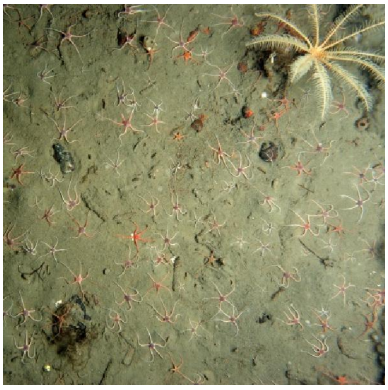
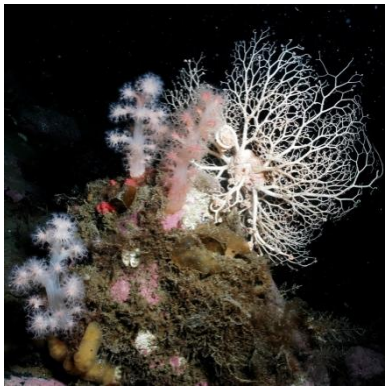
Development of minimum standards for long-term monitoring of marine bottom-living fauna communities in the Arctic-Atlantic: Pilot study in Greenland

Udvikling af minimum standarder for langtids-monitering af havbundens dyresamfund i Arktisk-Nordatlanten: Pilotstudie i Grønland



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Development of minimum standards for long-term monitoring of marine bottom-living fauna communities in the Arctic-Atlantic: Pilot study in Greenland

Udvikling af minimum standarder for langtids-monitering af havbundens dyresamfund i Arktisk-Nordatlanten: Pilot studie i Grønland

by

Martin E. Blicher, Nanette Hammeken Arboe, Lis L. Jørgensen, AnnDorte Burmeister, Gudmundur Gudmundsson, Steinunn H. Olafsdottir, Jan Sørensen, Ellen Kenchington and Phillippe Archambault

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Sammenfatning

Dette arbejde er motiveret af en øget offentlig og videnskabelig bekymring om den potentielle påvirkning af klimaforandringer og menneskelige aktiviteter, såsom bundtrawling og olie- og gasefterforskning, på biodiversitet og funktion af havbundens biologiske samfund (benthos) i arktis, og mulige afledte effekter på hele det marine økosystem.

For at adressere disse bekymringer, har et netværk af forskere, tilsammen repræsenterende hele den arktisk-atlantiske region, anbefalet at der udvikles fælles standarder for monitering/overvågning af benthos, som kan implementeres som en integreret del af nationale fiskeundersøgelses-surveys i området.

I denne rapport beskriver vi disse nationale surveys og de involverede forskningsskibe, og identificerer overlappet i de involverede nationers muligheder for benthos indsamlinger. Dette overlap kan betragtes som en mulig minimum standard for benthos monitering på regional skala.

På baggrund af den analyse anbefaler vi at implementere et "trawl bifangst program" på fiskeundersøgelsesskibe. Forslaget indebærer at bifangsten af hvirvelløse bunddyr skal sorteres ombord og enten identificeres og registreres af to specialister på skibet, eller alternativt præserveres og opbevaret for senere identifikation af specialister på land.

Norge, Rusland og Canada har allerede implementeret denne metode på deres nationale surveys, hvor det har vist at være en omkostnings-effektiv måde at tilvejebringe værdifuld viden om arktiske benthos samfund. Der er tilsvarende muligheder på nationale surveys i Island, Færøerne og Grønland, men de er indtil videre uudnyttede.

I perioden 2015-17 vil det foreslåede Trawl Bifangst Program blive igangsat ombord på Grønlands Naturinstituts forskningstrawler, RV Pâmiut i grønlandske farvande. Det vil foregå gennem et "Benthos Ekspert Udvekslingsprogram" som involverer specialister fra alle nationer i arktisk nordatlanten. Udover at kortlægge havbundens fauna i Grønland vil dette skabe en platform for vidensdeling og –opbygning. Det langsigtede mål er at skabe et fælles vidensgrundlag, som kan fungere som springbræt til at etablere egentlig langtidsmonitering på tværs af den arktiske del af Nordatlanten. Dette vil skabe mængder af ny viden om en understuderet økologisk komponent, til anvendelse inden for natur-, miljø- og fiskeriforvaltning både nationalt og internationalt.

Summary

This work is motivated by an increasing public and scientific concern about potential impacts of climate changes and human activities, such as bottom trawling and oil and gas exploration, on the ecological function and biodiversity of biological communities linked to the arctic seabed (benthos), and possible derived effects on the marine ecosystem as such.

To address these problems a network of researchers together representing the Arctic-Atlantic region has recommended the development of some common benthos monitoring standards that could be implemented as an integrated part of national fish research surveys in the area.

In this report we describe the national groundfish survey activities and the research vessels involved, and identify the overlap between nations in terms of possibilities for benthos

sampling. This overlap should be considered as a possible minimum standard for regional-scale benthos monitoring.

Based on this analysis, we recommend implementing a “trawl bycatch program” on fish research vessels. This implies that the invertebrate bycatch in the groundfish trawls is sorted onboard, and either identified and registered by two specialist taxonomists on the ship, or alternatively preserved and saved for later identification by specialists on land. Norway, Russia and Canada have already implemented this approach on their national surveys and it has proved to be a cost-effective approach to gain valuable knowledge about Arctic benthic communities. A similar potential is found for the surveys in Iceland, Faroe Islands and Greenland, but it remains unutilized at present.

In the period 2015-17 the proposed trawl bycatch approach will be put into practice onboard RV Pâmiut in Greenland waters through a “benthos expert exchange program” involving specialists from all Arctic-Atlantic nations. Besides mapping benthic fauna in Greenland this will create a platform for knowledge sharing and -building. The long-term goal is to create a common Arctic-Atlantic knowledge base acting as a stepping stone to establish actual long-term monitoring programs across the Arctic-Atlantic region. This will produce a lot of new knowledge about an understudied ecological component, and provide a valuable tool in nature-, environmental- and fisheries management both nationally and internationally.

Background and objective of this report

The general lack of knowledge about biodiversity, functional importance and vulnerability of biological communities linked to the sea floor (benthos) in the Arctic has received increasing attention in relation to environmental and fisheries management in recent years. The primary concerns are related to the potential impacts of bottom trawling, oil and mining activities, and climate changes. There is a general consensus that monitoring of benthos communities is needed, and that such monitoring should facilitate the comparison of status and trends on long-term scales, and across regions and nations. Accordingly, it was recently suggested by an international working group under Arctic Council's organization, Conservation of Arctic Flora and Fauna, that existing national fish research vessels should be used as platforms for cost-effective long-term benthos monitoring in the Arctic (CBMP 2013).

In 2014 this consortium of researchers from institutions in Greenland, Iceland, Faroe Islands, Norway, Canada and Russia, together representing the Arctic and sub-arctic marine areas of the North Atlantic, received funding from Nordic Atlantic Cooperation (NORA) and the Nordic Council of Ministers to develop recommendations and a suggestion for a protocol for standardized long-term monitoring of marine benthic invertebrates in the Arctic-Atlantic that could be integrated in existing national groundfish surveys.

The scope of this report is thus to give an introduction to applied methods for the study of marine benthos, and a brief overview of potential logistical platforms for future benthos monitoring, in order to identify the possibilities shared across the nations. This information will be translated into a proposal for a realistic and cost-effective trans-Atlantic approach to mapping and long-term monitoring of benthic communities in the Arctic.

Implementation of the suggested protocol is planned in Greenland waters as a pilot study in 2015-17 on RV Pâmiut through a benthos expert exchange program involving specialist researchers from all Arctic-Atlantic coast nations.

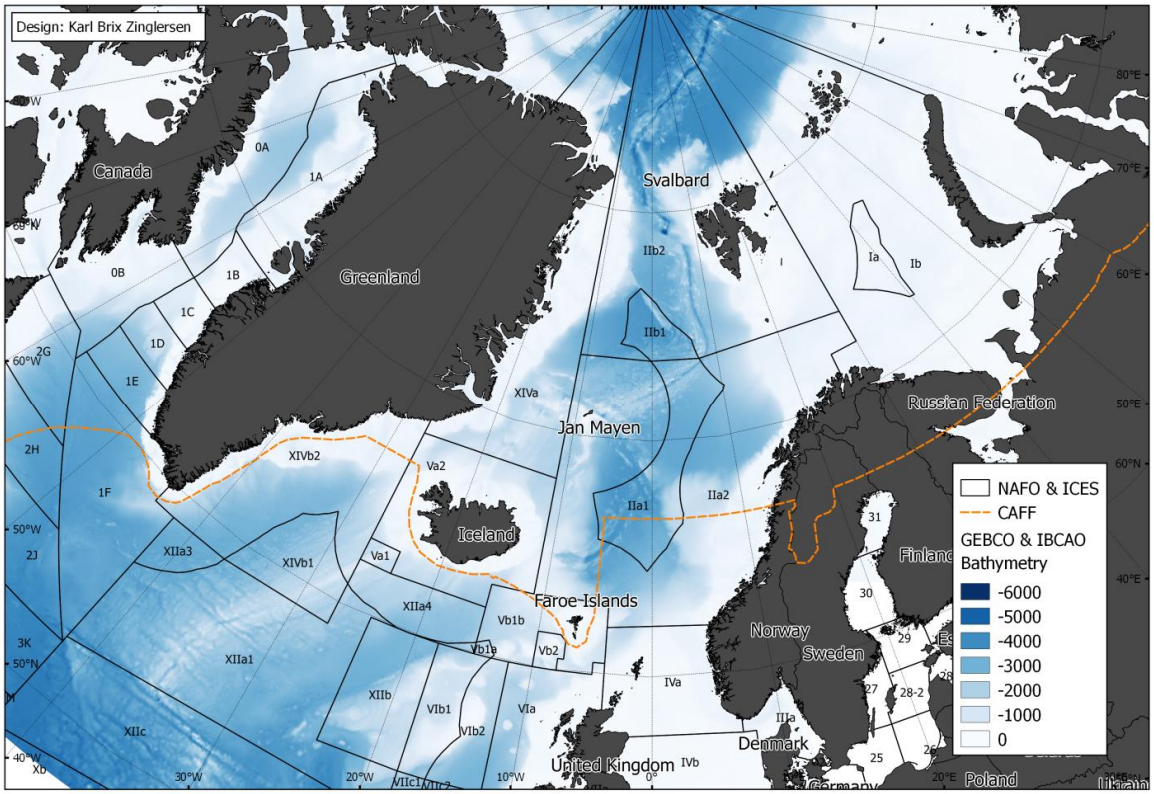

Fig 1. Map of the North Atlantic, with NAFO and ICES coded areas. The red line indicates the CAFF designation of the Arctic, i.e. the approximate southern limit of the area of interest in this report.

