ICES Journal of
Marine Science

ICES CIEM International Council for the Exploration of the Sea / Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2018), 75(5), 1768–1778. doi:10.1093/icesjms/fsy040

Original Article

Mapping of marine sediments on the Greenland West Coast: contributions of fishers' ecological knowledge

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Jørgensbye, H. and Wegeberg, S. Mapping of marine sediments on the Greenland West Coast: contributions of fishers' ecological knowledge. – ICES Journal of Marine Science, 75: 1768–1778.

Received 20 September 2017; revised 12 March 2018; accepted 13 March 2018; advance access publication 2 April 2018.

The rapidly changing climate is pushing the Greenland fishing footprint northwards. With bottom fisheries moving into hitherto unmapped areas, large knowledge gaps regarding the environment in which the fishery takes place ensue. Mapping sediment in these areas is a time consuming and expensive task. Recognizing that fishers have considerable local ecological knowledge can help bridge this knowledge gap. A workshop including ship masters and factory managers on factory trawlers was conducted in order to understand how their knowledge transpired when mapped. This knowledge was compared to historical data and recent bottom photos to develop a better understanding of the differences and similarities between the methods used. The fishers had a good knowledge of sediment types; further some fishers expressed that the topography has changed over time due to intensive trawling. Even though this fishery is undertaken in a high technology environment on large trawlers, the long-time experience of the fishers can contribute to large scale knowledge of marine landscapes. These results are useful when mapping sediments in the future and can also provide a basis for further investigations of changing topography due to trawling.

Keywords: bed armouring, fishers' ecological knowledge Greenland, iceberg scour, sediment, trawl fishery, trawling-induced sediment displacement

Introduction

The notion of Traditional Ecological Knowledge (TEK) has gained increasing momentum in the fisheries research community during recent decades. Early research was mainly in small scale tropical fisheries, and often with an emphasis on the traditional cultural component (Haggan et al., 2003; Silvano and Valbo-Jørgensen, 2008). On the other side of the globe, scientists in the Arctic also have a long tradition of collaborating with the indigenous communities (Huntington, 2011; Johnson *et al.*, 2015). Fishers Ecological Knowledge (FEK) collected on trawlers without the perspective of "indigenous" knowledge is rarer, but there are a number of studies, especially from the North Atlantic (Fuller and Cameron, 1998; Baelde and Baelde, 2003; Bergmann *et al.*, 2004; Shepperson *et al.*, 2014; Paterson *et al.*, 2018). Knowledge gained on board strictly commercial highly technical factory trawlers, is an area still to be explored. While factory trawlers have been fishing the high seas since the 1960s (especially trawlers from the USSR), the industrial scale fishery examined in this study is still a first or second generation fishery for Greenland skippers (FAO, 2003).

The connection between FEK and western scientific data is not always straightforward, as one can supplement the other or directly contradict it. Cross verifying information from the two traditions has often been suggested as a best practice, albeit it can prove difficult (Shepperson *et al.*, 2014). If both types of datasets are consistent, the confidence of the data is more plausible (Mark, 1987; Huntington *et al.*, 2004). The fishers themselves are often interested in a more direct link, and incorporating informal knowledge and FEK in more formal discussions has been a theme for years in Greenland fisheries policies (Jacobsen, 2013; Jacobsen and Delaney, 2014; Jacobsen and Raakjær, 2014; Hedeholm *et al.*, 2016).

Most papers concerning FEK centres on fish and fishery. Other environmental knowledge, like habitat characteristics, gained as a

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"by-product" of the fishery is rarer (Fuller and Cameron, 1998; Williams and Bax, 2003; Bergmann *et al.*, 2004; Bevilacqua *et al.*, 2016; DeCelles *et al.*, 2017). Information on habitat and other biodiversity parameters is becoming more important with commitments to ecosystem-based management gaining momentum. The mapping of marine sediments is of importance when predicting where vulnerable marine ecosystems (VME) can be found. FEK can contribute with information to this area where scientific information is often scarce or non-existent.

Since the trawl fishery started in Greenland in 1935, the sea floor type or sediment has been of interest to the fishing industry and the scientific community alike (Smidt, 1957a), both for habitat preference of catches and protection of fishing gear. This interest resulted in numerous investigations which were carried out almost every summer in West Greenland since 1946, first by the Greenland Fisheries survey, and from 1995 by the Greenland Institute of Natural Resources (Smidt, 1957b; Horsted, 1969; Hjemmestyret, 1994). German-, Norwegian-, and Russian-national fisheries agencies also made trawl surveys to support their commercial fisheries in Greenland's waters (Hermann and Horsted, 1964). While the aim of the scientific surveys was to find new commercially viable fishing grounds, the fishing industry, personified by individual skippers, also built a considerable knowledge of sea floor suitability for fishing operations (Carlsson and Smidt, 1978). With the development of more sturdy gear and rock hopper equipment, trawling expanded to hitherto inaccessible fishing grounds. Combined with changing climate, and the resulting reduction in sea ice cover, some fisheries are now moving northwards into new fishing grounds.

This project aimed at describing the substrate types on the west coast off Greenland by the use of FEK from the shrimp fishing fleet in the area, and included historical knowledge and recent underwater photographs for cross comparison. The results may help identify areas of vulnerable marine habitats and highlight the ecological knowledge held by the fishers. The attention drawn to substrate types and large scale changes should lead to further investigations and support environmental certification of the fishery.

Material and methods

Study area and the shrimp fishing fleet

The Greenland west coast borders Canadian waters and international waters and stretches >2500 km through the subarctic to high arctic climate zones (Meltofte *et al.*, 2013). The two basins of the northern Labrador Sea and the southern Baffin Bay are separated by a shallower sill. Ice and icebergs found in this area influence and change the sediment, both by direct scouring and by shedding terrigenous sediments and dropstones when melting (Streuff *et al.*, 2017).

The modern off shore Greenland shrimp fishery is taking place on large trawlers 60 m long or longer. High tech equipment is the norm, with vessels more resembling a floating factory than the old-fashioned notion of a fishing vessel. At present only eight Greenland trawlers fish for shrimp. Officers are highly educated and hygiene and security rules are strictly enforced, and the masters and factory managers often have many years' experience with the fishery in West Greenland.

