Appendix: MSc thesis

The effects of shrimp trawling on the macrobenthic fauna of West Greenland

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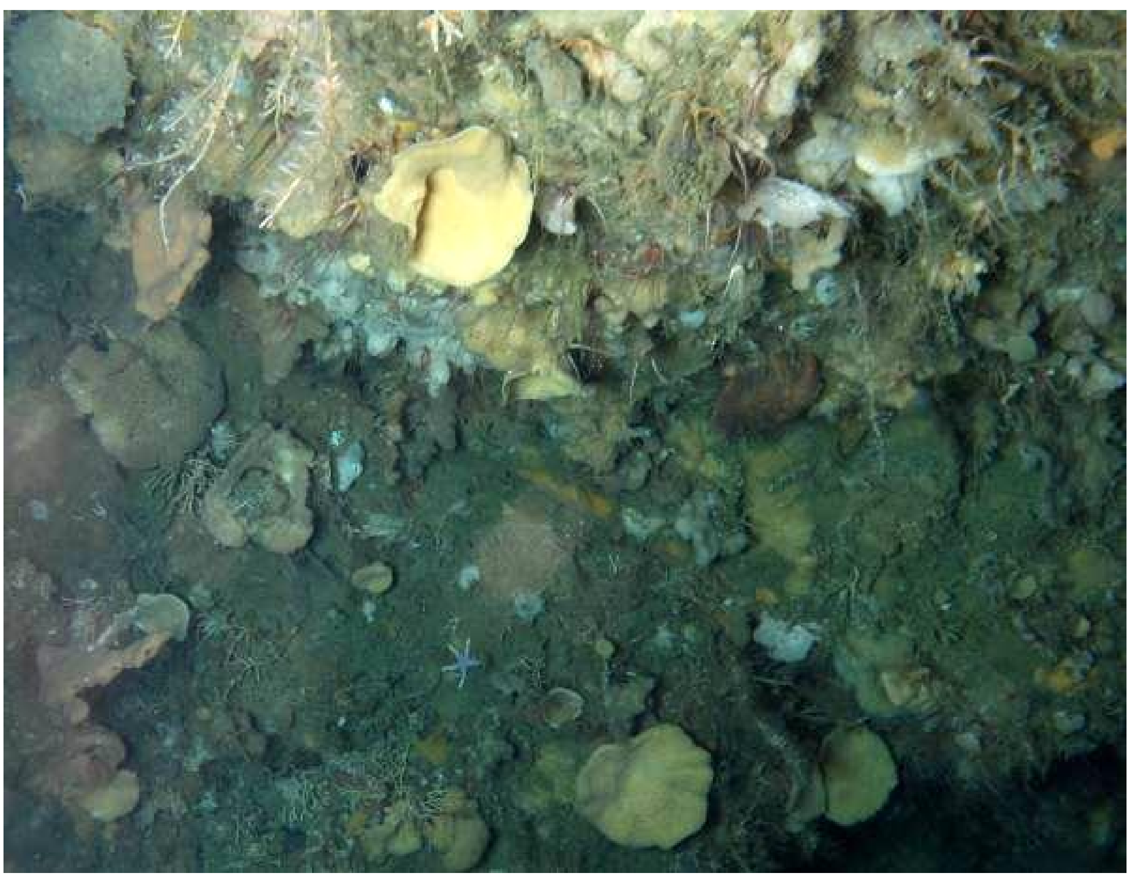
BIOLM005 MSci Research Project in Biological Sciences



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ABSTRACT

The effect of shrimp trawling on the macrobenthic community of the west Greenland continental shelf was investigated using photographs of the benthos to measure a number of community indicators. By counting the number and type of organisms in each image at stations subject to range of fishing intensity, diversity of different areas could be calculated. Organisms were hard to identify on the basis of images alone and also because of the lack of research in this area. Substrate, depth and geographic position were included as covariates in the analysis. There was a significant negative correlation between fishing intensity and biodiversity on the mixed mud substrate but not on other substrates. There was also a significant negative correlation between fishing intensity and the number of stylasterids (Hexacorallia) on the mixed mud substrate. This idea is supported by the fact that the mud substrate, which is the most simple, had the lowest diversity range regardless of fishing level. Data collection in future years should increase statistical power, particularly for the pebble substrate, and will allow the progression of particular areas to be studied. It will also give more meaningful results with regards to the effect of trawling on different substrates. Further research should include genetic analysis of bycatch samples, to help with identification of organisms, and could focus more on how long it takes for a fished area to recover once fishing stops.

INTRODUCTION

West Greenland shrimp fishery

The cold seas of the Arctic and sub-Arctic are productive and nutrient-rich and have contributed a high density of organisms to the many fisheries found there. There are both pelagic fisheries, for mobile fish such as cod, and bottom fisheries for epifauna and infauna, like shrimp and scallops. There is a long history in Greenland, particularly in the area of interest off the west coast, of fishing for the northern shrimp/coldwater prawn, *Pandalus borealis*. It has been the primary marine resource since the collapse of the cod, halibut and redfish fisheries in the 1960s, but the first shrimp fishery was started in western Greenland in 1935, more specifically after the collapse of the halibut fishery (Guijarro Garcia *et al*. 2006a). The fishery then expanded, particularly with the development of freezing and canning. Since 1970, the offshore West Greenland fishery has made up most of the Greenland catch (Guijarro Garcia *et al*. 2006a).

Shrimp fishing is a type of trawling, and in general there are two types of trawl used: beam trawls and otter trawls. In the West Greenland fishery, otter trawls are used, where the fishing vessel drags behind it a cone-shaped net, the mouth of which is kept open by otter boards (Marine Stewardship Council). Beam trawls use a heavy beam and may also have tickler chains attached, which are heavy chains that stir up the mud or sand in front of the net to dislodge the fish. Both methods have immediate and long-term negative ecosystem effects.

Impact of trawling on the benthos

The immediate effects include destruction of biogenic three-dimensional structures (such as corals) and both direct and indirect death of organisms. The direct effect of fishing is death of organisms caused by fishing gear. Indirect death on the other hand is that after contact with the fishing gear, for example, because of increased vulnerability to predators, as in scallops (Veale *et al*. 2000a), or is caused by changes in habitat (Guijarro Garcia *et al*. 2006a).

Direct death of an organism includes not just that of the target organism but also other ‘undesirable’ species caught by unselective fishing gear, called by-catch. Most of the global by-catch is associated with shrimp trawling, with other types of bottom trawl taking second place (Alverson *et al*. 1994). Shrimp trawling is particularly associated with by-catch of juvenile fish, which is detrimental not only to the ecosystem but also to other fishing industries, particularly cod.

As well as the immediate effects, trawling (and dredging) can also have long-lasting damaging impacts, causing decreases in biodiversity and species richness and overall number of organisms. A decrease in the abundance of organisms is obvious when direct and indirect mortality is considered, but the other two consequences are a little more complicated. They relate to differences in mortality in different organisms because of different morphologies and habitat niches, and on different substrates. Different organisms are more or less vulnerable to damage from fishing gear: on the whole, organisms with a hard exoskeleton or shell(s) are less affected by impact from fishing gear than fragile (Hall-Spencer *et al*. 2002) or soft-bodied organisms. In addition, sessile fauna are more vulnerable than infaunal or mobile (Eleftheriou & Robertson 1992; Kaiser *et al*. 2000; McConnaughey *et al*. 2000), to an extent suspension feeders more than scavengers, and benthic macrofauna on moving sand substrates are more resilient than those on gravel or rubble substrates (Eleftheriou & Robertson 1992).

This differential survival from a fishing event leads to changes in the structure of the benthic ecosystem, because it wipes out certain groups of organisms. This immediately reduces richness (the number of different species or taxa), and diversity. Biodiversity is usually measured as a function of richness and evenness, which is the distribution of organisms across the taxa. The reduction in richness can cause particular species that do survive to dominate (often overwhelmingly), as they are able to fill the ecological niche of organisms lost, and because pressures on resources such as food or shelter may be lifted. This then decreases evenness because the abundance of organisms is not spread evenly across the taxa.

In a study of the effects of scallop dredging, observations that species diversity and richness, and number of species and individuals decrease significantly with an increase in fishing effort were thought to be a result of homogenisation of the habitat (the substratum) (Veale *et al*. 2000b), which is one of the most important long-term effects of trawling (Thrush & Dayton 2002). Homogenisation of the substratum refers to the loss of three-dimensionality, i.e. the loss of biogenic structures that create a complex topography. This complex topography is of particular significance in this study because it is both linked to a high level of biodiversity (cold-water coral gardens play a similar ecosystem role to coral reefs in shallow tropical waters) and is thought to be particularly at risk from trawling. Biogenic 3D structures in this area are cold-water corals, which do not form the reefs of their tropical counterparts but similarly act as refugia for other organisms. In particular, reefs have been found to protect juvenile fish from predation, including the larvae of the commercially valuable redfish (Baillon *et al*. 2012).