Introduction

Utilization of marine resources plays a central role in the culture and economy in all countries in the Arctic-Atlantic (i.e. Greenland, Iceland, Faroe Islands, Norway, Russia and Canada). Knowledge based management is a key element to ensure sustainability of the commercial harvesting of living resources.

In recent years recommendations towards a more ecosystem based approach to fisheries management has been put forward (e.g. ICES 2014, Fletcher 2005, Garcia et al. 2003; Pikitch et al. 2004, Sainsbury et al. 2000, Ruckelhaus 2008, Levin 2009, Walther & Möllmann 2013). The idea of extensive ecological survey programs including monitoring of physical and biological oceanography (plankton), benthos and non-commercial fish species, are mainly based on the idea that a better understanding of the ecological processes within a system, and of the degree of ecological disturbance of fishing will lead to better management of fish stocks and other marine resources, and conservation of the marine ecosystem, with respect to biodiversity, structure and functioning. A key objective is to avoid irreversible ecosystem impacts of human activities, and at the same time ensure an appropriate balance between conservation and responsible use. But even though these considerations seem well-documented and reasonable from a scientific perspective, it has proven difficult in many countries to implement these ideas in the management of the living marine resources. In the Arctic-Atlantic Norway and Russia has jointly implemented extensive programs for long-

term monitoring of the whole marine ecosystems (e.g (Michalsen *et al*., 2013 and http://www.imr.no/tokt/okosystemtokt_i_barentshavet/nb-no) including benthos (Jørgensen et al 2014). One of the major reasons for this is probably the trade-off between the considerable short-term economic costs of an ecosystem based approach to management of fisheries and other marine resources, and the expected, but more uncertain, long-term economic gains of such an extensive management approach. However, in recent years documentation of the ecological impact and sustainability of fisheries, and a following certification (Marine Steward Council, MSC Eco-label) has significantly affected the market for fish products, and in this way opened up the possibility for shorter-term gains by using a more broad approach to management.

In this report we will not go into a detailed discussion of full-scale holistic approaches, but focus only on the benthic fauna. It may be considered a first step towards actual ecosystem monitoring, but this is not within the scope of this project. Benthic fauna and benthic habitat structure have received special attention in management in relation to ecological sustainability and direct impacts of bottom trawling (e.g. http://www.mafcons.org, http://www.msc.org/). Moreover, oil and gas exploration in off-shore areas in the Arctic has lead to concerns about the vulnerability of the benthic ecosystem to exploration and exploitation activities in these areas. But the attention towards the benthic environment is also motivated by the fact that benthic organisms is an absolute key component in the marine ecosystem in the Arctic in terms of biodiversity and energy flow, and several invertebrate species are known as the dominant prey for species of fish, seabirds and mammals (Born et al. 2003, Bluhm & Gradinger 2008, Blicher et al. 2009, Blicher et al. 2011, Piepenburg et al. 2011). Benthic infauna live embedded in the substrate while epifauna are associated with the substrate surface. It is well-known that large and habitat forming epifauna, such as sponges and corals that may create biodiversity hot spots and act as nursery habitats for fish and invertebrates, are extremely vulnerable to physical disturbance, such as trawling and oil drilling (Jones 1992, Rogers 1999, Collie et al. 2000, Hall-Spencer et al. 2002, Olsen et al. 2007, Althaus et al. 2009, Trannum et al. 2010). Benthic ecosystems in the Arctic are also directly or indirectly affected by ongoing climate changes through potential changes in the timing and type of primary production, which will affect the flux of organic material (i.e. food) to the benthos; ocean acidification that may affect taxa with calcium carbonate skeleton, and species range shifts caused by temperature changes (Orr et al. 2005, Grebmeier et al. 2006, Fabry et al. 2008, Wassmann et al. 2010, Węsławski et al. 2011, Grebmeier 2012).

Benthic organisms are excellent candidates for monitoring purposes. Long-lived benthic species can act as multiyear, long-term integrators of a variety of marine processes. Large infauna are normally stationary in marine sediments, and thus their community distribution patterns reflect export production from the overlying water column. Some of the strongest signals of climate change in the sub-Arctic have come from the study of benthic infauna in the Northern Pacific (Grebmeier et al. 2006, Grebmeier 2012). Methodologically consistent long-term sampling of benthic fauna in the Arctic-Atlantic will provide similarly robust monitoring tools. However, for large parts of the arctic and subarctic neither the physical nor biological settings in the benthic environment is well described, and initiatives towards

developing long-term monitoring has to be taken in order to be able to document state and trends of the benthic biodiversity and functioning.
By describing existing scientific, logistical and technical settings on national fish research surveys in each Arctic-Atlantic country we aim to provide an overview of the possibilities for mapping and monitoring of benthic fauna within these existing settings. This information is crucial for decision makers and for the management to assess if and how such national programs should be implemented in the future.

Introduction to applied methods for studying marine benthic fauna

Different methods for benthos sampling are used for different purposes and habitats. For a complete description of benthos community structure and biodiversity, several methods would have to be applied, and for information about environmental settings, additional sampling would be required. In some habitats the level of destruction caused by the sampling in itself can be an issue to consider. In the section below we briefly introduce some common methods and provide pros and cons in relation to its potential use on existing national fish research surveys. Ship time is expensive and therefore, to minimize extra costs, a critical parameter is obviously to what degree benthos sampling can be incorporated into existing survey routines. Similarly, the man hours needed for analyzing samples, which can be a significant cost, is evaluated.

Groundfish and shellfish trawls

Bottom trawls are found in numerous designs for commercial fishing of demersal fish and shrimps. Main components are the doors, foot-rope (with rockhoppers) and head-rope (with floats) making up the opening of the trawl (>10m wide), and a conical shaped trawl bag with a cod-end. As the name implies, bottom trawls are not designed for sampling benthic invertebrates, and catch efficiency compared to epibenthic sledges is low (down to 0.5%) and biased towards certain types of fauna (Gilkinson 2013). A Linney bag can be attached to the belly of the trawl to collect what goes through the trawl mesh and get a signal of small bycatch organisms (Kenchington et al. 2012). Still, analyses of benthos bycatch in bottom trawls can only be used as an indicator or proxy for the true biomass or abundance of invertebrate species. Nonetheless, if carried out consistently over a large number of stations, the large swept area and the usefulness on a wide range of sediment types may qualify it as an alternative to conventional scientific samplers for documenting relative spatial patterns in the distribution of epibenthic megafauna; at least for species known to be vulnerable to trawling such as large erect species including some sponges and corals. In Norwegian and Russian surveys in the Barents Sea the benthos bycatch in bottom trawls is identified onboard by two taxonomic specialists. The bottom trawls require relatively large areas of homogenous seabed, which put some limitations to where it can be deployed.

- PROS: Simple to implement on fish research vessels (already in use), direct coupling to shrimp and groundfish studies, sampling on soft and hard substrates, samples can be processed by specialists onboard, does not require extra ship-time for sampling (if linked solely to existing trawl survey stations)
- CONS: Low and biased catch-efficiency, not quantitative, restricted to epibenthic megafauna, destructive to the seabed, no info about sediment characteristics, restricted to areas with simple bathymetry.

Epibenthic trawl, sledge and dredge

Beam and Agazziz trawls can be used for qualitative or semi-quantitative sampling of epifauna. The width of the trawl opening can be from 2m to 10m. Dependent on the design, the trawls can be used on small as well as larger ships, at shallow as well as relatively large depths, and under difficult sea conditions. The nets are designed to skim the surface of the seabed, and because of the larger area covered compared to a grab or corer, these trawls are useful for collecting scarcer members of the epifauna.

The somewhat smaller sledges and dredges (width <1m) have the same function as the trawls, but may be preferred due to the ease in handling and in areas with densities of fauna, where a large sampling area is unnecessary. In contrast to trawls, some designs of sledges and dredges work well on rock and stone grounds, and areas with complex bathymetry.

- PROS: Simple in use, easy to implement, sampling locations independent of trawl stations, high catch efficiency of epifauna, (semi-) quantitative if haul length is registered, large sampling area, useful on all bottom types
- CONS: Inefficient infauna sampling, destructive to the sea bed, no info on habitat structure, sampling time (approx. 1h per haul, 1 haul per station), processing time (approx. 0.5-1d per sample), not coupled to fisheries data or standard routines, extra ship time needed, destructive

Grab, corer and box samplers

Animals inhabiting sediments can be sampled quantitatively by grab or corer. The grab/corer is lowered vertically from a stationary ship and captures slow-moving or sessile epifauna, and infauna. Sampling area is typically 0.1 to 0.25m^2. There are several types of instruments based on the same principles; however the sampling efficiency on different types of sediments and the burrowing depth can differ. One of the most commonly used grab samplers is the Van Veen grab or modifications of it. Its' simple and effective use on a range of different sediment types, depths, sea conditions and ship sizes has made it popular. However, one weakness of grabs compared to e.g. box corers is the limited (an uneven) depth penetration of only c. 10cm in firm sediment, which is not enough to capture deep burrowing infauna.

