Imperial College London

Mapping and classifying the seabed of West Greenland

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September 2015

A thesis submitted for the partial fulfillment of the requirements for the degree of Master of Science/Research at Imperial College London

Formatted in the journal style of Polar Biology

Submitted for the MRes in 2015

Declaration

I declare that this thesis

"Mapping and classifying the seabed of West Greenland" is entirely my own work.

For the present study, photographic survey aboard the R/V Paamiut was performed by Dr. Chris Yesson and Dr. Kirsty Kemp, who supervised this project. Image processing, habitat classification, mapping, development of the model and analyses were entirely my own work. I received guidance and advice from my supervisors at various stages of my work (during image processing, substrate identification, editorial comments on my thesis).

Sarah Gougeon, 1st September 2015.

Word count: 5985

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Abstract

Marine benthic habitats are facing increasing pressure from human activities. Trawling causes serious damage to seabed ecosystems. Our knowledge of the distribution of these habitats is largely incomplete. The polar region is home to a significant shrimp trawl fishery, which is undergoing assessment by the Marine Stewardship Council (MSC) for a certificate of sustainability. Assessing the region's habitats to improve our understanding of their vulnerability to anthropogenic stressors is an important step in this assessment. Photographic surveys of the seabed of the West Greenland shelf were conducted over 5 years. More than 2000 images were sampled from 223 sites ranging from 60ºN to 72ºN in depths of 61-725m. Images were grouped into habitat classes and were compared with anthropogenic and environmental data. A classification model, based on the environmental characteristics of stations was used to classify the entire western shelf. Seven classes were identified for a broad-scale classification. The spatial distribution of habitats was found to correlate with temperature and latitude. Muddy sediments appear in northern and colder areas whereas sandy and rocky areas appear in the south with warmer sites and high-energy input. Trawling effort is concentrated on the northern muddy-sand habitats as well as on tiny rocky areas. Gravelly areas are under low fishing efforts. The production of the first habitat classification and map of the West Greenland shelf enables mapping of species and habitat distributions, which is important for future management efforts and conservation of the benthic ecosystems.

Key words: West Greenland; benthic habitats; continental shelf; habitat modelling

Introduction

Seabed habitats are a crucial part of marine ecosystems. The deep-sea habitats are rich in biodiversity and host many widespread and economically important species (Costello et al. 2010, Rex and Etter 2010). However, deep-sea benthic habitats are still poorly studied with only 5-10% of deep-seabed habitats having been mapped with a level of detail comparable to the terrestrial environment (Wright and Heyman 2008). Therefore, our knowledge of the diversity and distribution of these habitats as well as their functioning and vulnerability to anthropogenic stressors is largely incomplete. This is particularly true in polar regions and greater depths. Currently very little information is available on the West Greenland deep-sea benthic habitats. Substrate types (rock, mud and gravel, mixed substrate) have been only basically described in areas that are exploited by the shrimp fishery, in the relevant fishery management plan (Lassen et al. 2013).

Fishing has been identified as the most pervasive threat to marine biological diversity (Bohnsack et al. 1996, NRC 2002). Three quarters of the world's continental shelf is subject to trawling and dredging (Kaiser et al. 2006). Unfortunately, this method can have severe impacts on marine ecosystems. It may cause physical disturbance of the biogenic and abiotic habitat structure (Puig et al. 2012). Bottom trawling can affect habitats by damaging and reducing structural ecosystems and habitat complexity (Rice 2006, Simpson and Watling 2006) but can also reduce major habitat features and alter seafloor structure. It is estimated that the loss of coral and sponge habitat due to bottom trawling is comparable to terrestrial deforestation (Watling and Norse 1998).

West Greenland is home to a commercially important shrimp trawl fishery, which is in the process of evaluation by The Marine Stewardship Council, an independent organisation that sets sustainability criteria for certification and eco-labelling. This is an effort to get MSC certification as a badge of sustainability. This MSC certification addresses three main principles: (1) condition of the fish stocks, (2) impact of the fishery on the marine environment, and (3) fishery management systems (Lassen et al. 2013). This process requires an independent assessment of the fishery's trawling impact on benthic habitats. This independent assessment is being conducted by researchers at the Institute of Zoology, London in collaboration with the Greenland Institute of Natural Resources and Sustainable Fisheries Greenland.

The West Greenland Coldwater Shrimp Trawl Fishery exploits *Pandalus borealis* between 150 and 600m in depth. The total allowable catch for west and east Greenland is estimated around 130,000 tonnes with 90% of this taken by the West Greenland fishery (Hammeken Arboe 2014). While slightly less damaging to the sea bed than other mobile gear (e.g. beam trawls, dredges) (Collie et al. 2000), the most commonly used otter trawls remove both target and non-target species (bycatch) (Kaiser et al. 2000). Additionally, trawl doors plough furrows through sediment that can remain for weeks or even years (Smith et al. 2000).

Our knowledge of the geographical range and ecological functioning of benthic habitat is still extremely limited due to the constraints of conventional seabed survey methods (Brown et al. 2011). Consequently, it's a real challenge to manage resources adequately and protect important areas. In order to address this concern there is an urgent need to produce marine benthic habitat maps to study community associations, diversity and vulnerability (Ehler and Douvere 2009, Reiss et al. 2014). A number of benthic mapping projects are currently being undertaken in Europe such as MESH (http-//www.searchmesh.net), MAREANO (http-//www.mareano.no), BIOMOR (Mackie et al. 2006). Several methods are used to perform habitat mapping such as *in situ* sediment sampling, underwater video, stills photography (known as ground-truthing techniques) but also new technologies such as acoustic backscatter and high-resolution seismic reflection. These techniques use sound sources of different frequencies to produce images of surface and subsurface features of the seafloor. Predictive modelling is one of the methods that has only recently been developed and applied in the marine environment (Young and Carr 2015).

A habitat can be defined as "a place where plants or animals normally live, characterised primarily by its physical features (topography, plant or animal physiognomy, soil characteristics, climate, water quality etc.), secondarily by the communities of plants and animals that live there" (Davies et al. 2004). Scientists have developed several methods to classify and describe habitats but the challenge is to provide a classification that is transferable. According to Brown et al., (2011) there are three main approaches for benthic habitat mapping: 1) Abiotic surrogate mapping; 2) Assemble first, predict later and 3) Predict first, assemble later. Several classification schemes have been developed. Common divisions in classification systems include biogeographical regions (Allee et al. 2000, Roff and Taylor 2000, Ehler and Douvere 2009), depth (Greene et al. 1999, Allee et al. 2000, Roff and Taylor 2000, Connor et al. 2004, Ehler and Douvere 2009), geomorphology (Greene et al. 1999; Allee et al. 2000, Ehler and Douvere 2009) and substrate type (Greene et al. 1999, Connor et al. 2004). Other aspects of seafloor are included in some classifications but less frequently encountered: currents, wave exposure, relief and slope (Leathwick et al. 2012). Furthermore, some habitat classification has been developed at different depths and geographical scales (e.g.: the North-eastern North America Region (Valentine et al. 2005). The system by which habitats are classified within Europe is the European Nature Information System (EUNIS) (http-//eunis.eea.europea.eu). It covers all types of natural and artificial habitats, marine, freshwater and terrestrial (Davies et al. 2004). However, this classification scheme is not applicable across the whole world as EUNIS is based on examples from the North Sea. Furthermore, the deep-sea section of the EUNIS classification needs further development (Galparsoro et al. 2012).

The specific aims of this study are to 1) perform a habitat classification by developing a modified version of the EUNIS scheme; 2) develop a classification model, based on the environmental characteristics of sampled stations to classify the entire western shelf into habitat classes without direct sampling 3) produce a continuous map of seabed classes over the western Greenlandic shelf. This predictive map will then be compared with levels of fishing effort to assess which habitat types are under most direct stress from human impact, and will directly contribute into the assessment of the shrimp trawl fishery for the MSC certification process.

Materials and Methods

Study area

The West Greenland shelf includes a diverse range of benthic habitats due to the diversity of environmental conditions in this area. The study area extends for more than 100 km offshore and spans across a latitude range from 85°N to 60°N (Figure 1). Many fjords and islands are present off the coastline as well as shallow banks (>50m) and deep troughs (>300m). West Greenland presents large marine embayments: Disko Bay with water depths between 200 and 400 m is characterised by a rough and irregular seafloor (Hogan et al. 2012). From an oceanographic perspective, in southwest Greenland, two water masses are predominant: the cold low-saline coastal water from the East Greenland Current; and the warmer, more saline Atlantic water (Myers et al. 2007). The south west continental shelf of Greenland is dominated by a rocky steep shelf slope and strong current whereas in the north-western region the current is weaker and water is colder due to ice cover and wider shelf break (Buch 2000, Yesson et al. 2015).

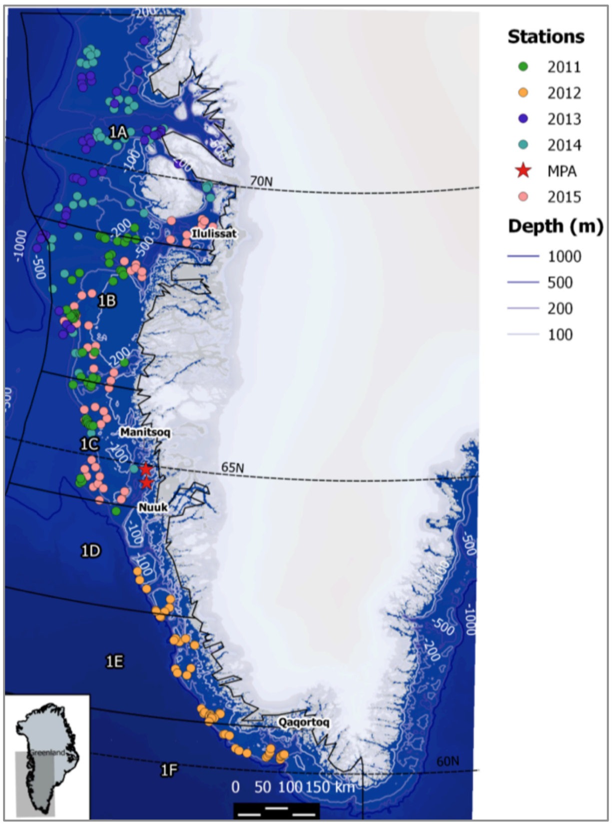


Fig.1 Location of sampling stations with NAFO divisions. Seabed photographs were taken on five cruises over five years between 2011 and 2015. (Map projection epsg:3411)

Administrative boundaries for fisheries management were implemented by the North Atlantic Fisheries Organisation (NAFO) to correspond with fish stock boundaries (Clay 1996). All research was conducted within NAFO divisions 1A to 1F (~58° - 73°N, -43 -58°E) (Figure 1).

