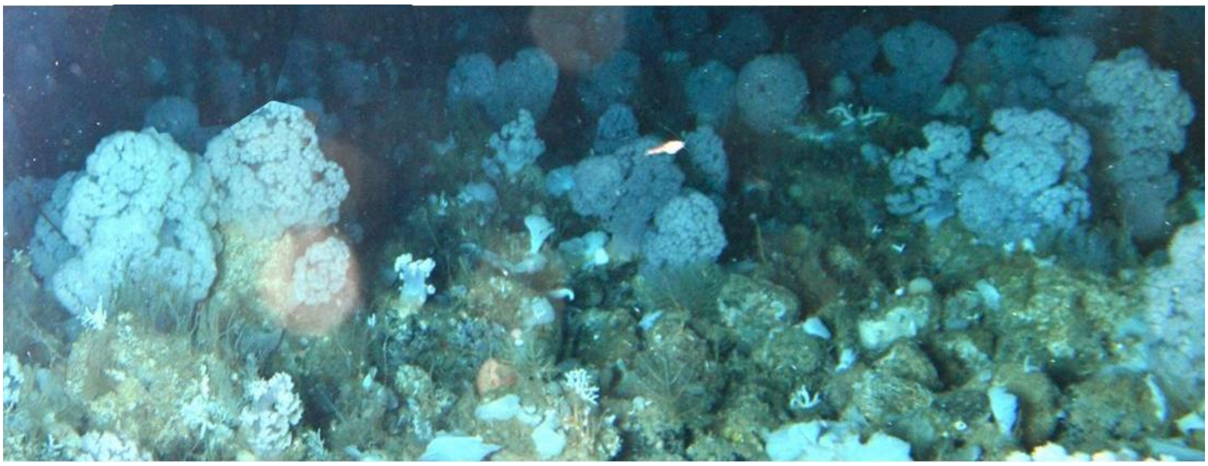
Final Report:

Diversity and ecosystem function indices of the macrobenthic community, West Greenland shelf (200-600m), in response to varied impact

Camera survey - *M/T Paamiut* SFW RejeFiskVest Survey Togt 1
June 11-20, 2011: Nuuk – Aasiaat



Report compiled by
K. Kemp
Institute of Zoology, Zoological Society of London, Regent's Park, London, NW1 4RY, United Kingdom

For
Sustainable Fisheries Greenland
c/o Grønlands Arbejdsgiverforening, Jens Kreutzmannip Aqq. 3, P.O. Boks 73, 3900 Nuuk, Greenland

Greenland Institute of Natural Resources
Kivioq 3, P.O. Boks 570, 3900 Nuuk, Greenland

Greenland Climate Research Centre
Kivioq 3, P.O. Boks 570, 3900 Nuuk, Greenland

Contents

1. (Draft) Final Report Statement of Work

This report is in fulfilment of the second stated aim of the contract for services between Sustainable Fisheries Greenland and The Zoological Society of London, to submit a draft final report including digital copies of all imagery, analysis of imagery and data analysis, and conclusions as to the variation of bottom type, depth, trawl-fishery history, on species abundance and diversity, and community composition based on camera survey work undertaken during leg 1 of the annual Greenland Institute of Natural Resources RejeFiskVest Survey, (Cruise report: Camera Survey submitted July 14, 2011). Following comments from SFG and other interested parties, the content of this report and the Cruise report of July 14th, will be submitted together with all data, to Sustainable Fisheries Greenland, the Greenland Climate Research Centre, and the Greenland Institute of Natural Resources.

2. Abstract
Variation in the biodiversity and composition of the benthic community in the region of 64 - 69ºN, 53 - 56ºW, and the potential association of this variation with bottom trawling for *Pandalus borealis* between 1996 and 2011, were investigated using biodiversity (H'), species richness (S) measures, and basic measures of community function and habitat structure, determined from image data collected at 46 locations in June 2011. The strong association of benthic macrofaunal communities with substrate type and depth was controlled for in the analysis. The impact of trawling activity cannot be interpreted with confidence within the limitations of this dataset, however the technique for data collection (camera survey) has been established as highly efficient and effective, and the procedure for subsequent processing and analysis has been developed to readily incorporate additional data, and to facilitate a robust and more conclusive benthic impact assessment analysis. The analysis procedure, limitations of the existing data, conclusions and recommendations for the structure of further work (both practical and analytical) which should be undertaken within this study remit are detailed here.

3. Introduction

3.1. The context and structure of this survey

Any activity which involves direct contact with the seabed has both a direct and indirect impact on the benthic ecosystem, and indirect impacts on the pelagic ecosystem. The first and most obvious impact of the trawl fishery for Northern Shrimp, *Pandalus borealis*, is the removal of the target organism from the faunal assemblage. Shrimp constitute an important link between the benthic and pelagic communities. Their daily cycle of migration into the water column to feed at night, and a return to the benthos during daylight hours means they spend roughly equal amounts of time as constituents of both, and are in some ways symbolic of the direct links between, and critical interaction of, these two components of the marine ecosystem. Neither the stock assessment of *Pandalus borealis*, nor any assessment of bycatch associated with this fishery are incorporated into this analysis, however the linkages between diversity and ecosystem function in the pelagic and benthic realms are important, and mentioned now because the data described here should ultimately be assessed in the context of the ongoing stock assessments of this fishery. This idea is returned to in the later stages of this report.

Additional direct impacts of any bottom-contact fishery are damage to structural habitat and mortality of non-target organisms. Enhanced mortality of non-target organisms which are damaged by ground gear and left more susceptible to predation (Kaiser and Spencer, 1994a; Veale et al 2000a, Guijarro Garcia and Ragnarsson 2006), and the ecosystem effect of the removal of biomass from the system, are indirect effects of trawling.

The data collected in this study are in the form of images of the benthos. From images the dominant substrate type of each location can be assessed and recorded, and the fauna which comprise the epifaunal community (living on the bottom as opposed to within it) of that point location can be identified and counted. Members of the infaunal community (living within the sand, mud or rock) can only be recorded if some indication of their presence is apparent on the surface (ie a siphon or feeding apparatus which protrudes from the substrate) and can be observed.

Realistically, visual observations are also largely restricted to the macrofaunal component of the community. Macrofauna are loosely defined as those organisms which are larger than 0.5mm, but this definition is more applicable to physical sampling/sieving than to image analysis. Most organisms of this small size will not be apparent in image data, and records will be biased towards organisms of at least 1cm in size.

The biodiversity measures therefore calculated from these images are not true biodiversity measures for the community as a whole, but heavily biased towards megafauna (fish, large corals and sponges and other large invertebrates), and epibenthic macrofauna, and incorporating records of infaunal organisms only where they were apparent. Discussion of the value of supplementing this type of visual-based impact assessment with some level of physical sampling of the benthos is included in this report.

3.2. Sources of natural variation in community composition.

The benthic macrofaunal and megafaunal community in the Arctic and elsewhere, is known to be strongly associated with substrate type and hydrography (Piepenburg 2000, Ambrose et al 2001). Sandy and muddy bottoms are generally dominated by infaunal organisms and the motile fraction of the macrofaunal community (starfish, holothurians, fish).The presence of harder substrate in the form of gravel/pebble or cobble/boulder is associated with a higher incidence of sessile, settling fauna (coral, hydroids). Sructurally complex substrate such as reef habitat (in the form of dead reef rubble or living reef), boulder-dominated habitat, is also often associated with a denser community assemblage.

The disturbance experienced by benthic communities impacted by bottom-contact gear is not consistent across all habitats. Sandy and muddy bottom communities are generally more resilient to disturbance than communities which characterise more complex (gravel/pebble/cobble or rubble) substrate (Eleftherious and Robertson 1992, Hall 1998, Guijarro Garcia and Ragnarsson 2006).

Natural shifts in benthic fauna composition in Arctic seas are also observed with changes in depth with different groups of organisms exhibiting dominance at various depth ranges (Sirenko 2003). The epibenthos of Arctic shelves is dominated by echinoderms (Piepenburg 2000, Ambrose et al 2001), and ophiouroids (brittlestars) in particular. Beyond 500m depth brittlestars are less abundant and sponges, bivalves, and holothurians dominate.

Existing knowledge of distribution, abundance and biodiversity of benthic communities in the Arctic is relatively fragmented. Biodiversity and ecosystem function can be assessed in a myriad of ways at, different spatial and ecological scales within a community, between communities and between regions. Most studies undertaken in the Arctic region compare within-community diversity, or diversity between communities along an environmental gradient (for example depth or productivity) (Ambrose 2003).

Photographic surveys have been undertaken around Svalbard (Piepenburg et al 1996), the Laptev Sea (Piepenburg and Schmid 1997), the Barents Sea (Piepenburg and Schmid 1996b), north Iceland (Peipenburg and Juterzenka 1994), and the east Greenland shelf (Piepenburg and Schmid 1996a), and physical sampling based studies have targeted both arctic shelf and basin depths (Ahrens et al 1997, Wollenburg and Kuhnt 2000, Vanaverbeke et al 1997, Pfannkuche and Thiel 1987, Vanreusel et al 2000, Piepenburg 1997). These studies have tended to be region-specific and not designed to necessarily be interpreted on a larger regional (ie “Arctic”) scale, but do suggest a diversity of Arctic shelf fauna that is comparable to temperate and even tropical shelf regions, and an impoverished community characterising Arctic deep basins relative to other deep-sea communities, even those at comparable southern latitudes (Ambrose 2003). However a systematic attempt to describe the patterns of benthic biodiversity in Arctic regions is clearly needed (Ambrose 2003).

The current study is an attempt to develop a basic understanding of the relationship between historical fishing intensity, and measures of biodiversity as indicated primarily by the composition, niche and functional groups represented in the epibenthic community, at point locations, and accounting for natural shifts in community structure associated with depth and substrate type.

4. Data processing

4.1. Image analysis procedure

Images were imported into Microsoft Powerpoint and a thin grid of 35 squares was superimposed upon each image (Figure 1). The total area within this grid was 56 x 40 cm. Substrate composition was estimated (as detailed below), and fauna observations were counted and recorded, within each of the 35 grid squares separately. The 35 substrate estimates were then combined to create one coverage estimate per image. In this way a very accurate record of substrate composition was achieved for each image. Perhaps more importantly, the division of each image into 35 smaller squares also ensured that the image was fully studied and all visible fauna noted and recorded. When viewing a larger field of view, such as one full image, the eye is drawn to focal points, obvious fauna and dominant rubble, and it is extremely easy to miss smaller, better hidden or better camouflaged organisms.

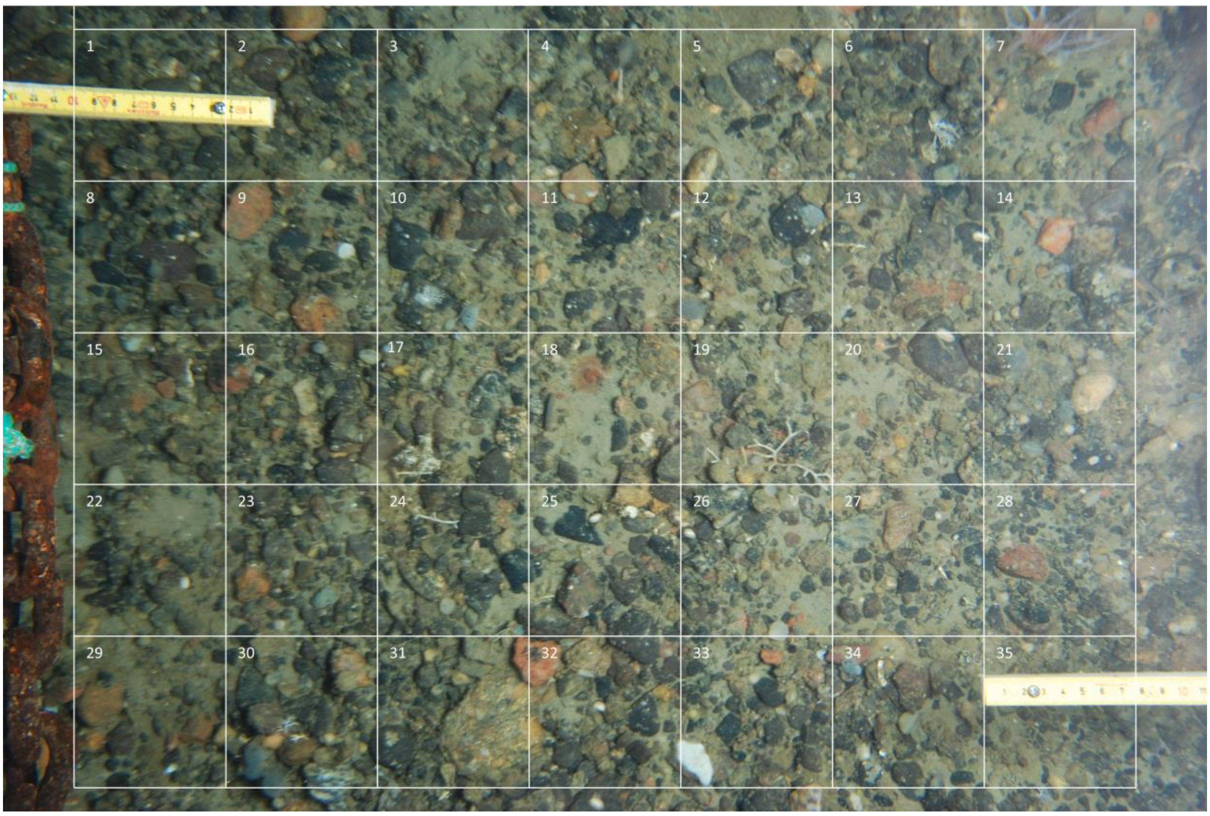


Figure 1. A grid of 35 squares was applied to control for consistency during image analysis.