Still, grabs and corers are essential tools for being able to describe infauna species composition and richness in sediments. Infauna species richness on the arctic shelves and banks can be up to c. 100 species per 0.1m^2 grab sample, and the infauna species

pool cannot be ignored neither in terms of biodiversity nor functioning of the marine ecosystem. But for the same reasons the sample processing is extremely time consuming and dependent on specialist taxonomic knowledge. Likewise, many replicates are needed to make a complete description of localities. The small sampling area also makes it an ineffective tool for sampling large epifauna species (megafauna) inhabiting the seafloor in much lower densities than smaller macroinfauna.

- PROS: Quantitative, sampling both infauna and epifauna, describes "true" species richness, provides info on sediment characteristics, sampling locations independent of trawl stations, work well in areas with complex bathymetry
- CONS: Not useful on hard and mixed substrates, small sampling area, sampling is time-consuming (.5-1h per sample, 5-10 replicates needed per station) and cannot be added to normal fish survey routines – additional independent ship-time needed. Processing / identification is time-consuming and dependent on specialist taxonomists (approx. 1-2 days per sample or more).

Photo and video

In recent years there has been a rapid development of underwater photographic and video gear. Following this development camera surveys are now commonly used as a non-destructive tool for documenting and quantifying epibenthic assemblages. There are still several practical and technical challenges in operating underwater cameras from a ship in deep off-shore areas. And even more so if we move away from simple towed camera systems or drop-cameras with a manual trigger mechanism when it hits the seabed, to a Remotely Operated Vehicle (ROV) with live feed to the ship.

Camera surveys are time-consuming, but the resulting images or video material is often impressing in quality and loaded with information about the epibenthic community as well as the substratum. It works particularly well for hard-bottom localities and areas with complex bathymetry, which are otherwise difficult to describe quantitatively.

Although there are several software programs available for easing the Image processing, it can be an extremely time-consuming task. Moreover, image quality and lack of physical samples for ground truthing may set limitations to the taxonomic level of derived datasets.

- PROS: Quantitative, non-destructive, useful on all substrate types, work well in areas with complex bathymetry, in-situ information (e.g. feeding, refuge), some info on surface substratum. Systems have become cheaper in recent years (starts at c. 50.000 Euros).
- CONS: Info restricted to epibenthos, limited taxonomic resolution, time-consuming to survey large areas, processing of photo and video material is time-consuming.

Acoustics

Sea floor habitat type strongly affects benthic species composition, and substrate is regarded a key parameter for explaining spatial variations in faunal assemblages. Surficial seabed classification is possible using acoustic imaging systems such as multibeam echosounder and sidescan sonar. Multibeam systems acquire both bathymetry (depth) and backscatter (intensity) data, and the derived habitat maps can reveal sea floor morphological and sediment textural attributes (e.g. rough, smooth, hard, soft, gravel, shells, sand, mud). It can also be used to document and describe biogenic structures such as coral reefs (Kostylev et al. 2001, Brown et al. 2011, Freitas et al. 2011). Sufficient ground truthing is necessary either by visual imaginary of the sea floor (photographs, video) or sediment sampling. For mapping purposes ships equipped with a multibeam system need to follow transect lines placed close enough to ensure full coverage of the sea floor. Distance between transect lines will therefore depend on water depth (closer on shallow depths). Coverage of large areas is in any case time consuming and therefore often limited by available ship time. However, provided sufficient ground truth sample data, acoustic data can be an invaluable tool for the purpose of mapping and/or modeling the distribution of various faunal assemblages, including both demersal fish and benthic invertebrates.

- PROS: large-scale mapping, info on surface substratum and bathymetry, and potential occurrences of large biogenic structures, such as corals and sponges, non-destructive.
- CONS: Not suitable for monitoring. Ground-truthing needed (sediment sampling, camera or other), cannot be added to normal fish survey routines, additional independent ship-time needed.

Collection of environmental data (explanatory parameters)

Spatial and temporal changes in the environmental settings such as water temperature, salinity, nutrients, pH, phyto- and zooplankton production, and sediment characteristics are assumed to affect benthos communities directly or indirectly. Therefore, such physical and biological data is key for the purpose of understanding the status and trends in benthos communities, and for potential future modeling efforts.

There are numerous methods for collecting such physical and biological data, and a detailed overview will not be given here. However, much valuable information about the water column can be obtained via CTD profiling, measuring salinity, temperature, depth and optionally other parameters such as oxygen and fluorescence. A CTD should be lowered vertically at a controlled speed (c. 0.5-1m/s) from a stationary ship, and stations are often laid out along transects in order to cover an area of interest. CTD profiling is an essential tool for studying local as well as large-scale hydrographic features. A simpler, cheaper and more time-efficient way to obtain bottom water temperature is by means of a logger mounted on a bottom trawl or other types of sampling equipment. However, the lack of information about the water column above limits its value in a pure hydrographic context.

Sediment characteristics such as grain size distribution, amount of photosynthetic pigments and organic matter can be estimated via sediment cores or grab samples (see above). Such data will give a detailed (but local, see above) description of the benthos habitat type, and of the food conditions for the benthic fauna.

- PROS: Essential for the detection of causal relationships.
- CONS: Ship-time needed for sampling can be substantial and affect normal survey routines.

Potential or existing platforms for annual monitoring of benthic fauna in the Arctic-Atlantic

In this section we will briefly describe the existing national survey activities with the potential for being, or already is, involved in benthos monitoring in the Arctic-Atlantic. Obviously, the available resources vary greatly between nations, which are reflected in the logistical and scientific setups.

For the development of common standards we need, therefore, to first of all consider the type and quality of data that can be obtained and the consistency in samplings, as more important than the amount of data. A lack of methodological standardization and inconsistent taxonomic resolution will prevent us from observing potential temporal and spatial trends, which is the primary scope of monitoring.

By identifying such an overlap in the possibilities between nations we intend to provide the framework for a cost-effective and methodologically standardized trans-Atlantic benthos monitoring protocol.

Norway and Russia (Barents Sea)

The Barents Sea ecosystem surveys are good examples of how a benthic sampling program can be integrated into traditional fish research surveys. Based on a strong Norwegian-Russian collaboration bottom trawl surveys have gradually developed into actual ecosystem surveys.
The single stock fish-survey conducted by the Institute of Marine Research (the Scientific Institute for the Ministry of Fishery and Coastal Affairs) in the 1960's developed toward a multi-stock fish survey in the 1970's, and further into an Ecosystem Fish Survey from 2003.

Area description. The Barents Sea covers approximately 1.6 million km^2 and is bordered by the Norwegian Sea to the west, the Norwegian and Russian mainland to the south, Novaya Zemlya to the east and the Arctic Ocean to the north. The average depth is 230 m with several bank areas between 50 and 200 m and basins and trenches down to a maximum depth of about 500 m at the western boundary.

Bottom trawl sampling. The annual joint Norwegian - Russian Ecosystem Survey provides data for assessments of fish stocks and the changing conditions of the Barents Sea ecosystem (http://www.imr.no/tokt/okosystemtokt_i_barentshavet/nb-no).

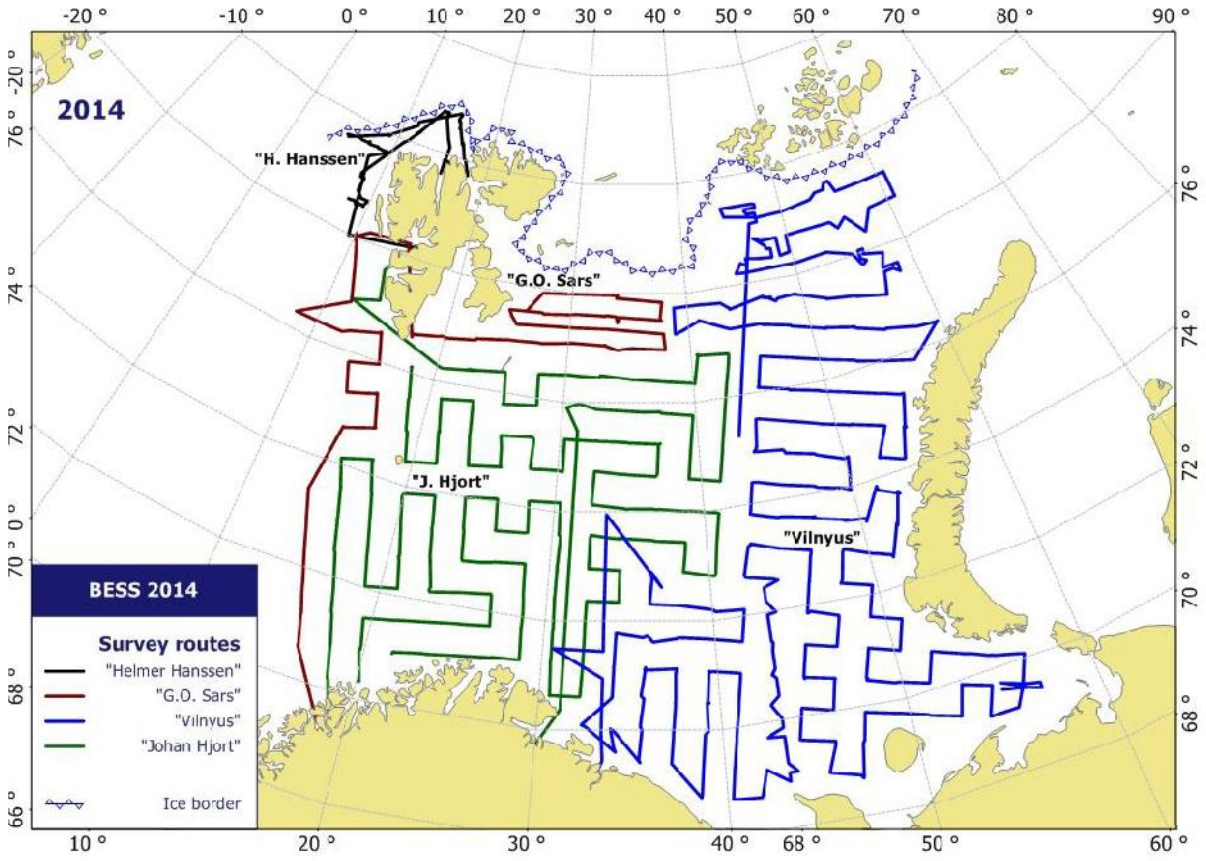

Fig. 2. Illustration of the Barents Sea area including research vessel tracks on the ecosystem surveys in August-October 2014.