Sea bed imaging

In the present study, more than 2000 photographs of the seabed of the West Greenland shelf have been analysed, from 223 sites ranging from 60ºN to 72ºN (Figure 1). Photographic surveys of the sea floor of West Greenland Shelf were carried out aboard the R/V Paamiut over 5 years, in collaboration with the Greenland Institute of Natural Resources (GINR). Stations between Nuuk and Ilulissat were photographically sampled in 2011 (N=44) and 2015 (N=49). Stations between Nuuk and Qaqortoq were sampled in 2012 (N=45); stations between Ilulissat and North of Disko Bay were sampled in 2013 (N=38) and stations between Ilulissat and Upernavik were sampled in 2014, in addition to two newly established protected areas outside Nuuk (N=47).

The image sampling was conducted using a drop camera, Nikon digital SLR camera DSC-10000 contained within a Digital Ocean Imaging Systems (DOIS) deep-sea camera housing, and fitted with a 200W-S Remote Head Strobe flash unit (DOIS, Model3831). All of this equipment was mounted on a weighted steel frame. To optimize the seabed imaging, a weight suspended below the frame triggered the camera when it made contact with the seabed. Each image sampled an area of approximately 0.3m^2 and the sites varied in depth between 61 and 725 m. An average of ten images were captured at each sampling station. The location, time, depth and length of winch wire extension were recorded for each image. To ensure subsequent pictures did not sample the same area the camera was raised 10-20 m off the seabed for 1 min in between pictures. In general, during the 1 minute interval between pictures the ship and camera would drift approximately 20 to 50 meters. The selection of station locations was made with the aim of sampling a range of different depths, seabed sediments types and levels of fishing impact. The sampling was constrained by other ship activities, weather and equipment failures. Stations were a minimum of 10 nautical miles apart (Yesson et al. 2015).

Image processing – Habitat Classification

Photographs of each station were grouped into a habitat class based on a modified version of the EUNIS scheme (Davies et al. 2004). The main differentiation between the classes was the substrate type; the importance of substrate in determining the distribution of benthic marine organisms is established (Howell et al. 2010). Images were processed using an ID template compiled as part of the project incorporating the distinct seabed types encountered during analysis. The template was created by grouping different stations with the same features including substrate type (sand, mud, sandy-mud and rock), substrate bioturbation (animal trails, burrows) and living animals (Appendix IX). Sedimentary structures such as ripple marks on seabed and the softness of the substrate were essential information for determining categorisations during image processing. Different colours of the substrate also helped in the classification. Each time a new seabed type was observed in an image, the main patterns were defined, the novel class was given a name and added to the template (Appendix I). Some seabed classes have been grouped together in accordance with the updated Folk sediment triagon (Connor et al. 2004, Davies et al. 2004), for example gravelly muddy sand class was grouped with gravelly muddy for consistency (Appendix IV). These classes were chosen because they are biologically meaningful (the quantity of mud has an important influence on the related biology); the number of different habitat classes is thereby kept minimal. Data from these images were aggregated in station-level for analysis.

Habitat modelling and mapping

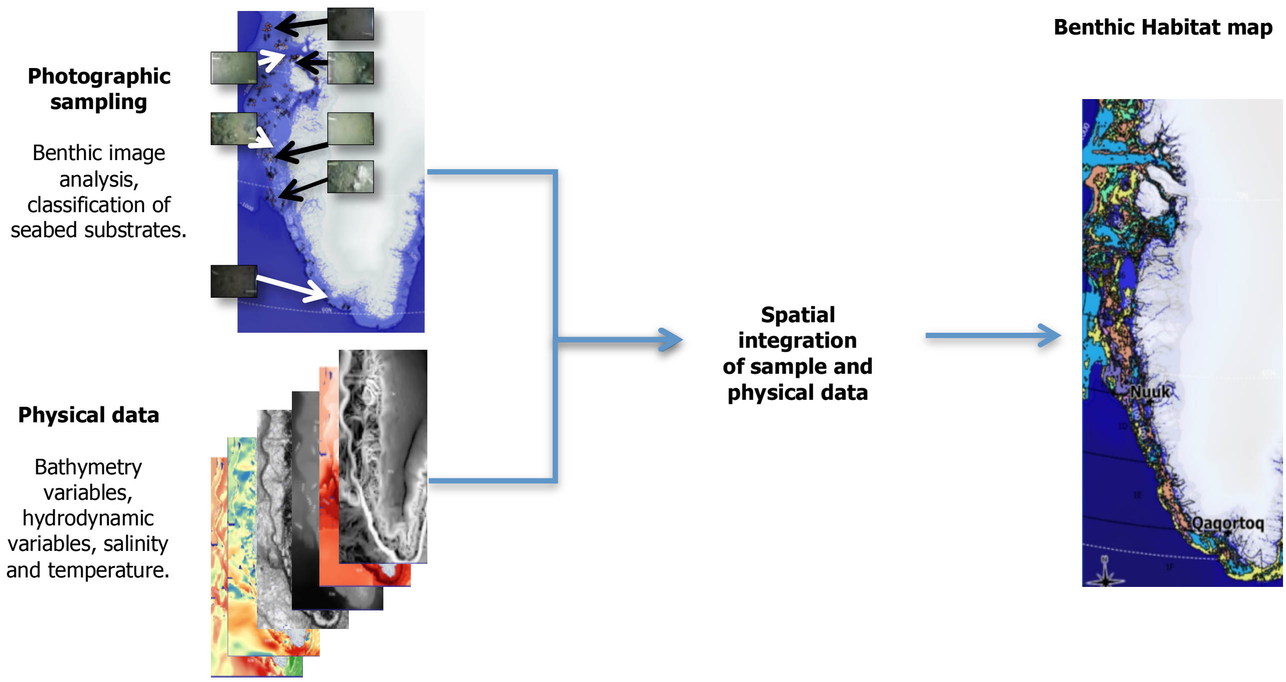


Fig.2 Schematic representation of the main steps used to produce a habitat map of The Greenlandic shelf; the combination of several raster layers, analysis and classification by substrate of benthic images.

Benthic ecology in the ocean is influenced by both seabed geomorphological aspects and the above water column characteristics. The environmental layers used were chosen to provide geographical information on these parameters (Table 1). Data were extracted from each environmental layer for every sampling station. Some stations lacked associated environmental data; in these cases a buffer of the size of pixel 3500 m was specified. The value obtained referred to the closest pixel. Accuracy of depth layer data was evaluated by comparing recorded depth from the photographic survey with inferred depth from bathymetry data. Inferred depths were obtained from a bathymetry grid using the package raster in R. Records with differences of greater than 500m between the two depth values were omitted (Yesson et al. 2012). Fishing effort data were box cox transformed using the 'bcx' function

(Box and Cox 1982) in MASS R package (Venables and Ripley 2002) (Appendice II). These data were the sum of yearly impact values prior to the year the benthic images were taken (cumulative fishing impact). Sampling stations that were located outside the Exclusive Economic Zone (EEZ) were excluded from the analysis in order avoid generating a false negative for trawling occurrence. Fishing data were only used for years up to 2013. Existing datasets from 2014 to 2015 are incomplete and not used.

Table 1 Environmental variables used in this study for habitat mapping and with description and references.

	Variable	Source	Native resolution	Unit	Description
Bathymetry variables	Depth	IBCAO	0.5 x 0.5km	Meters	Derived from IBCAO bathymetry layer and downscaled using QGIS.
	Fine Scale Slope	IBCAO	0.5 x 0.5km	Degrees	Produced by terrain analysis in QGIS from IBCAO bathymetry grid and then downscaled within QGIS.
	Coarse Scale Slope	IBCAO	3.5 x 3.5km	Degrees	Slope layer produced in LandSerf, from IBCAO bathymetry grid, with values representing slope over a distance of 35km.
	Ruggedness Index	IBCAO	0.5 x 0.5km	Meters	Layer produced by terrain analysis in QGIS from IBCAO bathymetry grid and downscaled within QGIS.
Hydrodynamic variables	U	MyOcean	12.25 x12.25km	Meters per second	Current value detailing velocity in metres per second from West to East, from the TOPAZ4 Arctic Ocean Reanalysis dataset, and up-scaled.
	V	MyOcean	12.25 x12.25km	Meters per second	Current value in metres per second from South to North, taken from the TOPAZ4 Arctic Ocean Reanalysis dataset, and up-scaled.
Chemical variables	Salinity	MyOcean	12.25 x12.25km	PSU (Practical Salinity Unit)	Salinity obtained from the TOPAZ4 Arctic Ocean Reanalysis dataset; up-scaled using a cookie cutter process.
Other variables	Temperature	MyOcean	12.25 x12.25km	Degrees Celsius	Obtained from TOPAZ4 Arctic Ocean Reanalysis dataset, upscaled using a cookie cutter process from a bespoke python script.
	Fishing	Dr C. Yesson from data supplied by GINR	3.5 x 3.5km	Minutes	Values of number of hours trawled by the Greenland shrimp fishery, 1986-2013.

High correlation between variables can confound model fitting. To avoid this problem, a correlation analysis of environmental layers was performed using the Pearson correlation with the 'cor' function in the stats package of R (version 2.11.1, http-//www.R-project.org/). Some variables showed high correlation with other variables (Appendix III), particularly between rugosity and slope (correlation value of 0.98), and temperature and salinity (correlation value of 0.90). If two environmental layers are heavily correlated (>0.90) then this can lead to over-fitting of the model; removing one of the layers from the analysis ensures the variables tested remain distinct (Yesson et al. 2012). Rugosity and salinity were excluded from the analysis as they were highly correlated with other main environmental measures. Fine and coarse slope data were log transformed; current data were square root transformed for both U and V currents.