Materials

Composite maps of sediment information were produced from combining fishers' ecological knowledge (FEK) as well as historical published and unpublished data. The following materials were included: (i) FEK from a workshop held in Nuuk, Greenland, in 2010, followed up with semi-structured interviews in 2017; (ii) sea floor visual survey material produced in connection with oil exploration drilling campaigns in 2010 and 2011; (iii) sediment data from unpublished old fishing journals; and (iv) data obtained from digitalization of published sea floor maps in old literature (Table 1).

Recent data (FEK and sea floor photos)

Fishers' ecological knowledge was obtained from nine officers of the trawling fleet attending the workshop. The participants included officers (masters and factory managers) from shrimp trawlers, as these fisheries represent the offshore fishery with bottom touching gear (bottom trawl), and as holders of the exact positions of where the fishery has taking place. The aim was to describe sediment types in the fished area based on their knowledge and terminology. The workshop resulted in habitat information on seven paper maps.

In addition, three of the most experienced officers, a master and a factory manager added further information to the FEK data in informal interviews in 2017. The interviews were considered necessary to clear up different uses of terminology. Further, by including these interviews of staff from a Greenland Halibut fishing vessel, the area surveyed were expanded. The trawl fishery for Greenland Halibut takes place in much deeper waters than the shrimp fishery, mainly seawards of the shelf break.

Additional fisheries data in the form of logbook information from the Greenland halibut fishery were obtained from the Greenland Fisheries License Control office (GFLK).

Two hundred and sixty-six pictures, produced in connection with the oil exploration drilling campaign by Capricorn Greenland Exploration 1 Ltd in 2010 and 2011 and the associated developed Environmental Impact Assessment were analysed for signs of bed armouring due to scouring. As the photos were obtained as part of an environmental study programme connected to drilling wells, the photos only represent these selected areas in the survey blocks. The photos were taken in a limited areas West of the Disko island in August and September 2010, in the Disko West license block (PAR, 2010). The camera system employed was a Seatronics DTS6000 camera with real-time camera link to the surface (Capricorn, 2010a).

Another number of photos from Capricorn Greenland Exploration 1 Ltd drilling programme in 2011 were obtained from the Lady Franklin license block. These photos were used to verify historical data. The photos were obtained in the same manner as above but from deeper water (from approximately 1000 to 2000 m). Technical details can be found in the original report (Capricorn, 2011a).

Historic data

A literature study was conducted identifying articles with visual information (maps) showing sediment types. The abbreviations used in the text are mentioned in Table 1.

In the 1960s and early 1970s a large effort were made by the government to map fishing banks. Data from these old scientific cruise logbooks and fishing journals, that are stored at DTU Aqua in Charlottenlund, Denmark, The Danish National Archives, Denmark, and at the Greenland Institute of Natural Resources in Nuuk, Greenland, are included in the study. The term "Fishing

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Table 1. List of maps found in the literature search.

Title translated to English	Abbreviation used in text	Reference
Seabed sediments	1899 data	Bøggild (1899)
Natural history of the Greenland shrimp fishing grounds	Fish bank maps	Smidt (1957b)
Surveys of the shrimpstock in the Julianehaab District	Fish bank maps	Horsted (1960)
Relief and bottom sediments of the shelf and continental slope of the Northwestern Atlantic	1965 data	Авилов (1965)
Shrimp in the Davis Strait	Fish bank maps	Horsted (1969)
Shrimp surveys	Fish bank maps	Fiskeriundersøgelser (1973)
Fishing journals and cruise logbooks	Point data	Unpublished

The titles in English (translated) are given, as the original titles are in Danish or Russian. The abbreviation used in the text, and the references are listed.

journals" refers to the journal kept for each fishing episode on scientific cruises, logging the place, time, wind conditions, and various notes. Cruise logbooks and fishing journals in this context are not to be confused with the logbook that is mandatory on commercial fishing trips.

For more details on historic data, please consult Supplementary material.

Methods

To obtain FEK information in a methodological manner from the workshop, the consensus workshop method was used (Stanfield, 2002). This method has broad application and is widely recognized for its participatory approach that honours diverse perspectives and individual creativity as a way to reach a consensus. The definition of consensus was taken from Stanfield (2002). The method was slightly adjusted by using paper maps in the scale 1:400,000 of the Greenland West coast instead of cards or sticky notes as the method otherwise requires. The fishery officers worked with one focus question, which was narrow to obtain as precise information as possible: "Define the substrate types and map where they are found". The habitat types mentioned by the officers were; "soft", "fairly soft", "hard", "semi hard", "soft with many rocks", and sand. This relatively simple sediment classification reflects the interest of the fishers of identifying areas where shrimp can be found but trawls not destroyed by rocky or otherwise irregular sea floor. Observations of hard bottom on the shelf break or the edge surrounding deep basins were recorded. Areas "where it is not possible to fish due to rough bottom" were not digitized as rough bottom, as this classification did not necessarily refer to sediment type but to topography.

An intensive and systematic search for original maps or other primary documentation was conducted in relevant archives. Cruise logbooks and journals were visually inspected for information about sediment type and the information entered in a database.

Information from GFLK in the years 2013–2015 was anonymized and in the form of gridded data.

Maps (hand drawn and published) were geo-referenced and digitized in the geographic information system (or GIS) program ArcGIS 10.0. Old maps were scanned, and the projection adjusted, and old black and white maps were colour coded based on the sediment type. Bathymetry and contour lines were extracted from the IBCAO project version 3.0 (Jakobsson *et al.*, 2012). All data were gridded in 5000 m × 5000 m cells. Grid size is known to influence the result of local knowledge data and a grid size analysis was carried out before deciding on the grid used (Shepperson *et al.*, 2014). Details may be lost in a larger grid size, i.e. lower resolution, as point data may overlap leading to points potentially being "masked" and hence excluded from the analysis. A smaller grid size is often desirable in order to obtain most details, but, in this case, a larger grid size was chosen due to the low resolution of original map data.