Hydrography, plankton, demersal and pelagic fish stocks, benthos, seabirds, and marine mammals are sampled or observed at more than 400 stations and during extensive cruise tracks covering more or less the whole Barents Sea in August-September (Fig. 2). (http://www.imr.no/tokt/okosystemtokt_i_barentshavet/sampling_manual/nb-no) and a annual IMR-PINRO report are produced (http://www.imr.no/tokt/okosystemtokt_i_barentshavet/survey_reports/nb-no, http://www.imr.no/tokt/okosystemtokt_i_barentshavet/toktrapporter/nb-no). The sampling is based on a regular grid spanning about 1.5 million km^2 with fixed positions of stations which makes it possible to measure changes in spatial distribution over time. Educated personal (technical staff or scientists with benthic background) from both PINRO and IMR are in charge of the benthos program on the Norwegian ships in order to encourage knowledge exchange between Russian and Norwegian benthos experts, while PINRO scientists are in charge of the benthic work on the Russian vessel.

The benthic invertebrates are collected with a bottom trawl (used primarily to provide data for cod and shrimp assessments), and has been identified since 2006. The trawl is a Campelen 1800 bottom trawl rigged with rockhopper ground gear and towed on double

warps. The mesh size is 80 mm (stretched) in the front and 16–22 mm in the cod end, allowing the capture and retention of small-sized fish and the largest benthos from the seabed (benthic megafauna). The horizontal opening is 11.7 m, and the vertical opening 4-5m (Teigsmark & Øynes 1982). The trawl configuration and bottom contact is monitored remotely by Scanmar trawl sensors.
The standard distance between trawl stations is 35 nautical miles (65 km), except north and west of Svalbard where a stratified sampling is adapted to the steep continental shelf. The standard procedure is to tow 15 minutes after the trawl has made contact with the bottom, but the actual tow duration ranges between 5 min and 1 h and data are subsequently standardized to 15 min trawl time. Towing speed is 3 knots, equivalent to a towing distance of 0.75 nautical miles (1.4 km) during a 15 min tow.

The trawl catches are recorded using the same procedures on d the Norwegian research vessels *G.O. Sars*, *Johan Hjort* and *Helmer Hanssen* (www.imr.no/tokt/nb-no) and the Russian research vessel *Vilnius* to ensure comparability across Barents Sea regions.

The benthic megafauna is separated from the fish and shrimp catch, washed, and identified to lowest possible taxonomic level, in most cases to species, onboard the vessel. Species identification includes internal quality control, with standardization of taxon names performed during subsequent workshops and then according to WoRMS (http://www.marinespecies.org) when possible. An electronic identification manual and photo-compendium developed through identification of the trawl-sampled benthos from 2006-2010 are used in addition to identification litterature in order to promote standardized species identification. Difficult taxa are photographed, and in some cases brought back as preserved voucher specimens for further identification.

Wet-weight biomass is recorded with electronic scales (Marel series 1100) in the ship laboratories, and the numbers of individuals are registrered for each taxon. For colonial organisms (sponges, colonial ascidians, bryozoans, hydrozoans), only biomass are recorded.

Only animal fragments with the head-part intact are counted, but as colonial species could not be counted, the abundance values are representing only part of the benthic megafauna taken by the trawl. The biomass determination includes all fragments.

All data is entered into a benthos-database administered by PINRO, read more in (http://www.imr.no/tokt/okosystemtokt_i_barentshavet/sampling_manual/nb-no)

The daily cost per person is a 12 hours working day and a addition of Nkr 2500 per day (Norwegian cruise rate).

Greenland

In Greenland waters ground fish and shrimp surveys are carried out using two research vessels, one for offshore areas (RV Pâmiut) and a smaller vessel for inshore areas (RV Sanna). RV Sanna replaced RV Adolf Jensen in 2012.

RV Pâmiut is a stern trawler (1084 BT, ice strengthened class A) built in 1971 and is owned by GINR. The ship has wet- and dry laboratories, equipped with microscopes and a fume hood, and computers with access to the GINR shrimp and fish database. Internet access is limited. On deck there is two trawl lanes, making it possible to change between different trawl types. RV Pâmiut is equipped with two winches mounted with up to 3000 meters of wire, which can be used for CTDs, cameras, grabs, box-corers and other equipment. RV Pâmiut is equipped with an observation barrel, which can be used in studies of sea mammals and birds.
There is accommodation for up to 25 persons. Pâmiut is crewed with 11 to 13 persons. The scientific staff on the surveys normally amount from 5 to 7 persons. Daily cost (including all staff) is 100.000 Dkr.

Every year from June to September RV Pâmiut covers the continental shelf on the Greenland West coast from 59°30'N up to 72°30'N, and on the East coast from 59°30'N up to 67°N.

Two types of surveys are conducted in both West Greenland and East Greenland:
Combined shrimp-fish surveys using a Cosmos 2000 trawl with a 20 mm mesh size in the cod-end with 'rock-hopper' ground gear comprising steel bobbins and rubber disks on depths down to 600 meter. Trawling is conducted only during day time (from 08.00 UTC to 20.00). Towing time is 15 minutes and towing speed is between 2.0 and 2.5 knots. Since 1999 survey stations have been positioned using 'buffered random' sampling, in which stations are placed randomly with the constraint that a minimum distance between them, which depends on station density within the stratum, must be observed. Since 1999 about 50% of the stations included in the preceding year's design have been repeated as fixed stations in the following year, the others being placed, as before, using the buffered sampling rules. The combined fish-shrimp survey in West Greenland has been conducted since 1988 and in East Greenland since 2008. Target species are shrimp, cod, Greenland halibut and redfish, but all fish species caught is recorded.
Greenland halibut surveys using an Alfredo III trawl with a mesh size of 140 mm and a 30 mm mesh-liner in the cod-end. The ground gear is of the rock hopper type. The depth interval surveyed is from 400 to 1500 meter. Trawling is conducted day and night. Towing time is 30 minutes and average towing speed is 3.0 knots. Station lay-out is based on random allocation with a buffer zone around each station. The Greenland halibut survey in West Greenland has been conducted since 1997 and in East Greenland since 1998. Target species are Greenland halibut, grenadiers and redfish, but all fish species caught are registered.

In East Greenland the shrimp-fish and Greenland halibut surveys are conducted concurrently within the same period (from July to August). In West Greenland the shrimp-fish survey is conducted during June and July and the Greenland halibut survey is conducted during September.

Common for shrimp-fish and Greenland halibut surveys

Scanmar acoustic sensors are mounted on the trawl doors, and a *Furuno* trawl-eye on the head rope. Door-spread readings are recorded during all tows and used for swept area calculations, and the reading from the trawl-eye is used to judge when the trawl has settled and the tow can be deemed started.

Bottom temperature is measured with a *Starmon* sensor mounted on one of the trawl doors. Temperature is recorded at intervals of 30 s with a resolution of 0.01°C. The average temperature for each haul is calculated after retrieval of the sensor.

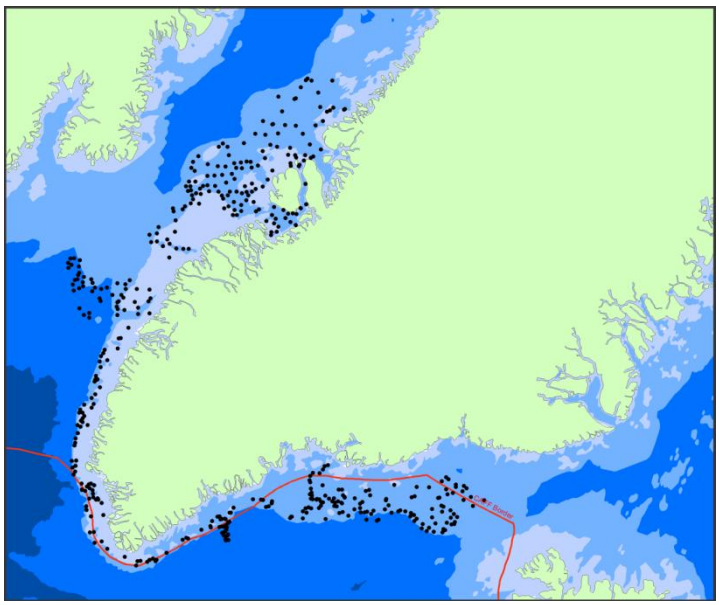

Fig. 3. Greenland and surrounding waters. Black dots indicate trawl stations on RV Pâmiut surveys in 2014. The red line indicates the CAFF border.

RV Sanna is 458 BT and built in 2012 and is owned by GINR. It is built as a multifunctional ship and used for assessing cod (gill net surveys), Greenland halibut (long line and gill net surveys) and snow crab (using crab-traps and beam-trawl). In addition RV Sanna is used in the MarineBasis programme collecting long-term oceanographic data on key physical, chemical and biological parameters of the fjord Nuup Kangerlua. It is also used for studies of marine mammals and birds and in some seismic studies.

The ship has wet- and dry laboratories including a laboratory intended for use of chemical agents and a laboratory with temperature control and a - 80°C freezer. The laboratories are equipped with microscopes and fume hoods and computers with access to the GINR shrimp and fish database. Internet access is limited.

