Does an alternative perspective of imaging capture additional information on benthic habitats and the impacts of otter trawling at the shrimp fishery site of West Greenland's continental shelf?

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Abstract

Previous studies on the effects of otter trawling on benthic habitats on West Greenland's continental shelf have used a drop-down camera to photograph the seafloor at a perpendicular angle. This method is not suitable for capturing larger benthic organisms which are, therefore, not accurately represented in the analysis from those studies. This study used a GoPro positioned at a higher elevation to the drop-cam to capture wider-angled images at the same sites used during the final 1 ½ years of the previous study. Multidimensional scaling models and univariate linear models were used to analyse the similarities and differences between the two imaging methods according to class abundance of each taxon per site. Of 46 sites and 46,000 observations, MDS plots exhibited clear groupings between GoPro and drop-cam data while combined data revealed trawling distance as a significant influence on taxa abundance and diversity in line with current literature. The GoPro camera had a sampling bias for larger macro fauna while drop-cam images were biased for microfauna taxa by excluding the larger macrofauna more at risk from trawling. The drop-cam found a higher number of taxa with sites having a higher abundance and diversity. The results indicate a more holistic approach can be achieved by combining both methods of imaging. This allows each method of imaging to compensate for the other method's shortcomings. However, a standardised method is required to be developed for the GoPro to allow for more robust analysis.

Introduction

The benthic living organisms are a vital part of marine ecosystems providing ecosystem services such as nutrient cycling, carbon storage and water filtration (Yesson et al., 2016). In the arctic and subarctic there is a diverse range of species including the commercially important northern shrimp *Pandalus borealis* (Bergström, 2000; Costello et al., 2010). This shrimp has become the main source of income for Greenland’s economy. The shrimp exports account for approximately 50% of Greenland’s total exports (Statistics Greenland, Statistics for 2011; Wieland, Storr-Paulsen, & Sünksen, 2007). This same shrimp fishery has caused an increase in disturbances on the arctic seabed, which, causes an overall decrease in benthic species diversity by removing sessile epifauna. Many of these are vital ecosystem engineers (Clark et al., 2016; Pusceddu et al., 2014). Previous studies of the benthic habitats in West Greenland and studies on the effects of trawling have relied on a system of a drop-down camera taking images perpendicular to the sea floor. This method may exclude larger sessile organisms which form a vital component of benthic habitats. No marine habitat remains unaffected by androgenic changes and the west coast of Greenland has experienced medium to high impacts (Halpern, Walbridge, Selkoe, & Kappel, 2008). This increases the importance of monitoring these habitats because the economy of Greenland is so dependant upon the continued production of shrimp from benthic habitats.

West Greenland benthic communities

Many factors influence benthic diversity, both natural and anthropogenic and, accordingly, the composition of communities varies along the west continental shelf. In the northerly latitudes of the arctic and subarctic, the sediments are subjected to a process known as iceberg scouring. This process can plough sediments, breaking or moving seabed fauna at a depth up to 600m. This leads to a natural cycle of disturbance along the continental shelf sediments and, to a certain degree, benthic communities have adapted to this disturbance (Lee, Vanhove, Peck, & Vincx, 2001). Studies have shown that the process kills or removes sessile slow-growing organisms, such as corals and sponges, while pioneer organisms thrive (Curtis, Poppe, & Wood, 2013; Gutt, Starmans, & Dieckmann, 1996). These stronger currents prevent soft sediments remaining stationary creating more rocky seas bed such as those seen south of 70°N. Here, hard substrate specialist taxa such as Anthozoa, Bryozoa, Hydrozoa, and Porifera are more more evident (Yesson et al. 2015). Moving north, the currents are weaker creating soft substrate habitats with soft substrate organisms such as *Pandalus borealis,* the northern shrimp, currently being farmed by the West Greenland fishery (Yesson et al., 2015).

Impacts of the West Greenland shrimp fishery

The West Greenland Coldwater Prawn Fishery uses otter trawls to catch shrimp and, in total, produced 50% of Greenland's exports (Statistics Greenland, Statistics for 2011). To prevent the netting scraping the seabed, the boat uses a rolling rockhopper gear with 72mm chains to reduce damage to the benthic communities. Otter trawlers have a similar effect to iceberg scouring (Simon, 2013). By ploughing the sea bed, the trawlers break or remove seabed fauna and, evidence suggests, decreases oxygen levels in the sediments, thereby causing anoxia conditions. (Van Dolah, Wendt, & Levisen, 1991; Warnken et al., 2003). However, the trawling increases the level of disturbance above the natural level even with the introduction of semi-pelagic doors to reduce impact (He et al., 2004). The higher levels of disturbance benefit colonisers or pioneer species with fast growth rates and short life cycles. Scavengers and opportunistic species benefit from an increase in dead or dying animals left behind (De Juan, Thrush, & Demestre, 2007). Trawling is particularly harmful to immobile species. The trawling affects areas of low natural disturbance where communities are less adapted to such disturbance. The high disturbance areas have even shown little to no change in community structure. Trawling has been shown to increase fast-growing species with larger and slower species becoming rarer and overall diversity decreasing (Simon, 2013; Van Dolah et al., 1991; Yesson et al., 2017).

Impacts of climate change

Climate change causes a range of impacts upon benthic communities of Greenland as arctic and subarctic areas are particularly sensitive to the effects. No marine area remains unaffected by human impacts such as climate change (Halpern et al., 2008). The arctic ocean has been shown to have ocean surface temperatures rise more rapidly than other areas in the world (Marshall et al., 2014). This has led to some members of benthic communities migrating further north: including the northern shrimp. Studies show that species with smaller bodies and faster life cycles, such as shrimp, shift their habitat ranges quicker than other species (Perry et al., 2005). As the climate changes and sea temperatures continue to rise, shrimp will move further north while slower-growing organism, such as corals, remain further south (Hamilton, Brown, & Rasmussen, 2003; Perry et al., 2005; Wieland & Hovgård, 2009). Many taxa in these communities are slow-growing and immobile and struggle to move with shifting climates. Although climate change is a natural process, unprecedented change, as experienced in recent years, means these organisms cannot adapt to the climate shift northwards. (Hoegh-Guldberg & Bruno, 2010). In addition to a shifting climate, a greater area of sea is ice-free for longer periods of the year. This extends both the time and area available for trawling (Marshall et al., 2014; Sswat, Gulliksen, Menn, Sweetman, & Piepenburg, 2015). In Greenland, the majority of icebergs are a result of glacial melt which in recent years has increased with rising temperatures, particularly in North-West Greenland (Chen, Wilson, & Tapley, 2011). In turn, this leads to an increase in iceberg scouring along the seafloor (Barnes, 2011, 2017). This increases the need to minimise the effects of trawling, which mimics iceberg scouring, if the negative impact of anthropogenic activities on benthic communities is to be reduced.