To assess the degree of disturbance of the sediment, the 266 sea floor photos from depths between 100 and 200 m were inspected for signs of bed armouring and undisturbed sediment. This depth interval was chosen due to the large amount of visual material available, but also as it fulfilled two important requirements according to the analysis: (i) These depths have a relatively homogenous sea floor; there are no major changes in fauna, and as the light is extinct there is no macroalgal growth (Jørgensbye and Halfar, 2017; Pedersen, 2011; Petersen and Smidt, 1971); and (ii) these depth may be influenced by iceberg-scouring as well as commercial and scientific trawling for shrimp and cod (ICES, 2015; Weidick *et al.*, 2007). The fauna communities resembled other fauna communities at the same depths on the Greenland west coast and was not considered unique for the area (Capricorn, 2010a, 2010b).

Sessile fauna was used as a proxy for undisturbed conditions with no sign of, e.g. trawl activity or ice scour (Figure 1). The following criteria were used to sort the pictures into five categories of disturbance.

(1) Ancient growth: Coral reef or other bioherm was considered ancient growth. These represent very old habitats, from decades to millennia. They are very vulnerable to damage from icebergs or trawls.

(2) Old growth: Lush and dense growth of sessile fauna without signs of damage. The age of this habitat is not known, but it is probably years to decades old (Figure 1).

(3) New growth: emerging cover of fast growing fauna like soft corals (Figure 1).

(4) Damaged: Areas with broken sessile fauna that looked relatively fresh (many and slender white calcified parts) and fine sediment that has not been winnowed away. Must be considered to represent relatively recent damage (Figure 1).

(5) Paved sediment: Sediment where pebbles, gravel, or sand was dominant with a paved quality (bed armouring). Some older broken parts of sessile fauna could be present (calcified parts which were not fresh looking) (Figure 1).

At least 50% of the photo had to be covered by one of the five sediment types to be allocated to a category.

Results

The FEK data covers areas north and south of the area of historical information on the shelf. The FEK data shows a graduation

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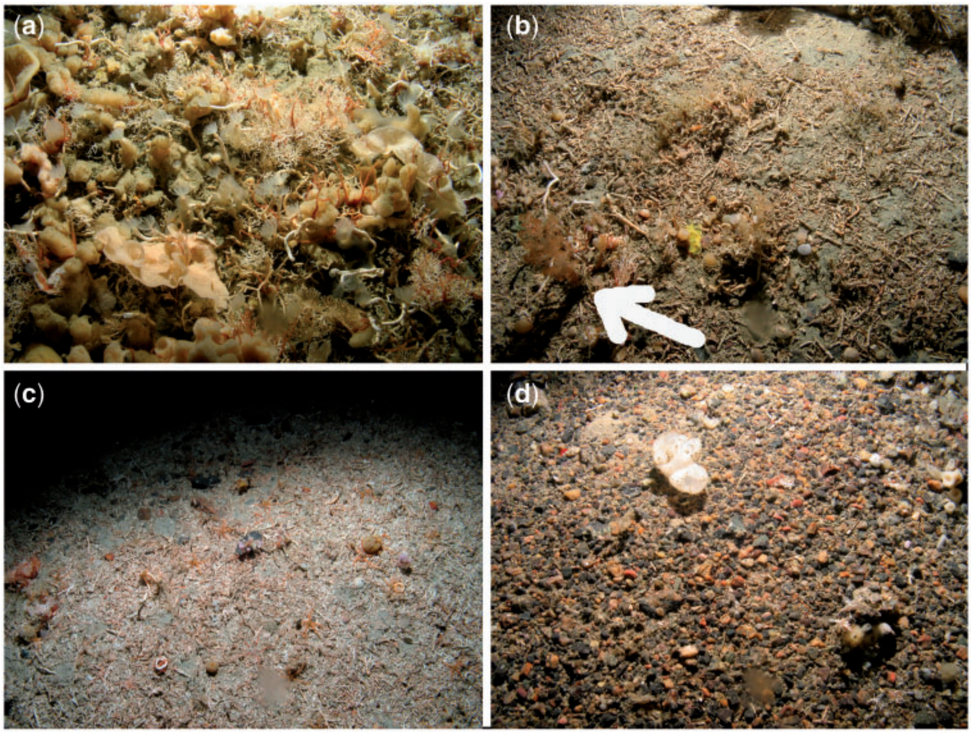

Figure 1. Different types of sediments and sediment covering. (a) Old growth, the sediment is covered with sessile organisms; hardly any sediment can be seen. (b) New growth emerging on sediment that shows signs of having been disturbed, the arrow points to a soft coral. Broken branches can be seen amongst pebbles and fine-grained sediment. (c) Sessile organisms showing clear signs of recent damage with the bottom covered by broken branches or pieces of sessile organisms. (d) Bed armouring, pebbles cover the bottom without fine grained sediment.

from south to north from harder to softer sediment with "semi hard" in the south, and "soft" and "fairly soft" in the north (Figure 2). When plotting the fisheries data from the Greenland halibut fishery a northern and southern area of uniform sea floor suitable for this fishery emerges (Figure 2, left). As the fishery only takes place on soft- and low topography seafloor, the fishery pattern is a substitute for other data showing soft/silty substrate. In the area closed for Greenland halibut trawling, no data can be obtained from the Greenland halibut fishing fleet but shrimp can be fished, therefore FEK data is available from this area.

The 266 photos from the Capricorn Greenland Exploration 1 Ltd drilling Programme in the Sigguk license block in the Disko West area were sorted into the five categories, and no ancient growth was found. Damaged fauna was the most common category found on 44% of the pictures, with old growth the most uncommon found on only 10% of the photos (Figure 1). Paved sediment was found on 24% of the pictures and new growth on 22% of the pictures. Damage to sessile fauna was very obvious on many pictures, indicating scouring activity. "Paved" surfaces consisting of pebbles can probably be interpreted as bed armouring caused by winnowing. In-between sessile fauna and pebbles with sandy/muddy sediment could be seen. In some pictures the movement of the camera stirred up sediment, indicating a muddy component.

When collating all obtained data (combining historical and recent data) in a map of the Greenland west coast, a strong resemblance between the data layers emerges. A zonal analysis that show the frequency distribution of cell values in one dataset within classes of another dataset was carried out (Supplementary material), supporting a strong correlation between the observations through the decades using iso depth lines as area boundaries.

