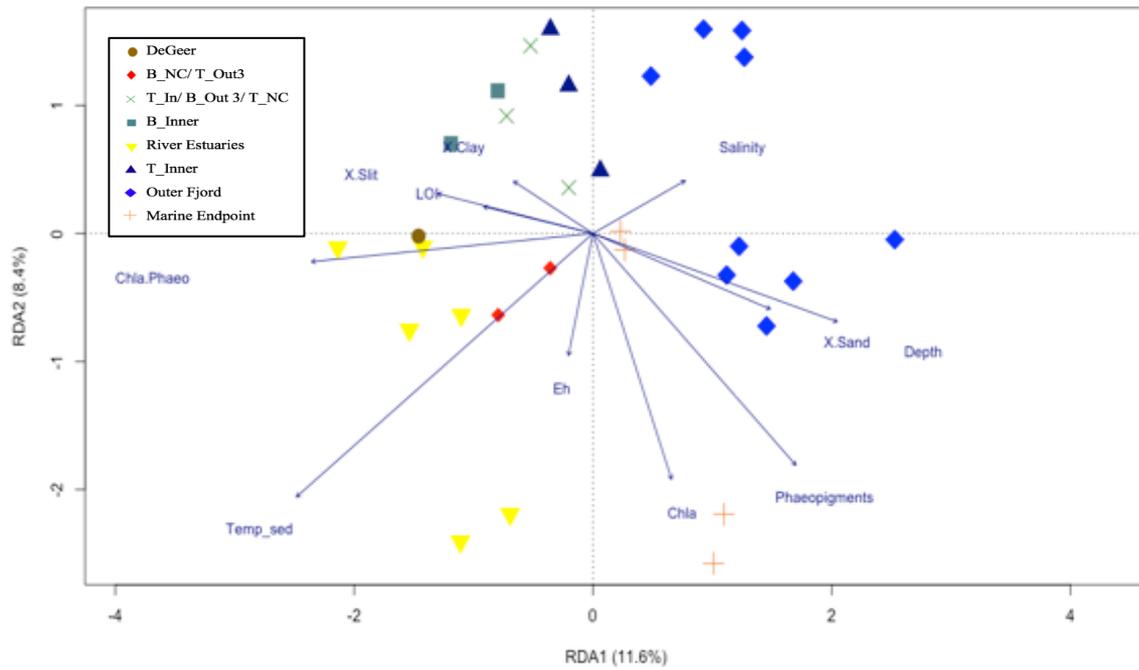
Figure A4: Redundancy analysis (RDA) of 4th root transformed community data as a response to scaled and centered environmental variables (blue arrows).
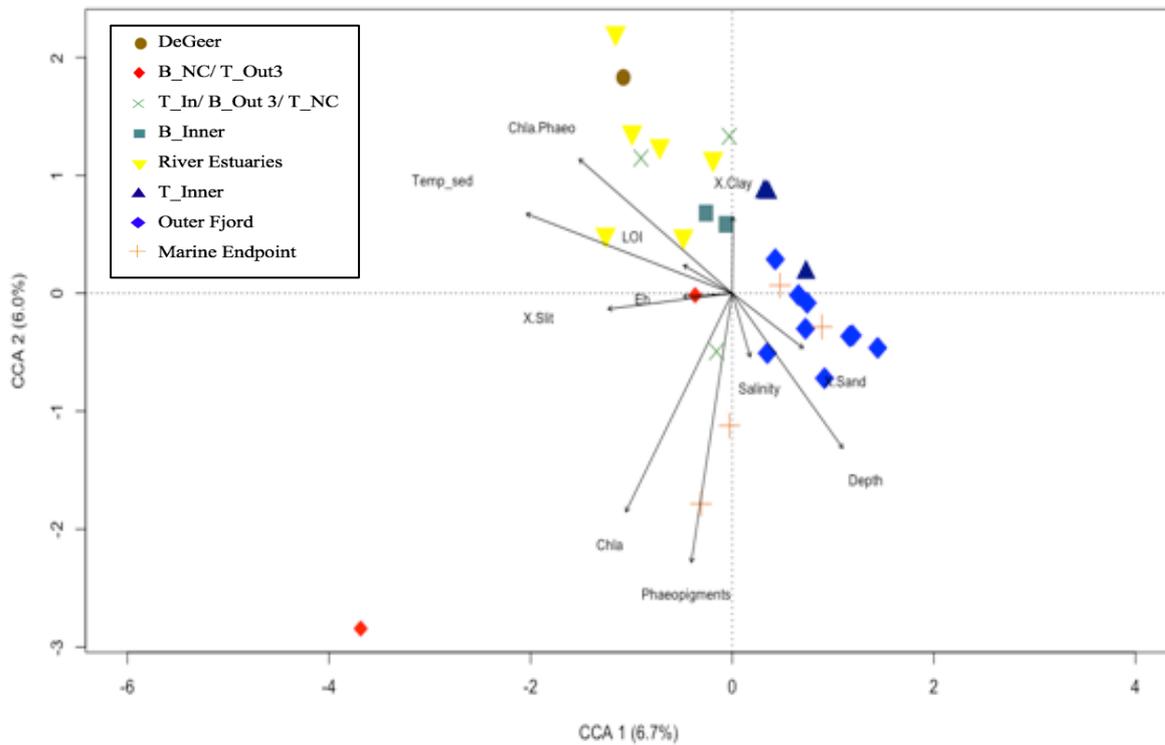