4.1.1. Substrate

Substrate observed in the images was categorised into 5 types: mud, sand, gravel, pebble, and cobble. Susbtrate type was recorded as percentage-cover of each of these types. Shell debris and coral rubble, although arguably both substrate types that differ from the others only on the basis of their biogenic rather than geomorphic origin, were recorded as single observations (not percentage cover estimates).

These substrate categories are in general accordance with the Surface Geology Compnent (SGC) of the Coastal and Marine Ecological Classificaiton Standard developed by NOAA and NatureServe (USA) classification scheme. It should be recognised that there are subtle differences in substrate categorizations generated from analysis of images and those generated from the analysis of actual sediment samples physically collected by a grab, core or dredge. Geologists may sometimes dispute image-generated substrate categorisations because they take no account of the underlying geological component (ie bedrock, carbonate hardground etc) which cannot be assessed in this way. However from a biological perspective image-based substrate categorisations are informative and relevant as they refer to the upper few centimetres of the sea-bed which are visible, and which are the critical component to the fauna themselves.

All substrate records were made using these 5 categories. However for the purposes of the analysis undertaken and described in this document, several of these categorisations were merged to form a simplified classification scheme consisting of: sand/mud, gravel/pebble, cobble, and mixed (Figure 2). Furthermore each station was assigned to only one of these categories dependent upon the dominant substrate (Table 1). The simplification of the dataset at this stage is discussed further below (section 4.2 and 4.3).

Table 1. Distribution stations amongst substrate categories

Dominant substrate	Stations
Mixed	st2, st6, st12
Cobble	st22
Pebble/gravel	st1, st4, st7, st8, st13, st14
Sand/mud	st5, st11, st15, st16, st17, st18, st19, st20, st21, st23, st24, st25, st26, st27, st28, st30, st31, st32, st33, st34, st35, st36, st37, st38, st39, st40, st41, st42, st46

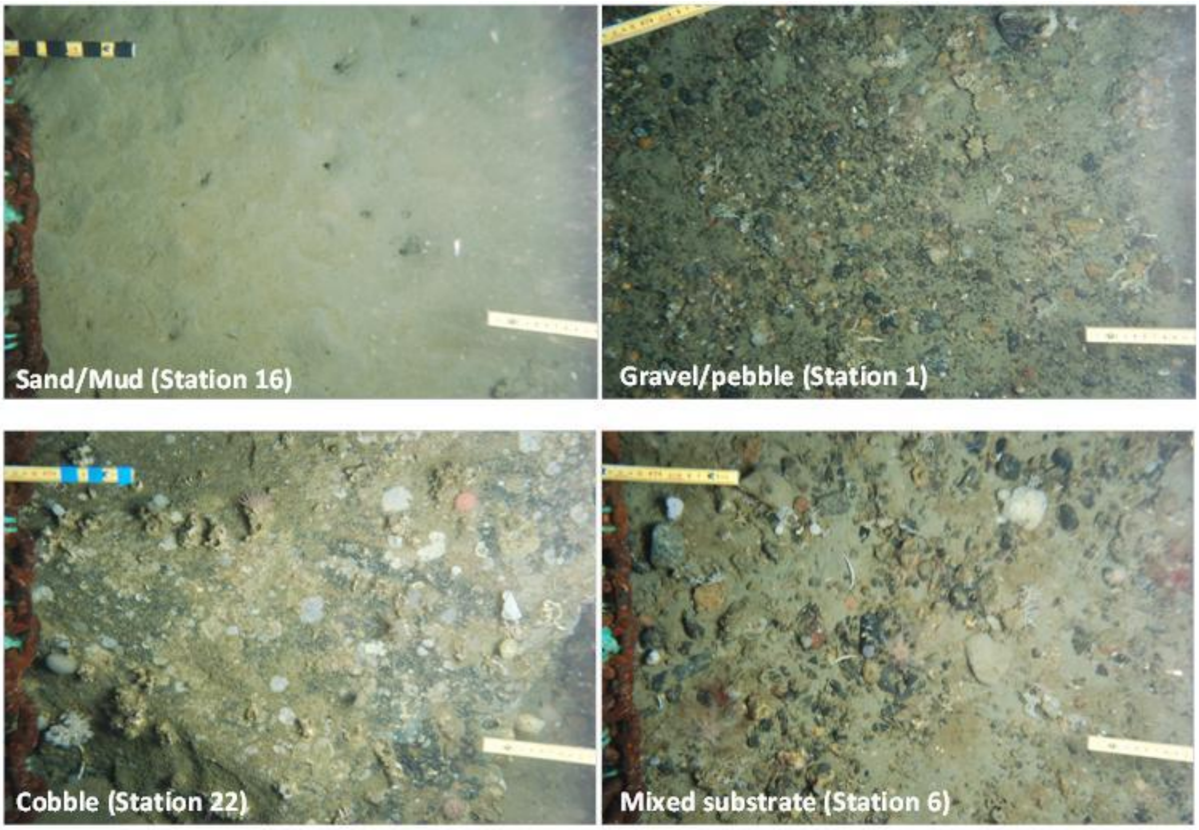


Figure 2. Substrate classification scheme consisted of 4 substrate types: sand/mud, gravel/pebble, cobble, and mixed.

4.1.2. Fauna

In the first instance, and while establishing familiarity with the fauna of the region, fauna observations were recorded at a very basic level of categorization: soft coral (bushy and hornlike), stylasterid (very small, small, large), sponge (bulbous or encrusting) etc. The degree of taxonomic specificity to which benthic marine fauna can be identified from images is limited. Usually organisms can not be identified beyond class or subclass level with any certainty; often identification is restricted to taxon level. This is not only a feature of image data. Many benthic organisms are not straightforward to identify even when observed under a microscope, and several cannot be confidently identified to species or even genus level without molecular analysis to confirm identifications (this is particularly true of soft corals). For this reason a multi-tiered system of recording was developed. Observations were recorded at a broad (phylum) level, but also allocated to a "finest-level categorisation" group, and any possible true taxonomic levels between these two (Table 2). Finest-level categorisation is not a taxonomically sound categorisation. Within different classes of organisms the means by which individuals can be reliably and repeatably categorised varies. While individual fish, octopi or large macrofauna such as ophiouroids and asteroids can often be readily identified to species level from image data, sponges, ascidians and worms lend themselves better to a descriptive categorisation such as "encrusting", "solitary", "bulbous". The finest level categorisations to which fauna within each class were divided are outlined in (Table 2, Figures 3-11) and described below.

Table 2. The finest level categorisations to which fauna within each class were divided

Phylum	Class	Subclass	Order	Family	Finest level categorisation	Description
Cnidaria	Anthozoa	Octocorallia			Octocoral	
		Hexacorallia	Actinaria and Corallimorpharia (Anemones and jewel anemones)		Anemone	
			Scleractinia (Stony corals)		Stony coral	
			Zoanthida (Zoanthids)		Zoanthid	
	Hydrozoa	Hydroida			Hydroid	
				Stylasteridae (Hydrocorals)	Stylasterid	
Porifera (Sponges)					Encrusting	(Includes repent and papillate forms)
					Massive	(Includes globular, pedunculate, tubular and flabellate forms)
					Arborescent	
Bryozoa					Encrusting	
					Soft	(fleshy/lobed/tufted)
					Erect	(rigid)
Ascidians*					Colonial	
					Solitary	
Annelida	Polychaeta			Sabellidae	Worm with tentacle crown/sworl	
				Serpulidae	Worm mass/tube mass	
				Spirorbidae	Hard spirals	
Mollusca	Gastropoda				Snail	
	Bivalvia				Bivalve	
	Scaphopoda				Scaphopod	
	Cephalopoda				Octopus	
					Squid	
Echinodermata	Asteroidea				Seastar/Starfish	
	Echinoidea				Urchin	
	Ophiuroidea				Brittlestar	
Crustacea	Malacostraca				Crab	
					Shrimp	
					Hermit crab	
					Spider crab	
Pisces**	Osteichthyes (teleosts)				Individual species identifications	
	Chondrichthyes (elasmobranchs)					

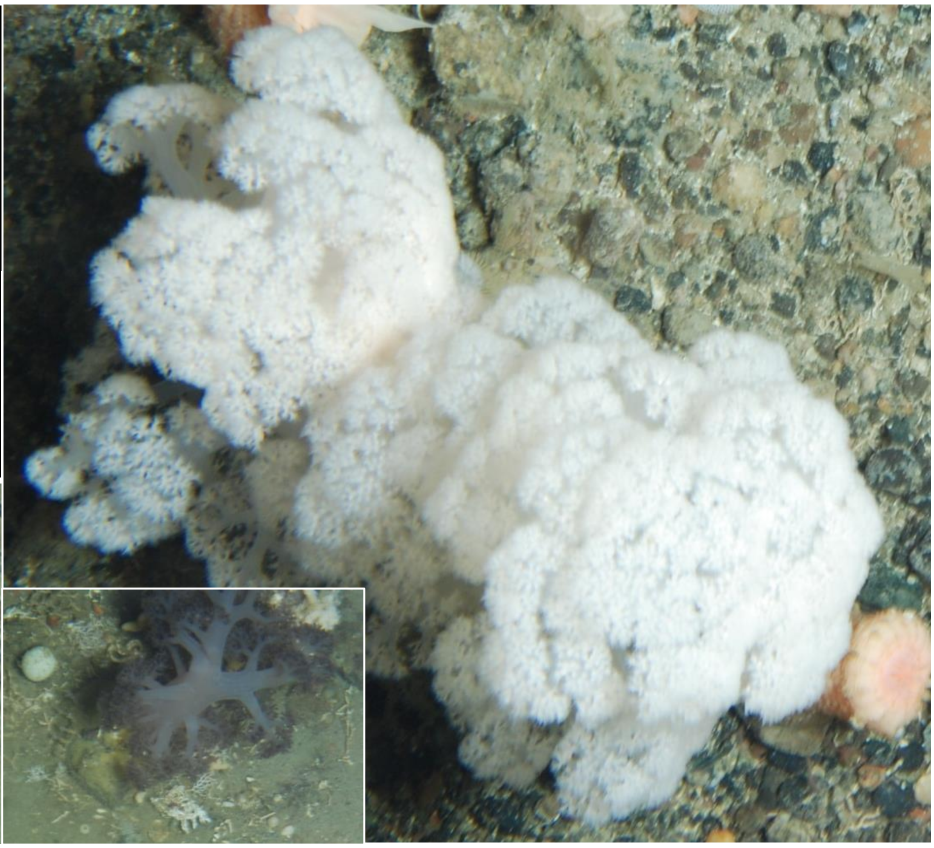
*Chordata (Subphylum Tunicata (urochordates))

**Chordata (Subphylum Eurochordata (vertebrates))

PHYLUM CNIDARIA

Class	Anthozoa
Subclass	Octocorallia
Order	
Family	
Finest level categorisation	Octocoral
Description / note	

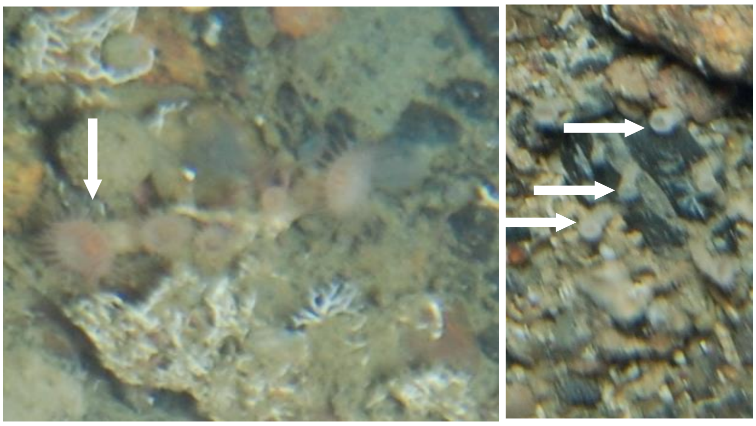
Soft corals are very difficult to identify to species (or even genus) from photos, and even when examined under a microscope. The white coral is possibly *Driftia sp.,* or *Capnella sp*.