Cold-water corals are even more fragile to physical disturbance than tropical shallow water corals because in the deep waters they inhabit, photosynthesis is impossible so they are not strengthened in the same way by the calcareous photosynthetic zooxanthellae (Hall-Spencer *et al*. 2002). Furthermore, shallow water corals have evolved to cope with wave action, whereas in deeper waters there is little natural disturbance so they may be less able to protect themselves against that caused by man (Hall-Spencer *et al*. 2002). With reference to the factors mentioned above that increase vulnerability to fishing; cold-water corals are particularly at risk, being fragile, sessile suspension feeders. This in turn could threaten the biodiversity of the whole ecosystem through the removal of sensitive species.

Despite the problems associated with bottom trawling, the West Greenland Coldwater Prawn Fishery was certified as sustainable by the Marine Stewardship Council in February 2013.

This study aims to investigate the relationship between fishing intensity and biodiversity of the benthic ecosystem, using images of the benthos to assess abundance and diversity of epifauna in particular and relate it to metres trawled over 25 years from 1986-2010.

MATERIALS AND METHODS

Study area

The study area is off the west coast of the southern tip of Greenland, which makes up part of the West Greenland fishery (North Atlantic Fisheries Organisation Convention Area 1, specifically 1D and 1E). In the June 2011 and June 2012, researchers accompanied fishermen on board the trawl vessel Paamiut. At particular stations, an underwater camera contained in a cage was lowered off the side of the boat to take photographs of the benthos (Fig. 1). Grab samples were also taken using DayGrab, and photographs take on board the ship of by-catch samples. Location was recorded using GPS and depth measured using the ship's bathymetric sounding. The 2011 data collection for the pilot study headed north to Aasiaat from the capital Nuuk, whilst the 2012 trip (the data from which is the focus of this report) went south from Nuuk to Qatorqoq (Fig. 2).

Stations were chosen based on fishing intensity data and substrate in order to get a range of conditions, although there were some limitations regarding minimal deviation from the existing course.

Fig. 1 Benthic camera (left) and DayGrab (right) in use

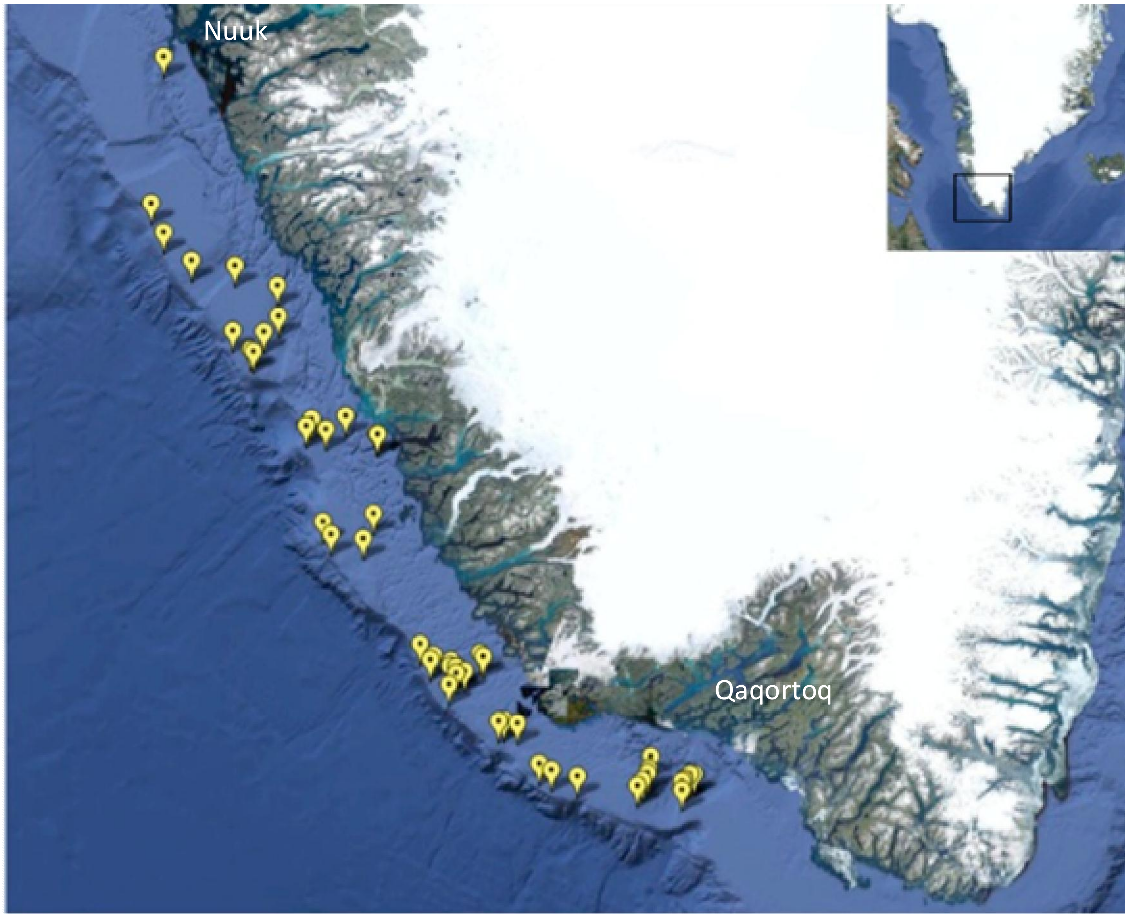

Fig. 2 Image stations 0-48 between Nuuk and Qaqortoq **(2012)** (image taken from Google Maps)

While the areas are likely to be similar, it should be noted that the trip from Nuuk to Aasiaat crosses into the Arctic Circle whereas south of Nuuk is sub-Arctic. Both boreal and Arctic species are known in the area, and previous research has shown that the fauna of this area may be as diverse as temperate and even tropical reef areas (Piepenburg 2005).

There are many distinct faunal assemblages depending on geography, depth, and substrate, and these may vary in biodiversity regardless of fishing. These variables must therefore be accounted for when investigating changes in biodiversity in order to ensure that any changes found are, as far as possible, just a result of fishing and not reflecting other possibly confounding factors.

Predictably, muddy and sandy soft substrates tend to be dominated by burrowing infauna and motile macrofauna, whilst there are more sessile fauna found on harder substrates. Similarly there are distinctive communities according to depth, with zonation occurring at different levels from shallow banks and transition zones through to troughs and slopes (Piepenburg *et al*. 1997), and particularly high diversity in shallow waters (<150m).

The stations fall within the same depth class (±300m) because they reflect the target zone for shrimp fishing. Depth is nevertheless included as a covariate because some stations lie very close to the shore, while others are at the edge of the continental shelf.

Location also affects diversity because it impacts upon food abundance, which is seen as perhaps the most important limiting factor in this area, being controlled as it is by limited primary productivity at the surface (KANUMAS Western Greenland report).

Latitude in particular affects primary productivity because as a measure of how northerly the location is, it indicates temperatures and therefore rate of primary production, and in this case also extent of ice cover. Longitude in this instance indicates to an extent how close the station is to the coast or the shelf break, which in itself can be an indication of depth.

Data collection

Photographs were uploaded onto the computer for identification. The 2011 pilot study (Kemp 2011) used division of the images into 35 squares in Microsoft Powerpoint and organisms counted and recorded in each grid square. This method was time-consuming without significant additional benefits in data quality (Kemp, pers. comm. 2013). For the 2012 data, photographs were studied in quarters on iPhoto and organisms recorded for the entire image in Microsoft Excel. Zooming in to 4x magnification was sufficient resolution to count the organisms accurately.

Organisms were classified to lowest possible taxonomic level and recorded in Microsoft Excel based as far as possible on taxonomy (Table 1). Characteristics used are explained in Appendix 1. In some cases, however, physical characteristics were used to classify organisms within the phyla where it was thought important to distinguish between different 'types' when taxonomic morphological characteristics were unknown. Sponges were classified as branching, encrusting or globular and bryozoa as soft, encrusting or erect. The precedent for this is a study carried out on sponges in Australia where diversity observations did not vary whether calculated according to species or morphological type (Bell & Barnes 2001). Although ascidians can be classified as solitary or colonial, this was not clear enough in the images.

In this study area, it is impossible to classify every organism to species level because of limited existing studies of regional fauna to draw on. Use of imagery also places limitations on the level of identification possible; genetic analysis of bycatch samples may help with this in the future. Individual organisms could sometimes be classified down to species level, but this was not incorporated into the analysis because of the large number of classifications already being used. Despite this, they helped to give an overview of the diversity of the seabed and improve knowledge of the fauna of the study area, and are included in the guide of the features used to classify and identify organisms (Appendix 1).

Classification of substrate

During the construction of the full database, 10 substrate categories in total were recorded using the Surface Geology Component classification scheme of the Coastal and Marine Ecological Classification Standard developed by NOAA and NatureServe as a guide. The categories used initially were: mud/sand, boulder/bedrock, pebble, rubble, mud/rubble, mud/pebble, mud/cobble, pebble/rubble, cobble/pebble and mud/pebble/rubble.