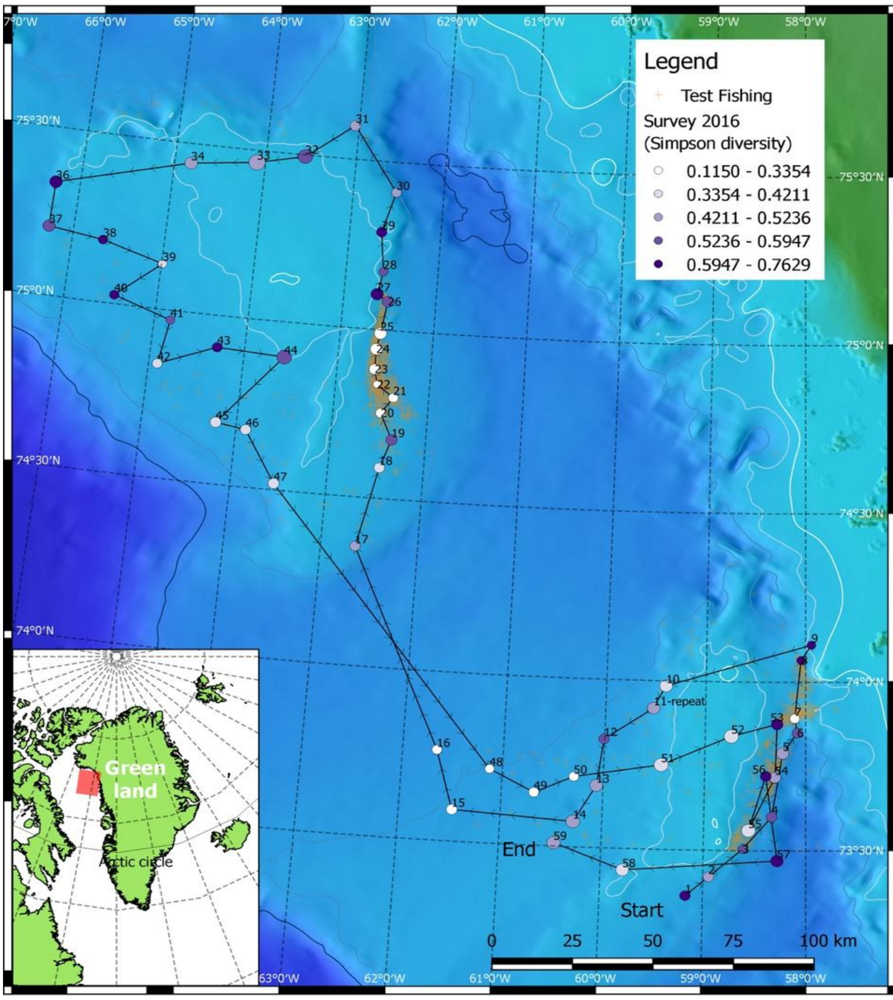
Methods for imaging benthic habitats

Studying deep sea habitats is not easy. It is the largest ecosystem in the world but also the least studied (Ramirez-Llodra et al., 2011). The extreme conditions found within the deep sea requires expensive specialist equipment able to withstand such conditions. Common methods used include direct sampling of species to count abundances and diversity at different sites and taking images of the habitat (Beazley, Kenchington, Murillo, & Sacau, 2013; Pieieter & Schmpenburg, Did, 1997; Piepenburg & Schmid, 1996). Habitat characteristics on the seafloor can be extrapolated to some degree using acoustic techniques but lack of natural light means it is difficult to image without providing light sources able to withstand high pressures of the deep sea (C. J. Brown, Smith, Lawton, & Anderson, 2011; Kostylev et al., 2001). Previous studies used a drop-down camera attached to a cage to image the West Greenland seafloor (Yesson et al., 2017). These images were used to analyse the biodiversity of several hundred sites over 1000 km and if heavily fished areas have lower levels of diversity. Previous studies using this method have not captured the larger organisms present because they simply do not fit under the cage used for the drop-down camera (Figure 2). Each picture captures roughly $0.3m^2$ and is perpendicular to the sea bed. This means members of the Perciformes genus, larger sea sponges and corals wouldn't fit within these dimensions and mobile species like shrimp often flee the camera. Recent technological advances in cameras have produced useful tools such as GoPros. These cameras can store hours of footage and are easily mounted at an angle with casings designed for extreme conditions such as ice, water, darkness and pressure (https://cam-do.com/products/deep-water-monitoring-enclosure). By comparing their data against the data of an image at a wider angle we can determine if an alternative perspective offers additional information. A survey conducted in 2016 added an angled GoPro to the housing of the drop-cam (Figure 2). The higher position provided a different view of the environment and enabled capturing larger organisms in the GoPro images. If larger organisms show the same trends as smaller organisms identified by the drop-cam, studies of larger organisms may be easier to conduct. This is because they are easier to count and identify therefore saving time and effort in data collection. These larger species would be difficult to image on a 2016 drop down camera (Figure 2, Yesson et al., 2017). It is likely a camera at a wider angle would more easily identify the effects on these species. Large sessile organisms often missed by the drop-cam, but caught on the GoPro angled at a higher altitude, could reveal a greater negative impact than previous estimations.

This paper will examine different imaging methods used to study benthic communities in the West Greenland shrimp fishery and whether they offer new information on the effects of trawling.

Aims

The aim of this study is to identify whether new imaging techniques can be used to determine the composition of benthic communities and impact of trawling upon the sea bed.



Station	Date	Depth	Longitude	Latitude
1	22/09/16	382	-59.1665	73.3647
2	22/09/16	376	-58.9428	73.4215
3	22/09/16	377	-58.6163	73.5043
4	22/09/16	516	-58.3327	73.6004
5	22/09/16	484	-58.2269	73.7888
6	23/09/16	354	-58.0823	73.8498
7	23/09/16	405	-58.108	73.8925
8	23/09/16	435	-58.045	74.065
9	23/09/16	461	-57.9398	74.1105
10	23/09/16	335	-59.4014	73.9852
11-repeat	24/09/16	381	-59.5202	73.9184
12	24/09/16	426	-60.0052	73.823
13	24/09/16	358	-60.0651	73.6841
14	24/09/16	345	-60.2812	73.5752
15	24/09/16	492	-61.475	73.5939
16	24/09/16	586	-61.6586	73.7683
17	25/09/16	381	-62.6434	74.3541
18	25/09/16	298	-62.4616	74.5915
19	25/09/16	335	-62.3574	74.6763
20	25/09/16	334	-62.4944	74.7538
21	25/09/16	391	-62.3744	74.8017
22	25/09/16	366	-62.5582	74.8379
23	25/09/16	365	-62.5968	74.8824
24	26/09/16	358	-62.5985	74.9424
25	26/09/16	382	-62.5681	74.9897
26	26/09/16	381	-62.5163	75.0852
27	26/09/16	177	-62.64	75.1053
28	26/09/16	251	-62.5931	75.1732
29	26/09/16	385	-62.649	75.2901
30	26/09/16	381	-62.5238	75.4107
31	26/09/16	319	-63.0428	75.6
32	27/09/16	183	-63.5672	75.4951
33	27/09/16	171	-64.0943	75.4642
34	27/09/16	188	-64.8184	75.4417
36	27/09/16	313	-66.2677	75.3376
37	27/09/16	283	-66.2696	75.2053
38	27/09/16	290	-65.6649	75.185
39	28/09/16	282	-64.9878	75.1349
40	28/09/16	350	-65.4612	75.0266
41	28/09/16	327	-64.8263	74.9713
42	28/09/16	392	-64.9068	74.839
43	28/09/16	275	-64.2931	74.9057
44	28/09/16	194	-63.5704	74.8959
45	28/09/16	378	-64.2179	74.6838
46	29/09/16	343	-63.8959	74.6707
47	29/09/16	402	-63.5442	74.5192
48	29/09/16	503	-61.1267	73.7202
49	29/09/16	443	-60.6779	73.6572
50	29/09/16	407	-60.2905	73.7085
51	30/09/16	252	-59.4314	73.7507
52	30/09/16	156	-58.7391	73.8386
53	30/09/16	297	-58.2831	73.8754
54	30/09/16	509	-58.3021	73.7175
55	30/09/16	379	-58.56	73.5596
56	30/09/16	381	-58.3935	73.7212
57	01/10/16	181	-58.2784	73.4704
58	01/10/16	297	-59.7811	73.4365
59	01/10/16	354	-60.4612	73.5103

Figure 1 A map showing the sites used in this study and the location of the West Greenland shrimp fishery. Source Yesson et al. 2017

Methods

Data Collection

Benthic images were collected during the summer of 2016 during an expedition along the west coast of Greenland between 73°0’N, 57°0’W and 76°0’N, 70°0’W. Images were collected using a drop-down camera at 57 sites in the area. The drop-down camera was attached to a cage and took images of roughly $0.3m^2$. 10 images were taken at each site with a minute drift interval between each image captured. Together with the 10 images, a GoPro camera and torch were attached to the side of the cage to take a continuous video. The video footage was then used to capture 10 images at the same time and location as the drop-down camera but at a different and wider perspective of approximately 3m wide and 5m deep. This was achieved by simultaneously screenshotting the video as soon as the flash from the drop-down camera was viewed. This allowed for larger organisms, that wouldn’t fit under the cage, to be incorporated into the study (Figure 2). Further details on imaging technique are found at Yesson et al. (2015, 2016).

