ZSL Institute of Zoology LIVING CONSERVATION

November 2014

2nd Annual Report
Institute of Zoology Greenland Benthic Assessment
June 2013 – Nov 2014

Report compiled by

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1. Executive summary

- *This report describes work undertaken between June 2013 and November 2014. This includes* ***two seasons of fieldwork*** *conducted aboard M/T Paamiut - summer 2013 and summer 2014.*
- *A re-analysis of 2011 data was undertaken to improve the quality of this data to the standard at which we are now operating.*
- ***Historical imagery*** *from the region has been incorporated into the project and analysis of this begun*
- *A* ***comprehensive analysis*** *of all analysed images to date (2011 – 2013) was undertaken*
- ***Habitat suitability modelling*** *for the region was undertaken*
- ***Genetic*** *analysis of bycatch coral samples continues*
- *Work from this project was presented to an international audience of benthic biologists and others in Tromsø, Norway.*
- *Extensive discussions regarding the development of GINR's* ***proposed bycatch monitoring program*** *were productive. Sharing of image identifications and guides is underway.*
- Plans for **2015 survey** and analysis are underway.

2. Field survey summary

2.1 Field survey 2013

Summary: Dr Kirsty Kemp and student Irina Chemshirova undertook survey work aboard the M/T Paamiut SFW RejeFisk Survey Leg 2, led by Henrik Lund of GINR, between Ilulissat and Nuuk, June 26 – July 9, 2013.

The survey resulted in the collection of 400+ photos of the seafloor from 42 stations between Ilulissat and Nuuk, over 12 days. No days were lost to bad weather but some hours were forfeited to other work (CTD, extra halibut trawls, or steaming to check ice conditions) on 6 nights.

Personnel: Dr Kirsty Kemp (KK) has been the project leader since 2011. Irina Chemshirova (IC) is a BSc student from Imperial College, University of London. She joined Dr Kemp and Dr Yesson's research team for 12 months between her 2nd and 3rd year BSc studies, as part of a "Year in Research" scheme aimed at giving promising research scientists first-hand experience of the research environment. In this year she re-analysed the survey images collected and first analysed in 2011. In doing this she improved the standard of analysis to that developed and achieved (for the 2012 images) by Poppy Simon (detailed in 1st Annual Report, 2013). In addition she developed a BSc-level research project aimed at analysing historical images from this region, which she later achieved and which is also reported upon in this document (see section 3.2). IC and ZSL sourced funds for travel and accommodation (£650 Percy Sladen Memorial Fund, and £550 Andrew Croft Memorial Fund) for Irina Chemshirova to join Dr Kirsty Kemp on the survey.

Mission: The priority for this survey was as previous surveys: to continue collecting benthic images over a gradient of trawling effort to facilitate investigation of the relationship between community composition and fishing impact.

GINR provided shrimp trawl fishing data from 1975 to 2013, and cod trawl fishing data from 1999 to 2011 for the survey region (not currently incorporated in analysis) We used these data to target sites with a variety of impact from “unfished” - no reported trawling activity (9 sites), to “recovery” - where trawling occurred historically but not in the past 10 years (20 sites), and “fished” areas with recent trawling activities (Figure 1).

Equipment: The benthic camera purchased by IoZ in 2012 was used for the first time during this survey (for all work) and performed very well.

Bycatch processing: No grab sampling was undertaken. The bottom was mostly muddy, with only one or two stations that might have warranted taking a grab for epibenthos.. Instead 156 specimens of benthic organisms were collected from the fishing bycatch for further identification work (both taxonomy and genetics). 133 full specimens and 50 partial (tissue) specimens were stored individually in ethanol. 51 partial (tissue) specimens stored in RNA Later. These collections were dominated by sponges, sea stars and brittlestars, but also included amphipods, anemones, basketstars, bivalves, bryozoans, corals (including seapens and stylasterids), crinoids, crustaceans, gastropods, holothurians, hydroids, picnagonids, a possible pteropod, sand dollars, polychaetes (including nereid worms), seaweesd, shrimp, urchins, worm tubes, other worms, and some specimens that are as yet unidentified.

2.2. Field survey 2014

Summary: Dr Chris Yesson, and student Taylor Gorham, undertook survey work aboard the M/T Paamiut SFW RejeFisk Survey Leg 2, led by Henrik Lund of GINR, between Ilulissat and Nuuk, June 26 – July 9, 2014.

The survey was extremely successful. More than 500 photos of the seafloor were collected over 14 days from 48 stations spanning 72°N down to 64°N (Figure 1). No days were lost to bad weather.

Personnel: Dr Chris Yesson (CY) is a postdoctoral researcher at IoZ. He participated in the 2012 benthic survey on the Nuuk-Qaqortoq route. He has been examining genetic diversity of cold water corals from Greenland and other areas in the North Atlantic.

Taylor Gorham (TG) is an MSc student from Imperial College, University of London. She has previous experience conducting seabed surveys in shallow systems. In spring 2014 she began examining images from our 2013 image survey as part of her thesis project and conducting a community composition analysis on these data in relation to trawling effort.

Mission: The priority for this trip was to continue our work taking benthic images over a gradient of trawling effort in order to investigate the relationship between community composition and fishing impact. This year we had an additional requirement. On last year's cruise, we discovered that during the 1970s and 1980s Per Kanneworff and colleagues conducted seabed surveys using a similar camera system. Thanks to GINR and Ole Tendal we now have access to these images, so we set out to revisit these historical sites in order to compare the same locations 40 years after the original images were collected. We successfully sampled 19 of these sites on this survey. The majority of the remaining sites sampled by Per Kanneworff are coincident with leg 1 of the annual survey. It is our intention to visit these sites in 2015.

Equipment: ZSL's benthic camera was used for imaging the seabed. The newly acquired frame weighting system proved a success. Previously a chain was lashed to the base of the frame to provide extra weight. The new plate weighting was a significant improvement on the chain, providing a less bulky weighting system that did not encroach into the images.

Night-time sampling was shared between the camera survey conducted by ZSL, CTD operations and a nighttime trawl for halibut following usual survey operations, and sampling mud for diatoms conducted by Diana Krawczyk of GINR. Mud sampling utilised IoZ's day grab, purchased for the 2012 survey. Both camera and grab operate from the CTD winch, and both cannot be operated at the same time. In order to maximise sampling, a modification was made to the camera frame. A small mud corer was fitted to the outside of the base of the camera frame. This sampled approximately $60cm^3$ of mud as the camera touched the bottom during image sampling. This was sufficient for the diatom survey and resulted in a significant improvement in sampling efficiency. A limited number of grab samples were still conducted to provide a comparison with the camera-based sampler. CY collected mud samples from 7 of these grabs. It is hoped these samples will form part of a future metagenomics project examining microbial diversity in mud habitats.

Incident: On day 3 of the cruise, the ship was struck by a large iceberg during a trawl. The platform from which the camera, grab and CTD operations are normally conducted was completely destroyed. Additional damage resulted in two cabins suffering minor flooding from a broken pipe. The ship was forced to return to port in Aasiaat, creating a significant delay of more than 24 hours including repair time and transit to and from port. After repairs, the winch was repositioned nearer the door to the CTD room, and operations were conducted directly from the winch room, rather than from the platform, which was removed from the doorway. Camera and grab surveys were successfully conducted by leaning out of the winch room, after a makeshift safety barrier was positioned over the open doorway. Operations were slowed down by the requirement to bring equipment back on deck after every station, but this did not result in a significant delay. It is hoped that the platform will be repaired in time for next year's surveys.

Protected area: At the request of Helle Jorgensbye of DTU two stations were sampled in the area closed to fishing along the coastline above Nuuk (Figure 2). These are the first benthic images of this area and provide important evidence of framework forming sponge habitats (Figure 3) that we have not seen in other stations we have surveyed.

Bycatch processing: This year (2014), GINR are implementing a new protocol to document and collect all benthic fauna taken as bycatch to become a reference collection of benthic fauna for the area. On the first leg of this year's surveys, this was conducted by the scientists and students conducting the shrimp stock assessment. Processing the main catch of the trawl is a time-consuming activity, without the additional requirement of processing benthic bycatch. Therefore CY and TG took on the responsibility to collect and document the benthic bycatch for the duration of the cruise. This was found to be a useful activity that will aid us in identifying benthic taxa from the images. In a continuation of previous year's activities, all coral bycatch was subsampled for our ongoing project to examine genetic diversity of soft corals in the area. A total of seventy coral samples were taken back to the Institute of Zoology at the end of the cruise.

