North Water Polynya Conference

Copenhagen 2017

Pikialasorsuaq pillugu Ataatsimeersuarnermi Qitiusumik apeqqutigineqartut akissutaallu

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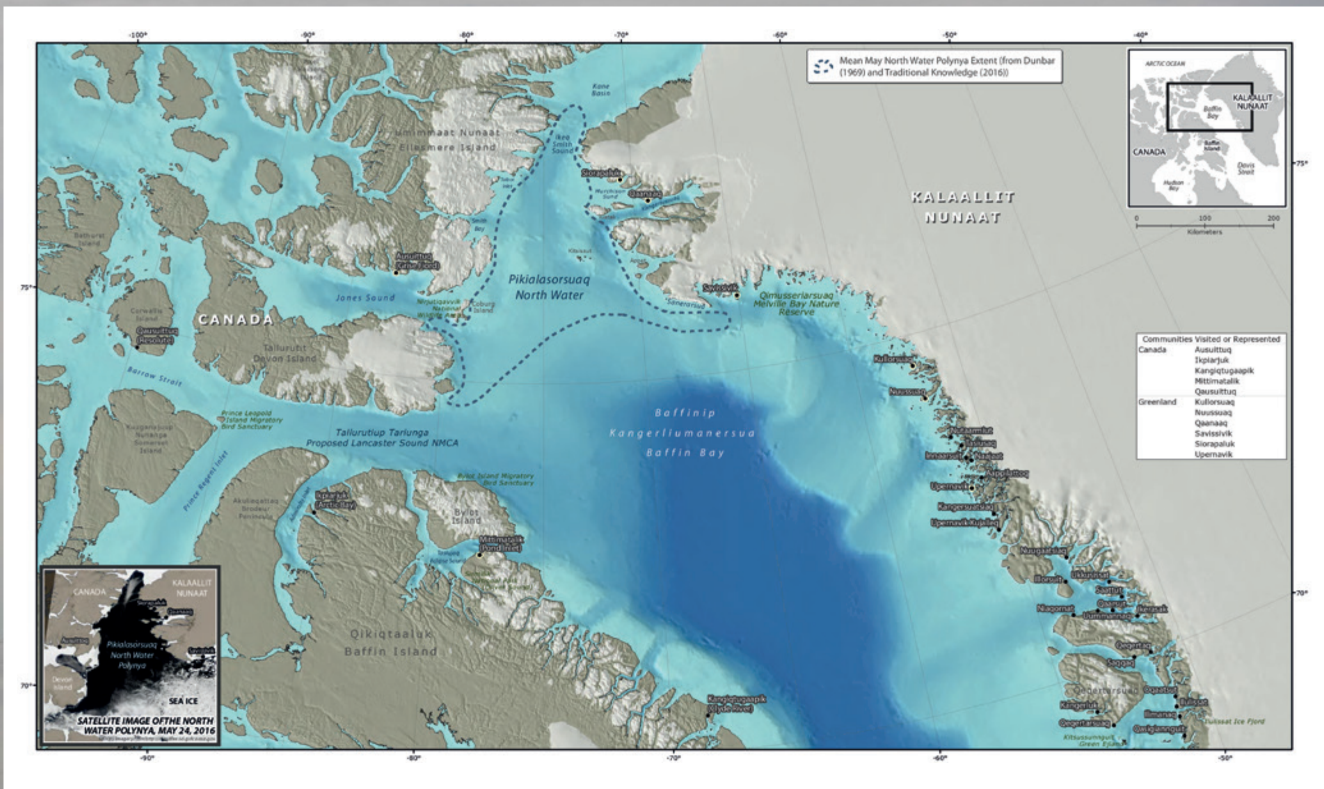

WHITE PAPER

North Water Polynya Conference Copenhagen 2017

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Introduction

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The North Water Polynya (NOW) is a unique ecosystem, which provides important ecosystem services for communities of the NOW, and forms the basis for globally important High Arctic biodiversity. However, as is evident for residents as well as for scientists, the system is currently changing rapidly due to both climatic and societal changes. To cope with these changes up-to-date information on the state, dynamics and trajectories of the North Water Polynya ecosystem is urgently needed, and therefore scientists from different natural science disciplines met in Copenhagen in November 2017 to present new research results and discuss the potential future of the polynya as well as possible ways forward in research. At the conference, scientific results were presented to researchers and stakeholders. However, the conference also provided an opportunity for local voices to be heard, as well as for discussions on how local residents can be better involved in defining research questions, and benefit more from research activities and results in the future. The idea of the conference was to provide an up-to-date status on the dynamics of the polynya ecosystem from the natural science community to various stakeholders and the wider public. It is our hope that this conference report will be of value also for further discussions of socio-economic political and management issues.

The scientific exploration of the North Water Polynya ecosystem has had some major stepping-stones, beginning with Dunbar (1969) and Stirling (1980), and the understanding of the ecosystem took a major leap forward with the International North Water Polynya Study (Demming et al. 2002). This study was undertaken as a combined icebreaker/ice-camp endeavor over a 3-year period from 1997 to 1999. In 1998, a continuous 5-month research effort encompassed spring and summer, and in 1999, the fieldwork captured the late-summer situation and the formation of the polynya in fall. The many interdisciplinary oceanographic and ecological studies carried out between 1997 and 1999 spurred a huge number of publications, including a special issue of *Deep Water Research II* (vol. 49, 2002). Following the International North Water Polynya Study, in depth research on other polynyas has enabled a rewarding comparative approach, which amongst other things has highlighted the uniqueness and global importance of the North Water Polynya (Smith and Barber 2007). More recently, Heide-Jørgensen et al. (2016) has surveyed key marine mammal species wintering in the North Water Polynya, and the NOW project (2014-18) studied the dynamic interactions between living resources and human societies in a long-term perspective in the Greenland part of the polynya, employing an interdisciplinary research approach involving archaeologists, biologists, paleo-ecologist, and anthropologists. The results of that project were published in a special issue of *Ambio* (Vol. 47, Supplement 2, 2018).

In this conference report we present extended abstracts of the presentations, and a summary of the panel debate (p. 144) and the research planning workshop (p. 147). All presentations were recorded on video and can be viewed at this URL: https://vimeopro.com/vcube/north-water-polynya-conference-copenhagen/page/1.

For an introductory overview of the physical, biological and chemical processes of the polynya, we refer to the keynote talk by Barber et al. (p. 28). Dumont (p. 38) and Rasmussen et al. (p. 47) shed light on the dynamics of the ice bridge, which is responsible for the polynya formation, and how variability in the ice bridge affects the ecosystem. Fortier et al. (p. 58) focus on the gap in our understanding of the North Water ecosystem during winter, and by means of isotope analysis, Causey et al. (p. 65) and Eulaers et al. (p. 60) demonstrate how food webs are currently undergoing rapid changes. The dynamics of the ecosystem are also addressed by Appelt et al. (p. 50), who employ a long-term perspective using historical and archaeological records as proxies for ecosystem change.

An overview of the important populations of marine mammals and seabirds is given in a keynote talk by Heide-Jørgensen (p. 88), and more detailed information on particular marine mammals, seabirds, raptors and fish is presented by Hansen et al. (p. 91), Garde et al. (p. 93), Mosbech et al. (p. 96), Møller et al. (p. 72), Burnham et al. (p. 101), and Boje (p. 104). Johansen et al. (p. 106) highlight important hunting areas of local communities in the region based on GPS-mapping conducted by occupational hunters, and Egede et al. (p. 111) presents a web-based interactive atlas of local knowledge on the North Water ecosystem, collected by the Pikialasorsuaq Commission.

In a keynote talk, Boertmann et al. (p. 116) give an overview of the various human stressors of the ecosystem, presently and in the future. Contaminants are the focus of Dietz et al. (p. 119), who demonstrate how the traditional lifestyle and diet in the North Water region are challenged by long-range mercury pollution from the industrialized world, and Burnham et al. (p. 134) further report on mercury contamination across 24 bird species. The nearby offshore oil licenses in the Greenland part of northern Baffin Bay have recently been given up, but local industrial activities may potentially still cause marine oil spills and disturbance of marine mammals by underwater noise from marine traffic and seismic surveys. Kyhn et al. (p. 126) presents the rationale behind, and recent experience with, the current Greenland precautionary regulation of seismic surveys, and by modelling oil spill trajectories, Frost (p. 122) illustrates how far ranging the impact of a marine oil spill can be. Spatial Tools for conservation planning in the Eastern Canadian Arctic were presented by Keenan (p. 139) from WWF-Canada.

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Key Questions and Key Messages – from the North Water Polynya Conference

We have extracted a number of key questions and tried to structure the key messages so we as far as possible include answers to the questions raised during the panel debate with locals and stakeholder representatives, to provide a quick summary of the conference:

1 *How stable is the polynya? What is going to happen with the oceanography and sea ice conditions in the near future?*

The presence of the polynya depends mainly on the annual formation of an ice arch/bridge in Nares Strait, which blocks the inflow of drifting sea ice from the Polar Basin. In recent decades, we have observed that the ice arc in Nares Strait is becoming more unstable and variable, and so are the fast ice edges bordering the polynya. This means that the sea surface is covered with drift ice for a greater part of the year. With global warming and increased climate variability, this trend is expected to continue. Of importance for the sea ice conditions in the polynya are also the persistence of strong northerly winds during winter, sweeping the sea surface south of the ice arc free from the new ice that continuously forms, as well as it provides input of relatively warm water from the south by a branch of the West Greenland Current. How these factors will be affected by climate change is however unclear.

2 *Will the changes in sea ice conditions and oceanography affect the primary productivity (algae growth) and food web of the polynya?*

The North Water Polynya is characterized by high primary productivity over a long growing season. The primary production depends on light, nutrients and stability (stratification) of the surface waters. When the ice arch persist during spring, there is little drift ice resulting in plenty of light, upwelling of nutrients from deeper waters and enough stability in the upper water column to keep the algae suspended within the photic zone, where they can grow. This creates the foundation for a long productive spring and summer season. When the ice arch is not formed, or only persist for a short period, the annual primary production in the polynya area is lower. However, this is not fully resolved, and there may be a geographical shift in this situation so that a larger part of the primary production occurs further to the south in Northern Baffin Bay.

The large high arctic copepods are key species in the food chain of the North Water Polynya. They graze on the algae and there is a strong coupling between the grazer's productivity and the available algae biomass. So, when there is a change in algae production, we must also expect changes further up in the food chain. How these changes will play out is not resolved yet, and it is complicated because new species due to climate change are moving in from the south. For example, capelin may in the near future become an important predator of the high arctic copepods in the North Water Polynya, and compete with Arctic cod and little auk for the invertebrate food in the water column. Furthermore, the large high arctic copepods, rich in lipids, may be replaced by smaller copepod species, less rich in lipids, as a response to warming and predation. Such a change towards smaller and less energetically rich prey items will be a challenge for a species like the little auk, which catches the copepods one by one.

3 *How will the important populations of harvested marine mammals and seabirds change in the near future?*

The populations of marine mammals and seabirds in the North Water Polynya have been the foundation of human communities in the area for millennia. The harvested populations are mostly considered in good condition and the harvest is generally regulated within sustainable levels. Harvest of polar bear (*Ursus maritimus*), narwhal (*Monodon monoceros*), beluga (*Delphinapterus leucas*)and walrus (*Odobenus rosmarus*) is regulated by quota. Beluga and walrus are considered to have potential for increasing in abundance as the populations have been reduced to low levels. Ringed seals (*Phoca hispida*) and little auks are considered ubiquitous and the harvest is unregulated. Most other species have a hunting season limiting the harvest.

When there are large changes in the distribution and abundance of the prey species in the bottom of the food chain, marine mammal and seabird distribution and abundance will change over time as well. However, marine mammals and seabirds also depend on certain habitat to be able to forage, for example sea ice to hunt from (polar bear) or rest on (walrus), and their distribution and abundance are also affected by disturbance from e.g. hunting and boat traffic. Therefore, population development is not straight forward, and it is recommended to monitor populations of key species and secure sustainable use by assessing the impact of e.g. disturbance and hunting within an ecosystem-based approach to adaptive management.

4 How will the cumulative impact of industrialization affect the area in the future?

Currently, there is an impact from long-transported pollutants, while the impact from ship traffic is limited and no mineral extraction takes place. However, there are a number of mineral exploration projects, including the Dundas Ilmenite titanium project (high-grade sand), which is about to develop into extraction and hence may increase shipping and disturbance. All offshore oil licenses have been given up in the Greenland part of the northern Baffin Bay and new licensees are not expected in the near future. Canada has no oil licenses in the area, but is preparing a Strategic Environmental Impact Assessment for oil activities in Baffin Bay.

Long-transported mercury is the single most important pollutant in the area. The mercury contamination in especially narwhal meat is alarming, and can cause an intake high above recommended levels for humans. The long-transported mercury comes from burning of coal, artisanal and small scale gold mining and the use of mercury in the industrialized part of the world, which pollutes the air. Global atmospheric processes transport the polluted air to the Arctic, where mercury is deposited and assimilated in the food chain. The international Minamata Convention tries to curb the pollution, but the increasing trend in mercury concentration has not yet been reversed.

More shipping in relation to tourism and mining, and especially seismic surveys, may increase underwater noise and lead to significant impacts on the distribution of marine mammals. Potentially, animals may be scared away from important habitats and hunting areas, where they are harvested locally. Caution, including the use of monitoring and adaptive management, is advised.

5 *How can science and research help informing planning and management decisions?*

Science and research can increase the understanding of the ecological dynamics of the North Water Polynya ecosystem, and help build a monitoring program to inform on adaptation options to future changes. While this conference focused on presenting the available scientific knowledge there is a need to grasp the entire socio-ecological system in an interdisciplinary and collaborative research effort, and build an integrated monitoring program to inform an ecosystem based management approach.

6 *How can locals be better involved, benefit and have influence on the research?*

From the local residents there is a strong appeal for more information about upcoming scientific studies, more coordination of scientific activities, more involvement of locals in the work, and consistent dissemination of the results of the studies locally. Among the scientists at the conference, there was great interest in dialogue with locals and involving locals in their research. As an answer to the wishes of the locals, a proposal for a joint science hub in Qaanaaq was welcomed. This could serve as a fix point for the collaboration between scientists and locals and as a logistical coordination center for research activities in the area. Aside from the many practical benefits to both parties, such an initiative could serve to strengthen the dialogue between locals and scientists, educate the young, engage locals in science, and promote a greater sense of local ownership of the many scientific studies taking place in area. Such a center could also prove vital for a community based monitoring program of the North Water Polynya socio-ecological system.

Introduktion

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Nordvandet er et unikt polynie, som bidrager med vigtige ressourcer til den befolkning, der lever af og omkring Nordvandet. Nordvandet er også fundamentet for en højarktisk biodiversitet af global betydning. Det er imidlertid tydeligt for såvel lokalbefolkningen og videnskabsfolk, at Nordvandsområdet i dag undergår hastige forandringer, klima- og samfundsmæssigt. For at imødegå og tilpasse sig disse ændringer er der behov for ny viden af højeste kvalitet om tilstanden, dynamikkerne og udsigterne for økosystemet i Nordvandet. Derfor mødtes videnskabsfolk fra forskelige naturvidenskabelige discipliner i København i november 2017 for at præsentere og diskutere den nyeste forskning om Nordvandet. Formålet var også at diskutere fremtiden for Nordvandet og finde ud af, hvilke nye forskningstiltag der er påkrævede. På konferencen blev videnskabelige indlæg præsenteret for både fagfæller og interessenter, som eksempelvis danske og grønlandske myndigheder og en lokal fangerforening. Konferencen gav også mulighed for, at lokalbefolkningen fra Nordvandet kunne komme til orde. Det blev diskuteret, hvordan Nordvandets befolkning nemmere kan få indflydelse på at definere relevante forskningsspørgsmål og drage nytte af de forskningsaktiviteter, der kommer til at foregå i fremtiden. Formålet med konferencen var at levere en opdateret status på dynamikkerne i polyniets økosystem direkte fra de naturvidenskabsfolk, der arbejder i området, til de grupper, der har interesse i området, såvel som den almindelige offentlighed. Det er vores håb, at denne konferencerapport vil være et værdifult bidrag til fremtidige socioøkonomiske og forvaltningsmæssige diskussioner.

Den videnskabelige udforskning af Nordvandets økosystem bygger på en række store landvindinger begyndende med Dunbar (1969) og Stirling (1980), og forståelsen af økosystemet rykkede et stort skridt fremad under det Internationale Nordvandspolynie-studie (Demming et al. 2002). Dette studie blev udført fra en isbryder og teltlejre på isen over en treårig periode fra 1997-99. I 1998 blev der gennemført fem måneders kontinuerlige forskningsaktiviteter fra foråret henover sommeren, og i 1999 blev den sene sommer-situation og dannelsen af selve polyniet om efteråret beskrevet. De mange interdisciplinære oceanografiske og økologiske studier, der blev udført mellem 1997 og 1999, resulterede i et stort antal videnskabelige publikationer, inklusiv en specialudgave af *Deep Water Research II* (vol. 49, 2002). Efter det Internationale Nordvandspolynie-studie er der gennemført omfattende undersøgelser af en række andre polynier. Det har givet mulighed for frugtbare sammenligninger, der yderligere har understreget den globale betydning af Nordvandspolyniet (Smith and Barber 2007). Senere har Heide-Jørgensen et al. (2006) på baggrund af flytællinger estimeret bestandsstørrelsen for en række af de vigtigste havpattedyrarter, der overvintrer i Nordvandet. I det interdisciplinære NOW-projekt (2014-18), som var et samarbejde mellem arkæologer, biologer, palæoøkologer og antropologer, blev de dynamiske interaktioner mellem levende ressourcer og mennesker i den grønlandske del af Nordvandspolyniet studeret i et langtidsperspektiv. Resultaterne af NOW-projektet blev publiceret i en specialudgave af tidsskriftet *Ambio* (Vol. 47, Supplement 2, 2018).