Figure A5: Canonical Correspondence Analysis (CCA) of 4th root transformed community data and scaled and centered environmental variables (black arrows).
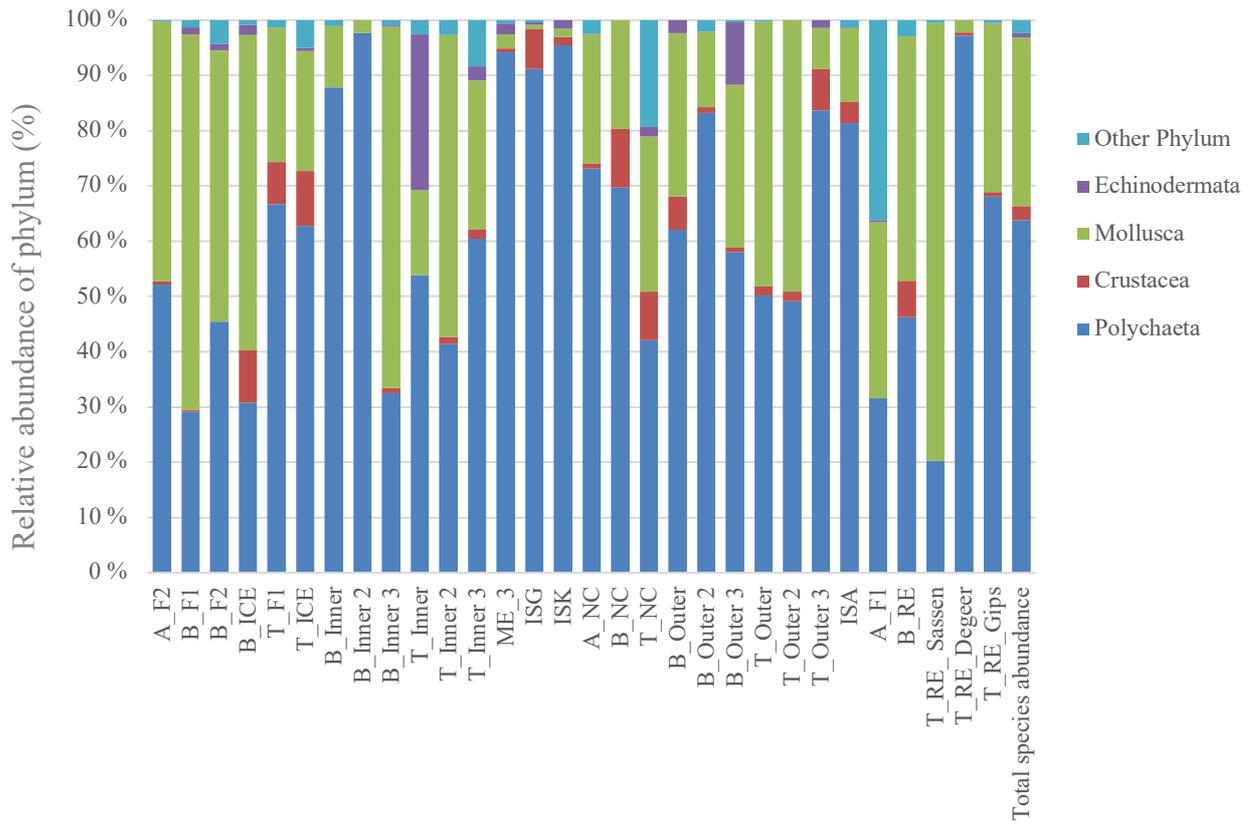
Figure A6: Total relative abundance of phylum at each station and the overall total phylum abundance on the right side.

