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Epibenthic and Demersal Fish Community Structure and the Effects of Environmental Conditions in the Sub-Arctic Fjords Vengsøyfjorden and Kaldfjorden

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Cover page photograph of Kaldfjorden

Courtesy of Kathy Dunlop

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Abstract

Epifauna are organisms that live on, or close to, the sediment surface and commonly consist of taxa such as sea anemones, sea/brittle stars, and crustaceans. These communities have an important role in redistributing and remineralizing marine organic matter, and as prey for commercially important shellfish and fish. The structure of epibenthic communities can be important indicators of anthropogenic pollution and its environmental impact. Demersal fish are also important to the benthic ecosystem as both predator and prey creating a link between pelagic and benthic ecosystems. Epibenthic communities of sub-Arctic fjords have been poorly studied, resulting in a lack of knowledge on their structure. Despite this, sub-Arctic fjords in Norway are heavily used for fisheries, aquaculture and recreation. To address this lack of information, this study investigates the biodiversity, density and structure of epibenthic fauna and demersal fish communities, and the environmental drivers affecting community structure in two fjords located in the Troms region of northern Norway (Kaldfjorden and Vengsøyfjorden). Images were collected using a drop camera in December 2017 and corresponding bottom trawls were conducted in April 2019. Images were analyzed to quantify the epibenthic community using the annotation software Biigle 2.0 – Browsing and Annotation Large Marine Image Collection. Multivariate analysis was applied to examine epifaunal community structure between the fjords and the effects of the environmental factors temperature, salinity, depth, and substrate composition. A total of 67 taxa and 11 phyla were identified in the images; 44 taxa and 6 phyla were identified in the trawls. Dominant phyla by taxon numbers included Chordata, Mollusca and Echinodermata; the dominate phyla by density were Chordata, Arthropoda and Echinodermata. Mean density estimates of epifauna ranged from 0.009 individuals per m^2 (images) and from 0.047 to 0.096 individuals per m^2 (trawls). The epibenthic communities were found to be significantly different between the two fjords, with the difference being driven mostly by the environmental factors depth and substrate composition (i.e. the presence of gravel and cobble substrate). Image analysis showed that Kaldfjorden had a higher diversity and density of epifauna, however trawl data found a higher density of epifauna in Vengsøyfjorden particularly due to the high number of *Pandalus* shrimp caught there. The demersal fish communities were also found to be different between the two fjords, with Kaldfjorden having a higher density but lower diversity of fish. While the two fjords have a few species in common, the epifaunal and demersal fish communities found in both fjords showed clear differences. Increasing the knowledge of the benthic communities creates a baseline of the area, which can be used to assess the effects of anthropogenic pressures and climate change on fjords.

Keywords: Epibenthos; Demersal Fish; Fjords; Sub-Arctic; Environmental Factors

1 Introduction

1.1 Fjords

Fjords are coastal features created by glacial erosion that form a steep sided, coastal erosional trough filled in by the sea. They can occur at mid to high latitudes in both the Northern and Southern Hemispheres and are found in polar, subpolar, and temperate climates. The water characteristics of fjords are estuarine in nature, where freshwater flowing from inland sources mixes with saltwater from the ocean. The result is a stratified system with a layer of brackish water at the surface and saline water at the bottom (Howe *et al.,* 2010). The dynamics of sediments that enter a fjord and subsequently how they move throughout the fjord depends on where the sediments are derived from. In fjords with a strong river-influence, terrestrial inputs have a greater influence on the structure of fjord sediments. In wave and tidal-influenced fjords, marine inputs have a greater influence on the structure of fjord sediments. The circulation and transport of sediments in fjords is also dependent on the fjord bathymetry (depth) and oceanography cycle (e.g. water exchange with the open ocean). (Syvitksi & Shaw 1995). The shape of a fjord can also influence fjord sedimentation dynamics, with the steep slope of the fjord walls often directing the transport of sediments to the fjord floor, in a way similar to that observed in deep-sea canyons and trenches (Ichino *et al*., 2015; Jamieson *et al*., 2010).

1.2 *Northern Norway*

Northern Norway is the defined as the two northernmost counties in Norway; Nordland and the now combined Troms and Finnmark (Regjeringen.no, 2019). The fjords of northern Norway are influenced by three water masses; low salinity water from the Baltic Sea, saline Atlantic Ocean water, and low salinity water from inland Norwegian rivers (Holte *et al.,* 2004). Accordingly, the northward moving Norwegian Coastal Current is comprised of runoff from rivers and fjords along the Norwegian coast in addition to water from the Baltic Sea flowing into the Kattegat Sea and runoff from Europe into the North Sea (Skarðhamar & Svendsen 2005). Northern Norwegian fjords can be described as sub-Arctic in that they experience a high latitude light regime. However, compared to higher latitude Arctic fjords, these sub-Arctic fjords have higher temperatures and a limited amount of sea-ice coverage, and are not significantly impacted by glaciers (Wassmann *et al.,* 1996).

1.3 *Benthic Communities*

Benthic communities play an important role in the redistribution and remineralization of marine organic matter (Ambrose *et al.,* 2001; Bluhm *et al.,* 2009). Through this role they connect the benthos to surface waters through the exchange of nutrients, energy and mass; a process known as benthic-pelagic coupling (Renaud *et al.,* 2008; Griffiths *et al.,* 2017). Many benthic ecosystems, particularly in deeper waters, rely on the flux of surface detritus to the seafloor as their primary food source (Smith *et al.,* 2009). Benthic communities can be indicators of the level and effects of organic enrichment in surface waters from natural (Ruhl *et al.,* 2004; Ruhl 2007), industrial (e.g. aquaculture) (D'Amours *et al.,* 2008; Salvo *et al.,* 2017) or municipal sources, and may serve as a proxy for the overall health of an ecosystem (Gray *et al.,* 2006). The benthic community can be divided (broadly) into two faunal communities. One is the epifaunal community (also known as the epibenthos). These are the organisms that live on or directly above the sediment. The second is the infaunal community (or endobenthos) and these are organisms that make up the benthic community that live within the sediment (Hestetun *et al.,* 2018). Epifaunal communities generally are composed of a combination of sessile invertebrate fauna such as bryozoans, cnidarians and ascidians, along with mobile taxa such as arthropods and echinoderms. Phyla commonly found in northern fjords are Cnidaria (e.g. sea anemones), Mollusca (e.g. bivalves), Echinodermata (e.g. brittle stars), Annelida (e.g. polychaetes), Arthropoda (e.g. crustaceans) and Chordata (e.g. fish) (Gulliksen & Bahr 2001; Holte *et al.,* 2004; Laudien & Orchard 2012). Taxa from the phyla Mollusca (usually marine snails), Cnidaria (usually sea anemones), Echinodermata (usually sea stars or brittle stars) and Annelida (usually bristle worms) are most often reported as having the highest densities or highest diversity in studies of northern Norway and the Arctic (Kędra *et al.,* 2012; Jørgensen *et al.,* 2015). The phyla and different taxa within them can play different roles in the epifaunal community. Some taxa are suspension feeders (e.g. certain polychaetes, cnidarians and bivalves), others are grazers/deposit feeders (e.g. certain ophiuroids and polychaetes), and some are predators (e.g. pisces and asteroids). There are also epifaunal species/taxa that are of economic value to Norway. For example, some are harvested by the fishing industry (e.g. cod and shrimp/prawn) (Hopkins & Nilssen 1990;

Salvanes & Nordeide 1993; Sswat *et al.,* 2015; Hestetun *et al.,* 2018), while others are a food source for fish and marine mammals (e.g. whales) which are part of the tourism industry (Santos & Falk-Petersen 1989; Bluhm & Gradinger 2008; Aniceto *et al.,* 2018).

1.4 *Epifauna Sampling Techniques*

Collecting data using imaging techniques, like photographic transects, are a useful means for providing *in situ* information on the seafloor epibenthic community because they are nondestructive and can be repeated, without altering the fauna or substrate of an area (Jørgensen & Gulliksen 2001). Image techniques also offer the ability to sample areas that are difficult to study using other techniques (e.g. trawls and sediment grabs) (Gulliksen & Bahr 2001). There are several methods that can be used to collect images of the sea floor community including ROVs (remote operated vehicles) (Zhulay *et al.,* 2019), drop cameras (Sswat *et al.,* 2015), AUVs (autonomous underwater vehicles) (Lucieer & Forrest 2016) and tow cameras (Taylor *et al.,* 2016). The disadvantages of collecting data using imaging techniques are a lack of voucher material (physical specimens) and the difficulty in obtaining high taxonomic resolution of the organisms observed in the images.

Using trawls as a method of sampling provides physical specimens, which makes obtaining a higher taxonomic resolution possible. One of the disadvantages of using trawls as a sampling method, is the destructive nature of the trawls. Trawls have been shown to negatively affect different aspects of a benthic community such as its biomass and species richness (Jennings *et al.,* 2001; Hiddink *et al.,* 2006).

1.5 *Environmental Factors*

The primary environmental factors that are known to affect epibenthic community distributions are the hydrography, substrate composition and food availability. Hydrography is the physical characteristics of a water mass, which includes the temperature, salinity, depth and currents (NOAA, 2020). Temperature and salinity are important environmental factors because organisms have preferred temperature and salinity ranges that they can survive in and require to complete their life cycle (Hutchins 1947; Lenz *et al.,* 2011). Another environmental factor that affects epibenthic communities is substrate composition. Hard bottom or rocks of a certain size, for example, provide places for organisms to attach to (Silberberger *et al.,* 2019). Current velocity can also affect the type of substrate found and the epifaunal community observed there (Pisareva *et al.,* 2015). Areas of hard substrates are often found where there are strong currents that do not allow suspended sediments to settle out of the water column (Holte *et al.*, 2004; Hestetun *et al.*, 2018). In some high Arctic fjords in Svalbard additional environmental factors including ice coverage for parts of the year, calving icebergs/glaciers, and sediment from glacial meltwater are known to influence the structure of benthic communities (Włodarska-Kowalczuk & Pearson 2004; Węsławski *et al.*, 2011; Włodarska-Kowalczuk *et al.*, 2012). In addition, food availability (i.e. the vertical flux of organic material from the surface) is a factor that can affect the epibenthic community, in particular their densities (Grebmeier *et al.*, 2015).

1.6 *Objectives*

This project aims to provide an understanding of the composition of epifaunal and demersal fish communities in the poorly studied benthic habitats of the sub-Arctic fjords Kaldfjorden and Vengsøyfjorden, northern Norway. A second aim is to understand the structure of the epifaunal community in relation to the fjord environmental factors (water, temperature, salinity, depth and substrate composition).

1.7 *Hypotheses*

1) Epifaunal and demersal fish communities are significantly different between the fjords Kaldfjorden and Vengsøyfjorden.
2) The structure of the benthic community is influenced by the studied environmental factors.

2 Methods

2.1 *Study Area*

Sampling was conducted in Vengsøyfjorden (69 45.44˚N, 018 40.33˚E) and Kaldfjorden (69 48.72˚N, 018 31.56˚E), fjords located in the Troms region of northern Norway (Figure 1.a and b). These fjords, like the majority of fjords in Troms County, are narrow with sills and are less than 200 m deep. Some of these fjords are connected to the ocean through narrow inlets (Wassmann *et al.*, 1996). Vengsøyfjorden and Kaldfjorden are connected to each other, with Kaldfjorden forming an inland arm of Vengsøyfjorden. Vengsøyfjorden is approximately 13 km long and oriented in a west to east direction with a bottom depth around 270 meters (Kartverket, 2020). It is bordered by Vengsøya to the north and Kvaløya to the south. The mouth of the fjord opens onto an area of the ocean that is densely populated with small islands, where the depth of the fjord becomes shallower. There is fishing activity in Vengsøyfjorden (e.g. prawns) (FAO, 2011).

Kaldfjorden is approximately 14 km long with a bottom depth that varies from between 100 and 200 meters. The inner part of the fjord has sills that occur at depths of less than 50 m (Pedersen & Mikkola 2001; Velvin *et al.*, 2008). The very inner part of the fjord is located close to the settlement of Kjosen and this area of the fjord has been characterized as having good water exchange and no sills present at depths of less than 50 m. The rest of Kaldfjorden is an open coastal area that is greater than 10 km long and has sills that occur at depths greater than 50 m. Current measurements taken in the fjord by Witte & Dahl (1991) found an inward flowing current along the southern and western sides and an outward flowing current along the northern and eastern sides (Pedersen & Mikkola 2001 and references therein). Kaldfjorden also has fishing and industry activities occurring in the fjord (e.g. salmon aquaculture and a fish oil plant) (Vågen 2018).

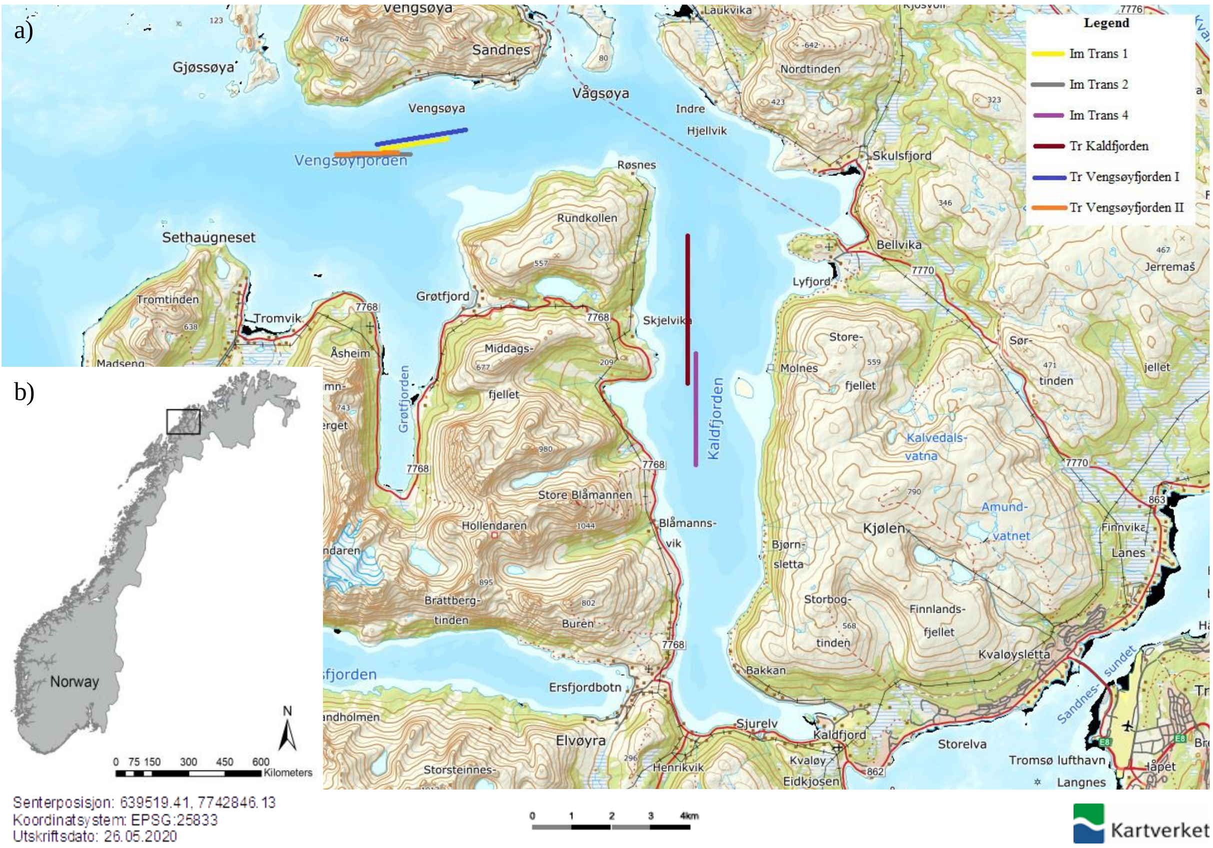

Figure 1. Map of the study areas in **a)** Vengsøyfjorden and Kaldfjorden showing the photographic transects (Im) from December 2017 and the trawls (Tr) from April 2019, and **b)** the location of the study area in relation to the rest of Norway. *The maps are modified from kartverket.no.