I denne konferencerapport præsenterer vi udvidede resuméer af konferencens videnskabelige præsentationer, af paneldebatten mellem alle interessenterne (s. 144), og af den videnskabelige planlægnings-workshop (s. 147), der fandt sted den sidste dag. Alle præsentationer blev filmet og kan ses her: https://vimeopro.com/vcube/north-water-polynya-conference-copenhagen/page/1.

For et overblik over Nordvandets fysiske, biologiske og kemiske processer henviser vi til Barber et al. (s. 28). Dumont (s. 38) og Rasmussen et al. (s. 47) kaster lys over dynamikken af den isbro, der er ansvarlig for dannelsen af polyniet, og hvordan variation i isbroen påvirker polyniets økosystem. Fortier et al. (s. 58) fokuserer på vores manglende viden om Nordvandets økosystem om vinteren, mens Causey et al. (s. 65) og Eulers et al. (s. 60) viser, hvordan fødenettene i Nordvandet er under hastige forandringer. Appelt et al. (s. 50) adresserer økosystemets dynamik i et lagtidsperspektiv ved hjælp af historiske og arkæologiske proxyer for forandringer i økosystemet.

Heide-Jørgensen et al. (s. 88) giver i sin keynote-præsentation et overblik over de vigtigste bestande af havpattedyr og havfugle. Hansen et al. (s. 91), Garde et al. (s. 93), Mosbech et al. (s. 96), Møller et al. (s. 72), Burnham et al. (s. 101) og Boje (s. 104) giver mere detaljeret information om specifikke havpattedyr-, havfugle- og fiskearter. Johansen et al. (s. 106) identificerer de vigtigste fangstområder for Nordvandsbefolkningen, baseret på en GPS-kortlægning udført af fangere i området. Egede et al. (s. 111) præsenterer et web-baseret interaktivt atlas over lokalviden fra Nordvandet indsamlet under Nordvandskommissionen.

I sin keynote-præsentation giver Boertmann et al. (s. 116) et overblik over de forskellige menneskelige aktiviteter, der kan påvirke Nordvandets økosystem negativt, nu og i fremtiden. Dietz et al. (s. 119) fokuserer på miljøfremmede stoffers betydning i økosystemet, og viser hvordan den traditionelle kost og levevis ved Nordvandet er udfordret af forurening med langtransporteret kviksølv fra den industrialiserede verden. Burnham et al. (s. 134) rapporterer ligeledes om kviksølvforurening i 24 fuglearter. Olielicenserne i den nærliggende grønlandske del af Baffinbugten er for nyligt blevet opgivet og tilbageleveret, men industrielle aktiviteter kan potentielt stadig forårsage oliespild og forstyrrelse af havpattedyr på grund af undervandsstøj fra skibstrafik og seismiske undersøgelser. Kyhn et al. (s. 126) præsenterer rationalet bag den gældende regulering af seismiske undersøgelser i Grønland og giver eksempler på erfaringer med store seismiske undersøgelser i Baffinbugten. Frost fra WWF Danmark (s. 122) illustrerer hvor langtrækkende effekterne af et oliespild kan være, og Keenan fra WWF-Canada (s. 139) præsenterer rumlige værktøjer til brug for naturbevarelse i arktisk Canada.

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Centrale spørgsmål og svar fra Nordvandskonferencen

Under paneldebatten mellem videnskabsfolk, lokale, interessenter og forvaltere blev der stillet en række centrale spørgsmål. Som resumé af paneldebatten har vi nedenfor gengivet disse spørgsmål og så vidt muligt forsøgt at svare kort på dem ud fra den ud fra den viden, der blev præsenteret under konferencen.

1 *Hvor stabilt er polyniet? Hvad sker der med oceanografien og havisen i den nærmeste fremtid?*

Tilstedeværelsen af Nordvandspolyniet beror hovedsageligt på dannelsen af isbroen i Nares Strædet, som blokerer for indstrømningen af drivis fra Ishavet og holder polyniet åbent. Gennem de seneste årtier har vi observeret, at isbroen er blevet mere ustabil og varierende, hvilket også gælder de øvrige fastiskanter, som afgrænser Nordvandet. Isbroens manglende stabilitet betyder, at havoverfladen nu oftere er dækket med drivis end det tidligere var tilfældet. Med global opvarmning og stigende klimasvingninger forventes det, at denne udvikling fortsætter. For at holde polyniet åbent, er det også afgørende, at der er stærke vedvarende nordlige vinde om vinteren, der kan blæse havoverfladen syd for isbroen fri for den nyis, der hele tiden dannes pga. de lave temperaturer. Dette medvirker også til, at der strømmer relativt varmere vand mod overfladen fra en gren af den nordgående Vestgrønlandske Strøm. Hvordan disse faktorer vil blive påvirket af klimaforandringer er dog uklart.

2 *Vil forandringerne i havisen og oceanografien påvirke primærproduktionen og fødenettet i Nordvandet?*

Nordvandet er karakteriseret ved en høj primærproduktion over en lang vækstsæson. Primærproduktionen afhænger af lys, næringsstoffer og stabilitet i lagdelingen af overfladevandlagene. Når isbroen holder foråret igennem er der begrænset med drivis, hvilket betyder at lyset bedre kan trænge ned i vandet, samtidig med at der kan trænge næringsstoffer op fra de dybere vandlag. Hvis lagdelingen i vandet er stabil, kan planteplanktonnet (alger) holde sig oppe i lyszonen, hvor det kan vokse og formere sig. Dette skaber grundlaget for en lang og produktiv forårs- og sommersæson. Når isbroen ikke etableres, eller kun eksisterer i en kort periode, er den årlige primærproduktion i Nordvandet lavere. Dette forhold er dog ikke fuldt forstået, og der kan være nogle geografiske forskydninger, således at en større del af primærproduktionen foregår længere mod syd i den nordlige del af Baffinbugten.

De store højarktiske vandlopper er nøglearter i fødekæderne i Nordvandet. De græsser på alger (planteplankton), og der er en stærk kobling mellem vandloppernes mængde og den tilgængelige algebiomasse. Når der sker et skifte i algeproduktionen, må vi derfor også forvente forandringer højere oppe i fødekæderne. Hvordan disse forandringer vil udspille sig er endnu ikke afklaret, og forholdene kompliceres yderligere af nye arter, der kommer til sydfra på grund af klimaforandringerne. Lodden (*Mallotus villosus*) kan eksempelvis i den nærmeste fremtid blive et vigtigt rovdyr for de højarktiske vandlopper i Nordvandet, og dermed udgøre en konkurrent for polartorsk (*Boreagadus saida*) og søkonger (*Alle alle*). En anden konsekvens af de stigende temperaturer kan være, at de store højarktiske vandlopper, der er rige på fedtstof, fortrænges af vandloppearter sydfra, som er mindre og samtidig indeholder mindre fedt. En sådan forandring mod vandlopper med lavere næringsværdi vil være en udfordring for en art som søkongen, der fanger vandlopper én ad gangen.

3 *Hvordan vil de vigtige bestande af fangstdyr (havpattedyr og havfugle) forandre sig i den nærmeste fremtid?*

Bestandene af havpattedyr og havfugle i Nordvandet har været fundamentet for områdets mennesker i årtusinder. Udnyttelsen er for de flestes arters vedkommende bæredygtig, fordi fangsten er reguleret og holdt på bæredygtige niveauer. Fangst af isbjørn (*Ursus maritimus*), narhval (*Monodon monoceros*), hvidhval (*Delphinapterus leucas*) og hvalros (*Odobenus rosmarus*) er reguleret gennem kvoter. Det anses for muligt, at hvidhval og hvalros vil stige i antal, fordi bestandene tidligere har været reduceret meget kraftigt pga. fangst. Ringsæl (*Phoca hispida*) og søkonge anses som så talrige at fangsten ikke er reguleret. For de fleste andre arters vedkommende er fangsten reguleret gennem fastsættelse af en jagtsæson.

Når der sker store ændringer i fordelingen og antallet af et byttedyr lavt i fødekæden, vil fordelingen af havpattedyr og havfugle højt i fødekæden også ændre sig over tid. Havpattedyr og havfugle har også brug for bestemte habitater for at være i stand til at søge føde. Det kan for eksempel være havis til at jage fra (isbjørn) eller hvile på (hvalros), og fordelingen og antallet af havpattedyr og havfugle vil også blive påvirket af forstyrrelser fra jagt og skibstrafik. Samlet set er det svært at forudsige bestandsudviklingen for havpattedyr- og fugle, og det anbefales derfor at overvåge nøglearter gennem optællinger med jævne mellemrum for at sikre en bæredygtig udvikling. Forvaltningen bør være adaptiv og økosystembaseret, og løbende tilpasses de markante forandringer som Nordvandet i disse år undergår.

4 Hvordan vil de kumulative effekter af industrialisering påvirke Nordvandet i den nære fremtid?

Langtransporterede miljøfremmede stoffer påvirker allerede økosystemet i Nordvandet, mens effekten af skibstrafik er begrænset. Indtil videre er der ingen miner med aktiv udvinding af råstoffer. Der er dog et begrænset antal mineralprojekter, inklusiv Dundas Ilmenit titanium-projektet ('tungsand'), som er ved at udvikles til produktionsfasen. Det forventes derfor, at skibstrafikken vil øges med mulige forstyrrelseseffekter til følge. Alle offshore olielicenser i den grønlandske del af Baffinbugten er blevet opgivet, og nye licenser forventes ikke udstedt i den nære fremtid. Canada har ingen olielicenser i området, men er dog ved at forberede en strategisk miljøvurdering for olieaktiviteter i Baffinbugten.

Langtransporteret kviksølv er langt den vigtigste forureningskilde i området. Kviksølvforureningen særligt i narhvaler er alarmerende høj og det kan være årsag at mennesker indtager mere end den anbefalede grænseværdi. Den langtransporterede kviksølv stammer fra afbrænding af kul, primitive/små guldminer, samt fra brug af kviksølv i den industrialiserede del af verden. Globale atmosfæriske processer transporter den forurenede luft til Arktis, hvor kviksølv afsættes og optages i fødekæderne. Den internationale Minamata Konvention forsøger at bremse forureningen, men den stigende trend i kviksølvkoncentrationen er endnu ikke vendt.

Forøget sejlads i forbindelse med turisme og minedrift, og særligt seismiske surveys, vil forøge undervandsstøjen og kan føre til markante ændringer i fordelingen af havpattedyr. Potentielt kan dyrene skræmmes væk fra vigtige habitater og fangstområder, hvor dyrene udnyttes lokalt. I denne sammenhæng bør der udvises forsigtighed, og der tilrådes regelmæssig overvågning af bestandene samt adaptiv forvaltning.

5 *Hvordan kan videnskab og forskning hjælpe i forhold til planlægnings- og forvaltnings-beslutninger?*

Forskning fører til en øget forståelse af de økologiske dynamikker i Nordvandet, og kan bidrage til at opbygge et overvågningsprogram, der kan informere om tilpasningsmuligheder i forhold til fremtidige ændringer. Nordvandskonferencen fokuserede på at præsentere den nyeste naturvidenskabelige forskning, men der er et behov for at forstå hele det socio-økologiske system gennem en interdisciplinær tvær-videnskabelig indsats, og for at opbygge et integreret overvågnings-program, der kan informere en forvaltningsproces, der ser på hele det socio-økologiske system.

6 *Hvordan kan de, der lever ved Nordvandet, blive involveret i, drage fordel af og få indflydelse på den forskning, der foregår i området?*

Fra de, der bor ved Nordvandet, blev der udtrykt et stærkt ønske om lokal forankring af de mange videnskabelige projekter, der gennem-føres i området: Fra mere information om kommende videnskabelige projekter, over bedre koordinering af projekterne, til bedre inddragelse af lokale i det videnskabelige arbejde, og ikke mindst for konsekvent lokal formidling af resultaterne efterfølgende. Mellem de videnskabe-lige deltagere på konferencen var der stor forståelse og respekt herfor, og man vil gerne i dialog med lokale og inddrage dem i forskningen. Som et svar på ønskerne fra de lokale blev det foreslået at lave en "forskningshub" i Qaanaaq. En sådan hub kunne være udgangspunkt for samarbejde mellem lokale og tilrejsende videnskabsfolk, samt tjene som logistisk koordineringscenter for forskning i området. Bortset fra de mange praktiske fordele for begge parter kunne et sådant initiativ også forstærke dialogen mellem lokale og forskere, uddanne unge, engagere lokale i forskningen, og bidrage til en stærkere følelse af lokalt ejerskab over de mange videnskabelig projekter, der udføres i området. Hub'en kunne også vise sig afgørende for et lokalt forankret overvågningspro-gram af Nordvandets socio-økologiske system.

Aallaqqaasiut

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Pikialasorsuaq immikkooruteqarluinnartumik ukiuugaluartumiluunniit ammalatarsuuvoq inoqarfinnut qanitaminut pisuussutinik uumassusilinnik qitiulluinnartumik pilersuisuusoq. Taamaqataanik Pikialasorsuaq, nunarsuup issittoqarfii tamakkivillugit isiginiarlugit, issittumi uumassusillit ataqatigiiffiinut tunngaviulluinnartumik pingaaruteqartupilussuulluni uummaviuvoq. Maanna Pikialasorsuup qanittuini najugaqartunit ilisimatusartartunillu erseqqilluinnartumik paasineqarpoq Pikialarsorsuaq silap pissusiata inuiaqatigiinniillu iliuuserineqartartut allanngoriartornerinit peqquteqartumik – sukkasuupilussuarmik – allanngoriartorfiusoq. Allannguutaareersut allannguutaasinnaasussallu kingunissarisinnaasaat atoruminarsarniarlugillusooq iliuuseqartariaqarnissanut ilisimasanik nutaanerpaanik pitsaanerpaanillu tunngaveqarnissat qulakkeerniarlugit Pikialasorsuarmi uumassuseqassutsit ataqatigiiffiini pissutsit qanoq innerannik, uumassusillit allannguutinut malinnaasinnaassusiannik tunngassuteqartunik, kiisalu Pikialasorsuarmi uumassusillit ataqatigiiffiisa qanoq allannguuteqarsinnaanerinik naatsorsuutinik suliaqarnissanut paasissutissanik ilisimasariaqakkanik nutaarluinnarnik pitsaasunillu pisariaqartitsisoqarpoq. Tamannarpiaq peqqutaalluni ilisimatusariaatsinit assigiinngitsunik sammiveqartuninngaanniit Pikialasorsuaq pillugu ilisimatusaatigineqarsimasunit paasisat nutaanerpaat saqqummiussorniarlugit ilisimatusartartut november 2017 ataatsimeersuarnermi saqqumiisinneqarlutillu oqallitsinneqarput. Tamatumani siunertarineqarluni Pikialasorsuup siunissaata oqallisigineqarnissaa aammalu ilisimatusaatigisariaqakkat pisariaqartut nutaat suunerinik erseqqissaateqarnissaq. Ataatsimeersuarnermi ilisimatusartartut sammisaqaqatiminnut soqutigisaqartunullu attuumassuseqartunut allanut suliaminnik saqqummiussuipput, soorlu assersuutigalugu nunatsinni Danmarkimilu Avatangiisinut Aqutsiveqarfimmeersunut aammalu Kalaallit Nunaanni piniartut peqatigiiffianneersunut. Aamma Pikialasorsuup eqqaani najugaqartut ataatsimeersuarnermi peqataatinneqarput oqariartuuteqarsinnaanissaminnullu periarfissinneqarlutik. Pikialasorsuup eqqaani najugaqartut ukiuni aggersuni ammalatarsuarmi ilisimatusaatigineqarsinnaasunik siunnersuuteqarsinnaanerat qanorlu akuutinneqarsinnaanerat iluaqusersorneqarsinnaanerallu aamma eqqartuiffigineqartunut ilaapput.

Ataatsimeersuarnerup siunertarivaa Pikialasorsuarmi uummassusillit ataqatigiiffiisa allanngoriartornermut qanoq malinnaalluartigineranik ilisimatusartartunit tamakkuninnga sulialinnit toqqaannartumik innuttaaqataasunut soqutigisalinnut tamaginnut ilisimalersimasat suunerinik saqqummiussuinissaq. Neriuutigaarput ataatsimeersuarnermit nalunaarusiatsinnit siunissami inuiaqatigiit aningaasaqarnerannut, naalakkersuinikkut aammalu aqutsinernut tunngassuteqartunik nalilersuisarnissaanni atorluarneqarsinnaasunik immersueqataasinnaassalluta.