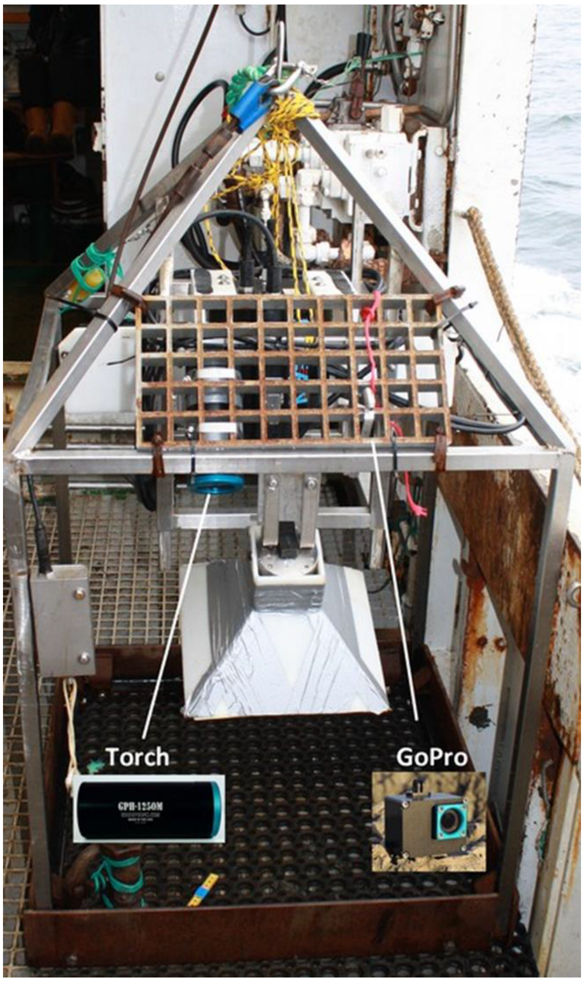


Figure 2 shows the cage used to house the drop-cam, GoPro and torch used to collect images at each site during the 2016 expedition Source: Yesson et al., 2017

Site Selection

The 59 sites were selected to incorporate range of benthic habitat types and variables to allow for the full impact of the trawling on the area to be established.

Depths ranged from 61-725m along the West Greenland Continental Shelf (Figure 1).

Image Analysis

Not all 59 sites produced images useful for analysis. Camera failures and sediment disturbance meant that each site did not produce 10 high quality images and so were excluded from analysis. Torch failures also prevented video footage at several sites. Sites required both good video images and drop-down camera images to be used.

To make the study consistent, a minimum of 5 images were required to include the site in the analysis. For sites with more than 5 images, the total for each taxon was calculated in every possible combination of the 5 or more images, for the video images and seafloor images separately, following the method in Yesson et al 2017. These were then added together for each individual site. Simpson's diversity, Shannon index, species evenness, and total number of taxon classes were calculated using the vegan package in R for different imaging perspectives, separately and together (Oksanen et al 2016).

Models

For this study, I used both linear models and non-metric MDS (multidimensional scaling) to assess the differences between the two imaging techniques.

The linear models measured the diversity (Simpson's diversity) or abundance, the response variables against the independent variables. The latter were trawling impact (measured as trawling distance) and measures of the environment. The environmental variables used were salinity, depth, temperature, sea ice thickness and current speed. Temperatures were measured at the sites of image collection while the other variables were from the TOPAZ4 Arctic Ocean Reanalysis threedimensional oceano-graphic model (http://marine.copernicus.eu/documents/PUM/CMEMS-ARC-PUM-002-ALL.pdf). For this analysis, abundance and current speed were log transformed to make the spread of data normal.

MDS analysis creates metrics of site similarity based on community composition which can be used to visualise similarity between sites. MDS was achieved in R using the vegan package (Oksanen et al 2016). Analysis was performed on the combined dataset of drop-cam and GoPro images to investigate the influence of method on findings.

The salinity, temperature, depth, current speed, sea ice, trawling distance and seafloor class (mud, mud mix, pebble and rubble) were superimposed on top using the envfit function of the vegan package in r. This was to investigate the effect the variables have upon the groupings of sites (Oksanen et al., 2016). The analysis was repeated for the GoPro and drop-cam images separately to compare the groupings of sites for different methods of data collection.

Results

A total of 46 sites of the 59 sites were selected to compare imaging techniques. 13 sites were not included due to poor image quality, lack of images or due to changes in angle and perspective of the GoPro position. A full list of sites used and their individual data is provided in the appendix. 43 different taxa were observed with over 43,000 total observations (combined station average observation). A maximum of 11 taxa were observed at a single site on the GoPro, 29 on the drop-cam and 29, in total, when combined (Table 1). On average, drop-cam images produced higher abundance ratings with a median of 702 vs the GoPro's 36.5 and a total combined figure of 745. The Simpson's diversity index for the GoPro again was lower by a lesser degree at 0.472 vs 0.489 for the drop-cam and combined of 0.504. However, the highest Simpson's diversity figure of 0.822 for any site was found with the GoPro at site 31 containing 10 different taxa.

	GoPro	Drop-cam	Combined
No. of Stations	46	46	46
Abundance			
Min	5	207.5	216.5
Max	503.5	2779	3282
Median	36.5	702	745
Simpson			
Min	0.06	0.115	0.151
Max	0.822	0.763	0.779
Median	0.472	0.489	0.504
Number of Taxa			
Min	3	11	14
Max	11	29	29
Median	5	20	21
Depth (m)			
Min	156	156	
Max	586	586	
Median	365.5	365.5	
Sea ice (m)			
Min	0.531	0.531	
Max	0.635	0.635	
Median	0.6005	0.6005	
Current Speed (m/s)			
Min	0	0	
Max	0.022	0.022	
Median	0.003	0.003	
Trawling Distance (m)			
Min	51.07	51.07	
Max	20545.19	20545.19	
Median	4334.39	4334.39	
Temperature (C˚)			
Min	-0.232	-0.232	
Max	1.100	1.100	
Median	0.732	0.732	
Salinity (g/Kg)			
Min	33.941	33.941	
Max	34.479	34.479	
Median	34.316	34.316	

Table 1 Station summary data showing the maximum, minimum and median of environmental conditions, trawling distance. Calculated in R

Table 2 Taxon summary data of observations for the GoPro, Drop-cam and combined data

	Total observations of taxa			
Taxa	Combined	GoPro	Drop Cam	% GoPro
Annelida	24104	0	24104	0
Anopla	2	0	2	0
Anthozoa	655	234	421	35.7
Arthropoda	11.5	0	11.5	0
Ascidiacea	2662.5	66.5	2596	2.5
Asteroidea	57	12	45	21.1
Bivalvia	754.5	0	754.5	0
Brachiopoda	0	0	0	0
Bryozoa	217.5	93	124.5	42.8
Bryozoa.encrusting	549	248.5	300.5	45.3
Bryozoa erect	462.5	0	462.5	0
Bryozoan soft	420	1	419	0.2
Cephalopoda	1	0	1	0
Chaetognatha	3	0	3	0
Cnidaria.indet	54.5	0	54.5	0
Crinoidea	6.5	1.5	5	23.1
Echinoidea	4.5	4	0.5	88.9
Ctenophora	46.5	0	46.5	0
Elasmobranchii	7	0	7	0
Enopla	4	0	4	0
Foraminifera	220.5	0	220.5	0
Gastropoda	233.5	17	216.5	7.3
Holothuroidea	159	1	158	0.6
Hydrozoa	641.5	15.5	626	2.4
Malacostraca	567	208	359	36.7
Maxillopoda	73.5	0	73.5	0
Mollusca	99.5	0	99.5	0
Nemertea	11.5	0	11.5	0
Ophiuroidea	10174	1919.5	8254.5	18.9
Perciformes	10	9	1	90
Poecilosclerida	1	0	1	0
Polychaeta	791.5	725.5	66	91.7
Polyplacophora	3.5	0	3.5	0
Porifera	1162.5	143.5	1306	11.0
Porifera.encrusting	46	1	47	0
Porifera.massive	11.5	0	11.5	8
Pycnogonida	8	0	8	8.0
Rhynchonellata	14.5	0	14.5	0
Scaphopoda	24.5	0	24.5	0
Scyphozoa	4.5	0	4.5	0
Spinulosida	4.5	0	4.5	0
Suberitida	11	0	11	0
Thaliacea	25.5	0	25.5	0