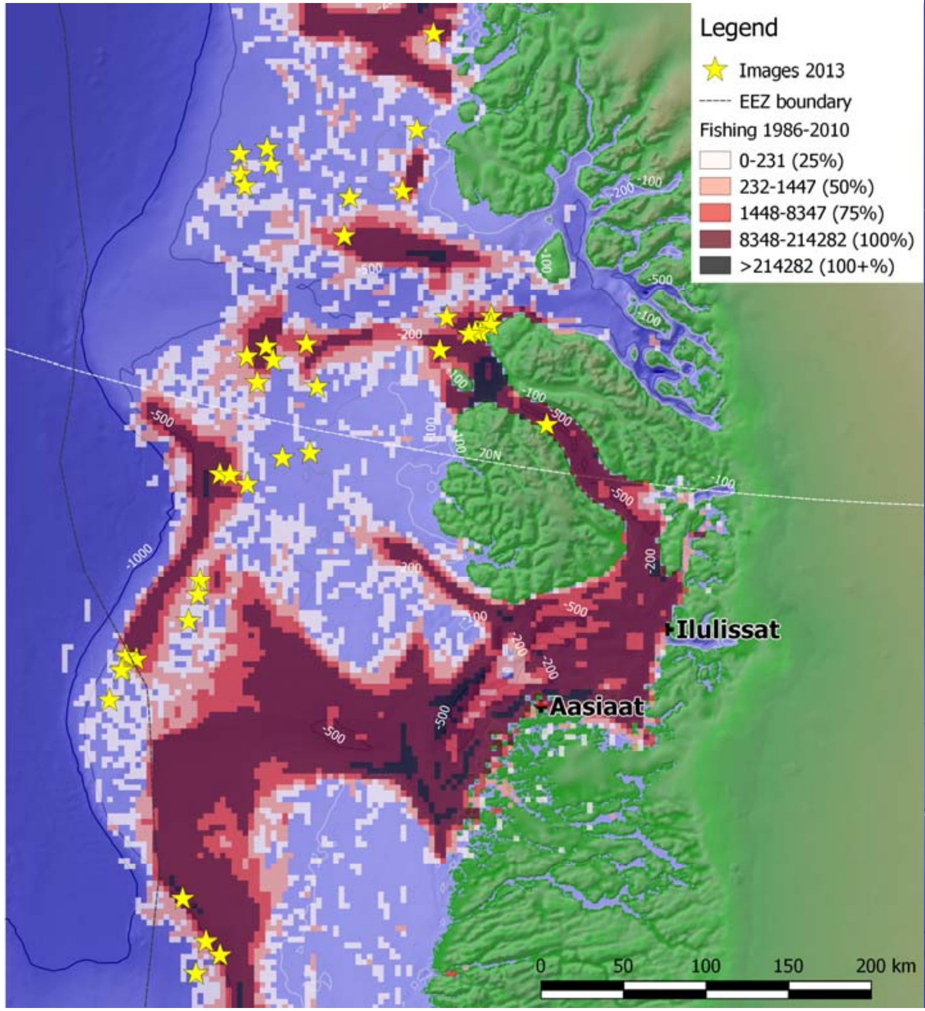

Figure 1. Camera stations 2013 (yellow stars). Fishing intensity in red and pink.

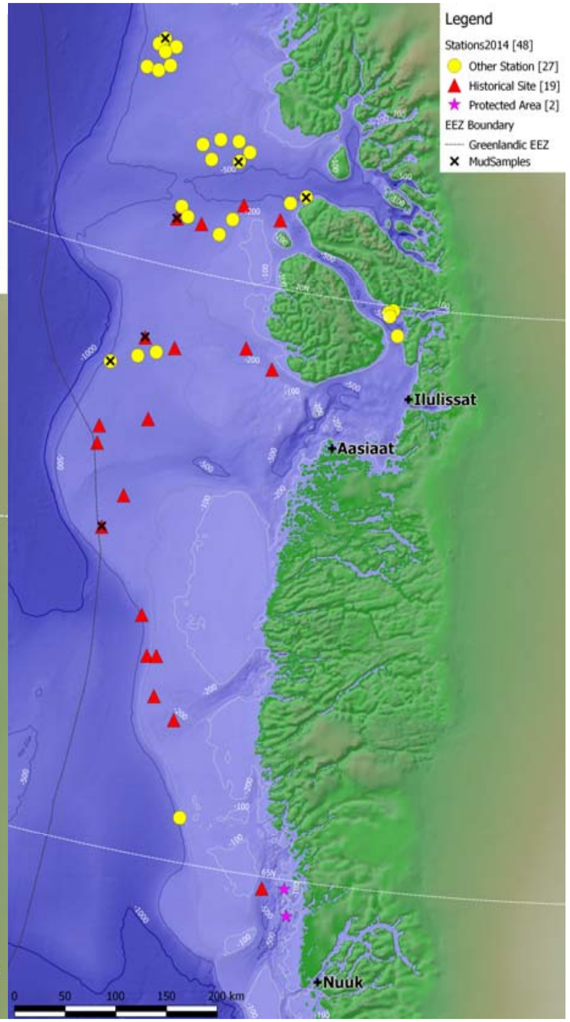

Figure 2. Figure 2. Camera stations 2014 (yellow circles, red triangles and pink stars)

Figure 3. Benthic image taken at the protected area of Station 47 at approximately 200m depth. The image shows an aggregation of sponges on a steep slope. (Photo: Institute of Zoology.

3. Output

3.1 Overview of analysis to date

The analysis of benthic images has been continuously revised during the course of the project. This can be characterised by a gradual improvement of taxon identifications and an increased sophistication of analyses.

Taxon Identification

The identification of benthic organisms can be very difficult. Identifying species can be problematic for taxonomic experts even when the specimen is in hand. We are seeking to identify a very wide range of organisms from photographs, often with restricted view of the target organisms (i.e. buried or partially obscured by other organisms). There are few region-specific reference materials, so we have been building up knowledge of the local benthic species throughout the project.

In 2011 the provisional analysis for the pilot project aimed to identify taxa to at least the level of Phyla for a limited number of images per station. The MSc project examining the 2012 survey data expanded the number of images examined per station and expanded identifications to lower taxonomic levels for some taxa. In 2013 we revisited the identifications made for the 2011 data and expanded the number of images used for analysis. We also sent our student to an identification course to enhance her ID skills. The 2013 field survey included sampling of benthic bycatch to provide physical specimens for comparison. Some problematic specimens were taken to taxonomists to provide expert identifications. In 2014 the introduction of the Poseidon software (developed in collaboration with computer scientists at UCL) improved the speed and efficiency of identifications. For example, the facility to access previous examples of specific organisms allows an instant view of observed variation within the target organism, allowing a more informed decision on identification.

The analysis of each year of images has been used to revise and enhance a photographic guide to benthic taxa of the area, using our own images to give examples of variations observed within Greenland. This guide (and in-house expertise) is passed on to the next round of identifications, so constantly improving both resolution and quality of identifications.

Fishing data

Initial analysis for the pilot study examined fishing data in using a 6-category classification scheme, based on cumulative 5 year means of trawl lengths from 1996-2010. The limited dataset from one years survey made it difficult to interpret these results. The classification scheme was subsequently simplified into 3 groups (fished, unfished, recovery), which increased data per-category and allowed a direct comparison of these categories. However, classifications are, by design, simplifications of the data and can hide interesting patterns. The comprehensive and revised trawling effort dataset provided by GINR in 2012 permitted a more sophisticated approach covering and extended time period (1986-2011). These data record start and end positions and times of trawls, but inferring trawl distance from such data is difficult because many trawls do not track a straight line from start to finish. It was felt that measuring time rather than distance created a more realistic picture of effort. Our current analyses seeks to utilise these data in several ways, firstly as total cumulative fishing impact, secondly as time-limited cumulative impact (i.e. in the last 10 years) and, importantly, time since last trawl event, which provides an opportunity to investigate recovery times.

Analysis of diversity and fishing effort

The primary objective of our analyses has been to examine diversity as a response to fishing effort. There are many metrics of diversity, ranging from organismal and taxonomic counting, through to indices such as the Shannon-Wiener, Simpson and Evenness. As the project has progressed we have been testing more diversity indices to provide a more comprehensive overview of diversity. The metrics we have considered involve counting and identifiying organisms in our images. Other diversity metrics go beyond counting organisms to measure the size or mass. These have not been considered in our analysis. Biomass cannot be calculated from 2 dimensional images include biomass. While it is possible, theoretically, to estimate size from the surface area covered in the image. However, this would be prohibitively time consuming and would require a student to pick out the area by hand for every organism in every image. An estimate could be made from an inspection of the image, but this would not be reliable. Another approach to diversity would be to examine functional rather than taxonomic groups, we would like to try this at some point in the future.

Our initial treatment of fishing effort as categorical data, led us to perform comparison tests of diversity between groups of sites. This was a simplified approach that seemed appropriate for limited datasets based on one year of samples. As we have increased sampling over multiple years, so we have taken advantage of larger datasets to employ more sophisticated analyses. Treating the fishing effort data as continuously varying numbers allowed us to emply a linear model approach where we examine how variation in fishing effort explains observed diversity. However, a direct comparison of only fishing effort and diversity discounts the potential that additional variable may be driving both measures. Our surveys cover a large area over the continental shelf of western Greenland and there are significant environmental changes over these areas, including sea temperatures, depth, currents and substrata. In order to be sure that an observed relationship between fishing effort and diversity is not driven by environmental variation we must incorporate environment into our analyses. Our most recent analyses employs generalised linear models to test the significance of the diversity~fishing effort relationship alongside depth, slope, current speed, temperature, salinity and substrata. One corollary of such an analysis is we simultaneously examine the influence of environment on diversity.

The improvements in identification, treatment of data and analytic methodology has increased the confidence in our findings and provides a robust foundation for our work.

3.2 Re-analysis of 2011 image dataset

In 2011 400+ images where collected during a short pilot survey and study. In that year the great success of the camera survey resulted in the collection of 3x more images than initially predicted. Consequently time needed for processing and analyses was also much greater, and students were employed to assist with data gathering from the images. The full dataset was not used in the analysis reported in the 2011 pilot study as there was not time to undertake a quality check on student records, nor to investigate potential inconsistencies between multiple image analysts. The 2011 data analysis was therefore limited to one image per station and the data archive was built in such a way that it could be readily updated with this additional data once it had been controlled for quality and consistency. Similarly, the data archive was arranged to allow for improvement of the level to which organisms could be identified and named, as our knowledge of the habitat and community improved.

Between June 2013 and June 2014 a re-analysis of the data collected in 2011 was undertaken in order to raise the quality of that dataset to match that of 2012 and 2013, taking advantage of improved analysis software (Poseidon software, developed as part of this project – see section 3.6) and greater species identification capability which has developed over the past two years. Full details are given in Appendix 1.

3.3 Establishing historical baselines of benthic diversity and community composition

Between 1975 and 1986 photographs were taken of the seafloor in our region of interest, by Per Kanneworff (GINR). We were notified of the existence of these images by Henrik Lund in June 2013, and they were then made physically available to us by Ole Tendal of the Copenhagen Zoological Museum, and Helle Siegstad of GINR. This historical dataset is of great interest in the context of this project. We have repeatedly to address the reality that we lack baseline (pre-impact) data of the regions we are studying, and that this limits our approach to interpretation of disturbance impact and forces a predictive and model-based approach over direct observation. Images of the study site taken 30-40 years ago are therefore of very great interest.