Whilst many pictures were taken at each station, the quality of the images was not necessarily the same. Many stations included pictures while the camera was being moved or with clouds of sand brought up by the landing of the camera gear on the seafloor. Since the calculations of species richness and diversity both rest on exact numbers of different organisms, any photographs where individual organisms were not clear were noted and not used in the analysis. In total, out of an initial 585 photos taken, 399 were deemed usable. In order to make an equal assessment of the diversity of each station, four images were used for the analysis of each station. Although there are more images from many of the stations, using more than four images per station would have excluded many other stations. Where there were more than four images in a station, the first four usable images were taken.

Substrate categories were then redefined because of substantial overlap between many of the ten categories, and because some of the rarely observed categories, such as boulder, were lost following the cutting of the images. It was also considered that too many categories would weaken the analysis. The initial 10 categories were condensed to 4: mud, pebble, mud mixed (mud with pebble, cobble or rubble) and rubble (on its own or with pebble or cobble (Fig. 3).

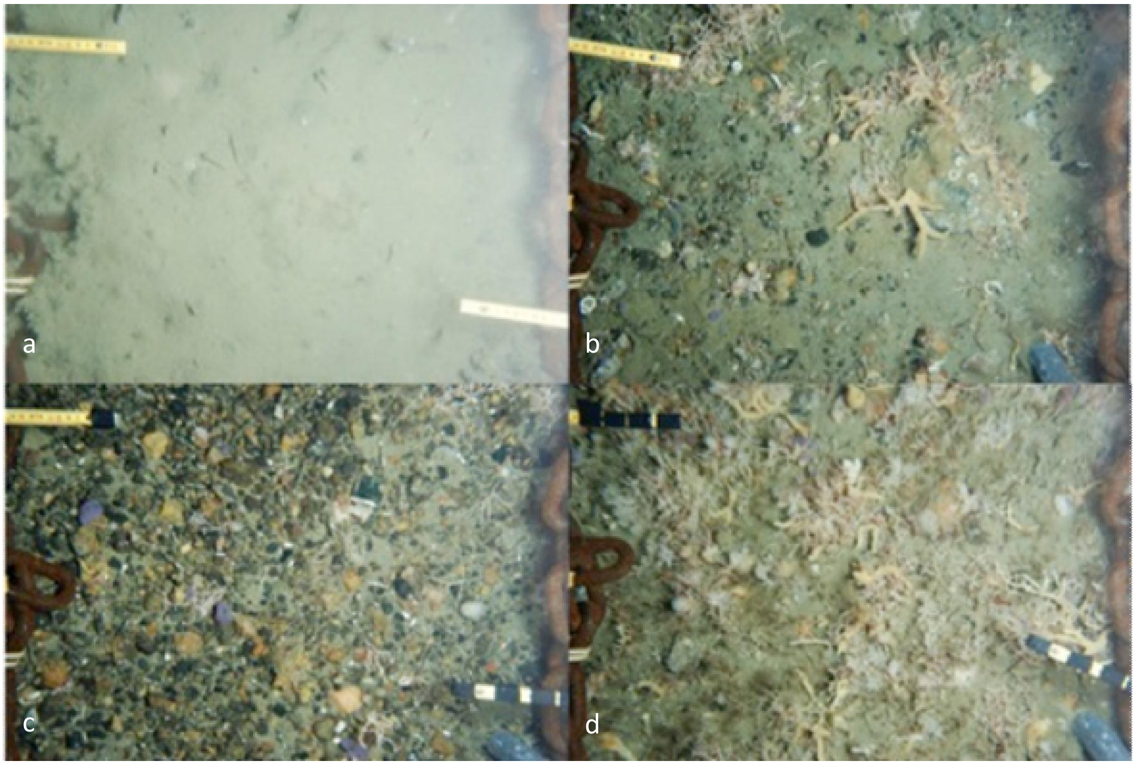

Fig 3 Examples of substrate classifications. **a** mud, **b** mud mixed, **c** pebble, **d** rubble

Table 1 Taxonomic classifications used and their corresponding habitat niche and functional group

Phylum	Cnidaria					
Class	Anthozoa				Hydrozoa	
Subclass	Octocorallia	Hexacorallia				
Order	Soft corals	Stony corals	Anemones	Zoanthids	Hydroids	Stylasterina
Functional group	Filter feeder	Filter feeder	Filter feeder	Filter feeder	Filter feeder	Filter feeder
Habitat niche	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile

Phylum	Echinodermata					**Annelida**
Class	Starfish	Brittle stars	Sea urchins	Holothuroids	Crinoids	Polychaetes
Subclass						
Order						Sabellidae
Functional group	Multiple strategy	Multiple strategy	Predator	Filter feeder	Filter feeder	Filter feeder
Habitat niche	Benthic motile	Benthic motile	Benthic motile	Infauna	Sessile	Sessile

Phylum	Mollusca				Brachiopoda
Class	Gastropods	Bivalves	Scaphopods	Cephalopods	Articulata
Subclass					
Order					Terebratulida
Functional group	Predator	Filter feeder	Filter feeder	Predator	Filter feeder
Habitat niche	Benthic motile	Infauna	Infauna	Non-habitat forming	Sessile

Phylum	Porifera			Bryozoa		
Class	Massive	Encrusting	Arborescent	Erect/forked	Encrusting	Soft
Subclass						
Order						
Functional group	Filter feeder	Filter feeder	Filter feeder	Filter feeder	Filter feeder	Filter feeder
Habitat niche	Sessile	Encrusting	Sessile	Sessile	Encrusting	Sessile
Phylum	Arthropoda			Chordata		
Class	Malacostraca		Pycnogonida	Ascidians	Chondrichthyes	Ocsteichthyes
Subclass						
Order	Decapoda	Isopoda	Sea spiders			
Functional group	Predator	Predator	Predator	Filter feeder	Predator	Predatorr
Habitat niche	Benthic motile	Benthic motile	Benthic motile	Sessile	Non-habitat f...	Non-habitat f...

Habitat niche and functional group

The taxonomic (and few morphological) groups used to classify the organisms in the images were also assigned a functional group (based on feeding type) and habitat niche (Table 1). Habitat niche and functional groups used in the 2011 pilot study were redefined based on further research. Habitat niche and functional group are included in the analysis because they represent another factor of diversity, that of function and niche within the ecosystem. Specific responses of different groups have already been observed: sedentary epifauna in the eastern Bering Sea were seen to significantly decrease in number and diversity with fishing, whereas mobile epifauna and infaunal bivalves did not show a significant directional response (McConnaughey *et al*. 2000).

Assigning habitat niche was relatively easy, and in fact possible just through observation of the images, with almost all groups assigned a single habitat niche without the need for further research. The only group that presented a problem was the holothurians, observed both as infauna and as benthic motile macrofauna. Since, however, the holothurians move only between burrows, it was decided that they should be recorded as infauna.

Functional group, which in this study refers to feeding type, was harder to classify. For purposes intended it is necessary to assign each taxonomic group to just one functional group, but in reality just a single species can belong to a number of functional groups and in this study the organisms have not even been identified to species level. Brittle stars are generally characterised as filter feeders but one species found in this area, *Ophiura sarsii*, has been observed predating on fish and squid that swim too close to the bottom. Another, *Amphiura filiformis*, has been observed to change feeding type according to the tides; it is a filter feeder when current velocity is high, and deposit feeder when low (Solan & Kennedy 2002). Starfish (Asteroidea), also can be predators, scavengers, deposit feeders and suspension feeders. In the future, to analyse functional groups it may be better to classify the individuals in each image, rather than assigning a functional group to the taxonomic groups. This would entail significantly more work, but it could potentially be done alongside the original classification of the images. Within the limits of this study, functional groups were assigned according to what most representatives of a group seemed to be doing, or were assigned to a multiple strategy group, indicating those, like brittle stars and starfish, that change their feeding type according to availability of different food sources.

Fishing intensity

Fishing was measured in metres trawled per annum, which had already been estimated using logs from the fishermen of the start and end point and time of each trip. This data was provided by the Greenland Institute of Natural Resources. The logs provide at the very least a minimum value for metres trawled, because it assumes that the trawl vessel moves between two locations in a straight line, which might not be the case (Chris Yesson, pers. comm.). Equally, using only location data this would give a value of 0m if the start and end point of a trip were the same, but including time records can be used to indicate where this might not be the case.

In the pilot study, fishing logs of 15 years, from 1996-2010, were used. In 2012, records going as far back as 1986 were obtained. This raw fishing data comprises total metres trawled at each station in 5-year blocks: 1986-90, 1991-95, 1996-00, 2001-05, 2006-10.

Fishing data was required for analysis in both continuous and categorical format. For the continuous data, the raw data was summed to give total metres trawled over 25 years and log-transformed to give a more normal distribution.

The first three categories used were:

- Fished
- Unfished
- Recovery

The recovery category refers to stations trawled any time between 1986-2005 but not for the 5 years after that. The distribution of stations according to these simplified fishing categories and the substrate categories is shown in Table 2, and represented on a map in Appendix 2.