Pikialasorsuup uumassuseqassutsip ataqatigiiffiinut pingaaruteqarneranik uppernarsaatit ilisimatuussutsikkut misissuinernik tunngaveqartut soqutiginaateqarnerusimasullu aallartiffeqarput Dunbarimik (1969) aamma Stirlingimit (1980), tamatumalu kingorna uumassuseqassutsit ataqatigiiffiisa pingaaruteqarluinnartuunerinik paasisaqarnerusoqarpoq nunat tamalaat Nordvandspolyniestudie-mik taallugu suliaqarneranni (Demming et al. 2002).

Misissuinerit taakkua umiarsuaq sikunik aserorterussuaq atorlugu aammalu immap sikuani tammaarsimaffeqarluni ukiuni pingasuni 1997-imiit 1999 ilanngullugu ingerlanneqarput. Allaat immap sikuani tamaarsimaffeqarluni qaammatini tallimani atasuinnarmik 1998-imi upernarneraniit aasaq ilanngullugu ammalatarsuaq malinnaavigineqarpoq. Misissuinerit ukiup tulliani 1999-imi ingerlateqqinneqarput, tamatumuuna aasamiit ukiaq ilanngullugu misissuisoqarluni, taamaalilluni ukiariartulernerani ammalatap pileriartornera allaaserineqarluni. Ukiut pineqartut ingerlaneranni ilisimatusariaatsit akimorlugit suleqatigiissuteqartoqarluni misissuisarnerit ingerlanneqarneranniit inernerit ilisimatusaatigalugu allaaserisarpassuarnik kinguneqarlutik saqqummiunneqarsimalerput. Misissuinerit taavani ammalatap imartaata allaaserineqarneranik aammalu taavani ammalatarsuarmi uumassuseqassutsit ataqatigiiffiinut tunngassuteqartunik allaaserinninnerupput. Allaaserisanut ilaavoq *Deep Water Research II* (vol. 49, 2002) immikkut Pikialasorsuarmik samminniffiusoq saqqummersinneqarsimammat. Pikialasorsuup misissuiffigineqarnerata kingorna nunarsuarmi allani ammalataqarfiit arlalissuit misissuiffigineqarsimapput, taakkununngalu sanilliussinikkut paasineqarluni Pikialasorsuup immikkooruteqarluni nunarsuarmiunut tamanut pingaaruteqarnera (Smith and Barber 2007). Pikialasorsuup imartaani ukiisartut imaani miluumasut pingaarnerit amerlassusiat paasiniarlugu Heide-Jørgensen et al. (2006) kisitsisimapput. NOW suliniummik taaneqartumi (2014 – 2018) Pikialasorsuup eqqaani najugaqartut aammalu ammalatarsuarmi uumasuusut akornanni ukiorpaalussuarni kingumut qiviarluni misissuinerni Pikialasorsuup inunnut pingaarutaa ilisimatusariaatsinit sammivinnit arlalinniit isiginnilluni, soorlu inuiaqatigiilerisunit, biologinit, uumassuseqassutsit ataqatigiiffii immikkut sammisaralugit itsarnisarsiuunit aammalu nalinginnaasumik itsarnisarsiuunit suliniuteqarnikkut qulaajaaviginegarsimalerpoq. Taakkunannga NOW suliniutikkut misissuinernit inernerusut ilisimatuusutsikkut allaaserinnittarfimmi *Ambiomi* immikkut naqitami (Vol. 47, Supplement 2, 2018) saqqummersinneqarsimapput.

Uani ataatsimeersuarnermit nalunaarusiami ataatsimeersuarnerup ingerlanerani ilisimatuussutsikkut tunngaveqartumik saqqummiussat itisilikkamik eqikkaavigineqarnerat saqqummiunneqarput, ilanngullugit aamma saqqummiinerit aallaavigalugit soqutigisaqartut oqallitsinneqarnerannit (s. 144) kiisalu naggataagut ilisimatuussutsikkut suliarineqartussat pilersaarusiorniarlugit ilisimatusartartut ullormi kingullermi ataatsimiitinneqarneranni oqaatigineqartut ilanngullugit (s. 147) saqqummiunneqarput. Saqqummiinerit tamavimmik immiunneqarlutik takusassiarineqarput, uanilu takuneqarsinnaallutik: https://vimeopro.com/vcube/north-water-polynya-conference-copenhagen/page/1.

Pikialasorsuup imartaata sannaa, akui uumasoqassusialu tamakkulu tamarmik qanoq sunniivigeqatigiittarnerinut tunngasut pillugit paasisaqarusuttunut innersuussutigerusupparput Barberip suleqataasalu allaaserisaat (s. 28). Dumonti (s. 38) Rasmussen et al.-ikkullu (s. 47) sikukkut "ikaartarfissuup" pingaarnertut Pikialasorsuarmik pinngortitseqataasarneranut tunngassuteqartunik, tamatumalu Pikialasorsuarmik ukiut tamaasa ammalatanngortitseqataasarneranik allaaserinnipput. Fortier et al.-ikkut (s. 58) immikkut isiginiarpaat Pikialasorsuup ukiuunerani uummassusillit ataqatigiiffiinut pingaaruteqarnerujussuata misissuiffigineqarnissaa allaaserineqarnissaatalu amigaataanera, uffa Causey et al. (s. 65) Eulaers et al.-kkullu (s. 60) paasissutissiissutigerusukkaat uumasut nerisareqatigiittarnerisa immikkuualuttortai sukkasuumik allanngoriartulersimasut. Appelt et al.-kkullu (s. 50) malugeqquaat uumassusillit ataqatigiiffiisa ukiorparpassuit ingerlanerini nikerarsinnaasarnerat, tassa itsarnisarsiuut allattugaataat naapertorlugit assaasarneritigullu allannguutaasartut paasineqarsimasut uppernarsaatitullusooq atornerisigut.

Heide-Jørgensen et al. (s. 88) ataatsimeersuarnerup siunniussarisassaanik ersersitsisussamik saqqummiinermi imaani timmissat miluumasullu pingaaruteqarnerusut kisitsisinngorlugit amerlassusiannik takussutissiornissaq sammivaat. Hansen et al. (s. 91), Garde et al. (s. 93), Mosbech et al. (s. 96), Møller et al. (s. 72), Burnham et al. (s. 101) kiisalu Boje (s. 104) miluumasut, timmissat, aalisakkallu aalajangersimasut pillugit sukumiisunik saqqummiussaqarput. Johansen et al. (s. 106) GPS atorlugu nalunaarsuinikkut Pikialasorsuarmi piniarfiusartunik piniartut namminneerlutik nalunaarsuisimanerinik saqqummiipput. Egede et al. (s. 111) Pikialasorsuaq pillugu ataatsimiititaliamit internetsikkut periarfissiissutit atorlugit suliarineqartumik sumiiffimmi najugaqartut ilisimasaannik qarasaasiaq atorlugu attaveqatigiissutigineqarsinnaasutut ilusilerlugu takutitassiaq saqqummiuppaat.

Ataatsimeersuarnerup siunniussarisassaanik ersersitsisussamik saqqummiinermi allami Boertmann et al.-kkut (s. 116) Pikialasorsuup inuit iliuusaannit pitsaanngitsumik maannakkut sunnerneqarsimalereerneranik siunissamilu sunnerneqarsinnaaneranut tunngassutillit sammivaat. Dietz et al.-kkut (s. 119) avatangiisinut mingutsiterutit uumassuseqassutsit ataqatigiiffiinut akulerunnermikkut ulorianaateqalertarnerat aammalu mingutsiterutit aatsitassat oqimaatsut arrortikkuminaatsullu, assersuutigalugu kviksølvit, nunanit suliffissuaqarnermik ingerlatsiveqarfinniit ungasikkaluartumiittunilluunniit avatangiisinut aniatittagasa nunarsuup issittortaanut apuuttarnerat, qanorlu ilillutik uumassusillit nerisareqatigiinnerannut akuleruttarnermikkut nunap inuisa nereriaasinnut ajornartorsiortitsisalernerinut tunngassutilinnik saqqummiipput. Burnham et al.-kkut (s. 134) nalunaarutigaat timmissani imarmiuni 24-ni aatsitassamik arrortikkumiinaatsumik kviksølvimik mingutsitsimanerit uppernarsillugit paasisimallugit.

Uuliasiornissamik akuersissutit, Pikialasorsuarmut qanittumi kujataatungaaniittumi Baffin Bugtimi ujarlernissanut, tunniunneqarsimasut taamaatiinnarneqarlutik oqartussanut utertinneqarnikuupput. Kisiannili sumiiffinni, Pikialasorsuarmut kalluaasinnaasuni, suliffissualiorsinnaanerit eqqarsaatigalugit uuliaarluertoqarsinnaanera aammalu pilersitnikkut imartami pineqartumi uumasunut akornusersuutaalersumik, soorlu umiarsuit angallannerulernerisigut imaluunniit nipi atorlugu immap naqqanik sajuppillatsitsisarluni uuliamik ujarlertoqaqqilissagaluarput, tamakkua Pikialasorsuup uumassuseqassutsimut pingaarutaanik innarliisinnaasutut aarlerilersitsisinnaapput. Kyhn et al.-kkut (s. 126) Kalaallit Nunaanni nipi atorlugu immap naqqanik sajuppillatsitsisarnerit pisortanit aqutsivigineqarnerini iliuusissatigut maleruagassat aalajangersarneqarnerini ilisimalersimasat tunuliaqutaasut pillugit saqqummiipput aammalu taamatut Baffin Bugtimi misissuerujussuartoqarneranit misilittagaalersunik saqqummiussillutik. Frost WWF Danmark-imi (s. 122) atorfeqartoq taamatut nipi atorlugu immap naqqanik misissuisarnerni immap iluani nipip sumorsuaq sunniisinnaaneranut tunngassutilinnik saqqummiivoq. Kiisalu Keenan Canadami WWF-imi (s. 139) atorfeqartoq nunagisamini qarasaasiaq atorlugu, matumani assersuutigalugu GPS paasissutissanik aammalu paasissutissanik qaammataasat atorlugit aaneqartartunik iluaquteqarluni, pinngortitamik allanngutsaaliuinermik suliaqarsinnaanernik assersuutinik saqqummiivoq.

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Pikialasorsuaq pillugu Ataatsimeersuarnermi Qitiusumik apeqqutigineqartut akissutaallu

Ilisimatusartartut, sumiiffimmi najugaqartut, soqutigisaqartut, aqutsisullu akornanni oqallitsitsinermi apeqqutit qitiusumik immikkoorutillit arlallit qaffakaatinneqarput. Taakkua ilisimasatik aallavigalugit akissutigisaat ilanngullugit, taamaalilluta ataatsimeeqatigiinnermit eqikkaanertut ersersikkusuppagut apeqqutigineqartut akissutigineqartullu saqqummiunnerisigut:

1 *Pikialasorsuup pissutsiminut iinnarnissaa naatsorsuutigisinnaavarput? Immap sikullu pissusaat siunissami qaninnermi qanormita piniarpat?*

Pikialasorsuup pisarnermisut innissaanut apeqqutaalluinnartoq tassaavoq Narres Strædemi immap sikusarnera aammalu siku ikaartarfittut taaneqartartup pinngortarnera. Ikersuarmi taanna aalaakkaasumik sikugaangat Qalasersuup imartaaneersut sikorsuit kujammut sarfaassaasarnerat unittarpoq, taamaalillunilu Pikialasorsuaq ammalatarsuanngortarpoq sikujuitsoq. Sikup ikaartarfittut taaneqartartup ukiuni qulikkaani kingullerni marlunni pisarnermisut ittuaannarani naatsorsuutissaajunnaariartulernera allanngoralersumillu sikusalersimanera maluginiarneqarsimavoq. Taamatullu aamma ippoq Pikialasorsuarmi ammalatarsuarmut siku killiliisoq, taanna aamma aalaakkaavallaarunnaarsimavoq pissusaalu allanngoralersimallunilu. Tassa ima oqarsinnaalersimavugut, imaq ukioq kaajallangajallugu aalaakkaasumik naatsorsuutissaasumillu sikuusarunnaariartorpoq, sikkorikkunnaariartorluni aalasumik sikoqaleriartorpoq. Silap pissusiata allanngoriartornera kiisalu silap sakkortusiartuinnartumik nikeriapiloortalernerata pissutsit taamaaleraluttuinnarnerannik kinguneqartut siunissami taamaaginnarnissaat naatsorsuutigineqarpoq.

Pikialasorsuarmut avatangiisaasup immap sikuata qanoq issusia Pikialasorsuup piuneranut aalajangiisuulluinnartuusarpoq. Sikkorilluaraangat Pikialasorsuaq pissusissamisoortumik piusarpoq, sikkorissappallu atasuinnarmik sakkortoorsuarmillu avannarsuartariaqartarnissaa pisariaqassaaq Pikialarsorsuup, pingaartumik kujasinnerusortamigut, sikuaraluartarneri anorersuarnit tinngunneqartuartarmata. Tamatuma peqatigisaanik imap kissarnerusup Kalaallit Nunaata kitaata imartaani avannamut sarfartup ilakitaa avannamut Pikialasorsuup tungaanut sarfartarpoq. Ilumut sarfap taassuma silap pissusiata allanngorneranit sunnerneqarnissaa ilisimaneqanngilaq.

2 Immap sikuata aammalu imarsuit pissusaasa allannguuteqariartulernerisa kingunerisaannik tappiorannartunik uumassutissioqqaarneq aammalu uumasut nerisareqatigiittarneranni immikkuualuttortat sunnerneqarsinnaappat?

Pikialasorsuup immikkoorutigaa uumassutissanik tappiorannartuliorfissuunini aammalu tamakku ukiup ataatsip iluani alliartorsinnaanissaminnut piffissamik sivisuumik periarfissagissaarnerat. Tappiorannartunik uumassutissioqqaarneq pissappat qaamaneq, uumassutissat mikinerpaartaat kiisalu immap qaatungimigut qaleriissarnerata naatsorsuutigineqarsinnaasumik pissuseqarnissaa pisariaqarpoq. Pikialasorsuup avannaatungani siku, ikaartarfimmik taagorneqartup, upernaaq ilanngullugu aalaakkaagaangat sikut ingerlaartut amerlagisassaaneq ajorput, taamaammallu qaamaneq immamut akulloqqussinnaasarluni. Peqatigisaanik uumassutissat mikinerpaartaannik immap itinerusortaaneersunik qaffaassineq pisinnaaleraangat aammalu immap qaavatungaani pissutsit aalaakkaariaraangata, uumassutissallu mikinerpaartaat immap itinerusortaaniit qaffaassat qaamaneqarfimmiiginnaleriaraangata, tappiorannartunik uumassutissioqqaarneq pisinnaalersarpoq. Pissutsit taamaariaraangata sivisuumik tappiorannartuliorluartoqarsinnaalersarpoq, tassa upernaaq aasarlu ilanngullugit pisarmat. Sikuli ikaartarfimmik taasaq aalaakkaasimanngippat imaluunniit sivikitsuinnarmik atasimappat Pikialasorsuarmi ukiumut tappiorannartuliorneq appasinnerujusumiittarpoq. Taamaavinnersorli uppernarsillugu suli paasineqarnikuunngilaq aammalu sumiiffigisaq apeqqutaalluni pissutsit allaasinnaasarmata, soorlu assersuutigalugu Pikialasorsuup kujasinnerusortaani tappiorannnartuliorneq avannaatungaani pisunut sanilliullugu annertunerusinnaavoq.

Pikialasorsuarmi issittup illerai (uumasuaqqat tappiorannartut) pingaarnertut uumasoqatigiiupput. Taakku quajaateeqqanik (uumassutissioqqaatinik) naasuaqqanillu tappiorannartunik nerisaqartuupput, taamaattumillu uumassutissioqqaatinik pilersitsiortortarneq aammalu taakkua illeqqanit nerisarineqartarnerisa atassuteqarnerat pilersitsiortornermi aalajangiisuulluinnartarpoq. Tassa naasuaqqanik tappiorannartunik pilersitsiortorneq appasippat, taava naatsorsuutigineqassaaq tamatuma uumasut nerisareqatigiiaarnerannut aamma kinguneqarnissaa. Tamatuma allannguuteqarsinnaanera qanoq sunniuteqassanersoq suli ilisimaneqanngilaq, paasiuminaatsortaqaqimmatami aammalu silap pissusiata allanngoriartornera malillugu uumassusileqatigiiaat avannamut illuariartuaarnerat malunnarmat. Assersuutigiinnarlugu Issittoqarfimmi piffissami aggersumi ammassaat (*Mallotus villosus*) illeqqanik nappateqalersinnaasut pingaarnerpaartarilersinnaavaat, taamaalillunilu eqaluaasanut (*Arctogadus glacialis*) appaliarsunnullu

(*Alle alle*), tamakkutortartunuttaaq allanut, unammillertinngorsinnaassallutik. Taamatut Issittup illerai ikinnerulerlutik uumasunit nerisaanerat unammissutigineqarnerulerpallusooq, illeqqanit allanit mikinerusunit inangeriartuaarneqalissapput. Issittup illerai (uumasuarai tappiorannartut) illeqqanut allanut sanilliullugit uumassutissartaqarnerungaarlutik orsoqarluartuupput, illeqqanillu allanit mikinerusunit inangerneqariartuaalissagaluarpata taakkua inangiisussat orsukinneralutillu uumassutissartakinneruppput. Illeqqat anginerusut mikinerusunit inangerneqariartuaalissagaluarpata tamanna uumasut ilaannut ajornakusoortitsilersinnaassaaq, tassami soorlu appaliarsuk Issitttup illeraanik ataasilakkaarilluni nerisarmat.