Table A1: ANOSIM pairwise test output, for fjord differences using community data. A: Adventfjord, B: Billefjord, T: Tempelfjord and F: Isfjorden. If sign. level is < 5% then the clusters are not different by ANOSIM.

Pairwise Tests Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
A, B	0,199	12,6	364	364	46
A, T	-0,102	69,2	455	455	315
A, F	0,778	2,9	35	35	1
B, T	0,039	22,2	1352078	999	221
B, F	0,192	12,3	1365	999	122
T, F	0,084	28,6	1820	999	285

**R – statistic values varies between -1 to 1, where values close to 1 indicate large between group variation. Negative value indicates large within group variation, and 0 means that there is no difference within group and between groups.

Table A2: ANOSIM pairwise test output of groupings from the significant clustering (E: River Estuary, G: Outer Fjord, C: T_In/B_Out2/T_NC, F: T_Inner and H: Marine Endpoint). If sign. level is < 5% then the clusters are not different by ANOSIM.

Pairwise Tests Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
E, G	0,848	0,1	5005	999	0
E, C	0,852	1,2	84	84	1
E, F	0,87	1,2	84	84	1
E, H	0,71	0,5	210	210	1
G, C	0,934	0,5	220	220	1
G, F	0,704	0,5	220	220	1
G, H	0,68	0,1	715	715	1
C, F	0,593	10	10	10	1
C, H	0,926	2,9	35	35	1
F, H	0,852	2,9	35	35	1

**R – statistic values varies between -1 to 1, where values close to 1 indicate large between group variation. Negative value indicates large within group variation, and 0 means that there is no difference within group and between groups.

Table A3: Overview of phylum, taxa and abundance present at the glacier influenced cluster groups (B_Inner and T_Inner)

Cluster groupings	Phylum	Taxa	Abundance
B_Inner	Annelida	Ampharitidae	1
	Annelida	*Artacama proboscidea*	4
	Annelida	Capitellidae	3
	Annelida	*Caulleriella* sp.	205
	Annelida	*Chaetozone* sp.	541
	Annelida	*Cossura longocirrata*	176
	Annelida	*Eteone* sp.	2
	Annelida	*Heteromastus filiformis*	3
	Annelida	*Lumbrineris* sp.	5
	Annelida	*Nepthys* sp.	2
	Cephalorhyncha	*Priapulus caudatus*	2
	Mollusca	*Macoma* sp.	23
	Mollusca	*Mya truncata*	3
	Mollusca	*Parvicardium minimum*	5
	Mollusca	*Thyasira* sp.	6
	Mollusca	*Yoldiella* spp.	3
T_Inner	Annelida	*Aglaophamus malmgreni*	8
	Annelida	*Ampharete* sp.	2
	Annelida	*Aricidea* sp.	1
	Annelida	Capitellidae	7
	Annelida	*Capitella* sp.	2
	Annelida	*Chaetozone* sp.	43
	Annelida	*Cossura longocirrata*	5
	Annelida	*Eteone* sp.	1
	Annelida	*Lumbrineris* sp.	33
	Annelida	*Lysippe labiata*	1
	Annelida	*Melinna cristata*	1
	Annelida	Orbiniidae	1
	Annelida	*Phoele* sp.	4
	Annelida	*Phyllodoce groenlandica*	1
	Annelida	*Polycirrus* sp.	17
	Annelida	*Praxillella gracilis*	2
	Annelida	*Scoloplos* spp.	24
	Annelida	*Spio* sp.	1
	Annelida	Terebellidae	1
	Arthropoda	*Arrhis phyllodoce*	2
	Arthropoda	*Eudorella emarginata*	5
	Arthropoda	Paguridae	1
	Arthropoda	*Themisto* sp.	1
	Cephalorhyncha	*Priapulus caudatus*	10
	Cephalorhyncha	Priapulidae	3
	Cnidaria	*Cerianthus Iloydii*	2
	Echinodermata	*Ophiura* sp.	1
	Mollusca	*Chaetoderma* sp.	5
	Mollusca	*Cylichna occulta*	1
	Mollusca	*Ennucula tenuis*	8
	Mollusca	*Macoma* sp.	5
	Mollusca	*Mya arenaria*	1
	Mollusca	*Nuculana* sp.	2
	Mollusca	*Thyasira* sp.	18
	Mollusca	*Yoldiella* spp.	52

Table A4: Overview of phylum, taxa and abundance present at the T_In/B_out2/T_NC cluster group.

Cluster groupings	Phylum	Taxa	Abundance
T_In/B_Out2/T_NC	Annelida	*Ampharete cirrata*	3
	Annelida	*Ampharete* sp.	1
	Annelida	Ampharetidae	2
	Annelida	*Aricidea* sp.	1
	Annelida	*Aphelochaeta* sp.	1
	Annelida	Cirratulidae	14
	Annelida	*Chaetozone* sp.	23
	Annelida	*Eteone* sp.	1
	Annelida	*Euchone papillosa*	2
	Annelida	*Harmothoe* sp.	1
	Annelida	*Glycera capitata*	1
	Annelida	*Levinsenia gracilis*	1
	Annelida	*Lumbrineris* sp.	30
	Annelida	*Lysippe labiata*	3
	Annelida	Maldanidae	2
	Annelida	*Notomastus latericeus*	1
	Annelida	*Nereis* sp.	1
	Annelida	Nepthyidae	5
	Annelida	Paraonidae	1
	Annelida	*Pholoe* sp.	3
	Annelida	Scalibregmatidae	2
	Annelida	*Scalibregma inflatum*	1
	Annelida	Terebellidae	6
	Annelida	*Terebellides stroemii*	18
	Arthropoda	Eusiridae	4
	Arthropoda	Pagaridae	1
	Cnidaria	Edwardsiidae	9
	Cnidaria	*Halcampa* sp.	3
	Mollusca	*Astarte* sp.	1
	Mollusca	*Cuspidaria* sp.	1
	Mollusca	Solenogaster	1
	Mollusca	*Ennucula tenuis*	7
	Mollusca	*Macoma* sp.	1
	Mollusca	*Scissurella crispata*	1
	Mollusca	*Thyasira* sp.	21
	Mollusca	*Yoldiella* spp.	3

Table A5: Overview of phylum, taxa and abundance present at the B_NC/T_Out3 cluster group.