Areas roughly corresponding to the shelf were defined as "near shore sediments" by the 1899 survey. This was also the main area mapped by other data mentioned in this study. The area defined as "grey clay" by the 1899 survey had overlapping information with other surveys. For more details on the overlap of data, please consult Supplementary material.

The areas characterized as soft in the FEK data are located at the bottom of canyons and in an area north of the town of Sisimiut. The point data adds a few areas with boulders to the soft sediment, and the fish bank maps also show these sea floor areas as muddy or soft.

Fishers' ecological knowledge data on "fairly soft" only overlaps with the 1965 survey in one place, which was classified as "sand". In this area, there is a 77% overlap between the two sets of information (Figure 3). A small area inside the 200 m iso line is characterized as "fairly soft" from the FEK data. This detail was not captured by the 1965 or the 1899 survey, and probably represents sand. There is an overlap with the 1899 survey in the area "grey clay". Large areas encircled by the 100–150 m iso lines are defined as sand by the 1965 survey. Generally, there was little FEK data on these sandy areas, except the area mentioned above (Figure 3). The point data in this area added gravel, boulders, soft, clay, and hard bottom. It must be expected that small areas of gravel, boulders, and hard (or bedrock) are scattered across the shelf, but not necessarily areas large enough to be depicted on a small-scale map. The point data also show some sandy sediment

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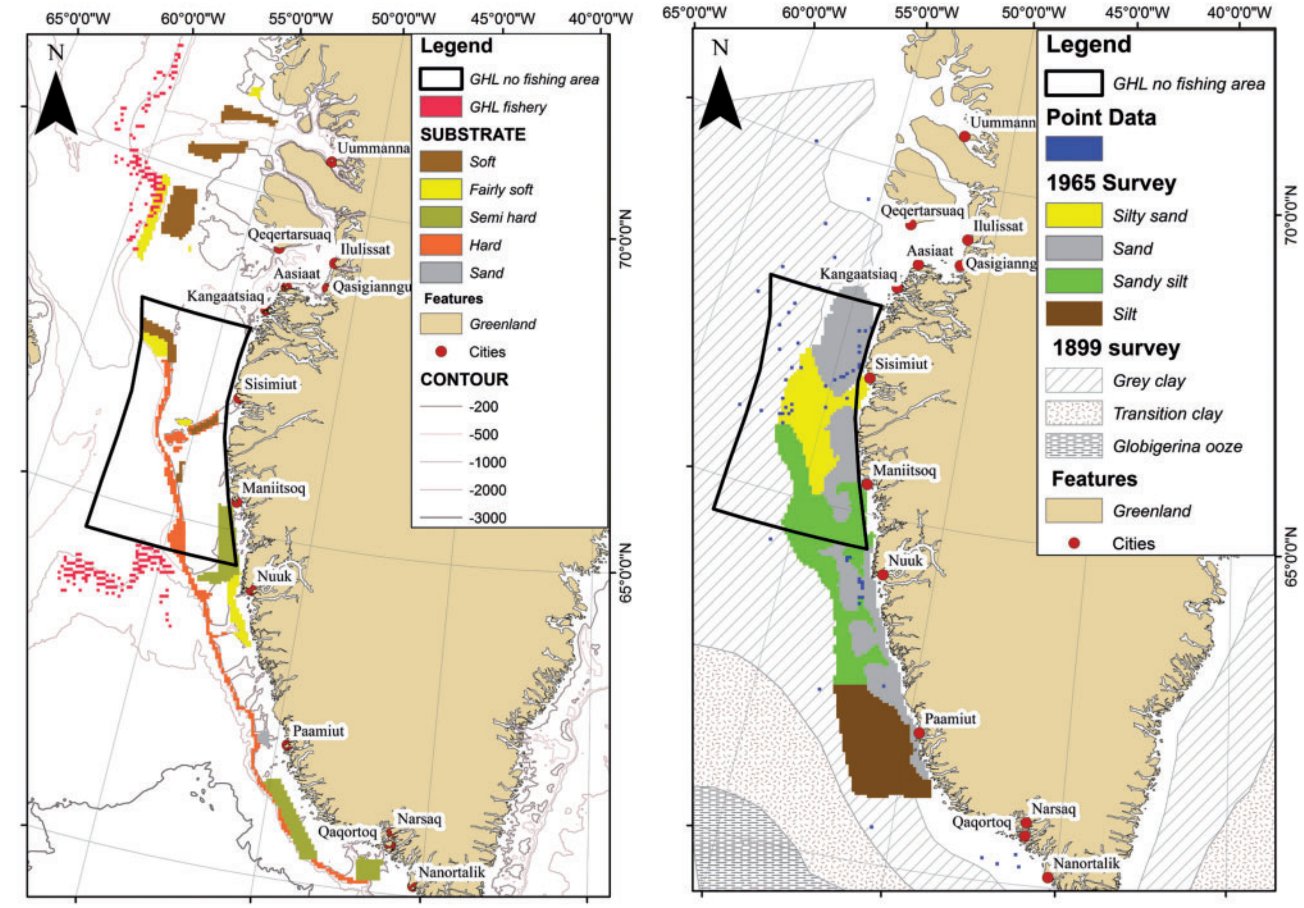

Figure 2. Left map: FEK information from the West coast of Greenland. The softness of the substrate increases to the north, except the category "hard substrate" which is found on the shelf break. The area fished by the Greenland halibut fleet is marked in red (GHL fishery), and the area closed for trawl fishery after Greenland halibut is marked GHL no fishing area. Right map: Colour coded information from the 1899 survey and the 1965 survey. The extent of the historical point data is shown in blue.

outside the area defined as sand in the 1965 survey (Figures 2 and 4).

The area defined as sandy mud by the 1965 survey overlaps with the FEK classification of "semi hard" (Figure 3). The FEK data is embedded in the sandy mud area, and conforms to it with approximately 80% accuracy. The 1965 survey adds a few points of gravel to the area. Besides this overlap, there is a small area in the south where the 1965 survey category of silt overlaps with semi hard. Point data correlating with FEK data of "semi hard" sea floor is restricted to clay and mud. A part of the sandy mud (1965) is categorized as grey deep sea clay by the 1899 survey. How much of the area included cannot be accurately quantified, as the borders of the 1899 survey are imprecise due to the measuring methods at that time.