3 *Imaani miluumasut timmissallugu pingaruteqarnerit siunissami aggersumi qanittumi allannguuteqarfissanerpat qanorlu?*

Pikialasorsuarmiittartut imaani miluumasut timmissallu inuup taavani ikiuni tusinde-likkaani uumasinnaasimaneranut toqqammaviusimapput. Tamakkua iluaqutigineqarnerat piujuartitsiniarnermik tunngaveqarluni ingerlanneqarsimavoq, piniagaanerammi killilersugaappput kiisalu pisat amerlassuserisartagaat peqassuseq innarlinngikkaluarlugu piniagaasarsimammata. Nannut, qilalukkat qernertat qaqortallu aarrillu piniagaanerat pisassiissuteqartarnertigut killilersugaapput. Ilimagineqarpoq qilalukkat qernertat qaqortallu killilersuinerup kinguneranik amerliartulerumaartut, tassami siusinnerusukkut qilalugarparpassuaqartarnikuuvoq piniagaanermillu kingunerisaanik ikileriarujussuarnikuullutik. Natsiit (*Phoca hispida*) appaliarsuillu amerlangaarmata sumi tamaaniittutut isigineqarput, piniagaanerallu killeqarnani. Sinnerinullu tunngatillugu piniagaanerat piffissaligaasumik killeqartinneqarpoq aammalu pisassiissuteqartarnikkut killilersugaallutik.

Uumasut nerisareqatigiinneranni nerineqartartut alliunerusut agguataarsimanerat allannguuteqaraangat taava nerisuusartut qulliunerusuniittutut taaneqartartut, tassa imaani miluumasut timmissallu, agguataarsimanerisa aamma piffissap ingerlanerani allannguuteqarnissaat naatsorsuutigineqarsinnaassaaq. Kisiannili imaani miluumasut timmissallu uummavinnik aalajangersimasunik neriniarfigisinnaasaminnik pisariaqartitsisarput. Immap sikua uummavittut assersuutigigutsigu, nannut aarrillu tamaani uumasuupput siku qasuersaarfigisarlugu aammalu piniagaaffigisarlugu. Tassa taakku piniagaanerminnik akornusersuutinilluunniit allanit, soorlu umiarsuit angallannernit, tunngaveqartumik siaruarsimanerat kiisalu amerlassusii allannguuteqarsinnaapput. Tamakkiisumik isiginnilluni sumiiffinni aalajangersimasuni imaani miluumasut timmissallu siunissami amerlassutsimikkut qanoq nikerarsinnaanerat naatsorsoruminaappoq. Taamaattumik sumiiffinni peqarfiunerusuni pingaarnerusunilu peqassutsit assersuutigalugu akornusersuutinut aammalu piniagaasarnerat eqqarsaatigalugu piujuartinniarnissaat amerliartortinniarnissaallu aammalu uumassuseqassutsit ataqatigiiffiisa mianerineqarnissaasa qulakkeerunneqarnissaat anguniarlugit aalajangersimasumik akulikinnerusumillu kisinneqartarnissaat siunnersuutigineqarpoq. Taamaalilluni naleqqussartuartumik aqutseriuseqarnissaq anguniarneqarpoq.

4 Sunniutaasimasut ataatsimut kattullugit suliffissuaqarnermik ingerlataqarnerup kingunerisaanik malunnarsiartuinnartumik sunniutaasinnaasut siunissami qanittumi Pikialasorsuarmut qanoq sunniuteqarsinnaappat?

Mingutsiterutinit ungasissorsuarmiit tingussaallutik imaluunniit sarfagussallutik issittumut apuunnikunit Pikialasorsuaq aamma sunnersimaneqarpoq, umiarsuilli angallannerinit aammalu aatsitassarsiorniarnerit kingunerisinnaasaannit suli annikitsuinnarmik sunnigaasimalluni. Pikialasorsuulli eqqaamiorisaani aatsitassarsiorniarluni pilersaarutigineqartut arlalialunnguupput, soorlu assersuutigalugu Dundas Ilmenit titanium suliniut ('sioqqat oqimaatsut') maanna ima siuarsimaatigilersimavoq piiaasinnaanngornissartik tikilivissimallugu. Piiaasoqarnissaali aallartippat umiarsuarnik angallannerit amerleriaateqassapput, qularnanngitsumillu taavani uumassuseqassutsinut akornusersuutaalissallutik. Baffin Bugtip Kalaallit Nunaannut sammerngani uuliasiornissanut akuersissutit tamarmik sussaarneqarlutik pisortanut utertinneqarsimalereerput, siunissamilu qaninnermi nutaanik akuersissuteqartoqarnissaa naatsorsuutaanani. Taamaaqataanik imartami Canadap tungaanoortumut uuliasiornissanut akuersissuteqartoqarnikuunngilaq, kisiannili canadamiut siunissami aggersumi taavani uuliamik ujarlertoqarsinnaalernissaa ammaanniarlugu piareersaasiorput.

Taavani mingutsiterutinik arrortikkuminaatsunik nassaarineqartartuni kviksølvi nalinginnaanerpaavoq. Uumasuni kviksølvimik annertunerpaamik mingutsitaasimasut tassaapput qilalukkat qernertat, tassa uippaanganaannartorsuarmik timiminni killissarititaasut qaangerujussuarlugit qaffasittorujussuarmik kviksølvimik akoqarmata. Taamaalilluni kviksølvi inunnut apuuttarpoq aammalu inummi annertunerpaamik timimiorisassap killinga qaangerujussuarlugu timimiuulersarluni. Tamakku ungasissumit mingutsiterutit aamarsuartornermit, aamarsuarnik ikumatitsisarnernit aammalu kviksølvimik atuisariaqartarnernit gultisiorfeeqqanillu mikisunik ittangasunillu atuisariaqartarnernit pisuupput. Taamaalillutik inuit tamaani najugaqartut killissarititaasut qaangerujussuarlugit timimiorilikkaminnik mingutsinneqarsimasuusarput. Tassa nunarsuup silaata aaqqissuussaanera naapertorlugu nunanit suliffissuaqarfiusuniit kviksølvi aniatinneqartartoq silaannakkoorluni Issittumi uumasut nerisareqatigiinnerannut akuleruttarpoq. Nunat tamalaat Minamatamik Isumaqatigiissutaata kviksølvimik mingutsitsineq pakkersimaarniartussaavaa, kisiannili annertusiartortumik kviksølvimik atuinerujartorneq suli illuanut saatinneqarnikuunngilaq.

Takornariartitsinerulernikkut aatsitassarsiulernikkullu immap iluani nipimik "mingutsitsineq" sakkortunerulissaaq, aammalu malunnaatilissuarmik imaani miluumasut siaruarsimanerinik allannguuteqartitserujussuarsinnaapput. Imaaratarsinnaavoq uumasut qimaatinneqarsinnaassasut taamaalillutillu uummavimminniit piniarfigaafigisartagaannilu pingaarutilinniit qimaatitaasinnaallutik, naak sumiiffigisaminni najugaqartunit iluaqutigineqaraluarlutik. Taamaattumik mianersortumik periuseqartussaatitaagaluarpugut: uumasut akuttunngitsumik aalaakkaasumillu malinnaaffigineqarnissaat misissuiffigineqartarnissaallu kiisalu naleqqussartuartumik aqutseriaaseqalernissap atugaalernissaa siunnersuutigineqarpoq.

5 *Qanoq iliornikkut ilisimatusarnernit inernerit aqutsinikkut pilersaarusiornernik aalajangersaanernillu tapertaasinnaappat?*

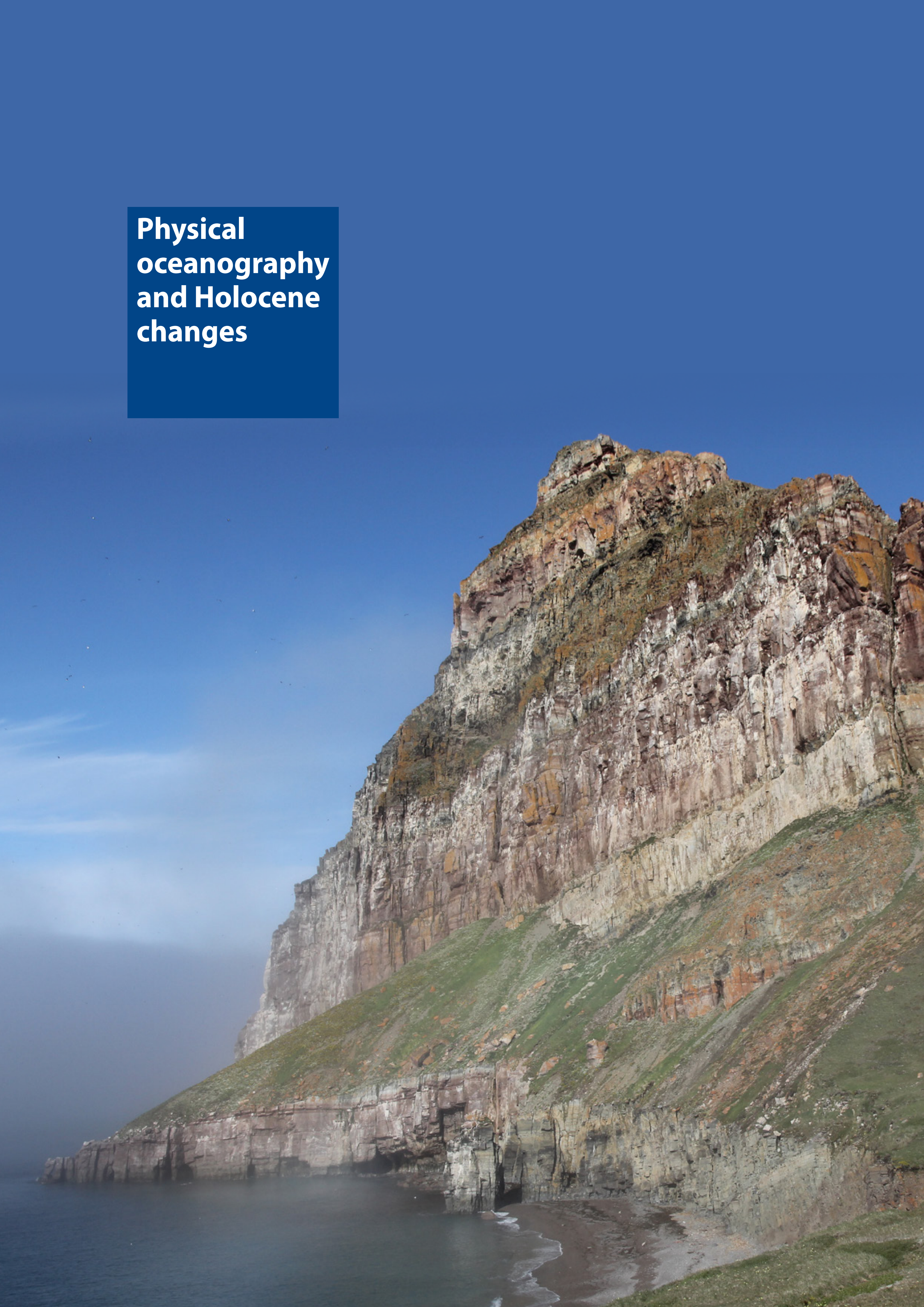
Ilisimatusartuarnerit Pikialasorsuarmi uumassuseqassutsit ataqatigiiffiinik pissutsinillu allanik paasisaqarnerunissamut siuarsaaqataasimapput, taamaalilluni misissuisarnertigut pissutsinik allanngoriartulersunik paasissutissiisarnikkut siunissami allannguutaasinnaasussanut naleqqussartuarnissanut periarfissiisarlutik. Pikialasorsuaq pillugu ataatsimeersuarnermi ilisimatusaatinit kingullerpaanit paasisat saqqummiussortineqarsimapput, kisiannili aamma inuiaqatigiit aningaasaqarnikkut aaqqissuussaanerinut tunngassutilinnik aammalumi ilisimatusariaatsinit allaniit tapiliussat ilanngullugit allanngoriartuutinik annertusisamik malittarinninnissaq pisariaqarpoq, piffissaagallartillugumi uumassusillit ataqatigiiffii naapertorlugit aqutseriuseqarnissat ikorfartorneqarsinnaaniassammata.

6 Pikialasorsuarmut attuumassuteqarlutik inuusut qanoq iliorlutik taavani ammalatarsuarmi ilisimatusartarnernik iluaquteqarniarsinnaappat imaluunnit sunniuteqarsinnaappat?

Pikialasorsuup eqqaani najugaqartut taavani ilisimatusaatigineqartartut sumiiffiit inuinit iluaqutigineqaannaratik atorsinnaassuseqarnissaannik sakkortuumik ujartuipput: piffissami aggersumi ilisimatusaatigineqartussat ilisimarusuppaat, suliniutigineqartussani ataqatigiissareqataarusupput, nunaqavissut suleqataanerunissaamik ujartuipput minnerunngitsumillu ilisimatusartartut paasisaminnik tamatigut nunaqavissunut apuussaqaqqittarnissaat piumasarisneqarluni.

Ilisimatusartartut ataatsimiinnermi peqataasut nunaqavissut piumasaqaataannut paasinnilluarput aammalu ataqqinnillutik nunaqavissullu piumasaannik akuersorlugit. Taamaammallu Qaanaami ilimatusartartut nunaqavissullu katersuuffissaannik pilersitsinissaq siunnersuutigineqarpoq. Katersuuffikkut nunaqavissut ilisimatusartartullu qaninnerusumik attaveqatigiilissapput, ataqatigiissaareqatigiinnerit pinerulerlutik, nunaqavissut akuutinneqarnerulerlutik peqataatineqartutut misiginerulerlutik, inuusuttut ilikkagaqarnerulerlutik aammalu sumiiffigisaanni ilisimatusaatigineqartartorpassuarnut piginneqataasutut misigisimanerulernissaat anguneqarsinnaassalluni. Pikialasorsuup nunaqavissunittaaq misissuiffigineqartalernissaanut iluatsittumik suleqatigiittalernissamut katersuuffiusussap aalajangiisuulluinnarnissaa ilimanarluinnarpoq.

Physical oceanography and Holocene changes



Keynote talk

Physical, biological, and chemical processes in the North Water (NOW) Polynya

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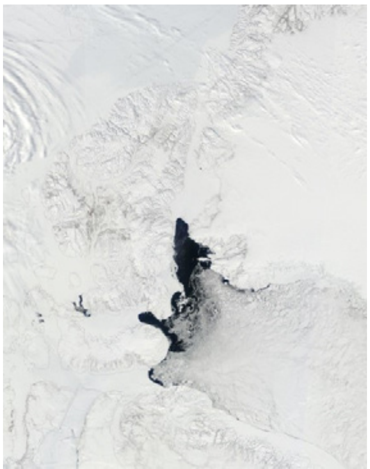


Figure 1. North Water Polynya in Baffin Bay. From NASA Worldview imagery.

Introduction

A unique feature of the Arctic environment are polynyas; areas of open water or thin ice that occur in regions where we would typically expect to find sea ice. Polynyas are created by the upwelling of oceanic heat or by strong winds that export ice from the region faster than it can form. Due to the presence of open water when the surrounding ocean is still ice covered, polynyas are known for being high in biological productivity and they provide a lot of heat to the ocean and atmosphere affecting circulation in both. Since atmospheric and oceanic conditions play a role in the formation of polynyas, these regions are sensitive to regional changes in atmospheric and oceanic circulation and temperature, as well as global climate change and variability.

The North Water (NOW) Polynya (Fig. 1), located in northern Baffin Bay between Canada's Ellesmere Island and Greenland, is the largest polynya in the Arctic and is home to a large and diverse biological ecosystem. It is heavily influenced by regional oceanic and atmospheric conditions, as well as the sea ice exported from the Arctic Ocean. In recent decades, there have been documented changes in regards to its physical, biological, and chemical processes; however, the changes have also identified knowledge gaps. With the continual monitoring of the region, these gaps can be narrowed and we can develop effective models to predict how the region will respond to further changes of the Arctic system.

The NOW Conference organizers requested this presentation to incorporate scientific advice into possible monitoring or adaptive management decisions for the NOW region. Topics addressed in our presentation included: sea ice, oceanography, climatology, lower trophic levels (e.g. algae), mid to upper tropic levels (e.g., fish and marine mammals), gas fluxes, contaminant fluxes, and modeling.

In what follows we provide an abbreviated subset of the key processes and a brief summary of each area. The information we presented at the NOW Conference was originally requested by the Inuit Circumpolar Council's Pikialasorsuaq Commission in order to explore options for international and regional management and conservation of the North Water Polynya. The interested reader can contract the lead author for the complete text in full or view the Report of the Pikialasorsuaq Commission (People of the ice Bridge: The Future of the Pikialasorsuaq, found here: http://pikialasorsuaq.org/en/Resources/Reports).