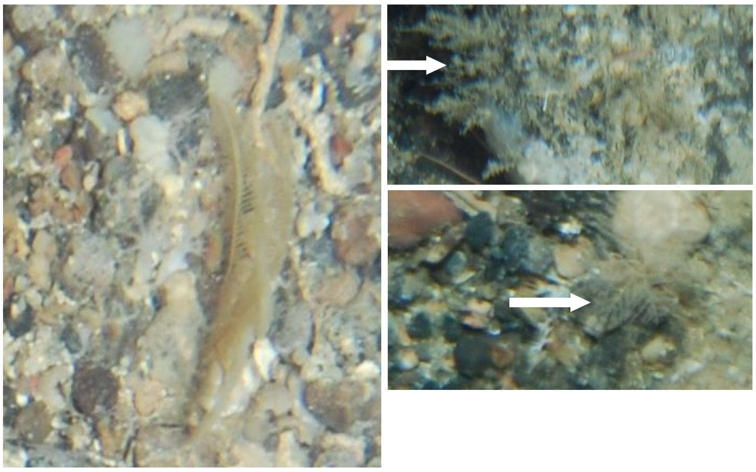
Class	Anthozoa
Subclass	Hexacorallia
Order	Actinaria
Family	
Finest level categorisation	Anemones
Description / note	

Includes anemones and jewel anemones (corallimorpharia)

Class	Anthozoa
Subclass	Hexacorallia
Order	Zoanthida
Family	
Finest level categorisation	Zoanthids
Description / note	



Class	Hydrozoa
Subclass	Hydroida
Order	
Family	
Finest level categorisation	Hydroid
The first image is possibly *Nemertesia ramulosa*, or *Nemertesia anntennina*. The hydroids in the top right image are likely to be in the family *Sertulariidae.*	



Class	Hydrozoa
Subclass	
Order	
Family	Stylasteridae (hydrocorals)
Finest level categorisation	Stylasterid
Description / note See section4.2.2. for discussion of stylasterid identification	

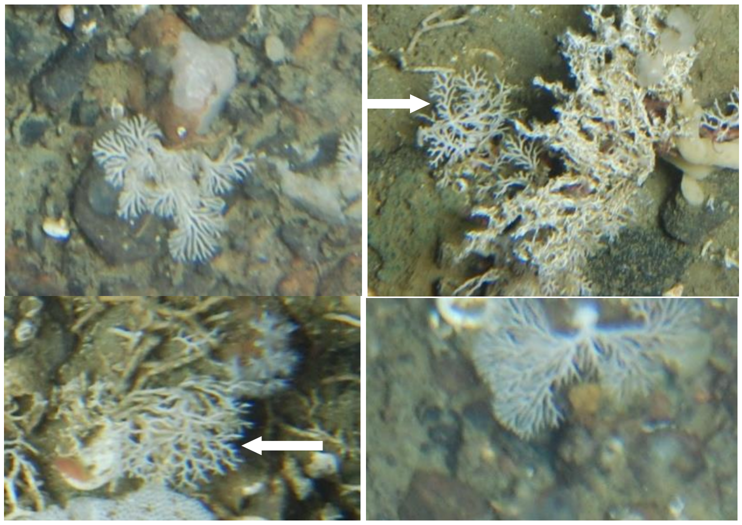
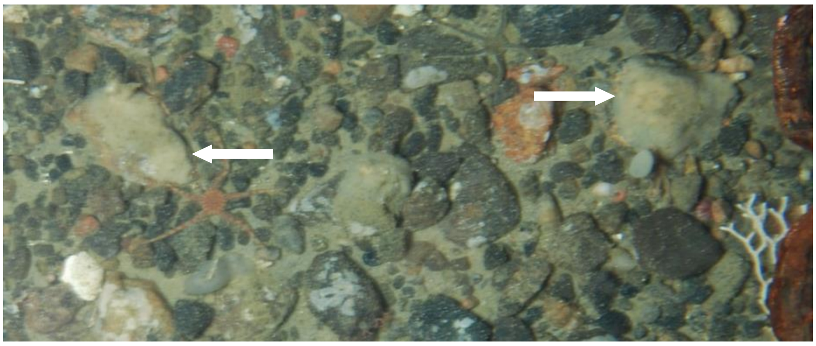


Figure 3. Finest level categorisations within the phylum Cnidaria

PHYLUM PORIFERA (SPONGES)

Class	
Subclass	
Order	
Family	
Finest level categorisation	Encrusting
Description / note	
Includes repent and papillate forms	



Class	
Subclass	
Order	
Family	
Finest level categorisation	Massive
Description / note	
Includes globular, pedunculate, tubular and flabellate forms	

Class	
Subclass	
Order	
Family	
Finest level categorisation	Arborescent
Description / note	
Includes arborescent forms	

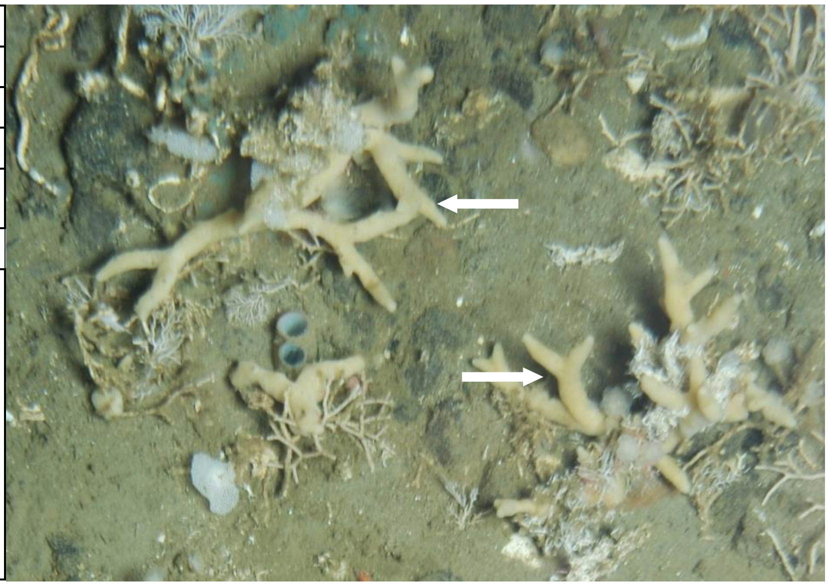
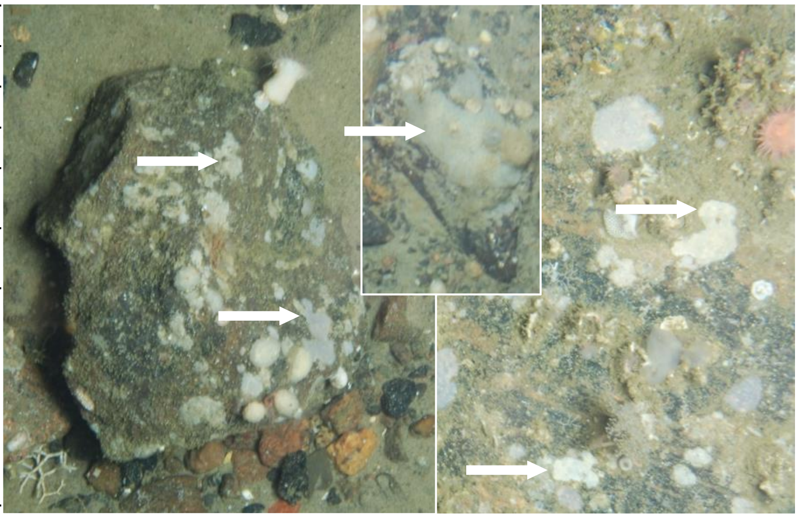


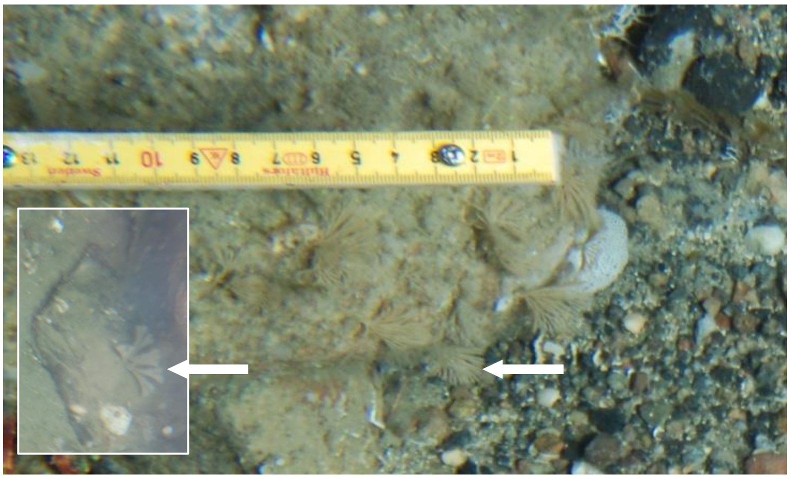
Figure 4. Finest level categorisations within the phylum Porifera

PHYLUM BRYOZOA

Class	
Subclass	
Order	
Family	
Finest level categorisation	Encrusting
Description / note	
Includes all encrusting forms	



Class	
Subclass	
Order	
Family	
Finest level categorisation	Soft
Description / note	
Includes all soft, fleshy, lobed colonies	



Class	
Subclass	
Order	
Family	
Finest level categorisation	Erect
Description / note	
Includes all erect, rigid forms	

Figure 5. Finest level categorisations within the phylum Bryozoa

ASCIDIANS (Phylum Chordata, subphylum Tunicata)

Class	
Subclass	
Order	
Family	
Finest level categorisation	Colonial
Description / note	

Class	
Subclass	
Order	
Family	
Finest level categorisation	Solitary
Description / note	
The animal in the first image is probably *Botrylloides aureum*	

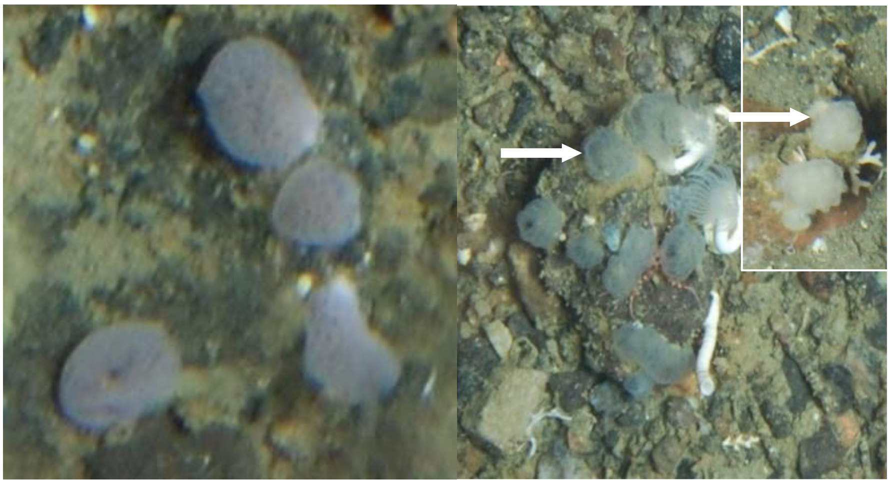
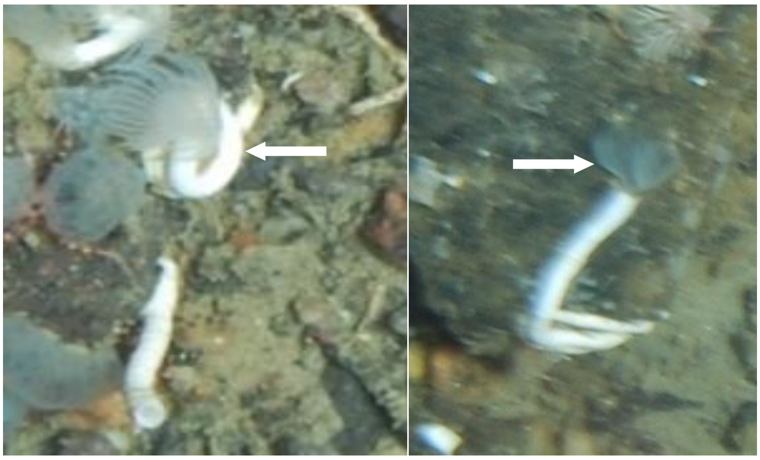