The Kanneworff image collection consisted of 56 reels of diapositive Kodak film. Location data to accompany the images was not available for the stations photographed between 1975 and 1976 so these could not be used. The remaining stations were mapped (Figure 4).

At IoZ a subset of 10 images from each station were individually scanned and digitised, and digital image quality maximised. Full details of image treatment are given in (Appendix 2). Complementary trawl data for the period (1975-1986) was made available to us by GINR.

First analysis of these images was designed as a study of change observed between 1970s and 1980s images. No significant change was observed in diversity indices between these time periods, though changes in individual taxa are apparent in some cases. Full details of image analysis and interpretation are given in Appendix 2.

The second phase of analysis will be a comparison of historical and present day images. We are currently targeting our photographic efforts (during the summer 2014 survey and the upcoming 2015 survey) to sample stations for which we have historical imagery., and have begun analysis of those stations for which we already have both historical and present-day images.

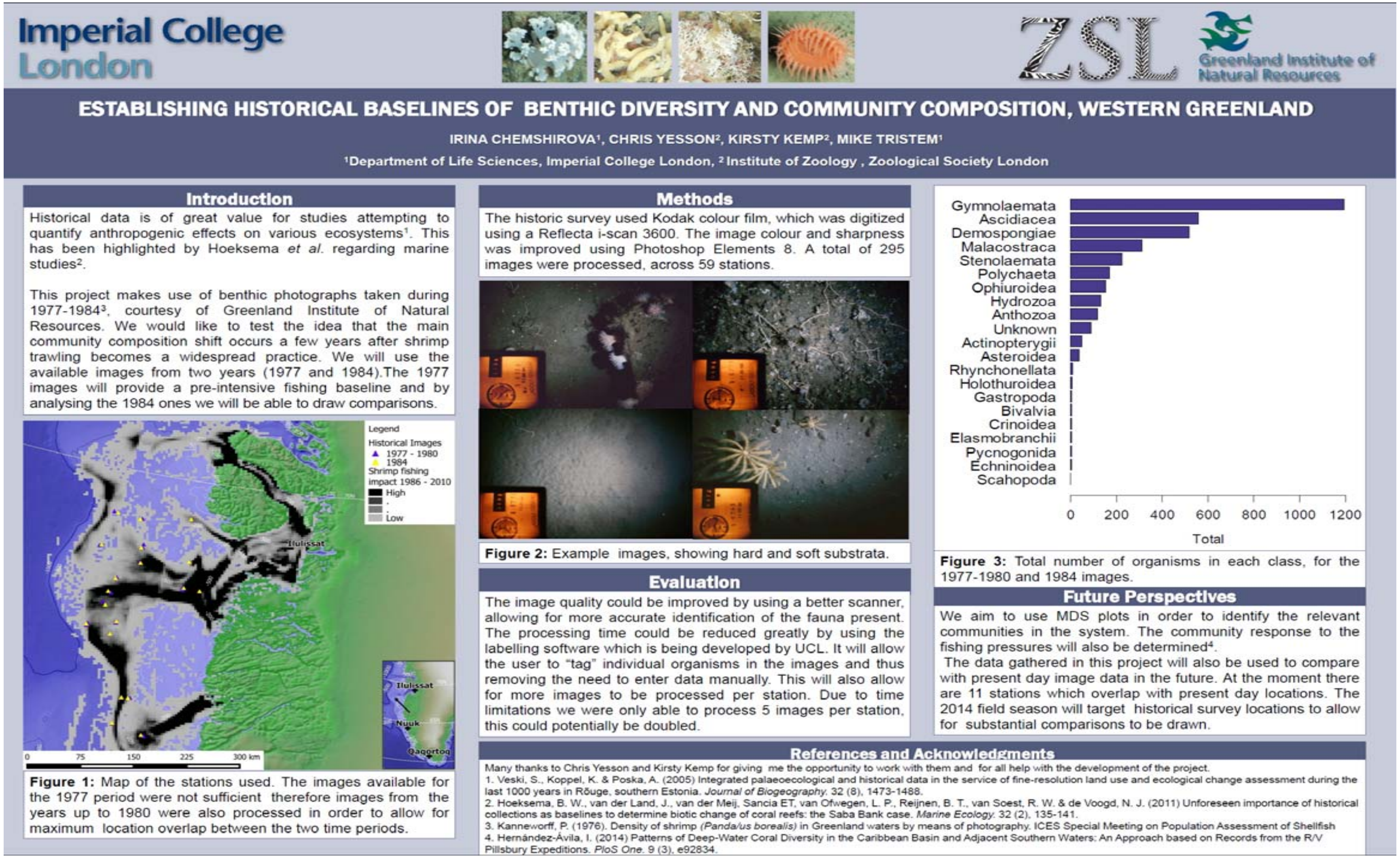

Figure 4. Poster detailing the BSc project undertaken by Irina Chemshirova.

3.4 Impacts of shrimp trawling on community composition (comprehensive analysis 2011 – 2013)

Analysis of 2011 imagery is reported in the initial pilot study and a re-analysis of it was undertaken this year and is presented in this report. Analysis of 2012 imagery is reported in the First Annual Report 2013. This year a comprehensive analysis which incorporated all data collected to date (2011 – 2013) was undertaken by Imperial College London MSc student Taylor Gorham (TG).

The project collated all existing data, and questioned whether particular organisms, community types or substrate types were notably more vulnerable to or affected by the disturbance impact of trawling. Community responses to both cumulative fishing impact and recovery time were tested in order to account for both the intensity and frequency of fishing. This study successfully measured some community effects of trawling on the scale of the west Greenland shelf.

Results show that the impact of fishing is dependent on the type of seabed. We find a significant negative correlation between taxonomic diversity and trawling effort in areas with soft sediment, but we find no significant relationship for areas with rocks and pebbles present. These results remain after factoring out the influence of broad environmental conditions, which reassures us that this pattern is not driven by an environmental sampling bias. However, these findings are counter to the expectations of ecological theory which suggests that areas with hard-bottom should be more vulnerable than soft-sediment areas. As a preliminary assessment, this study described plausible links between community dynamics and fishing, and identified major factors affecting survey data interpretation. These findings are based on data from 2011, 2012 and 2013. We have yet to process the images from 2014 and have a further 2 years of fieldwork planned. We will have greater confidence in these results after these additional data have been added.

This work is included here in full as Appendix 3. It is likely that this appendix will be the one of most direct interest at this point.

3.5 Habitat suitability modelling

A study examining the habitat suitability of several groups of Greenland's cold water corals was conducted in 2014 by Chris Turner, an MSc student from Imperial College London.
The project used direct observations of coral species from bycatch or benthic images to map distributions from existing data. Environmental data of seabed conditions was collated including temperature, salinity, topography and current speeds. These were used to develop models describing the environment at the locations where coral species occurred. The models predicted the distributions for the entire continental shelf of west Greenland and showed that there was no direct relationship of habitat suitability and trawling intensity.
This was a successful project that was presented as a poster during the ICES Symposium "Effects of fishing on benthic fauna and habitats" in Tromsø, Norway in June 2014 (Figure 5). Further details are given in Appendix 4.

3.6 Coral genetics

A study examining genetic patterns of Greenland's cold water corals was started in 2014 by MSc student Elizabeth Murphy from Imperial College, London. This study used corals collected as bycatch from the annual stock assessment trawls to examine the effectiveness of two gene regions for determining genetic patterns in the cold water coral family Nephtheidae. The study successfully sequenced more than 100 samples using the nuclear marker ITS (internal transcribed spacer), but encountered difficulties using the mitochondrial "barcode" region MutS. There are clear genetic patterns that agree with the broad morphology of this taxonomically complex group (Figure 6), which demonstrate the utility of the ITS region for future analyses. The genotypes are geographically widespread, indicating high gene flow over the area, but more gene regions and specimens need to be sequenced before conclusions can be made about the influence of fishing pressure on genetic diversity. Further details are given in Appendix 5.