Sea floor areas near the shelf edge are characterized as "hard" from the FEK data (Figure 4). The deeper canyon areas are characterized as "soft" with "hard edges" from the FEK data. This more detailed information is not mentioned in the 1965 survey. These details on canyons are supported by the much more detailed fish bank surveys. The point data show "hard" sea floor areas at the shelf edge complementing the FEK data.

The 1899 survey described the sea floor areas outside the 1965 survey. Sea floor at increasing depths is described as grey deep-sea clay, transition clay, and foraminifera clay (Figure 4). The 1965 survey also have information illustrated with icons that represent substrate in a limited area like shell hash or boulders (Figure 4, right). This "point" data from the 1965 survey describes clay (seven stations), blue clay (one station), sand (five stations), boulders (five stations), and hard (one station) situated in the area of grey clay from the 1899 survey (not depicted). The points fit very well with the 1899 categorization of grey clay. Boulders must be expected to be scattered in the area due to ice rafting with icebergs and mapped by the more detailed point data. There is good agreement between the FEK data and point data on the category "hard" bottom.

The 1899 survey has data from deeper waters, outside the shelf (Figure 4). The 1899 survey mentions brown or light brown Transition clay at around 1000 m merging into grey/light grey globigerina ooze (which is coarser and more sand like) at 2000 m and deeper. Also point data from unpublished fishing journals show dominance of clay from <1000 m depth. For more details on point data, please consult the figure in the Supplementary material. According to Bøggild (1899), this is valid for the southern part of West Greenland with local differences. The limited recent data, however, obtained as sea floor photos by Capricorn Greenland Exploration 1 Ltd, show fine clay particles at around 1000–1200 m (Capricorn, 2011a), which is in agreement with the 1899 map. The deepest areas surveyed by the drilling program are

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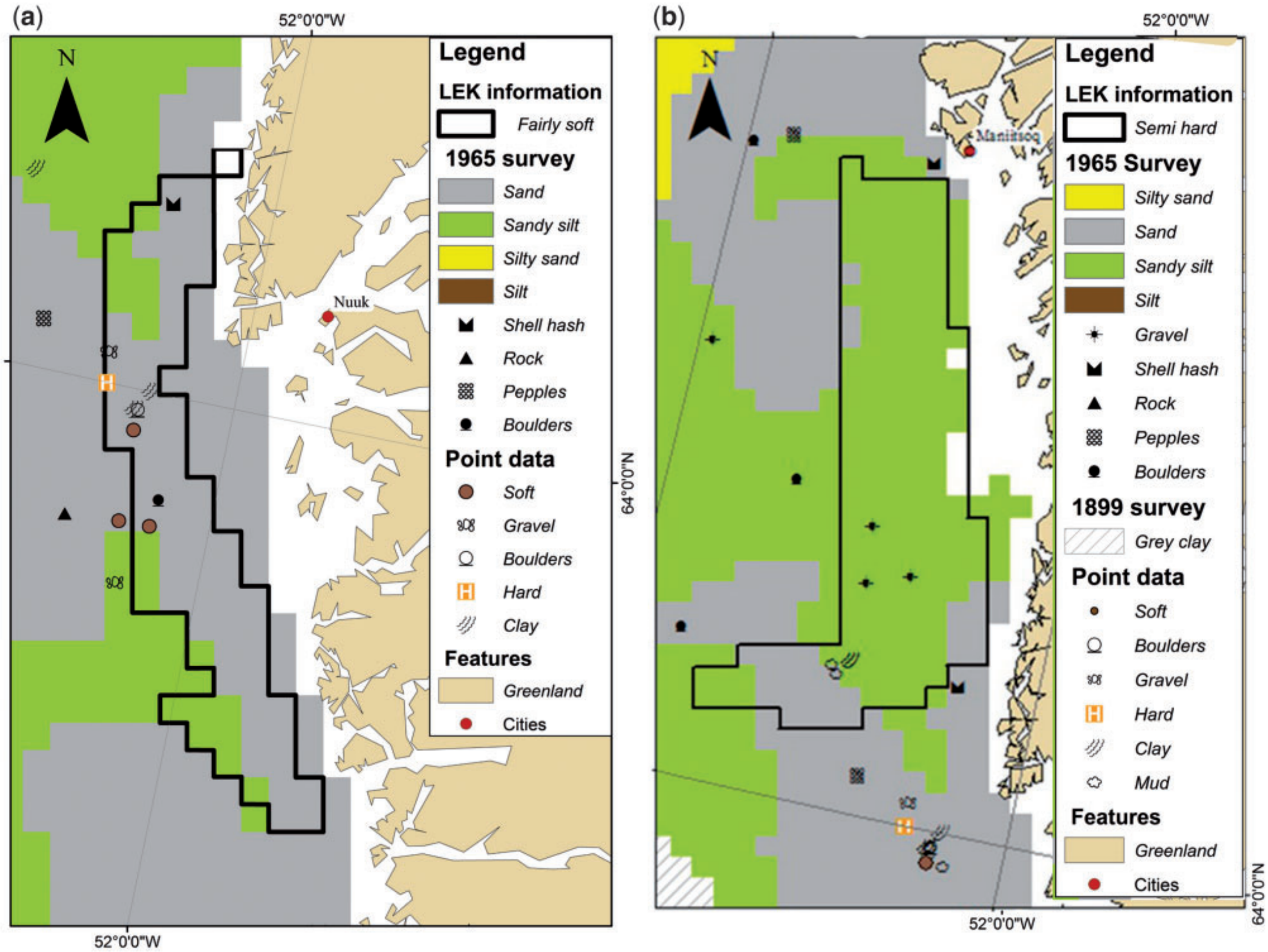

Figure 3. (a) Seafloor areas categorized as sand (1965 survey) and areas categorized as "fairly soft" (FEK). (b) Areas of sandy mud (1965 survey) compared to the FEK information on the "semi hard" substratum.

from approximately 2000 m (Figure 5). All the photos show a sand-like substrate (globigerina ooze?) with pebbles and drop-stones in some areas.