2.2 *Equipment*

2.2.1 *Image*

Images were taken using an Ocean Imaging Systems DSC 12000 camera system (referred to from here on as a yo-yo camera). The system consists of a Nikon D90 digital Single Lens Reflex (SLR) camera, a strobe light and a computer that controls image capture and lighting. Both the SLR camera and computer were contained inside a titanium housing. The camera settings were as follows: ISO 400, *f*-stop 8.0, and a 1/25 s exposure. The camera system was attached to a rectangular stainless steel frame with dimensions of 1.2 x 1.2 m, with four feet on the bottom of the frame (Figure 2.a.). Two lasers were attached to the frame and set 26 cm apart and in a parallel configuration, facing straight down to the seafloor. The set distance of the lasers provided a reference to measure the image area and allowed the density for epifauna to be estimated. The camera housing was attached to the frame so that it was perpendicular to the seafloor and allowed for the laser measurement to be applied to the entire image. The frame was lowered to the seafloor using a shipboard winch. A 3 kg weight attached to the frame (hanging 2.5 m below the lens of the camera) would trigger a switch causing the camera and strobe to fire simultaneously when the weight hits the seafloor (as described in Sweetman & Chapman 2011; 2015) (Figure 2.a). The height of the camera apparatus when images were taken varied from 1 – 2 m off the seafloor. Images were taken about every 10 m along the transect. The average area of the images was approximately 1.73 m^2, with a standard deviation of 0.31.

2.2.2 *Trawl*

Trawl sampling for epibenthic and bentho-pelagic fauna was conducted using a Campelen 1800 shrimp trawl. The Campelen trawl has a 35.6 m rock-hopper with 356 mm diameter rubber disks attached to the ground gear. The mesh size of a Campelen trawl varies between 80 mm in the wings (upper part) and 60 to 40 mm at the cod end (inner part) of the net (Figure 2.b). The decrease in mesh size along the length of the trawl net allows for the retention of smaller sized fish as well as larger sized benthic invertebrates as described by Walsh & McCallum (1997). SCANMAR sensors attached to the doors and along the top of the trawl net recorded the spread width of the opening of the net while it was being towed along the bottom.

Figure 2. Sampling equipment; **a)** the seafloor yo-yo camera system with the camera, strobe light, computer (in the housing) and the line leading to the weight below. **b)** The Campelen 1800 shrimp trawl net. Photographs courtesy of Kathy Dunlop **(a)**, and Bodil Bluhm **(b)**.

2.2.3 *CTD*

The bottom water temperature and salinity were collected with a *SeaBird SBE 911 plus* CTD near the image stations.

2.3 *Field Sampling*

2.3.1 *Image*

Photographic surveys were recorded along four 1 km long transects (two in each fjord) positioned in the center of the fjords, using the seafloor yo-yo camera system, in early December 2017. Depth ranged from 272 - 276 m (Vengsøyfjorden; Transects 1 and 2) and 172 - 174 m (Kaldfjorden; Transects 3 and 4). Transects 1 and 2 were sampled on the 1st of December 2017, while Transects 3 and 4 were taken on the 2nd of December 2017. The image transects were conducted from the RV *Johan Hort* which was moving at a speed ranging from 0.2 to 0.4 knots (0.37-0.74 km/h). Details of the photographic transects and their GPS coordinates can be found in Table 1. A total of 275 images were taken across the four transects.

2.3.2 *Trawl*

Corresponding trawls were taken in early April 2019 on the RV *Helmer Hanssen* along the same transect coordinates as the photographic transects. A total of three trawls were taken; two in Vengsøyfjorden and one in Kaldfjorden (due to time constraints). The Kaldfjorden trawl was taken as close as possible to the corresponding photographic transect, but could not be in the exact location due to the presence of a fish farm that was not there in 2017. A more detailed description of the trawls, including GPS coordinated can be found in Table 2.

The average speed of the trawls was approximately 3 knots and trawl length was approximately 1 km, with a duration of approximately 10 minutes of bottom contact.

Table 1. Details of the image transects including the date, time, depth and GPS coordinates of the image transects taken in Kaldfjorden and Vengsoyfjorden. *The average temperature and salinity that were taken over the course of each transect. †Substrates were identified during image analysis.

Fjord	Transect No.	Date	Depth (m)	Salinity (‰)*	Temperature (˚C)*	Substrate Identified†	Position Start	Position End	Start Time of Transect (UTC + 2h)	End Time of Transect (UTC + 2h)	No. of Images (Images Analyzed)
Vengsøyfjorden	1	1 December 2017	273	33.6	7.1	Mud/Silt	69 48.620˚N 018 29.6370˚E	69 48.676˚N 18 31.178˚E	5:48	7:38	30 (30)
Vengsøyfjorden	2	1 December 2017	272	33.7	6.9	Mud/Silt	69 48.571˚N 018 28.014˚E	69 48.572˚N 18 30.072˚E	17:56	20:29	62 (56)
Kaldfjorden	4	2 December 2017	174	33.6	7.1	Mud/Silt Shellsand Gravel and Cobble	69 45.584˚N 018 40.001˚E	69 47.079˚N 18 39.979˚E	21:13	23:00	59 (58)

Table 2. Details of the trawls taken in Vengøyfjorden and Kaldfjorden in April of 2019. The distance and area of the trawls were calculated using the door spread, speed and duration of the trawls recorded by the SCANMAR that was attached to the trawl net.

Fjord	Date	Depth (m)*	Door Spread (m)*	Speed (knots)*	Distance (km)	Area (km^2)	Position Start	Position End	Start Time of Transect (UTC + 2h)	End Time of Transect (UTC + 2h)
Vengsøyfjorden	2 April 2019	280	60.4	3	1.07	64.9	69 48.723321˚N 018 31.568259˚E	69 48.671544˚N 018 29.836513˚E	7:50	8:02
Vengsøyfjorden	2 April 2019	278	60.4	3	0.99	58.03	69 48.56857˚N 018 28.701763˚E	69 48.596561˚N 018 30.283690˚E	8:55	9:06
Kaldfjorden	3 April 2019	179	49.4	3	0.93	45.77	69 45.441382˚N 018 40.41906˚E	69 45.939271˚N 018 40.330222˚E	14:34	14:44

2.3.3 *Sample Processing*

2.3.3.1 *Image*

The images were analyzed and annotated using the annotation software, Biigle 2.0 – Browsing and Annotating Large Marine image collections (Langenkämper *et al.*, 2017) (https://www.biigle.de/). The epifauna and fish observed in each image were identified to the lowest taxonomic level possible and enumerated. Images were analyzed starting from the upper left corner (of the image), zooming in as far as possible before the image became too pixelated to recognize individual organisms, and then moving down the image to the lower left corner. The area in focus would then be shifted to the right and analysis would continue by moving back to the top of the image. Analysis would continue in this manner until the whole image had been analyzed. If there was a question about whether something was an organism or part of the substrate, it would be left unmarked and returned to after the rest of the image had been analyzed.

The analysis of a single image could take anywhere from 15 – 45+ minutes depending on the identification and number of organisms found in the image. Due to the amount of time it took to analyze/annotate images, only three of the four transects were analyzed (Transects 1, 2 and 4). A total of 151 images were analyzed and, of these, 144 images were used for statistical analysis. This is due to 7 of the images being obscured either mostly or entirely by suspended sediment thrown up when the feet of the camera frame hit the seafloor. During the course of image analysis and annotation, a taxa catalogue was built in Biigle 2.0. This catalogue could then be used as a reference resource throughout the image analysis to help with the identification/grouping of taxa found in the images. Polychaete tubeworms were found and labeled in the images but excluded from analysis due to the fact it was difficult to determine whether or not the tubes were inhabited. The names of the taxa were standardized to the current accepted taxonomy in the World Register of Marine Species using the match function.

The substrate found in each image was assigned a substrate category (i.e. shellsand, mud and silt, gravel and cobble) and the percent coverage of each category was recorded.

2.3.3.2 *Trawl*

The majority of the epifauna and fish taxa sampled by the trawls were counted, measured and weighed on board the boat. In cases where there were large quantities of a single species (e.g. *Pandalus* sp. and *Melanogramus aeglefinus*), the individuals were grouped into buckets according to size. Then a sub-sample of about 20 were taken from each bucket and measured and weighed. The number of that species in each bucket was then calculated by dividing the average weight, excluding the weight of the bucket. For the *Pandalus* sp., the buckets were weighed and an average weight of 0.5 g (pers. comm. Carsten Hvingel (IMR)) was used to calculate the number of *Pandalus sp.* in each bucket.

There were some specimens that could not be measured and weighed on board the ship due to some of the small specimens requiring a fine scale balance that must be used in the lab (i.e. *Ctenodiscus crispatus)*. These specimens were preserved in a 4% final concentration formalin solution and taken back to the lab to be measured and weighed. In the lab the specimens were rinsed with water for at least 30 minutes before being measured and weighed.

It should be noted that while the specimens caught in the trawls were measured and weighed, only the count data was used in the analysis for comparability with the image data.

2.4 *Data Analysis*

The dataset collected in Vengsøyfjorden and Kaldfjorden using the photographic transect and trawl sampling were analyzed to determine the structure of sessile epifauna benthic and demersal fish communities in the study fjords and to examine the effects of environmental variables.

2.4.1 *Image*

2.4.1.1 *Calculating abundances*

The density of the individual species/taxa found in each image was calculated by dividing the number of that species/taxa in the image by image area. The area of the image was calculated, using the set distance of the lasers (26 cm) as a reference, with the Biigle 2.0 measurement tool. The average abundance of each species/taxa and standard error was calculated for each fjord. Using EXCEL, histograms comparing the taxa densities between the two fjords were created. The two transects from Vengsøyfjorden showed similar epifaunal densities and were therefore combined to represent mean epifaunal densities to facilitate a comparison between the two fjords.

2.4.1.2 *Diversity, Evenness and Richness Indices*

The Shannon-Wiener diversity index was used to calculate the species richness of taxa recorded in the images.

$$H' = \sum_i p_i \log{(p_i)}$$

In this equation p_i is the proportion of the total number that comes from *i*th species (Clarke & Gorley 2015).

The Pielou's evenness index was used to find out how evenly the taxa were distributed in the images.

$$J' = H'/H'_{Max} = H'/\log S$$

In this equation H' is the Shannon-Wiener diversity index and H'_{max} is the maximum possible value of the Shannon-Wiener diversity index. The letter *S* represent the total number of taxa (Clarke & Gorley 2015).

The species richness for the fjords was calculated using the Margalef index.

$$d = (S-1)/\log N$$

In this equation the total number of individuals (*N*) is used along with the total number of species (*S*) to try and adjust for the possibility of more species being found with large numbers of individuals (Clarke & Gorley 2015).

2.4.1.3 *PRIMER Analysis*

The software Primer-E v.7 (Clarke & Gorley 2015) was used to conduct multivariate statistical analysis of the epifaunal community structure data recorded from the photographic transects. Epifauna density data was fourth root transformed and a Bray-Curtis (dis)similarity coefficient was applied to the transformed data to create a data matrix that multivariate analysis could be performed upon.

2.4.1.3.1 *Biological Analysis*

An *nMDS* (non-metric Multidimensional Scaling) analysis was used on the transformed epifauna data to visualize the dissimilarity in the epifaunal community composition between the two fjords. A SIMPER (Similarity of Percentage) analysis was also performed to determine which taxa were contributing most to the average dissimilarity between the two fjords. An ANOSIM (Analysis of Similarity) was used to determine if a significant difference in the epifaunal assemblage composition was present between the two fjords. Initially, a multivariate analysis (SIMPER, ANISOM and MDS) comparing the two transects from Vengsøyfjorden was conducted to determine if the community structures were significantly different from each other and if not, they could therefore be combined and the mean community data from the two transects analyzed for Vengsøyfjorden.

2.4.1.3.2 *Environmental Analysis*

Environmental data for the substrate composition on the fjord seafloors was obtained during analysis of the images. Depth was measured at the same time the images were taken. Temperature and salinity data were obtained from the CTD. To see if the combined environmental factors were a contributing predictor variable to the dissimilarity between the two fjords a RELATE analysis was conducted to compare the biological data to the environmental data. A CAP (Canonical Analysis of Principle) was used to visualize the influence of individual environmental factors on the epifaunal composition recorded in the images. A DistLM (Distance based Linear Modeling) analysis with a multiple stepwise regression was used to examine the influence of the individual environmental factors on the epibenthic community structure (Anderson *et al.,* 2008).

Using the statistical software R, a zero-inflated quasi - Poisson GLM (General Linearized Model) distribution was performed on the total densities of each image in both fjords. The quasi-Poisson test was used because of the presence of a large number of zeros in the data and due to the data being over distributed.

2.4.2 *Trawl*

The area of the trawls was calculated using the information provided in the SCANMAR file from the RV *Helmer Hanssen*. The information used to calculate the area of the trawl were distance, time, speed of the boat and the distance of the door spread. Using the duration of the trawl and the average speed of the boat, the distance the trawl covered was calculated using the equation d = rt; where d equals the distance covered, r equals the speed of the boat, and t equals the duration of time the trawl was on the bottom. Then using the calculated distance and the average door spread, the area of the trawl was calculated using the equation A = LW; where A is the area of the trawl, L is the distance of the trawl, and W is the distance between trawl doors. Using the calculated areas, the densities of the different taxa found in each of the trawls were calculated. Histograms of the densities of the taxa recorded in the trawls were created using EXCEL.