RV Sanna has the following equipment for shellfish and fish surveys: Trawl (the cod-end can be changed and hence the mesh size can be either 5mm, 20mm or 36mm), gillnets, longlines, crab traps and beam trawl. Bottom temperature is measured with a *Starmon* sensor mounted on the gear in use. Temperature is recorded at intervals of 30 s with a resolution of 0.01°C. The ship is also equipped with an A-frame and with two winches mounted with up to 2000 meter wire, which can be used for CTD, camera, grabs, box-corers and other equipment. In

addition there is an observation barrel, which can be used in studies of sea mammals and birds.
Every year from April/May to September/October RV Sanna cover the inshore areas of West Greenland. Monitoring Programmes includes: The MarineBasis programme, which is conducted during May in Nuup Kangerlua. In the area around Sisimiut a combined snow crab and cod survey is conducted. In the Disko Bay area a combined snow crab and Greenland halibut survey is conducted. In the fjords around Uummannak and Upernavik surveys on Greenland halibut are conducted. The rest of the time is spent on different projects not part of GINRs monitoring programme.
There is accomodation for 16 persons. RV Sanna is crewed with 6 - 7 persons. Depending on the survey type, the scientific staff ranges from 2 to 10 persons. Daily cost (including crew, not including scientific personel) is 40.000 Dkr.

Data entry for all shrimp and fish surveys

Station information is filled in with cruse ID, gear type, station, geographical location, tow information and temperature etc. Data on species level includes total weight and total number. Data on an individual level includes length and weight and for target species sex and maturity. Data are entered directly into GINRs Access database.

Monitoring of environmental factors

During the shrimp fish survey in West Greenland annual CTD transects (from the coast and westwards) recording temperature and salinity to trace climatic variations have been conducted by GINR since 1988 in cooperation with the Admiral Danish Fleet. Transects are placed along West Greenland from Cape Farewell (59°N) to Upernavik (72°30'N).

History of benthic sampling

A large number of benthic studies were conducted in Greenland waters by Danish research expeditions in the late 19th century and the first half of the 20th century. Many of the results were published in the series, *Meddelelser om Grønland*. Unfortunately, much of this historical data seem to be almost forgotten, as judged from recent scientific literature, assumedly because only a minor part of it is found in modern web based academic search engines, and neither available as digital copies.
But recently The Natural History Museum of Denmark initiated a compilation of the large amounts of historical records of benthos from Greenland waters in an attempt to provide a regional baseline (pers. com. Tom Schiøtte).
Since the 1970's benthos research in Greenland has been rather sporadic. Much of this recent literature is focusing on dominant species, functional structure and carbon flux, more than community species composition and biodiversity (REFS). Recent baseline studies in relation to oil exploration in shelf areas in West Greenland are a potential source of new information, but these data are still unpublished in scientific literature.

On a trial basis GINR started recording by-catch of corals and sponges on the RV Pâmiut shrimp-fish survey in West Greenland in 2011. This was parallel to a collaboration with a research team from Institute of Zoology, London, on a project on RV Pâmiut with focus on

seabed imaging. This project was initiated by the Fishery Organization, Sustainable Fisheries Greenland (Kemp & Yesson 2014). In 2013 registration of all taxonomic main groups of benthos (including corals and sponges) taken as by-catch in trawl hauls in West Greenland was initiated. In 2014 this was expanded to also include the East Greenland surveys. After determining benthos to 35 taxonomic main groups onboard RV Pâmiut samples were preserved in formalin for later species identification.

Iceland

Spring surveys. The Icelandic Groundfish Survey (IGS) has been carried out annually in the spring (end of February to mid-March) since 1985, by the Marine Research Institute (MRI). The survey is a significant part of the stock assessment and fishery advice for cod, haddock, redfish, tusk, ling, monkfish and several species of flatfish. Moreover, the survey provides information on the distribution and condition of many other fish species, as well as ocean temperatures.

Approximately 600 stations are sampled during the survey, on the continental shelf around Iceland to depths of 500 m. The sampling stations are fixed, thus, each year the same stations are sampled. Four or five ships (two research ships and trawlers) have performed the survey. This year, however the survey will be conducted with only one research ship and three trawlers. The survey time is around 26 days. In each trawler, there are two researchers/scientists pr. shift (two shifts) that perform the measurements, plus a cruise leader. In the research ships, there are usually three researchers/scientists pr. shift, plus a cruise leader. On board the research ships, there are laboratories and facilities for a number of researchers. The trawlers do not have these facilities and thus, are not suitable for external activity like sampling of benthos.

The survey gear and methods have been more or less unchanged over the study period. The trawl used for sampling is of the Mars type. The headline is 32.0 m long. The bobbin footrope is 18.30 m long, weighing about 3250 kg in air and 1270 kg submerged. Total weight of footrope (Danleno-Danleno) is about 4200 kg in air and 1900 kg submerged. The otter boards are of the "Poly-Ice" type no. 7, weighing about 1950 kg each. The towing speed is 3.8 knots over the bottom. The trawling distance is 4.0 nautical miles calculated with GPS when the trawl has set on the bottom until the hauling begins (i.e. excluding setting and hauling of the trawl). The front section of the trawl has a mesh size of 135 mm, the middle section (belly) 80 mm and the codend is covered inside with a 40 mm net. Sampling is performed night and day. Information on weather and other environmental factors is registered. Bottom temperature is measured with Starmon mini temperature recorders from Star-Oddi, placed on the upper belly or headline of the trawl. Cost of the research vessel is 140,000 DKK/day in 2015.

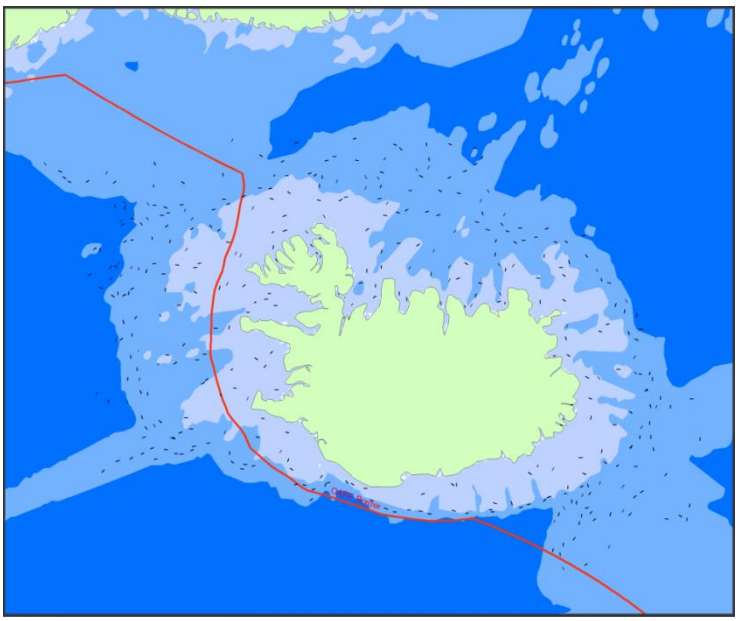

Fig. 4. Iceland and surrounding waters. Black dots indicate trawl hauls on annual bottom trawl research surveys. The red line indicates the CAFF border.

Autumn surveys. The Icelandic Autumn Groundfish Survey (AGS) has been conducted annually in October since 1996 by the Marine Research Institute (MRI). The objective is to gather fishery independent information on biology, distribution and biomass of demersal fish species in Icelandic waters, with particular emphasis on Greenland halibut (*Reinhardtius hippoglossoides*) and deepwater redfish (*Sebastes mentella*). The survey also obtains a second valuation of these factors on cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and golden redfish (*Sebastes marinus*), in order to improve the precision of stock assessments.

Approximately 400 fixed stations are sampled at the Icelandic continental shelf and slopes within the Icelandic Exclusive Economic Zone to depths down to 1500 m. The research area is divided into a shallow-water area (0-400 m) and a deep-water area (400-1500 m). Two ships perform the survey. One samples in shallow waters, and one ship samples in deep waters. Until 2013, the survey was conducted by two research ships, but in 2014 the survey was performed only by two trawlers. The arrangement of ships performing the survey for next year is uncertain. The bottom trawl used for sampling in shallow water is called "Golden Top" nr. 77. The headline is 31.0 m, the fishing line is 19.6 m. The rock hoppers used are 3 x 6.1 m, weighing 2,200 kg. The otter boards are PolyIce nr. 7 and weigh 1950 kg. Codend - mesh size is 40 mm, sweeps length 35 fm. The bottom trawl used for sampling in deep water is "Golden Top" nr. 78. The headline is 35.6 m, the fishing line is 22.6 m. The rock hoppers used are 3 x 7.33 m, weighing 2,200 kg. The otter boards are PolyIce nr. 8 and weigh 2700 kg. Mesh size is 40 mm, sweeps length 120 fm. The towing speed is 3.8 knots over the bottom. The trawling distance is 3.0 nautical miles calculated with GPS when the trawl has set on the bottom until the hauling begins (i.e. excluding setting and hauling of the trawl). Sampling is performed night and day. Information on weather and other environmental factors is registered. Bottom temperature is measured in °C, with Scanmar thermometer or similar instrument.

Data entry for groundfish surveys. Station information is filled in with cruise ID, gear type, station, geographical location, tow information etc. Data on species, length, numbers counted, sex, maturity and weight are entered directly into a computer that is connected to Marel weighing machine (using SeaScale data collection program). This also accounts for the stomach-analysis data. Environmental information are added on the station. All data is stored in Oracle database.

Monitoring of environmental factors. Annual observations of temperature and salinity to trace climatic variations have been conducted by the MRI on some fixed stations since 1950. Since 1970, longtime monitoring of the oceanography (physical- and chemical) of Icelandic waters have been conducted on fixed stations four times a year, in February / March, May / June, August / September and October / November. Nutrients, primary production of phytoplankton and zooplankton abundance and diversity is studied during spring cruises. Continuous monitoring of the inflow of Atlantic water into the area north of Iceland is also carried out by MRI using moored current meters. The MRI also carries out Seabed mapping with multibeam echo sounder, providing high resolution maps with bathymetrical and backscatter data. To date, a 12% of the Icelandic EEZ has been multibeam mapped. These maps have proven valuable for benthic habitat mapping, such as mapping the distribution of cold-water corals. They have also provided great information on the marine geology, revealing many different geomorphological features on the seafloor.