Support vector machine (SVM) model was implemented using the e1071 R package (Meyer and Wien 2014). The data were divided into two parts. The first part was used to build the model and the second to test it to see whether the model could predict the sediment classes of the test data. This allows to assess whether the model is transferable or whether it has been over-trained to make too specific a prediction. SVM objective is to define the optimal boundary that separates classes in featured space (the optimal separation hyperplane). The classification is based on which side of the decision boundary the data point falls. After choosing the boundary which maximises the distance between classes, the 'optimal' hyperplane is chosen based on the maximum margin principle.

Parameter tuning of the SVM model to the training data is a crucial step to find a balance between creating a model that is able to classify the training data correctly without overfitting to the random fluctuations in the training data (Luts et al., 2010). Models were repeated with variations of parameters: cost (range -5-13) and gamma (-13-3). The most appropriate parameters for each model were selected based on the lowest cross-validated error score (Luts et al. 2010). The ranges over which to perform tuning were determined from values recommended in the literature (Meyer and Wien 2014).

After the model tuning process finished and the optimal model parameters selected, predictions were made on the test set using the chosen model from the tuning process. Kappa coefficient of agreement and the Diagonal of the table of agreement were calculated to evaluate the performance of the model. Kappa is used for comparison of the performance of classification of the model and presents a measure of agreement (by random chance). The Diagonal is used to evaluate the classification accuracy, which is the proportion of stations that were correctly classified. The closer the output values from the model to 1, the stronger the model performance.

Confidence assessment

The results from the habitat map were compared with physical samples collected using a grab sampler from 14 stations in 2015. The sediments were kept in 1.5 mL tubes prior to analysis under a microscope (Leica). A microscope fitted with a Leica camera DFC 420C was used to take photographs of the sediment at a magnification of X400. The resulting images were analysed for grain size analysis using Image J software (Schneider et al. 2012). Grain-size analysis is important in order to determine benthic habitat as the biology of any area of seabed with a grain size of mainly 2mm will be extremely different to the biology with cobbles or boulders (Robinson et al. 2009). The resulting picture was converted to a grey scale and particles were analysed using an automatic scale of 20 μm. These samples were analysed in order to check picture classification as well as for grain-size analysis.

The MSC report (Lassen et al. 2013) describes 30 traditional shrimp fishing areas between Cape Farewell in the south (62°N) to Upernavik in the north (74°N). 27 of these fall within our study area (Figure 3). These data are reported by skippers with four approximate coordinates and description of the seabed. Data were used to do a comparison with the substrate classification developed here. To achieve this, 1000 random points were created in QGIS software (version 2.8.1) in the selected areas and compared with the habitat classification. This will help to test this habitat classification and see whether it can be transferable for other datasets.

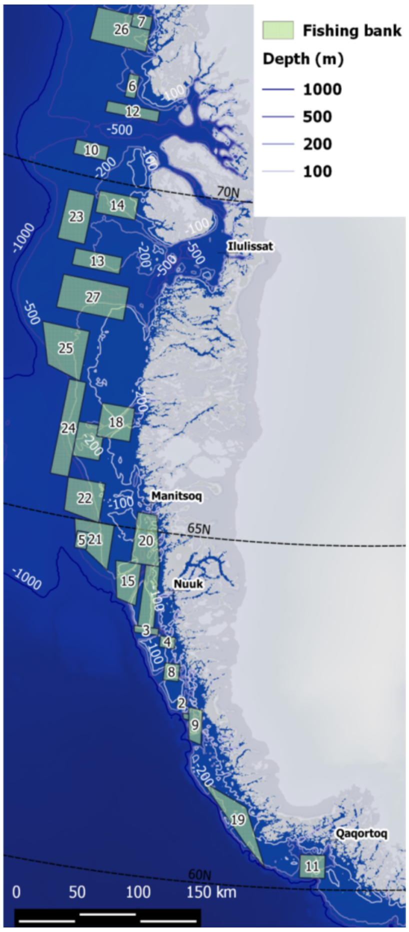


Fig.3 Shrimp fishing stations map described by skippers and represented here with green polygons (four coordinates were designed in MSC report (Lassen et al. 2013)). Map projection epsg:3411.

Fishing impacts

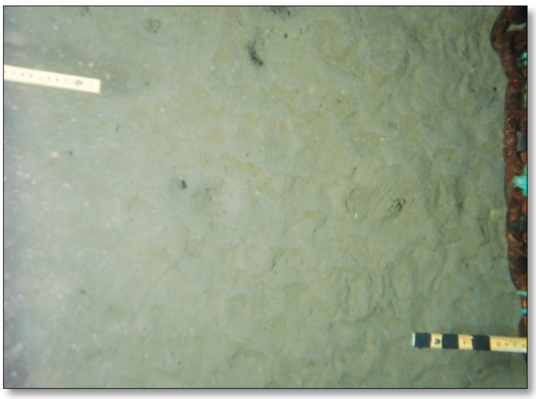
The habitat map was compared with fishing effort data site by site (NAFO) to determine which habitats are the most heavily fished. A clip was used to get the same extent between the two rasters grids using the 'crop' function in R in the raster package (Hijmans et al. 2015). The threshold between High and Low fishing impact (including no fishing) was defined using Jenks natural break in R using the 'classInt package' (Bivand 2015). The threshold value inferred was 94530.2 trawling minutes.

Results

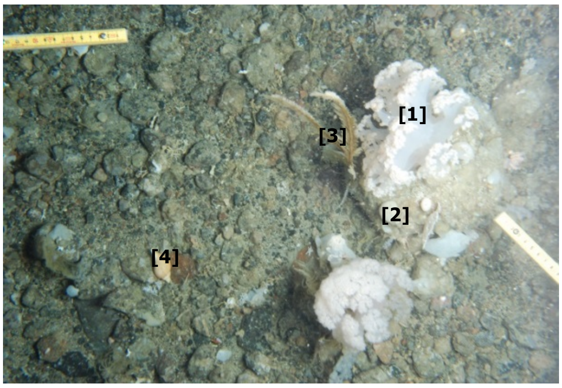
Habitat Classification

Seven classes were identified as relevant for a broad-scale classification of the West Greenland continental shelf (Figure 4 and 5, Table 2). Soft sediment classes include mud and muddy–sand. Mud sediments (M) (grain size <0.06mm) were identified by the softness of the sediments as well as presence of invertebrate burrows. Muddy-sand (mS) sediments are identifiable by the presence of ripples on the seabed as well as the contrast between the mud and sand sediments. The mixed sediments such as gravelly muddy (gM) are found usually with some small pebbles (2-4mm). Coarse sediment such as gravelly sandy (gS) is recognizable by the presence of animal tracks that are specific to sandy sediments with pebbles (4-64mm). Areas with no substrate visible are defined as coarse rocky ground. Bedrock with sand sediment (sR) or mud sediment (mR) are defined as distinct from the other classes because there are significant areas where bedrock occurs at the seabed surface in association with a thin, often discontinuous, covering of sediment.

Mud seabed substrate (mean value of 352.3m) and gravelly mud areas (307.9m) appear mostly in deeper waters (Table 2). Coarse sediments including bedrock with mud, sand sediments and gravelly sandy areas are found in the same geographic range as rocky areas. However sandy substrates (sandy bedrock and muddy-sand) are present in shallower areas (236.5 and 248.3 respectively). These classes are strongly separated in relation to temperature and latitude, with muddy areas (mR, M, gM, mS) appearing in the north (67.11° and 69.01°) and colder areas (1.83°C and 2.19°C) and sandy and rocky areas appearing in the south (64.07° and 65.63°) and warmer sites (3.29°C and 4.01°C) with high-energy input (Appendice V). Gravelly sandy substrate seems to have the largest variation in terms of temperature and latitude; this can be explained as it is the most widespread sediment along the coastline of the West Greenlandic shelf (Figure 6A). Gravelly sandy substrate seems to appear on high slope (0.05) in comparison to muddy sand substrate (-0.85) (Figure 5).



Muddy sand sediments with ripples and invertebrates burrows.
Station 31 from 2011 at a depth of 310 meters.



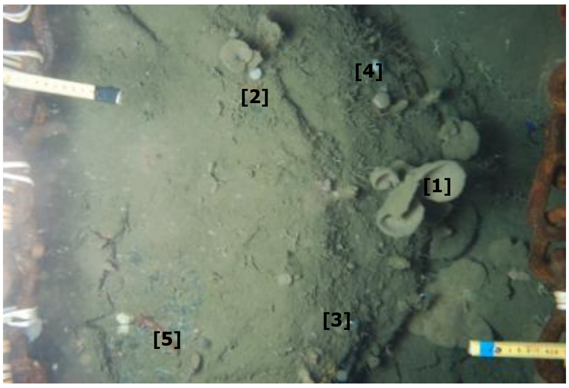
Coarse rocky ground with occasional boulder (0.25-3m), cobbles (64-256mm) and pebbles (4-64 mm).

Station 4 from 2011 at a depth of 388 meters.

(Example: soft corals (Alcyonaceae) **[1]**, Stylasteridae, Zoantharia sponges (Porifera) **[2]**, hydroids (Hydroidolina) **[3]**, bryozoans (Bryozoa), Gastropoda **[4]**, sea brittle stars (Ophiuroidea), worms (Nemertea) and chiton (Polyplacophora).

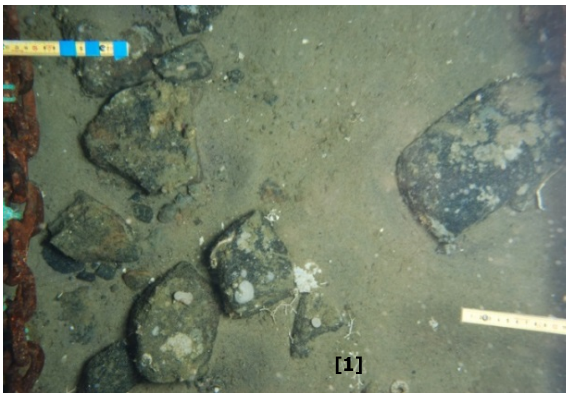
Muddy sediments with invertebrate burrows and *Pandalus borealis* (Decapoda) **[1]**.

Station 2 from 2014 at a depth of 374 meters.