The statistical analysis software package R was used to perform a t-test (Welch two sample) on the total abundance, fish abundance and epifauna abundance of the trawls from the two fjords. The normality and the homogeneity of variance were tested to ensure they met the model assumptions.

2.4.2.1 *Diversity and Evenness Indices*

The Shannon-Wiener diversity index and the Pielou's evenness index were calculated (equations can be found in the image analysis section above).

3 Results

3.1 *Biodiversity*

A total of 67 species/taxa and 11 phyla were identified in the three image transects together (Table 3). Of the 67 species/taxa about 35% were identified to the species level. The phyla with the most species/taxa present were Mollusca (14 species/taxa), followed by Echinodermata (13 species/taxa), Arthropoda and Cnidaria (9 species/taxa each) and Porifera (8 species/taxa) (Figure 3). A higher number of taxa were found in the Kaldfjorden image transect than in the Vengsøyfjorden image transects (Table 3). The number of species/taxa observed in each image varied from a minimum of zero species/taxa to a maximum of 25 species/taxa. In Kaldfjorden, the richness (Margalef) of the taxa observed was 8.79, while the Shannon-Wiener diversity index was 2.90 and the Pielou's evenness index was 0.69. A lower Margalef species richness was observed in the images at Vengsøyfjorden (3.81). The Shannon-Wiener diversity index here was 1.46 and the Pielou's evenness was 0.46 (Table 4).

A total of 44 species/taxa and 6 phyla were recorded in the three trawls altogether and 95% of the taxa were identified to a species level (Table 3). Demersal fish were dominate in the Kaldfjorden trawls by taxon number and therefore, taxa belonging to the phylum Chordata were found to be in the highest numbers here, while species belonging to the phyla Arthropoda and Echinodermata were found in higher numbers in the two Vengsøyfjorden trawls (Figure 6). The Kaldfjorden trawl had a Margalef's species richness of 3.12; a Shannon-Wiener diversity index of 1.62 and a Pielou's evenness of 0.50 (Table 4). The average of the two Vengsøyfjorden trawls had a species richness of 3.52, a lower Shannon-Wiener diversity index of 0.37 and a lower Pielou's evenness of 0.10 (Table 4).

Table 3. The species/taxa that were found in the images and trawls of Kaldfjorden and Vengsøyfjorden. The letter "X" denotes that the species was present in that particular image transect or trawl.

Phylum	Class	Species/Taxa	Trawl Kaldfjorden	Trawl Vengsøyfjorden	Image Kaldfjorden	Image Vengsøyfjorden
Annelida						
	Polychaeta	Aphroditidae			X	
	Polychaeta	*Neoleanira tetragona*		X		
	Polychaeta	*Phyllodoce groenlandica*	X			
	Polychaeta	Polynoidae			X	X
Arthropoda						
	Malacostraca	Amphipoda			X	
	Malacostraca	*Epimeria (Epimeria) loricata*	X			
	Malacostraca	*Eualus gaimardii*	X			
	Malacostraca	Isopoda			X	X

	Malacostraca	*Lithodes maja*		X	X	
	Malacostraca	*Munida* sp.			X	X
	Malacostraca	Mysidae			X	X
	Malacostraca	*Pagurus bernhardus*			X	
	Malacostraca	*Pagurus pubescens*	X			
	Malacostraca	*Pandalus* sp.	X	X	X	X
	Malacostraca	Pycnogonida	X		X	
	Malacostraca	*Spirontocaris liljeborgii*				
Brachiopoda					X	
Bryozoa					X	
Chordata						
	Actinopterygii	*Anarhichas lupus*	X			
	Actinopterygii	*Arctozenus risso*		X		

Actinopterygii	*Argentina silus*		X
Actinopterygii	*Cyclopterus lumpus*	X	
Actinopterygii	*Gadiculus argenteus*		X
Actinopterygii	*Gadus morhua*	X	X
Actinopterygii	*Glyptocephalus cynoglossus*	X	X
Actinopterygii	*Hippoglossoides platessoides*	X	X
Actinopterygii	*Lycenchelys kolthoffi*		X
Actinopterygii	*Mallotus villosus*	X	X
Actinopterygii	*Maurolicus muelleri*	X	
Actinopterygii	*Melanogrammus aeglefinus*	X	X

	Actinopterygii	*Merlangius merlangus*	X	X		
	Actinopterygii	*Microstomus kitt*	X			
	Actinopterygii	*Molva molva*	X	X		
	Actinopterygii	Pleuronectiformes			X	
	Actinopterygii	*Sebastes sp.*	X			
	Actinopterygii	*Trisopterus esmarkii*	X	X		
	Ascidiacea	Ascidia			X	X
	Elasmobranchii	*Amblyraja radiata*	X	X		
	Holocephali	*Chimaera monstrosa*		X		
Cnidaria						
	Anthozoa	Actiniaria			X	
	Anthozoa	*Bolocera tuediae*	X		X	X

	Anthozoa	*Cerianthus lloydii*			X	X
	Anthozoa	*Hormathia digitata*			X	X
	Anthozoa	*Hormathia sp.*			X	
	Anthozoa	*Pennatulacea*			X	X
	Anthozoa	*Urticina eques*	X	X	X	
	Anthozoa	*Urticina felina*		X		
	Anthozoa	*Virgularia tuberculata*			X	
	Anthozoa	Zoantharia			X	
Ctenophora						X
Echinodermata						
	Asteroidea	*Asterias rubens*			X	
	Asteroidea				X	X
	Asteroidea	*Astropecten irregularis*			X	

Asteroidea	*Ctenodiscus crispatus*	X	X	X	X
Asteroidea	*Henricia* sp.			X	
Asteroidea	*Hippasteria phrygiana*	X		X	
Asteroidea	*Psilaster andromeda*		X		
Asteroidea	*Solaster endeca*		X		
Asteroidea	*Stichastrella rosea*				X
Asteroidea	*Urasterias lincki*	X			
Echinoidea	*Echinocardium cordatum*		X	X	
Echinoidea	*Echinocardium flavescens*		X		
Echinoidea	Spatangidae				X
Echinoidea	*Spatangus* sp.		X		

	Ophiuroidea	*Ophiura sarsii*	X	X	
	Ophiuroidea		X	X	X
	Holothuroidea			X	
	Holothuroidea	*Parastichopus tremulus*	X	X	
Mollusca					
	Bivalvia	*Astarte* sp.		X	
	Bivalvia			X	
	Bivalvia	*Limaria loscombi*		X	
	Bivalvia	Nuculanidae			
	Bivalvia	Pectinidae		X	X
	Bivalvia	Yoldiidae		X	
	Gastropoda	*Aeolidia papillosa*		X	X
	Gastropoda	*Borealea nobilis*		X	X
	Gastropoda	*Buccinum* sp.		X	X

	Gastropoda	*Euspira pallida*	X		
	Gastropoda			X	X
	Gastropoda	*Neptunea* sp.		X	
	Gastropoda	*Neptunea despecta*		X	
	Gastropoda	Nudibranchia		X	X
	Gastropoda	*Scaphander punctostriatus*	X		
	Scaphopoda			X	
Porifera					
		Porifera A		X	
		Porifera (Encrusting)		X	
		Porifera sp.		X	
	Demospongiae	*Axinella infundibuliformis*		X	

	Demospongiae	*Axinella rugosa*	X
	Demospongiae	*Halichondria panicea*	X
	Demospongiae	*Hymedesmia paupertas*	X
	Demospongiae	*Polymastia* sp.	X
Unknown Phyla			
		Morphotype 1	X
		Morphotype 2	X
		Morphotype 4	X
		Morphotype 5	X
		Morphotype 6	X
		Morphotype 7	X
		Morphotype 9	X

Table 4. The species richness, Pielou's evenness, Shannon-Wiener diversity index values and the total number of species and individuals found in Vengsøyfjorden and Kaldfjorden for both sampling methods. *Values are based on an average.

Fjord	Method	Total Species	Total Individuals	Species Richness	Pielous's Evenness	Shannon-Wiener Index
Kaldfjorden	Image*	64	1291	8.79	0.69	2.90
	Trawl	25	2146	3.12	0.50	1.62
Vengsøyfjorden	Image*	23	321	3.81	0.47	1.46
	Trawl*	31	4959	3.52	0.10	0.37

3.2 *Density*

The mean density of epifauna in the images ranged from about 0.009 – 6 individuals per m^2. The mean density of species/taxa was generally higher in Kaldfjorden than in Vengsøyfjorden (Figure 3). The dominate phyla by density found in Kaldfjorden were Echinodermata (36% of taxa found), Cnidaria (19%), Brachiopoda (11%) and Mollusca (10%). In Vengsøyfjorden, Echinodermata (78% of all taxa found) and Mollusca (12%) were the dominate taxa by density (Figures 3 and 4; Table 3). The echinoderm species/taxa that were most common in the two fjords was the sea star *Ctenodiscus crispatus* and Ophiuroids (Figure 5). The most common cnidarian found was a sea anemone from the *Hormathia* genus (in Kaldfjorden) and the most common mollusc found was the nudibranch *Borealea nobilis* (in Vengsøyfjorden) (Figure 5). In both fjords, echinoderms had the highest densities in the images (Figures 3 and 4). The quasi-Poisson analysis comparing the total epifaunal densities in the images between both fjords was statistically significant ($p < 0.001$) with a t-value of -4.70. This shows that a significantly higher total density of epifauna was recorded in the Kaldfjorden images.

The total density of epifauna and demersal fish recorded in the Kaldfjorden trawl was 0.047 individuals per m^2. The total densities for the two trawls in Vengsøyfjorden were 0.067 and 0.096 individuals per m^2. The most common species/taxa were shrimp of the genus *Pandalus,* leading to the phylum Arthropoda contributing the most to density in the trawls (about 38% of total composition based on density in Kaldfjorden and about 93% in Vengsøyfjorden) (Figure 6). In Kaldfjorden, taxa belonging to the phylum Chordata occurred in the highest density (about 58% of the composition by density). In Vengsøyfjorden, the second most common taxon was Echinodermata (Figure 6; Table 3). Of the 25 species of epifauna caught in the trawls, 22 occurred in very low densities (e.g. one individual in a trawl) (Figure 7.a.). Of the remaining three species, the *Pandalus* sp. had the highest densities in both fjords with roughly 0.02 individuals per m^2 in Kaldfjorden and roughly 0.075 individuals per m^2 in Vengsøyfjorden. The sea star *Ctenodiscus crispatus* had the second highest density in Vengsøyfjorden (around 0.005 individuals per m^2), while the sea anemone *Urticina eques* had the second highest density in Kaldfjorden (about 0.001 individuals per m^2) (Figures 7.b and 8). Among the fish (Chordata), the species with the highest densities were haddock

(*Melanogrammus aeglefinus*) (about 40% in Kaldfjorden), capelin (*Mallotus villosus*) (about 42% in Kaldfjorden) and Atlantic cod (*Gadus morhua*) (about 25% in Vengsøyfjorden). (Figures 9 a, b and 10).

The t-test of the total density (epifauna and fish) of the trawls showed that there was a slight statistical difference between trawl densities (p = 0.041, df = 2.0). The density of epifauna caught in the trawls also showed a slight statistical difference between the trawls (p = 0.040, df = 2.0). The density of fish caught in the trawls was also significantly statistically different (p = 0.038, df = 2.0).

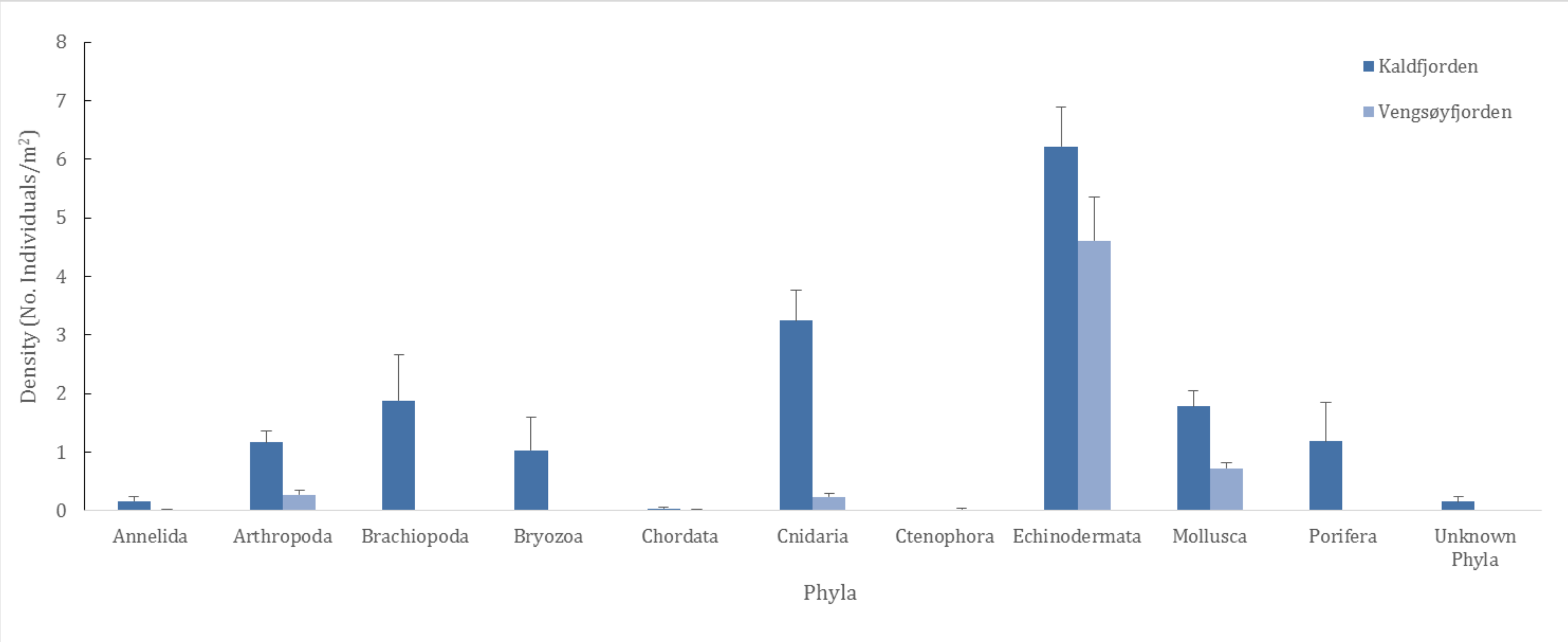

Figure 3. The average density of the phyla found in images recorded in Kaldfjorden and Vengsøyfjorden. Echinodermata had the highest average number of individuals found per m^2. *The error bars show standard error.