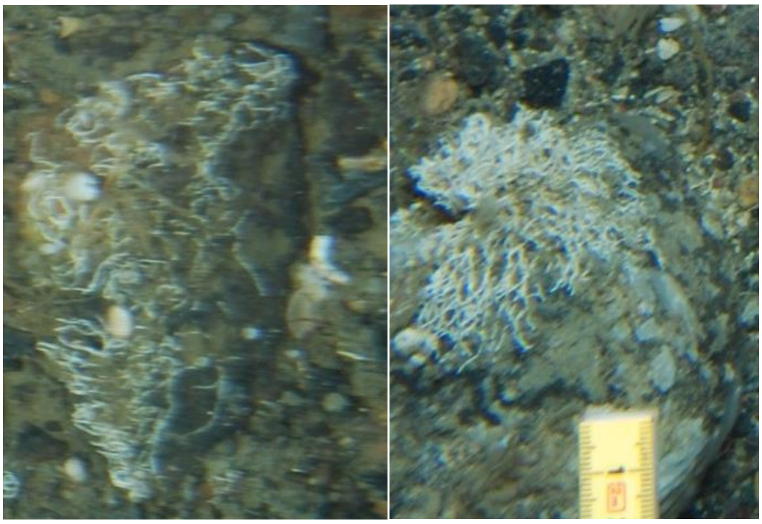
Figure 6. Finest level categorisations of ascidians (phylum Chordata, subphylum Tunicata)

PHYLUM ANNELIDA

Class	Polychaeta
Subclass	
Order	
Family	Sabellidae
Finest level categorisation	Worm with tentacle crown/ sworl
Description / note	



Class	Polychaeta
Subclass	
Order	
Family	Serpulidae
Finest level categorisation	Worm mass/tube mass
Description / note	



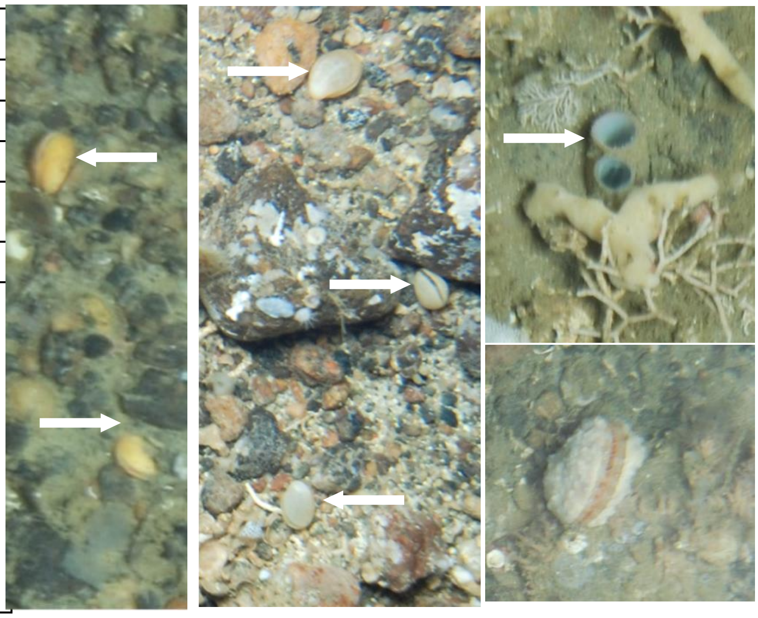
Class	Polychaeta
Subclass	
Order	
Family	Spirorbidae
Finest level categorisation	Hard spirals
Description / note	

Figure 7. Finest level categorisations within the phylum Annelida

PHYLUM MOLLUSCA

Class	Gastropoda
Subclass	
Order	
Family	
Finest level categorisation	Snails
Description / note	

Class	Bivalvia and brachiopoda
Subclass	
Order	
Family	
Finest level categorisation	Bivalvia and brachiopoda
Description / note	
Cannot distinguish reliably between the bivalves and brachiopods at this level. The white shells in the second image look like the brachiopod *fx. Terebratulina.* The siphon in teh top right image is likely that of a geoduc clam. Bottom right image is possibly the scallop *Pecten araneus*.	



Class	Scaphopoda
Subclass	
Order	
Family	
Finest level categorisation	Scaphopod
Description / note	

Class	Cephalopoda
Subclass	
Order	
Family	
Finest level categorisation	Octopus
Description / note	

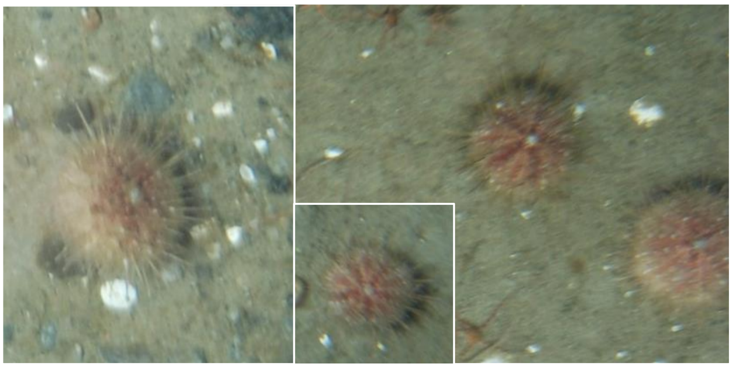
Figure 8. Finest level categorisations with in the phylum Mollusca

PHYLUM ECHINODERMATA

Class	Asteroidea
Subclass	
Order	
Family	
Finest level categorisation	Starfish (seastar)
Description / note	

Class	Ophiuroidea
Subclass	
Order	
Family	
Finest level categorisation	Brittlestar
Description / note	

Class	Echinoidea
Subclass	
Order	
Family	
Finest level categorisation	Urchin
Description / note	



Class	Holothuridae
Subclass	
Order	
Family	
Finest level categorisation	Holothurian
Description / note	

Figure 9. Finest level categorisations within the phylum Echinodermata

PHYLUM CRUSTACEA

Class	
Subclass	
Order	
Family	
Finest level categorisation	Crab
Description / note	

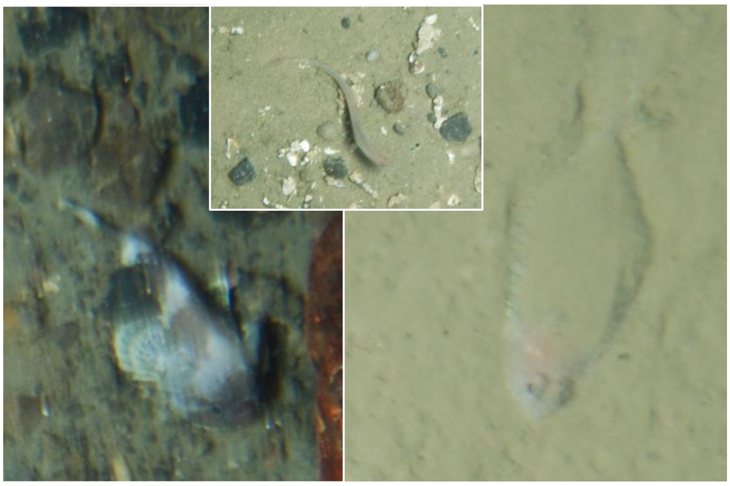
Class	
Subclass	
Order	
Family	
Finest level categorisation	Hermit crab
Description / note	

Class	
Subclass	
Order	
Family	
Finest level categorisation	Shrimp
Description / note	

Figure 10. Finest level classifications within the phylum Crustacea

PISCES

Class	Osteichthyes (teleosts)
Subclass	
Order	
Family	
Finest level categorisation	Fish (sp.)
Description / note	



Class	Chondrichthyes (elasmobranchs)
Subclass	
Order	
Family	
Finest level categorisation	Shark/ray/skate (sp)
Description / note	

Figure 11. Finest level classifications within the group pisces (phylum Chordata, subphylum Eurochordata)

Counting organisms according to their finest level categorisation is straightforward for those which exist as distinct individuals: a single urchin, or even a single soft coral colony that stands alone as an entity. It becomes more difficult when dealing with colonial or encrusting organisms such as bryozoans, hydroids, ascidians and sponges, and even serpulid worms which can form carpet-like cover over rocks and rubble (see Figures 4-7). For these organisms which could not be counted as individuals, a record of “1” was made if they were present in a grid square. This system was applied to encrusting and soft bryozoans, encrusting sponges, colonial ascidians, and hydroids when they formed a carpet-like cover and could not be identified as individuals.

Recording in this way (“1” or “0”) is essentially building a presence-absence dataset. With this in mind, a record was also kept treating all other groups (those individuals which could be identified and counted as individuals) in the same way. Regardless of whether a species was observed once or many times within one square it was recorded only one time as present in that grid. A presence-absence dataset therefore exists for all images from all stations. However for the purposes of this report, actual count data was used in the statistical analysis. No analysis has been undertaken on the pure presence-absence dataset.

During image processing representative examples of each type of fauna observed were collated and used for identification to a more informative level (genus and species when possible). This is an ongoing process which will benefit from collaboration between scientists working in northern regions.

4.1.2.1. Sponges

Sponges were categorised by morphology, not by family or genus/species. Single species within the phylum porifera can encompass a wide variety of colours, shapes and sizes, and as such are notoriously difficult to classify. However visual classification of sponges into morphological variant categories ,rather than taxonomic categories, is a tested means of establishing a qualitative estimate of sponge diversity (Bell and Barnes 2001). According to the system developed by Bell and Barnes (2001) sponges can be assigned to one of nine morphological categories: encrusting (EN), massive (MA), globular (G), pedunculate (PE), tubular (TU), flabellate (FL), repent (RE), arborescent (AR), pappillate (PA) (Figure 12). Classification in this way, although not taxonomically-based, is a realistic means of estimating the contribution of sponges to the biodiversity of the benthos especially from visual survey data. For the purposes of this study, these 9 categories were simplified to 3. Encrusting, repent and papillate sponges, often very difficult to distinguish from each other in the images, were classified as “encrusting”. Massive, globular, pedunculate, tubular and flabellate forms were classified as “massive”. Most of these morphotypes were not in fact encountered; the vast majority of sponges were massive or globular. Arborescent sponges were classified as distinct group.

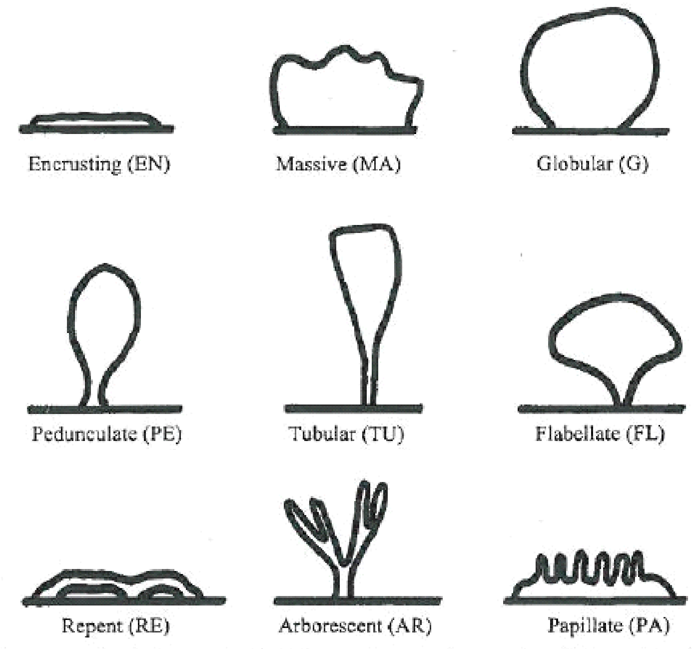


Figure 12. Categorisations of sponges by morphotype (taken directly from Bell and Barnes 2001).

4.1.2.2. Bryozoans and ascidians

All species within the phylum byrozoa are sessile and colonial and colonies exhibit a very wide range of shapes and sizes. Colonies can form encrusting sheets, soft, fleshy, lobed colonies, or erect, rigid growths. Bryozoans will grow on almost any surface including growing on other fauna, and though some can be identified through a distinct colony shape, most require much closer examination to enable identification. For the purposes of this work bryozoa where classified by morphology as: encrusting, soft, and erect colonies.

Ascidians (sea squirts) can be found as solitary individuals or as colonies, and will also settle and grow on almost any available surface. Identification of ascidians also usually requires close examination of the specimen. For the purposes of this work ascidians where classified in the simplest terms as colonial or solitary forms.

4.1.3. Rubble and debris

If observed covering notable areas, rubble and debris can be considered a substrate type in their own right. In the images collected during this study rubble (coral and other biogenic rubble) and shell debris were often observed but usually in a patchy distribution or as single shells or broken coral branches. For this reason they were recorded as individual observations rather than treated as a substrate type (and recorded as percentage cover). Broken coral and other forms of rubble, although occurring naturally on the seafloor, are also indicators of physical disturbance, and the relationship between these observations and fishing intensity in the region was further investigated (section 5).