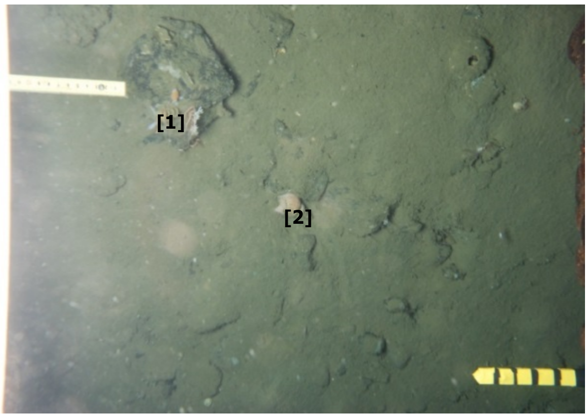
Bedrock with mud (<0.06mm), boulder (0.25-3m) and pebbles (4-64mm).

Station 18 from 2012 at a depth of 269 meters. (Example: Large sponge coral (Porifera) **[1]**, Ascidians (Ascidiacea), brittle stars (Ophiuroidea) **[2]**, worms (Sabellidae) **[3]**, bryozoans (Bryozoa) **[4]** and Decapoda **[5]**.



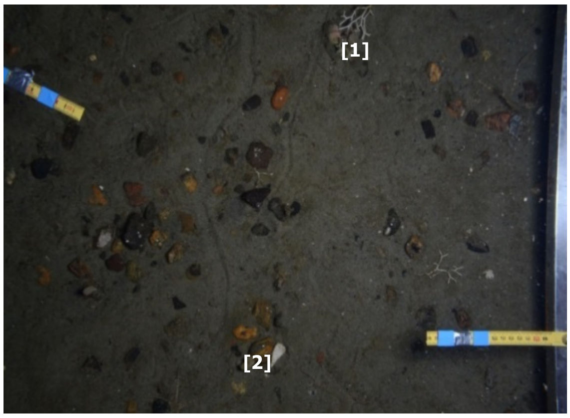
Bedrock with sand (0.06-2mm) sediment with boulder (0.25-3m) and pebbles (4-64mm).

Station 22 from 2011 at a depth of 164 meters. (Example: bryozoans (Bryozoa) **[1]**, shells (Bivalvia), brittle stars (Ophiuroidea), and Zoantharia sponges (Porifera).



Gravelly muddy sediments (<0.06mm).

Station 38 from 2011 at a depth of 198 meters. (Example: bryozoans (Bryozoa) **[1]**, shells (Gastropoda) **[2]**, brittle stars (Ophiuroidea), sea anemones (Actinaria) and sponges (Porifera).



Gravelly sandy sediments (0.06-2mm) **with animal tracks.**

Station 42 from 2014 at a depth of 175 meters. (Example: bryozoans (Bryozoa) **[1]**, shells (Gastropoda) **[2]**.

Fig.4 Benthic images illustrating each of the seven habitats encountered.

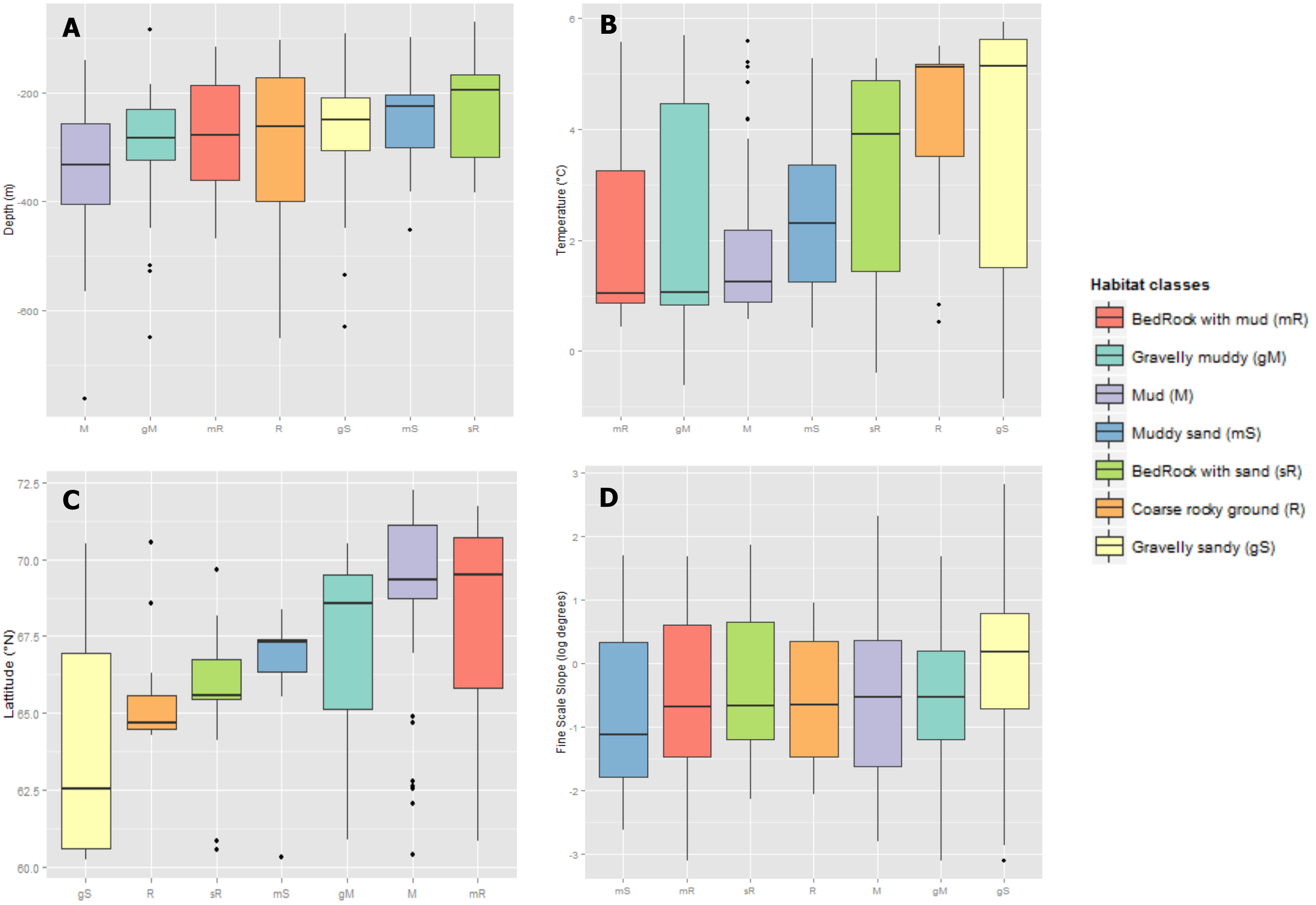


Fig.5 Box plots of the main environmental variables gathered from observation data: Depth (m), Temperature (°C), Latitude (°N) and Slope (log degrees) plotted against substrate types. Horizontal lines indicate median values, boxes indicate quartiles, whiskers show standard deviation, and open circles are outliers.

Table 2 Geographic extent (calculated in QGIS) and environmental mean and range of 7 groups defined by photographic classification of benthic substrates. (gM= Gravelly muddy, gS = gravelly sandy, M=mud, mR=bedrock with mud, mS=muddy sand, R=coarse rocky ground and sR=bedrock with sand).

Habitat classes		Extent (km^2)	Latitude (° N)	Depth (m)	Temperature (°C)	Current U (m/s)	Current V (m/s)	Fine Scale Slope (log degrees)	Coarse Scale Slope (log degrees)
gM	Mean	**26,704**	**67.11**	**307.9**	**2.19**	**-0.0041**	**0.0018**	**-0.5326**	**-0.7853**
	Range		[60.90-70.53]	[84-654]	[-0.61-5.70]	[-0.0382-0.0170]	[-0.0031-0.0737]	[-3.0945-1.6901]	[-2.4320-1.2964]
gS	Mean	**50,398**	**64.07**	**272.2**	**3.89**	**-0.01744**	**0.0191**	**0.05774**	**-0.2365**
	Range		[60.22-70.51]	[91-629]	[-0.8485-5.9277]	[-0.0744- 0.0522]	[-0.0211-0.06553]	[-3.0945-2.8173]	[-3.2049-1.6689]
M	Mean	**78,537**	**69.01**	**352.3**	**1.83**	**-0.0024**	**0.0030**	**-0.6008**	**-1.0920**
	Range		[60.39- 72.27]	[141-761]	[0.5739-5.5814]	[-0.0411-0.0162]	[-0.0104-0.0357]	[-2.8006-2.3213]	[-3.1483-0.7911]
mR	Mean	**45,173**	**67.92**	**277.0**	**2.01**	**-0.0019**	**0.0068**	**-0.5196**	**-1.2460**
	Range		[60.83-71.73]	[116-468]	[0.4364-5.5658]	[-0.0389-0.0193]	[-0.0063-0.0492]	[-3.0945-1.6901]	[-4.4569-1.0807]
mS	Mean	**14,790**	**66.66**	**248.3**	**2.44**	**-0.0002**	**0.0030**	**-0.8574**	**-1.4338**
	Range		[60.30-68.37]	[99-452]	[0.4174-5.2842]	[-0.0193-0.0204]	[-0.0028-0.0138]	[-2.6168-1.7018]	[-3.9736-0.1628]
R	Mean	**15,560**	**65.41**	**298.4**	**4.01**	**-0.0022**	**0.0117**	**-0.6038**	**-0.6636**
	Range		[64.27-70.56]	[104-651]	[0.5267-5.4961]	[-0.0192-0.0089]	[-0.0040-0.0370]	[-2.0548-0.960]	[-2.9470-0.4402]
sR	Mean	**8949**	**65.63**	**236.5**	**3.29**	**-0.0059**	**0.0134**	**-0.3449**	**-0.4668**
	Range		[60.56-69.64]	[71-383]	[-0.3838-5.2763]	[-0.0622-0.0099]	[-0.0039-0.0591]	[-2.1361-1.8599]	[-2.0206-0.3700]

Model performance

The statistical evaluation of the final model selected and the range of each parameters used in the analysis is presented in Table 3. The model presents an overall accuracy of 0.84 and a kappa coefficient of 0.81. The table of agreement presents the classes that are misclassified (Table 4). mR (bedrock with thin layer of mud (0.24)) and sR (bedrock with thin layer of sand (0.27) are the classes hardest to predict. The classes that present the least misclassification are: gravelly sandy substrate (0.09), coarse rocky ground (0.12), gravelly muddy (0.13), muddy-sand (0.14) and mud (0.15).