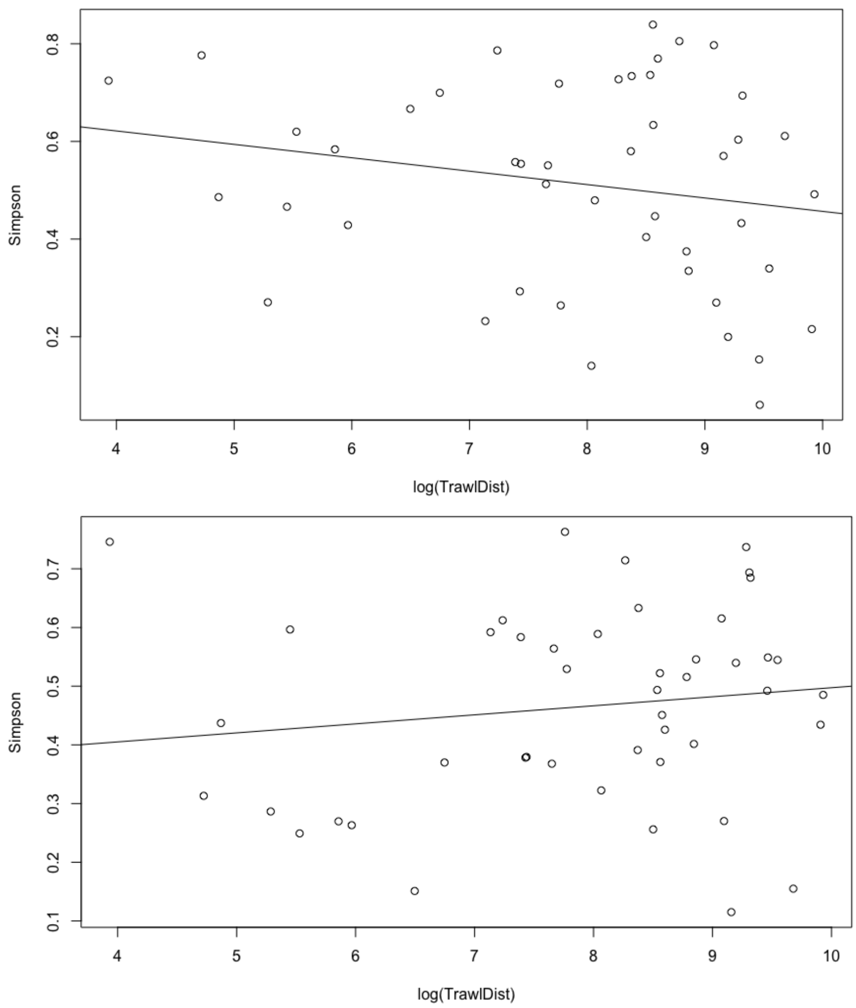


Figure 3 Univariate linear models for Simpson's diversity ~ logged trawling distance for both drop-cam data (bottom) and GoPro data (top). Produced using R with Lm function.

Linear models describing the influence of the environmental variables on diversity produced consistently negative and insignificant results so were excluded from further analysis. It should be noted that in scatterplots of univariate linear models of Simpson's diversity ~ trawling distance, the GoPro data showed negative relationship and the drop-cam data showed positive (Figure 3). In Abundance ~ environmental variables/trawling distance both the drop-cam and GoPro models showed similar relationships for each variable.

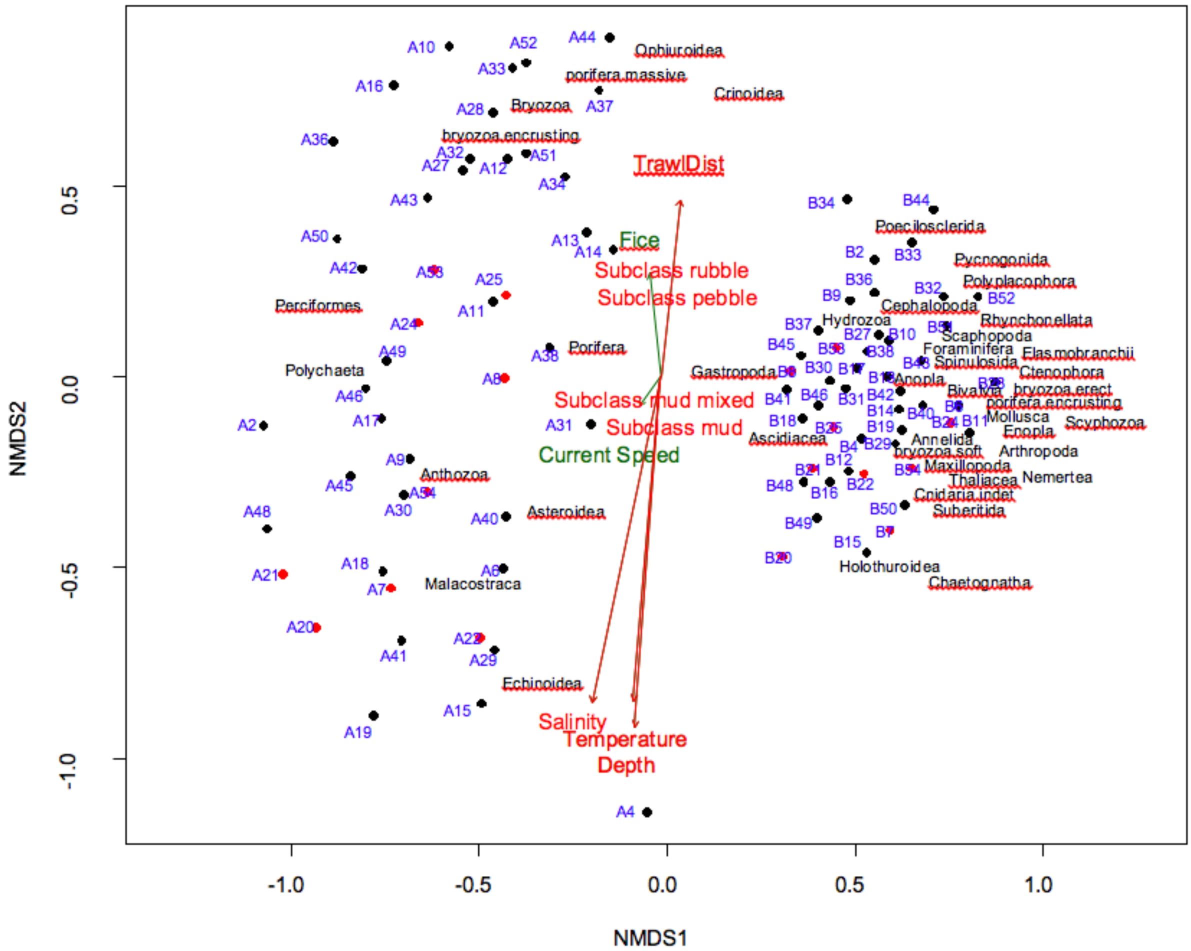


Figure 4 A multidimensional scaling plot using taxa abundancies as Axis 1 plotting GoPro data as A sites and Drop-cam data as B sites. Red sites were heavily fished sites. Environmental variables and trawling distance were plotted using envfit function. Red arrows were the environmental variables that were significant for site abundancies. Produced using vegan package in R (Oksanen et al 2016).

For the combined data (GoPro + Drop Cam) the most abundant taxa were Annelida with 24,104 observations (0% from GoPro), followed by Ophiuroidea at 10,174, (18.9% from GoPro), Ascidiacea 2,662.5 (2.5% from GoPro), and Porifera at 1,162.5, (11% GoPro). Almost all taxa had higher observations with the drop-cam with only Perciformes (90% GoPro), Polychaete (91.7% GoPro), and Echinoidea (88.9% GoPro), having higher observations with the GoPro.

The MDS models looked at similarities between sites based on abundances of species at the sites and environmental variables. Red sites were considered heavily fished while black were not. Two distinct groupings occurred, separating the GoPro data and the drop-cam data, indicating that observation method is the most important factor determining observed community composition.