Due to the detail of the raw data that was lost using just three categories, fishing was recategorised using additional levels. There is not yet the understanding to apply biologically meaningful categories, so these were based solely on numbers. The fishing data was converted to nautical miles and then two separate classification systems were used: one for each 5-year period in the station, and another for fishing over the total 25-year period (Table 3). In this case the recovery category refers to no fishing for 10 years.

Table 2 Distribution of stations between the substrate and fishing categories

Substrate	Unfished	Fished	Recovery
Mud	1	8	2
Pebble	2	0	2
Mud mixed	4	10	4
Rubble	4	1	4

Table 3 Fishing categories used for multivariate ANOVA

Nautical miles (5 yr period)	Category	Nautical miles (over 25 yrs)	Category
0	1	0-1	1
1-15	2	1-50	2
15-100	3	50-500	3
100-200	4	500-1000	4
200+	5	1000-2000	5
Recovery	6	2000+	6
		Recovery	7

Calculation of diversity measures

Following refining of the stations, diversity (H'), richness of taxa (S_t) and abundance (S_o) were calculated at each station. Diversity was calculated according to the Shannon-Wiener diversity index, where *R* is the total number of taxa in the data set and p_i is the proportional abundance of the *i*th type.

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

Diversity cannot be calculated if there are no organisms present, so an H' value of 0 represents a station with only 1 taxa, rather than a station with none. Values close to 0 signify either few species (low species richness), or many species but with one or more dominating over other more rare species (low evenness).

Proportional abundance was calculated for each taxon, as the sum of each taxon divided by total organism richness, and for phylum, habitat niche and functional group.
Phylum was incorporated into the analysis to make up for the bias that comes from identifying organisms down to the finest possible taxonomic level, which may be family in some cases, like starfish or shrimp, up to phylum, as in sponges and bryozoa. Finest-possible taxonomic level was still used, however, because of the additional data. The problem of categorising organisms to phylum is shown perhaps most obviously in the chordates, which includes both ascidians and fish.

Location data

Station locations were recorded on board using GPS. These WGS84 latitude and longitude coordinates were transformed to a polar stereographic coordinate system centred on Greenland to yield X and Y coordinates representing location on the east-west and north-south axes respectively, henceforth referred to as eastings and northings.

Data analysis

Distribution of the diversity and richness values was tested using Kolmogorov-Smirnov. The effect of fishing was first tested using multivariate ANOVA with the simplified fishing categories and substrate as explanatory variables, and then using multivariate ANCOVA with the simplified fishing as an explanatory variable but substrate as a covariate. The tests were then repeated using the more detailed categories for each 5-year period separately and then with all the five-year periods together as explanatory variables.
Categorising the fishing data reduces the volume quite substantially, and depth and location could not be included because of the need for categorical data. The correlation between the continuous fishing data and the dependent variables (diversity, richness and abundance) was then tested using linear regression with fishing, depth and location (eastings and northings) as independent variables.
As a categorical value, substrate could not be included as a variable in the linear regressions so separate regressions were carried out for each substrate type.

RESULTS

Fishing effect on ecosystem indicators

A total of 42 stations (out of an initial 48) were used in the analyses, with diversity, richness and abundance values calculated from four images per station.

There is a clear pattern, particularly in abundance, between stations using the simplified fishing groups. The unfished stations have highest abundance, then recovery and then fished (Fig. 4). In particular, echinoderms and cnidarians are clearly more abundant in unfished areas than recovery or fished areas. Benthic motile organisms are more abundant but there is no evidence of the reduction in sessile organisms predicted in the literature (Fig. 5). Non-habitat forming, infaunal and encrusting organisms are not present in high enough numbers to detect a pattern. Multiple strategy organisms are clearly negatively affected by fishing, due to the observed pattern in brittle stars (Fig. 6). There is no obvious pattern in filter feeders, and there are not enough predators for a pattern to be observed.

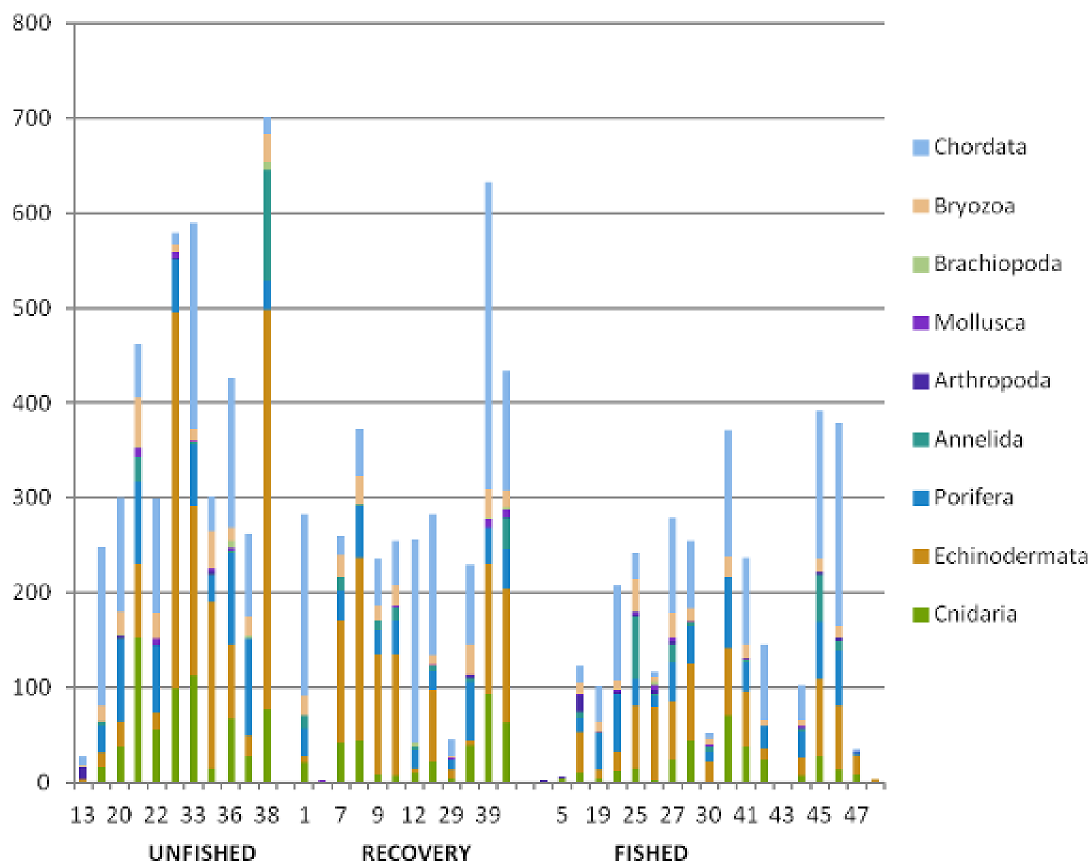

Fig. 4 Stacked column histograms showing the abundance of phyla in unfished, recovery and fished stations

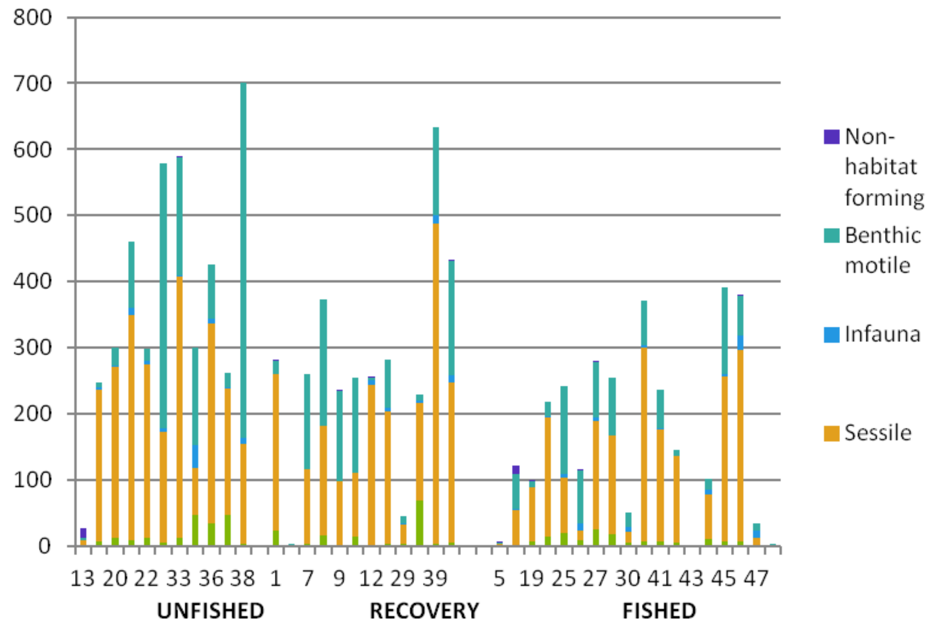

Fig. 5 Stacked column histograms showing the abundance of organisms in different habitat niches in unfished, recovery and fished stations