Cluster groupings	Phylum	Taxa	Abundance
B_NC/T_Out3	Annelida	Ampharetidae	4
	Annelida	*Ampharete finmarchica*	1
	Annelida	*Aphelochaeta* sp.	2
	Annelida	Capitallidae	3
	Annelida	*Caulleriella* sp.	5
	Annelida	*Circeis spirillum*	4
	Annelida	*Chaetozone* sp.	2
	Annelida	*Eteone* sp.	3
	Annelida	*Euone nodosa*	3
	Annelida	*Eucranta villosa*	3
	Annelida	Eunicidae	1
	Annelida	*Harmothoe imbricata*	34
	Annelida	*Laonice cirrata*	3
	Annelida	*Lumbrineris* sp.	23
	Annelida	*Marenzelleria wiereni*	37
	Annelida	*Paradoneis lyra*	5
	Annelida	*Polycirrus* sp.	8
	Annelida	*Scalibregma inflatum*	6
	Annelida	*Scoloplos* sp.	34
	Annelida	Syllidae	1
	Annelida	Terebellidae	3
	Annelida	*Terebellides stroemii*	19
	Annelida	Spionidae	2
	Arthropoda	*Balanus balanus*	2
	Arthropoda	*Caprella septentrionalis*	2
	Arthropoda	Calliopiidae	3
	Arthropoda	*Eualus* sp.	2
	Arthropoda	Caridea	1
	Arthropoda	Gammaridae	2
	Arthropoda	Lysianassidae	1
	Arthropoda	*Lilljeborgia* sp.	5
	Arthropoda	Pagaridae	2
	Arthropoda	*Pleustes* sp.	3
	Arthropoda	*Westwoodilla* sp.	1
	Echinodermata	*Ophiura* sp.	2
	Mollusca	*Astarte* sp.	1
	Mollusca	*Crenella decussata*	10
	Mollusca	Soloengaster	1
	Mollusca	*Ennucula tenuis*	7
	Mollusca	*Hiatella arctica*	7
	Mollusca	*Ischmochiton albus*	2
	Mollusca	*Lepeta caeca*	2
	Mollusca	*Liocyma fluctosa*	1
	Mollusca	*Macoma* sp.	3
	Mollusca	*Moelleria costulata*	2
	Mollusca	*Mya truncata*	1
	Mollusca	*Thyasira* sp.	1

Table A6: Overview of phylum, taxa and abundance present at the River Estuary cluster group. Part I, more species found in table A7.

Cluster groupings	Phylum	Taxa	Abundance
River Estuary	Annelida	*Aglaophamus malmgreni*	2
	Annelida	*Ampharete cirrata*	3
	Annelida	*Ampharete lindstroemi*	1
	Annelida	*Ampharete* sp.	1
	Annelida	Ampharitidae	7
	Annelida	*Amphrete baltica*	3
	Annelida	*Anobothrus gracilis*	1
	Annelida	*Artacama probioscus*	4
	Annelida	*Amage auricula*	1
	Annelida	*Aricidea* sp.	2
	Annelida	*Aricidea suecica*	3
	Annelida	*Brada* sp.	1
	Annelida	*Capitella* sp.	20
	Annelida	*Caulleriella* sp.	1
	Annelida	Cirratulidae	25
	Annelida	*Chaetozone* sp.	430
	Annelida	*Clymenella* sp.	4
	Annelida	*Cossura longocirrata*	3
	Annelida	*Eteone* sp.	57
	Annelida	*Euchone papillosa*	1
	Annelida	*Euclymene* sp.	10
	Annelida	*Harmothoe* sp.	2
	Annelida	*Heteromashus filiformis*	1
	Annelida	*Galathowenia* sp.	17
	Annelida	*Laonice cirrata*	3
	Annelida	*Lumbrineris* sp.	98
	Annelida	*Lysippe labiata*	2
	Annelida	*Macoma* sp.	435
	Annelida	*Maldane sarsi*	10
	Annelida	Maldanidae	11
	Annelida	*Notomastus latericeus*	2
	Annelida	*Nicomache personata*	22
	Annelida	*Pholoe* sp.	15
	Annelida	*Phyllodoce groenlandica*	1
	Annelida	Polynoidae	3
	Annelida	*Polycirrus* sp.	12
	Annelida	*Proclymene muelleri*	1
	Annelida	*Pygospio elegans*	26
	Annelida	Sabellidae	4
	Annelida	*Samytha sexcurrata*	4
	Annelida	*Scalibregma inflatum*	7
	Annelida	*Scolepsis* sp.	10
	Annelida	*Scoloplos* spp.	449
	Annelida	*Sigalion mathildae*	1
	Annelida	*Spio* sp.	1
	Annelida	*Trichobranchus glacialis*	2
	Annelida	Terebellidae	3
	Annelida	*Terebellides stroemii*	234
	Annelida	*Tharyx* sp.	16
	Annelida	Spionidae	8
	Annelida	Dorvillidae	1

Table A7: Overview of phylum, taxa and abundance present at the River Estuary cluster group. Part II.