Sea Ice: There are multiple sea ice types found in the NOW Polynya: first, second, and multi-year sea ice transported from the Arctic Ocean. First year ice refers to ice that has grown over one winter and melts completely in summer. Second year ice has survived one summer melt season. Multi-year ice has survived multiple summer melt seasons. Nares Strait contains both drift ice, i.e. that can move via ocean and wind currents, and land fast ice, which is affixed along the coasts and is able to resist wind and ocean currents. The ice in Nares Strait typically becomes landfast from the Lincoln Sea to Smith Sound sometime during late fall or early winter. The separation between landfast ice and drift ice in Smith Sound is an arch-like failure line (a crack in the ice) that is visible from space and becomes even more apparent when the polynya opens. During some years, the ice in Nares Strait never becomes landfast and the polynya will not open as wide. The different types of ice are important for the development of the NOW Polynya.

Oceanography: Strong surface winds from the north push Arctic waters southwards into the NOW Polynya region, and ultimately further south into Baffin Bay where they continue southwards as part of the Baffin Island Current (Muench 1971; Melling et al. 2001; Münchow and Melling 2008). This inflow of Arctic waters from the north represents one of two main sources of water to the NOW Polynya region. The other source of water comes from the West Greenland Current, which carries Atlantic waters northwards through Baffin Bay along the west coast of Greenland (Fig. 2). Both sources of water have their own distinct physical properties, such as salinity, temperature and density. When two different water masses (water from different sources with different properties) meet vertical stacking or layers of water masses with different properties will occur. Arctic waters are referred to as the Northern Assembly, whereas Western Greenland Current waters are termed the Southern Assembly (Bâcle et al. 2002).

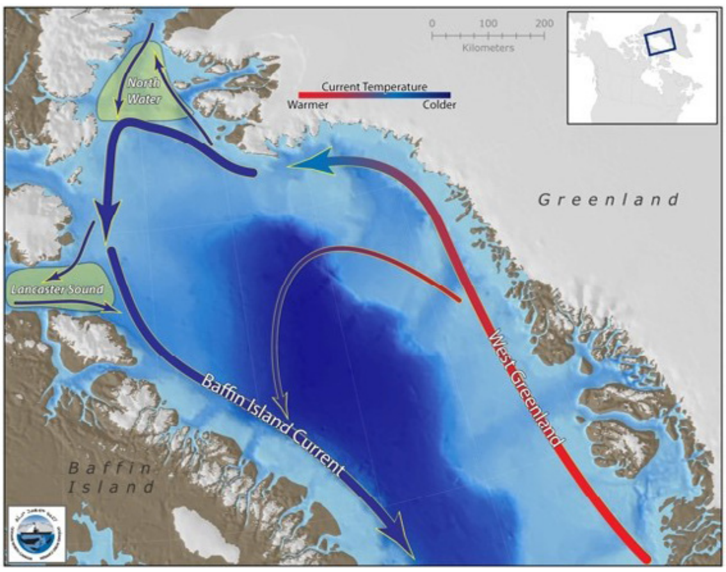
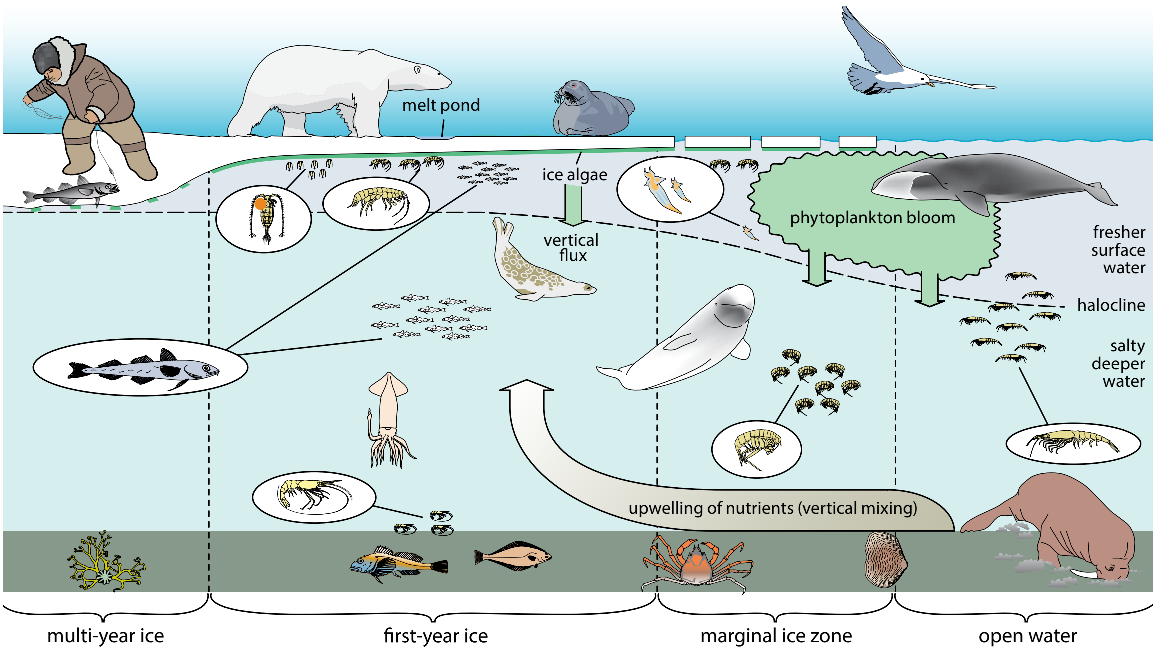


Figure 2. Ocean currents and circulation patterns in the NOW Polynya region. From PEW Charitable Trusts.

Climatology: Weather and climate regimes of the region depend on a number of features related to global atmospheric circulation patterns. These patterns represent standing or slowly evolving oscillations influencing the Arctic on seasonal to decadal time scales. These large-scale circulation patterns can affect how ice is transported around and out of the Arctic (Rigor et al. 2002). In addition, these circulation patterns can affect the number of storms that reach the NOW region (Rogers 1990; Clark et al. 1999). The Lincoln Sea, which is located where Nares Strait meets the Arctic Ocean, is often called a switch gate because these large-scale atmospheric patterns either transport thick multi-year ice to the coastline of northern Greenland or export it out of the Arctic, heavily influencing the ice types found in Nares Strait and Fram Strait.

Primary Producers and Consumers: The NOW Polynya is one of the most biologically productive regions of the Arctic because it is ice free much earlier in the spring than surrounding areas and contains a large amount of nutrients from the many water masses in the area. Dunbar (1981) first proposed that a hearty and resilient ecosystem base accounts for the plentiful wildlife in the region, and this hypothesis has been supported by numerous studies since then (Mei et al. 2003; Tremblay et al. 2006; Heide-Jørgensen et al. 2013). The food chain ranges from primary producers, organisms that produce their own food, at the bottom up to birds, fish, and marine mammals that feed off everything below them (Fig. 3).

Figure 3. The Arctic marine food web. From AMAP's Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost.



Secondary and Tertiary Consumers: The NOW Polynya provides important habitat for secondary and tertiary species throughout the year, both because it is highly productive (as described above and because the thinner ice and open water allows marine mammals access to the atmosphere to breath throughout the year. High abundances of marine mammals, fish, and birds utilize the NOW Polynya for hunting, resting, mating, rearing young, and overwintering. Ways that species utilize this area are described in the complete text.

Gas Fluxes and Ocean Acidification: The NOW Polynya is anticipated to be an important site for air-sea gas exchange. Only a few studies have been conducted in this region, so our knowledge is largely based on observations throughout the open water season and assumptions of wintertime processes (given the limited data that exists outside of the summer period). Whether the waters of the NOW region are an overall source (releases more than it absorbs) or sink (absorbs more than it releases) of a gas depends on a number of factors, such as the water mass characteristics, biological life of the area, and the timing of sea ice growth and melt. NOW could be a source of biogenic gases (produced by living organisms) such as dimethylsulphide (DMS), and is potentially a strong sink of carbon dioxide (CO_2). When the ocean absorbs CO_2, it reduces the magnitude of the greenhouse effect; however, this process results in major changes to ocean chemistry. Increases in CO_2 cause decreases in pH through the process of ocean acidification (OA). As the ocean becomes more acidic, the shells of many marine species are affected. The shells (made of calcium carbonate) will be more brittle and dissolve because of excess acid in the seawater. If waters of the NOW Polynya become more acidic (decrease the pH), there will be negative affects on marine life inhabiting the region. They will need to adapt to the new chemistry of their environment, impacting their survival and creating a domino effect up through the food chain. OA is a significant concern throughout the Arctic as cold water is more efficient at absorbing CO_2 than warm water.

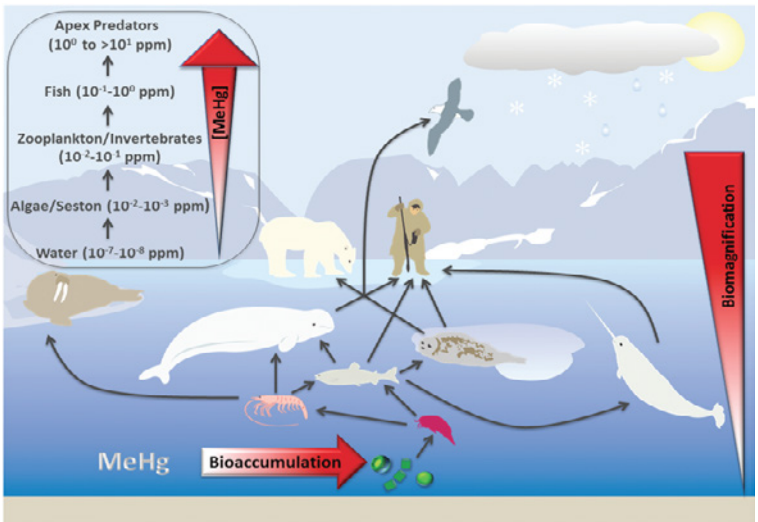


Figure 4. The bioaccumulation and biomagnification of methylmercury in a typical Arctic marine food web. From Lehnherr, 2014.

Contaminants: The NOW Polynya only has few local sources of contaminants (Bard, 1999). However, there is evidence showing the presence of multiple contaminants in the NOW Polynya and their threats to marine mammals and to Inuit who consume these animals (Fig. 4) (Campbell et al. 2005; Fisk et al. 2001). There are two groups of major concern: persistent organic pollutants (POPs), (including polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH)), and chlordane and trace metals (e.g., mercury, cadmium, zinc, and lead) (Braune et al. 2005). The amount of current-use pesticides and other emerging contaminants (e.g., polyfluorinated and polybrominated contaminants, crude oil and associated contaminants) to the NOW Polynya system are of concern as they are expected to increase over time (Morris et al. 2016).

Conclusions and Recommendations

The NOW Polynya is a very unique aspect of the Arctic environment. It is formed through a combination of physical processes, including the southerly moving Arctic Ocean current, strong northerly winds, and the export of sea ice from the Arctic Ocean. These three processes combine to form the ice arch at Smith Sound. This ice arch holds back the motion of southward flowing sea ice and icebergs in Nares Strait, allowing the southerly winds to push ice out into Baffin Bay, expanding the NOW Polynya southward.

Due to its large area of open water and availability of light deep into the water column, the NOW Polynya is one of the most biologically productive regions in the Arctic. Its short food web consists of: primary producers, micro- and meiofauna, birds, fish, whales, seals, and polar bears. The spring phytoplankton bloom attracts a diverse population of birds, whales, and seals, often the home of many species during winter and provides key migratory paths during the spring.

The NOW Polynya is also extremely important for both gas exchange and contaminant fluxes. The open water of the polynya plays a key role in the exchange of carbon dioxide from the ocean to the atmosphere as it acts as a sink. Increases of dissolved carbon dioxide increase the pH of the seawater, which leads to ocean acidification and can negatively impact the marine life of the region. In addition, sulfur fluxes, which play a major role in the global sulfur exchange and aerosol production, are low despite the NOW region being highly biologically productive. While the NOW region has few local sources of contaminants, POPs and trace metals have been found in high concentrations in the region as a result of biomagnification in the ecosystem. Contaminants originate from Asia, North America, and Europe, being transported by atmospheric and oceanic circulation, riverine transport, coastal erosion, glacier and permafrost melting, and migrating marine life.

This extended abstract presented a review and update on the current scientific knowledge of the NOW Polynya. The physical, biological, and chemical processes of the region were discussed in depth and with the emergence of knowledge gaps, we suggest a series of recommendations as per the below:

- Continued observations of the ice export, both sea ice and icebergs, through Nares Strait to understand and determine how the changing Arctic icescape will affect the formation of the NOW Polynya.
- Monitor the location and timing of the formation and melt of the ice arch to assist in understanding why the polynya opens earlier and the arch ice degrades earlier under specific oceanic and atmospheric conditions.
- Investigate the impacts of icebergs on the formation and melt of the ice arch.
- Determine what controls the sea ice gyre circulation in northern Baffin Bay and how this affects the southern boundary of the NOW Polynya.
- Examine how changes in both the atmosphere and sea ice circulation may be related to regional-scale climate processes.
- Quantify the vertical heat flux from the warm WGC waters to the surface layer and investigate its potential impact on sea ice production within the polynya.
- Determine the effect of increased glacial melting on the rate of warm WGC water inflow to the NOW Polynya region and how the glacial meltwater contributes to vertical mixing and stratification.
- Investigate how climate induced changes to inflowing water masses (e.g. warming of Atlantic water) impact the spatial development of the phytoplankton bloom across the NOW Polynya.
- Assess how a changing duration of the NOW Polynya may affect the length and magnitude of the phytoplankton bloom. Furthermore, assess how these changes may impact the health of aquatic grazers that are dependent on the timing of bloom development.
- Further elucidate the trophic linkages between ice and pelagic microbial life, aquatic grazers and large consumers in the NOW Polynya.
- Investigate habitat utilization of bearded seals to document life history, movement, and foraging ecology during all seasons within the NOW Polynya.
- Assess the behavior of bowhead whales and potential linkages to the phytoplankton bloom associated with the formation of the NOW Polynya. The overlap with the bloom would suggest this is an important foraging area for the bowhead.

- To determine how reliant the marine mammal populations of the NOW region are on Arctic cod, quantify the winter distribution and habitat utilization of different class sizes of Arctic cod.
- Assess the winter behavior and potential winter grounds of the ivory gull to assist in creating targeted management plans to manage population sizes.
- Wintertime observations of pCO_2 and DMS are required to have a better understanding of annual cycles in the region.
- Quantify changes in pCO_2 due to individual processes such as biological activity, water mass circulation, and freshwater inputs in order to understand how changes in each of these factors may influence marine carbon cycling in the future.
- Develop process-orientated studies to examine how the dynamic ice conditions affect the transport and transformation of contaminants across the atmosphere and ocean interfaces.
- Develop an understanding of ocean acidification in the NOW Polynya and project OA impacts on the marine ecosystem.
- Investigate how the timing and magnitude of the biological productivity affect the efficiency of contaminant uptake by the marine ecosystem.
- Establish a science-based basin scale observing system to monitor the evolution of the atmosphere, ocean, sea ice, contaminants and marine ecosystem components of the NOW Polynya.
- Establish a community-based monitoring program to link the scientific observations of NOW with the Inuit use of NOW and their reliance on the marine resources of this region.
- Integrate these two monitoring systems into a coordinated information system for the NOW Polynya which would be utilized by a broad range of policy and stakeholder groups.
- Examine how the NOW Polynya could become a component of a larger Baffin Bay Observing System (BBOS) thereby allowing for an increased understanding of the importance of the NOW Polynya on processes in Baffin Bay and downstream to the Labrador Sea and North Atlantic.

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Keynote talk

Climate change, carbon cycling and air-sea exchange

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Baffin Bay is one of the most productive marine systems in the northern hemisphere and represents an important connection between the Arctic Ocean and the North Atlantic. Baffin Bay is also an Inuit homeland and an important site for cultural resources and coastal interactions. Climate change is occurring particularly rapid in the region and long-term, and large-scale integrated studies are needed to understand the cascading effects from physical changes to the environment, ecosystems, and social, economic, and geopolitical conditions. By modulating the fluxes and configuration of ice and freshwater in Baffin Bay, the changing Arctic climate will affect ecosystem services regionally and in the western North Atlantic, as well as globally. Sea ice decline is one of the main causes for the rapid warming of the Arctic, and the flow of carbon from rivers into the Arctic Ocean affects marine processes, nutrients and the air–sea exchange of CO_2. River discharge has increased and the volume of Arctic glaciers and sea ice has radically declined in recent decades. Iceberg calving, accelerated melting, discharge of glaciers and the Greenland Ice Sheet are major contributors to global sea level rise. Changes in weather conditions and in the icescape of Baffin Bay including the release of numerous large icebergs and unpredictable ice hazards pose special challenges on an operational scale to safe transportation in the area.

Annual primary production in the North Water (NOW) is not well constrained. However, based on model results and satellite data on open water conditions, the primary production in the polynya is higher than in other places in the Arctic (Fig. 1).