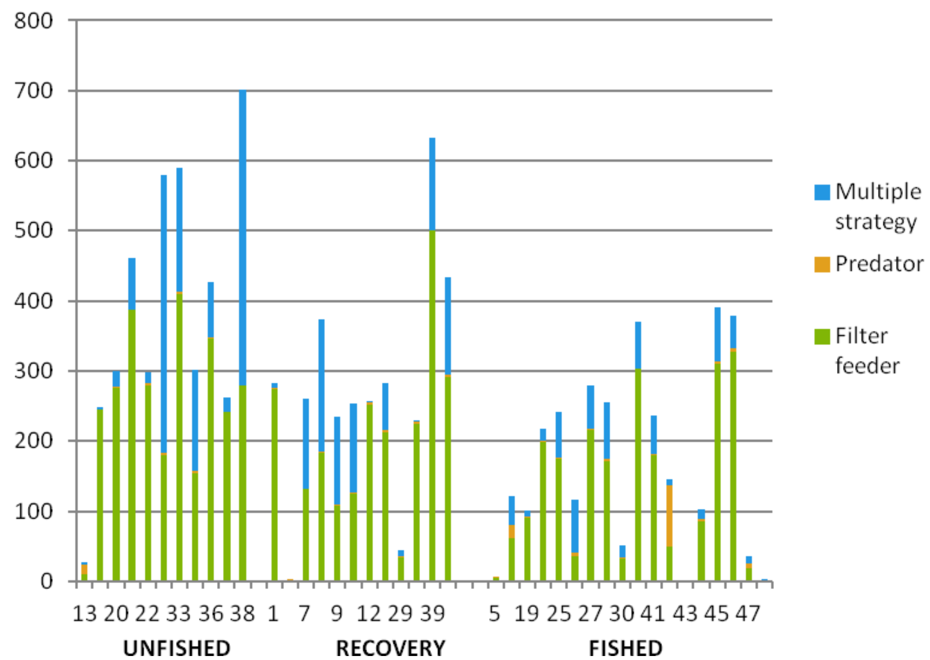

Fig. 6 Stacked column histograms showing the abundance of organisms in different habitat niches in unfished, recovery and fished stations

There was no impact of fishing on diversity, richness and abundance when the seven categories of fishing intensity were used (Table 4), but substrate had a significant impact on richness (MANCOVA, p = 0.021, n = 42). When fishing was categorised more simply, however, fishing had a significant effect on abundance (MANCOVA, p = 0.042, n = 42) and substrate a significant effect on diversity (MANCOVA, p = 0.006, n = 42) and richness (MANCOVA, p = 0.008, n = 42) (Table 5). The effect of substrate on diversity is demonstrated by the different ranges of diversity on different substrates (Fig. 7).

Table 4 Significance values from multivariate ANCOVA of the effects of fishing (7 categories) on diversity, richness and abundance, with substrate as a covariate.
Significant differences are indicated as *P<0.05, **P<0.01

	Diversity (H')	Richness (R)	Abundance (S_o)
Fishing	0.934	0.567	0.934
Substrate	0.083	0.021*	0.164

Table 5 Significance values from multivariate ANCOVA of the effects of fishing (3 categories) on diversity, richness and abundance, with substrate as a covariate.
Significant differences are indicated as *P<0.05, **P<0.01

	Diversity (H')	Richness (R)	Abundance (S_o)
Fishing	0.245	0.835	0.042*
Substrate	0.006**	0.008**	0.236

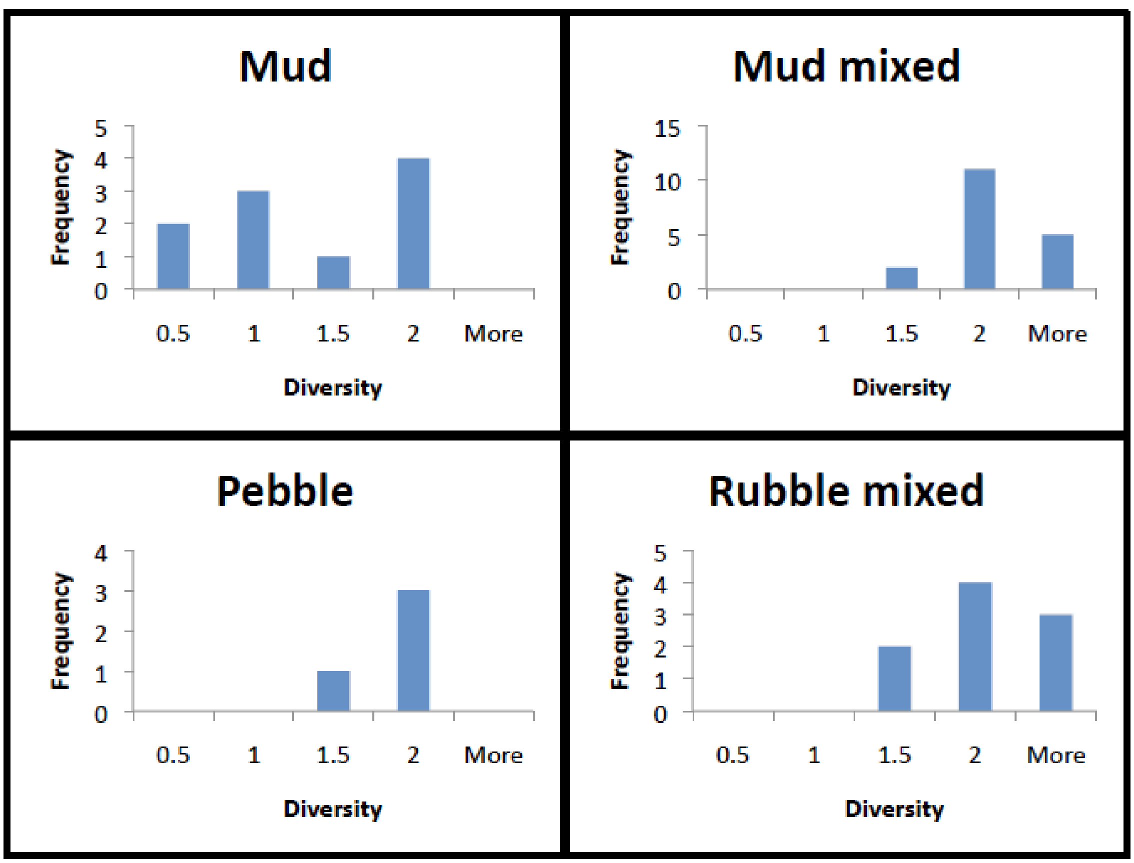

Fig. 7 Histograms of the distribution of diversity according to substrate, from a range of 0-2.5

Table 6 Significance values from linear regression of fishing, eastings, northings and depth against diversity Significant differences are indicated as *P<0.05, **P<0.01

	Pebble	Mixed mud	Mud	Rubble
Fishing	-	0.014*	0.200	0.496
Eastings	-	0.022*	0.098	0.705
Northings	-	0.017*	0.093	0.501
Depth	-	0.193	0.725	0.480

When continuous data was used, fishing was significantly negatively correlated with diversity (linear regression, p = 0.014, n = 19) in mixed mud substrates, as were eastings (p = 0.022, n = 19) and northings (p = 0.017, n = 19) (Table 6).

Northings was also significantly correlated with abundance on the mixed mud substrate (p = 0.029, n = 19) but there were no significant correlations with richness, and of any of the dependent variables on other substrates.

Fishing effect on specific taxonomic groups

Specific taxonomic groups to be studied further were chosen based both on scientific literature and after considering patterns apparent in the distribution of various taxa (Fig. 8). The numbers observed throughout the stations also had to be taken into consideration; although it would have been interesting to look at soft corals, for example, they were not present in large enough numbers for any pattern to be meaningful.

Stylasterids were chosen because of their reported importance in diversity as biogenic structures (Buhl-Mortensen *et al*. 2010). They are markedly more abundant in unfished areas than recovery and fished areas but a difference between recovery and fished areas is less clear (Fig. 6). This is apparent both in graphical illustration and statistical testing, where fishing is significantly negatively correlated with abundance of stylasterids (linear regression, p = 0.042, Slope = -2.833) on the mixed mud substrate, but not on other substrates.

The high numbers of brittle stars throughout all stations meant that a pattern was visible in brittle stars above all other taxa. They are by far the most abundant taxon. They were also chosen because of interest in the new feeding type, 'multiple strategy' created for them and starfish (starfish were not abundant enough to observe any pattern). Brittle stars are more abundant in unfished areas, followed by recovery and then fished areas. Although the pattern is not statistically significant on separate substrates, for example mixed mud (n = 19, p = 0.076, B = -9.068), it is highly significant when all the data (n = 42) is used (p = 0.003, B = -11.001). It is possible that more data for the separate substrates might make patterns more clear.

Fishing was not significantly correlated with the abundance of massive sponges or holothurians on any substrate, or indeed on all the substrates combined.