Cluster groupings	Phylum	Taxa	Abundance
River Estuary	Arthropoda	*Arrhis phyllodoxe*	2
	Arthropoda	*Anonyx* sp.	1
	Arthropoda	*Balanus balanus*	1
	Arthropoda	*Brachydiastylis resima*	3
	Arthropoda	*Centromedon* sp.	2
	Arthropoda	*Caprella septentrionalis*	2
	Arthropoda	*Diastylis* sp.	7
	Arthropoda	Euphausia	2
	Arthropoda	*Hyas* sp.	1
	Arthropoda	Isopoda	1
	Arthropoda	*Lilljeborgia* sp	6
	Arthropoda	*Melita* sp	2
	Arthropoda	*Pagarus* sp.	1
	Arthropoda	Pagaridae	2
	Arthropoda	*Pontoporeia femorata*	2
	Arthropoda	*Westowodilla* sp.	1
	Cephalorhyncha	*Priapulus caudatus*	13
	Cephalorhyncha	Priapulidae	2
	Chordata	*Pelonaia corrugata*	117
	Cnidaria	Actiniaria	1
	Echinodermata	Holothuroidea	2
	Mollusca	*Astarte* spp.	41
	Mollusca	*Cychlina* spp.	67
	Mollusca	*Crenella decussata*	1
	Mollusca	Solenogaster	7
	Mollusca	*Ennucula tenuis*	27
	Mollusca	*Liocyma fluxhosa*	31
	Mollusca	*Littorina obtusata*	1
	Mollusca	*Mya arenaria*	45
	Mollusca	*Mya* sp.	13
	Mollusca	*Mya truncata*	29
	Mollusca	*Musculus niger*	2
	Mollusca	*Nuculana* sp.	7
	Mollusca	*Parvicardium minimum*	1
	Mollusca	*Rissoella* sp.	3
	Mollusca	*Serripes groenlandicus*	21
	Mollusca	*Thyasira* sp.	423
	Mollusca	*Yoldia hyperborea*	4
	Mollusca	*Yoldiella* spp.	4
	Nemertea	Nemertea	1
	Sipuncula	Sipuncula	1

Table A8: Overview of phylum, taxa and abundance present at the Outer Fjord cluster group. Part I, more species found in table A9.

Cluster groupings	Phylum	Taxa	Abundance
Outer Fjord	Annelida	*Aglaophamus malmgreni*	10
	Annelida	*Aricidea* sp.	1
	Annelida	*Ampharete* sp.	2
	Annelida	Ampharetidae	25
	Annelida	*Artacama probioscus*	12
	Annelida	*Brada* sp.	2
	Annelida	Capitellidae	4
	Annelida	*Caulleriella* sp.	58
	Annelida	*Circeis spirillum*	1
	Annelida	Cirratulidae	62
	Annelida	*Chaetozone* sp.	154
	Annelida	*Eteone* sp.	11
	Annelida	*Euone nodosa*	3
	Annelida	*Euchone papillosa*	2
	Annelida	*Euchine analis*	3
	Annelida	*Eunice pennata*	2
	Annelida	*Heteromastus filiformis*	2
	Annelida	*Glycera capitata*	2
	Annelida	*Galathowenia* sp.	64
	Annelida	*Laonice* sp.	1
	Annelida	*Laonice cirrata*	3
	Annelida	*Levinsenia gracilis*	1
	Annelida	*Lumbrineris* sp.	245
	Annelida	*Lysippe labiata*	25
	Annelida	*Melinna* sp.	3
	Annelida	*Maldane sarsi*	48
	Annelida	Maldanidae	15
	Annelida	*Myriochele heeri*	2
	Annelida	*Notomastus latericeus*	17
	Annelida	Nepthyidea	1
	Annelida	*Nepthys* sp.	1
	Annelida	*Paradoneis lyra*	4
	Annelida	*Nothria conchylega*	1
	Annelida	*Pholoe* sp.	12
	Annelida	*Phylo norvegica*	7
	Annelida	*Pectinaria* sp.	2
	Annelida	*Pectinaria koreni*	1
	Annelida	*Phyllodoce* sp.	3
	Annelida	Polynoidae	1
	Annelida	*Polycirrus* sp.	49
	Annelida	*Polydora* sp.	1
	Annelida	*Praxillella gracilis*	14
	Annelida	*Proclea* sp.	1
	Annelida	*Spiochaetopterus typicus*	26
	Annelida	*Scalibregma inflatum*	4
	Annelida	*Scoloplos* spp.	65
	Annelida	*Spio* sp.	6
	Annelida	*Spio filicornis*	1
	Annelida	Terebellidae	5
	Annelida	*Terebellides streomii*	139

Table A9: Overview of phylum, taxa and abundance present at the Outer Fjord cluster group. Part II, more species found in Table A10.