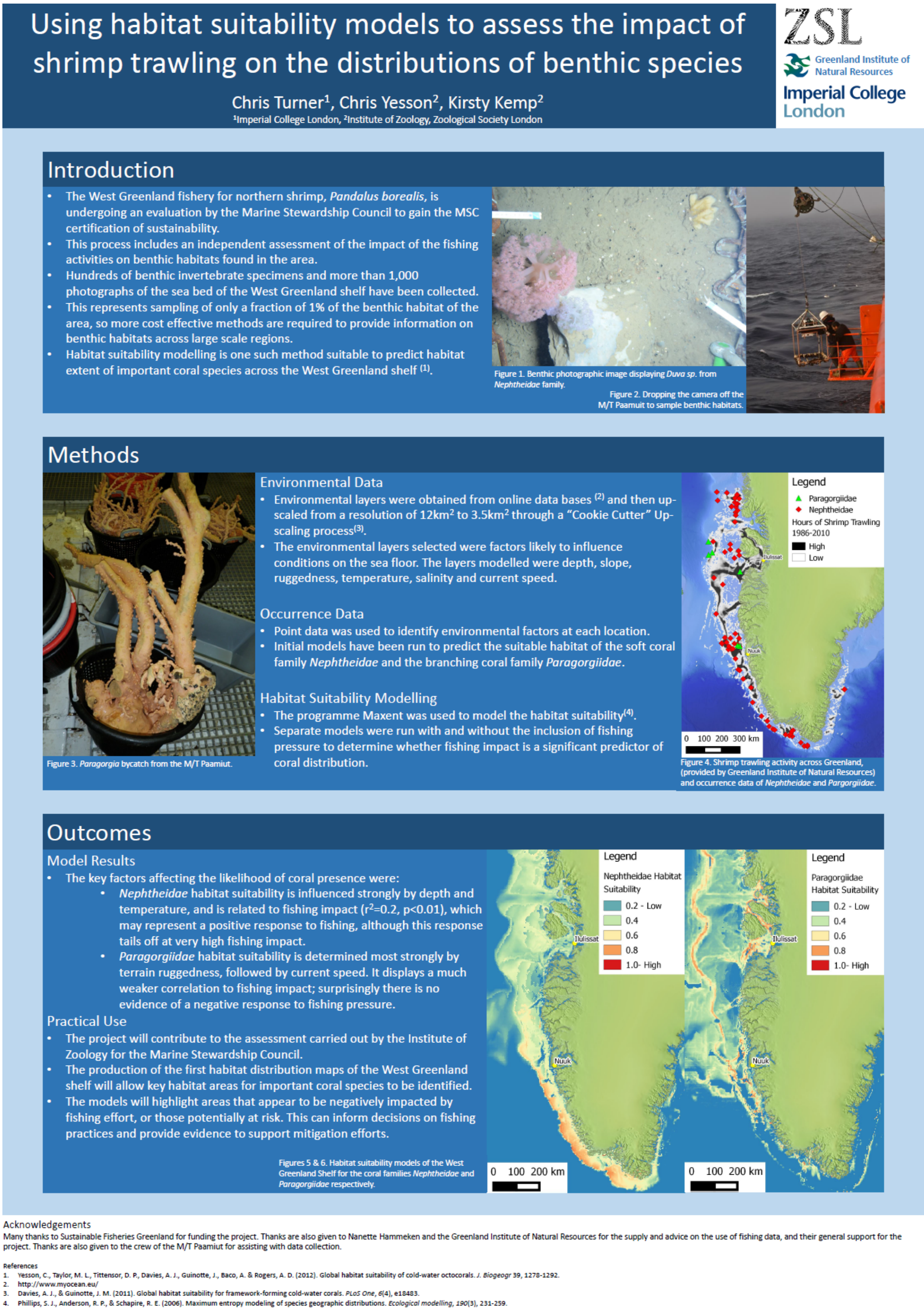

Figure 5: Poster describing the MSc project of Chris Turner, presented at the ICES symposium " Effects of fishing on benthic fauna and habitats" in June 2014.

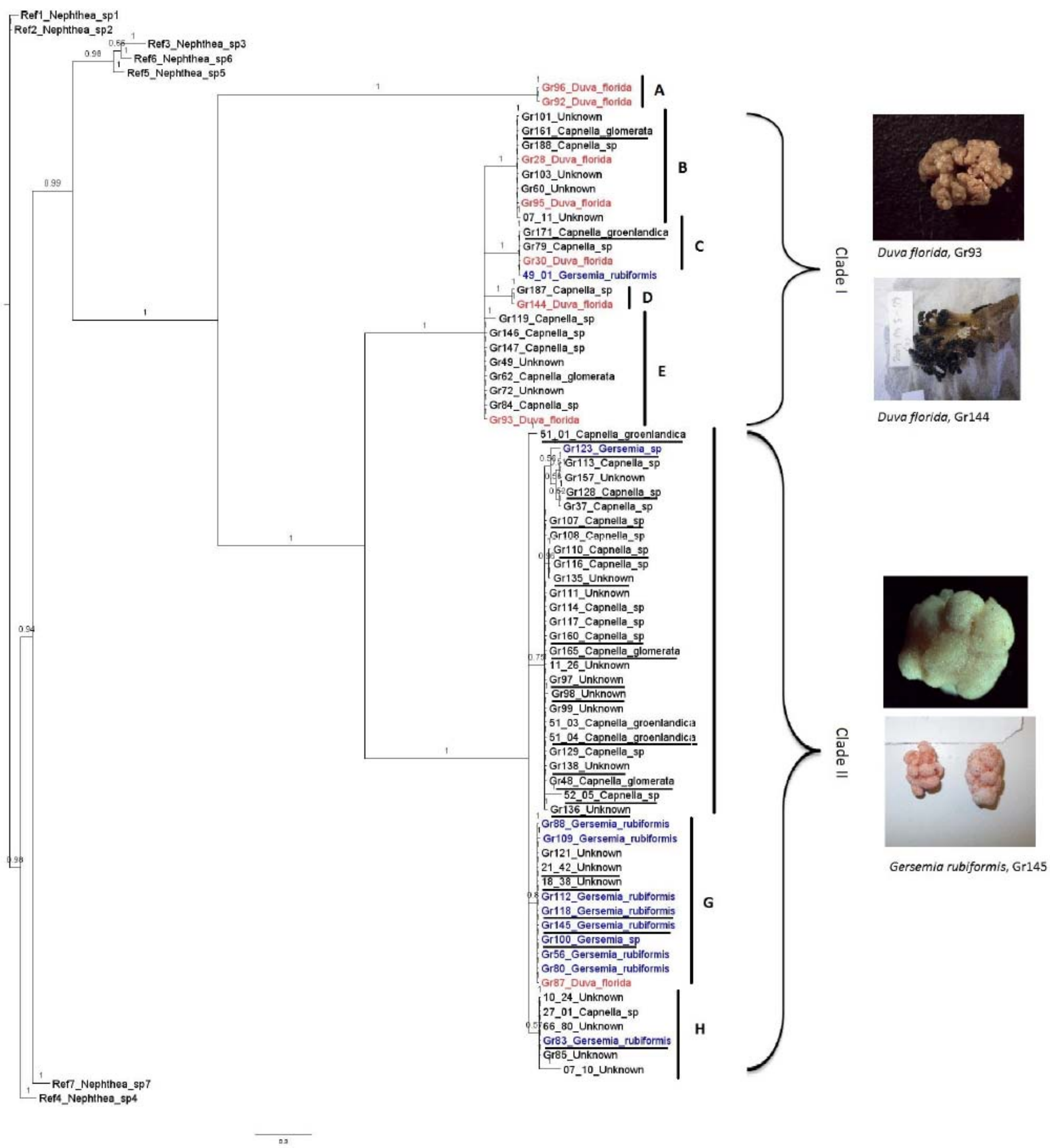

Figure 6: Provisional phylogeny of corals of the family Nephtheidae based on the ITS2 sequence region. There are two distinct clades representing the *Duva* and *Gersemia* morphologies.

3.7 An Interactive Labelling Tool for Marine Life Detection

The collaboration with University College London (UCL) computer science department, which was begun in 2011, has yielded results. Dr Edward Johns was recruited to replace Dr Grigorios Skolidis in August 2013 and employed for one year. Dr Johns further developed and completed the production of a software tool to facilitate image analysis, now known as *Poseidon*.

Our initial inspection of seabed images for ecological impact analysis was carried out manually. This is laborious and time-consuming, and even experts in the field are challenged when faced with identifying the many benthic species from imagery. Software to facilitate this labelling is currently rudimentary and the process typically involves separate, and often generic, visualisation and databasing tools. As shown in Figure 7, this requires independent interaction with the two separate components - a tedious and inefficient solution.

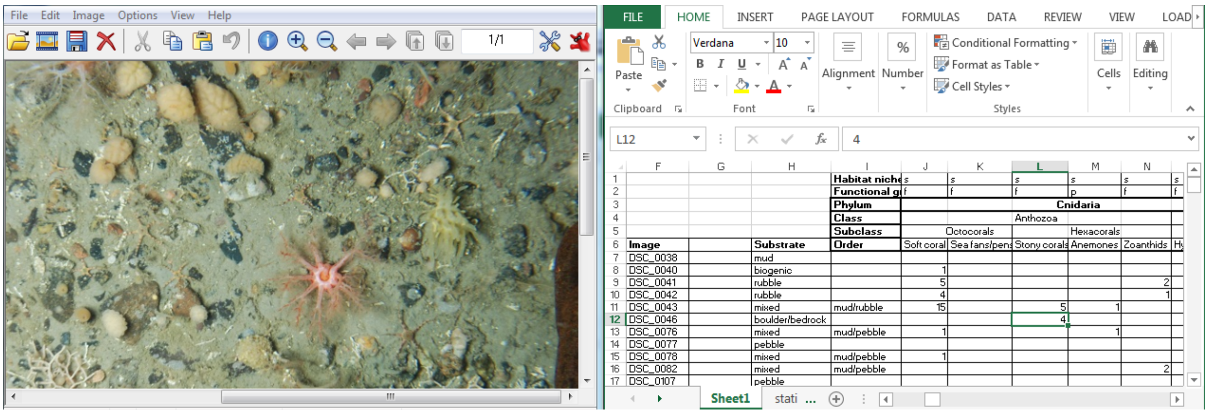

Figure 7. The old method for labelling based on generic visualisation and manual data entry into a spreadsheet.

We determined to improve the speed of labelling by developing an interactive tool to assist the human labeller, combining visualisation and databasing into an intuitive interface. This tool is complete and known as Poseidon. In conjunction, computer scientists working on this could use the process to support development of state-of-the-art techniques in computer vision and machine learning which aim to enable autonomous labelling by the computer in parallel with manual labelling from the human expert. The resultant tool (Poseidon) was built specifically with marine life detection in mind, but is highly generalisable to other biodiversity monitoring tasks and wider projects with similar requirements.

Poseidon: The Labelling Tool

Poseidon is a user-friendly, web-browser-based interface which enables users to manually label species of marine life across a set of seabed images. As shown in Figure 8, organisms recognised by the user in the image can be highlighted and annotated directly through the interface. Each annotation is automatically stored in a database for biodiversity evaluation, which also allows for subsequent editing or refinement at a later date. To enable large-scale labelling of the same set of images, including crowd-sourcing initiatives, multiple users can log-in through their own accounts. This also allows for transfer of knowledge between different users: expertly-labelled data may be used to teach non-expert users about the appearance of each species, and a confidence measure may be imposed for each label based on the user's track record and experience.