4.2. Constraints to the scope of image analysis

4.2.1. Building a robust dataset

Ideally all images from each station would be fully analysed and the complete dataset subjected to statistical analysis. Similarly, as species are generally recognised as the essential baseline for understanding diversity, ideally all faunal records would be identified to species level, and incorporated into the analysis. This level of detail was not possible at this stage for two reasons.

When initially planning the camera survey undertaken in June, the number of images which could be realistically collected was estimated at 4–6 images from 4 stations per night. Over a duration of 8 nights this was expected to result in 160 images (~32 stations) available for analysis. In reality the camera survey was very much more time-effective than predicted. A minimum of 6-10 good images were collected from 49 stations over the duration of the cruise, giving a total of 464 images. This was almost 3 times more than expected, and than accounted for when planning the schedule for analysis. The success of the fieldwork was encouraging, however time constraints required a re-think of the approach to analysis of the image dataset.

The choice of sampling stations targeted during the camera survey was made entirely based on the need to gather images from areas which had been subjected to a range of fishing intensities, and from a variety of depths. No prior knowledge of substrate type went into the choice of locations. The 49 stations that resulted varied widely in substrate type, depth, fishing intensity and latitude. They also varied widely in the historical pattern of fishing. Some locations were trawled very heavily between 1996 and 2001 with minimal or no trawling since. Others were not targeted by the fishery until the past 5 years. These patterns are important in terms of trying to understand both the level of disturbance that the benthos has been subjected to, and what time or opportunity it has had to recover. For these reasons it was deemed more valuable at this point to gain a broad perspective on the patterns which characterise each station, and to develop a system of image analysis and data treatment which could be enhanced and improved with additional data, than to undertake a completely comprehensive analysis of very few stations.

Six images per station were analysed. This required the work of 3 people. Variation in skill and level of familiarisation with the regional fauna meant that these records needed to be checked for consistency between viewers before the data could be entered into the analysis. One image per station has been fully checked, and only data from these checked images have been subjected to analysis (see section 3.3 for further discussion of this point). 39 of the total 49 stations were completed to this level. The distribution of these stations into depth categories and trawl history categories is summarised for quick reference in Tables 3 and 4 respectively.

4.2.2. Limitations to fauna identification

Benthic organisms, particularly encrusting fauna, can be extremely difficult to distinguish from each other. There are undoubtedly observations in this dataset which have been wrongly categorised. Organisms recorded in the stylasterid category may, on closer inspection, belong to a number of families of invertebrates that form networks of hard white tube cases resembling hydrocorals. Encrusing sponges and colonial carpeting ascidians are equally likely to be confused with each other. From images of this resolution it is difficult to confidently distinguish between bivalves and brachiopods. Certain organisms categorised as bryozoans may on closer inspection turn out to be sabellariidae worms or hydroids. The occurrence of encrusting organisms in general (sponges, bryozoans, ascidians, worms), is vastly underestimated because they simply cannot be distinguished from substrate or from each other in many cases.

However, it is important to note that while designations may not always be ultimately correct, and can certainly be improved upon with input from specialists, incorrect identifications will nevertheless still accurately reflect the contribution of that organism to the structural component of the ecosystem (erect/rigid versus soft, encrusting or motile) and likely also the functional component and ultimately remain valid and extremely useful in terms of describing the community assemblage.

4.3. Organisation of data processing to facilitate the building of the dataset

The taxonomic level to which identifications can be made impacts upon the biodiversity, richness and distribution measures ultimately derived from the dataset. Clearly the value and accuracy of these ecosystem measures improve as the identification level improves.

The data archive has been built in such a way that it can be readily updated with this additional data once it is available, as well as readily updated with the existing data from the 5 remaining images analysed for each station, once these have been checked for quality and consistency. This process can also be relatively easily expanded upon to incorporate data from other sources such as information gained from physical samping (section 8).

5. Data Analysis

Each station was assigned to categories dependent upon the dominant substrate (Table 1), depth categories (Table 3) and trawl history category (Table 4), and five indices of ecosystem structure and function were calculated for each station:

- Biodiversity (H') on a finest level classification
- Species richness indices as a total number of organisms counted (S_o)
- Proportional abundance of each phylum represented
- Proportional abundance of habitat niche represented
- Proportional abundance of functional group represented

Table 3. Distribution stations amongst depth categories

Depth (m)	Stations
100-150	st21, st33
150-200	st11, st12, st13, st14, st18, st19, st22, st38
200-250	st15, st16, st17, st20, st23, st24, st25, st26, st27, st28, st30, st31, st36, st40, st41, st42
250-300	st1, st32, st34, st35, st37, st39, st46
300-350	st2, st8
350-400	st7
400-450	st4
450-500	st6
500-550	st5

Table 4. Distribution of stations amongst trawl history categories

Trawl history categorisation	
Z	st14, st21, st22, st38, st39, st40, st42
L	st2, st7, st13, st32
LM	st4, st6, st12, st15, st18, st19, st33
HM	st1, st11, st16, st17, st20, st23, st24, st31, st34, st35, st36, st37
H	st5, st8, st25, st26, st27, st28, st30, st41, st46

PR	st4, st6

5.1 Calculation of community indicators

Biodiversity is generally defined on the basis of two factors: species richness (the number of species in the community), and species evenness (the relative abundance of species in a community). A high value of species richness is an obvious indicator of higher diversity within a community. Species evenness is equally important in the context of describing and understanding a community. A community dominated by one species (ie with low species evenness or a wide range of relative abundance measures), is less diverse than one characterised by a more even distribution of species.

5.1.1 Species richness

Richness was calculated at two scales for each station: number of taxa observed (S_t) and number of organisms counted (S_o).

5.1.2. Diversity (Shannon-Wiener diversity index)

The Shannon-Weiner index (H') is a commonly applied measure of species diversity which incorporates both species richness and evenness. The minimum value of H' is 0, which would describe a community with a single species. Higher H' values are associated with greater diversity and a community that is not generally dominated by a few species.

H' was calculated in two ways for each station.

- Based on the total record of organisms observed at the finest taxonomic level (see section 4.1.2, Table).

- Based on presence-absence data (see section 4.1.2)

The analyses described in this report use only H' calculations based on the *total record of organisms observed at the finest taxonomic level*.

5.1.3 Proportional abundance measures

Species-level measures of diversity and evenness are not, on their own, sufficient indicators of the health and function of an ecosystem or community. Ecosystem function is affected by a complex web of interactions within the community itself. The representation within the community of different functional groups (which can be categorised by behaviour, feeding-type, trophic level, morphology, etc.) is as important, if not more important, than the number or diversity of species themselves. The concept of relative or proportional abundance (or evenness, as described above) can be equally applied to functional groups within the community. Three broader-level community descriptor measures were investigated here.

5.1.3.1. Phylum-level representation

Recording and treating fauna observations by 'finest taxonomic level' (section 4.1.2), though a valid record of diversity within the community, skews the interpretation of real taxonomic groupings. Although many individuals within the echinodermata, crustacea, and vertebrata phyla can relatively easily be identified to species level from image data, this is simply impossible for many cnidaria and tunicate, and especially bryozoa and porifera. For this reason the finest-level true taxonomic grouping that can be confidently assessed across all groups is phylum. Observations were therefore grouped by phylum and the proportional abundance of each phylum calculated for each station. Note that the generic term 'pisces' was used to encompass all fish observations.

5.1.3.2. Habitat niche

Differences in morphology, or perhaps more accurately in the contribution of different types of organisms to the three dimensional structure of the community, was addressed by categorizing the fauna in terms of the habitat niche they represented. 'Habitat niche' is a vague term and a somewhat arbitrary categorization, but was designed to reflect the three dimensional nature of the community, as created by the fauna itself (ie not dictated by the substrate). This feature of benthic communities, the biogenic habitat created by the organisms themselves, is important. The three dimensional structure provided by stony corals in the form of reefs and soft coral or sponges and other epifauna in the form of gardens or community assemblages, is known to enhance the diversity and biomass of the rest of the associated community. This effect is difficult to quantify but attempts to do so in northern waters is currently the focus of a major collaborative European project (CoralFISH Project, EU Framework 7). For the purpose of describing the biogenic habitat of the stations in this study, fauna were categorised into six groups: encrusting, sessile 1-5cm, sessile 5cm+, infauna, benthic motile, and pelagic motile (Table 5).

Table 5. Assigned habitat niche categorisations
* indicates acknowledgement of a very arbitrary categorisation

Encrusting	Sessile 1-5cm	Sessile 5cm+	Infauna	Benthic motile	Pelagic motile
Encrusing porifera	Zoanthids	Octocoralia	Bivalve	Gastropod	Octopus
Encrusing bryozoa	Anemones	Large stylasterids	Scaphopod	Starfish	Fish
Hard spirals (annelida)	Hydroids	Aborescent porifera	Scallop*	Urchin	Shark/ray/skate
	Small stylasterids			Brittlestar	Shrimp
	Massive porifera*			Holothurian*	Amphipod
	Erect and soft bryozoa			Crab	
	Colonial and solitary ascidians			Hermit crab	
	Mass of tubes (annelida)				
	Tentacle sworl (annelida)				

5.1.3.3. Functional groups (feeding)

Modeling ecosystem structure and function also generally necessitates the categorization of fauna into functional groups based on feeding behaviour or trophic level. Again, this type of categorization is somewhat arbitrary and can be undertaken on a spectrum of broad or specific groupings, but is another attempt to quantify or illustrate the community in terms of the interactions between members of the assemblage. For the purpose of this study fauna were categorised into three broad functional groups: filter feeders, grazers and predators (Table 6). The very basic level of this categorization must be stressed; very few organisms fall neatly into one single functional group.

Table 6. Assigned functional group categorisations.
*indicates acknowledgement of a very arbitrary categorisation

Filter feeders	Grazers	Predators
All cnidaria*	Gastropod	Octopus
All porifera*	Starfish*	Fish
All bryozoa	Brittlestar	Shark/ray/skate
All tunicata*	Urchin	Shrimp*
All annelida*	Holothurian*	Amphipod
Bivalve	Hermit crab	Crab*
Scaphopod		
Scallop*		

5.2. Treatment of the fishing data

A trawl history categorisation was assigned to each station. Trawling intensity was calculated as the average nautical miles trawled per year for each five year period (1996-2000, 2001-2005, 2006-1010). These 5-year averages were then *summed* and this sum used to designate trawl history categorisation.

Trawl history categorisations are:

- Z (ZERO): no trawling in the 15 year historical record
- L (LOW): sum of 5yr average annual trawled distance is 0-15 nm
- LM (LOW-MEDIUM): sum of 5yr average annual trawled distance is 15-100 nm
- HM (HIGH-MEDIUM): sum of 5yr average annual trawled distance is 100-200 nm
- H (HIGH): sum of 5yr average annual trawled distance is > 200 nm
- PR (POTENTIAL RECOVERY SITE): any site were trawling activity has been undertaken 15-5 years ago, but where there has been no activity in the past 5 years

These are arbitrary designations. “Low” does not designate a biologically low or safe limit, only a categorisation designated to facilitate the choice of survey target areas. This method of summing 5 year averages in favour of using a mean of all 15 years simply amplifies the differences between stations.

5.3 Statistical analysis of the dataset

Initially, one-sample Kolmogorov-Smirnov tests were conducted to test the distribution of the data. The results of these analyses are presented in Appendix 1. Significant results were found in the majority of cases, which serve to indicate non-normality. The Johnson family of transformations was applied to attempt to normalize these measures, but distributions are too highly non-normal to be successfully transformed for parametric testing. For this reason, non-parametric tests were utilized in subsequent analyses.

The analyses conducted aims to understand the relationship between fishing intensity recorded in 5 ways (mean 1996-2001, mean 2001-2005, mean 2006-2010, as a sum of each five year mean, and as a mean over 15 years) and the 6 response variables which describe the ecosystem (species richness, diversity, rubble count, and proportional abundance indices of phylum, niche and functional group), accounting for expected effects of depth and substrate type on these ecosystem measures.

These analyses utilize Spearman's rho, a non-parametric correlation coefficient, as well as quantile regression, which is a more robust form of linear regression, preferred when outliers, non-normality, or other violations of the assumptions of linear regression are present within the data.

Initially, a set of Spearman's correlation coefficients were conducted between the measure of depth and all ecosystem measures included in these analyses. None of these analyses were found to achieve statistical significance, indicating that within this limited dataset depth is not associated with any of the ecosystem measures used. For this reason, depth was not included as a control in any of the subsequent analyses. Additionally, a series of Kruskal-Wallis one-way analyses of variance were also conducted between substrate type and all ecosystem measures. In cases where a significant result was found, indicating significant differences in the ecosystem measures on the basis of substrate type, substrate type was included in the following regression analysis. A finding of non-significance served to indicate that substrate type was not a significant predictor of the ecosystem measure in question, and so was excluded from the subsequent regression analysis. In these situations, as no factors needed to be controlled for, Spearman's rho was utilised as opposed to a quantile regression analysis.