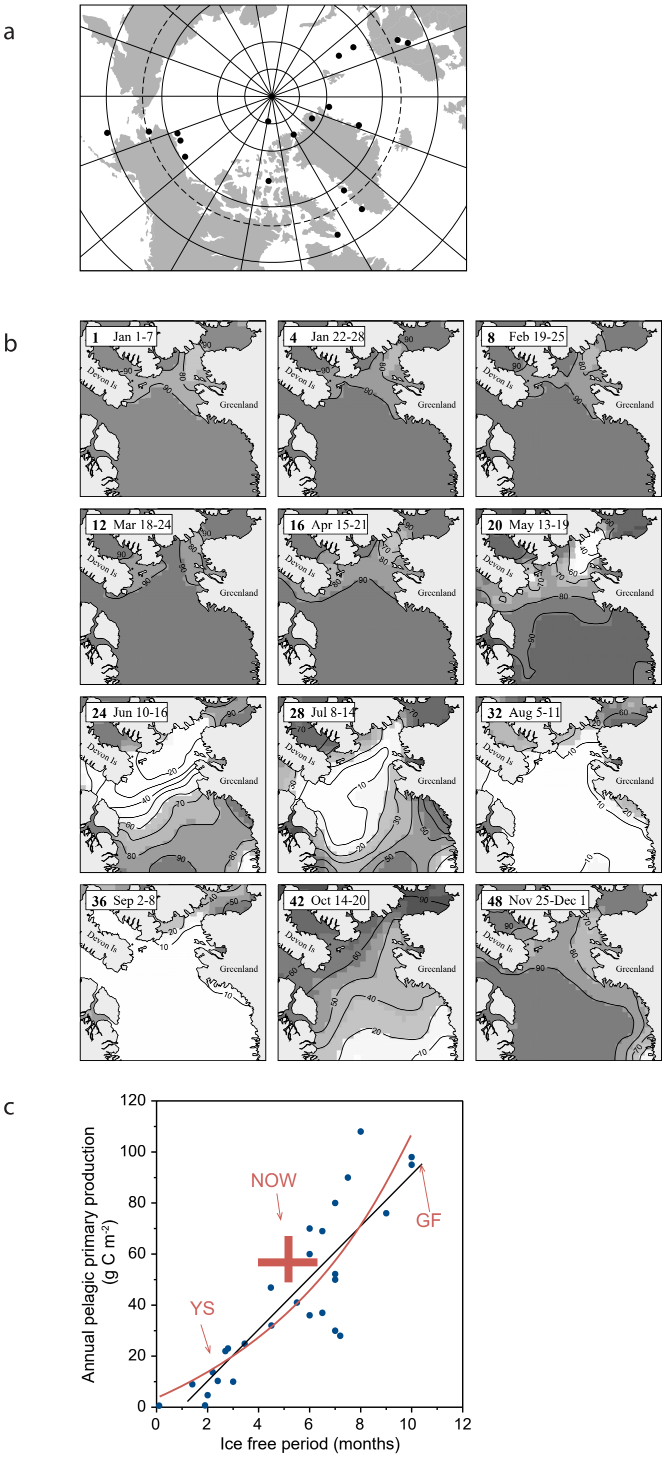

Figure 1. a) Data of primary production compiled from various Arctic regions.
b) Open water conditions in the NOW.
c) Annual primary production versus the length of the productive open-water period.
(The figure is redrawn from Rysgaard et al. (1999)).

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The North Water ice bridge shape and life cycle variability and its impact on the ecosystem

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Introduction

The exceptional biological primary production of the North Water, like an oasis in the desert, attracts fish, seabirds, marine mammals (Brown and Nettleship, 1981) and polar bears, and has compelled Inuit and European hunters and fishermen at many occasions in history, as well as the attention of the scientific community as early as the mid-twentieth century (Muench, 1971). The ice bridge is a striking feature of tremendous significance for the formation of the polynya as we know it. In fact, the polynya owes its very existence to the formation of this bridge, and ceases to exist stricto sensu as soon as the ice bridge collapses (Ingram et al. 2002). Although debated for a long time (Dunbar and Dunbar 1972), prevailing winds and currents causing sea ice to drift southward away from the ice bridge is the primary cause of polynya events and the most determinant factor for the size and duration of the polynya. Upwelling of warm water plays only a secondary role in that matter (Melling et al. 2001), but is certainly crucial for other physical and biogeochemical aspects (Dumont et al. 2010).

The formation and stability of the ice bridge until its final break-up, in other words its life cycle, are very difficult to predict on short and long timescales. The reasons why an ice bridge forms are fairly well understood and are rooted to granular material dynamics. During aerial surveys Dunbar (1969) noticed that the shape and location of the northern limit are remarkably stable. She described it as a fast-ice bridge forming a convex curve across the narrow head of Smith Sound, adopting here the point of view of the polynya. If we rather describe it from the point of view of sea ice, the fast ice bridge has a concave shape, which is indeed a signature of a very common behaviour of granular materials called arching (Wieghardt 1975, Mehta et al. 2009).

Arching is a phenomenon happening in granular materials put under stress. It is observed in many different situations: gravity flow in a hourglass, pedestrian or vehicle traffic, baggage in a conveyor belt, sand rock formations, etc. It does not specifically relate to the formation of a physical arch, but rather to a re-distribution of stress, where stiffer components of the system attract more loads (Hirshfeld et al. 1997). A physical arch, like the concave fast-ice edge defining the northern limit of the polynya, is defined as a stress-free surface separating a static material and a flow region. Technically speaking, arching does not necessarily imply a polynya. The formation and stability of a physical arch depends on three things: the geometry of the domain (converging channel), forces acting on the material (large scale atmospheric and oceanic forcing's) and the internal strength of sea ice. If we model the ice as a granular continuum, cohesion and strength are the most important parameters determining the formation and stability of the physical arch (Sodhi 1977, Dumont et al. 2009). If the ice cover is made of individual free drifting floes, arching depends on their size (diameter and thickness) and shape.

Despite this relatively good understanding of the underlying principles, the complexity and variability of the relevant environmental processes in the North Water makes it very difficult to predict at short and long time scales. For instance, ice in Nares Strait is generally a mixture of multiyear ice drifting from the Arctic, first year ice formed locally and icebergs that may interact with the seabed in shallow areas.

In a context of climate change and global warming, profound transformations in the cryosphere are to be expected and since the polynya is fundamentally driven by sea ice dynamical processes, it becomes useful and even necessary to adopt definitions and concepts that reflect the dynamical nature of the polynya. The main goal of this paper is take advantage of the long-term ice chart database and to characterize the recent history of the physical arch life cycle. For this we use historical ice charts from Canada and Denmark to quantify the variability of the arch break-up date on inter-annual to decadal time scales. We then use satellite-derived ice concentration data combined with results from the ice chart analysis to highlight the impact of the ice arch formation (or not) on the incoming solar radiative field and provide insights as to how the North Water may respond to climate change. Methods are presented in section 2, results are presented in section 3 and discussed in section 4.

Methods

Ice charts

The recent history of the Nares Strait ice arch is built from a visual analysis of ice charts obtained from the Canadian Ice Service (CIS) and The Danish Meteorological Institute (DMI). Charts are generally produced with various sources of data that are available to ice experts at the time of analysis, which includes weather and oceanographic information, visual observations from shore, ship and aircraft airborne radar, and satellite imagery (http://ice-glaces.ec.gc.ca/).

CIS charts cover the period 1968-2017 with a variable seasonal coverage: from 1968 to 1979 only the summer season is covered, starting on 20 May at the earliest with an exception in 1970 where it began in April. The systematic coverage of the winter period began with a monthly coverage in 1980, intensified to a biweekly coverage in 2007 and to a weekly coverage in 2012. DMI charts cover the period 2000-2017 with at least a weekly coverage over the whole year. The DMI coverage is weekly all year-long during the period 2000-2009 and intensifies to twice per week in 2010.

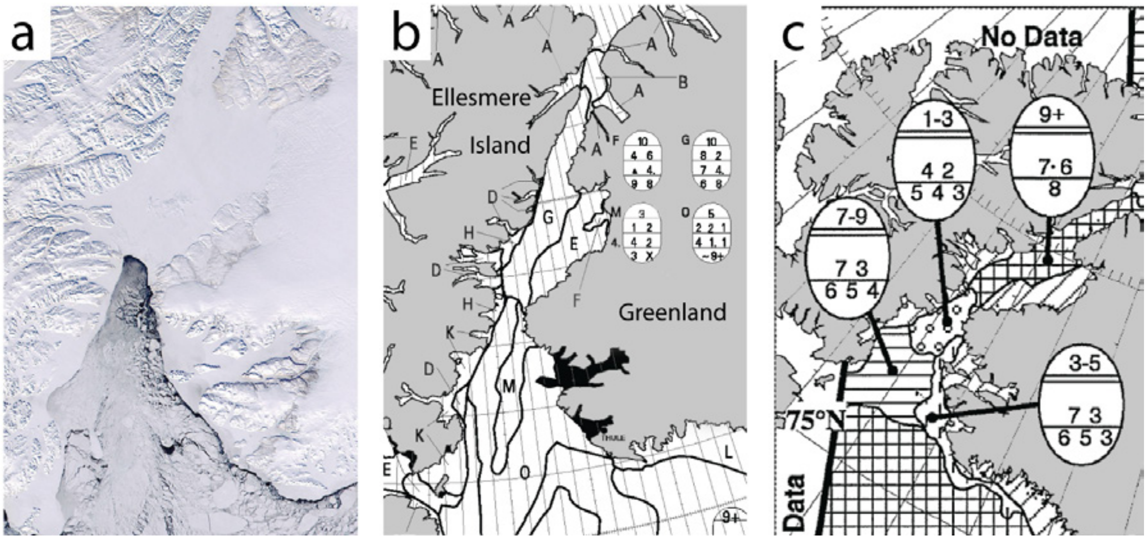

Figure 1. a) MODIS image of the North Water Polynya and the ice bridge on the 23 April 2002 (week 17); b) Extract of the Canadian Ice Service (CIS) ice chart (1 May 2002, week 18); c) Extract of the Danmarks Meteorologiske Institut (DMI) ice chart (28 April 2002, week 17). For clarity, land masses were colored in gray and only relevant egg codes were kept.

Ice charts display information about ice concentrations, stages of development (age) and form (floe size) of ice in a simple diagram referred to as the egg code that is associated with closed polygons (Meteorological Service of Canada, 2005). Two adjacent polygons have different egg codes (see Fig. 1 for an example). As discussed in the introduction, an arch is a failure between two distinct dynamical ice states: landfast ice and mobile ice. Modern ice charts use a specific color code for landfast ice, which is distinct from any other mobile ice. However, even without this color code arches are very likely to separate two different egg codes characterizing a change in concentration, age or form. Even if the concentration and stage of development are the same, a change in the form is very likely since the arch is indicative of dynamical failure resulting in smaller floes on the downstream side.

Two criteria are defined in order to decide whether an ice arch is present and that can be considered as a stable feature. The first one is that a concave line must join Ellesmere Island and Greenland at their closest distance point (~78.6 °N). The line can be formed by a set of connected lines, as long as it is concave overall. For example, if a concave line connects two along-channel lines delineating landfast ice areas (see Fig. 1 for an example of such along-channel lines) it is considered as an arch-like ice failure indicating flow stoppage.

The second criterion is that the total concentration (noted C_t) north of the arch must be at least 9. This means that the first number at the top of the egg must be 9, 9+ or 10. When an arch is present, the downstream concentration is noted and the polynya is categorized as closed if $C_t \in [7\,;10]$, semi-open if $C_t \in [4\,;7[$ and open if $C_t \in [0\,;4[$. When the concentration is given as an interval (e.g. 7-9), which is common in DMI charts, the average value is used (in this case 8).

The downstream concentration varies by as much as 2 to 5 tenths from one chart to another and between CIS and DMI charts of the same week. Ice charts are issued at different dates and they are produced using different sources of information that are interpreted by different persons. Moreover, sea ice concentration can vary significantly within days and even hours due to advection, ice formation and melt and other processes affecting how the raw signal is transformed (e.g. changes in roughness, surface temperature, etc.). On the other hand, CIS and DMI charts agree very well about the location and shape of landfast ice areas as well as on the presence/absence of the arch, making it a reliable source of information about the dynamical state of the ice.

Each chart is associated with its ISO 8601 week number and a one-week uncertainty is implied. The presence of the ice arch in charts has been verified using Synthetic Aperture Radar (SAR) and MODIS satellite images when available (an example is shown in Fig. 1a), confirming the reliability of the charts for characterizing these features.

Light and ice concentration

If ice charts are deemed reliable for assessing the presence/absence and long-term stability of the arch, they are not ideal for assessing ice concentration at relevant scale. Forced by winds and currents, ice concentration can vary rapidly from one day to another, which can't be captured by a weekly evaluation. In order to evaluate the strength of a polynya and more specifically the role it plays as a window in the ice cover letting light penetrate and fuel primary production, we calculate the cumulative radiative energy that penetrates the ocean during the primary production period. The shortwave radiative flux penetrating the ocean is calculated simply by

$$Q_{SW\downarrow} = Q_0\,(1-\alpha)(1-A)$$

where Q_0 is the top-of-the-atmosphere shortwave radiative flux, α accounts for light attenuation by clouds following Reed (1977) an A is the ice concentration. Sea ice is considered here as a perfect reflector. The cumulative radiative energy, in J m^{-2}, is calculated as the integral from 1 January to 31 October of a given year, which spans more than average polynya time window. Sea-ice concentration data were taken from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI-SAF) Global sea-ice concentration reprocessing dataset 1978–2009 (http://osisaf.met.no) and the total cloud cover is extracted from the ECMWF ERA-Interim re-analysis.

Results

Arch break-up

Ice chart analysis results are summarized in Figure 2. The first date of appearance of the arch is highly variable from one year to another: it can be as early as week 41 (first half of October) in 1970 or it can simply never form. It can also form, last a few weeks, break-up and form again later. The polynya break-up date (red boxes in Fig. 2) is defined as the last occurrence of the ice arch and also varies inter-annually. In some cases early break-ups like in 1995 and 2008 seem to be associated with a late first appearance, but we found no significant correlation. It either means that the two phenomena are not related, or that there is a lack of data to confirm a correlation.

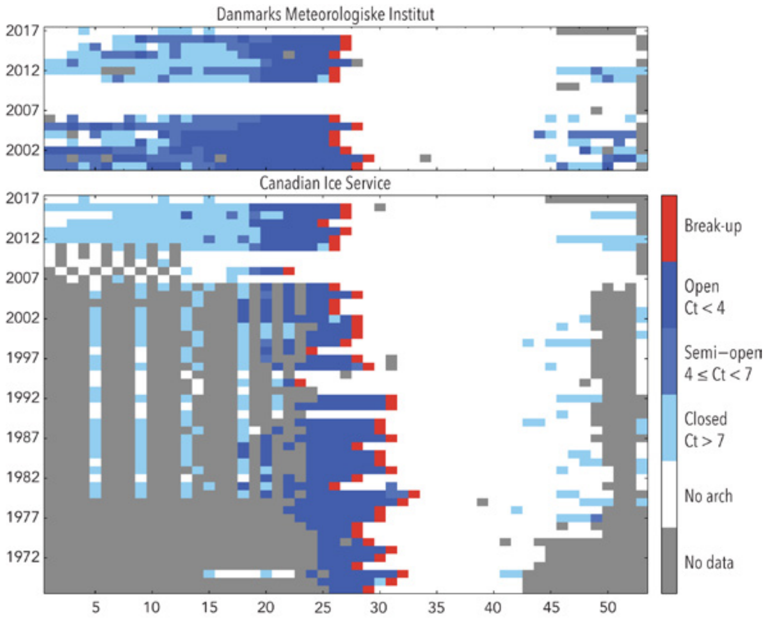

Figure 2. Nares Strait ice arch analysis performed on CIS (1968-2017) and DMI (2000-2017) ice charts. The arch break-up (in red) corresponds to the last occurrence of an ice arch series that lasted at least two weeks.

For a polynya to form, we require that the arch is present at least two consecutive weeks. According to this criterion, the polynya did not form in 1990, 1993, 1995, 2007, 2009, 2010 and 2017, i.e. seven years in total over the last 49 years. In 2008, the arch formed very late in spring and had the shortest life on record according to CIS data. This is not replicated in the DMI database due to the upstream concentration criterion that was not met. However, an arch was visible in DMI charts during weeks 20-22 so that we here consider that 2008 was a polynya year. Figure 3 shows the break-up date as a function of the year for CIS and DMI datasets. Both datasets agree with one another within a one-week uncertainty.

A first visual assessment of the time series shows an abrupt transition in 1994, before which the average break-up week is around week 31 and after which it is around week 27, corresponding to a one-month

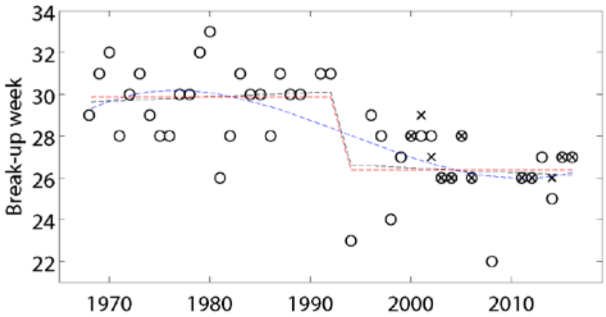

Figure 3. Yearly break-up week according to CIS (circles) and DMI (crosses) databases. Dashed lines show constant piecewise (red), linear piecewise (black) and third-order polynomial regression fit (blue) to the data. The constant piecewise regression with a break point at year 1994 is the one that minimizes the residual variance.