History of benthic sampling and present studies. Benthic research was initially performed by Danish research expeditions in the North Atlantic, off Greenland and Iceland, including the Ingolf-Expedition (1895-1896), the Thor Expedition (1903) and the Dana Expedition (1920-22). These expeditions provided a fundamental knowledge of the marine life in these regions and are still very valuable. Much of the records on the benthic fauna have been published in the series Zoology of Iceland (Published by the Carslberg-Fond, Rask-Ørsted-Fond, Sáttmálasjóður and Ríkissjóður Íslands). Nearly all research on benthic fauna following these expeditions were targeted to only specific locations for different reasons. Most often they were targeted for environmental investigations prior to some planned activity in particular fjord or area.
Until the early 1990's, holistic information on Icelandic benthic invertebrate fauna was relatively sparse, in particular for deep waters. This changed with the Benthic Invertebrates of Icelandic waters, the BIOICE project, carried out between 1991 and 2002 by the Icelandic Museum of Natural History (IMNH), the Marine Research Institute (MRI), and the University of Iceland. The objective of BIOICE was to provide a comprehensive view of the biodiversity and distribution of benthic invertebrates in Icelandic waters. During seventeen BIOICE cruises (1991-2002), more than 1412 samples were collected on 579 stations at depths between 20 and 3100 m.

The Marine Research Institute is currently mapping and describing the benthic habitats around Iceland. The distribution of cold water corals, with the objective of identifying areas where *L. pertusa* is in need for protection, has been in focus the past years. In 2003, information on the historical and present distribution of coral grounds off Iceland was obtained from local fishermen through interviews and questionnaires (Steingrímsson and

Einarsson, 2004). In 2004, MRI conducted the first survey to explore cold-water corals with underwater video and photography, targeting areas classified at high risk. A total of 18 ROV (remote operated vehicle) transects were carried out during the cruise. Additional surveys, with a total of 119 transects, were conducted in 2009, 2010 and 2012, on the south and southeastern shelf and on the Reykjanes Ridge, using a ROV and a campod (a towed video and photograph platform). The 2009 and 2010 surveys were conducted in collaboration with the FP7 funded CoralFISH project. Data collected during these cruises was used to delineate areas in need for protection. As a result, in 2005 and 2011 the Ministry of Fisheries and Agriculture approved regulations to establish a series of marine protected areas (MPAs) with a total area of 480 km^2 (Ólafsdóttir & Burgos 2012).

Targeted sampling of benthos has not been a part of the groundfish surveys and benthos has never been monitored in Icelandic waters. In 2015, a pre-study will be made to estimate the feasibility to add benthic monitoring to either spring- or autumn survey. Other surveys with bottom touching gear are stock assessment of shrimp (*Pandalus borealis*) and *Nephrops norvegicus*. These surveys are however less suitable for monitoring of benthos.

Faroe Islands

Ground fish surveys in the Faroe Islands.

The Faroes have a long history of benthic research and surveys. The waters around the Faroe Islands are frequently visited by research vessels due to the location between the British Isles and Iceland where the deep cold water from the Norwegian Sea passes by in the narrow straight between the Faroe Shelf and the Faroe Bank heading for the depths in the South Atlantic. One of the major contributions to the general knowledge of the benthic invertebrate fauna of the waters around the Faroe Islands is BIOFAR project, an inter-Nordic collaboration with scientific contributions from the Faroes, Denmark and Norway. The project was carried out between 1989 and 1995 and the objective was to provide a comprehensive list of the benthic invertebrates and their distribution within Faroese waters. More than 800 stations were sampled at depths between the seashore and 1500 m and more than one hundred papers are so far published in different scientific journals from the BIOFAR material.

The Faroese Marine Research Institute is the largest of the marine institutions in the Faroes and carries out ground fish stock assessments twice a year. This research is incorporated into the specialist working groups under the International Council for the Exploration of the Sea (ICES), which then provide the basis for the Faroese Marine Research Institute's advice to the Government.

Two study areas are defined: The Faroe Plateau and the Faroe Bank. The surveys collect fishery-independent information necessary for the assessment of stock status for the three economically most important species: cod, haddock and saithe. These are measured in different ways, while all other fish species are only registered in numbers and weight. The

sampling protocol does not include any invertebrate species except nephrops and cephalopods.

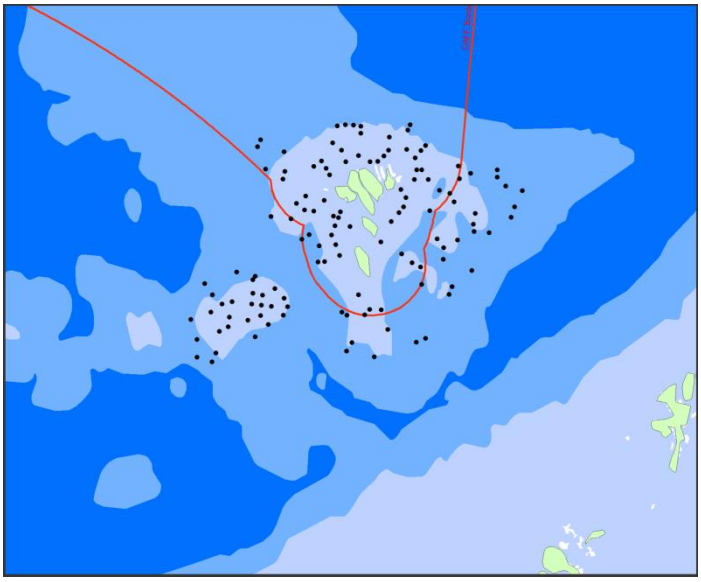

Fig. 5. Faroe Islands and surrounding waters. Black dots indicate trawl monitoring stations on annual surveys. The red line indicates the CAFF border.

100 stations are monitored in early spring and 200 stations are monitored in August, where off 100 are the same as in the spring survey. Faroe Bank south off the Faroes is monitored in a similar way.

The august survey has 24-hour sampling days, while the spring survey has 12-hour samling days.

Before 1993 the stations were randomly chosen, but have been fixed since 1993. The gear used is a 112 feet “box” trawl with 40 mm mesh size. In this period both gear and vessel have been unchanged.

Fig. 6. The Faroes research vessel, Magnus Heinason, which is run by The Faroese Marine Research Institute and used for national bottom trawl research surveys.

The Faroese Marine Research Institute runs the research vessel "Magnus Heinason". The vessel was originally built as a stern trawler in 1978 and was rebuilt to research vessel in 1982 and the vessel is manned with a ten ship crew and can accommodate a total of 18 persons (up to 8 researchers). The running costs are about 80,000 DKK / day

Technical information: - Length (LOA): 44.5 m - GRT: 669 - Main engine: 1800 HK M.A.K - Electricity: 3 x 380/220 V AC, 2 x MTU, 288 kW, 1500 rpm Equipment for position: - GPS and DGPS - ARPA-radar

Echo equipment: - Simrad EK60 (38 and 200 kHZ split-beam transducers) - Simrad sonar (SP 70)

Other equipment: - Bottom trawls - Pelagic trawls - Simrad ITI trawl monitoring system - Plankton nets - CTD with rosette, fluorometer and light sensor - ADCP - Fast Repetition Rate Fluorometer

Station information is filled in with cruse ID, gear type, station, geographical location, tow information etc. Data on species, length, numbers counted, sex, maturity and weight are entered directly into a computer that is connected to a digital weight. All data is stored in an Oracle database.

Canada (Baffin Bay, Davis Strait)

The DFO Central and Arctic Region annual multi-species stock assessment surveys began in 1999 and are the cornerstone of Canadian research surveys in the Eastern Arctic. Seven study areas are defined: northern NAFO 0A, southern NAFO 0A, Canadian zones SFA0, SFA1, SFA3 and western Hudson Strait. The study area surveyed varied from year to year but since 2014 has focused on 0A-south, 0B and the shrimp Western Assessment Zone (formerly part of SFA3). The surveys collect fishery-independent information necessary for the assessment of stock status for the commercial exploited species: northern shrimp (*Pandalus borealis*) and striped shrimp (*Pandalus montagui*) and Greenland halibut (*Reinhardtius hippoglossoides*). They also provide distribution and abundance information on all species collected in the trawls including benthic invertebrates. In particular, the sampling protocol includes identification (to the lowest possible level) of corals and sponges and corresponding total weights by set. ID keys have been developed to facilitate with this. As the invertebrate fauna of this region is not well known, as part of the protocol, a system of support from regional labs has been put in place that allows the Scientist in charge of the survey to collect representative or unknown specimens that can be later confirmed back in the lab.

Surveys have been conducted with the Greenland Institute of Natural Resources' (GINR) research vessel Pâmiut using either an Alfredo (with a 30 mm liner in cod end which increases retention of benthic invertebrates) or Cosmos shrimp trawl (with a 20 mm liner in

cod end) depending on the focus species of the particular survey. The Pâmiut is crewed by a biologist and 6 technicians working 24 hour sampling days with a vessel cost of 100,000 DKK / day in 2015. The target set for the Alfredo trawl is 3.0 knots towed for 30 minutes and for the Cosmos trawl 2.6 knots for 15 minutes. Trawl geometry is monitored for door spread, net height and bottom contact with wing spread introduced in 2009. Environmental data, temperature, salinity and depth (CTD), is collected with Seamon, Star-Oddi and Seabird CTD equipment. A trawl mounted Conductivity-Temperature-Depth (CTD) system provides vertical hydrographic profiles for each trawl haul. This is supplemented with hydrographic transect lines. Surveys are stratified random in design based on stratum area proportions with a two set minimum. Sampling sites are allocated using the buffered random sampling protocol. Shrimp surveys sample waters from 100-800m stratified in contours of 100-200, 200-300, 300-400, 400-600 and 600-800m. Greenland halibut surveys sample waters from 400-1500m (Fig. 7). Recently, there was a change in strategy for the shrimp surveys. In the future they will be conducted through collaboration between DFO and the industry from a commercial trawl vessel. Corals and sponges will still be recorded but other benthic species will not be identified to the same degree of accuracy as in previous shrimp surveys with RV Pâmiut.