Table 3 Model Performance and parameters. Diagonal represents the proportion of the total number of correct predictions and kappa coefficient is the diagonal adjusted to consider the amount of agreement that could be expected due to chance alone.

Parameters	Parameter description	Tuning Range	Best value
C	The cost parameter determining how many data are included in creating the decision boundary, a small value will consider more observations.	-5 -13	2
Gamma	The kernel smoothing parameter defines the shape and complexity of the resulting decision boundary.	-13 -3	0.5
Cohen's Kappa	Diagonal corrected for agreement by chance.	0.03 -0.25	0.81
Diagonal	Percentage of data points in the main diagonal of table of agreement.		0.84

Table 4 Table agreement for the best performing model. (gM= Gravelly muddy, gS = gravelly sandy, M=mud, mR=bedrock with mud, mS=muddy sand, R=coarse rocky ground and sR=bedrock with sand).

		Predicted class frequencies							
Observed class frequencies		**gM**	**gS**	**M**	**mR**	**mS**	**R**	**sR**	**Misclassification**
	gM	26	2	1	0	1	0	0	0.13
	gS	1	39	0	2	0	0	1	0.09
	M	4	0	41	3	0	0	0	0.15
	mR	4	1	4	32	1	0	0	0.24
	mS	0	3	0	1	25	0	0	0.14
	R	1	0	1	0	0	15	0	0.12
	sR	0	0	1	2	1	0	11	0.27

Habitat map

The spatial distribution of habitats is presented in Figure 6A. The results are split into two regions – North (NAFO zone 1A, 1B, 1C) and South (NAFO zone 1D, 1E, 1F) of the West Greenland Shelf. Mud habitat covers the largest area (78,537 km^2) particularly in Baffin Bay, near Ilulissat (Disko bay) and north of Nuuk in deeper areas (more than 500m). Other habitat types covering a large extent are gravelly sandy (continental slope), bedrock with mud sediment (along the coast) and gravelly mud. Coarse rock ground habitat is also present mostly near Nuuk (south of Greenland). Rocky habitats (R, mR, sR) cover in total 69, 683 km^2.

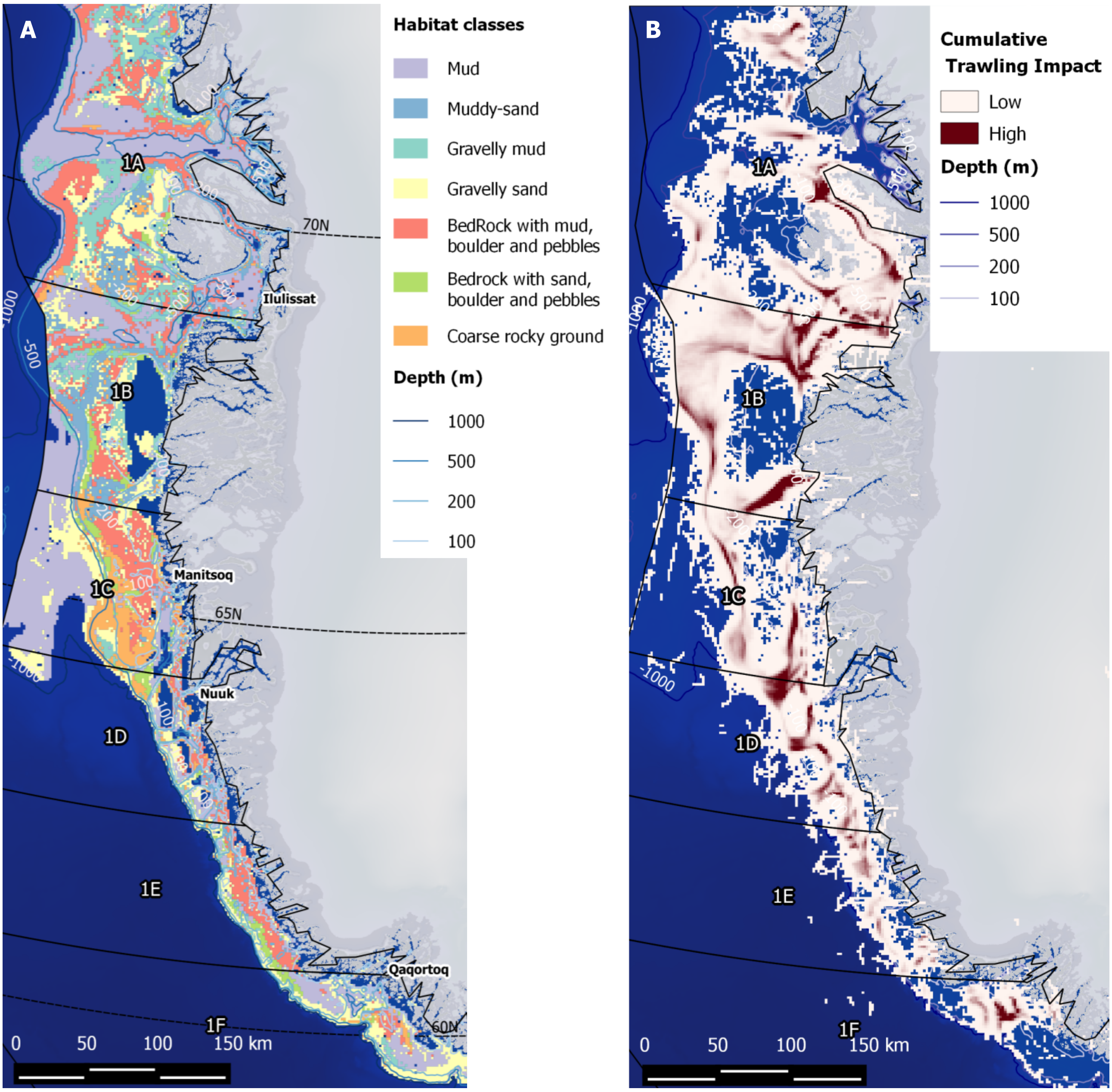


Fig.6 Maps of West Greenland: Habitat map (A) developed with an image survey and a SVM model approach and (B) cumulative fishing efforts. Map projection epsg:3411.

Fishing efforts

The map in Figure 6B presents the cumulative fishing efforts from 1986 to 2013 throughout the West Greenland shelf. Although trawling occurs across the entire study area, the focus of fishing effort is concentrated on soft-sediment habitats (zone 1A). Binomial proportion test results are presented in Appendix VII and cumulative fishing efforts by NAFO divisions are presented in Appendix VIII. Muddy-sand sediment is the habitat, which is most heavily impacted by fishing (19.57%; *p value=2.1e-16*). Mud sediment is less fished. Rocky areas are impacted (11.81%; *p value=1.327e-5*). Gravelly muddy and bedrock with mud sediments (*p value=0.03*) are the habitats that are the least fished (*p value=5.746e-06*) (Figure 7).

In zone 1A, where most of the photographic survey has been undertaken, the habitat most threatened by fishing is muddy habitat (35.35%) even if it is not a significant difference between high and low fished areas (*p value=0.06*). Rocky areas, though not predominant in the north, seem to be impacted as well with 10.61% of the fished areas exposed to high fishing effort (*p value=9.75e-08*).

There is evidence that gravelly muddy substrate is less fished (*p value=4.50e-05*). In zone 1B, interestingly, muddy areas are less fished (13.17%). However, muddy sand areas are by far the most targeted (30.11%; *p value=3.51e-09*). A small portion of southern rocky areas is under trawling efforts (9.95%; *p value=8.4e-06*). Low fished areas are bedrock with sandy sediments. Considering zone 1C, muddy areas are concentrated into deeper regions, perhaps explaining their low impact of 15.53% (*p value=6e-12*).

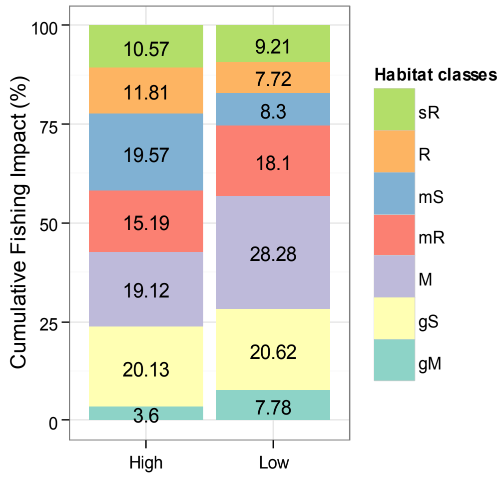


Fig.7 Cumulative fishing impact (%) from 1986 to 2013 observed in each habitat class across the entire study area. (gM= gravelly muddy, gS= gravelly sandy, M= mud, mR= bedrock with mud, mS= muddy sand, R= coarse rocky ground and sR= bedrock with sand).

Muddy sand is under fishing impact here with 21.36% (*p value=7.17E-05*). However, where rocky substrate is predominant, only 9.71% is in areas exposed to high fishing compared to 18.98% in low fishing impact areas. In zone 1D, rocky areas are really small but present in between sandbanks and are under fishing efforts (20.13%; *p value=6.3e-3*). Bedrock with mud sediment along the coast is less impacted with 21.59% falling within low fishing regions (*p value=5.41E-05*). In zone 1E, bedrock with mud sediments are subjected to less fishing impact and most of the fishing occurrence is in coarse rocky ground (26.67%, *p value=8.5e-3*). Zone 1F where gravelly sandy substrate predominates shows a pattern of greater impact in muddy sand sediments (40.48%; *p value=2.1e-16*). Gravelly sandy sediments are not under fishing effort (*p value=5.6e-3*), neither is bedrock with mud sediment (*p value=0.04*).

Map confidence assessment

The substrate description from the MSC report was compared to the benthic habitat classification developed in our study. Four classes were similar to the classes presented here: mud substrate, gravelly muddy (described in several ways in the MSC report see Appendix VI), bedrock with mud sediment (describe as mixed rock with mud bottom / mixed but mostly muddy or rock with sometimes mud) and rock. No classes with sand substrate were directly described. For this purpose, muddy-sand class, bedrock with sand sediment and gravelly sand were grouped with the closest substrate: mud, bedrock with mud sediments, and gravelly mud respectively.