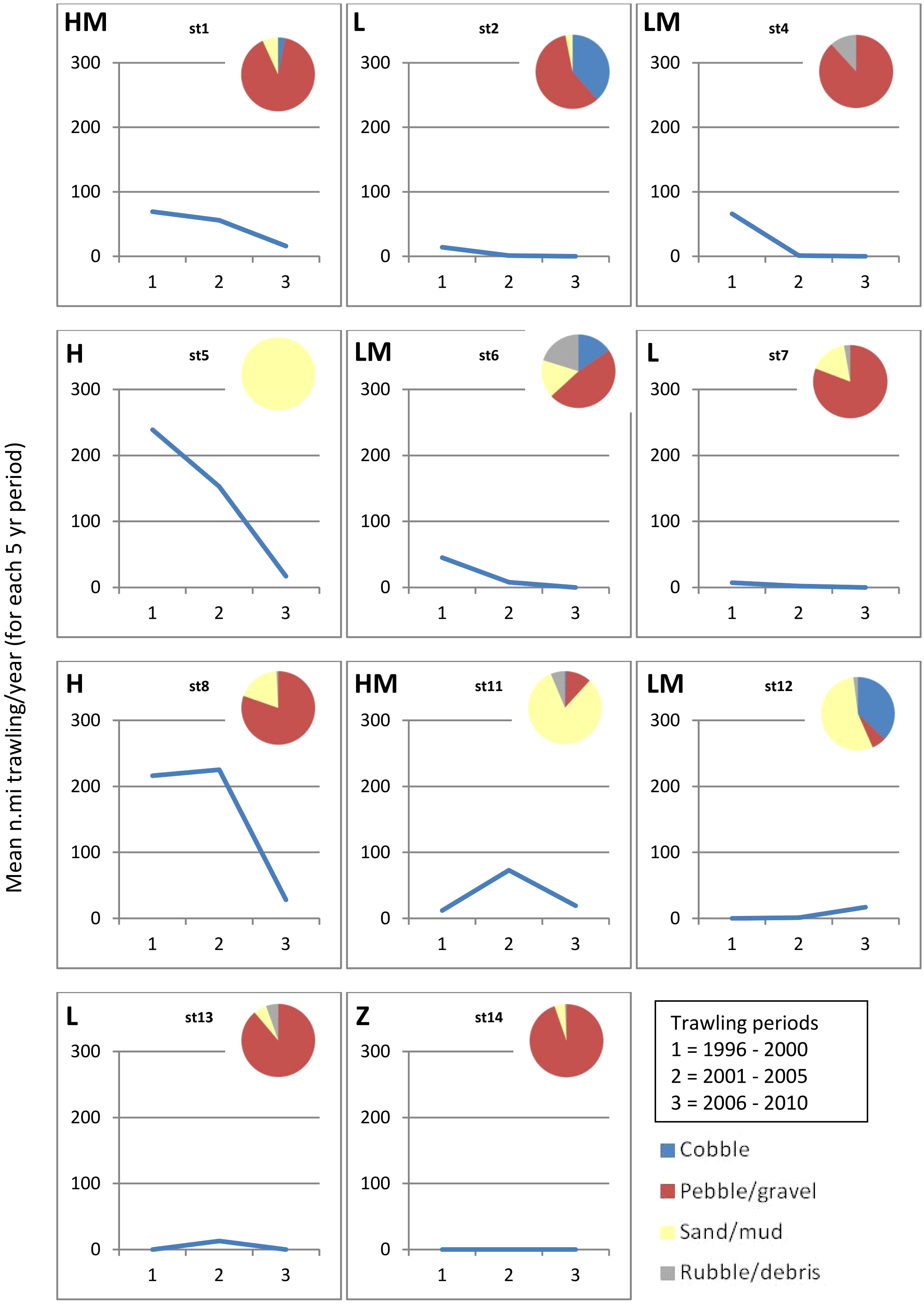
6. Results

6.1 Description of stations

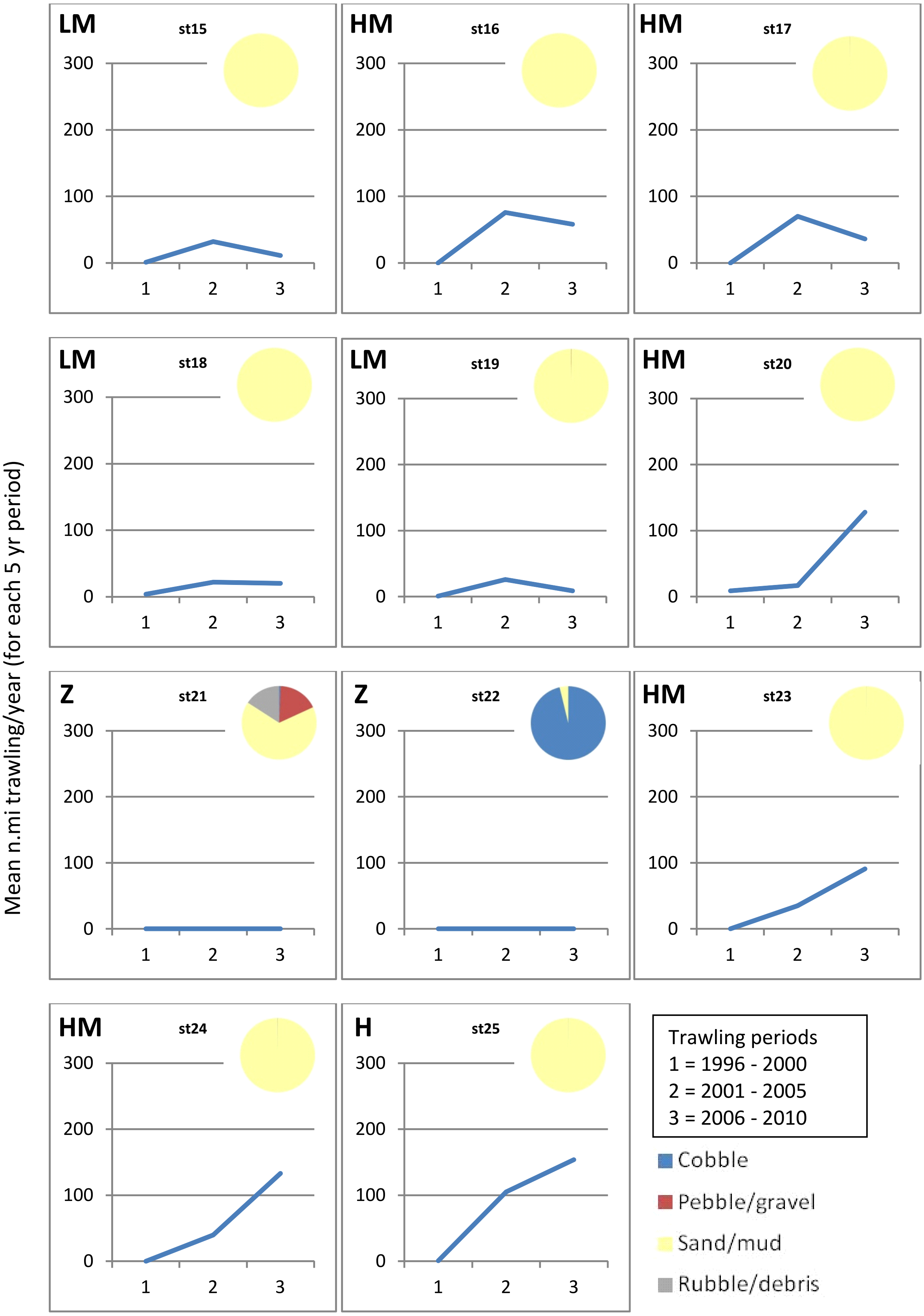
The data collected in this study are in the form of 56 x 40 cm images of the benthos. From snapshots of these dimensions it was not possible to directly observe physical trawl marks, and no lost gear was observed. Boulders which showed some signs of having been turned (which often results from being rolled by ground gear) were observed periodically.

An overview of the patterns of fishing intensity, the substrate observed at each station and the geographic distribution of stations sampled is given in Figure 13. With the exception of cobble substrate, all substrate types were represented across a wide depth range (Figure 14). The proportional abundances of phyla at each station varied widely and are illustrated (grouped by the dominant substrate type found at that station) in Figure 15.

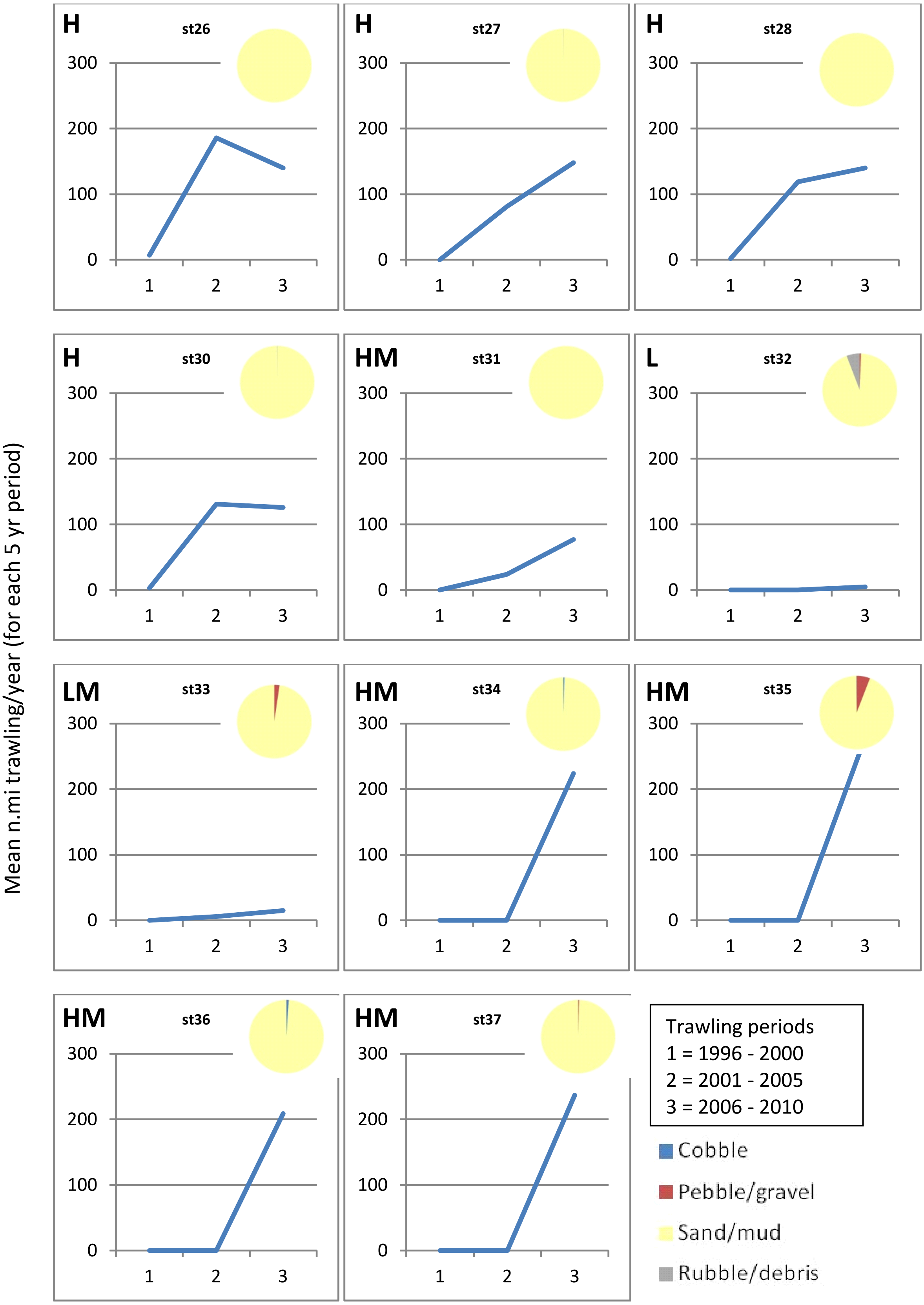
The majority of stations surveyed fell between 200 and 300m depth (Figure 16), and high intensity fishing (mean n.mi trawling/15 yrs) between 1996 and 2001 was generally targeted between 200 and 350m depth (Figure 17).