Discussion

Recent data

The different terminologies and methodologies between the geological, biological, and FEK traditions are prominent, and are a barrier in interpreting the results. Surveys made with different perspectives and traditions are difficult to compare, especially if the choice of words for real life phenomena has not been coordinated. Even though all methods are based on the best available knowledge of the time, the different methodologies and sometimes arbitrary terminologies makes some surveys more suitable than others for the purpose of reflecting an abiotic habitat.

This study shows that even though the fishery is modern and uses the newest technology, the fishers still have a good knowledge of fished areas, especially on the less complex sediments (deeper water). This is comparable to surveys in Canada, the US, and the Irish Sea, where fishers proved to have a good knowledge of sediment types, comparable to the categories found in this study (Bergmann *et al.*, 2004; DeCelles *et al.*, 2017; Fuller and Cameron, 1998). The officers have many years of experience, and they expressed interest in their knowledge being formalized in other contexts as well, opening up for a continued cooperation between the industry and scientists. In some areas, the FEK information fit very well with the scientific surveys. In other areas the results are more ambiguous. The reason for this can partly be ascribed to the different terminologies and scale in both time and place. While the different methods show the same overall pattern, the methods are not able to reflect the more heterogeneous sediment patterns and small-scale differences on the shelf. The results can also be ambiguous due to the different interests of the fishers and geologists, and the different needs and levels of knowledge.

The historical point data fits well with other information from FEK and historical data, and in some cases the point data add information to the small-scale maps. This signifies the fact that the shelf area has a complex topography and sediment pattern, which is also evident from other surveys (Buhl-Mortensen *et al.*, 2010; Streuff *et al.*, 2017). When considering the depth range, the point information fits well with the general picture of sand and shell hash in shallower water, and with a range of different sediments on the shelf, mud in depressions, and hard bottom on the "edges." In this study, the point data was used to support other information, and the arbitrary notation of sediments and the non-standardized terminology, makes it difficult to utilize this data in any consistent manner.

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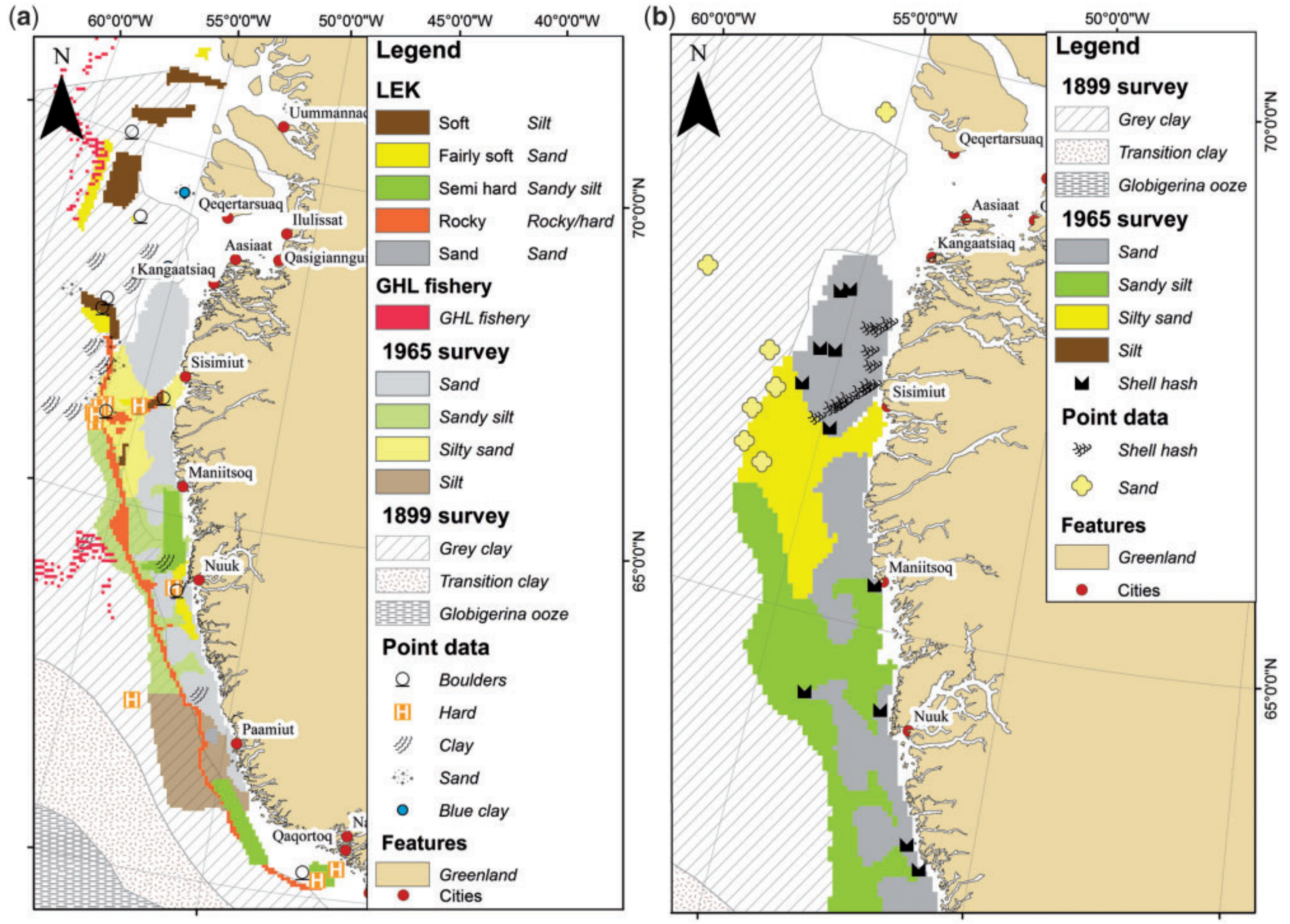

Figure 4. (a) Composite map with areas of FEK information, the 1965 survey, and the 1899 survey. Point data that intercepts with the 1899 survey are added, except sand which can be seen in the right hand map. The Greenland halibut fishing tracks are shown with red squares (GHL fishery). (b) Historical information from the 1899 survey, 1965 survey, and point data from fishing journals. Shell hash and sand areas from the 1965 survey and the point data are shown on the map. Bioclastic shell hash localities are scattered in the sandy areas, 11 from the 1965 survey and 13 from the point data.