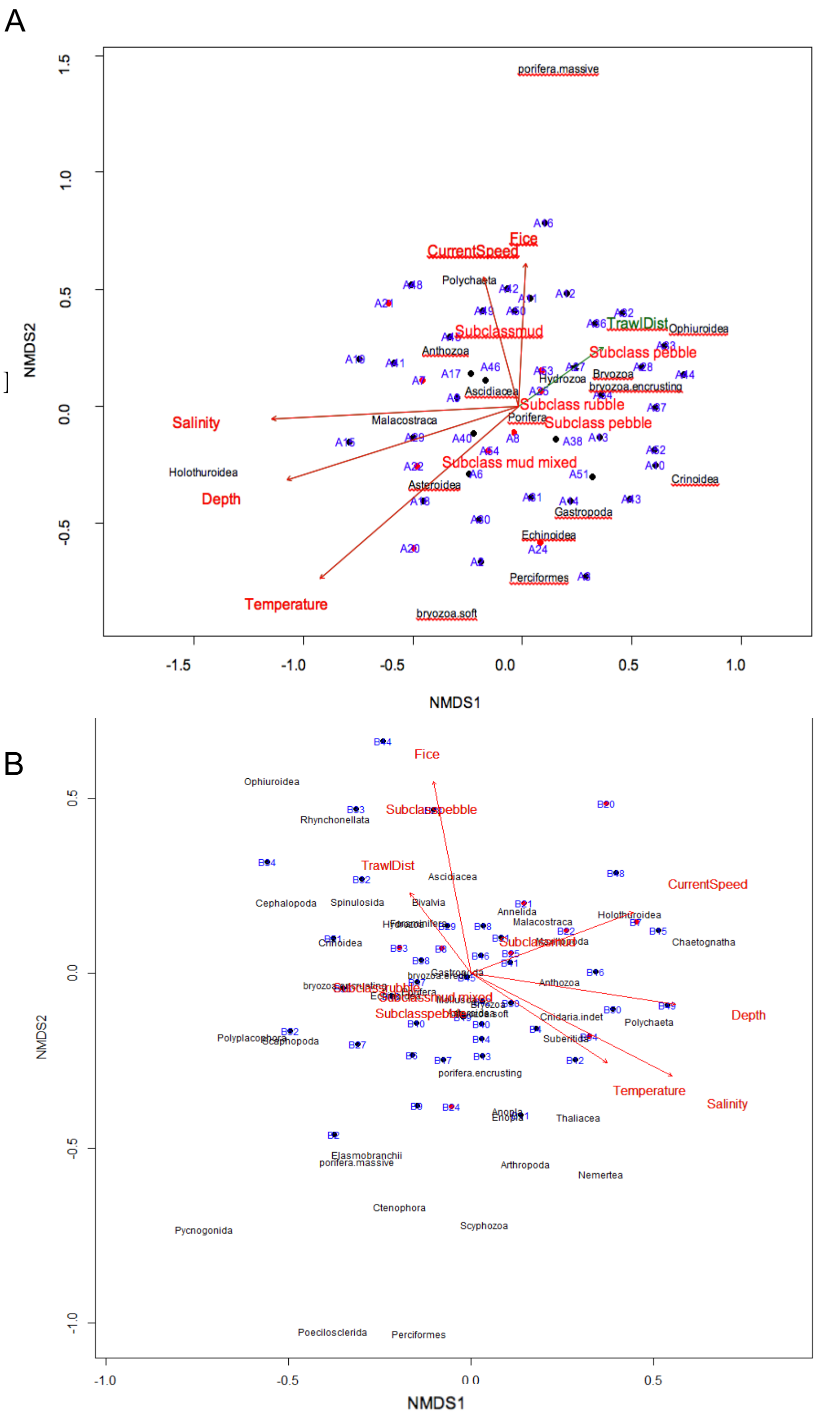


Figure 5 shows drop-cam (A) and GoPro (B) data separated into two MDS plots with taxa abundances as Axis 1 and environmental variables superimposed on top using envfit function. Red sites are the sites considered heavily fished. Red arrows represent the environmental variables that were significant for site abundancy. Produced using vegan package (Oksanen et al 2016).

The analysis was also run for the two groups separately to see, within these groups, if there were any similarities between sites. Both sets of data showed no obvious groupings but did show the variables are more significant in the arrangement of sites on the plot. Salinity, depth and temperature are significant influencers of community composition in both groups with current speed being significant (P>0.005) in the drop-cam data. Notably, environmental factors have a greater influence than

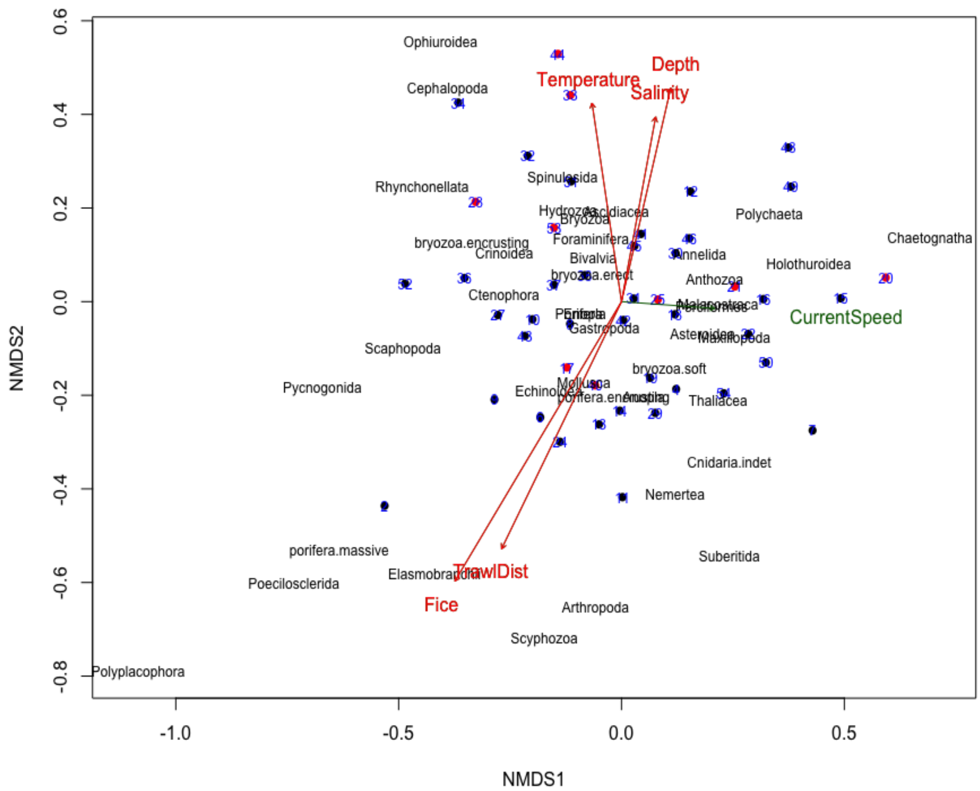


Figure 6 A multidimensional scaling plot using taxa abundance as Axis 1 (NMDS1) plotting GoPro data and drop-cam for each individual site total taxa abundance. Red sites were heavily fished sites. Environmental variables and trawling distance were plotted as variable axis using envifit function. Red arrows was the environmental variables that were significant in site abundance. Produced using vegan package (Oksanen et al 2016).

trawling, and there is no significant influence of trawling on the composition based on GoPro images.

A MDS plot was created with the GoPro and drop-cam data combined into single sites rather than 2 separate groups. This analysis highlighted trawling distance (TrawlDist) and sea ice (Fice) as significant factors (P>0.05) as well as temperature salinity and depth having some significance in the arrangement of sites based on taxa abundance.