Mean n.mi trawling/year (for each 5 yr period)
HM st1
L st2
LM st4
H st5
LM st6
L st7
H st8
HM st11
LM st12
L st13
Z st14
300
200
100
0
1 2 3
Trawling periods
1 = 1996 - 2000
2 = 2001 - 2005
3 = 2006 - 2010
Cobble
Pebble/gravel
Sand/mud
Rubble/debris



Mean n.mi trawling/year (for each 5 yr period)
LM
st15
HM
st16
HM
st17
LM
st18
LM
st19
HM
st20
Z
st21
Z
st22
HM
st23
HM
st24
H
st25
300
200
100
0
1
2
3
Trawling periods
1 = 1996 - 2000
2 = 2001 - 2005
3 = 2006 - 2010
Cobble
Pebble/gravel
Sand/mud
Rubble/debris


Mean n.mi trawling/year (for each 5 yr period)
H
st26
H
st27
H
st28
H
st30
HM
st31
L
st32
LM
st33
HM
st34
HM
st35
HM
st36
HM
st37
300
200
100
0
1
2
3
Trawling periods
1 = 1996 - 2000
2 = 2001 - 2005
3 = 2006 - 2010
Cobble
Pebble/gravel
Sand/mud
Rubble/debris

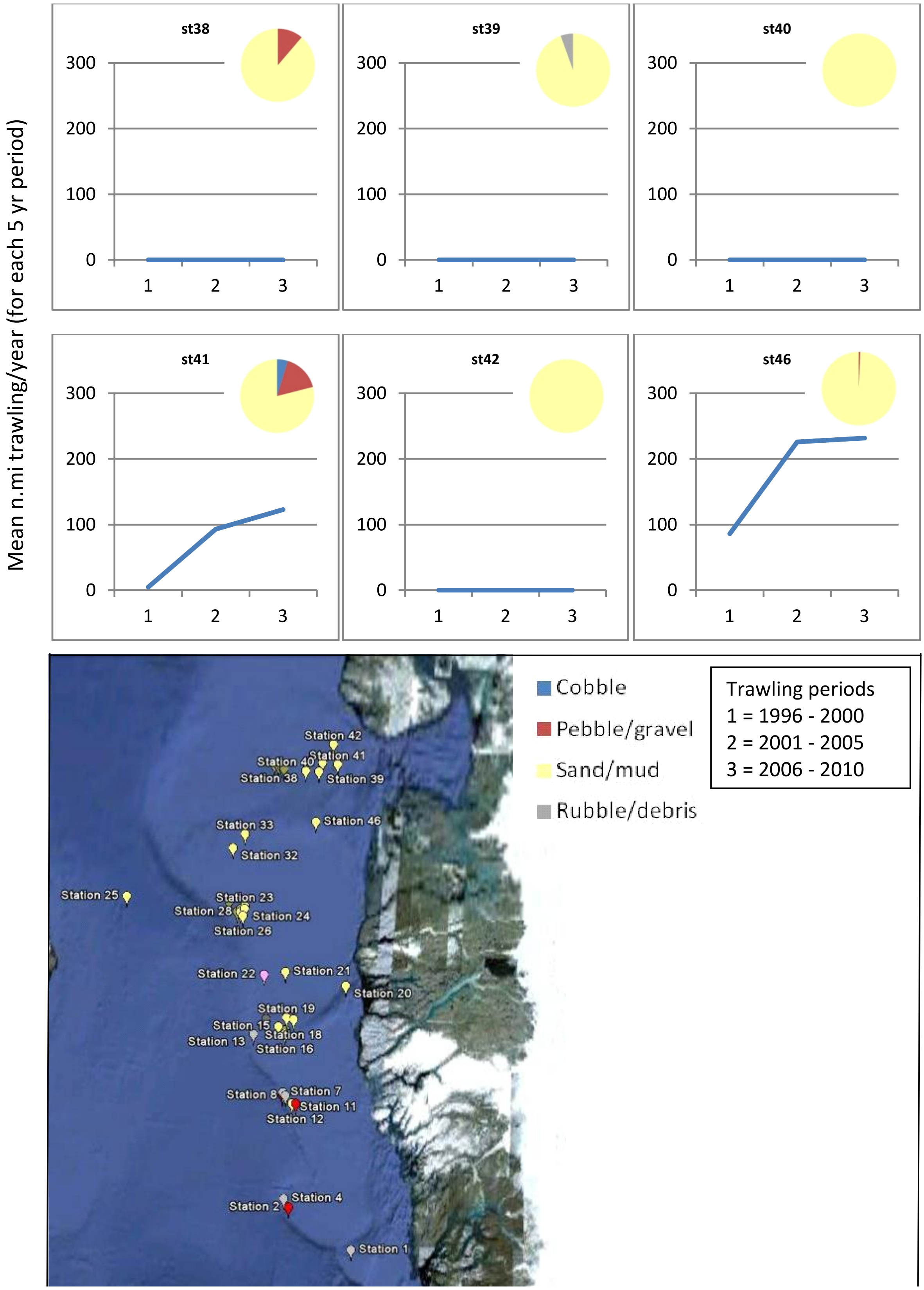


Figure 13. The pattern of fishing activity (1996-2010) and the substrate type apparent at all stations. The category to which each station was assigned for statistical analysis is also given as Z, L, LM, HM and H (see section 3.4).

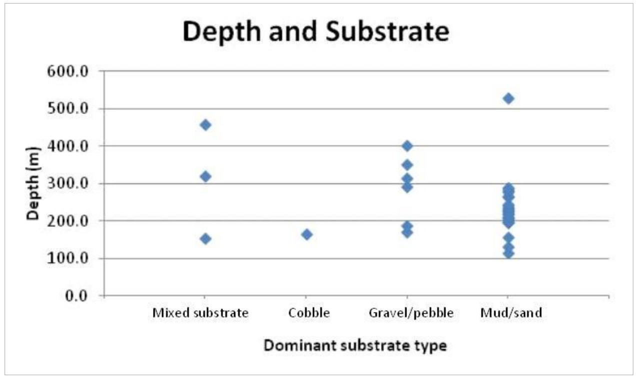


Figure 14. With the exception of cobble substrate, all substrate types were represented across a wide depth range.

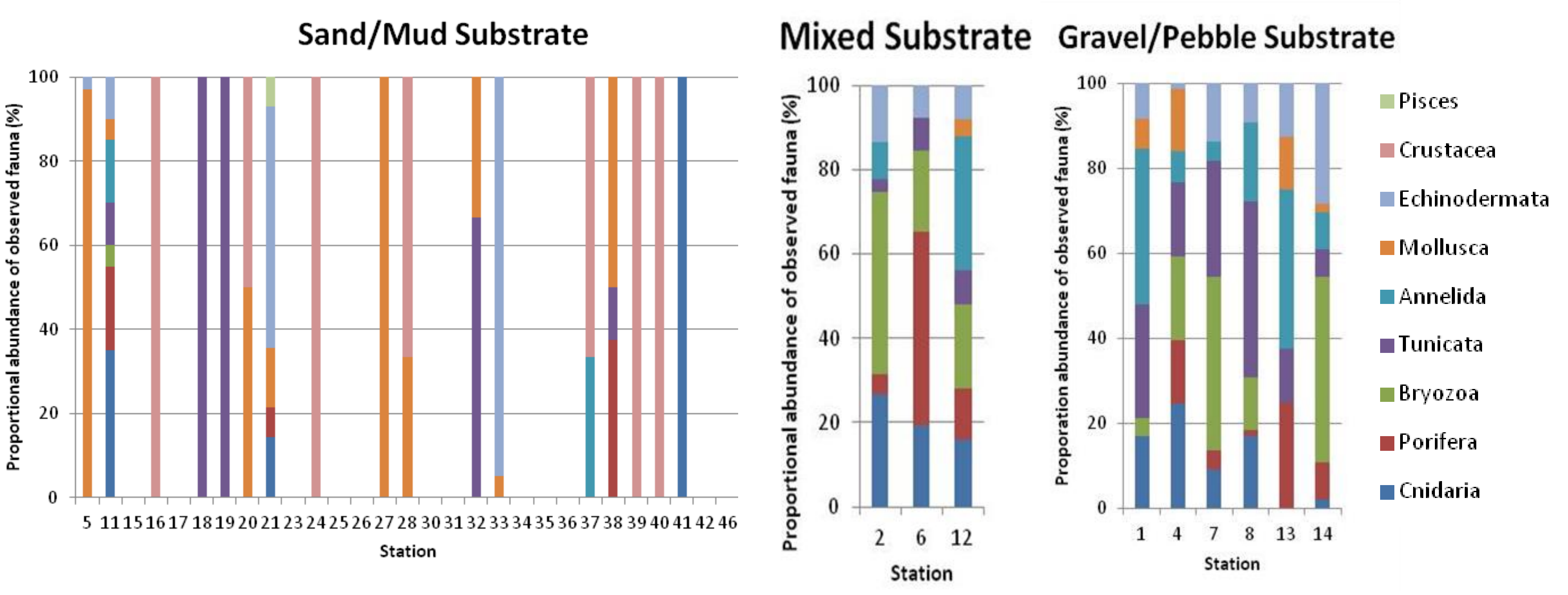


Figure 15. Proportional abundances of phyla at each station, grouped by the dominant substrate type found at that station.

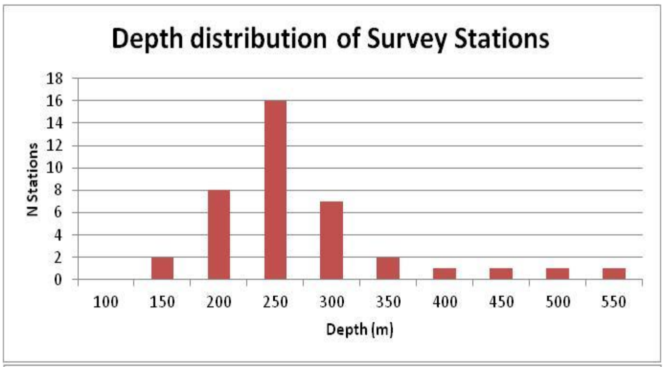


Figure 16. The majority of stations surveyed fell between 200 and 300m depth.

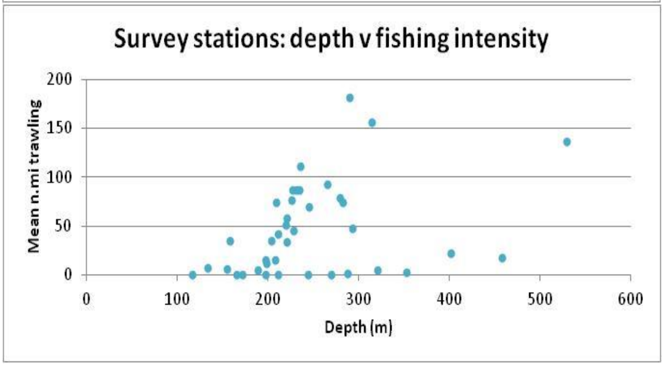


Figure 17. High intensity fishing (mean n.mi trawling/15 yrs) between 1996 and 2001 was generally targeted between 200 and 350m depth.

6.2. Testing the relationship between fishing and ecosystem measures

No significant effect of variations in fishing intensity was found with regard to the number of taxa, diversity (H', Shannon-Wiener index), rubble count, phyla (with the exception of echinodermata), niche measures (with the exception of infauna and benthic motile), and the functional group of predators (Table 7).

The 1996-2000 trawling measure was found to have a significant positive impact on species richness (the number of organisms), and a significant negative impact on the echinoderm phylum, the benthic motile niche, and the grazers functional group. In addition, the 2006-2010 trawling measure had a significant negative impact on the infauna niche and the filter feeders functional group (Table 7).

No other trawling measures (2001-2005, 2006-2010, sum of 5 year means and 15 year mean) significantly impacted on any of the ecosystem measures (Table 7). The small sample size included in these analyses greatly reduces the power of statistical testing and this is discussed further below.