Table 2. Summing up terms used by the fishery ship masters and factory managers and the geological terms used in the 1965 survey.

FEK information	Geological term
Soft	Silt/mud
Fairly soft	Sand
Semi hard	Sandy silt
Hard	Bedrock and other hard features
Sand	Sand

The comparison is not 1:1 for all sediments, and the categories of “fairly soft” and “semi hard” are not well resolved compared to the narrow definition of the geological terms.

Former glacial influence formed the Greenland seascape on the shelf, and banks like “Store Hellefiskebanke” were formed by moraines. These coarse deposits reflect the high influence of terrigenous deposits and/or glacial marine depositions overlaying basal tills, as described from Greenland and Antarctica (Anderson *et al.*, 1980; Weidick *et al.*, 2007). Coarse sediment like gravel pebbles and cobbles have been overlaid with finer sediments in many places, depending on the sediment load, current strength, wave action, and ice conditions (Авилов, 1965; Sanchez-Vidal *et al.*, 2015). Coarse sediments were not commonly reported in the literature and were not depicted as the primary sediment in the existing maps. Point data and the 1965 survey show pebbles and gravel scattered on discrete locations of the shelf. The recent FEK data shows “semi hard” substratum in large sea floor areas, as do the photos from the, however, limited sample areas. The apparent lack of coarse sediments in the historic sources could be an artefact of the sampling method using piston- and gravity core samplers and conventional trawls that are not suited for sampling sediments at all. The recent FEK data points to a gradient in sediments from “semi hard” in the south to softer sediment types in the northern sea floor areas (Figure 3). The northernmost areas reflect the fishing fleet following the northwards movement of the shrimp into hitherto unfished areas (Arboe and Kingsley, 2013; Hammeken, 2013 Burmeister and Kingsley, 2016). This information highlights the use of FEK as a management tool in new fishing areas where standardized geological surveys have not been carried out.

The large areas of sand showed in the 1965 survey fit well with the depositional setting that must be expected in this seafloor area (Figure 4), and which are affected by currents and tidal

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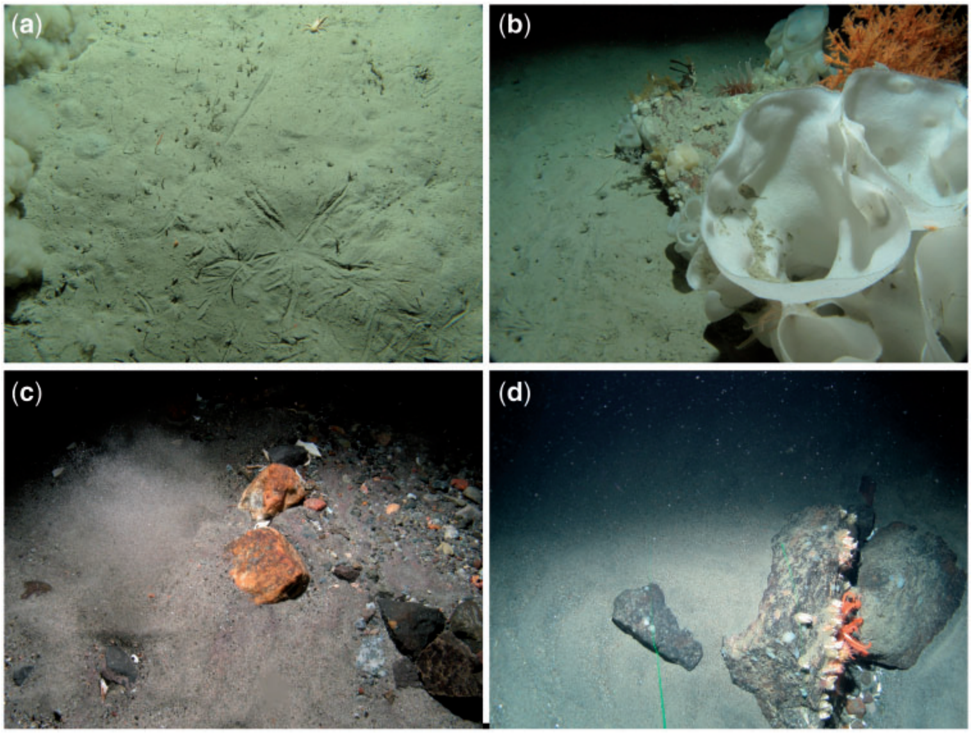

Figure 5. Examples of the differences between sediments from 1000 m depth and 2000 m depth. (a) 1000 m: Fine sediment; disturbance by the ROV is seen as a cloud in the left side of the photo. Lebensspuren are seen in detail on the sea floor and a squat lobster (*Anomura sp.*) is observed in the top right corner. (b) Dropstone surrounded by the same fine sediment with lebensspuren. On the stone, a glasssponge (probably *Asconema setubalense*), the black coral *Stauropathes arctica* and a sea anemone (Actiniaria). (c) 2000 m: The coarse sediment did not raise high above the seafloor when disturbed. Picture (d) Dropstones surrounded by coarse sediment without lebensspuren but with current ripples on the surface. Large barnacles (Cirripedia) and the arms of a brisingid seastar (Brisingida) are seen. Photos from Capricorn Greenland Exploration 1 Ltd Drilling Programme 2010.

dynamics (Streuff *et al.*, 2017). The point data and the 1965 survey data both have several shell hash locations, the formation of which is dependent on environments with relatively high energy and are often concordant with sand (Kidwell *et al.*, 1986; Hendy *et al.*, 2006). Allochthonous (deposits moved from their original site of formation) beds of shell hash derived mainly from barnacles, scallop, other molluscs and echinoderms seem to be common on the shelf north of Nuuk, and probably beyond based on the old surveys and this study (Авилов, 1965; Horsted, 1965, 1969; Jørgensbye and Halfar, 2017). In Greenland, this habitat is poorly investigated but this survey show that it is widespread and should receive more attention.