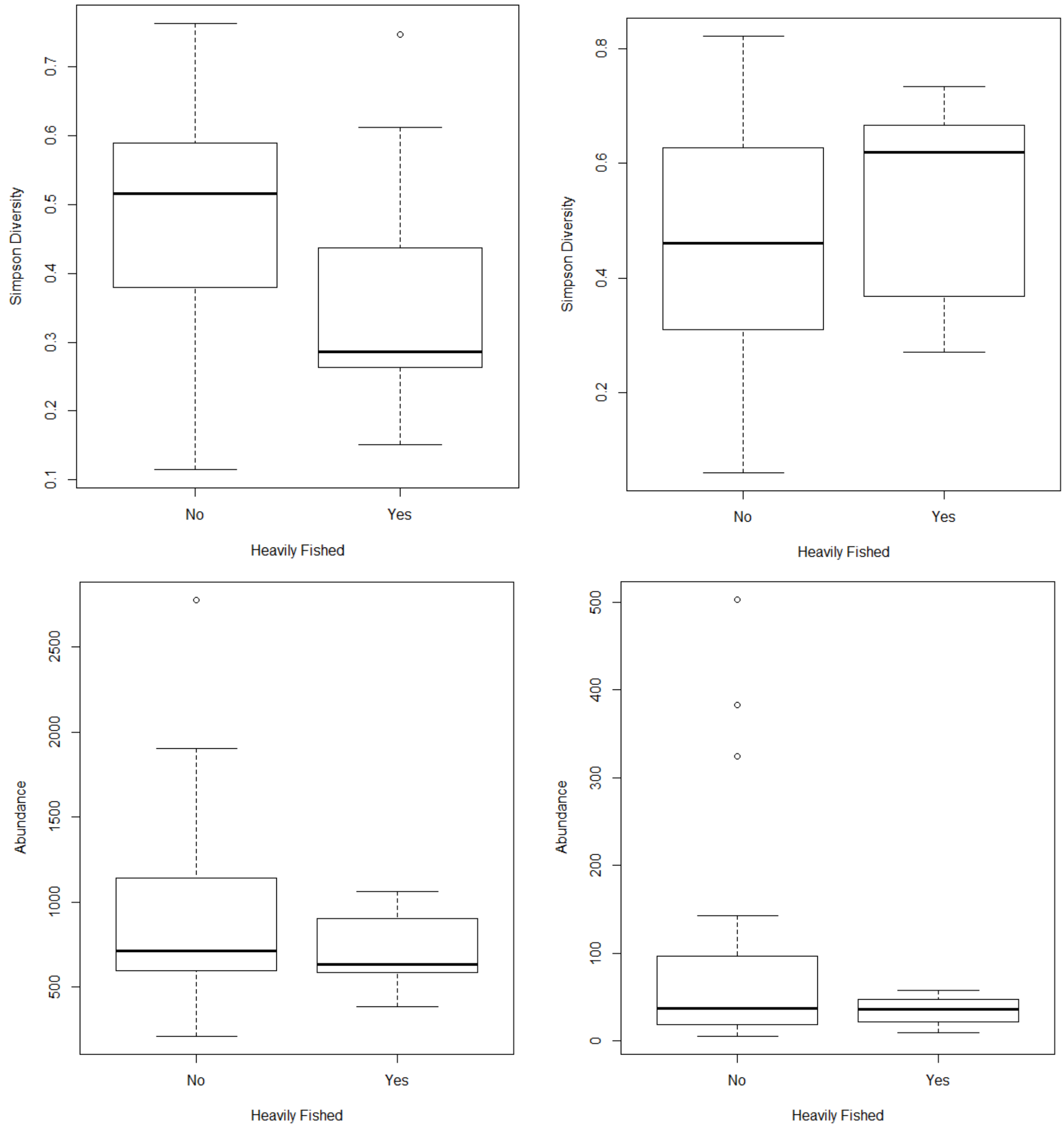


Figure 7 Box and whisker plots for drop-cam (left) and GoPro (right) for both Simpson's diversity and taxa abundance against heavily fished and regular sites. 9 sites were considered as heavily fished and 37 were considered regular sites.

Of the 46 sites 9 were considered heavily fished sites. These were sites, 7, 8, 20, 21, 22, 24, 25, 53 and 54 (Figure 1). The drop-cam data showed these sites as having lower taxa abundance and diversity, while the GoPro data showed higher taxa diversity and similar taxa abundance. Drop-cam data had a wider spread of data compared to the GoPro data and fewer outliers indicating more variability within this data set. Heavily fished sites also had very narrow spreads especially in the GoPro data.

GoPro Drop-cam

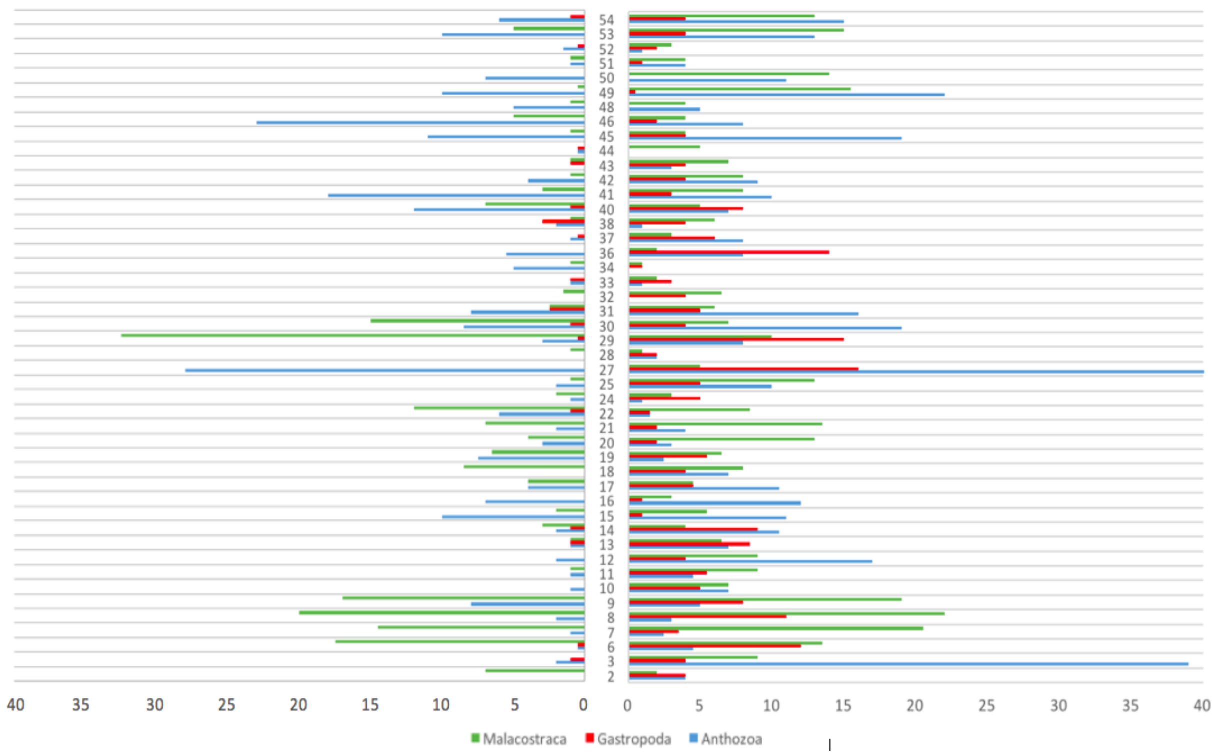


Figure 8 Stacked bar chart showing the abundancies of 3 taxa, Malacostra, in green, Gastropoda red and Anthozoa in blue at each site.

A few taxa were selected for further analysis into the number of observations made between GoPro and drop-cam imaging techniques. Malacostraca (including shrimp and crabs), Gastropoda (snails) and Anthozoa (including corals) were selected as they were found in both sets of images at most sites. At heavily fished sites 7, 8, 20, 21, 22, 24, and 25 there are peaks in Malacostraca and lower levels of larger taxa found in the Anthozoa family.

Discussion

The methods of imaging West Greenland benthic communities on the seafloor based on drop-cam images run the risk of excluding larger and/or more mobile organisms (Yesson et al., 2016). The method of using a drop-cam provides a standardised view of slow-moving and smaller organisms on the seafloor but data from past studies do not accurately reflect numbers of larger organisms in taxa such as Asteroidea (starfish), Malacostraca (including shrimp) and Perciformes. For example, *Umbellula* (the sea flower) of Anthozoa is a large (1-2m) seapen that is vulnerable to trawling (Øseth, Jørgensen, Renaud, & Andrade, 2016). This was only seen once in the drop-cam images (as a bent stem), but it appeared multiple times in the GoPro images. It remains unclear whether a drop–cam accurately shows the impacts of trawling in the west Greenland shrimp fishery on the larger and potentially most vulnerable benthic communities. New imaging technologies such as GoPros could provide cheaper and quicker methods of analysing these communities so vital to Greenland's export of shrimp and its main source of income (Statistics Greenland, Statistics for 2011).

Sampling Bias

The data collected showed a significant difference in the observed community composition based on the method of observation.
In this study, I compared the number of observations of species between two methods of imaging using a drop-cam and a GoPro. The images for both were taken at the same time but from different perspectives. I used multidimensional scaling models to highlight similarities between the sites with both types of image based on taxa abundance data at each site. My findings showed two clear groupings separating the GoPro images and drop-cam images on the MDS plot. We observed more taxa in the drop-cam compared to the GoPro. This was created by a sampling bias between the two methods (Table 1, Table 2). It was not random to find smaller taxa with the drop-cam and larger taxa with the GoPro. This is partly due to the

GoPro failing to pick up smaller organisms. So, despite some sites having high abundances of these taxa it did not reflect the true abundance. Similar problems were observed in a study on deep water corals in a gully off Canada which recorded a distinct lack of smaller coral species. (Mortensen & Buhl-Mortensen, 2005). Higher resolution images could reduce this bias by identifying smaller species in the same images (Lirman et al., 2007). My results highlight that the Yesson et al. (2017) study could be missing important data by using the drop camera alone, particularly for Atseroidea, Malacostraca, Perciformes, Antrozao and Polychaete. Many sites showed higher readings for the GoPro data which results from capturing the larger sessile organisms in Anthozoa and the faster organisms such as shrimp in Malacostraca: these are less frequently caught by the drop-cam. Increasingly, video transects are being used to assess larger organisms like fish, coral reefs and for benthic mapping (Kendall et al., 2005; Langlois et al., 2010; Pelletier, Leleu, Mou-Tham, Guillemot, & Chabanet, 2011). The GoPro captures a much wider area increasing its potential to capture more organisms in a single image but creates a bias for larger organisms. These are easier to spot, from a distance, compared to microfauna. However, this bias could be useful for Greenland as the GoPro can effectively assess the shrimp populations and their shift northwards due to climate change and particularly following recent declines in Southwest Greenland waters (Hamilton et al., 2003; Wieland & Hovgård, 2009).