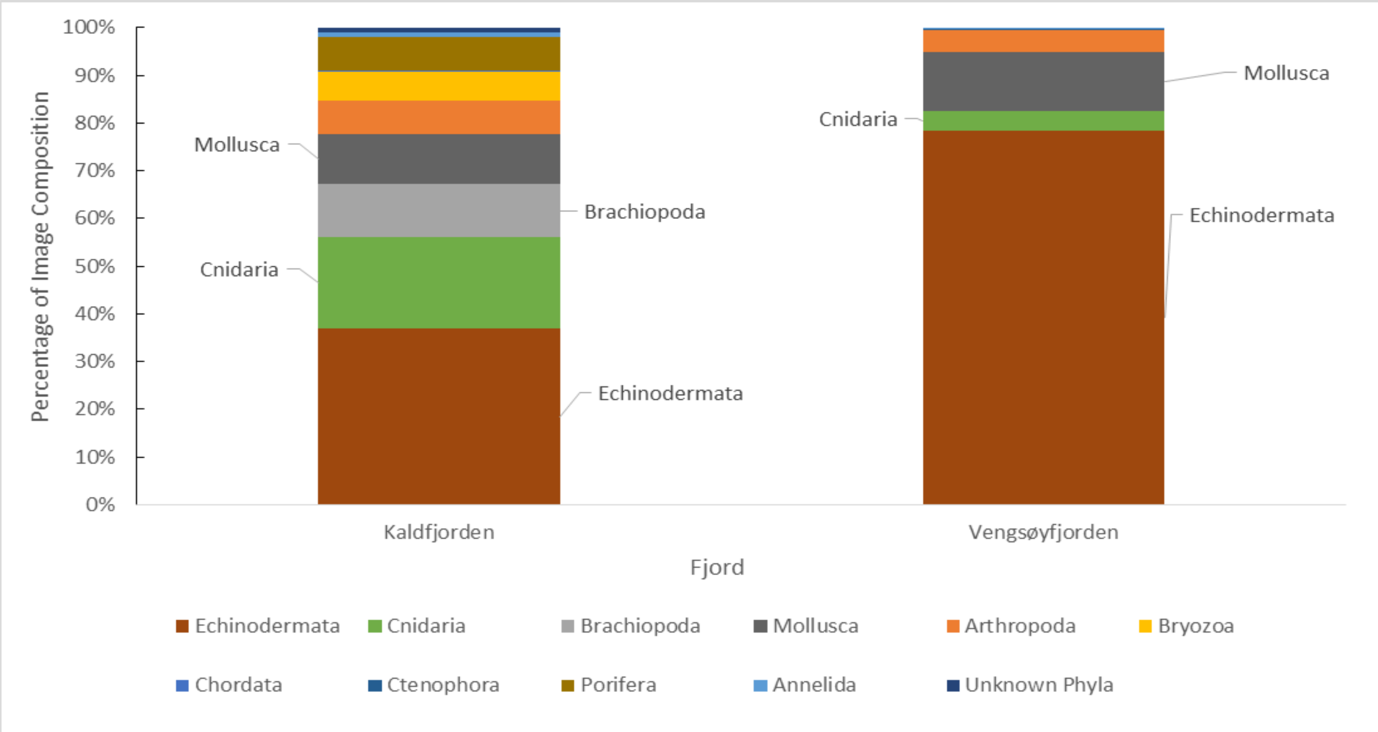

Figure 4. The percent composition of epifaunal phyla in the images of Vengsøyfjorden and Kaldfjorden based on density. In both fjords Echinodermata had the highest percentage of the composition, with roughly 35% of the composition in Kaldfjorden and almost 80% in Vengsøyfjorden.

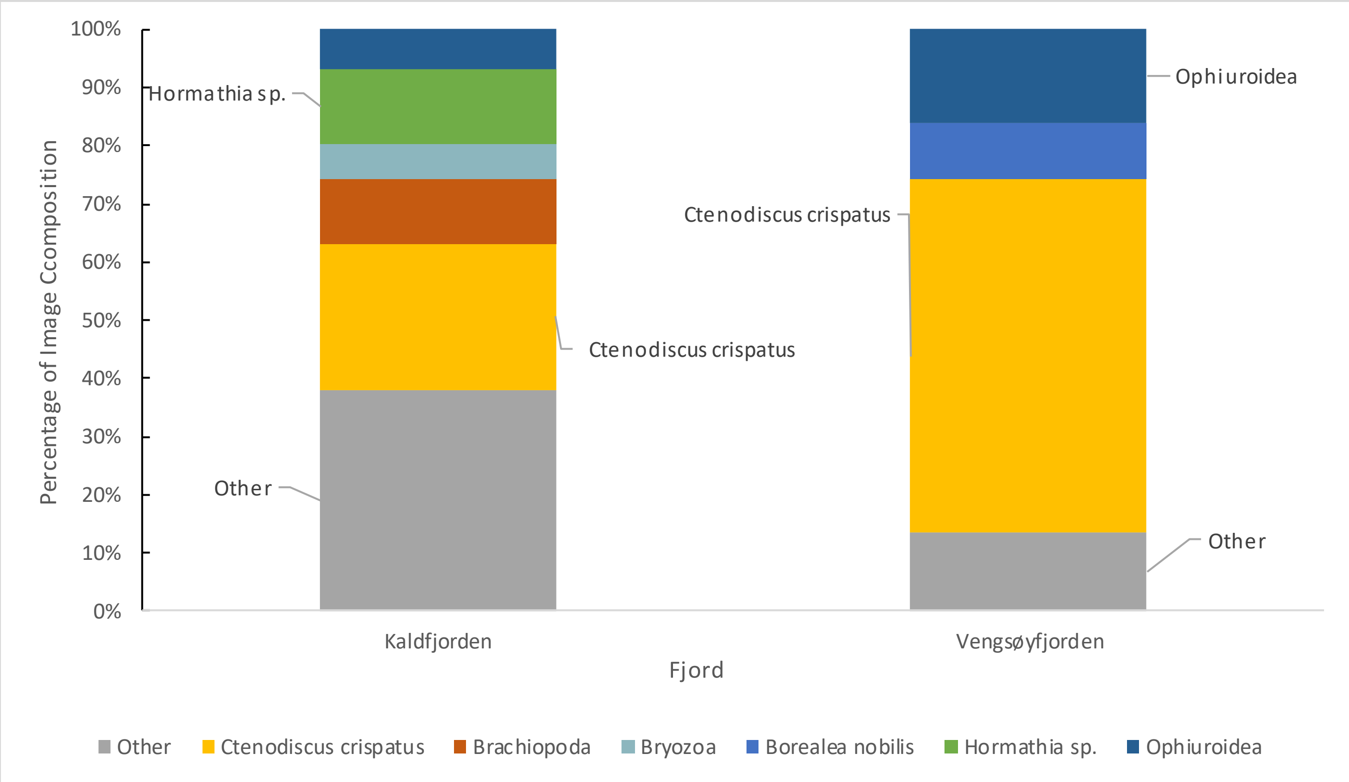

Figure 5. Percent composition of species/taxa found in the images for each fjord. The category "Other" contains species/taxa that had densities under 5% of the total composition. The following species/taxa are found in the "Other" category: Actiniaria, *Aeolidia papillosa*, Ascidia, *Astarte* sp., *Asterias rubens*, Asteroidea, *Astropecten irregularis*, *Axinella infundibuliformis*, *Axinella rugosa*, Bivalvia, *Bolocera tuediae*, Bryozoa, *Buccinum* sp., *Cerianthus lloydii*, Ctenophora, *Echinocardium cordatum*, *Lithodes maja*, Gastropoda, *Halichondria panicea*, *Henricia* sp., *Hippasteria phrygiana*, *Parastichopus tremulus*, Holothuroidea, *Hormathia digitata*, *Hymedesmia paupertas*, *Limaria loscombi*, *Munida* sp., Mysidae, *Neptunea* sp., *Neptunea despecta*, Nuculanidae, Nudibranchia, *Ophiura sarsii*, *Pagurus bernhardus*, *Pandalus* sp., Pectinidae, *Pennatulacea*, Pleuronectiformes, Polynoidae, Porifera spp., Proifera A, Porifera (Encrusting), Pycnogonida, Scaphopoda, Spatangidae, *Spirontocaris liljeborgii*, *Stichastrella rosea*, Isopoda, *Polymastia* sp., *Virgularia tuberculata*, Aphroditidae, Amphipoda, *Urticina eques*, Yoldiidae, Zoantharia, Morphotype 1, Morphotype 2, Morphotype 4, Morphotype 5, Morphotype 6, Morphotype 7, and Morphotype 9.

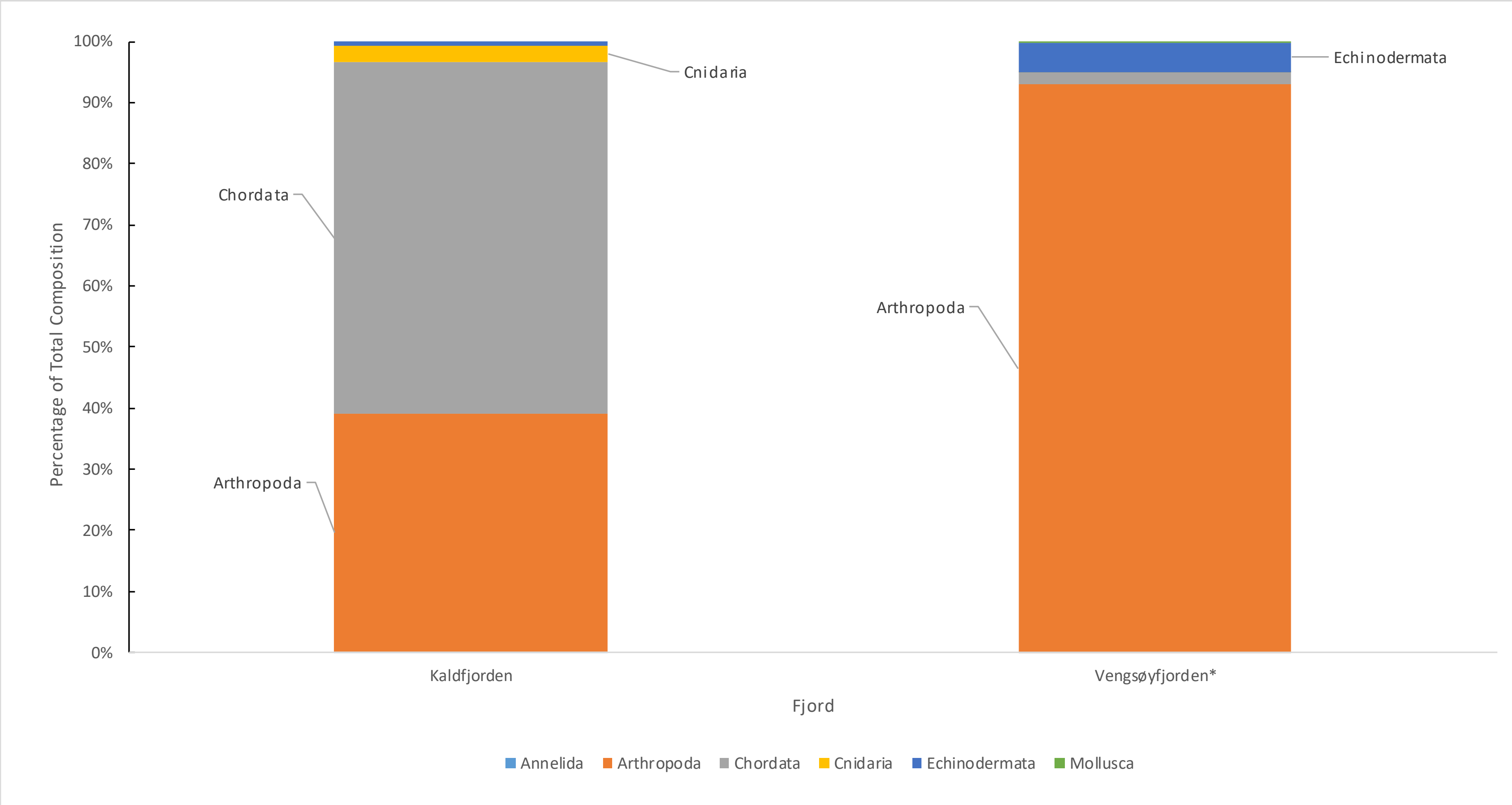

Figure 6. The percentage of the total composition of the phyla found in the trawls conducted in Kaldfjorden and Vengsøyfjorden April 2019. In Kaldfjorden the phyla with the highest percentage of the composition were Chordata (about 40%) and Arthropoda (about 50%). In Vengsøyfjorden, the phylum with highest percentage of the composition was Arthropoda (about 90%). *The average of two trawls conducted in Vengsøyfjorden.