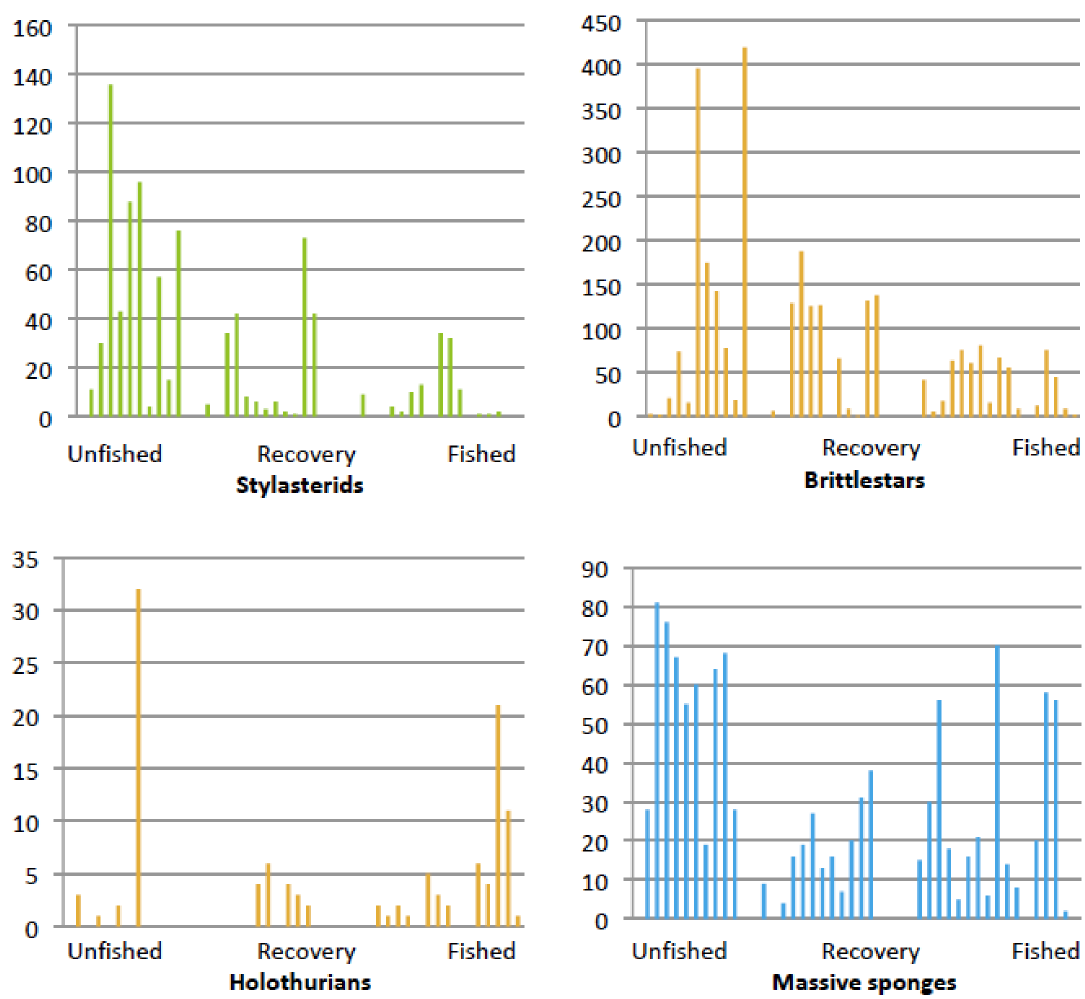

Fig. 8 Histograms of the abundance of different taxa across unfished, recovery and fished areas

DISCUSSION

Results

There is extensive evidence in the literature for a negative correlation between bottom fishing and diversity, species richness and abundance of the benthic ecosystem. Where most other studies have focussed on fishing impact on just one substrate (e.g. Eleftheriou & Robertson 1992), perhaps because of the strong correlation between substrate and faunal assemblages, this study looks at the impact across a range of substrates. While interesting, this may be the cause for some of the non-significant results.

There are three particularly interesting observations in this study. The first is that organism abundance is significantly higher in unfished areas than fished, the second is that benthic diversity on the mixed mud substrate is significantly negatively correlated with fishing, and the third is that the community on the mud substrate has a lower diversity range than mixed mud and rubble substrates. Diversity and abundance are both important ecosystem indicators, meaning that they can be used to draw conclusions about the state of the ecosystem.

Mud is the only substrate to have communities of zero diversity, either containing no organisms or those of just one species (or in this case taxon). More data is clearly needed for the pebble substrate in order to get any results, significant or not, but it is also possible that more data could change the results for the other two non-significant groups. More data may well confirm that fishing does not have a significant effect on the rubble and mud stations but it should be noted that the mixed mud substrate, where fishing has a significant effect, is also the substrate with the most stations. Extra data will allow the relationship between fishing and the state of the benthos to be studied with regards to different substrates, and may show a difference in resilience and vulnerability on different substrates. Spatial analysis of data like that represented in Appendix 2 could also highlight relationships between fishing level and substrate. This relationship is likely to be complicated because the two factors can interact. Fishermen may choose to avoid particular substrates where trawling is difficult, and focus on smoother substrates, like mud. Alternatively, it is possible that some substrates are the result of fishing, as with the rubble substrate discussed below.

There may be a problem with the substrate categorisations themselves. The rubble category in fact also included living biogenic structures as well as rubble, although there is actually often a change from the former to the latter with fishing in the area. In theory if all rubble areas were previously full of biogenic structures then this should be accounted for in the fishing data but perhaps it would be better to separate the two groups because they are likely to have different diversity ranges. It can, however, be difficult to tell on looking at the picture whether something is alive, and should therefore be counted, or dead and should be considered as a rubble substrate, which could create problems if it was decided to separate the two categories.

It is also interesting that many of the other studies that cover the differences between substrate types refer to hard and soft substrates (e.g. Kaiser *et al*. 2001, Cryer *et al*. 2002). While the categories mud and pebble do cover this, there is no separate category for sand or mud over bedrock, which might superficially look like sand/mud but in fact represents a different habitat. Mud typically has a high proportion of infauna because it offers a burrowing substrate, whereas sand over bedrock will not have infauna but may have a high proportion of sessile organisms. In these circumstances then it may be best to assign substrate category by looking at the fauna present, for example a number of holothurians might indicate a mud substrate whereas stylasterids and erect bryozoans indicate a hard substratum.

The significant effect that fishing has on stylasterid numbers is very interesting with regards to the other results because of the wealth of research linking stylasterids and other 3D biogenic structures to higher diversity. The lack of relationship between fishing and diversity in the MANCOVA analysis could be an indication of problems with the measurement of diversity in this study, rather than a real reflection of the impact of fishing on diversity.

The distribution of brittle stars is interesting for different reasons; it could be hypothesised that the brittle stars might respond well to fishing because of their multiple feeding strategies, which could have made them more resilient to disturbance and allowed them to outcompete other groups. The marked decrease in brittle stars, and significant impact of fishing (when substrate is not accounted for) might be an indication that the majority of brittle stars in this area are filter feeders rather than scavengers or predators.

Patterns in the distribution of holothurians not very evident given the low numbers generally but it seems that, apart from one particular unfished station, holothurian numbers are greater in fished than unfished areas. This is in line with previous research on scallop dredging suggesting that holothurians, in particular *Cucumaria frondosa*, are resilient to bottom fishing (Guijarro Garcia *et al*. 2006). This did not, however, come out in the regression analysis so more data is needed to be sure of any relationship, if there is one.

As mentioned above, it is possible that the methods used to assess the community, and the measurement of diversity used are not entirely compatible, because so many community members are missed out, for example, many infaunal organisms. It is also possible that the huge range in numbers seen in these communities means that the Shannon-Wiener index is not the ideal measure of diversity in this situation. Shannon-Wiener diversity does not take into account the fact that some organisms might only ever be present in small numbers (like starfish), so their presence alone may be an indication of biodiversity even if the actual numbers are dwarfed by other organisms common in large numbers (like brittle stars, ascidians or polychaetes). For example, one station (33) has 589 individuals in 18 taxa, (this is among the highest of all the stations for both abundance and richness), but it has one of the lowest diversity scores because most of the individuals are in three taxa. In contrast, station 47, which has just 35 individuals across 10 taxa, scores higher in terms of diversity because the total number of individuals means that they cannot be spread as unevenly, even though in fact most of the individuals are found in just two taxa. A different station (37) with less than half the number of individuals (of station 33), and just 12 taxa represented, again has a higher diversity score because the majority of the individuals are in five taxa, even though two of these have far more even than the other three.
Incorporating total number of individuals as well as diversity might be more appropriate in a situation like this where one picture could have over 400 individuals of one taxon. It also might be possible to transform the data such that the effect of dominant taxa is reduced (Morris *et al.* in press).

While considering the measure of diversity, it is also important to look at how the diversity index was obtained. It is usual for the index to be a measure of species-level diversity, but in this case this was not possible. Species-level diversity could give a different idea of fishing impact on diversity, although abundance would remain the same because the total number of organisms would not change.
There have, however, been suggestions that it is easier to detect anthropogenic change at

higher levels than species; Veale *et al*. (2000b) reduced an original species list to higher taxonomic groupings in line based on the theory of Warwick (1988a). It is also important to remember that identifying to species level would be not only a much greater commitment in terms of time to collect the data but also in analysis in terms of dealing with the resulting dataset. Studies of the impact of fishing on species diversity often look at the species of just one order (e.g. Hall-Spencer *et al*. 2002) or family (e.g. Kaiser *et al*. 1999).