Cluster groupings	Phylum	Taxa	Abundance
Outer Fjord	Arthropoda	*Arrhis phyllonyx*	6
	Arthropoda	Ampeliscidae	1
	Arthropoda	*Anonyx* sp.	5
	Arthropoda	*Brachydiastylis resima*	2
	Arthropoda	*Campylaspis* sp.	6
	Arthropoda	Cumacea	1
	Arthropoda	*Diastylis* sp.	9
	Arthropoda	*Diastylis goodsiri*	3
	Arthropoda	*Diastylis spinosa*	1
	Arthropoda	*Diastylis rugosa*	1
	Arthropoda	*Eudorella emarginata*	22
	Arthropoda	*Haploos* sp.	10
	Arthropoda	*Leucon* sp.	6
	Arthropoda	*Themisto* sp.	1
	Arthropoda	*Westwoodilla* sp.	3
	Cephalorhyncha	*Priapulus caudatus*	9
	Cephalorhyncha	Priapulidae	13
	Chordata	Styelidae	1
	Chordata	*Pelonaia corrugata*	1
	Cnidaria	Actinaria	3
	Cnidaria	*Cerianthus Iloydii*	1
	Echinodermata	Echinoidea	3
	Echinodermata	*Ophiocten sericeum*	3
	Echinodermata	*Ophelina acuminata*	1
	Echinodermata	*Ophiura affinis*	25
	Echinodermata	Ophiuroidae	11
	Echinodermata	*Ophiura* sp.	1

Table A10: Overview of phylum, taxa and abundance present at the Outer Fjord cluster group. Part III.

Cluster groupings	Phylum	Taxa	Abundance
Outer Fjord	Mollusca	*Admete* sp.	5
	Mollusca	*Alvania* sp.	7
	Mollusca	*Astarte* sp.	5
	Mollusca	*Arctinula greenlandica*	2
	Mollusca	*Bathyarca glacialis*	3
	Mollusca	*Bathyarca* sp.	1
	Mollusca	*Bathyarca pectunculoides*	1
	Mollusca	*Cheatodermata* sp.	15
	Mollusca	*Ciliatocardium ciliatum*	2
	Mollusca	*Cychlina* sp.	6
	Mollusca	Cuspidariidae	5
	Mollusca	*Cuspidaria* sp.	10
	Mollusca	*Cychlina alba*	1
	Mollusca	*Cychlina occulata*	5
	Mollusca	*Dacrydium vitreum*	78
	Mollusca	Soloengaster	28
	Mollusca	*Ennucula tenuis*	64
	Mollusca	*Frigidoalvania janmayeni*	9
	Mollusca	*Hiatella arctica*	5
	Mollusca	*Lepeta caeca*	19
	Mollusca	Lepetidae	3
	Mollusca	*Liocyma fluctuosa*	1
	Mollusca	*Macoma* sp.	99
	Mollusca	*Mya arenaria*	3
	Mollusca	*Mya truncata*	1
	Mollusca	*Musculus niger*	8
	Mollusca	Myoidea	1
	Mollusca	Nudibranchia	1
	Mollusca	*Nuculana* sp.	54
	Mollusca	*Pandora glacialis*	1
	Mollusca	*Parvicardium minimum*	3
	Mollusca	Rissoidae	2
	Mollusca	*Retusa obtusa*	30
	Mollusca	Thyaridae	2
	Mollusca	Tellinidae	2
	Mollusca	*Thyasira* sp.	98
	Mollusca	*Yoldia* sp.	7
	Mollusca	*Yoldiella* spp.	633
	Spincula	Sipincula	1

Table A11: Overview of phylum, taxa and abundance present at the Marine Endpoint cluster group. Part I, more species found in table A12.

Cluster groupings	Phylum	Taxa	Abundance
Marine Endpoint	Annelida	Ampharetidae	3
	Annelida	*Ampharete finmarchica*	1
	Annelida	*Ampharete goesi*	1
	Annelida	*Artacama probioscus*	3
	Annelida	*Aricidea suecica*	1
	Annelida	Capitellidae	1
	Annelida	*Caulleriella* sp.	8
	Annelida	*Chaetozone* sp.	112
	Annelida	*Cossura longocirrata*	4
	Annelida	*Eteone* sp.	19
	Annelida	*Euchone* sp.	1
	Annelida	*Euclymene* sp.	57
	Annelida	Flabelligeridae	2
	Annelida	*Glycera capitata*	2
	Annelida	*Galathowenia* sp.	30
	Annelida	*Laonice* sp.	1
	Annelida	*Laonice cirrata*	1
	Annelida	*Lumbrineris* sp.	377
	Annelida	*Lysippe labiata*	5
	Annelida	*Melinna* sp.	1
	Annelida	*Maldane sarsi*	188
	Annelida	Maldanidae	15
	Annelida	*Myriochele oculata*	4
	Annelida	*Notomastus latericeus*	29
	Annelida	Nepthyidae	1
	Annelida	*Paradoneis lyra*	9
	Annelida	Paraonidae	1
	Annelida	*Pholoe* sp.	2
	Annelida	*Pectinaria* sp.	1
	Annelida	*Phyllodoce* sp.	3
	Annelida	Polynoidae	1
	Annelida	*Polycirrus* sp.	7
	Annelida	*Prionospio* sp.	1
	Annelida	*Praxillella gracilis*	2
	Annelida	Sabellidae	1
	Annelida	*Spiochaetopterus typicus*	13
	Annelida	*Scalibregma inflatum*	2
	Annelida	*Scoloplos* spp.	279
	Annelida	*Spio* sp.	18
	Annelida	Terebellomorpha	2
	Annelida	*Terebellides stroemii*	1