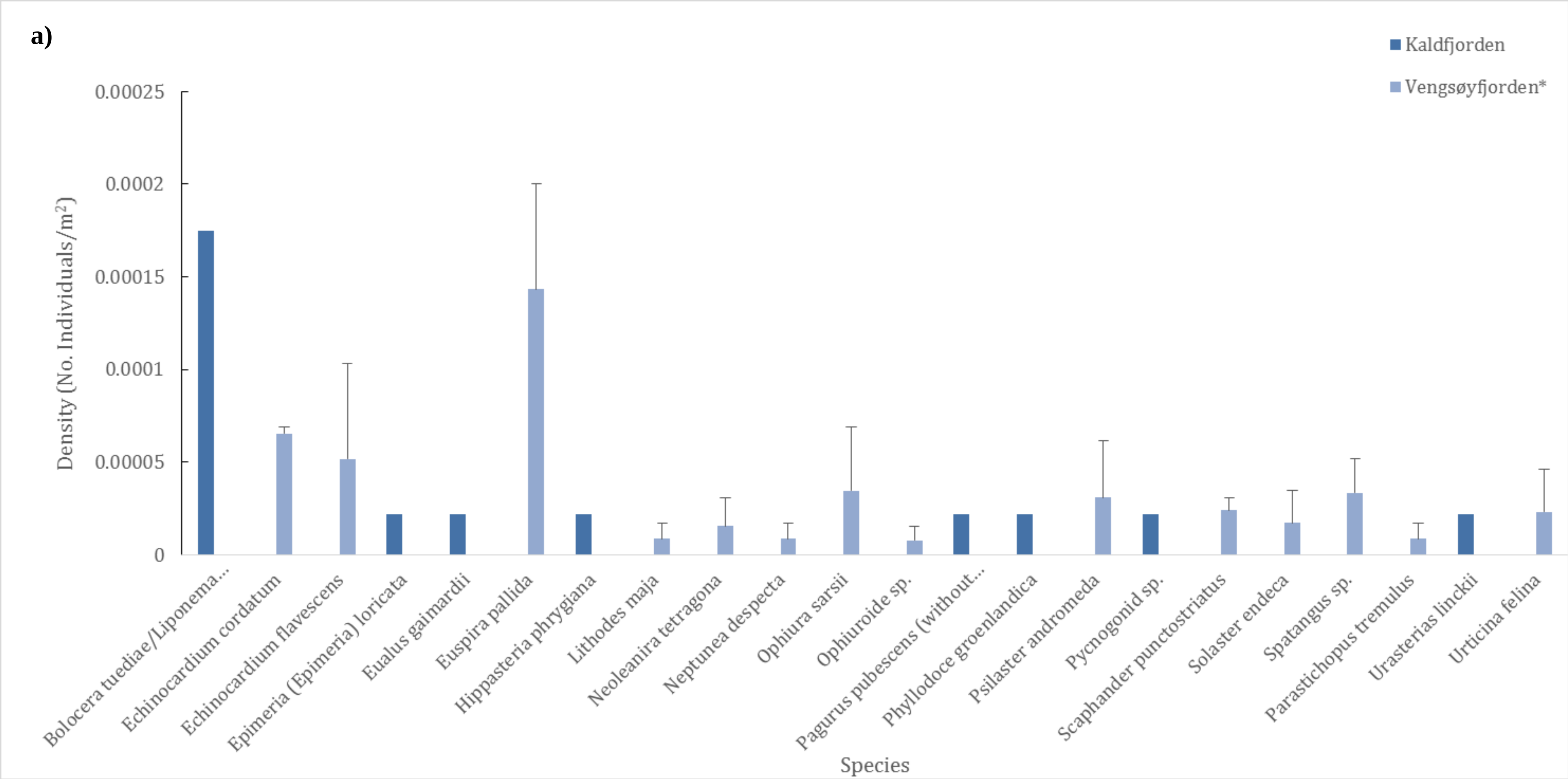

Figure 7. The average densities of the epifauna found in the trawls conducted in Kaldfjorden and Vengsøyfjorden April 2019. **a)** The sea anemone *Bolocera tuediae/Liponema mulitcome* had the highest density (about 0.00017 individuals per m^2) in Kaldfjorden, while the gastropod *Euspira pallida* had the highest density (about 0.00015 individuals per m^2) in Vengsøyfjorden. *The average of the two trawls in Vengsøyfjorden. The error bars represent the standard error.

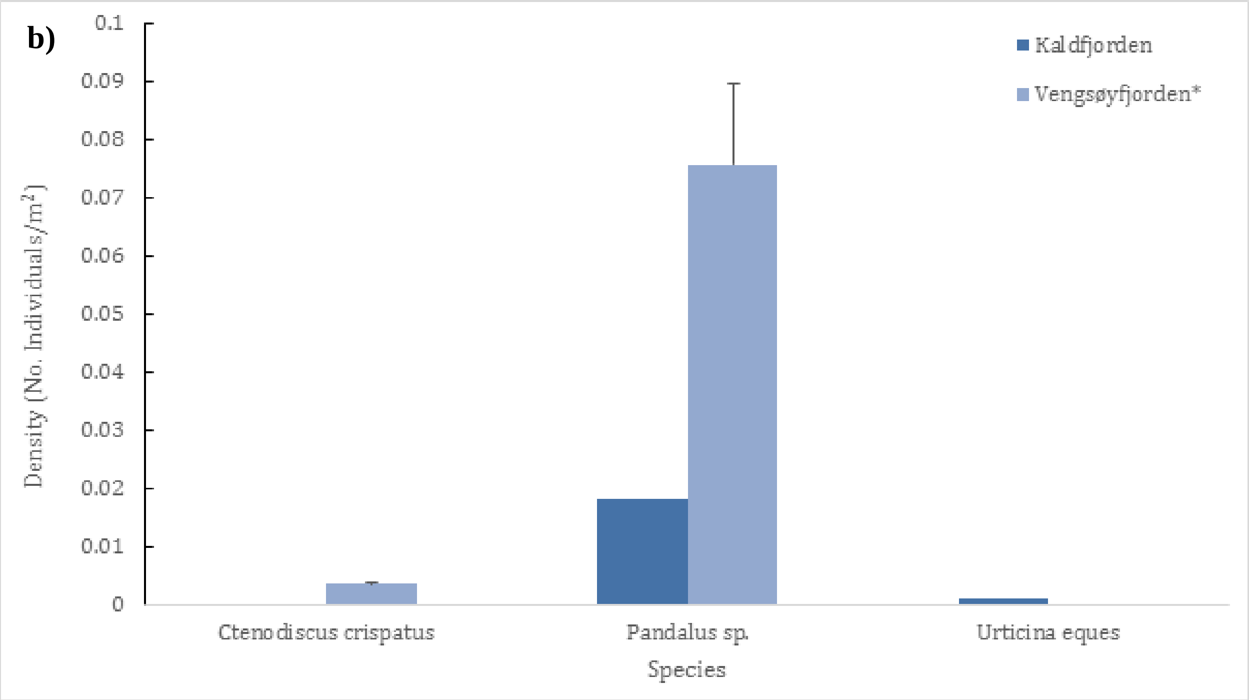

Figure 7. b) Due to the high densities of the sea star *Ctenodiscus crispatus* (about 0.005 individuals per m^2 in Vengsøyfjorden) and prawns from the genus *Pandalus* (about 0.075 individuals per m^2 in Vengsøyfjorden and about 0.02 individuals per m^2 in Kaldfjorden), and the sea anemone *Urticina eques* (about 0.001 individuals per m^2 in Kaldfjorden) were best represented in their own histogram. *The average of the two trawls in Vengsøyfjorden. The error bars represent the standard error.

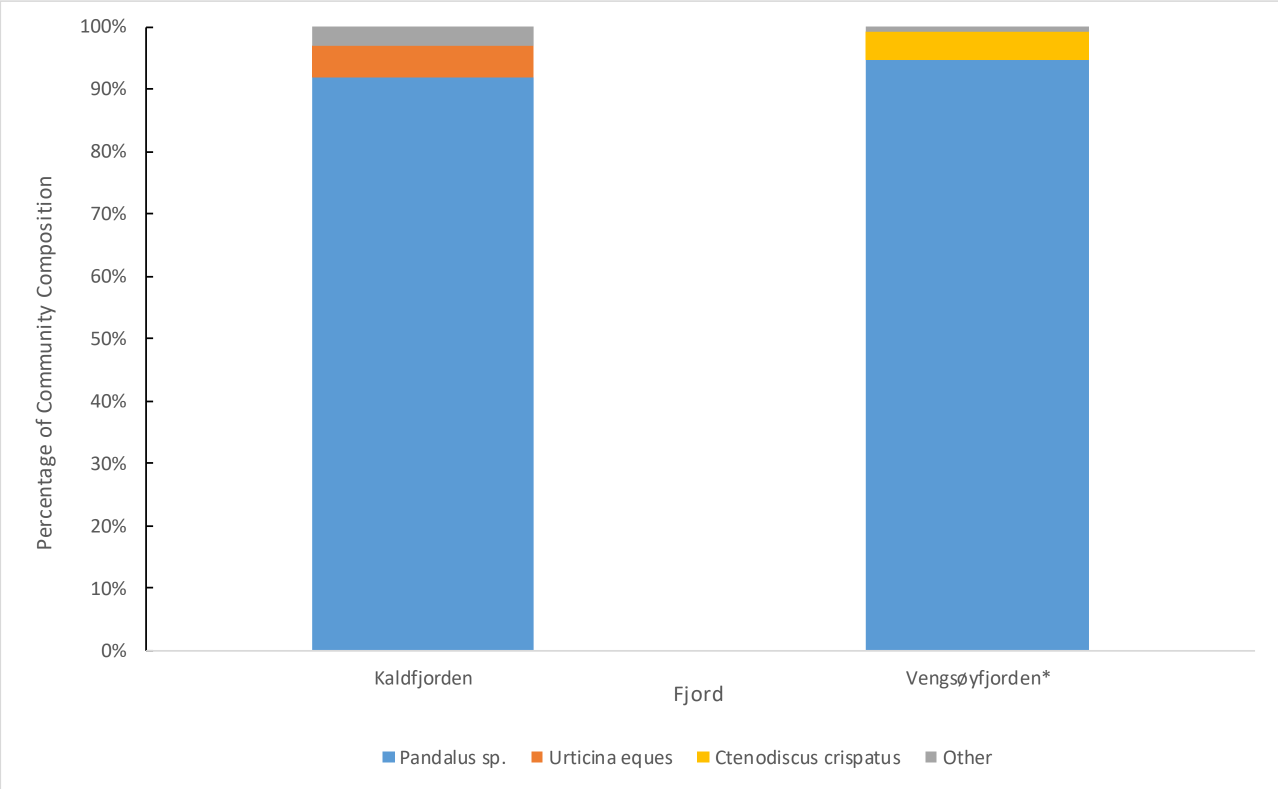

Figure 8. The relative abundance of epifaunal species or taxa for the trawls of Vengsøyfjorden and Kaldfjorden. The category "Other" contains the species that has less than 5% of the abundance in the trawls. The species contained in this category are: *Bolocera tuediae, Echinocardium cordatum, Echinocardium flavescens, Epimeria loricata, Eualus gaimardii, Euspura pallida, Hippasteria phrygiana, Lithodes maja, Neoleanira tetragona, Neptunea despecta, Ophiura sarsii, Ophiuroide* sp., *Pagurus pubescens, Phyllodoce groenlandica, Psilaster Andromeda,* Pycnogonid sp., *Scaphander punctostriatus, Solaster endeca, Spatangus* sp., *Parastichopus tremulus, Urasterias linckii, Urticina eques,* and *Urticina felina*. In Kaldfjorden, *Pandalus* sp. made up about 92% of the total trawl and *U. eques* made up about 5% of the trawl. In Vengsøyfjorden the *Pandulus* sp. made up 95% of the total epifauna in the trawl and *C. Crispatus* made up about 5% of the trawl. *The average of two trawls conducted in Vengsøyfjorden.

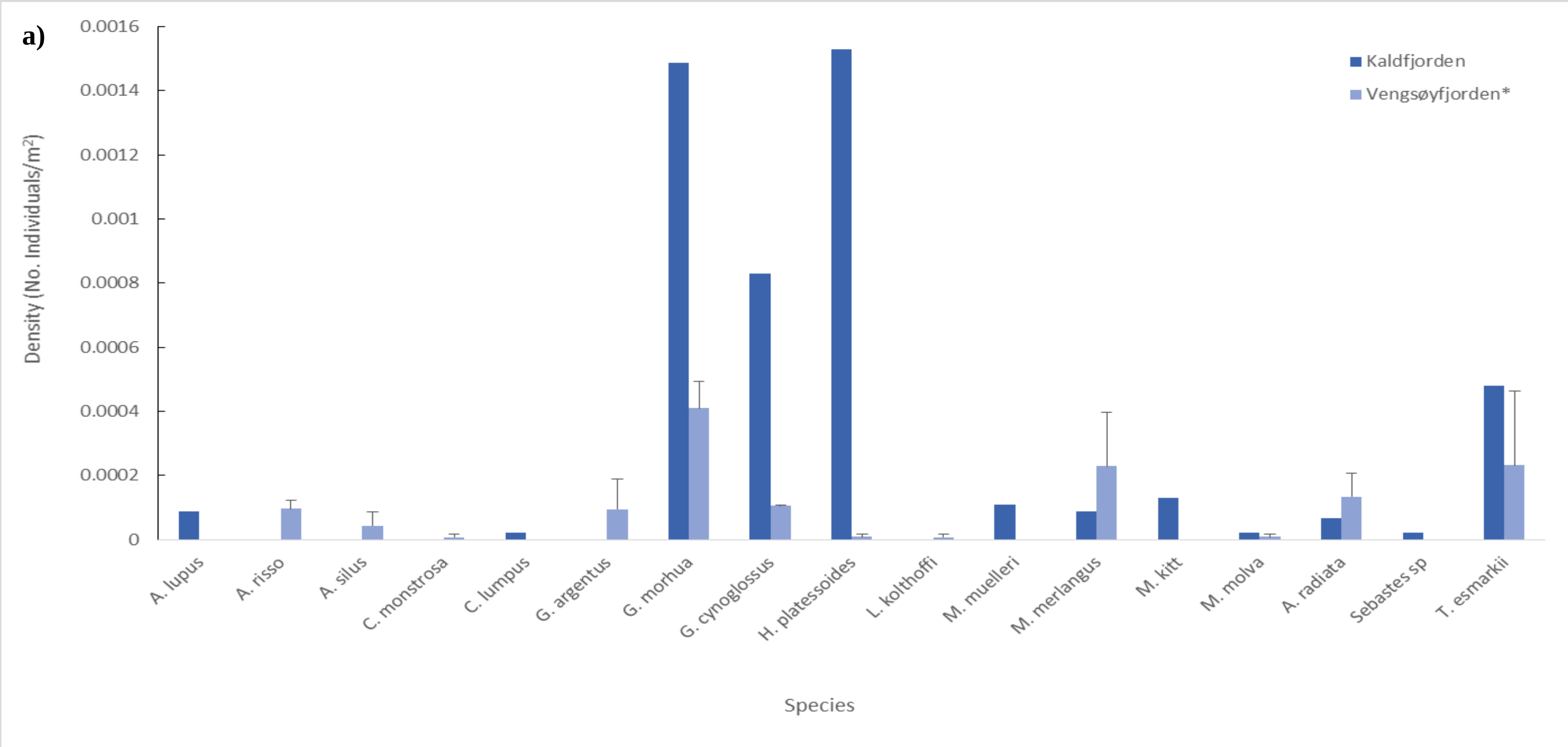

Figure 9. The density of the fish taxa found in the trawls conducted in Vengsøyfjorden and Kaldfjorden April 2019. **a)** Atlantic cod *(Gadus morhua)*, witch (righteye flounder) *(Glyptocephalus cynoglossus)* and American plaice *(Hippoglossoides platessoides)* had the highest densities in Kaldfjorden. While Atlantic cod, whiting *(Merlangius merlangus)* and Norway pout *(Trisopterus esmarkii)* had the highest densities in Vengsøyfjorden *Vengsøyfjorden in the average of two trawls and the error bars represent the standard error.