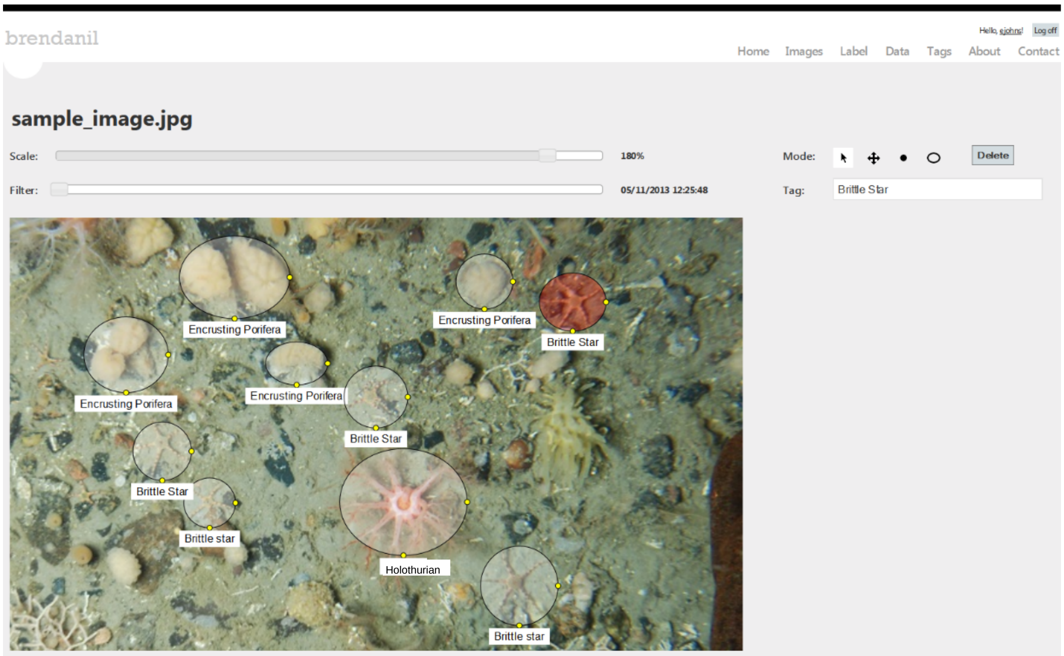

Figure 8. The new all-inclusive tool in operation allowing for intuitive labelling and annotation.

Computer Vision and Machine Learning

Recent developments in computer vision research have provided for automatic object detection and recognition frameworks with success in some real-world applications, and this work has enabled us to begin the development of our own bespoke recognition engine for marine life recognition. By allowing a computer to observe the behaviour of shape, texture and colour across several training images of each species, models for each species can be learned by the computer and subsequently used to detect instances of organisms in each new image. Together with the visual appearance of each species, further cues such as the appearance of the substrate or the presence of other nearby organisms are being incorporated into the overall recognition pipeline.

In addition an interactive component for cases when the computer is unsure of the identity of an organism can be developed. Here, the labelling tool will query the user and ask for a manual label to be provided for a region highlighted by the computer, after which the system will update its own appearance model for that species. In the long run, as the computer is then able to provide its own labels with increasing accuracy, the number of manual labels required should be dramatically lower than if this interactive component was not present. For optimum efficiency, the query at any one time will be that which maximises the computer's gain in understanding of the image. As such, the queried region will be that which the computer is most uncertain about over all image regions, rather than a region for which the computer has already been able to make a confident classification of the species present.

As shown in Figure 9, a shortlist likely candidate species, together with exemplar images, can be shown to the user based on the computer's own assessment of the organism's identity. This is important in assisting the training of non-expert labellers who may have no prior knowledge of a species' appearance. Furthermore, this interactive learning allows for the system to be initiated with only one manually-labelled example of each species, and incrementally train itself based on each new label provided by the user.

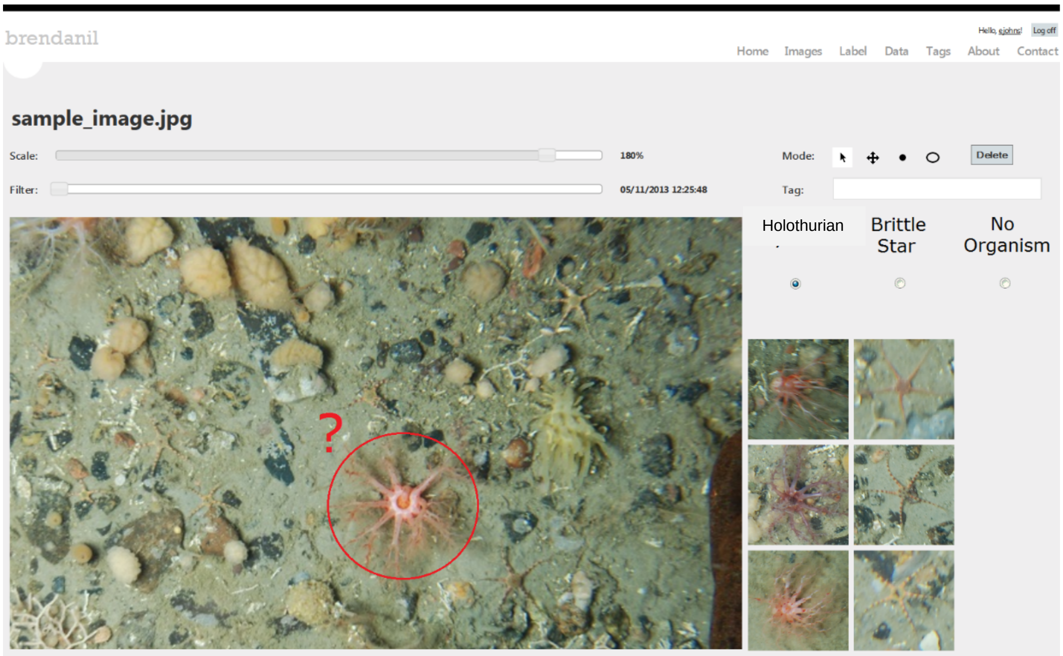

Figure 9. The labelling tool in operation with interactive learning. Images on the right represent typical examples of some candidate species representing the red circle on the left.

In tandem with this work Dr Johns used the seabed images to develop an interactive Machine Teaching algorithm that enables a computer to teach difficult visual concepts to a human. This research showed that a teaching strategy that probabilistically models the learner's progress, based on their correct and incorrect answers, produces "experts" in a shorter time. These computer vision and machine learning developments are interesting to us as they are the basis of an efficient learning tool for biologists working with image-based data.

4. Other updates

Dr Kirsty Kemp and Dr Chris Yesson attended an ICES symposium entitled "Effects of fishing on benthic fauna and habitats" in Tromsø, Norway (17-19th June 2014). This trip was funded by IoZ, but was used to present and promote our work in Greenland. Dr Kemp gave a presentation to the symposium outlining this project and presented some provisional results (slides presented in Appendix 6). Dr Yesson presented a poster on the habitat suitability modelling project (Figure 5 above).

Chris Turner, a former MSc student who worked on habitat suitability modelling, has agreed to work with us in early 2015 as an intern. Chris will help in the construction of a benthic image library and input data from the 2011 and 2012 surveys into the Poseidon software.

We are in discussions with several fully funded new PhD students who are interested in conducting their doctoral investigations on themes closely related to our current research objectives.

5. Collaborative advances with GNIR

Collaboration between IoZ and GINR continues to be both friendly and fruitful.

Dr Chris Yesson attended a workshop to discuss plans to implement a benthic monitoring program operating alongside the annual stock assessment cruises. The workshop was held at GINR and hosted by Nannette Hameken and Martin Blicher. CY's travel was funded by IoZ. The trip was used to present the work we have been doing on this project and provide advice and assistance on the future monitoring program based on our experience working in Greenland since 2011.

The Benthic Arctic Monitoring (BAM) program is the ideal long-term solution to the continuous assessment of the benthic ecosystem. The plan involves adding benthic bycatch monitoring to the annual surveys and would be a cost-effective solution that utilises existing resources to examine material that would otherwise be thrown overboard. Several dedicated surveyors will identify and weigh all benthic bycatch. These data will be collected and collated alongside the stock assessment data and permit the long-term monitoring of the seabed. Annual reports will compare present findings with historical findings permitting year-on-year assessment and the ability to detect and respond to changes. This is based upon a long established program operated in the Barents Sea by Norwegian and Russian scientists.

Initially it will rely on overseas experts to participate on survey cruises to identify bycatch organisms. The aim is to train GINR staff and students to perform identifications and eventually be self-sustaining. The project will permit Arctic-wide comparisons with similar monitoring projects (at present only in the Barents Sea, but there are plans to conduct similar projects in Faroes and Iceland). This project will take several years to get going, and we are keen to assist in its initiation and implementation. Once established it could theoretically fulfil the benthic monitoring requirements of all bottom-contact fisheries wishing to ascertain MSC certification.

However, even with our image library, identification of all bycatch to fine taxonomic resolution is a difficult task. Initially it will require collaboration with a wide variety of taxonomists, along with the production of reference materials, and the training of GINR staff. It is important that the annual surveys include people dedicated to processing the benthos. This requires a commitment from GINR to staff the survey with at least one and ideally two people with sufficient experience and expertise to process the bycatch. GINR have received a substantial (Nordic) grant to begin these surveys and bring in taxonomic expertise until 2017.

One comment to come out from the workshop was that the bycatch rates for the western shrimp fishery seem to be very low. The only times we see 'a lot' of biomass in the bycatch is when the survey hits a sponge field, and this is predominantly on the east coast and is not coincident with the major fishing regions.

We (IoZ) are keen to assist the establishment of a long term bycatch monitoring program. Already we have helped the pilot collection of all benthos on the 2014 surveys. We will continue to assist during the surveys of 2015 and 2016 and will be on board for the first full monitoring on leg 1 of the 2015 survey. GINR invited IoZ to participate in the first benthic monitoring planning workshop in Nuuk in October 2014. IoZ funded Dr Chris Yesson to attend this workshop and presented findings from our 4 years of surveys and provided advice on the implementation of future surveys. IoZ will use the images collected since 2011 to establish a reference library of the benthos of West Greenland to help compile identification materials specific to the survey regions. We encourage SFG to support the long term benthic monitoring program.