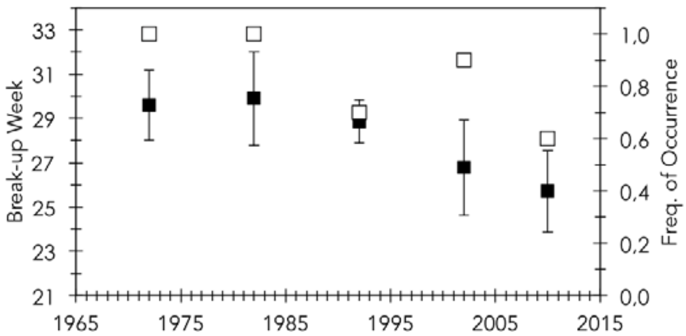

Figure 4. Decadal average and standard deviation of the break-up week (left axis, filled squares) and frequency of occurrence (right axis, open squares) of the physical arch.

advance. An analysis of the long-term trend shows that a piecewise constant regression with a break point in 1994 is effectively the one that minimizes the standard deviation of the residual, which is 1.7 weeks once the piecewise constant trend has been removed. Table 1 summarizes results of the long-term statistical analysis made on all years during which an arch formed. Figure 4 shows the decadal average of the break-up week as well as the decadal average of the frequency of occurrence drops from 100% before 1990 to 72% after that.

Table 1. Long-term statistics of the arch break-up week as assessed from CIS ice charts.

	Average	Median	Std. Dev.	Range
Overall	28.3	28	2.45	11
Before 1994	29.9	30	1.62	7
After 1994	26.4	27	1.83	9

Cumulative radiative energy

Although not very precise, since it does not account for the non-zero and time-dependent transparency of the ice, the cumulative radiative energy calculated here is still a good indicator of the impact of the polynya on the ecosystem given its large variability in terms of timing and size. Figure 5 shows the arch break-up period before and after 1994

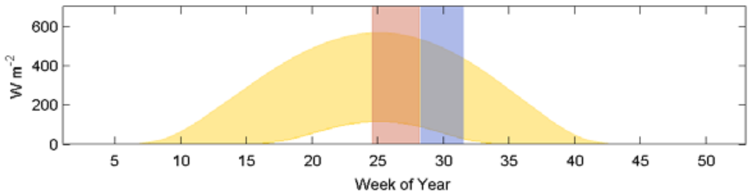

Figure 5. The yearly cycle of daily maximum and minimum top-of-the-atmosphere solar irradiance (yellow shaded area) superimposed with the arch break-up period before (blue) and after (red) 1994.

superimposed with the yearly cycle of the top-of-the-atmosphere solar irradiance. Such an advance, if indicative of similar changes in the timing of the polynya itself, may have had profound impacts on the marine ecosystem. The top panels of Figure 6 show a comparison between arching and no-arching years (see section 3.1). The impact of the ice bridge is only subtle is we focus on the maximum levels of cumulative energy reached in the area. However, one of the very clear effects of not having an ice bridge is that light penetrates much sooner and in larger quantities in the Kane Basin, north of the usual location of the polynya. The second important result is that despite the absence of an arch and ice flow stoppage, there is a strong polynya signal in eastern Smith Sound. The ice flows southward hugging the coast Ellesmere Island and thus let less light penetrate. Comparing the periods before and after 1994 (bottom panels of Fig. 6), one can see that the polynya allows much more light to penetrate, indicative of a combination of earlier opening, larger polynya and less ice formation during polynya events.

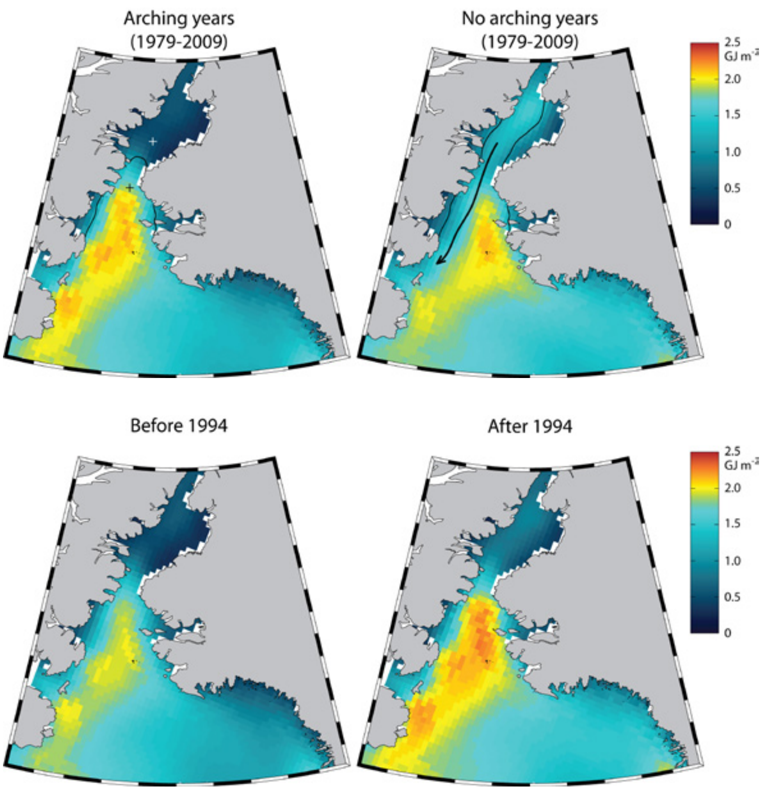

Figure 6. Cumulative radiative flux integrated from 1 January to 31 October of a given year, average over different periods: for all years that the arch formed (top left) and did not formed (top right), for the period 1968-1993 (bottom left) and 1994-2009 (bottom right). Thin black lines on the top panels shows the approximate location of landfast ice edges, and the arrow illustrate the southward Arctic surface current.

Conclusion

The southern end of the landfast ice cover that forms in Nares Strait constitutes the northern end of the North Water Polynya and takes the form of a concave arch joining the narrow head of Smith Sound. This feature is fairly well understood as a signature of a granular material that is put under stress and that resist northerly winds and currents. Ice charts derived from high resolution information obtained from satellites and aerial surveys, provide an excellent long-term database of that phenomenon, which is very important to the formation and maintenance of the North Water Polynya.

The arch database that is presented here shows that the arch break-up date is highly variable. Since 1968, it varied between week 22 and 33 (11 weeks range). However, a statistical analysis reveals that an abrupt change of the average break-up week happened around the year 1994, week 29.9±1.62 before and week 26.4±1.83 corresponding nearly to a month advance in break up. Nothing significant could be said about the arch formation, both because of a lack of data and because of the larger variability (if not stochasticity) of this process.

The main conclusions to be remembered from this study are first, that no arch does not mean no polynya and second, that the North Water has experienced significant changes in the ice phenology over the last five decades, potentially linked to changes observed in primary production (Marchese et al. 2017, Blais et al. 2017). Evaluating the predictability of the ice arch life cycle is still very challenging and will require further studies, but the dynamical information provided by the database derived from ice charts has a great potential for advancing our understanding through informed and targeted field studies of ice dynamics in the area.

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The representation of the North Water in coupled ocean and sea ice models

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The North Water Polynya is located in the southern part of the Nares Strait at the entrance to Baffin Bay. It is characterized as an area that opens up early in spring due to a combination of sea ice bridges that form and breakup in Nares Strait and wind that moves the sea ice away from the coast. When ice bridges forms in Nares Strait the transport of thick ice from the Arctic Ocean is blocked. This makes it a special area for sea ice physics and a very challenging area to model as the current state of the art models are not build to model sea ice without motion. This study utilizes a coupled state of the art ocean model (HYCOM, Chassignet et al. 2007) and sea ice model (CICE, Hunke and Dukowicz, 1997; Hunke, 2001) that covers the Lincoln Sea, Nares Strait and the northern part of Baffin Bay. The domain is shown in Figure 1. The study is based on two experiments where the first is a hindcast study that covers the period from summer 2005 to summer 2009. The aim of this experiment is to demonstrate the skill of the model in order to represent the polynya and the sea ice physics associated with this. The second experiment is a climate prediction with the aim of investigating the future development and characteristics of the NOW. The difference between the two experiments is the forcing at the boundaries and from the atmosphere.

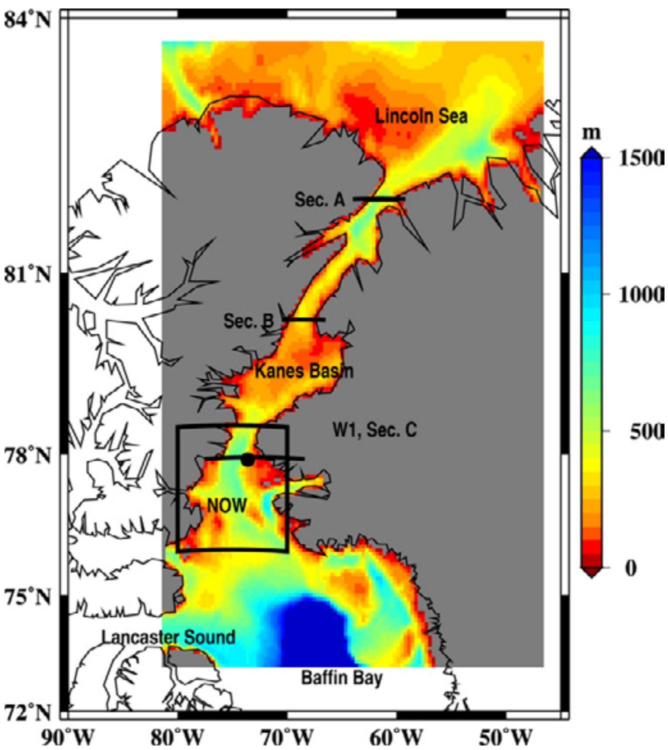

Figure 1. Model domain for ocean and sea ice model. Resolution ranges from 4 km in the north to 10 km in the south. The approximate area of the North Water Polynya (NOW) is outlined in the black box. Color scale indicates the depth of the ocean.

Table 1. Ice flux through section A in the Northern part of Nares Strait.

	Area flux 10^3 km^2 year^{-1}	Volume flux km^3 year^{-1}
2006	14	20
2007	69	120

The formation of the ice bridge influences the transport of sea ice through the Nares Strait. The ice flux has been calculated approximately through section A in Figure 1. The result is shown in Table 1.

The modeled ice area fluxes are approximately 80 % of what has been measured based on satellite images by Ron Kwok [2007]. There is a big difference in the ice flux from 2006 to 2007. This is due to the fact that there was no ice bridge formed in winter/spring 2007, thus sea ice continuously drifted southwards through the Nares Strait and into the area of the North Water. The result is consistent with observations.

NOW is not only seen in late spring when it opens up earlier than the surroundings. There are also cases where strong winds open up the area in winter; however it quickly freezes over again. One example of this is seen in Figure 2. It is clearly seen that the model opens the polynya as a result of a strong wind event towards south west that moves the ice away from the coast. The area quickly freezes over and the sea ice cover in February will return to 100%

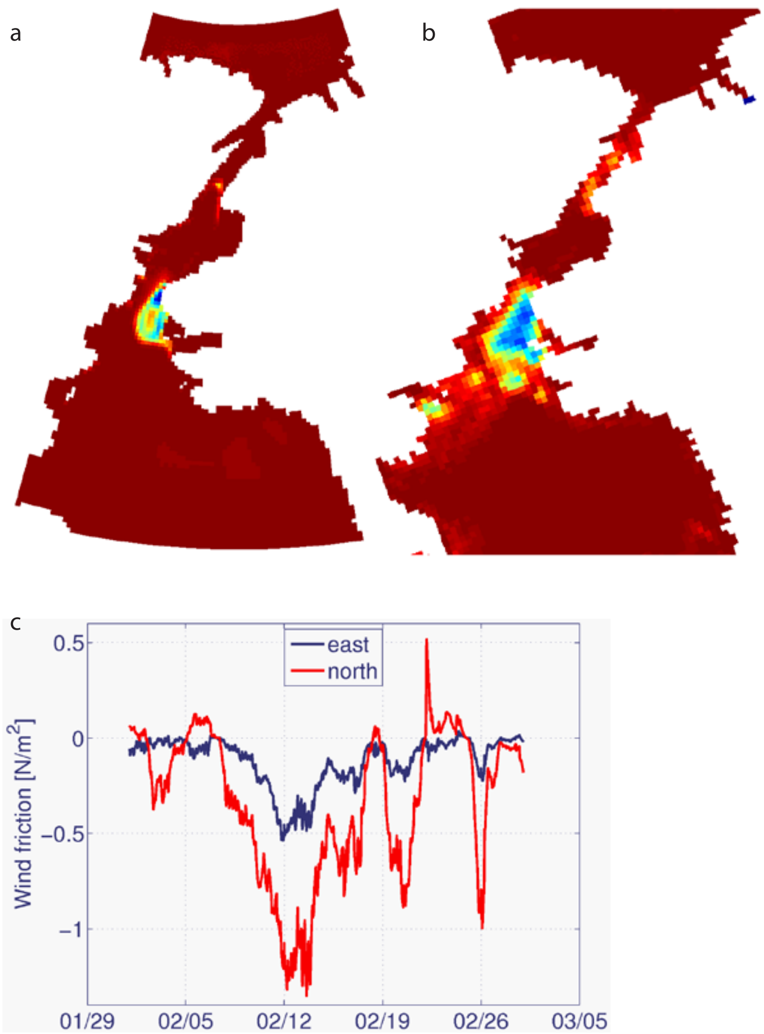

Figure 2. Opening of the Nares Strait on the 13th of February 2006. a) is modeled, b) is observed from OSISAF [Eastwood, 2011] and c) is the wind speed within the polynya from the forcing data. Positive is defined towards east and north.

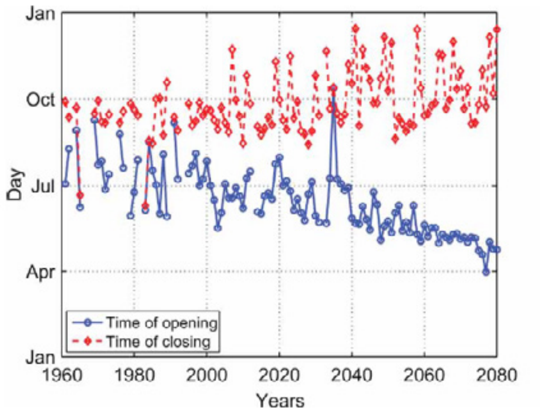

Figure 3. Opening and closing of the NOW. Defined to be open when the ice concentration is less than 20%.

This study defined the polynya to be open when the ice cover is less than 20%. Based on experiment 2, Figure 3 shows the time of opening and closing of the polynya. There is large interannual variation but the trend is that the polynya will remain open for longer periods of the year. This trend increases especially after 2040.

Additional details regarding this study can be found in Rasmussen et al. (2010) and Rasmussen et al. (2011).

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Historical and archaeological records as proxies for the dynamics of the North Water Ecosystem

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This paper highlights some of the potentials of archaeological and historical records as proxies for understanding the dynamics of the ecosystem of the North Water. These sources are indeed 'indirect' or proxies and only through contextualisation can they provide data in the sense of natural science. Our records are by nature fragmented, in non-quantifiable format, cannot be reproduced, and the interpretive process is filled with pit-falls. They are however often the only access we have to evidence of life beyond the era of flight-surveys and satellite images.

During the multi-disciplinary "NOW-project" (2014-2017) a number of relevant questions and concepts were identified as crucial to future investigations of the long-term success of human living in High Arctic environments (see reports and article available on www.now.ku.dk).

Archaeological sources

Potentials

Information on the past fauna of the North Water comes from animal bones and other faunal materials excavated from well-preserved culture layers (middens and house floors) on a number of archaeological sites. However, faunal remains are rarely preserved at the earliest sites in the area reaching 4.500 years back in time (Saqqaq, Independence I and early Dorset culture sites), and only the late Dorset and Thule culture sites (c. 750 AD – present) have provided substantial amounts of bones allowing more detailed analyses.

Through faunal analyses carried out by archaeo-zoologists, the archaeological sites provide information on the local and regional presence of different biotic resources at various times. A number of analytical methods provide insights into the time of year, that the different animal species were present in a given area. Combinations of data from several sites within a given period may further provide insights into the overall distribution and migration patterns of the different animal populations.

Well preserved culture layers on sites close to the North Water may also provide a multitude of proxy data concerning past micro- and macro-climates and vegetation. Analyses of pollen- and macrofossils as well as insect remains are quite strong indicators in this respect.

In recent years geo-genetic and isotopic analyses based on faunal materials from archaeological sites have become relatively inexpensive and reliable. Such analyses enable us to describe aspects of past eco-systems such as "genetic bottle-necks", feeding-patterns or heavy-metal contaminants.

The settlements of pre-historic and historic societies generally are situated close to marine areas rich in game; the settlement patterns of the different chronological periods thus serve as proxies for the distribution and extent of polynyas, ice ledges and ice berg banks through the last four millennia.

As the sites in general were situated right at the sea shore, often directly on the beach, the position of the sites from a given period reflect ancient shore lines and thus provide data on the topography of the North Water through the last four millennia.

Limitations

As seen, the potentials of using archaeological sources as proxies for animal life and environment are great. However as in many other disciplines there are several challenges;

Large portions of the lands around the North Water have only been sporadically surveyed for archaeological sites and most of the known sites were excavated several decennia ago with quite coarse methods. Few faunal materials were collected and assemblages are often a mixture of different settlement phases. No samples for palynological or entomological analyses were collected during these early excavations in the 1930s or 40s. Moreover, early pre-Inuit sites are much less visible than the sites of the late Dorset and Thule culture and thus early sites are heavily underrepresented in the record. In a large area bordering the North Water – from Wolstenholme Fjord in the North to south of the Melville Bay – all pre-Inuit sites that originally were situated at the beach are now washed away or submerged. Finally, the preservation conditions on sites around the North Water are often poor partly due to generally very slow soil formation on the sites.