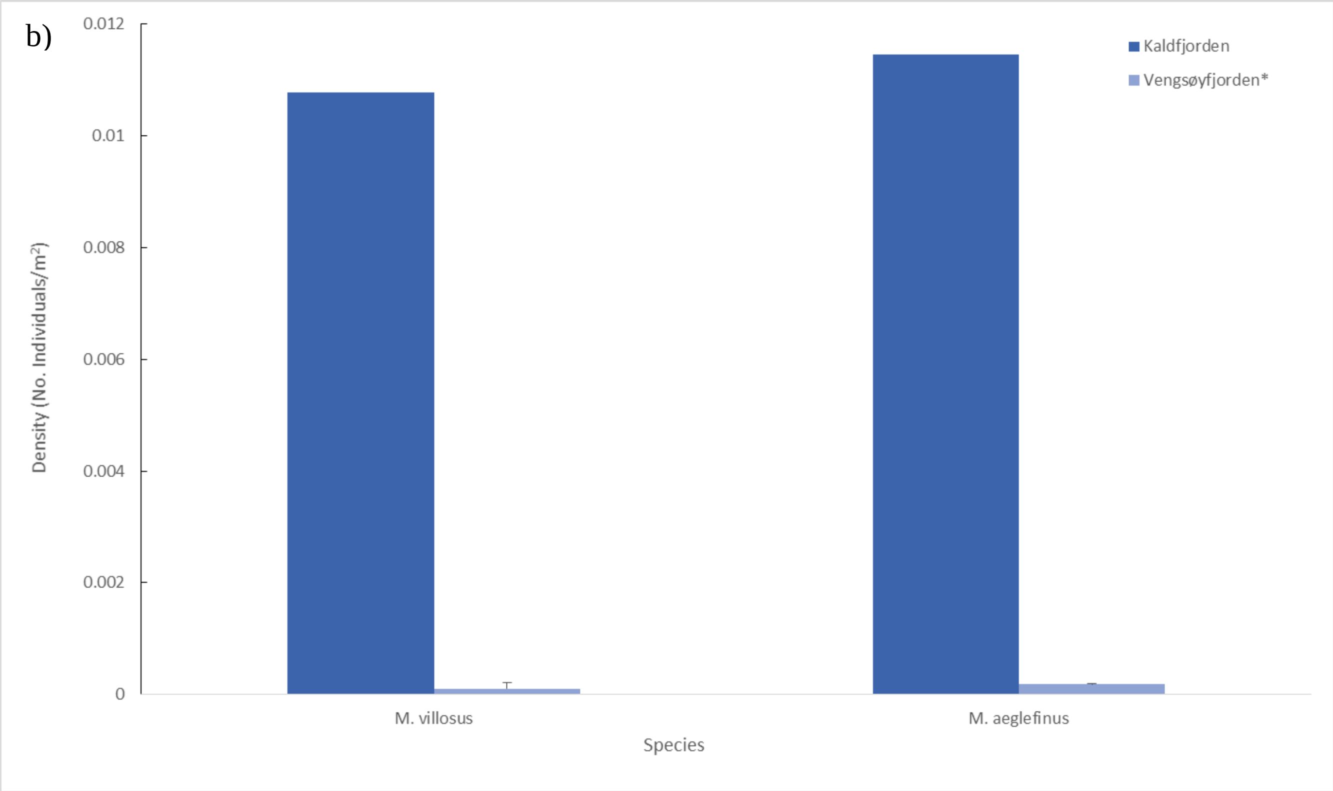

Figure 9. b) The density of capelin *(Mallotus villosus)* and haddock *(Melanogrammus aeglefinus)*. The densities of these two fish species were very high in Kaldfjorden (about 0.011 and 0.012 number of individuals per m^2 respectively) and were best represented in their own histogram. *Vengsøyfjorden is the average of two trawls, and the error bars represent the standard error.

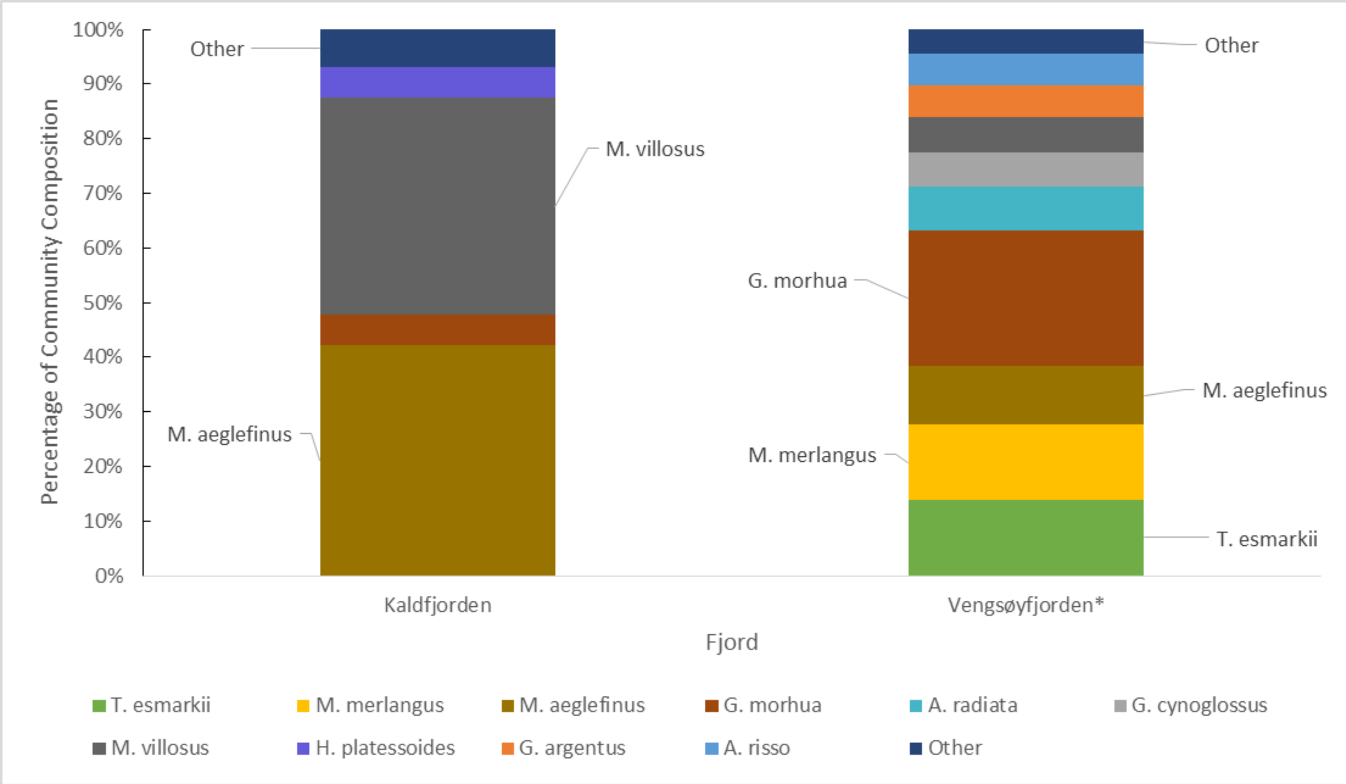

Figure 10. The percent composition of the fish species caught in the trawls for the two fjords. The "Other" category contains fish species that were less than 5% of the total density of fish caught in the trawls. The species found in the "Other" category include: *M. kitt, M. molva, A. lupus, A. silus, C. monstrosa, C. lumpus, L. kolthoffi, M. muelleri,* and *Sebastes* sp. In Kaldfjorden *M. aeglefinus* and *M. villosus* made up the highest percentage of the fish caught in the trawl with about 42% and 40%, respectively, of the total density. In Vengsøyfjorden, *G. morhua*, *M. merlangus* and *T. esmarkii* made up the highest percentage of the fish caught in trawl with about 25% and 14% (each for *M. merlangus* and *T. esmarkii)* of the average trawl abundance. *Vengsøyfjorden is an average of two trawls.

3.3 *Community Structure*

The MDS analysis showed a clear separation between the epifaunal community structures of the two fjords based on the image data (Figure 11). Two images (images 34 and 64) were excluded from the MDS analysis because they did not contain any epifauna. The results of the ANOSIM analysis of the images detected a significant difference between the epifaunal community composition (global $R^2 = 0.398$, $p = 0.001$). The global R value of 0.398 indicates that there is a moderate dissimilarity between the epifaunal communities of the two fjords. The results of the SIMPER analysis can be found in Table 5. *Hormathia* sp., *Ctenodiscus crispatus*, Ophiuroidea, *Borealea nobilis*, Zoantharia, Brachipoda and *Buccinum* sp., combined, contributed 50% to the dissimilarity by either very different densities or by being absent altogether in Vengsøyfjorden.

3.4 *Biological and Environmental*

The CAP analysis between the studied fjords showed a similar clear separation in the epifaunal assemblages between the two fjords as the MDS analysis. Vectors overlaid on the CAP ordination plot showed that substrate and depth had the most influence on the community patterns between the two fjords (Figure 12). Coverage of the substrates shellsand and, gravel and cobbles were important in Kaldfjorden and mud and silt were important in structuring the epifaunal community in Vengsøyfjorden. The RELATE analysis showed that there was a small influence on the epifauna community structure by the environmental factors recorded with a low Rho value of 0.243 and a p-value of 0.001.

The DistLM multiple regression model marginal tests supported the CAP results by showing that some of the environmental factors tested had more influence than others on the epifaunal community composition. The environmental factors that had the highest proportional effect on the epifaunal communities were depth (15%, $p = 0.001$) and the coverage of the substrates: shellsand (14%, $p = 0.001$) and mud and silt (13%, $p = 0.001$) (Table 6.a). Of these environmental factors, depth (15%, p=0.001) and gravel and cobble substrate (3.3%, p=0.001) caused the highest variation between the community composition in the fjords (Table 6.b). The BEST fitting model for these two variables accounted for 18% of the total variation between the two fjords (Table 6. c).

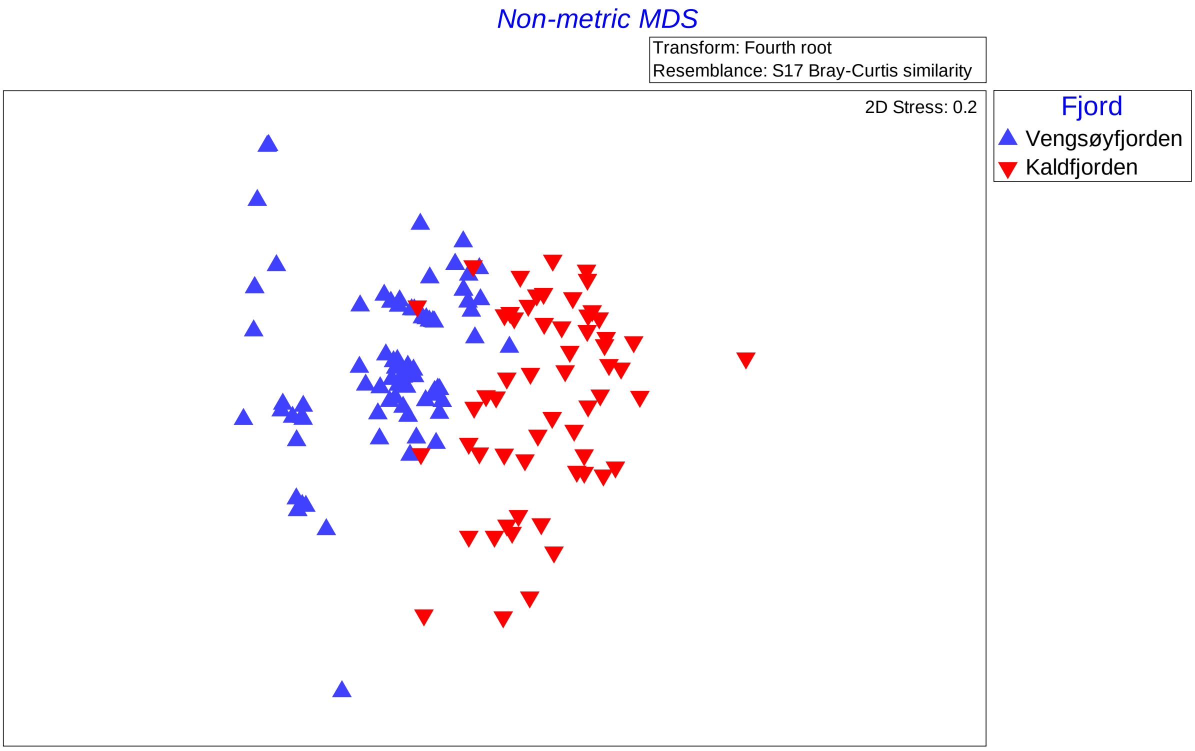

Figure 11. The non-metric MDS (multidimensional scaling) analysis, based on a Bray-Curtis dissimilarity resemblance matrix, on density data of epifauna found in the images from Vengsøyfjorden and Kaldfjorden. The analysis shows the dissimilarity of the epifaunal communities of the two fjords.