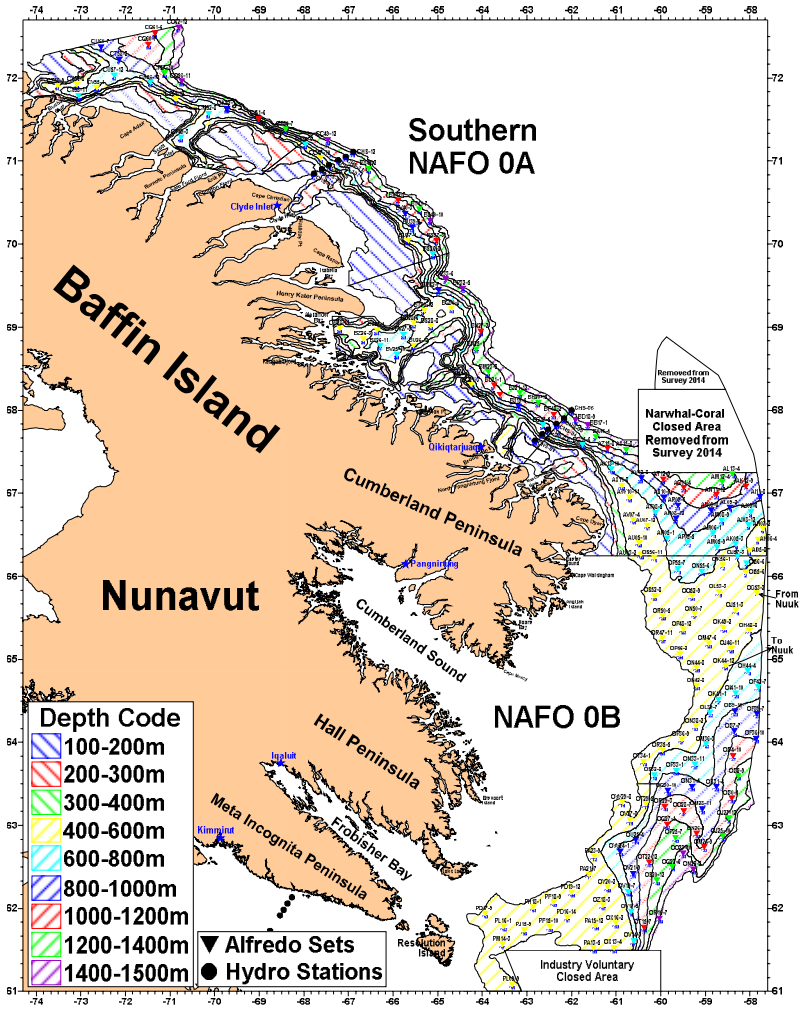

Fig. 7. Overview of the Canadian annual multi-species stock assessment survey in the offshore areas of Davis Strait and Baffin Bay in 2014. NAFO areas 0A and 0B with sampling localities and depth codes are indicated.

All data from the trawl surveys are recorded in the same Access database. Corals and sponge data are extracted and passed on to a specialist in that field. Eventually the survey data are archived in an Oracle database.
In 2011 the Government of Nunavut commissioned the 65 foot fisheries research vessel MV Nuliajuk which works both inshore and offshore waters and has deployed a variety of sampling gears which have collected data on benthic species for targeted research. The Nuliajuk works in the inshore waters of eastern Baffin Island: Cumberland Sound, Scott Inlet, Sam Ford Trough, Merchant's Bay at depths from 200 to 1400 m (depending on sampling gear) and has participated in the Greenland Halibut survey and multi-species fish surveys. She is equipped with benthic longlines, bottom trawl, benthic gillnets, CTD, scientific winch, crane, a small lab that can be divided into wet and dry areas, electronic scales (0.01 g to kg), weatherproof computer, lab computer, navigation electronics and software, satellite internet access (slow and temperamental). The vessel is manned with five ships crew (captain, mate, two deckhands, trainee) with fishing experience and up to five science crew (technicians / students / biologist). Survey routines operate from late July to early October, depending on sea ice; follow stratified (by depth) random sampling designs; undertake scientific sampling during a 12 hour period (ship can travel during off-hours); with longline sets of 12 hours, bottom trawl of 30 min at 3 knots, gillnet sets over days. The daily cost is ~$6000 per day (all ship costs including food, fuel, ship crew salaries) + science crew salaries + research consumables (e.g. bait, batteries).

Similarly, DFOs CCGS Hudson has conducted targeted benthic sampling in the Eastern Arctic. In particular, grab samples and underwater imagery have been collected in support of the Arctic Council Circumpolar Marine Biodiversity Monitoring Plan for the benthos. CCGS Hudson can accommodate a scientific crew of 28, work 24 hour days and is ice strengthened. The cost is ~$30000 per day.
Benthic sampling has also been a feature of the ArcticNet program operating from the CCGS Amundsen and led by university research interests. DFO conducts annual oceanographic monitoring (1990 to present) along a transect running from Hamilton Bank on the Labrador Shelf (53°40' N, 55°30'W) to Cape Desolation on the Greenland Shelf (60°30'N, 48°15'W) under the Labrador Sea Monitoring Program. This line is referred to as AR7W or the Atlantic Repeat Hydrography Line 7 West of the 1990-2002 World Ocean Circulation Experiment, and forms part of the Canadian Atlantic Zone Off-Shelf Monitoring Program (AZOMP) led by the Ocean and Ecosystem Sciences Division of the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, Canada. Physical, biological and chemical data are collected following standard protocols. Temperature, salinity and density profiles are measured using a Conductivity-Temperature-Depth (CTD) system deployed at a fixed set of stations along the AR7W line. Oceanographic data collected from this program have been used to interpret and model benthic species distributions in the region.

Country	Greenland			
Area	West Greenland		East Greenland	
Survey	Shrimp Fish Survey	Greenland Halibut Survey	Shrimp Fish Survey	Greenland Halibut Survey
Ship(s) - research vessels only	RV Pâmiut	RV Pâmiut	RV Pâmiut	RV Pâmiut
Cost per day (ship and all staff)	100000DKK	100,000DKK	100,000DKK	100,000DKK
Additional scientific staff 1 person per day	2000DKK	2000DKK	2000DKK	2000DKK
Berths (Number)	24	24	24	
Crew	11 to 13	13	13	
Scientific Staff	5	7	7	
Berths left	6 - 8	4	4	
Duration of survey (days)	47	15	37	
Number of stations (trawl hauls)	225	60	95	70
Trawl type	Cosmos 2000	Alfredo III	Cosmos 2000	Alfredo III
Mesh size codend (mm)	20	30	20	30
Daily sampling period (trawling)	08.00 - 20.00 UTC	24 hour	08.00 - 20.00 UTC	24 hour
Tow duration (minutes) or distance (nm)	15min	30min	15min	30min
Towing speed (knots)	2.0 - 2.5	3	2.0 - 2.5	3
Area covered (NAFO / ICES)	1B-1F, part of 1A and part of 0A	1C and 1D	14B	14B
Longitude (South to North)	59°30' N to 72°30' N	62°30' N to 66°15' N	59°30' N to 67°00' N	61°45' N to 67°00' N
Depth interval (meter)	50 - 600	400 - 1500	50 - 600	400 - 1500
Area surveyed (km2)	186,220	52,306	118,107	37,397
Benthos sampling; equipment available/part of standard survey (+=yes, - = no)				
Groundfish trawl	+/-	+/-	+/-	+/-
Beam trawl/dredge/sledge	+/-	+/-	+/-	+/-
Grab/corer	+/-	+/-	+/-	+/-
Camera	+/-	+/-	+/-	+/-
Video	-/-	-/-	-/-	-/-
Acoustic	-/-	-/-	-/-	-/-
Environmental sampling; equipment available/part of standard survey (+=yes, - = no)				
CTD	+/+	+/+	+/+	+/+
Trawl temp logger	+/+	+/+	+/+	+/+
Water sampler	+/-	+/-	+/-	+/-

Table 1a.

Country Area	Faroe Islands		Iceland	
Survey	Feb-March	August	Feb-March	October
Ship(s) - research vessels only	Magnus Heinason	Magnus Heinason	Árni Friðriksson (ÁF) + 3 other ships	Árni Friðriksson (ÁF) in deep + 1 other ship in shallow waters
Cost per day (ship and all staff)	80,000DKK	80,000DKK	140,000DKK (ÁF, only ship)	140,000DKK (ÁF, only ship)
Additional scientific staff 1 person per day	-	-	5000DKK	5000DKK
Berths (Number)	18	18	33	33
Crew	9	13	18	18
Scientific Staff	4	5	7 (without benthos)	7 (without benthos)
Berths left	5	0	11	11
Duration of survey (days)	28	28	26	24
Number of stations (trawl hauls)	129	229	Total 562; around 130 for ÁF	Total 380; 162 in shallow; 220 in deep (ÁF)
Trawl type	112 feet Box	112 feet Box	Mars trawl	“Golden Top”nr.77 in shallow /"Golden top" nr. 78 in deep
Mesh size codend (mm)	40	40	40	40
Daily sampling period (trawling)	12hour	24 hour	24 hour	24 hour
Tow duration (minutes) or distance (nm)	60min	60min	4nm	3nm
Towing speed (knots)	3-3.5	3-3.5	3.8	3.8
Area covered (NAFO / ICES)	Vb1b, Vb2	Vb1b, Vb2	Va1, Va2	Va1, Va2
Longitude (South to North)	60°30' N to 62°30' N	60°30' N to 62°30' N	63 to 67°N/10 to 27°W	62 to 67°N/10 to 0°W
Depth interval (meter)	65-700	65-700	20-500	20-400/ 150-1500
Area surveyed (km2)	47,000	47,000	250,000	150,000
Benthos sampling; equipment available/part of standard survey (+=yes, - = no)				
Groundfish trawl	+/+	+/+	+/+	+/+
Beam trawl/dredge/sledge	-/-	-/-	+/-	+/-
Grab/corer	-/-	-/-	+/-	+/-
Camera	-/-	-/-	+/-	+/-
Video	-/-	-/-	+/-	+/-
Acoustic	+/-	+/-	+/+	+/+
Environmental sampling; equipment available/part of standard survey (+=yes, - = no)				
CTD	+/-	+/-	+/-	+/-
Trawl temp logger	+/+	+/+	+/+	+/+
Water sampler	-/-	-/-	+/-	+/-

Table 1b.