6. Plans for 2015

Plans for the 2015 field season are already underway. Our focus for 2015 will be to revisit the remaining sites for which we have existing historical images in order to maximise the data for temporal comparison. We have arranged with GINR to participate in Leg 1 of the 2015 survey, which will give us the opportunity to target the majority of outstanding historical stations. Additionally, this survey will be the first to incorporate the complete benthic bycatch program, and we will assist in the operation. We will continue to play a role in the development of the benthic bycatch monitoring project.

We anticipate engaging at least another 3 students in 2015. We have advertised two MSc projects related to analysing seabed images and have already had expressions of interest for both projects. Arrangements are in place for Amy Cohen of University of Essex to conduct her final year undergraduate thesis examining the historical images (as described in section 3.2).

We are in the process of writing manuscripts which we expect to complete and have published in 2015. The first is on the community composition of the seabed of west Greenland based on 2011-2013 surveys. The second is a habitat suitability modelling study based on the MSc project of Chris Turner. See the timeline below for an outline of future activities.

7. Timeline

2011

- (Jun) Pilot project begins
- (Jun) First fieldwork (Paamiut survey leg 1) – camera survey
- (Nov) Submission of pilot project report (2011 survey). Analysis of diversity patterns in response to fishing impact based on provisional identifications at coarse taxonomic resolution and simple fishing effort categories

2012

- (Jun) Project N561 (24 months) begins
- (Jul) Fieldwork (leg 3) - camera survey and grab sampling
- (Oct – May 2013) MSc project by Poppy Simon – "The effects of shrimp trawling on the macrobenthic fauna of West Greenland". Based on 2012 survey. Simple fishing impact categories
- (Nov 2012 – Oct 2013) Year in Research project by Irina Chemshirova - "Impact of trawling on benthic marine organisms off the Greenlandic shelf, 200 to 600 meters depth". Based on 2011-2012 surveys, including a revision of 2011 data. New approach treating fishing impact as continuously variable data rather than simple classifications
- (Oct) Grigorios Skolidis joins the project and UCL computer science collaboration begins

2013

- (Jul) Fieldwork (leg 2) – Camera survey and bycatch sampling
- (Aug) Dr Chris Yesson joins the project to work on spatial and genetic analyses
- (Aug) Dr Edward Johns joins the project to replace Dr Grigorios Skolidis to work on computer science development
- (Nov) First project report & project meeting
- (Nov) Acquire Per Kanneworf's benthic images from 1970s & 1980s
- (Dec) Present research at ZSL annual research conference in London, UK

2014

- (Feb-Jun) BSc project by Irina Chemshirova – "*Establishing historical baselines of benthic diversity and community composition, Western Greenland*". Using historical images to examine diversity patterns in 1970s and 1980s
- (May) Project N626 (32 months) begins
- (May-Sep) MSc project by Taylor Gorham – "Community composition of seabed habitats around Greenland: What is the impact of the shrimp fishery?". Based on 2011-2013 surveys. Improve techniques analysing diversity responses to fishing impacts, factoring in environmental patterns. Assess taxon-specific responses to impact.

- (May-Sep) MSc project by Chris Turner – "*Creating a benthic habitat map for the West Greenland shelf*". Use Habitat suitability modelling to create continuous distribution estimates for key coral groups.
- (May-Sep) MSc project by Lizzie Murphy – "*Can we see the genetic fingerprint of fishing impact on the cold water corals of Western Greenland*?" Examine DNA barcodes of Nephtheid coral bycatch.
- (Jun) Present research at ICES symposium "*Effects of fishing on benthic fauna and habitats*" in Tromsø, Norway
- (Jul) Fieldwork (leg 2) – Camera survey revisiting sites of historic images, mud and bycatch sampling
- (Aug) Dr Edward Johns leaves the project. The Poseidon software is finished and was used successfully to manage taxon identifications by students in 2014
- (Oct) Attend benthic bycatch workshop hosted by GINR. Assist planning for full bycatch monitoring in 2015
- (Nov) Draft 2nd project report & project meeting
- (Dec) Submit manuscript to ICES journal of marine science describing benthic community composition from 2011-2013 surveys

8. Projected timeline

2015

- (Jan) Revised 2nd report
- (Jan-Mar) Chris Turner to work as intern to prepare image library of bycatch specimens to assist new monitoring program
- (Mar) Submit manuscript on habitat suitability modelling of corals
- (Apr-Jul) BSc project by Amy Cohen – Examine diversity patterns from 1970 to present day
- (May-Sep) MSc project – Diversity and fishing impacts. Add in 2014 survey data and revise analysis
- (May-Sep) MSc project – Seabed analysis using EUNIS classifications. Write-up project for journal submission.
- (Jun) Fieldwork leg 1 – Camera survey revisiting remaining historical stations and full scale benthic bycatch monitoring (in collaboration with GINR)

- (Aug) Present research at Deep Sea Biology Symposium, in Aveiro, Portugal
- (Nov) 3rd project report

2016

- (May-Sep) MSc project – Genetic diversity of Nephtheid corals. Add 2014-2015 specimens. Write up project as manuscript
- (May-Sep) MSc project – Diversity changes and fishing impact 1970-present day. Add 2015 images to complete historic comparison (write-up project for journal submission)
- (Jun) 10 day benthic research cruise – Camera survey and other sampling tbc
- (Jul-Nov) Final analysis of present-day diversity patterns in relation to fishing impacts. Write manuscript to submit to journal
- (Nov) Draft final report

2017

- (Feb) Final report due at the end of the project

9. Summary

Since the initial feasibility study in 2011, this project has steadily grown to incorporate the many strands of ecological research detailed here and in the appendices below. The evidence base upon which we base interpretations of impact and recovery dynamics, and from which we will ultimately draw conclusions regarding best practice for limiting detrimental ecological damage, has consequently also expanded steadily and continues to grow. By the end of this project we will have conducted 6 surveys covering approximately 300 stations and culminating in the collection of 3000 images. This will constitute a significant and comprehensive dataset, unique for the region, and we anticipate being able to perform a robust, conclusive analysis on the impact of the trawl fishery on the benthic environment. This analysis will be presented in the final report.

Appendices

Appendix 0 (referenced in 1st Annual report 2013)

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

Poppy Simon_MSc project 2013 (link to pdf)

Benthic images from 42 stations from the 2012 survey (leg 3 Nuuk to Qaqortoq) were used to analyse taxonomic composition of survey stations. As the first project to analyse the benthic images, a lot of time was spent identifying taxa.

Comparisons of diversity and taxonomic composition were made between the different fishing regimes. Fishing data from GINR was used to classify sites into three categories: unfished (no trawling data for site), recovery (historically fished, but untouched since at least 2005) and fished (recent fishing activity). Furthermore, sites were grouped into 4 categories based on substrata, namely mud, pebble, mud-mixed and rubble.

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. Results were limited at this early stage by the low level of sampling.

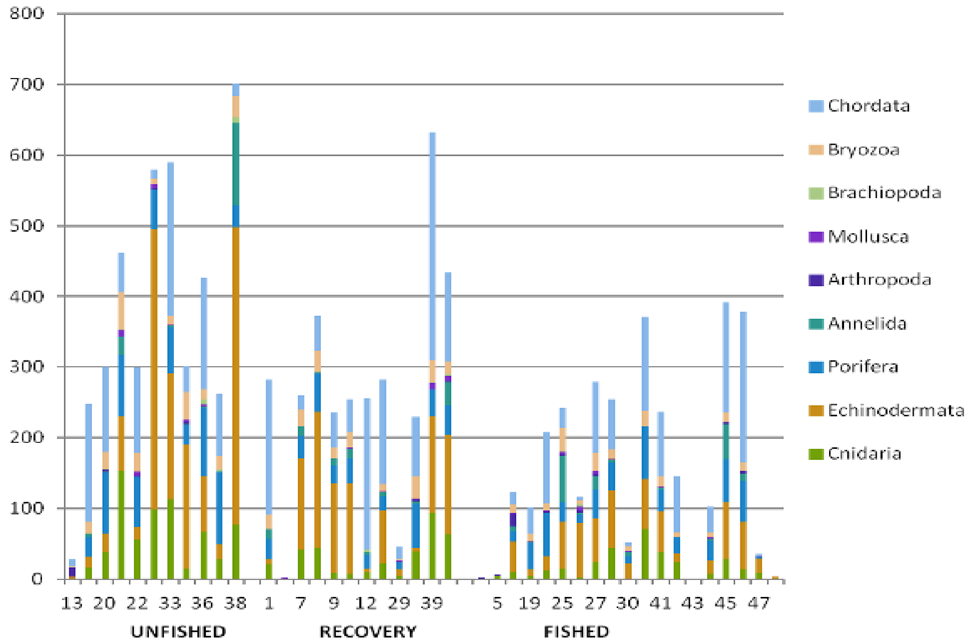

Figure 1. Taxonomic composition of each site. Although abundance appears lower on fished sites, there is an inherent bias that makes this an unfair comparison. Fished sites are typically on soft bottomed areas, which are typically less diverse than rocky/pebbled areas.

Appendix 1

"Impact of trawling on benthic marine organisms off the Greenlandic shelf, 200 to 600 meters depth"

Irina Chemshirova_Year in Research 2013(Link to pdf)

This project built on the foundations of Poppy Simon's 2013 thesis, incorporating images from the 2011 survey and improving identifications from 2012. This project examined images from 80 stations, finding 44 higher level taxa. Species accumulation curves suggest that sampling was relatively complete.

The analysis used regression models to examine the response of diversity to fishing impact (measured in hours of trawling). Sites were divided into hard (rocky) and soft (muddy) substrata. Overall there appeared to be a negative impact of trawling effort, but this was not consistent over different substrata (Figure 2). Soft substrata have been found to be more sensitive to trawling. This is likely to be due to the frequency at which they are exploited. The diversity of hard substrata has been found to increase with trawling intensity. The sensitivity of Vulnerable Marine Organisms (the main habitat builders) was highlighted by their rapid decline with trawling intensity.