Areas of discrepancy between the MSC report and our habitat classification are shown in the confidence map (Figure 8). These areas correspond to rocky areas where the MSC report assigns one substrate to an extensive area (27 405 km^2, 39 234 km^2, 49 787 km^2). In our habitat map, extensive areas (17, 24, 22 on the map) include substrate ranging from mud sediment in deeper areas to bedrock with mud substrate as well as some rocky areas. Small fishing banks (1,2,4,8) present confidence scores between 60 to 80% except near Nuuk (areas ranging from 2018 to 7632 km^2) where confidence score is 100%.

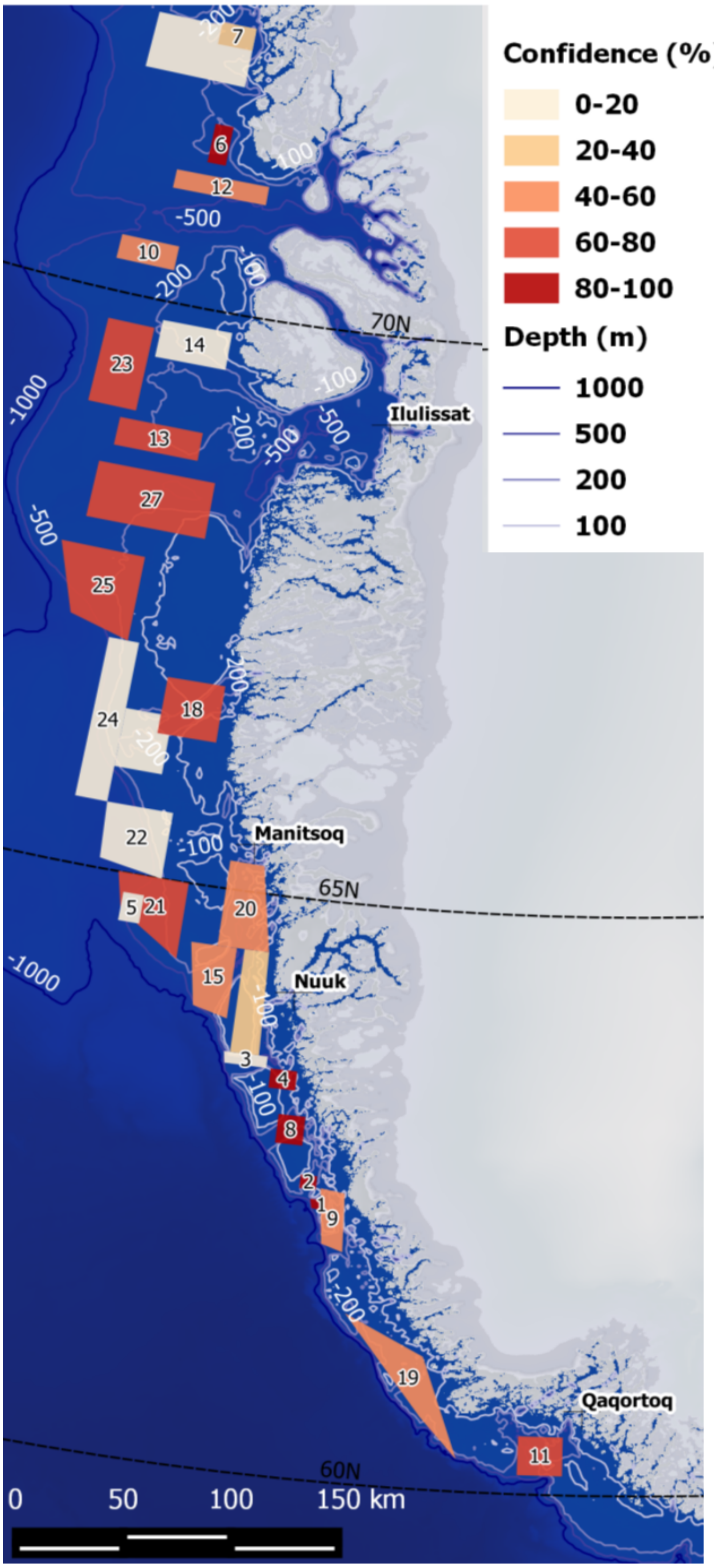


Fig.8 Confidence map for the West Greenland habitat classification. Confidence corresponds to the percentage of random sampling points assigned to the same equivalent habitat classes described in MSC report (Lassen et al. 2013). Number on the polygons represents ID number for fishing bank name (see Appendix VI). Map projection epsg:3411.

Discussion

This study presents the first benthic habitat classification and map of the West Greenland shelf and the first map based assessment of the vulnerability of those marine habitats. Seven habitat classes are developed according to *in situ* sampling and predictive modelling. Northern areas are dominated by soft sediments habitats, with deeper muddy areas off the continental shelf. Southern areas of the west coast of Greenland are rockier with strong currents. Trawling is occurring in all regions of the study area but is predominant in the soft sediments classified as muddy-sand sediments.

The habitat classification system presented in this study is similar to other existing classification systems except that classes defined here have been guided by known variation of community composition. The main classifier in this study is substrate type, which is known to be considerably important in determining the distribution of marine ecosystem (Sejr et al. 2010, Freese et al. 1999). Our classes differ from the EUNIS classification system (Davies et al. 2004) where substratum is divided as follows: rock and artificial hard substrata, mixed substrata, sand, muddy-sand, mud, bioherms. Similar classes include rock and artificial hard substrata, which might correspond to coarse rocky ground in our study, mixed substrata, include gravelly mud and gravelly sand, muddy sand and mud refers to the same class. No bioherms/biogenic classes were included into our classification they were not a predominant feature of our sampling stations. The Artic classification most relevant to our study area is the MAREANO classification (Bellec et al. 2009). Similar to this study, Bellec et al., (2009) found mud substrate in deeper areas with weak currents. Gravelly sand sediments were found in shallower areas with high-energy input, as is also the case in our predictive map. The habitat classification employed here is in accordance with most of the recommendations presented in Galparsoro et al., (2012) for improvement of EUNIS deep-sea habitat classification: bedrock with mud or sand were included in our classification. These are referred as seabed surface in association with a thin, covering of sediments leading to a mosaic of rock and sediment habitats with potential unique biological communities (Coggan and Diesing 2011, James et al. 2011). Substrate with same grain size can support significantly differing species composition depending on whether it is mobile or stable; therefore some study includes this element as part of their classification systems (Allee et al. 2000, Kaiser et al. 2006). No substrata stability classes were included in our study; most of our samples were deeper than 60m and were consequently assumed not be subjected to wave action (Blanchard et al. 2004).

Our classification is strongly related to temperature, which supports the assumption that our classification reflects faunal change, as community structure is usually influenced by temperature (Jorgensen et al. 2014, Yesson et al. 2015). Slope is a proxy for substrate type, as highly sloped areas are subjected to less sediment deposition, resulting in the exposure of rocky outcrops (Genin et al.

1986). However, in this study there is not a clear pattern, which result from the coarse scale and spatial resolution being used.

Deep-sea benthic habitats can be especially vulnerable to fishing impacts and very little is known about them (Roberts 2002). Trawling gears shift boulders and flatten sedimentary bedforms causing an increasingly homogenous habitat as trawling persists (Rice 2006). In fact, the US National Research Council outlined the main impact of bottom trawling as the reduction of habitat complexity (NRC 2002). The Western Greenlandic region has been subjected to fishing for many years (Lassen et al., 2013). Consequently, comparison of results with un-fished areas as completed in previous studies was not possible (Collie et al. 2000, McConnaughey et al. 2000). In our study, gravelly substrates subjected to higher energy input are found to be less exposed to fishing efforts. This might be because this habitat is not suitable for the burrowing invertebrate *Pandalus borealis.* High energy level habitats (gS, R) are correlated with higher recovery time than low energy habitats (Rice 2006). We found that muddy-sand substrate is the most fished habitat. Shrimp tend to live in soft-bottom substrate and therefore the most commonly targeted areas are expected to be mud and muddy-sand substrate (Lassen et al. 2013, Yesson et al. 2015) as is confirmed in our study. It appears that climate change is driving shrimp stocks further north (Kemp 2015 pers. comm.). Considering the distribution of habitats within NAFO divisions (in 1A greater abundance of mud sediments), soft bottom habitats and communities will be increasingly subjected to trawling impact in this area.

Stress caused by human impacts does not directly affect substrate type but indirectly through community composition. In fact, substrate type as mentioned before is a good proxy for community composition. Collie et al., (2000) and Lassen et al., (2013) found hard substrates to be more sensitive to fishing disturbance than sandy communities. This is in accordance with the results of our study; rocky area, although this habitat represents a tiny portion of seabed, is significantly impacted and therefore vulnerable. Discerning different surface texture can help predict where different species are likely to be found. Hard substrates usually support an abundance of emergent epifauna, while soft substrata are normally characterised by burrowing or motile infauna (Watling and Norse 1998).

Confidence assessment using information published in the final MSC report (Lassen et al. 2013) might not be the most robust approach as i) the report used to general terms such as "rocky" "muddy" "mixed" which don't always match our classification (made to a greater level of details) ii) the coordinates provided are based on approximate geographic span (ranging from 2018 km^2 to 65 886 km^2) iii) it is tabulated from simple observations by skippers on factory shrimp vessels. A potentially more suited approach would be to compare the map directly with geological data. The MSC report highlights new research conducted from oil exploration surveys at the Greenland Institute of Natural Resources, which may provide such data. The confidence assessment provided by the present study gives an insight into the value of the final habitat map and it is encouraging, as areas near Nuuk have been described in MSC report as exactly same substrate class than the one predicted in our study.

There are several caveats to the study that are important to consider, and that future work could look to improve upon. The study is based on abiotic variables collected from oceanographic models (http://catalogue.myocean.eu.org/static/resources/myocean/pum/MYO2-ARC-PUM-002-ALL_V4.1.pdf) at a coarse resolution. Habitat modelling is a predictive tool and consequently the environmental variables used should not be considered to be perfect descriptors of the deep-sea environment. Fishing effort data is calculated as the time taken for each vessel to trawl a path across the seafloor from start to end coordinates. However, this calculation assumes trawl to be a straight line. As this is unlikely to be the case, trawling "minutes" are conservative estimates. The habitat map presented in this study shows the predicted distribution of habitat classes in the period 2011-2015. This study does not attempt to account for temporal changes. However, the distribution of habitat will depend on the natural variability in the area. Though this must be considered, all sampling stations were more than 60m deep meaning that none of them are likely to be subject to significant wave disturbance (Blanchard et al 2004). There is also evidence from the North Sea suggesting that sediment distribution patterns with high grain size might remain stable over decades (Pingree and Griffiths 1979).