Table A12: Overview of phylum, taxa and abundance present at the Marine Endpoint cluster group. Part II.

Cluster groupings	Phylum	Taxa	Abundance
Marine Endpoint	Arthropoda	*Arrhis phyllonyx*	6
	Arthropoda	Ampeliscidae	5
	Arthropoda	*Brachydiastylis resima*	3
	Arthropoda	*Byblis gaimardi*	1
	Arthropoda	*Diastylis* sp.	5
	Arthropoda	Euphausia	1
	Arthropoda	*Eudorella emarginata*	3
	Arthropoda	*Haploos* sp.	7
	Arthropoda	*Idotea granulosa*	1
	Arthropoda	*Lilljeborgia* sp.	31
	Arthropoda	*Lepodepecreum* sp.	2
	Arthropoda	*Pleustes* sp.	1
	Arthropoda	*Pontoponeia fermorata*	4
	Arthropoda	*Syrrhöe crenulata*	1
	Cephalorhyncha	*Priapulus caudatus*	1
	Echinodermata	*Ophelina acuminata*	4
	Echinodermata	*Ophiura ophiura*	3
	Echinodermata	Ophiuroidae	1
	Mollusca	*Astarte* sp.	4
	Mollusca	*Bathyarca glacialis*	1
	Mollusca	*Cheatodermata* sp.	1
	Mollusca	Soloengaster	1
	Mollusca	*Ennucula tenuis*	2
	Mollusca	*Frigidoalvania janmayeni*	2
	Mollusca	*Liocyma fluctuosa*	1
	Mollusca	*Macoma* sp.	30
	Mollusca	*Moelleria costulata*	2
	Mollusca	*Mya truncata*	1
	Mollusca	*Nuculana* sp.	2
	Mollusca	Gastropoda	1
	Mollusca	*Thyasira* sp.	23
	Mollusca	*Yoldiella* spp.	9
	Sipincula	*Golfingia elongata*	4
	Sipincula	Golfingiidae	1
	Sipincula	*Golfingia margaritacea*	1
	Sipincula	Sipincula	1

Table A13: Overview of phylum, taxa and abundance present at the DeGeer cluster group.

Cluster groupings	Phylum	Taxa	Abundance
DeGeer	Annelida	Capitellidae	11
	Annelida	*Capitella* sp.	83
	Annelida	*Chaetozone* sp.	4
	Annelida	*Eteone* sp.	11
	Annelida	*Scoloplos* spp.	10
	Mollusca	*Macoma* sp.	4
	Nemertea	Nemertea	1
	Polychaeta	*Spio* sp.	4
	Polychaeta	Spionidae	50

Table A14: Overview of environmental variables taken at each of the 30 stations.