These regression models do not incorporate environmental factors, which may be driving the observed results

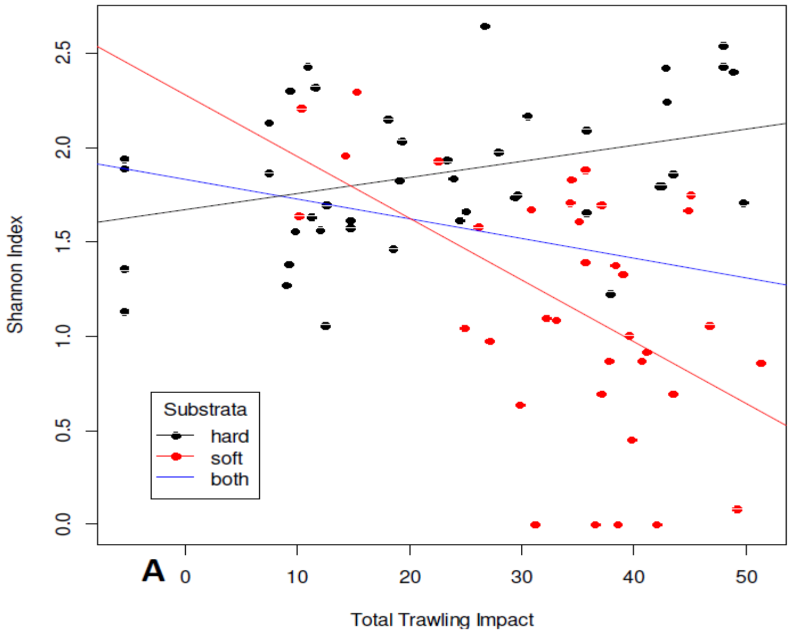

Figure 2. Linear regression showing the relationship of diversity (Shannon Index) and trawling impact (log of total number of trawling hours). Overall there is a negative response of diversity to trawling effort, but the pattern is opposite for sites on soft and hard substrata.

Appendix 2

"Establishing historical baselines of benthic diversity and community composition, Western Greenland"

Irina Chemshirova_BSc 2014 (Link to pdf)

A static view of present day diversity does not allow any analysis of change. The benthic images taken by Per Kanneworf in the 1970s and 1980s are a unique record of the Greenland shelf seabed and present an opportunity to examine change.

This project examined images from the 1970s and 1980s. The benthic fauna observed in the images were identified following protocols established for the present-day images and site level diversity metric were calculated. Nineteen sites had repeat sampling in the 1970s and 1980s.

Comparing diversity during both time periods there is no clear pattern of change over time (Figure 3). Data on historical fishing effort was provided by GINR. Changes in diversity were compared with trawling intensity (Figure 4). The analyses revealed that trawling intensity had negligible effect on the communities formed. Substrata was found to be the main factor influencing community composition. We hypothesise that the short window of time (4 years for some stations) we looked at was not sufficient for any changes due to trawling activity to occur.

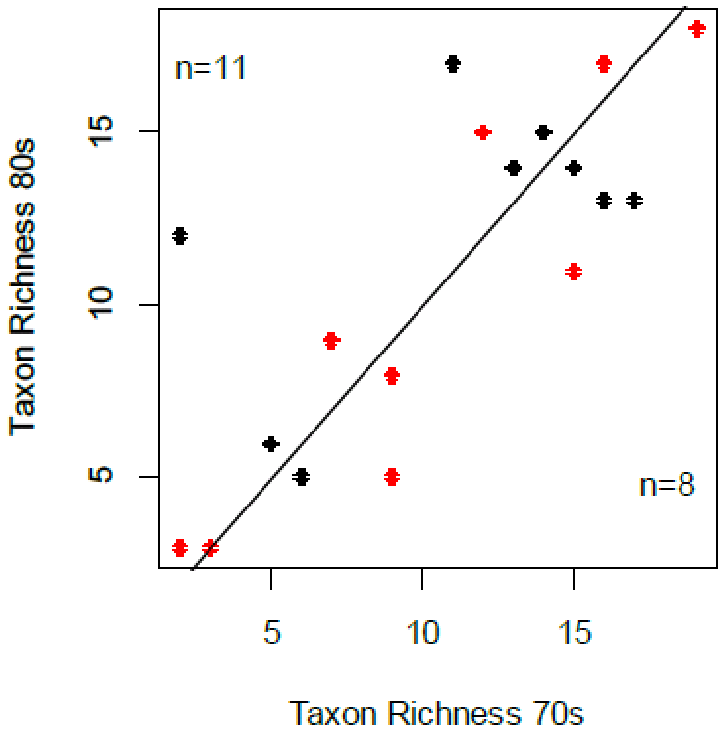

Figure 3. Comparison of taxon richness for sites sampled in both the 1970s and 1980s. There is no clear pattern of increase or decline in diversity over this time.

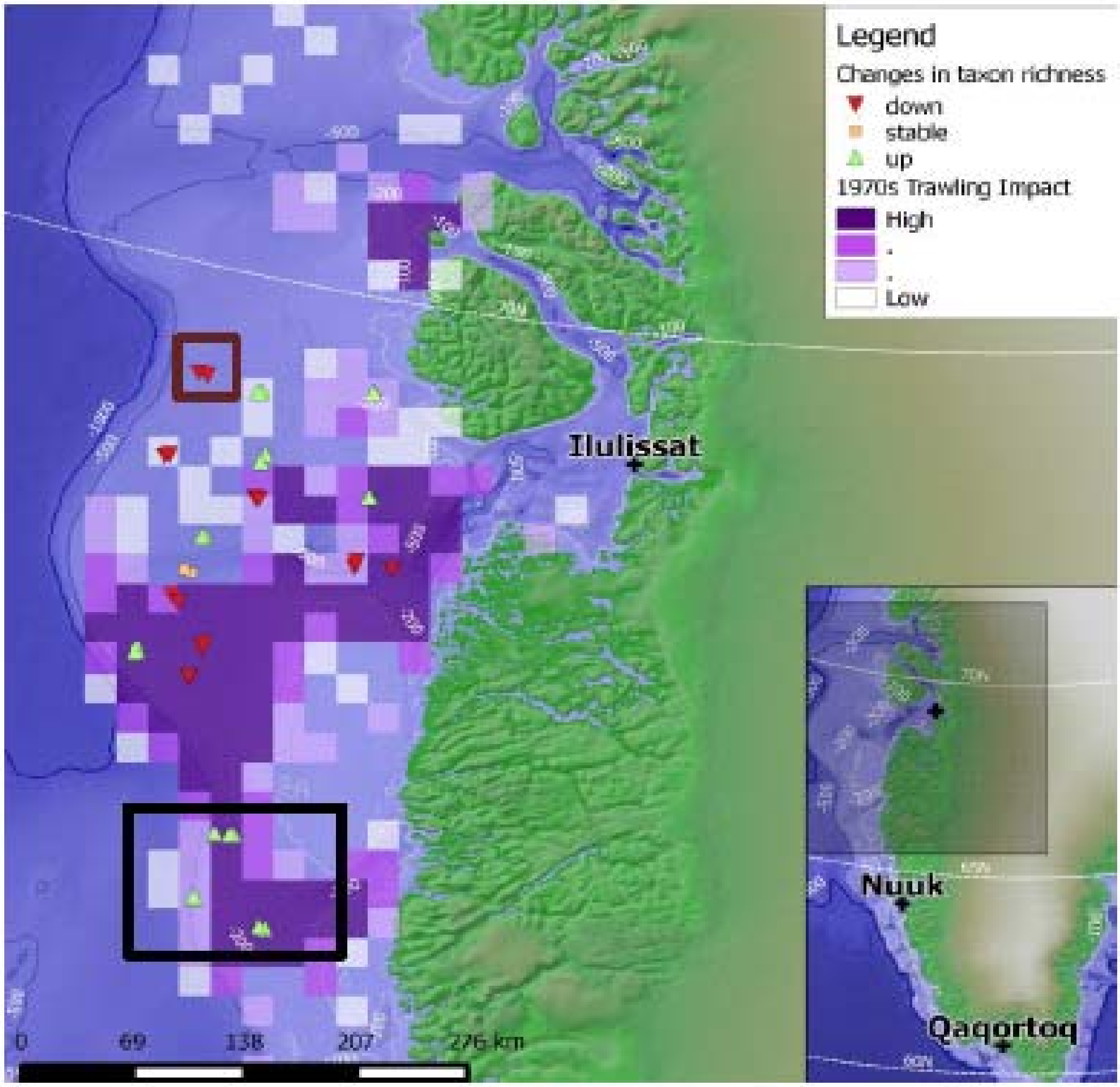

Figure 4. Geographic summary of changing diversity between the 1970s and 1980s. Areas with heavy fishing have sites with both increases and decreases of diversity.

Appendix 3

"Community composition of seabed habitats around Greenland: What is the impact of the shrimp fishery?"

Taylor Gorham_MSc 2014 (Link to pdf)

Abstract: Long term sustainability of fisheries requires an ecosystem approach to fisheries management (EAF). Knowledge of the ecosystem impacts of fishing is necessary to support an EAF, but describing the links between benthic biodiversity and fishing is challenging on the spatial scale of entire fisheries because of the heterogeneity of habitats and community responses. A large scale observational study was carried out on the benthic community impacts of the west Greenland shrimp trawl fishery in order to inform future ecosystem-based management as part of a sustainable seafood certification process with the Marine Stewardship Council. This represents a preliminary step in the first benthic impact assessment undertaken for this fishery, and the first characterisation of benthic communities on the west Greenland continental shelf. Univariate and multivariate biodiversity indicators were used to analyse community data collected from seabed images. Major differences in community composition between rocky substrata and sandy/muddy substrata were encountered. Significant negative impacts of trawling were detected on soft substrata, primarily due to the destruction of rare keystone structures. Impacts of trawling on rocky substrata were not detected at the community level, but were apparent for vulnerable taxa, including hydroid corals (family Stylasteridae), and soft corals (order Alcyonacea). Despite high levels of environmental noise and uncertainty about historical status of benthic communities, this study shows that large scale approaches can be successful in linking fishing pressure to community composition, and therefore in supporting future ecosystem-based management.