Future improvement to the environmental data used in the analysis would be possible, through a better selection of variables and an improved spatial resolution. More detailed bathymetry data will increase the resolution for depth and temperature data, the two most important factors in this analysis. Current layers did not emerge as strong classification factors. Improvement of the spatial resolution of current data will potentially be helpful. The habitat map could be developed further through the introduction of another layer providing information on glacio-marine sediments. Iceberg scouring is a likely natural disturbance agent, as the Greenland ice sheet actively produces icebergs that can run aground in water as deep as 600m (Gutt 2001). This could suggest presence of boulders deposited by glaciers (sometimes too large to be moved by currents), which could represent marine habitats of high ecological importance. Muddy-sand sediments are also common in iceberg ploughmarks (Bellec et al. 2009). However, little information is published about iceberg distribution in West Greenland, beyond the facts that the majority of icebergs come from Disco Bay and that they are less abundant than in the Antarctic (Gutt 2001). Further work refining the sediment grain size data using methods such as physical collection with grab samplers could help to provide a more consistent dataset of sediment distribution across the Greenland EEZ.

Identifying areas that are vulnerable to fishing impacts is important for monitoring and conservation management. Fishing affects marine habitats and ecosystems in a number of ways depending on the type of fishing gear used as well as the spatial and temporal extent of fishing. At present, there are two newly established marine protected areas outside Nuuk, these are sponge-dominated habitats that have never been trawled due to high rugosity of the area (Lassen et al. 2013). Our results indicate that NAFO divisions 1A and 1B are the most impacted regions. These areas are mostly comprised of muddy-sand substrate, which emerges as the substrate type most heavily fished and therefore under most direct stress from human impact.

Conclusion

These results will feed directly into the MSC assessment of the shrimp trawl fishery currently being carried out by the Institute of Zoology on behalf of Sustainable Fisheries Greenland. The production of the first habitat classification and map of the West Greenland shelf contributes greatly to future research by combining community composition observations with environmental data to develop models, which describe the environmental preferences of benthic organisms. This enables the mapping and prediction of the location of species and habitats across the West Greenlandic shelf. While this study has focused on West Greenland, the approach taken here is applicable to the whole of the deep-sea and is highly valuable information for future management and conservation of the marine benthic ecosystem.

Acknowledgments

I would like to thank my supervisors Dr. Kirsty Kemp and Dr. Chris Yesson (ZSL) for their constant help and advice. Thanks are also given to Chris Turner, Jess Fisher and Màté Vakarcs for their assistance into substrate classification and for their company throughout the project.

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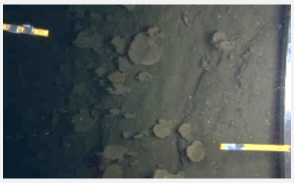
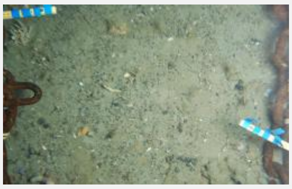
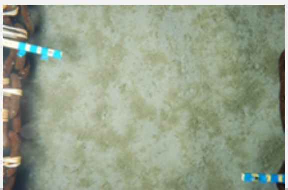
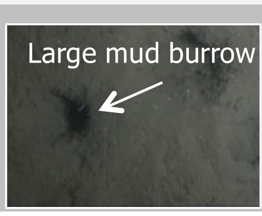
Appendices

Appendix I: Template compiled during analysis representing the seven habitat classes of the West Greenland classification with their specificity (bioturbation: sand ripples, thin animal tracks, burrows and mounds).

Sea bed substrate	Typical example	Bioturbation		
Coarse rocky ground (R)				
Bedrock with mud (mR)				
Bedrock with sand (mS)				
Gravelly sand (gS)				
Gravelly mud (gM)				
Muddy-sand (mS)				
Mud (M)				

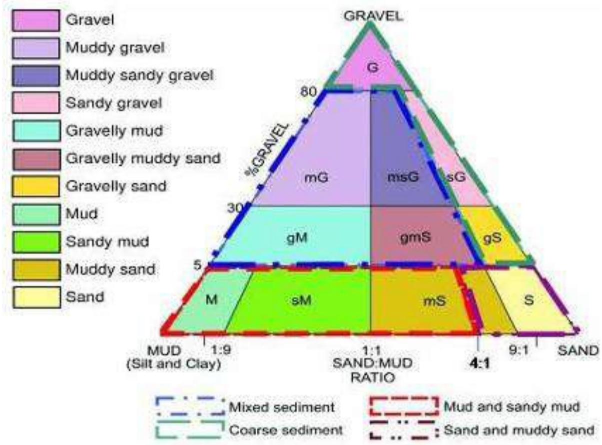
Appendix II: Summary of the transformations performed on the environmental variables. Significant P values indicate non-normality. The significant p-values are presented in bold.

	Shapiro test		Shapiro test after logarithmic transformation		Shapiro test after boxcox transformation		
	w	**p-value**	**w**	**p-value**	**w**	**p-value**	lambda value
Temperature	0.868	3.57E-13	0.893	1.32E-11	0.905	7.23E-11	0
Depth	0.947	2.15E-07			0.992	**0.224**	1.8
Salinity	0.938	3.35E-08	0.938	3.29E-08	0.938	3.18E-08	6.65
Fine slope			0.985	0.018	0.987	0.033	0.7
Coarse slope			0.993	**0.316**			
Ruggedness	0.732	2.20E-16			0.987	**0.037**	-0.1
Current U	0.987	**0.033**					
Current V	0.980	**0.002**					
Fishing	0.678	2.2e-16			0.935	2.186e-08	0.1

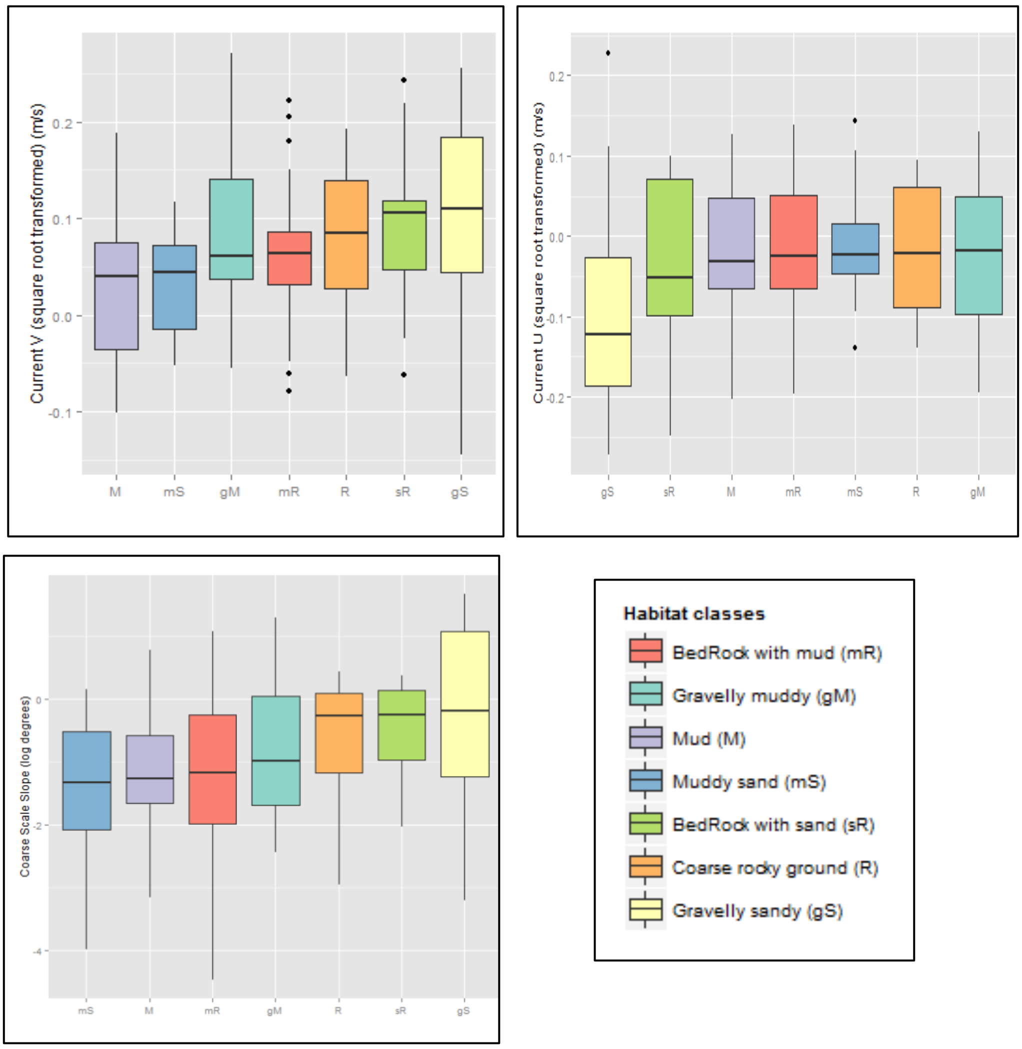
Appendix III: Summary of the correlation test performed on the environmental variables. Values close to 0.90 (defined as highly correlated) are in bold.

	Temperature	Depth	Salinity	Fine slope	Coarse slope	Ruggedness	Current U	Current V
Temperature	.							
Depth	0.135	.						
Salinity	**0.905**	-0.137	.					
Fine slope	0.525	-0.098	0.540	.				
Coarse slope	0.550	-0.160	0.574	0.666	.			
Ruggedness	0.534	-0.156	0.543	**0.982**	**0.880**	.		
Current U	-0.565	-0.138	-0.413	-0.392	-0.451	-0.375	.	
Current V	0.539	0.066	0.234	0.222	0.351	0.213	-0.306	.

Appendix IV: Sediment re-classification of the Folk Triangle (Connor et al. (2006))



Appendix V: Boxplot of environmental variables gathered from observation data: Current V (South to North in m/s), Current U (West to East in m/s), and Slope (coarse scale in log degrees) plotted against substrate types. Horizontal lines indicate median values, boxes indicate quartiles, whiskers show standard deviation, and open circles are outliers.