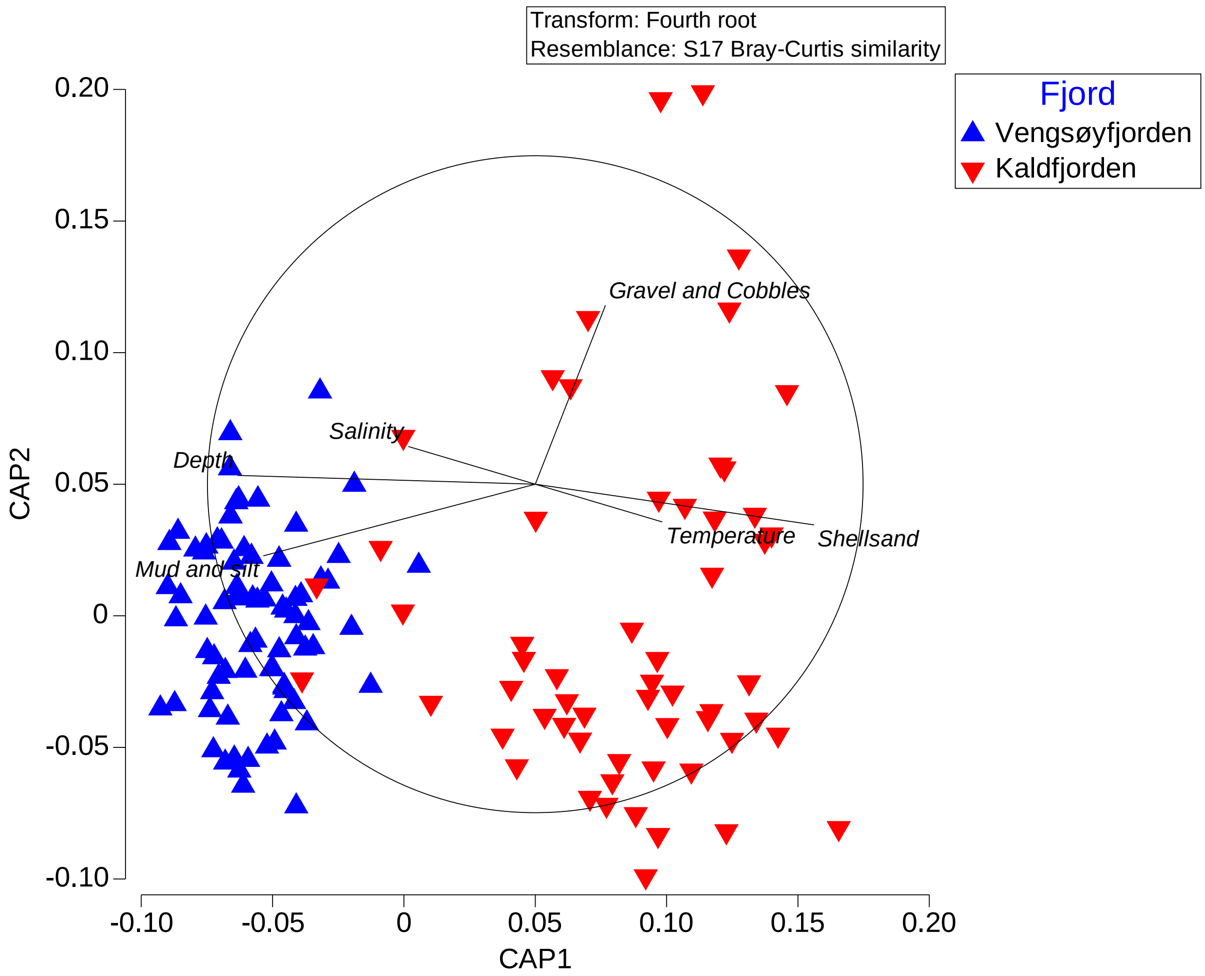

Figure 12. The composition of the epifauna taxa in Vengsøyfjorden and Kaldfjorden using a Canonical Analysis of Principle coordinates (CAP) based on a Bray-Curtis dissimilarity. The overlaid axes show the correlations between the epifauna composition and the environmental and habitat (substrate) characteristics. The depth and substrate had more of an effect on the epifaunal community composition than temperature and salinity.

Distinguishing Taxon	Average Abundance (No. of Individuals)		Contribution (%)	Cummulative (%)	Average Dissimilarity of the two fjords (%)
	Vengsøyfjorden	Kaldfjorden			
Hormathia sp.	0.00	0.80	10.92	10.92	77.6
Ctenodiscus crispatus	*1.02*	1.38	9.97	20.90	
Ophiuroidea	0.65	0.39	8.49	29.38	
Borealea nobilis	0.50	0.16	6.66	36.04	
Zoantharia	0.00	0.50	6.63	42.67	
Brachiopoda	0.00	0.42	3.94	46.61	
Buccinum sp.	0.01	0.35	3.55	50.16	
Bolocera tuediae	0.25	0.05	3.47	53.62	
Bivalvia	0.00	0.28	3.34	56.97	
Isopoda	0.01	0.24	3.12	60.08	
Mysidae	0.12	0.14	2.86	62.94	
Gastropoda	0.02	0.24	2.43	65.37	
Pagurus bernhardus	0.00	0.23	2.34	67.71	
Pycnogonida	0.00	0.20	1.97	69.68	
Munida sp.	0.08	0.14	1.96	71.64	

Table 5. SIMPER analysis results of epifauna data from images taken in Kaldfjorden and Vengsøyfjorden showing the species/taxa that had the greatest contribution to the difference between the epifaunal communities in the two fjords.

a) **Marginal Tests**

Variable	SS (trace)	Pseudo-F	P	Proportion
Depth	58755	25.28	0.001	0.15
Gravel and Cobbles	14756	5.62	0.001	0.038
Shellsand	52720	22.27	0.001	0.14
Mud and silt	49068	20.51	0.001	0.13
Temperature	12413	4.68	0.001	0.032
Salinity	12413	4.68	0.002	0.032
Residual df	**142**			

b) **Sequential Tests**

Variable	AICc	SS (trace)	Pseudo - F	P	Proportion	Cumulative	Residual df
Depth	1118.2	58755	25.28	0.001	0.15	0.15	142
Gravel and Cobbles	1114.6	12986	5.77	0.001	0.033	0.18	141

c) **BEST Solutions**

AICc	r^2	RSS	No. Vars	Selections
1114.6	0.18	$3.01708e^{+05}$	2	1, 8

Table 6. DistLM results showing which of the environmental factors tested had more influence on the epifaunal community composition. The environmental factors that had the highest proportional effect on the epifaunal communities were depth and the coverage of the substrates shellsand and mud and silt. Of these environmental factors, depth and gravel and cobble substrate caused the highest variation between community composition in the fjords.

4 Discussion

4.1 Results Summary

In summary, this study improved the knowledge of the previously unmapped epibenthic biodiversity and density in two sub-Arctic fjords. The study shows that the composition and community structure of the epibenthic and demersal fish communities observed in the sub-Arctic fjords Kaldfjorden and Vengsøyfjorden are distinctly different despite these fjords being part of a single continuous fjord system. In general, the epifaunal communities observed in image transects contained more taxa in Kaldfjorden than in Vengsøyfjorden. The overall densities were also higher in Kaldfjorden than in Vengsøyfjorden. Taxa from the phylum Echinodermata had the highest densities in both fjords. The phylum Cnidaria had the second highest densities in Kaldfjorden, while the phylum Mollusca had the second highest densities in Vengsøyfjorden. In Kaldfjorden, the epifaunal taxa that represented the highest percentage of the community composition was the sea star *Ctenodiscus crisptaus*. Other taxa found to make up more than 5% of the composition in Kaldfjorden were: brachiopods, bryozoans, ophiuroids, and an anemone of the *Hormathia* genus. In Vengsøyfjorden, *C. crispatus* represented the highest percentage of the community composition, while the other taxa representing more than 5% of the community composition were ophiuroids and a nudibranch species, *Borealea nobilis*.

In the trawls, more species of epifauna were found in Vengsøyfjorden than in Kaldfjorden. The phylum with the highest density for epifauna from the trawls was Arthropoda, with *Pandalus* sp. being the dominate taxon in both fjords. The high densities of *Pandalus* sp. caught resulted in Vengsøyfjorden having a low species diversity index, but a high density. In Kaldfjorden, the species with the second highest density was the sea anemone *Urticina eques*. In Vengsøyfjorden, the species with the second highest density was *C. crispatus*. Overall, Vengsøyfjorden had a higher diversity of fish species, which was dominated by Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), and Norway pout (*Trisopterus esmarkii*). Conversely, the fish community in Kaldfjorden was of a higher density but a lower diversity compared to Vengsøyfjorden. Haddock (*M. aeglefinus*) and capelin (*M. villosus*) were the dominant species in Vengsøyfjorden. The environmental factors depth and coverage of the substrate types gravel and cobbles and, mud and silt, were found to significantly affect the community composition of the epibenthic communities observed in the images.

4.2 Epifauna and Demersal Fish

4.2.1 *Biodiversity*

The phyla and taxa found in this study are in agreement with previous studies of benthic epifauna in northern Norway that found phyla of epifaunal taxa to include mostly Cnidaria, Mollusca, Annelida, Arthropoda, and Echinodermata (Gulliksen 1978; Gulliksen & Bahr 2001). The same epifauna phyla have also been found to be well represented in epifaunal communities in other high latitude and Arctic regions; including Greenland, Svalbard, the Barents Sea and the Canadian Arctic Archipelago (Jones *et al.,* 2007; Laudien & Orchard 2012; Roy *et al.,* 2014; Jørgensen *et al.,* 2015). The most taxon rich epifauna phyla in this study was Mollusca (14 taxa in the images, 3 taxa in the trawls) and Echinodermata (13 taxa in the images, 11 taxa in trawls). One study of epifauna in the Barents Sea found Mollusca to be the most taxon rich (Jørgensen *et al.,* 2015), while Sswat *et al.,* (2015) found Mollusca to be taxon rich, it was not the most taxon rich phylum. In the Canadian Arctic Archipelago, Arthropoda was the most taxon rich phylum (Fredriksen 2018), and in western Greenland, Echinodermata was the most taxon rich (Mayer & Piepenburg 1996). The same phyla found in the images of this study were also found in the trawls, with the exception of Brachiopoda, Bryozoa, Ctenophora and Porifera. These four phyla were only found in the images.

The taxon richness of the invertebrate epibenthos in the image analysis of this study was generally comparable to other studies but was lower than has been observed in some other areas of the high north. A total of 45 taxa and 8 phyla were found in an image analysis of the epifaunal community of Kangerdlugssuaq Fjord located in eastern Greenland (Jones *et al.,* 2007), at a similar latitude to Kaldfjorden and Vengsøyfjorden. The taxa and phyla are generally comparable to, but slightly fewer than, the 67 taxa and 11 phyla found in the images of Kaldfjorden and Vengsøyfjorden. Some of the taxa found in Kangerdlugssuaq Fjord belonged to the same classes as taxa that was found in this study (e.g. Actinaria, Asteroidea, Ophiuroidea). In contrast, Sswat *et al.,* (2015) found more than twice as many taxa (141) in their images and a similar number of phyla (9) in Kongsfjorden in Svalbard. The large number of taxa found could be due to the fact that Sswat *et al.*, had 26 sample stations and this study had a much smaller number of stations. On Arctic shelves, taxon numbers found in imaged-based studies were on the same order of magnitude as in the present study. In the Canadian Arctic Archipelago, 33 taxa could be identified (Fredriksen 2018), 15 taxa were identified in the Chukchi Sea (Ambrose *et al.*, 2001), and 91 taxa in northeast Greenland (Mayer & Piepenburg 1996). Direct comparison is limited due to differences in effort and image quality of the different studies. The level to which species identification can occur in images is also reduced in image-based studies versus when a physical specimen is available.

The taxon richness of the epifauna in the trawls of this study, 44 taxa and 6 phyla were found in 3 trawl hauls for this study, were lower than other trawl studies in the high north. A (beam) trawl study of Balsfjorden, located in close proximity to Kaldfjorden and Vengsøyfjorden, found 91 taxa in a total of 22 trawls (Tranang 2017). Trawls in Kongsfjorden, Svalbard, found nearly twice as many taxa (107), but a similar number of phyla (9) from a total of 26 trawls (Sswat *et al.*, 2015) and in Northeast Greenland, 276 taxa were found in 22 trawls (Fredriksen 2018). The higher number of taxa found in these studies is most likely due to the larger number of trawls conducted.

The trawls in Kaldfjorden and Vengsøyfjorden caught 19 species of fish. Trawls conducted in Ullsfjorden and Arnøya (northern Norway) as a part of the Marine Biodiversity (BIO-2513) course taught by The Arctic University in Tromsø (UiT), caught 11 and 13 species of fish respectively. The trawl from Ullsfjorden had 7 species in common with the trawls from this study and the trawls off of Arnøya had 9 species in common (Hansen *et al.*, 2018). They also caught another species of fish (*Sebastes norvegicus*) that came from the same genus as a fish from our trawls that was unable to be identified below the genus level. Of the 19 species of fish caught in Kaldfjorden and Vengsøyfjorden, 10 were also caught by Salvanes & Nordeide (1993) in trawls conducted in Masfjorden (western Norway). Their trawls also caught another species of the *Sebastes* genus (*Sebastes viviparous*). The study of Masfjorden conducted trawls seasonally (winter, spring, summer and autumn) and, the trawls conducted in spring (the same time of year the trawls in Kaldfjorden and Vengsøyfjorden were carried out) sampled a total number of 31 species of fish. The difference in the number of species caught could be due to the difference in latitude between Malsfjorden and

Kaldfjorden and Vengsøyfjorden; Masfjorden is further south than Kaldfjorden and Vengsøyfjorden.

4.2.2 *Density*

The density range for the images in this study were 0 to 127.5 individuals per m^2, which are similar to what other image studies in the Arctic have found. Epifauna in the Canadian Arctic Archipelago were found to have densities of 5 to 209 individuals per m^2 (Fredriksen 2018), while North of Svalbard epifaunal communities were found to have densities of < 0.5 to 37 individuals per m^2 (Sswat *et al.,* 2015). In Kongsfjorden, epifaunal densities ranged from 4 to 98 individuals per m^2 (Laudien & Orchard 2012); epifauna from Kangerdlugssuaq Fjord in eastern Greenland had densities ranging from 0.2 to 6 individuals per m^2 (Jones *et al.,* 2007).

The total density (epifauna and fish) recorded in the Kaldfjorden trawl was 0.047 individuals per m^2, which was lower than in most other trawl-based studies in the high latitudes. The total density for the two trawls in Vengsøyfjorden were 0.067 and 0.096 individuals per m^2. In the Chukchi Sea, densities of < 1 to 71 individuals per m^2 were found (Bluhm *et al.,* 2009) and, a study of the Canadian Arctic Archipelago found densities of < 1 to 382 individuals per m^2 (Roy *et al.,* 2014). The fact that densities of the trawls for this study were on the lower end of what other studies around the Arctic have found might be explained, in part, by the larger mesh size used in this study, than was used for the referenced studies. The fish and the shrimp caught in the trawls accounted for a large portion of the trawl densities in the present study. Trawls in the Barents Sea were found to have the lowest mean abundance (2-734 individuals in a trawl) in the southwestern stations (off of northern Norway) when fish and shrimp were not included in the analysis of the data (Jørgensen *et al.,* 2015). This is similar to the number of epifauna found in trawls in this study when fish and shrimp were removed from the data.

In terms of density, the dominate epifauna taxa recorded in the images from Kaldfjorden and Vengsøyfjorden came from the phylum Echinodermata. Similarly, echinoderms have been found to contribute the most to epifaunal density in many Arctic shelf regions, for example in the Chukchi Sea (Ambrose *et al.,* 2001; Bluhm *et al.,* 2009), the Beaufort Sea (Ravelo *et al.,* 2015), and in the Canadian Arctic Archipelago (Roy *et al.,* 2014; Fredriksen, 2018). In the images from Kaldfjorden and Vengsøyfjorden, there were two dominate echinoderm species/taxa, one was *Ctenodiscus crispatus* and the other was ophiuroids. Ophiuroids have previously been found to be the dominate class in an image-based study of an area of the shelf and slope region just north of Svalbard (Sswat *et al.*, 2015). Ophiuroids, however, were not the dominate taxa found in the images of Kaldfjorden and Vengsøyfjorden, but did account for the second highest percentage of image composition (based on density) for Vengsøyfjorden. The most dominate echinoderm species by density found in both the images and the trawls at Vengsøyfjorden, *C. crispatus,* was also one of the dominate species in trawls from a station located in the southwestern Barents Sea (an area that included the Tromsø Plateau and the North Cape Bank) was (Jørgensen *et al.,* 2015).