In this respect therefore, counting by phylum may be the most appropriate because it would give a measure of diversity across the same level of classification, but it would also lose a lot of diversity. In this report, starfish and brittle stars, for example, are only identified to class, not order like the Cnidaria, so according to lowest taxonomic level, the diversity is low even though it is easy to see in pictures that diversity can be very high. Whilst in brittle stars, high abundance seemed to coincide with diversity in morphology, in the sponges high numbers are found in both homogenous and incredibly morphologically diverse areas (Simon, pers. obs.).

When considering diversity, richness and abundance it is also important to consider those organisms that are missed by this study. Infauna are likely to be highly underestimated in this study because many may not be visible at the surface. It is indicated by the presence of scaphopod shells in surface rubble that these are present in a community, but they cannot be counted because when they are alive they are buried. This may also be the case with many worm cases seen on the surface and molluscs, although the worm cases do sometimes seem to have worms in. Gastropods may be more easily distinguished because living ones seem to leave trails, so it can be assumed that if there is no trail, the shell is empty. Scallops are well known in the area, being another fishery product, but are rarely, if ever, seen in the photographs. This is also relevant to the discussion of the mud substrate, because this substrate is particularly likely to have infauna, and indeed the lower diversity range seen on this substrate may be a reflection of this rather than true lower diversity.

Other organisms missed by photographic surveying are those that are too small to see in the photographs. Macrofauna are usually defined as organisms larger than 0.5mm, i.e. they are retained in a sieve of mesh size 0.05mm. In this situation, however, it is unlikely that many organisms below 1cm will be seen. Even if the resolution were high enough, it is also very rare for the image to be of high enough quality in terms of focus and sharpness, given the difficult nature of photography 200m deep in the ocean.

In terms of treatment of the fishing data, the seven categories seemed to weaken the analysis but just three categories loses a lot of the detail in the data. Continuous data is advantageous in this respect because more detail is kept, but in the linear regression analysis it was not possible to study the effects of substrate as well as fishing. It is also significant that the results only indicate a correlation, rather than attributing a definite source of variation. MANCOVA therefore is also useful, although it has its own problems, and better categorisation of the fishing data might allow more information to be extracted. This could be done either through the addition of another fishing category, to represent higher and lower intensity, or another recovery category where the length of time without fishing is changed.

Future studies

The most important future for this area of research is collection of more data. At the moment, despite the huge number of photographs and vast amount of data collected, the analysis necessitates a huge reduction in what is used, for instance, data collected from 15 images in one station becomes just one diversity score. More data is vital in order to test the pebble substrate analysis, and this is likely to also help further analysis of the rubble and mud stations. It is also important for analyses that require categorisation of the data, for example when substrate and fishing categories are combined as in Table 1. This could also indicate relationships between fishing and substrate. Currently there are no fished stations with pebble substrate, but this may well simply be a result of sampling, rather than any indication of correlation. Collection of more data over the next few years will allow the relationship between fishing and substrate to be better studied and will also be hugely useful in following the progression of particular areas over time, particularly with regards to the impact of continued or halted fishing.

This relates to another important part of future work, which will be to study the potential for fished areas to recover. This study has only shown graphically that the recovery stations seem to lie between fished and unfished in terms of diversity, but it has not been possible to obtain specific statistics on this. It would also be very interesting to change the recovery category to try to look at how long exactly it takes an area to recover, by changing the parameters that define recovery category, to 5, 10 and 15 years of no fishing, for example, would allow the study of how long it takes an area to recover.

Further to analysis of particular taxa, it might also be interesting to look at the relative impact of fishing and substrate; are particular taxa more affected by one than the other? More data would also allow regressions to be carried out on more taxa than the few mentioned here. Henry *et al*. (2003), for example, suggest that soft corals may react better to disturbance than stony corals but the count of soft corals is not large enough here to test that. It would also be interesting to look further at organisms that might be resilient to fishing, such as tubeworms, since they are infauna with hard casing, and some of them at least are visible in images because of their fans. The effect on brittle stars should also be investigated further because although there was no significant correlation between fishing and abundance on individual substrates, the slope was nevertheless very steep, and the correlation on all substrates was highly significant.

Conclusion

This study clearly shows how diverse the fauna of this area are. In a 2005 review, Piepenburg cites a number of studies evidencing that the Arctic is at least as diverse as the Antarctic. Traditionally the Arctic has been thought to have poor biodiversity; in fact it seems that both the Arctic and Antarctic have intermediate species richness. This study lends support to that notion, as it shows variation in faunal assemblages, particularly according to substrate and fishing. Marine research has always lagged behind terrestrial, and of marine, shallow water coastal research has been the priority. Now, deep-sea research is a rapidly expanding field but the impact on fishing on benthic communities in this region shows that it is important still to research the continental shelf. Data from future years, along with perhaps a few changes to the methodology regarding substrate identification, for example, should provide clarification on the precise effects of fishing on the fauna of this area.

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APPENDIX 1

CNIDARIA

SOFT CORALS

a. Unknown
b. Maybe *Drifa sp.*
c. Unknown
d. Unknown
e. Unknown

NB. These are very hard to identify from images. Other possibilities are *Duva sp.* or *Capnella sp.*

STONY CORALS

Uncertain

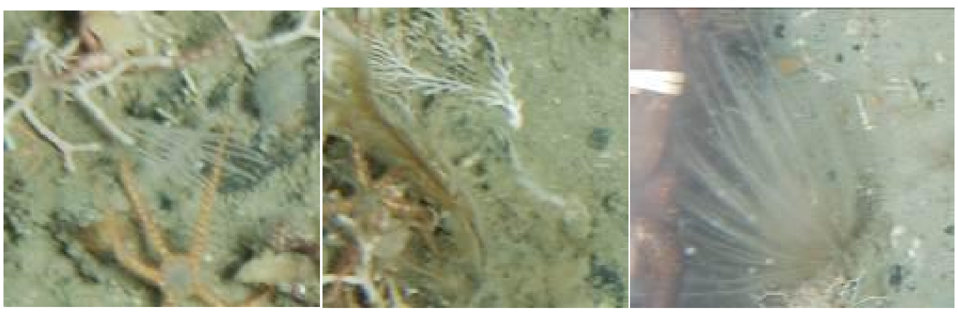
SEA ANEMONES

a. Maybe *Stomphia coccinea*
b. Unknown
c. Maybe *Bolocera tuediae*

ZOANTHIDS

All unknown

HYDROZOA



a. Sertulariidae
b. Maybe *Nemertesia ramosa*
c. *Nemertesia antennina*

NB. a. and b. are Plumulariidae

STYLASTERINA

All Stylasteridae

BRACHIOPODA

TEREBRATULIDA

Maybe *Terebratulina sp.*

NB. Superficially similar to bivalve molluscs but valves are unequal

ECHINODERMS

ASTEROIDEA

a. *Hippasteria phrygiana*
b. *Ceremaster granularis*
c. *Henricia* sp.
d. *Solaster endeca*
e. Maybe Solasteridae because it has >5 arms but not found any similar
f. *Pteraster militaris*

OPHIUROIDEA

a. *Ophiura sarsii*
b. Unknown
c. Unknown
d. Maybe *Ophiopholis aculeata*
e. Unknown
f. Maybe *Ophiopholis aculeata*

Short stubby brittlestars may be *Stegophiura* sp.
Other species found in the area are: *Ophiocten sericeum, Ophiura robusta, Ophiura ophiura*

HOLOTHUROIDEA

a. *Cucumaria frondosa*
b. *Cucumaria frondosa*
c. Probably also *Cucumaria frondosa*
d. *Psolus phantapus*
e. *Psolus phantapus*
f. Unknown

ECHINOIDEA

a. Probably *Echinus esculentus*
b. Unknown
c. Unknown

NB. Sea urchins can be hard to identify because species hybridise.