Station		Date	Dec.long	Dec.lat	Fjord	Grab size	%Fullness	Depth (m)	Salinity (psu)	Temp (C)	Phaeo (ug/L)	Chla (ug/L)	Chla:Phaeo	Eh (ORP)	%Clay	%Slit	%Sand	%LOI
A_F1	1	30.08.2018	78,2335833	15,6909333	Adventfjord	4	95	6,5	32,96	5,2	618,29	415,03	0,67	-301,75	36,04	61,34	2,62	7,1
A_F2	2	30.08.2018	78,2451167	15,6724667	Adventfjord	4	82,5	43	35,11	4,6	2650,47	652,19	0,25	-63,6	42,68	56,21	1,1	7,7
A_NC	3	04.09.2018	78,2714167	15,584	Adventfjord	4	85	24	35,52	4	5459,67	2104,79	0,39	-112,05	29,36	51,15	19,48	7,3
B_RE	4	24.08.2018	78,7018	16,5833667	Billefjord	4	72,5	11	35,22	3,96	2822,63	2318,24	0,92	343,63	37,96	59,45	2,58	9,4
B_Inner	5	28.08.2018	78,6486667	16,904	Billefjord	1	100	46,3	35,86	0,9	2151,5	1240,15	0,59	-70,9	38,58	60,16	1,26	10,7
B_Inner 2	6	28.08.2018	78,652	16,937	Billefjord	1	100	26,6	34,27	2,6	555,34	174,91	0,32	-87	43,16	54,46	2,38	12
B_Inner 3	7	28.08.2018	78,6606667	16,9016667	Billefjord	1	90	31,5	34,27	1,5	4339,69	1137,38	0,28	-3,4	22,78	63,52	13,71	3,8
B_F1	8	28.08.2018	78,652	16,516	Billefjord	1	75	65,6	34,6	0,8	3456,82	1358,73	0,4	138,8	22,8	64,06	13,14	4,1
B_F2	9	29.08.2018	78,6271667	16,5203333	Billefjord	1	100	137	34,78	-0,9	6585,98	681,83	0,1	12	30,58	61,94	7,48	5,5
B_Outer	10	08.08.2018	78,512333	16,2485	Billefjord	1	80	103,6	34,53	1,37	3293,3	800,41	0,24	-44,3	17,47	36,51	46,02	7,2
B_Outer 2	11	29.08.2018	78,4861667	16,3313333	Billefjord	1	60	39,7	34,16	1,9	9346,55	3349,88	0,36	-155,3	44,02	52,4	3,58	11
B_Outer 3	12	29.08.2018	78,4746667	16,1091667	Billefjord	1	40	87,5	34,16	2,5	7773,57	2193,73	0,28	-178	44,84	52,31	2,85	11
B_ICE	13	29.08.2018	78,5395	16,3493333	Billefjord	1	100	86,3	34,71	-0,7	5904,19	1422,96	0,24	-149,6	43,38	53,81	2,81	10,2
B_NC	14	24.08.2018	78,5843333	16,58805	Billefjord	4	26,5	9	34,35	5,08	17508,68	9960,71	0,57	95,6	29,44	66,52	4,04	8,4
T_RE_Sassen	15	20.08.2018	78,3481667	16,80145	Tempelfjord	4	94,75	10	9,12	5	658,09	800,41	1,22	432,53	31,95	57,16	10,89	6,8
T_RE_Degeer	16	20.08.2018	78,3487333	16,3527333	Tempelfjord	4	66,25	23	35,56	4,9	549,21	627,49	1,15	391,45	32,6	60,91	6,48	9,5
T_RE_Gips	17	22.08.2018	78,4372833	16,5474667	Tempelfjord	4	76,25	8,5	32,23	5,65	2107,52	2015,86	0,95	370,56	44,2	54,81	0,99	9,4
T_Inner	18	27.08.2018	78,4335	17,2751667	Tempelfjord	1	100	41,5	32,32	2,7	885,41	637,37	0,72	63,7	45	53,47	1,53	9,4
T_Inner 2	19	27.08.2018	78,4323333	17,324	Tempelfjord	1	100	30,2	32,32	2,7	623,44	731,24	0,72	63,7	45,86	52,87	1,27	8,6
T_Inner 3	20	27.08.2018	78,4441667	17,2998333	Tempelfjord	1	100	36,1	32,32	3,1	610,34	359,69	0,67	87,8	40,67	54,77	4,56	8,1
T_Outer	21	27.08.2018	78,3785	16,4703333	Tempelfjord	1	100	42,7	32,31	3,1	8218,4	1986,21	0,24	196,6	47,99	50,94	1,08	6,7
T_Outer 2	22	27.08.2018	78,3706667	16,5406667	Tempelfjord	1	100	89	31,38	0,7	9583,52	1986,21	0,3	145	45,85	52,62	1,53	7,7
T_Outer 3	23	27.08.2018	78,4131667	16,3136667	Tempelfjord	1	30	43,7	32,3	3,5	11570,88	2579,11	0,23	-420	47,24	50,39	2,37	4,6
T_F1	24	28.08.2018	78,4048333	17,0558333	Tempelfjord	1	100	83,5	32,31	0,8	5845,29	2075,15	0,36	228,8	44,93	52,68	2,39	5,9
T_ICE	25	28.08.2018	78,3713333	16,8658333	Tempelfjord	1	100	98	32,31	1	7209,86	2075,15	0,29	109	43,06	55,19	1,76	9,5
T_NC	26	22.08.2018	78,4267	17,0983	Tempelfjord	4	96,25	16	35,35	4,05	2642,48	3527,75	1,34	303,43	42,79	54,58	2,63	11,2
ME_3	27	29.08.2018	78,427	15,8251667	Isfjord	1	90	214	36,68	2,4	9466,76	5691,83	0,6	-197	45,75	53,1	1,14	10,1
ISG	28	17.08.2018	78,1285	13,999	Isfjord	1	100	274	34,31	4,7	20838,13	13098,14	0,63	158,7	25,21	56,7	18,09	7,2
ISK	29	18.08.2018	78,3213333	15,1696667	Isfjord	1	100	250	34,71	0,5	6261,2	2994,14	0,48	305	27,51	66,44	6,05	6,9
ISA	30	18.08.2018	78,1285	13,999	Adventfjord	1	100	90	34,3	2,98	12492,15	5098,93	0,41	395	35,95	60,8	3,24	7,7