Other taxa that contributed a large portion to the total density were nudibranchs, particularly the species *Borealea nobilis* (in Vengsøyfjorden), brachiopods, bryozoans and a *Hormathia* sp. (all three in Kaldfjorden). Polychaetes, in contrast, were found to be the dominate taxa in Kongsfjorden (Laudien & Orchard 2012). Tubeworm polychaetes were noticed in the images of Kaldfjorden (where most of the tubeworms were seen) and Vengsøyfjorden, but had to be excluded from the results due to difficulties in determining whether or not the tubeworms were alive. Two species of polychaetes were caught in the trawls, but only three individuals were caught and therefore did not make up a large part of the trawl density. The presence of tubeworms and polychaetes in the trawls does suggest, however, that polychaetes are a component of the benthic communities in Kaldfjorden and Vengsøyfjorden, but are likely to be a part of the macrofauna.

There was a large difference in the densities of shrimp found in the images and the trawls. *Pandalus* sp. were found in high densities in the trawls, but very few individuals were found in the images. In their study of the west Greenland Shelf, Yesson *et al.,* (2015) noted the shrimp species *Pandalus borealis* might be underrepresented in their results, because of its diurnal migration pattern. *P. borealis* are close to the seafloor during the day and rises in the water column at night (Bergström 2000), and their image data was collected at night. In Balsfjord (Troms, Norway), recruitment in the *P. borealis* population was found to start becoming evident in February and that eggs hatched in the first part of April (Hopkins & Nilssen 1990). A combination of these two patterns may explain the large difference between the images and trawls. The image transects were taken in early December, after the region has entered the polar night period, at times of day that were before and after the brief “twilight” during the day. This could have resulted in the shrimp being up in the water column, instead of close to the seafloor. The trawls were taken in early April during daylight hours, when the shrimp would have been close to the seafloor.

The number of fish caught in the trawls ranged from 93 to 1240 and densities ranged from 0.0016 to 0.027 individuals per m^2. Kaldfjorden had the highest number (1240 fish caught) and density of fish caught (0.027 individuals per m^2). Haddock (*Melanogrammus aeglefinus*) was the fish that had the highest density in the trawls, with the highest densities occurring in Kaldfjorden (a total of 524 individuals were caught). They are known to be abundant all along the Norwegian Coast (Giæver *et al.*, 1995; Olsen *et al.*, 2010). The species with the second highest density in Kaldfjorden was capelin (*Mallotus villosus*) (a total of 493 individuals were caught). Stocks of capelin are known to occur in the Barents Sea and Balsfjorden (Gjøsæter 1998; Olsen *et al.*, 2010). Atlantic cod (*Gadus morhua*) were found in both Kaldfjorden and Vengsøyfjorden. Kaldfjorden had the highest density of cod between the two fjords, but here cod made up a small percentage of the trawl composition. There could be a possible trophic association between the cod and the capelin caught in the trawls. The primary food source for cod, after they reached a length of 40 cm to 50 cm, is capelin. Krill and shrimp/prawns are known to be the primary food source of cod that are less than 40 cm in length (Santos & Falk-Petersen 1989). Vengsøyfjorden had high densities of *Pandalus* sp., and the fish species with the highest density, and percent composition of the trawl, was cod. Looking into gut content of the cod would be a way to determine if indeed a trophic association is occurring in Kaldfjorden and Vengsøyfjorden with prey items.

It can be seen that there is a difference in the densities of fauna found in the images and trawls from Vengsøyfjorden and Kaldfjorden. Average densities in the images had a maximum of 6 individuals per m^2, and densities of the trawls had a maximum density of 0.096 individuals per m^2.   However, there was also a difference in the species caught. There were very few fish and shrimp found in the images, yet the Kaldfjorden trawl was predominately species of fish and the Vengsøyfjorden trawl was mostly predominately *Pandalus* sp.

4.3 *Environmental Drivers of Community Structure*

4.3.1 *Substrates*

Substrate type was found to affect the structure of the epifaunal benthic communities found in the images of Kaldfjorden and Vengøyfjorden. Kaldfjorden was found to have more taxa in the images, which was perhaps related to the seafloor of Kaldfjorden consisting of a greater range substrate types than Vengøyfjorden. Three different substrates were seen in images along the transect of Kaldfjorden (mud/silt, shellsand and, gravel and cobble). A greater diversity of substrate types found in Kaldfjorden is therefore capable of providing more microhabitats. On the continental shelf of northern Norway, higher densities of epifauna were found on substrates that were heterogeneous (Jørgensen & Gulliksen 2001) compared to homogenous substrates. In Kongsfjorden, a greater diversity of fauna (both infauna and sessile epifauna) were also found in heterogenous substrates (Buhl-Mortenson *et al.,* 2012). An important regulating factor of benthic community structure in the Chukchi Sea, was also found to be sediment heterogeneity, with a positive correlation in diversity with increased heterogeneity and a negative correlation in diversity with increased homogeneity (Grebmeier *et al.,* 1989).

In addition to providing habitat diversity, coarser sediments also provide surfaces for sessile epifauna to attach to. There were more sessile epifauna (e.g. poriferans and bryozoans) found in the images containing more mixed and hard bottom substrate in Kaldfjorden. This is consistent with other studies that found higher densities of sessile epifauna on hard substrates, on the continental shelf of Norway, the West Coast of Greenland, and the coastal water around the Norwegian Svalbard Archipelago (Buhl-Mortenson *et al.,* 2012; Ronowicz *et al.,* 2013; Yesson *et al.,* 2015). Taxa found to be associated with hard substrates include Porifera, Bryozoa, Hydrozoa and Anthozoa (Yesson *et al.,* 2015, this study). One species that was consistently found on soft bottom substrate in this study was *C. crispatus*, which is consistent with what other studies have found in the Barents Sea and Balsfjorden (Jørgensen *et al.,* 2015; Tranang 2017). Another taxa found on soft bottoms in this study were ophiuroids, which have also been found on soft bottoms in the Beaufort Sea, Chukchi Sea and Barents Sea (Jørgensen *et al.,* 2015; Ravelo *et al.,* 2015; Bluhm et al., 2009). The reason for finding certain taxa, or species, like *C. crispatus* on soft bottoms might have to relate to their preference for deposit feeding (Degen & Faulwetter 2019). Another taxon found only on soft bottom substrates in this study were nudibranchs, particularly the species *Borealea nobilis*. Conversely, a study of Ikka Fjord in southwest Greenland, found nudibranchs only on hard substrates (Thorbjørn & Petersen 2003).

4.3.2 *Depth*

Depth is another environmental factor that has been found to influence differences in benthic communities and is known to affect both the density and diversity of a benthic community through food availability (Bluhm *et al.,* 2005). However, biodiversity patterns can become less clear with depth and are not necessarily driven by depth itself. A study of the Barents Sea found that depth did not necessarily affect the benthic community, but other factors like water mass and ice cover had a stronger influence on the benthic community (Cochrane *et al.,* 2009). The area of Kaldfjorden that was sampled was shallower than the area of Vengsøyfjorden that was sampled and, was found to have higher species richness. This is similar to what was found in the North Barents Sea (Sswat *et al.,* 2015) and on coastal Svalbard (Meyer *et al.,* 2015*)*. It is in contrast, however, to what was found in a Greenlandic fjord where species richness increased with depth (Jones *et al.,* 2007). The difference between our study and the Greenland study could be explained by evidence of iceberg disturbance in Kangerdlugssuaq Fjord at shallower depths (Jones *et al.,* 2007).

4.3.3 *Hydrography*

The hydrography (salinity and temperature) of the two fjords was fairly similar (Table 1) and did not appear to have an effect on the community structure. The similarity in the salinity and temperature measurements between the fjords could be influenced by the fact that measurements were taken at a depth of over 100 m, where factors that might affect salinity and temperature at shallower depths (e.g. terrestrial runoff, air temperature) may not play a role. The salinity and temperature of the surface waters could very well have been different than what was recorded at depths of over 100m. The image transects were taken in December and winter storms could have mixed the water column in the fjords resulting in a more homogenous water mass. Another factor influencing consistent salinity and temperature in the two fjords is how good the water exchange is with the ocean and how often it occurs (Howe *et al.,* 2010).

5 Reflections

5.1 *Methodology*

Due to the fact that this was a study for a Master's thesis, time constraints and vessel availability made it impossible to conduct the trawl samples in the same time frame as when the images were taken (December). The differences seen between the images and trawls thus may in part be a result of seasonal differences the benthic community experiences in Kaldfjorden and Vengsøyfjorden. To further test the effects of seasonality on epifaunal and demersal fish communities, the methodologies employed in this study could be repeated at different points in time during the year. A seasonal change that might affect the benthic communities is the vertical flux of organic matter from the surface to the bottom, which can vary from season to season (Lalande *et al.,* 2020), and even from year to year (Reigstad *et al.,* 2000).

The image transects and trawls were taken in the central part of the fjord, which happens to be the deepest areas of the fjords. This provides knowledge on the benthic communities in the deeper parts of the fjords, but not what the benthic communities might look like in shallower locations. Increasing the spatial resolution of the sampling area to include shallower depths would expand the spatial resolution of the study. The use of detailed substrate mapping would also prove useful to improve the planning of further benthic studies in these fjords.

Further investigation into additional environmental factors (e.g. currents, organic carbon deposition) would help provide a better understanding about the dynamics of the epifaunal communities. In this study only temperature, salinity, depth and substrate coverage were investigated. Temperature and salinity did not have much of an influence on the structuring of the benthic community, because they are rather similar across the deep basin stations that were sampled. Depth and substrate type did have an effect on the benthic community, but it remains unclear what other factors are influential. Data on additional environmental factors like currents, water mass distribution and organic carbon input are just now becoming available for the study area (Lalande *et al.,* 2020; Jones *et al.,* in review), but were not available in time for inclusion in this analysis. Another factor that could be driving the difference between the two fjords is the availability of food. The downward flux of organic material can affect not only the composition of benthic fauna, but also their density

(Wassmann *et al.,* 1996*;* Jones *et al.,* 2007). To get a more complete picture of the benthic community of Kaldfjorden and Vengsøyfjorden, further studies in the area are recommended to include these other factors.

5.2 *Sampling Methods*

5.2.1 *Photographic Sampling*

The use of photographic techniques to sample a study area has positive and negative aspects. The positive aspects are that photographic sampling does not disturb or destroy the study area, which allows for the possibility of resampling an area multiple times without impacting the study area. The images provide a permanent record of what that area looked like at that given time, which can be reviewed multiple times and years after they were initially taken. This could prove useful in studies that are time series based, or are monitoring the effects of pollution or industry on an area (Hamoutene *et al*., 2016; Sutherland *et al*., 2018; Keeley *et al*., 2020).

The negative aspects are that only organisms that are clear and well-lit within the field of view and on the sediment surface can be seen. The distance from the bottom (i.e. far from the bottom versus close to the bottom) can also affect the data that can be obtained from images. The type of image sampling (e.g. video, still photography) used can also influence the faunal densities recorded (Christiansen 1993). The taxonomic level to which organisms can be identified can be hindered by the resolution of the image. Another downside to photographic samplings is that more mobile organisms can swim away from the camera; a possible reason as to why very few fish and *Pandalus* sp. were seen in the images. Other studies comparing photographic sampling with other methods (e.g. suction sampling) have found that the density of some species is underestimated in photographic sampling. Species are not accounted for due to being "hidden" (i.e. under rocks, in sediment), and that information is reliably obtained on only large and conspicuous organisms (Jørgensen & Gulliksen 2001). One additional downside is the length of time taken to analyze each image. In the current study, an image with a large number of diverse organisms, took upwards of an hour to analyze. The number of images recorded in this study was relatively small (close to 200), but other studies can have thousands of images to process (Piechaud *et al.,* 2019). The process of manually analyzing images is time consuming and, advances in automated image analysis (where machine learning algorithms are used to teach the software what to look for), are proving useful in shortening the amount of time spent on analysis (Zurowietz *et al*., 2018; Piechaud *et al*., 2019). Additionally, advances in camera technology, like underwater hyperspectral imaging, are improving the resolution of benthic imaging and the ability to identify smaller, less conspicuous, organisms (Chennu *et al*., 2013; Johnsen *et al*., 2013; 2016; Dumke *et al*., 2018; Foglini *et al*., 2019).

5.2.2 *Trawl Sampling*

As with the photographic techniques, there are positive and negative aspects to using trawls as a sampling method. One positive aspect of trawls is that they catch more mobile organisms which might not be captured in images. Taxonomic identification is generally more accurate with a physical specimen making identification down to a genus or species level possible. Trawl methods however do not provide information on the habitat or substrate composition of the sampling area. Trawls, especially bottom trawls, can be very destructive to the area sampled (e.g. suspending sediment, disturbing/destroying sessile organisms) (Hiddink *et al.*, 2006). The destructive nature of trawls means that, in theory, resampling an area and replicating the results is very difficult because the trawl changes the substrate environment. It is also difficult to accurately calculate the area sampled due to how a trawl works (e.g. can lift off the bottom and doors can vary in width apart from each other throughout the trawl duration) (Walsh 1997).

6 Conclusion

This study used a combination of benthic photography and trawl studies to provide insight into the epibenthic and demersal fish communities of two poorly studied sub-Arctic fjords. While the two fjords, Kaldfjorden and Vengsøyfjorden, have a few species in common, the epifaunal and demersal fish communities found in both fjords showed clear differences. Even though the two fjords are connected, the results of this study suggest that these differences in community structure are driven by differences in the environmental factors; depth and the coverage of the hard/mixed substrates between the two fjords. Increasing the knowledge of the benthic communities in these two fjords creates a baseline of an area’s benthic community. This knowledge can prove helpful when assessing how to use the two fjords sustainably as economic resources. For example, epifaunal communities are beginning to be utilized as indicators of benthic enrichment from fish farm waste in areas with mixed and hard bottom substrates were benthic grabs fails (Hamoutene *et al.,* 2016; Salvo *et al.*, 2017). Learning how an organism responds to changes in the environment, and what their tolerance levels are, can help to determine which organisms are sensitive to environmental changes (e.g. pollution from terrestrial sources and/or aquaculture or mining activities) (Aguzzi *et al.*, 2011). These particular species/taxa could then be used as indicators of the health of an area, or whether or not there is pollution/increased pollution in an area, particularly in relation to the aquaculture industry. Having a visual image of the impacts, could help bring about changes that would reduce or eliminate the negative impacts on marine ecosystems in the present and in the future.

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