CRINOIDS

a. Probably *Heliometra glacialis*
b. Maybe *Antedon sp.*
c. Probably *Heliometra glacialis*

MOLLUSCA

GASTROPODS

a. Unknown
b. Unknown
c. Nudibranchia

BIVALVES

a. *Threcia sp.*
b. *Threcia sp.*
c. Siphons of *Panopea generosa* (geoduck)

SCAPHOPODS

Unknown

CEPHALOPODS

a. Octopodidae probably *Eledone cirrhosa*
b. Maybe same species

NB. Pencil (Loliginidae) and bobtail (*Rossia sp.*) squid found in by-catch samples

PORIFERA

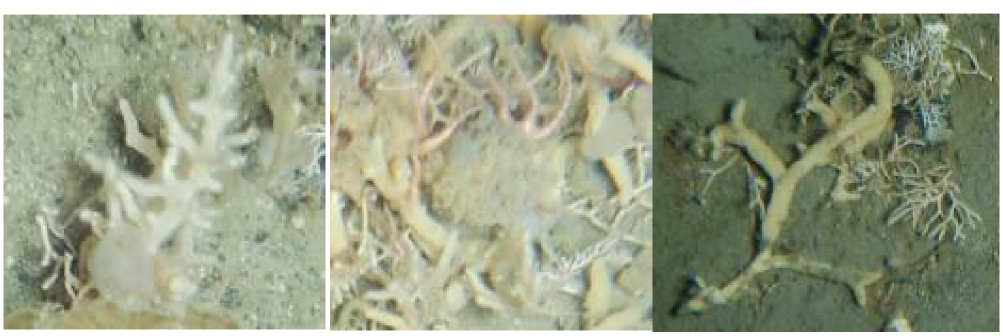
MASSIVE

a. Mycalidae – maybe *Mycale lingua*
b. Polymastiidae
c. Tetillidae – *Craniella zetlandica*
d. Probably Axinellidae
e. *Quasilina brevis*
f. Unknown

ENCRUSTING

a. Maybe *Aplysilla sulfurea*
b. Unknown
c. Maybe *Hymedesmia jecusculum*

ARBORESCENT/BRANCHING



All unknown

BRYOZOA

ERECT

a. *Hornera lichenoides*
b. *Reteporella lichenoides*
c. Unknown

FORKED

Unknown

SOFT

Unknown

ENCRUSTING

Unknown

ANNELIDA

POLYCHAETES

a. Sabellidae
b. Sabellidae
c. Serpulidae

ARTHROPODA

MALACOSTRACA

a. Unknown
b. Majidae
c. Paguridae (hermit crab)
d. Crangonidae, maybe *Argis lar*
e. Maybe *Pandalus borealis*
f. Maybe *Pandalus borealis*

ISOPODS

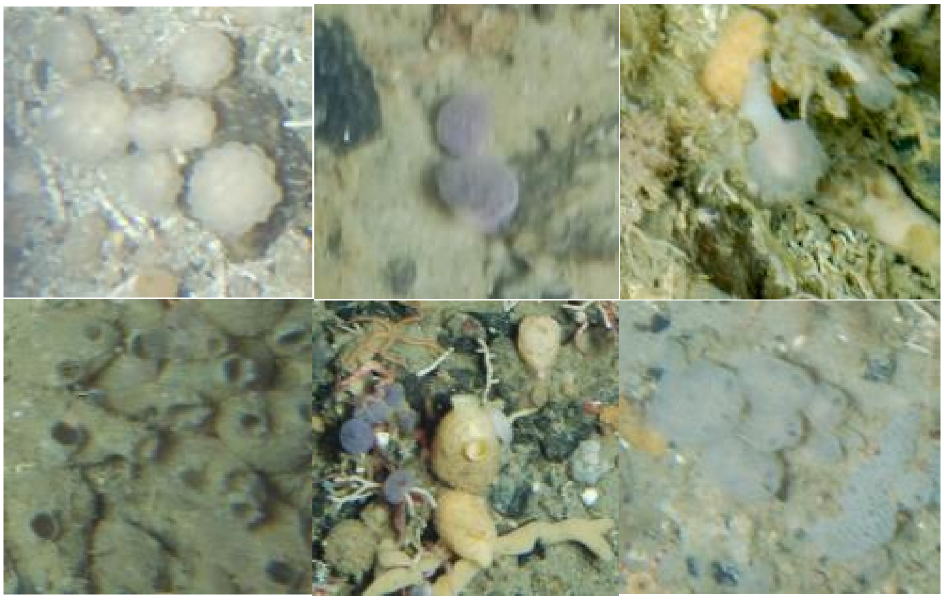
Unknown

PYCNOGONIDS

Unknown

CHORDATA

ASCIDIANS

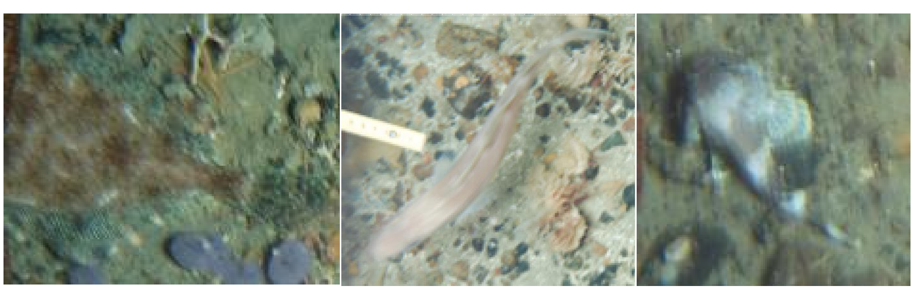


a. Ascidiidae
b. Styelidae, probably *Botrylloides aureum*
c. Unknown
d. Molgulidae, probably *Molgula manhattensis*
e. Maybe also Molgulidae
f. Unknown

CHONDRICHTHYES

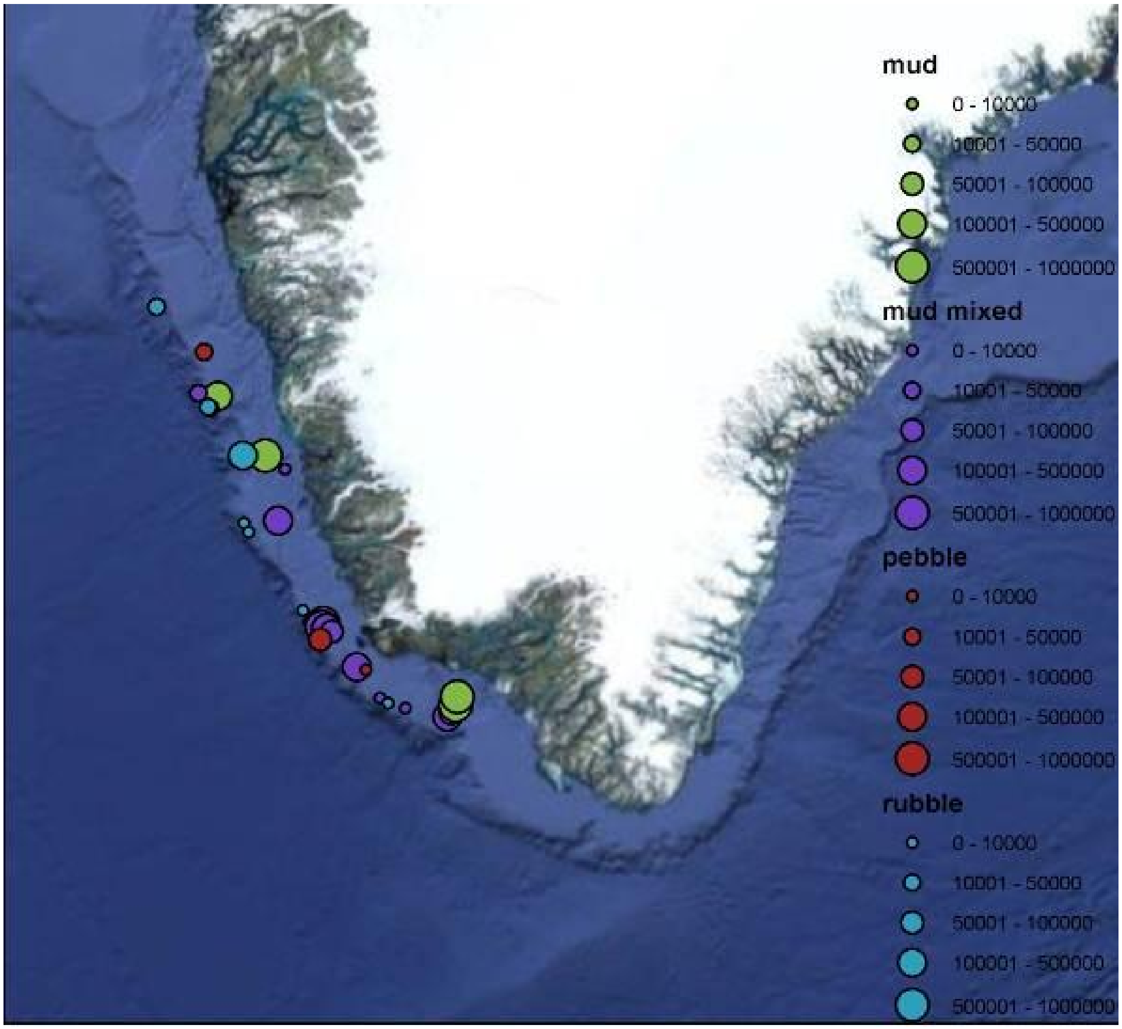
a. Shark egg case (mermaid's purse)
b. Rajidae

OSTEICHTHYES



a. Pleuronectidae
b. Gobiidae
c. Scorpaeniform – maybe Agoniidae or Cottidae

APPENDIX 2



Different fishing levels (metres trawled in 25 years) across the substrates of the stations in the 2012 survey.