The FEK area of "soft" and "fairly soft" seafloor sediment types overlaps with areas of grey clay from the 1899 survey. Why the fishers mention two different bottom types while the 1899 survey only mentions one, is difficult to establish based on this study. The fishery for Greenland halibut only takes place on heterogeneous clay or mud bottom in deeper water than the shrimp fishery, and the fished area (also called the fishing foot print) is a sound proxy for presence of clay or muddy sediment (Figures 3 and 4). The trawled footprint stretches farther north than the historical information and can be used to confirm that the uniform soft sediment continues further north into uncharted area. The 1899 report mentioned that boulders were transported with ice, and this mechanism was more distinct further north along the coast. The FEK data includes seafloor areas described as "soft with stones" north of Disko (not depicted), but this category is not used further south. The same trend is obtained from the surveys conducted by Capricorn Greenland Exploration 1 Ltd (Capricorn, 2011b). Together, these observations span more than a century, and express agreement between the classical expedition surveys, FEK, seafloor photography, and to a certain extent the point data from the fishing journals. This agreement is clearest in the homogenous sediment setting of the deep sea.

Greenland halibut fishery only takes place on uniform muddy sea floors at depths around 1000 m. The homogenous and flat sea floor is inferred from the fishery activities with fishery data from the last 2 years. The fishery takes place on the same fishing grounds, often in the exact same fishing tracks as the previous years. These tracks are known to be level and soft while the bottom nearby might be unfishable due to the uneven topography. In connection with obtaining the TRK data, it was mentioned that some trawl tracks go back to the first experimental fishery in 1991. It was also stated that these tracks had become more levelled out and broadened during the many years of trawling. The fishers stated that the more they trawl in a specific trawl track, the more Greenland halibut they caught, and speculated that it might be due to the fish feeding on invertebrates exposed by the trawl activity. This phenomenon has been documented for other species of fish (Arntz and Weber, 1970; Kaiser and Spencer, 1994; Groenewold, 2000), and hence seems to be a plausible explanation. A large area was closed for Greenland Halibut fishery and no recent information based on fishery is available for this area (Figure 2).

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Bottom touching trawl gear is known to cause winnowing, i.e. removing fine sediments from the disturbed bottom leaving behind the coarse sediments and gravel. The bottom will be capped by a thin layer of coarser sediment, also called bed armouring, which may be dependent on hydrodynamic regimes and repeated disturbances (Wiberg *et al.*, 1994; Puig *et al.*, 2012; Martín *et al.*, 2014; Pusceddu *et al.*, 2014). Intensified trawling, starting in the 1950s after cod and in the 1970s after shrimp, might have influenced the sediment structure in the same manner as iceberg scouring. The photos from the 2010 Capricorn Greenland Exploration 1 ltd drilling campaign showed that a large part of the sea floor at 100–200 m may be influenced by scouring, as indicated by the damage to sessile fauna on 44% of the photos. 24% of the photos showed sea floor with coarse sediment without sessile organisms (Figure 1). Iceberg scours, which are widespread on the Greenland shelf, are known to display rims of surface gravel and larger stones as a result of winnowing (Josenhans and Barrie, 1982; Pereira *et al.*, 1988; Weidick *et al.*, 2007). It was assessed that scours of 100 m across and 4 m deep were caused by icebergs, trawling was not considered, by Capricorn (2010a, 2010b). Unless high-resolution acoustic data, such as side scan sonar data, is used, it may be difficult to discern the difference between iceberg scour and trawl scour. Strong currents may also cause comparable large scale bed armouring effects, as previously described in the 1965 survey (Авилов, 1965). It is difficult to interpret what the source of the scouring is without further analysis of the fishing activities and iceberg drift patterns.

No “ancient growth”, like coral reefs, were observed. This was to be expected, as extensive bioherms have only been reported from much shallower or much deeper waters (Jørgensbye and Halfar, 2017; Kenchington *et al.*, 2017). The absence of these millennium old ecosystems is probably a combination of cold water and iceberg scour.

Large-scale alteration of the bathymetry has been reported from several continental slopes, but not from Greenland (Puig *et al.*, 2012). Considering the ongoing deep sea trawling, it must be expected that changes may be ongoing. Any future attempts of mapping or modelling sediments in Greenland must take into account the activities by the trawling fleet (of all trawl fisheries) to distinguish between natural or anthropocentric processes. Both activities of the Greenland and foreign fishing fleets in addition to the Greenland and foreign scientific trawl surveys have to be taken into account. An important finding was that fishers observe changed topography in the deep-sea due to trawling. While the reported changes are relatively minor, considering the few (and repeatedly trawled) tracks that exist, it is never the less interesting that the fishers themselves observed this change.

The different surveys presented here are, in overall, in agreement, but cannot substitute a thorough study with side scan sonar and benthic samples. This study compiles all sources that have been available, historic and recent, together with FEK, Mapping of marine habitats must consider the impact of trawling (commercial and scientific). The scale, scope, and terminology must be considered carefully, reflecting the intended use of the data. Further, large mapping projects in Norway and the UK (Diesing *et al.*, 2014; Buhl-Mortensen *et al.*, 2015) could be followed to align data for an even more comprehensive and comparable marine sediment, habitat and disturbance mapping.

Acknowledgements

This study was made possible by the participation of the officers from the Greenland fishing fleet. The Greenland Fisheries Licence Control (GFLK) contributed with data about the recent Greenland halibut fishery. Also the oil company, Capricorn Greenland Exploration 1 Ltd., contributed with underwater photos and videos from the seabed off West Greenland, and is gratefully acknowledged. The study was financed by a Ph.D. grant from the Home Rule Government, Sustainable Fisheries Greenland and Bank of Greenland. Sustainable Fisheries Greenland hosted the workshop and made follow up interviews possible. Thanks to Antoon Kuijpers from Department of Glaciology and Climate, GEUS for advice on Greenland glaciology. Thank you to the two proof-readers Rikke Becker Jacobsen and Jesper Boje. Also thanks to the Greenland Institute of Natural Resources.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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