Table 7: Summary of Quantile Regression Analyses and Spearman's Correlations

Measure	*Trawling*			*Fishing*		
	1996-2000	*2001-2005*	*2006-2010*	*Sum*	*Mean*	*Intensity*
Species Richness: N Taxa[a]	.004	.000	-.004	.000	.000	.000
Sand/Mud	-10.017***	-10.000***	-9.988***	-10.000***	-10.000***	-10.000***
Pebble/Gravel	.081	1.000	-2.066	-2.000	-2.000	-2.000
(Constant)	11.000***	11.000***	11.066***	11.000***	11.000***	11.000***
Species Richness: N Orgs[a]	.139***	.000	-.006	.000	.000	-.500
Sand/Mud	-49.252***	-49.000***	-48.667***	-49.000***	-49.000***	-48.000***
Pebble/Gravel	-15.052***	-4.000	-4.000	-4.000	-4.000	-4.000
(Constant)	50.000***	50.000***	50.000***	50.000***	50.000***	50.500***
H' (Shannon-Wiener index)[a]	-.001	.000	.000	.000	.000	.000
Sand/Mud	2.144***	2.152***	2.152***	2.152***	2.152***	2.152***
Pebble/Gravel	.211	.215	.215	.215	.215	.215
(Constant)	-2.144***	-2.152***	-2.152***	-2.152***	-2.152***	-2.152***

Rubble Count[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-2.000***	-2.000***	-2.000***	-2.000***	-2.000***	-2.000***
Pebble/Gravel	.714***	.714***	.714***	.714***	.714***	.714***
(Constant)	2.000***	2.000***	2.000***	2.000***	2.000***	2.000***
Phylum: Cnidaria[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-24.000**	-19.231*	-19.231*	-19.231*	-19.231*	-19.231*
Pebble/Gravel	-14.909	-10.140	-10.140	-10.140	-10.140	-10.140
(Constant)	24.000**	19.231*	19.231*	19.231*	19.231*	19.231*
Phylum: Porifera[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-12.000	-12.000	-12.000	-12.000	-12.000	-12.000
Pebble/Gravel	-3.304	-3.304	-3.304	-3.304	-3.304	-3.304
(Constant)	12.000	12.000	12.000	12.000	12.000	12.000
Phylum: Byrozoa[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-20.000***	-20.000***	-20.000***	-20.000***	-20.000***	-20.000***
Pebble/Gravel	-.247	-.247	-.247	-.247	-.247	-.247
(Constant)	20.000***	20.000***	20.000***	20.000***	20.000***	20.000***
Phylum: Tunicata[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-8.000***	-8.000***	-8.000***	-7.692***	-7.692***	-8.000***
Pebble/Gravel	18.761***	18.761***	18.761***	19.068***	19.068***	18.761***
(Constant)	8.000***	8.000***	8.000***	7.692***	7.692***	8.000***
Phylum: Annelida[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-10.000	-10.000	-10.000	-10.000	-10.000	-10.000
Pebble/Gravel	8.462	8.462	8.462	8.462	8.462	8.462
(Constant)	10.000	10.000	10.000	10.000	10.000	10.000
Phylum: Mollusca[b]	.060	-.016	-.189	-.099	-.099	-.115
Phylum: Echinoderm[a]	-.015***	.000	.000	.000	.000	.000
Sand/Mud	-13.645***	-13.433***	-13.433**	-13.433***	-13.433***	-13.433**
Pebble/Gravel	-1.145***	-.933***	-.933	-.933***	-.933***	-4.202
(Constant)	13.645***	13.433***	13.433**	13.433***	13.433***	13.433**
Phylum: Crustacea[b]	-.213	-.068	.125	.015	.015	-.018
Phylum: Pisces[b]	-.141	-.198	-.198	-.231	-.231	-.238
Niche: Encrusting[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-12.000	-11.940	-11.940	-11.940	-11.940	-11.940
Pebble/Gravel	12.691	12.751	12.751	12.751	12.751	12.751
(Constant)	12.000	11.940	11.940	11.940	11.940	11.940
Niche: Sessile (1-5 cm)[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-68.000***	-68.000***	-68.000***	-68.000***	-68.000***	-68.000***
Pebble/Gravel	-18.000***	-17.383***	-17.383	-17.383***	-17.383***	-17.383
(Constant)	68.000***	68.000***	68.000***	68.000***	68.000***	68.000***
Niche: Sessile (5 cm+)[a]	.000	.000	.000	.000	.000	.000
Sand/Mud	-4.000	-4.000	-4.000	-4.000	-4.000	-4.000
Pebble/Gravel	.545	.545	.545	-4.000	-4.000	.545
(Constant)	4.000	4.000	4.000	4.000	4.000	4.000
Niche: Infauna[b]	-.059	-.127	-.336*	-.207	-.207	-.226
Niche: Benthic Motile[a]	-.015***	.000	.000	.000	.000	.000
Sand/Mud	-13.645***	-13.433***	-12.000***	-13.433***	-13.433***	-13.433***
Pebble/Gravel	-1.145***	-3.574***	.500***	-.933***	-.933***	-.933
(Constant)	13.645***	13.433***	12.000***	13.433***	13.433***	13.433***

Niche: Pelagic Motile[b]	-.076	-.035	.256	.149	.149	.115
Functional Group: Filter Feeders[b]	.282	-.033	-.403*	-.217	-.217	-.217
Functional Group: Grazers[a]	-.015***	.000	.000	.000	.000	.000
Sand/Mud	-13.645***	-13.433***	-12.000***	-13.433***	-13.433***	-13.433***
Pebble/Gravel	-1.145***	-3.574***	.500***	-.933***	-.933***	-.933
(Constant)	13.645***	13.433***	12.00***	13.433***	13.433***	13.433***
Functional Group: Predators[b]	-.267	-.123	.056	-.067	-.067	-.094

*p<.05, **p<.01, ***p<.001; [a]Quantile Regression, [b]Spearman's rho.

7. Discussion

Within the limitations of the dataset to which statistical testing was applied, very few significant interactions between fishing intensity and the chosen measures of ecosystem diversity and function were found. This is not surprising and almost certainly reflects the current strength of the dataset, in terms of the level of detail incorporated, rather than a true absence of an ecosystem response to disturbance.

In particular, the current grouping of observed fauna into functional and niche groups is extremely simplistic, and the small sample size of images included in these analyses greatly reduces the power of statistical testing. An interpretation in ecological terms of the interactions which did show statistically significant relationships (both positive and negative impacts were observed in relation to the 1996-2000 and 2006-2010 fishing intensity data in particular) is not considered appropriate at this point.

However the ultimate objective of any initial biodiversity study is not only to document and describe the faunal assemblage of the target regions but to establish a procedure by which spatial and temporal changes in this assemblage can be detected, and these changes attributed appropriately to known causes of natural variability, or to disturbance impacts from an outside cause. The first surveys of a region are critical to establishing a baseline against which future variation can be measured. A pilot survey such as this one is invaluable for illuminating the strengths and limitations of the survey approach taken, and for the overall development of the most effective survey design.

Interpretation of any impact upon, or change within, a community is clearly most straightforward if the changes being assessed have occurred *after* baseline ecosystem patterns have been established. However retrospective interpretation of the magnitude and consequence of past impacts can be achieved and it is highly likely that this image set can ultimately be used for that purpose. It is abundantly clear that there is a vast amount of ecological information in the images gathered during this survey, and in the growing dataset being assembled from them that has not yet been incorporated into a full-scale analysis.

The direction which further analysis takes, and the design considerations of further surveying, depend very much on the question which is being asked. Bottom trawling, like anything that involves direct contact with the bottom, impacts not only the benthic faunal assemblage but also the substrate upon (and in) which they live. The latter has consequences for the resilience of the benthic community within a larger geographical region (in terms of their potential to recolonise an area after a disturbance) as the physical suitability of that habitat to recruits may have been altered. Proper site selection for surveying is critical and must include relatively pristine, unimpacted habitat in order to understand the natural diversity and variability within the system.

Furthermore, a true assessment of changes in the functional diversity of a community must include sampling of the infaunal fraction of the species assemblage. In a visual survey the infaunal groups are vastly under-sampled, being limited to those relatively large individuals that protrude out of the sediment (siphons, shells); small meiofaunal organisms, and larger infauna which were not protruding above the sediment surface at the time of surveying, are completely absent from subsequent assessments of functional diversity.

8. Potential and recommendations

Continued image analysis: Processing of these photographs to identify and tally visible benthic organisms should absolutely continue; as noted, there is a vast amount of ecological information in the images gathered during this survey that has not yet been incorporated into a full-scale analysis. This will require a greater number of people (possibly facilitating student training), and the input of expert opinion for identification of various benthic taxa.

Integration with other data: To identify signs of physical damage to habitats that might be due to trawling is difficult at this level of observation and these data should be integrated with other surveys in the region operating on a coarser scale of observation (possibly geological surveys, multibeam or acoustic).

Physical sampling: Although photography has proven to be more successful than core or grab sampling at quantifying the abundance and diversity of epibenthic communities in some cases (Ambrose 2003), the value of some level of physical sampling to be incorporated with a visual survey is apparent here. Species are recognised as the essential baseline for understanding diversity. Thus physical sampling and accurate identifications to establish reliable a reference base for species identifications should be considered.

Physical sampling would also enable biomass and basic diversity measures of the meiofaunal component. These species are completely overlooked in a visual study but arevvalid indicators of ecosystem health and function. Limited sampling (grabs, box, cores typically used to sample benthic communities) would be a valuable addition to this work.

Ground truthing: Considerable effort should be made to establish what the benthic assemblage of this region might have been prior to any historical disturbance from ground gear. Stations categorised as “zero” fishing, and those noted as potential recovery (PR) sites, must be much more carefully analysed. Further survey effort must prioritise targeting regions that can be confidently regarded as un-impacted – ideally regions which are large enough to take account of small scale variation in location data associated with fishing activity. The benthic component of the marine community is highly susceptible to direct and indirect disturbance effects of both natural and anthropogenic origin. A growing understanding of the community response to environmental change is improving our understanding of the importance of environmental variation (seabed composition, slope, exposure, temperature) in determining natural distributions, and therefore has far-reaching implications for our understanding of anthropogenic impacts, and ultimately for the development of evidence-based advice for ecosystem-based management practices. Note the incidental observation of very redfish during the trawl survey, coincident with a bycatch of very large Paragorgia colonies (Appendix 2).

ROV and side-orientated camera: Although drop-camera sampling such as that undertaken in this survey is by far the most robust and repeatable visual sampling method (as well as being the most cost and time effective), visual data from ROV transects would add enormous value to the existing and future drop-camera images by enabling a much finer scale analysis of natural shifts in community composition with depth and habitat. Similarly, images from a horizontally-orientated camera would facilitate an assessment of species diversity relative to “benthos height diversity” – a means of quantifying the value of the physical structure of the habitat to the diversity of the community assemblage.

9. Comment

The processing and analysis of this dataset was a vastly larger task than originally envisaged. The unexpected success of the camera survey was an extremely positive sign that this type of impact assessment can be effectively incorporated into the existing infrastructure for stock assessment, though it should be noted that such surveys will require a greater portion of dedicated shiptime as the target regions for data gathering (particularly regions which have been unfished and can function as control areas) become more specific. Note that in this, the first survey, data from virtually any region was of interest, and demands on ship time and movement could therefore be minimal within the constraints of the shrimp stock assessment schedule.

However the unexpected success of the camera survey also resulted in the collection of 3x more images than initially predicted, and than initially accounted for in the calculation of the time needed for processing and analyses. Consequently I employed two students part-time to assist with the first pass at data gathering from the images. Even then I did not include the full dataset (6-10 images from each station) in this analysis, but limited it to one image per station as described above, as there simply was not time for me to undertake a quality check on the student records. Instead, I built the data archive in such a way that it can be readily updated with this additional data once it has been controlled for quality and consistency. Similarly, the data archive is arranged such that species or genus-level identifications can be incorporated as the dataset grows, if associated physical sampling was undertaken in future surveys and enabled confident identification of organisms to this level.

A project such as this is invariably slowest in its early stages. Starting from the beginning, it was necessary to become familiar with identification of the regional fauna, recognise and accept the limitations of the data, and decide upon a taxonomic level at which identifications made from images were robust enough) to be valid. With these factors now in place, this process can be relatively easily expanded upon to incorporate more data from more sources (further surveys and/or sampling), expert input from specialists on identifications, and will constitute a highly valuable impact assessment process.

This analysis is not suitable for publication in a scientific journal at this stage, nor should it be interpreted as sufficiently comprehensive to in any way advise management policy. However, I would very strongly advocate for the completion of this work into a full visual-based impact assessment and subsequent publication. The full image dataset constitutes a valuable ecological dataset and should be treated as such, not restricted to the broad-scale level of interpretation possible within the context of this reporting period.

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Appendix 1: Tests of Normality on Independent and Dependent Measures

Measure	*D*	*p*
Species Richness: N Taxa	1.658	.008
Species Richness: N Orgs	1.937	.001
H' (Shannon-Wiener index)	1.887	.002
Rubble Count	2.412	<.001
Phylum: Cnidaria	2.254	<.001
Phylum: Porifera	2.327	<.001
Phylum: Byrozoa	2.653	<.001
Phylum: Tunicata	1.992	.001
Phylum: Annelida	2.544	<.001
Phylum: Mollusca	2.101	<.001
Phylum: Echinoderm	2.133	<.001
Phylum: Crustacea	3.078	<.001
Phylum: Pisces	3.360	<.001
Niche: Encrusting	2.756	<.001
Niche: Sessile (1-5 cm)	2.091	<.001
Niche: Sessile (5 cm+)	2.700	<.001
Niche: Infauna	2.416	<.001
Niche: Benthic Motile	1.930	.001
Niche: Pelagic Motile	3.058	<.001
Functional Group: Filter Feeders	1.849	.002
Functional Group: Grazers	1.930	.001
Functional Group: Predators	2.876	<.001
Depth	1.076	.197
Trawling: 1996-2000	2.451	<.001
Trawling: 2001-2005	1.461	.028
Trawling: 2006-2010	1.617	.011
Trawling: Sum	1.050	.220
Trawling: Mean	1.050	.220