Holistic Approach

Combining the results of multiple observations with an angled GoPro and drop-cam provided a more holistic view of the seabed habitats than previous methods (Lirman et al., 2007; Chris Yesson et al., 2017). A GoPro alone is not more effective for studies of benthic communities as several smaller species were not picked up (i.e. they are there but cannot be seen) by the GoPro. However, Yesson et al. (2017) failed to capture (i.e. there but too big to fit under the cage) larger species such as *Umbellula*, the seapen, with just the drop-cam. These live for decades but are frequently caught by otter trawls (Jørgensen, Planque, Thangstad, & Certain, 2016; Neves, Edinger, Layne, & Wareham, 2015). Accordingly, each method could compensate for the deficiency of the other. Combining the data sets of the GoPro and drop-cam for each site provided more significant results than the data sets did separately. These results were more in line with expectations showing the significant influence of trawling distance and sea ice cover on taxa abundance. This supports Yesson et al. (2017), who determined trawling distance as a determining factor in the overall abundance of benthic habitats. Other studies suggest only intensely fished areas will show lower diversity but these were researched in different regions and are less recent (Jennings & Cotter, 1999). Based on this data, I suggest, when looking at trends in site abundances of organisms, it is better to use the GoPro and drop-cam data combined. It is more likely to give an accurate representation of abundances and diversity of organisms together with any negative impacts that activities such as trawling have upon the benthic habitats.

Trawling Effects

Trawling intensity already accounts for 12-16% of overall variance in abundance for benthic habitats at the same sites used in this study (Yesson et al., 2016, 2017). The division of the points in Figure 4 was not due to the environmental variables or trawling intensity indicating that the different imaging method has produced different information on taxa abundances. Larger and more mobile organisms such as Perciformes, Malacostraca and Aesteoridea, were more likely to be found using the GoPro. The current literature shows these larger organisms (excluding Malacostraca) are those most affected by trawling and lead to changes in species composition due to the disturbance associated with trawling (Simon, 2013; Van Dolah et al., 1991; Chris Yesson et al., 2017). This does not include Perciformes just the larger and more sessile fauna. As the overall abundance of the larger and more sessile fauna falls, the abundance of opportunistic species like brittle stars and pioneer species increase after trawling. In the long term, even their abundance decreases as does overall animal biomass (Hansson, Lindegarth, Valentinsson, & Ulmestrand, 2000). As mentioned above, the GoPro fails to accurately pick out smaller organisms at the angle in this study. GoPros are more suited for continuous video feeds which are useful for line transects (Langlois et al., 2010; Pelletier et al., 2011). This offers an alternative method to measure benthic habitat, health, diversity and abundance. Video transect have already been used to study continental shelf reefs and habitats (Richmond & Stevens, 2014). The GoPro does capture the larger and faster organisms, the Malacostraca and Perciformes, but also the larger sessile slower organisms, the Bryozoa, Porifera massive, and Anthozoa, sea anemone and stony corals. These cannot always physically fit under the cage used for the drop-cam. Many of these are ecosystem engineers (Clark et al., 2016; Pusceddu et al., 2014). The GoPro is more useful as a tool to help study how the abundances of larger organisms are affected by trawling these areas. Video causes no disturbance to habitats when compared to drop-cams. The latter do cause disturbance albeit minimal (Mallet & Pelletier, 2014).

The taxa identified in both imaging methods some show similar trends e.g Anthozoa (Figure 8). This is where the GoPro becomes more useful it provides a quicker alternative to previous methods of analysis of megafauna in sites impacted by trawling. From a wider perspective, the images contain less viewable smaller species but a larger area than that covered by a drop-cam. It captures more of the habitat in one image. This method is also quicker because manually counting megafauna is more efficient than counting 100s of micro fauna. If the easy-to-view species in the GoPro images show the same trends as other taxa found in the drop-cam, they could be used as indicators of the effects of trawling on the health of the habitat (Collie, Escanero, & Valentine, 2000; Magni, 2003). Using video recordings, soft and stony corals found in Anthozoa taxa have already been shown to have a strong positive correlation with the total number of megafauna and microfauna in deep sea benthic communities off Nova Scotia (Mortensen & Buhl-Mortensen, 2005). Similar studies found consistencies between abundances in images and video methods. Even though the images, again, made smaller species viewable, the video showed the same trends. (Collie et al., 2000). These studies support this study, which proposes using a GoPro and video recordings is an alternative and effective way of monitoring damage done to benthic macrofauna from trawling.

Of the 46 sites used, 9 were considered heavily fished from trawling prior to data collection. The abundances and diversity for the drop-cam sites and abundance for GoPro sites showed similar trends with heavily fished sites showing lower abundances (Figure 6). This is due to otter trawling having an overall negative impact upon the diversity of areas affected. The process kills or removes sessile organisms from chains scraping the seafloor surface sediments (Hansson et al., 2000; Simon, 2013; Van Dolah et al., 1991; Chris Yesson et al., 2017). Although, disturbance is a natural process, an increase in the level of disturbance prevents habitats aging with properly developed macrofauna and so has a knock-on effect with species that use the macrofauna for shelter or food (Gutt et al., 1996). This is made worse by the continuing increase in sea temperatures leading to increased iceberg calving from Greenland's glaciers with a corresponding increase of iceberg scouring causing further disturbance (Barnes, 2017). Interestingly, the Simpson's diversity for the GoPro data, on average, increased with the heavily fished sites. This contradicts what we would expect to occur with diversity decreasing. The increase in decaying matter and open space immediately following disturbance can cause an influx of pioneer species and scavenger species such as in the Malacostraca class (De Juan, Thrush, & Demestre, 2007). This was found at several heavily fished sites in this study. There were higher numbers of Malacostraca and lower levels of large taxa of Anthozoa at several heavily fished sites. As already described, these larger taxa are those heavily affected by trawling (Hansson et al., 2000; Simon, 2013; Van Dolah et al., 1991; Chris Yesson et al., 2017).

Limitations and Future Studies

The GoPro footage in this study was unsuitable for studying microfauna and all smaller organisms. Many organisms are missed altogether from the GoPro or captured in very low numbers such as in Gastropoda, Annelida and Mollusca. This has been observed in other studies (Mortensen & Buhl-Mortensen, 2005). A further limitation is that the GoPro was difficult to standardise because the setup of the camera was sub-optimal. This resulted in partial visual obstructions in nearly all images with an inconsistent camera placement leading to changes in camera angle between sites. Several of the later sites had to be excluded from the analysis because the camera angle had changed significantly and presented a much wider view of the sea bed. This lead to much higher number of observations found on these sites and so would have lead to higher species abundance and diversity if included. Development of a consistent imaging method is required to allow for robust analysis as has been completed for other methods of seabed analysis using video (E. Brown et al., 2004).

Past studies have found video and images can be consistent in their species data (Collie et al., 2000). Several species were much easier to identify than others leading to either higher readings or wrong classifications. For example, shrimps were particularly easy to spot due to eye shine while Bryozoan and Porifera were easily confused the further from the camera they were. With my study and the previous study it was based on, it was difficult to identify the organisms to a species level with images alone (Yesson et al., 2017). This restricts the analysis as it can be difficult to accurately assess the species diversity of the benthic habitats (Langlois et al., 2010; Lirman et al., 2007). Collecting samples would improve this restriction but may also damage the communities being studied and could be completely unnecessary when the state of the habitat can be monitored using a higher taxon level. Impacts of trawling are also difficult to quantify as benthic ecosystems are extremely complex with large variations in conditions (Yesson et al., 2015).