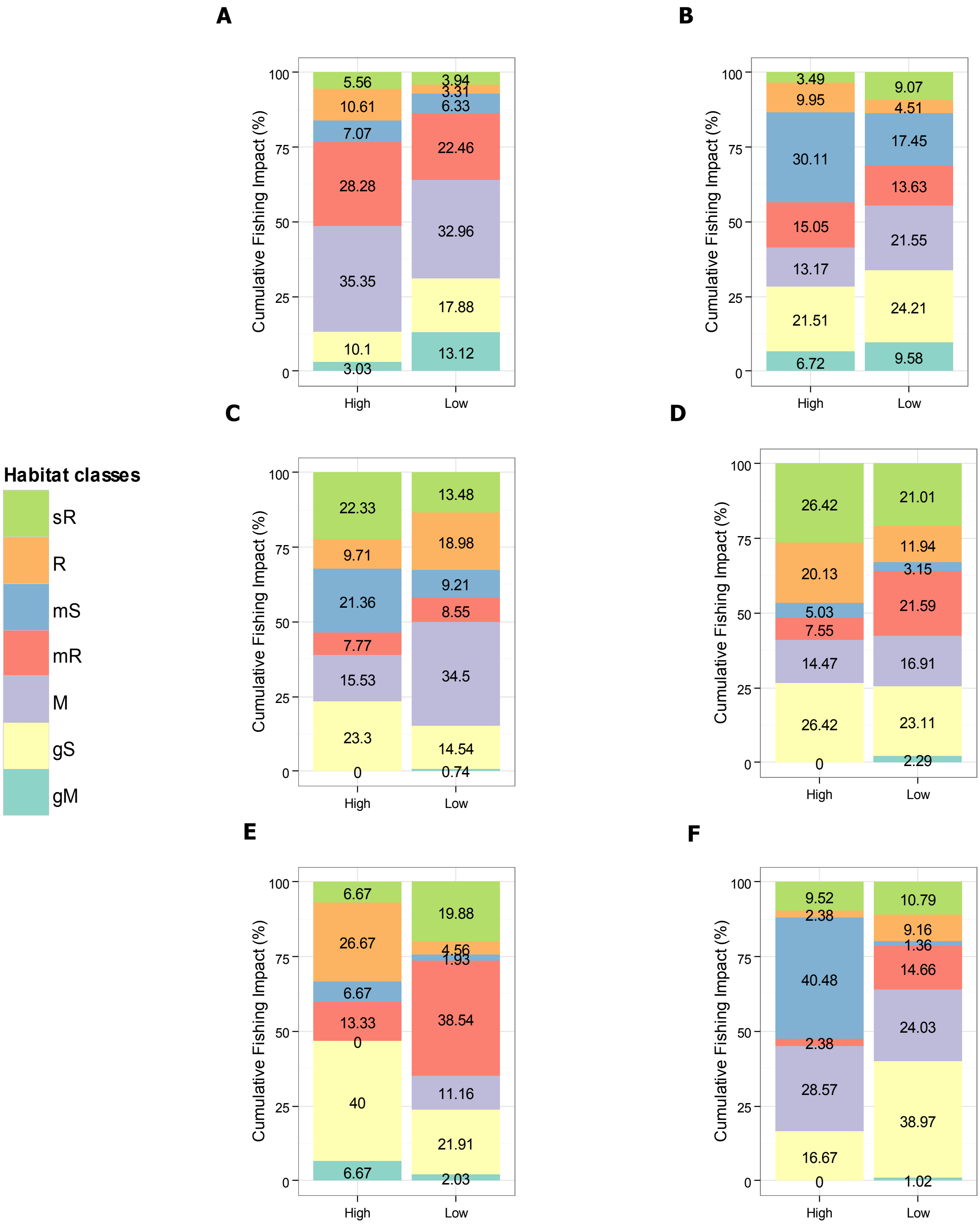
Appendix VI: Assessment of the habitat map predictions presented in this study. "Misclassification" corresponds to the rate at which randomly sampled points assigned to habitat classes other than that designed in the MSC report. N is the number of random sampling points in the area. Substrate description is as presented in the MSC report. (gM= Gravelly muddy, gS = gravelly sandy, M=mud, mR=Bedrock with mud, mS= muddy sand, R=coarse rocky ground and SR=Bedrock with sand)

ID	Fishing bank name	Range (km^2)	N	Misclassification	Habitat class equivalent as designated in this study	Substrate description as designated in the report
1	Ravns Dyb	2018	1	0.00	gM/M	Mixed (mud, gravel)
2	Danas Dyb	2176	3	0.00	gM/M	Mixed (mud, gravel)
3	Godthab Dyb	4854	2	1.00	R	Rock
4	Ost om Banken	4996	4	0.00	gM/M	Mud gravel
5	Naturhavnen	5903	3	1.00	gM/M	Mixed but mostly muddy
6	Spraengladningen	7060	7	0.00	gM/M	Mixed rock and mud bottom
7	No name	7617	11	0.72	M	Mud
8	Fiskenaes Dyb	7632	10	0.10	gM/M	Mixed (mud, gravel)
9	Frederikshab Dyb	12 637	11	0.47	gM/M	Mixed (mud, gravel)
10	Cigarbanke	13 920	27	0.41	gM/M	Very muddy including a few areas with gravel
11	Julianehabs Bugt	17 022	18	0.22	mR/R	Rock with sometimes mud
12	710 Nord	17 169	30	0.57	M	Very muddy
13	Diskokanten	23 312	29	0.21	gM/M	Gravel with muddy areas
14	Godhavns Rende	25 983	34	0.97	M	Mud
15	Store Felt	26 172	40	0.50	R	Rock
16	Ost om Fylla	27 197	30	0.63	gM/M	Mixed but mostly soft and muddy
17	Grunden og Hullerne	27 405	44	0.84	R	Rocky
18	Holsteinsborg Dyb	32 622	45	0.36	R/mR/M	Rocky on slopes and muddy in deeper areas
19	Enden	34 827	54	0.41	R/mR	Rock /coral
20	Sukkertop Dyb	35 903	55	0.55	M	Soft / coastal areas with corals
21	Sletten	36 431	38	0.29	R	Very stony
22	Kanten (Syd)	39 234	59	0.95	R	Rock
23	Nordvestkanten	39 584	57	0.21	gM/M	Mud gravel
24	Kanten (Nord)	49 787	67	0.96	R	Rock
25	Buen og Ost-Vest Kanten	54 315	91	0.34	R/mR/M	Rocky on slopes and muddy in deeper areas
26	720 Nord	54 539	65	0.86	M	Muddy to extremely muddy
27	Nordkanten af Store Hellefiskebanke	65 886	107	0.32	gM/M	Gravel with muddy areas

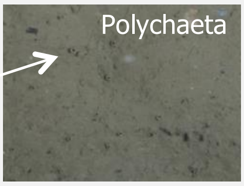
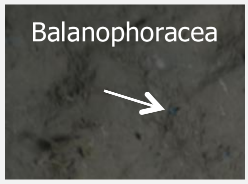
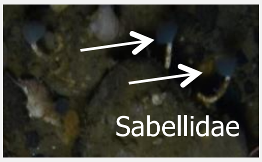
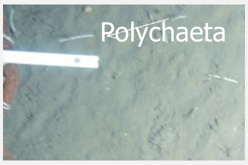
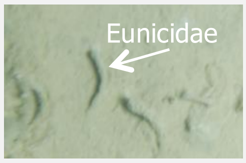
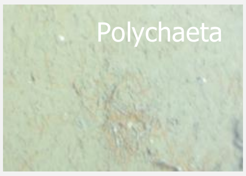
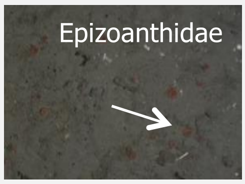
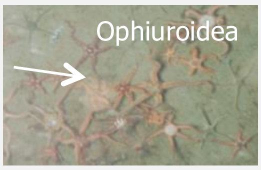
Appendix VII: Proportional binomial tests for fishing effort within each habitat class. Significant (p>0.05) values in bold.

NAFO zone	class	gM	gS	M	mR	mS	R	sR
1A	X-SQUARED	16.6	7.49	3.36	3.41	0.07	28.4	0.93
	df	1	1	1	1	1	1	1
	p-value	**4.50E-05**	6e-3	0.06	0.06	0.78	**9.75E-08**	0.33
1B	X-SQUARED	2.94	1.21	13.9	0.46	34.8	19.9	12.7
	df	1	1	1	1	1	1	1
	p-value	0.08	0.27	**1.92e-4**	0.49	**3.51E-09**	**8.14E-06**	**3.6e-4**
1C	df	1	1	1	1	1	1	1
	p-value	0.77	**0.01**	**6.00E-12**	0.91	**7.17E-05**	**2.43E-02**	**1.50E-02**
	X-SQUARED	0.08	5.44	47.3	0.01	15.7	5.07	5.91
1D	df	1	1	1	1	1	1	1
	p-value	0.10	0.41	0.51	**5.41E-05**	0.32	**6.3e-3**	0.15
	X-SQUARED	2.63	0.66	0.43	16.29	0.96	7.46	2.06
1E	df	1	1	1	1	1	1	1
	p-value	0.73	0.17	0.33	0.08	0.70	**8.5e-3**	0.34
	X-SQUARED	0.11	1.85	0.91	2.98	0.13	11.12	0.90
1F	df	1	1	1	1	1	1	1
	p-value	1	**5.6e-3**	0.62	**0.04**	**<2.1e-16**	0.21	0.99
	X-SQUARED	5.64e-31	7.6729	0.24484	4.0694	246.11	1.5447	9.03E-05
Entire study area	df	1	1	1	1	1	1	1
	p-value	**5.746e-06**	0.76	**3.438e-09**	**0.03**	**<2.1e-16**	**1.327e-5**	0.18
	X-SQUARED	20.5	0.09	34.9	4.68	132	18.9	1.71

Appendix VIII: Cumulative fishing efforts (as percentage of total fishing) for each habitat class and NAFO divisions (1A, 1B, 1C, 1D, 1E, 1F).



Appendix IX: Description of living organisms in hard and soft substrate compiled during the image processing. This will contribute for further research by comparing these communities with habitat classification developed in this study.

Substrate type	Typical example	Substrate type		
Hard		Soft		
Hard		Soft		
Hard		Soft		
Hard		Soft		
Hard		Soft		
Hard		Soft		
Hard