Taxa	Common Name	Response to Cum. Impact			Response to Recovery Time		
		Overall	Hard Substrate	Soft Substrate	Overall	Hard Substrate	Soft Substrate
Porifera encrusting	Encrusting sponge				+		
Porifera massive	Massive sponge				+		
Stylasterina	Lace coral	- -	- -		+ + +	+ + +	
Alcyonacea	Soft coral	-			+	+	
Polyplacophora	Chiton			- -	+		+ +
Eunicidae	Polychaete				+		
Terebratulida	Lamp shell	-			+ +	+	
Bryozoa encrusting	Sea mat	-		- - -			+
Bryozoa soft	Soft moss animal	-		- -			
Isopoda	Isopod					- -	
Balanomorpha	Barnacle				+		+ +
Asteroidea	Sea star	-			+		
Ophiuroidea	Brittle star	- - -		- -	+ + +		+ +
Holothuroidea	Sea Cucumber		+				

Table 1: Response of key taxa to fishing impact. Sybols +/- indicate direction of response (+ positive, -negative). Number of symbols shows significance (+++/---p<0.001, ++/-- p<0.01, +/- P<0.05

Appendix 4

"Can we see the genetic fingerprint of fishing impact on the cold water corals of Western Greenland?"

Lizzie Murphy_MSc 2014 (Link to pdf)

Cold water corals of the family Nephtheidae, are the most widespread corals on the western continental shelf of Greenland. As with all sessile filter feeders, there may be negative impacts of trawling, from physical removal of specimens, through to difficulties feeding from sediment plumes. Genetic analysis of these specimens may provide insight into population history that cannot be gathered by simply counting specimens. The taxonomy of the nephtheids is challenging, but examining genetic markers may bypass difficulties of mophological identifications based on small samples.

This project tested the utility of the genetic markers ITS1, ITS2 and MutS. Results showed clear divergence between Gersemia and Duva genera, but the 'Capnella' group were polyphyletic throughout. Initial misidentification and convergent morphologies can explain this. Mapping of phylogenetic clusters suggests little evidence for restricted gene flow and isolation of colonies, as a result of trawling. Lack of overlap in successful samples for all three regions show more informative and congruent markers are required before analysis into nephtheid diversity and response to fishing pressures can be furthered.

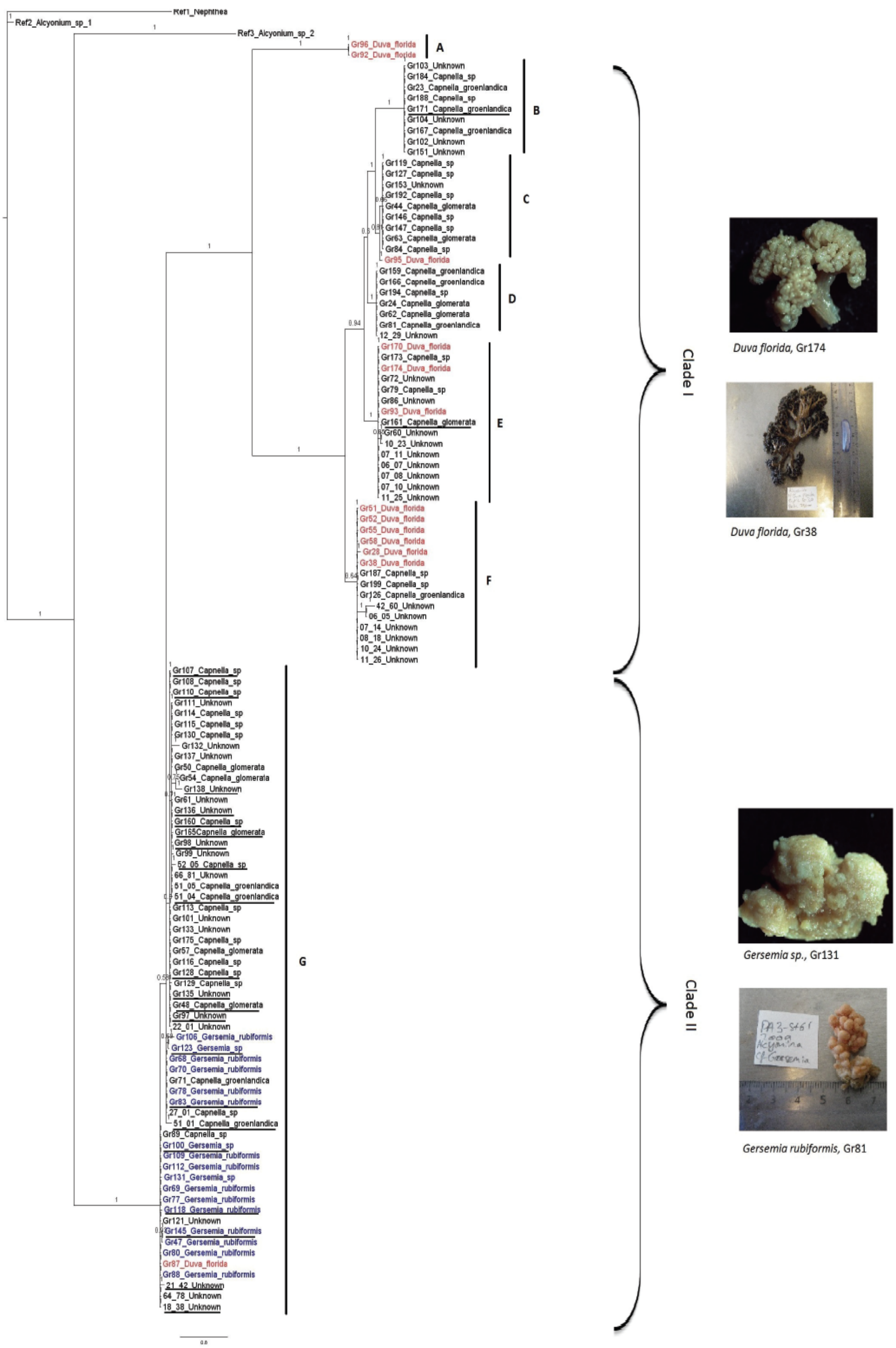

Figure 5. Phylogeny of Nephtheid specimens based on the ITS1 region.

Appendix 5

"*Creating a benthic habitat map for the West Greenland shelf*"

Chris Turner_MSc 2014 (Link to pdf)

Although we have been collecting seabed images and coral bycatch for several years the proportion of seabed sampled on the western shelf of Greenland remains limited. We cannot hope to directly observed corals on the entire seabed. This project created shelf-wide distribution estimates for key coral groups on the west Greenland shelf using first habitat suitability models. Three important coral groups were studied, the gorgonian sea fan *Paragorgia arborea*, the soft coral family Nephtheidae, and the sea pens Pennatulacea. Environmental layers for the seabed were generated from the IBCAO bathymetry grid and Outputs from the modelling process were analysed to identify key predicted habitat areas, the importance of different environmental variables, and the relationships of these coral with fishing activity.

Fishing pressure was not a significant predictor of coral distribution, although relationships between distribution and fishing pressure may be more complex that a simple linear response. The results of this study can help direct future in situ research, and can inform policy and fishing practices in order to ensure the protection of the benthic environment.

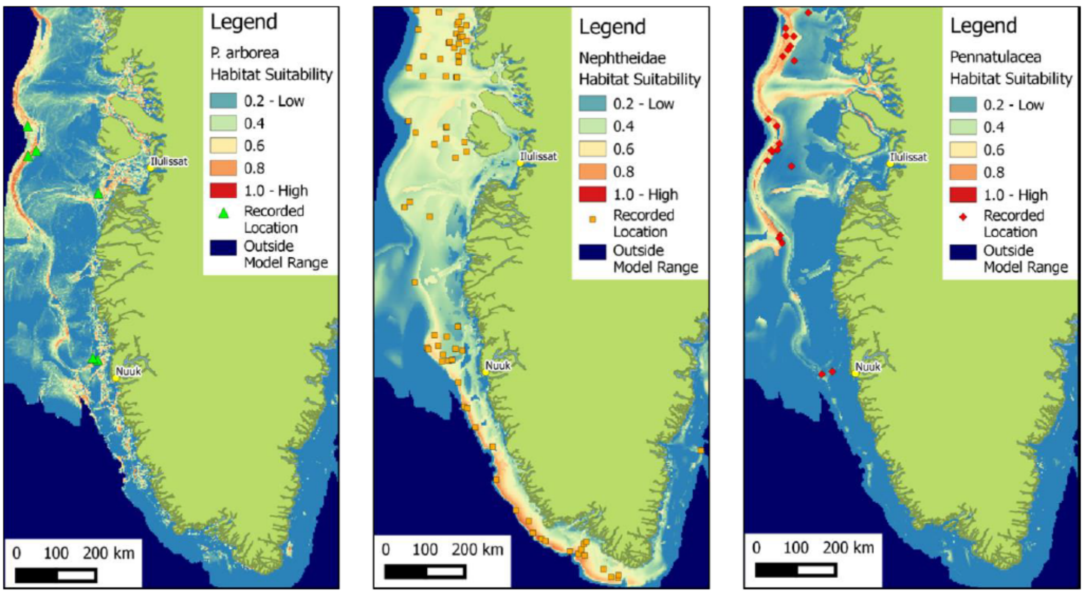

Figure 6. Habitat suitability models of the West Greenland Shelf. Nephtheids are widespread on the shelf. *P. arborea* is prevalent in high slope regions, while the seapens are found in deeper areas.

Appendix 6

Slides presented at the ICES symposium, Tromsø, June 2014 (link to slides)