This study also lacked heavily fished sites with only 9 of 46 being considered heavily fished from trawling. The data used only reflect 1 ½ years of the entire study area so may not reflect the true trawling effort in the region. With more heavily fished sites (for this study), it would be easier to convey a more complete picture of the negative effects on macrofauna and habitat quality which previous studies (not capturing larger organisms) could be missing.

For future studies, I recommend developing a standardized method for using a GoPro to capture images of benthic habitats, particularly stating the best angle and positioning for the camera. Although this study didn’t fully show the negative effects trawling has upon larger organisms, other studies have shown the reduction in larger organisms and the sometimes increase in opportunistic species (Gutt et al., 1996, Yesson et al., 2016, 2017). Studies have used video footage similar to the GoPro footage in studies of deep water corals so is likely to work in subarctic and arctic deep water coral systems. (Mortensen & Buhl-Mortensen, 2005). This could be extended to monitor movement of species or habitats north as the temperatures in the region continue to rise.

Conclusions

The positioning of cameras for seabed imaging and analysis was a vital component of the survey. Close-up cameras, such as drop-cams, are good for standardized imaging and studying microfauna abundance but miss larger taxa. Angled videos at higher elevations provided a wider perspective more useful for assessing the larger, potentially more vulnerable, taxa.

A more holistic approach to studying benthic habitats would use a combination of drop-cam and higher elevation angled video to capture both micro and macrofauna. However, to study the quality of benthic habitats more efficiently and economically, wider-angled images are better for studying abundances of macrofauna such as Anthozoa (including corals). These have proven useful as indicators of benthic habitat health and identified similar trends in abundance for sites in both data sets. It offers a viable alternative to previous methods. Although useful for studying macrofauna, the GoPro struggled to pick up microfauna and is best suited to a continuous video feed of a line transect. Further studies into the effects of trawling using a standardized GoPro method would be needed to assess its effectiveness as a tool for benthic habitat monitoring.

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Appendix

R Scripts

Aggregate Stations

```
d<-read.csv("ImageDataByClass.csv")
d<-read.csv("ImageDataByPhylum.csv")
names(d)[1]<-"Image"

# find station number
d$Station<-substr(d$Image,1,6)

# unique list of stations
st.list<-unique(d$Station)

# placeholder output based on median values
d.st<-aggregate(d[,2:(ncol(d)-1)],list(d$Station),FUN=median)
```

```
names(d.st)[1]<-"Station"

# loop through stations, finding mean value
for(st in st.list){
   # find all images for that station
   dst<-d[d$Station==st,]
   # find all unique combinations of 5 images from this set
   uc<-combn(1:nrow(dst),5)

   dj<-dst[uc[,1],]
   dst.reps<-aggregate(dj[,2:(ncol(d)-1)],list(rep(1,5)),FUN=sum)

   if(ncol(uc)>1){
      # find median values for each combo
      for(j in 2:ncol(uc)){
         dj<-dst[uc[,j],]
         dj.agg<-aggregate(dj[,2:(ncol(d)-1)],list(rep(1,5)),FUN=sum)
         dst.reps<-rbind(dst.reps,dj.agg)
      }
   }

   # find median
   dst.med<-apply(dst.reps,2,FUN=median)

   # write into station data
   d.st[d.st$Station==st,][,2:ncol(d.st)]<-dst.med[2:length(dst.med)]
}

# write data to station level data file
# write.csv(d.st,"StationByClass.csv",row.names=F)
write.csv(d.st,"StationByPhylum.csv",row.names=F)
```

Aggregate Taxa

```
# read image data
d<-read.csv("PoseidonProcessed20161114.csv")

# read taxon mapping table
t<-read.csv("WormsClassification.csv")

# transpose table
dt<-t(d[,2:ncol(d)])
# column names are images
colnames(dt)<-d$Image
dt<-as.data.frame(dt)



# fill final taxon names into new column
dt$Taxa<-as.character(t$FinalName[match(gsub('\\.','
',rownames(dt)),as.character(t$Orig))])

# aggregate by final taxon name
dt.agg<-aggregate(dt[,1:(ncol(dt)-1)],list(dt$Taxa),FUN=sum)

# transpose and assign taxon names as columns
d.agg<-t(dt.agg[,2:ncol(dt.agg)])
colnames(d.agg)<-dt.agg$Group.1

write.csv(d.agg,"ImageDataByClass.csv",row.names=T)
```

Create Poseidon Table

```
# Take Poseidon data export and create a table of image x taxa

# Input data exported from Poseidon
```

```
f<-"allImages.csv"
o<-
paste("PoseidonProcessed",as.character(Sys.Date(),format="%Y%m%d"),".csv",sep
="")

# read file
d<-read.csv(f,header=F)

# find stations
station.list<-as.character(d[,2][d[,1]=="Image"])
"Image Properties"

# add line to end of data
d<-rbind(d,c("Image Properties",""))

# list of taxa to search for
# generate list of taxa from all stations (excl last one)
taxon.list<-c("ophiuroidea") # seed list
for(i in 1:(length(station.list))){
   start<-which(d[,1]=="Tag")[i]+1
   end<-which(d[,1]=="Image Properties")[i+1]-1
   taxon.list<-c(taxon.list,str_trim(as.character(d[start:end,1])))
}
taxon.list<-unique(taxon.list)

# output data frame
output<-data.frame(Image=station.list)


# loop through taxa - extract data
for(t in taxon.list){
   # set up black column for this taxon
```

```
    output[[t]]<-rep(0,nrow(output))
}

# loop through images
for(st in 1:nrow(output)){
    print(st)
    # find start and end of station
    start<-which(d[,1]=="Tag")[st]+1
    end<-which(d[,1]=="Image Properties")[st+1]-1
    dst<-d[start:end,]
    # fetch taxon names
    tn<-str_trim(as.character(d[start:end,1]))
    for(t in tn){
        v<-as.numeric(as.character(dst[,2][str_trim(as.character(dst[,1]))==t]))
        if(length(v)>0){
            output[[t]][st]<-sum(v)
        }
    }
}

# write table output to csv
write.csv(output,o,row.names=F)
```

Linear Models (example)

```
# read in data
d<-read.delim("GoProsummarydata.txt")

## check data is normally distributed

# histogram of trawling effort
hist(d$TrawlDist)
# looks left skewed - try log transformation
```

```
hist(log(d$TrawlMins+1))
# too much transformation! try square root instead
hist(d$TrawlMins^0.5)

# can do a formal test on this
shapiro.test(d$TrawlMins) # p<<0.001
shapiro.test(d$TrawlMins) # p>0.001 not bad will have to do

#  set up new variable for transformed fishing effort
d$Fishing<-d$TrawlMins^0.5

# look at diversity vs some factors
# start with a simple regression
dMD.lm<-lm(log(Abundance)~Depth, data=d)
# scatter plot of diversity and fishing effort
plot(log(Abundance)~Depth, data=d)
# plot regression line
abline(dMD.lm)

plot(lm(log(Abundance)~Depth, data=d))
 summary(dMD.lm)
```

MDS Plot (example)

```
# read in the data
# species by site
d.sp<-read.csv("StationByClassMyData1.csv",row.names=1)

# environment by site
d.env<-read.csv("GoProsummary.csv",row.names=1)

# r package for analysis
```

```
require(vegan)
 (d.sp.MDS<-metaMDS(d.sp,trymax=100))
# plot ordination on main 2 axes
plot(d.sp.MDS, type="n")
points(d.sp.MDS, col=d.env$HeavilyFished, display="sites",pch=16,cex=1)
# add site names

text(d.sp.MDS, display="sites",col="blue",cex=0.75,)
# add species
text(d.sp.MDS, display="species",cex=0.75)

# try using the envfit proc to add in environment
env.fit <- envfit(d.sp.MDS, d.env[c("Depth","Fice","CurrentSpeed", "TrawlDist",
"Temperature","Salinity", "Subclass")],na.rm = TRUE, perm = 999)

# look at results - take note of p-values
env.fit
# add to the plot
plot(env.fit,col="darkgreen")
# put significant factors in red (choose a good significance value)
plot(env.fit, p.max = 0.5, col = "red")
```

Class Data
https://www.dropbox.com/s/uqj3cv4yl0v7oqz/combinedclassdata.csv?dl=0
Station Summary Data
https://www.dropbox.com/s/ssazq3vq97vb2sj/comparesummarydata.csv?dl=0