Country Area	Norway/Russia Barents Sea	Canada Davis Strait/Baffin Bay
Survey	August-September	Greenland Halibut survey
Ship(s) - research vessels only	Helmer Hanssen, GO Sars (GOS), Vilnyus, Johan Hjort (JH)	RV Pâmiut
Cost per day (ship and all staff)	200,000NKR	100,000DKK
Additional scientific staff 1 person per day	2,800 NKR + 12 working Hours	16,000DKK
Berths (Number)	GOS: 45, JH: 39	24
Crew	GOS: 15, JH: 14	13
Scientific Staff	Depends on project	7
Berths left	Depends on project	4
Duration of survey (days)	from 10 - 30 days per ship	32
Number of stations (trawl hauls)	400	184
Trawl type	Campelen 1800	Alfredo III
Mesh size codend (mm)	16-22	30
Daily sampling period (trawling)	24 hour	24 hour
Tow duration (minutes) or distance (nm)	15min	30min
Towing speed (knots)	3	3
Area covered (NAFO / ICES)	IIb2, IIb1, IIa1, IIa2, Ib, Ia	southern 0A, 0B
Longitude (South to North)	65 - 85°N	61°N to 72.7°N
Depth interval (meter)	<500	400-1500
Area surveyed (km2)	1,500,000	115,722
Benthos sampling; equipment available/part of standard survey (+=yes, - = no)		
Groundfish trawl	+/+	+/+
Beam trawl/dredge/sledge	-/-	+/-
Grab/corer	+/-	+/-
Camera	-/-	+/-
Video	-/-	-/-
Acoustic	+/+	-/-
Environmental sampling; equipment available/part of standard survey (+=yes, - = no)		
CTD	+/+	+/+
Trawl temp logger	+/+	+/+
Water sampler	+/+	+/+

Table 1c.

Development of minimum standards for benthic monitoring

As outlined above the logistical and scientific settings vary greatly between nations from already established extensive benthos monitoring programs on ecosystem surveys using multifunctional research vessels in the Norwegian and Russian Barents Sea, to traditional bottom trawl surveys without any supplementing samplings in Icelandic and Faroese waters (Table 1a-c). Based on this, we need to identify some minimum standards for benthos monitoring that 1) are realistic to be implemented given the logistical, scientific and economical settings within each country in the Arctic-Atlantic, 2) will provide a description of key components in benthos fauna communities, 3) has the potential to document large-scale and long-term trends in benthic indicators in relation to climate, trawling, oil exploitation and other potential anthropogenic and natural drivers.

As outlined above, there are significant costs related to benthos sampling (ship time, equipment, extra personnel) and sample analyses (specialist man hours) using conventional methods for benthos studies. It is likely to be outside the economic scope for some countries to implement such expensive programs, particularly as large-scale annual monitoring. Therefore, to reduce costs, it is suggested that minimum-standards for long-term and large-scale monitoring should be incorporated in the existing ship survey routines to the highest extent possible. This has been done successfully in the Barents Sea by Norwegian and Russian fish research vessels, and in the Eastern Arctic on Canadian and Greenlandic (chartered) vessels by implementing a trawl by-catch program (see above). During that process it was also concluded that grab/corer sampling of benthos was an extremely expensive approach in terms of ship-time for sampling and specialist man hours for identification, and should not be used for large-scale monitoring purposes, but rather for baseline mapping (*Pers. comm.* Lis Lindal Jørgensen). Similar challenges are found for photographic or video surveys, which are non-destructive and could provide important information about the physical characteristics of the seabed and biogenic structures, but also limited in terms of taxonomic resolution of the derived data, if not significant effort is put into 'ground truthing' (Kemp & Yesson 2014).

We therefore suggest that the trawl by-catch approach used in the Barents Sea by Norway and Russia, and in Canadian waters is adopted on to bottom trawl research surveys in Iceland, Faroe Islands and Greenland. It is a cost-effective approach, as no extra ship time is needed, and furthermore has the advantage that benthos sampling can be linked to existing survey routines (sorting, weighing, data entry and storage), procedures for collecting and storing metadata (depth, positions, temperature etc.) and relevant biological data (fish/shellfish catch). We recommend that trawl by-catch sampling represents minimum standards for benthos monitoring for the Arctic-Atlantic region. Despite the obvious limitations of such a program due to low and biased catch efficiency of bottom trawls (see above) and its restriction to the survey areas, it has proven effective for documenting qualitative and semi-quantitative large-scale distribution of benthic megafauna (Jørgensen et al 2014), and it would enable the initial detection of potential vulnerable habitats, valuable ecosystem components or areas subject to dramatic changes (e.g. biodiversity hot spots, coral or sponge gardens, nursery grounds). As a management action, the detection of such

potential focus areas could be followed up by more targeted benthos research using some of the methods outlined previously (e.g. photo/video, grab, acoustics) as in Canadian or Icelandic waters, or even more holistic ecological studies as seen on the Barents Sea Ecosystem surveys (see above). On some of the existing surveys, vessels are not in use for trawling during night time (e.g. West Greenland, Faroes spring surveys), and additional sampling could be conducted at no or limited extra ship time costs. In other areas this is not an option and funding for additional ship time would be needed.

Dependent on ship facilities and survey routines we suggest that one of three alternative approaches to benthos sampling is implemented on existing national bottom trawl surveys; priority as listed:

1. Two specialist taxomists attend bottom trawl surveys to identify and register benthos bycatch. Difficult species is preserved and saved for later identification assisted by a network of specialist taxonomists.
2. Trained personel (scientific/technical) sort and register benthos bycatch to main taxonomic groups on board. Samples are preserved and brought back to laboratory for ID by specialist taxonomists.
3. Technical crew preserve all invertebrate bycatch and bring back to laboratory for ID by specialist taxonomists.

Based on this rationale the authors of this report are developing a suggestion for a standardized trawl bycatch protocol for the Arctic-Atlantic. Furthermore, an Arctic benthos expert exchange program is initiated to ensure consistency and cross-regional standardization of sampling, species identification and data treatment. Below is a list of specific points that will be considered in the development of standardized trawl bycatch protocol.

- Standardization of sampling, subsampling, sorting into main taxonomic groups, measurements to be taken etc. Educate ship crew.
- Standardization of species identifications – one name to one species. Identification of benthos species is difficult and requires specialist knowledge. It is suggested that an Arctic-Atlantic benthos catalogue, containing photos and descriptions of all species caught on bottom trawl surveys, is produced to ease identification onboard and to ensure consistency in species identifications across surveys, years and nations. Collections of voucher specimens should be established and international workshops should be held regularly to develop and maintain the catalogue, and develop taxonomic skills.
- Standardization of data formats. Preferably benthos information should be entered in standard formats into existing databases, containing metadata about the trawl hauls (e.g. gear type, position, depth, time, haul speed, haul length, bottom temperature etc.). For the purpose of sharing data and

conducting cross-regional analyses standard formats for data and metadata should be presented in the protocol.

The proposed trawl bycatch program will be put into practice in Greenland waters in a time-limited research project, called Initiating North-Atlantic Benthos Monitoring (INAMon) in 2015-17 onboard RV Pâmiut with the participation of benthos experts from all Arctic-Atlantic countries with financial support from NORA, Nordic Council of Ministers and Greenland Institute of Natural Resources, and in collaboration with the fisheries organization, Sustainable Fisheries Greenland.

The total funding for the benthos program in Greenland is 2.5 million DKK in 2015-17. The geographical coverage over this period is identical to the entire survey area (Fig. 3). Expenses are distributed as follows (Table 2):

Item	Total cost (2015-17)
Travel costs and accommodation – 2-4 pers., 9 surveys	450,000DKK
Specialist salary, 2-4 pers., 9 surveys (c. 126 days + travel days)	1,338,930DKK
Workshop, travels costs, 10 pers.	120,000DKK
Workshop, salary, 6 pers.	161,967DKK
Database development, Data analysis, Report writing	419,400DKK

Table 2.

The own contribution of participating institutions to the program is >12 million DKK in ship time, travels and salary for biological assistants and researchers (surveys, database development, Identification catalogue, data analysis).

When established, the annual costs of a monitoring program in Greenland offshore waters with 2 benthos experts onboard RV Pâmiut on 3 of 6 annual surveys (2 year cycle) is estimated in Table 3:

Item	Annual cost
Travel costs and accommodation – 2 pers., 3 surveys	108,000DKK
Specialist salary, 2 pers., 3 surveys (c. 45 days)	299,000DKK
International Workshop, travels, 2 pers.	36,000DKK
International Workshop, salary, 2 pers.	42,000DKK
Suppl. Fauna ID, Data analysis, Report writing	252,000DKK
Total	737,000DKK

Table 3.

GINR's own financial contribution to this program by making the existing logistical platform available to the program would amount to c. 4 million DKK annually.

Scientific outputs

The results of potential future national monitoring programs should be presented to the management and stakeholders in annual assessment reports, as well as and in relevant international scientific fora, such as NAFO and ICES, and at conferences and in peer review scientific journals.

Conclusions

Based on a comparison of the existing national annual research surveys in the Arctic-Atlantic region we suggest including a standardized "Benthos trawl bycatch program" in survey routines. This is a cost-effective approach that will provide a description of key components in benthos fauna communities, enabling the initial detection of potential vulnerable habitats or valuable ecosystem components, and with the potential to document large-scale and long-term trends in benthic indicators in relation to climate, trawling, oil exploitation and other potential anthropogenic and natural drivers.

The suggested approach will be implemented as a pilot project on surveys in Greenland in 2015-17 with the participation of experts from all Arctic-Atlantic countries. This "Expert Exchange Program" will be a platform for knowledge sharing and –building with the overall objective to create a common Arctic-Atlantic knowledge base acting as a stepping stone to establish actual long-term monitoring programs across the Arctic-Atlantic region.

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