Likewise, interpreting the environmental proxy records from archaeological sites is not straightforward. Most obviously, the faunal material at a site has gone through a 'human filter' and does not reflect the composition of the fauna directly:

Firstly, the bones are often unevenly distributed depending on the spatial patterning of activities on the settlement – butchering areas, consumptions areas – and on clearing and sorting procedures. Thus, conclusions on the composition of the animal populations should ideally be based on bone samples from different zones on the sites.

Secondly, sites around the North Water are, like in other High Arctic regions, seasonal. Thus, the faunal material at a single site might only represent hunting activities from a few days or weeks of a yearly cycle. And the faunal materials might be a mixture of local and long distance transported bones as human subsistence around the North Water at all times was based on storing meat from rich seasons and consuming these stored resources during meagre times and often at places far away from the hunting grounds themselves.

Thirdly, important game species might be heavily underrepresented or simply not be present in the shape of bones at the site. This typically goes for remains of the biggest game like narwhal and bowhead whale. The heavy bones of these animals were left at the kill site and only selected pieces of bones reached the sites were they served as raw materials in toolmaking. Likewise, caribou is often heavily underrepresented in faunal materials as this game was hunted at great distances from the base camps and only bones from anatomical parts rich in meat and fat or marrow bones reached the site. We conclude that absence of evidence of some animal species in the archaeological record is not evidence of absence.

Historical sources

Potentials

Moving on to the historical sources; the account books of the local trading stations in Greenland provide important information on the outcome of hunting and they can serve as proxies for the distribution and density of game at various times. Christian Vibe may have been the first to put such records into use, even if with sporadic mentioning of the North Water area (Vibe 1939; 1950; 1967). Other sources of indirect information on the biotic resources can be gleaned from diaries and other accounts by local missionaries, colonial administrators, explorers and ethnographers. These historical sources may also provide information on changing sea-ice conditions both locally and across a region.

The historical sources containing proxy data related to the North Water ecosystem are diverse, including diaries and notes of researchers like Erik Holtved, Christian Vibe and Knud Rasmussen and trade post administrators like Peter Freuchen, and, later, trading lists of the Royal Greenlandic Trade Company and climatic information (including a detailed account of the ice-condition) on archive from US Air Force. Some of these data are collected and analysed by Grønnow (2016). These sources are a treasure trove for cultural research, but like the archaeological records they are not straightforward sources in relation to environmental reconstructions.

Limitations

Apart from the usual biases of historical sources, one of the obvious limitations is the short period of time they account for. Furthermore, the authors often had little to compare with when describing their impression of say the sea-ice cover or distribution of game in a given year.

Another pit-fall when using accounts of the number of furs, quantities of blubber and other products bought by the trading stations as a proxy for the distribution and density of various species across time is the impact of the market. For instance, the number of fox-pelts traded at Knud Rasmussen's Thule Station, rather reflects the varying demand by the European fur market than the density and size of the fox population around the North Water.

We thus suggest

The archaeological and historical records among others can provide insights into the state and development of the biotic resources in the North Water eco-system. But these sources are in the true sense of the word, proxies of environmental aspects, and must be used with caution.

Human society as part of the North Water Ecosystem – between the Local and the Global

The multi-scalar and multi-disciplinary perspectives on human societies employed during the NOW-project led to the identification of several key factors that across considerable time-spans ensured people a rich living in the Avanersuaq area – at the border of a High Arctic oasis.

A number of these key factors was conceptualised under the heading of Strategic Opportunism. This concept try to pin down the balancing between the ways peoples see their immediate or imagine their long-term needs, while being capable of responding to immediate challenges and new opportunities. Finding this balance in Avarnersuaq among others seems to be depending on multiple and entangled factors such as:

1. Access to diversified, flexible and relatively low-cost technologies.
2. A relatively easy access to information and to primary and secondary resources.
3. A social mind-set that include acceptance of a high degree of mobility and transport technology that can support this mobility.
4. A presence of resources that are in demand outside the Avanersuaq, whether biotic, a-biotic, human, or geo-political resources.
    - One example is the productive hunting of baleen whales among indigenous communities during the 14th to 16th century and British whalers from ca. 1819 to 1900 (Jeppesen et al. 2018). Another example is the large number of polar foxes skins produced in Avanersuaq that during the latter part of the 19th century and in the first half of the 20th century were in high demand for the European and American fashion industry. The fox pelts trade not only formed the economic basis of the Thule Station from 1910, but also constituted the most important source of financing of the famous Thule expeditions (see Fig. 1). From the 1930s until the 1970s the fox pelt were replaced by seal skins in economic importance (Hastrup et al. 2018).
    - From the beginning of the 8th century and well into the 19th century meteoric iron from the famous Innaanganeq (Cape York) meteorites ensured the different indigenous groups of Avanersuaq an important place in extensive trade/exchange networks across Arctic Canada (e.g. Jensen et al. 2015)

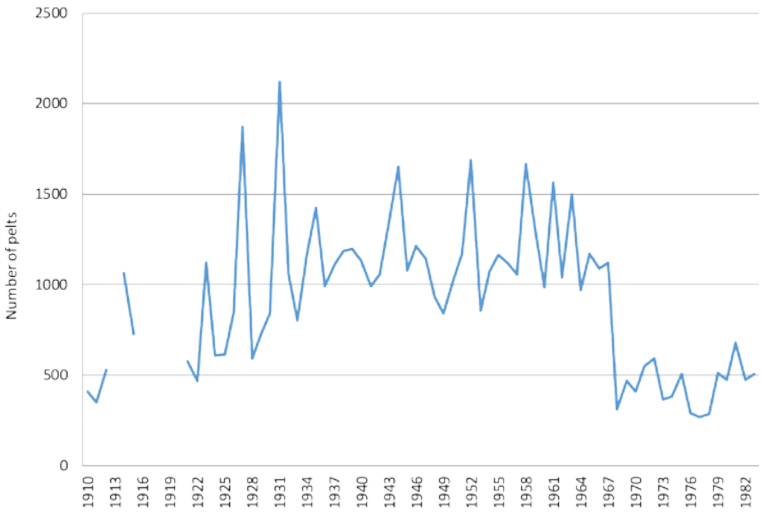

Figure 1. Fox pelts traded to the Thule Station from 1910 – 1983. Break in series reflect lack of data in the records. Original data are from Statistics Greenland, the Greenland Institute of Natural Resources (courtesy of Mads Petersen Heide-Jørgensen), and the trade records from the Thule Station (courtesy of Knud Michelsen and the Knud Rasmussen House).

- The uniqueness of the human and geo-political resources of the Avanersuaq is in part constituted by the areas "remoteness" – as viewed from the South. From the middle of the 19th century the back-up and skills of Inughuit at multiple occasions meant the difference between life and death to the European and American expedition members. During Robert Peary's and Knud Rasmussen's presence in the area Inughuit also played role as work force, among many others as expedition members. And continuing into the present a number of people deliver crucial practical services and work as advisors to outside scientists' work in the area. The "remoteness" of Avarnersuaq has since the establishment of Thule Airbase in 1950s made it geo-politically important.

5. An economy balancing between on the one hand side individual ability to collect resources and on the other sharing.

This list is by no means exhaustive, but does seem to form a productive venue for exploring some of the properties of the cultural and economic resilience of communities in Avanersuaq, which may well include learnings relevant for future decision-making.

The unique resources of the North Water and Avanersuaq today include narwhal (mataq) for the Greenlandic market and halibut for the international market. An increasingly important resource is the in-depth and inside understanding of the biotic systems, and the ice-scapes in and around the North Water that a number of individuals in Avanersuaq possess. These understandings (sometime called Traditional Ecological Knowledge or simply TEK) have become to be seen as a crucial among a number of scientific disciplines.

Acknowledgements
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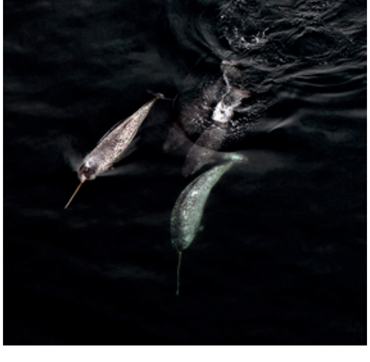

Marine productivity and food web studies

Keynote talk

The winter ecosystem: a gap in our understanding of the North Water

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The North Water arguably harbours the richest ecosystems of the Arctic. A review of what is known about some major components of the food web in the polynya emphasizes the want of information on their winter ecology. Although costly and logistically demanding, previous Canadian circum-annual expeditions of the CCGS Amundsen in Franklin Bay in 2003-2004 (CASES program) and the Amundsen Gulf in 2007-2008 (CFL program) have had a tremendous impact on our understanding of the winter ecosystem of Arctic seas in general and the Cape Bathurst Polynya in particular (Fig.1).

Another approach (less costly than the overwintering of an icebreaker) to monitor the winter ecosystem is the annual redeployment of oceanographic moorings over decadal scales. Such programs are conducted for example by the German Alfred-Wegener Institute in Fram Strait (Hausgarten Observatory) and by the Canadian ArcticNet in the Beaufort Sea (Long-Term Oceanic Observatory). Although the interpretation of the data requires several assumptions and caveats, the combination of sequential sediment traps, CTD sensors, and ADCPs, which record mesozooplankton movements, provides unique insights into the winter ecosystem. For instance, 6 annual cycles of trap records over 2009-2016 (2013-2014 lacking) illustrate the development of a late fall-winter microalgal production in 2012-2013 (October to February) and 2014-2015 (September to February) and winter production starting in February in 2015-2016 (Fig. 2). The analysis of the mesozooplankton also intercepted by the traps (swimmers) suggests that the reproduction of key species such as the copepod *Calanus hyperboreus* can be disrupted by such alteration in the annual cycle of availability of their microalgal food. These unique results are consistent with the recent satellite detection of an Atlantic-style autumn phytoplankton bloom over much of the Arctic (Ardyna et al. 2014) and the emerging notion that the winter ecosystems of Arctic seas are more active than previously believed.

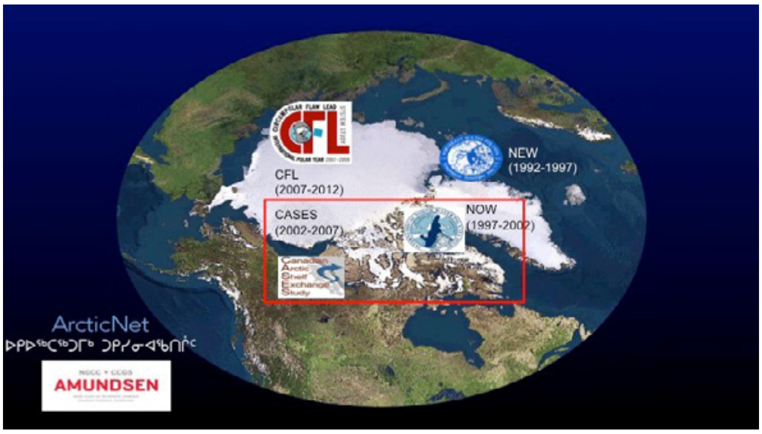

Figure 1. Map of the distribution of four major international polynya studies (NEW, NOW, CASES, CFL) in the Canadian/Greenland Arctic, including two overwinterings in the Cape Bathurst Polynya area (CASES, CFL).

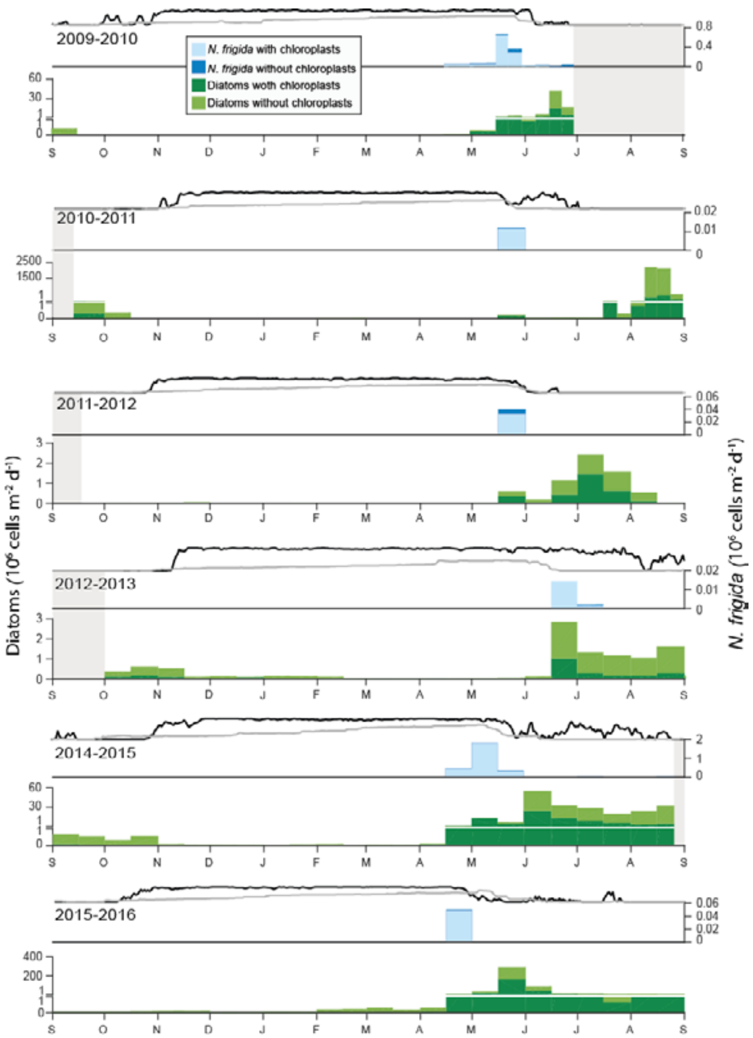

Figure 2. Six annual cycles of microalgal abundance in sediment traps moored at the shelf edge in the Beaufort Sea. Low but ecologically significant fluxes of microalgae were intercepted in the fall-winter in recent years (DeZutter et al. in preparation).

It is proposed that the international Arctic Ocean science community contemplates (1) the multinational deployment of a permanent oceanic observatory based on classical moorings and recent developments in marine robotics (e.g. the Baffin Bay Observing System, http://www.asp-net.org/sites/default/files/website_files/BBOS_6%20Apr.pdf), as well as (2) a scientific overwintering of the Amundsen and/or another icebreaker in the North Water in 2020-2021. Against the background of previous missions, the annual monitoring conducted by ArcticNet since 2004, and proposed international endeavours in Baffin Bay, such an overwintering expedition would help solve several aspects of the mythical North Water. Among many scientific objectives, the circum-annual mission would enable us (1) to inventory the ecosystems of the North Water to buttress the proposal to make the Pikialasorsuaq a Marine Protected Area (including Lancaster Sound); (2) to assess how climate change has affected the regional sea-ice regime and ecosystems relative to our last study of the area in the late 1990's; and (3) to document how the ecosystem services provided to Canadian and Danish Inuit communities will be affected by on-going changes.

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The use of ecogeochemical tracers to quantify food web dynamics in the North Water region

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The Northwater polynya (NOW) is a refuge of biological diversity and hence is among several Greenlandic ecoregions that have recently been proposed for adoption under the UNESCO's World Heritage Convention due to their critical value in safeguarding high biological activity and diversity. Nonetheless, these ecoregions have been subject to ongoing rapid environmental change, a.o. in sea ice dynamics, and therefore a quantitative assessment of the current-state and possible changing dynamics of its food web are of utmost importance to assess the resilience of its ecosystem as well as potential repercussions for the local Inuit depending on it.

Here we have analyzed stable carbon (C), nitrogen (N) and sulphur (S) isotopes in muscle tissue of several seabird, i.e. common eider *Somateria mollissima*, little auk *Alle alle*, black-legged kittiwake *Rissa tridactyla*, thick-billed murre *Uria lomvia*, black guillemot *Cepphus grylle*, northern fulmar *Fulmarus glacialis* and glaucous gull *Larus hyperboreus*, and several marine mammal species, i.e. hooded seal *Cystophora cristata*, harp seal *Pagophilus groenlandicus*, ringed seal *Pusa hispida*, narwhal *Monodon monoceros*, and polar bear *Ursus maritimus*. All species muscle samples, with the exception of those of black guillemot, polar bear and ringed seal, were collected during the summer seasons of 2013-2015 under the NOW project. Muscle tissue of polar bear as well as a vast temporal collection of black guillemot and ringed seal muscle tissue were gathered under the Arctic Monitoring and Assessment Programme as well as several sampling campaigns organized by the Department of Bioscience of the Aarhus University. Moreover, we include published data on several seabird species sampled in 1998 in the NOW (Hobson et al. 2002). Using the muscle tissue stable C, N and S isotope data we calculated species-specific stable isotope niche (IN) size, which are a promising proxy for a species' ecological niche, and for calculating the species' estimated tropic position (TP) using two different trophic enrichment factors considered plausible for arctic ecosystems, i.e. TEF=3.8 (Hobson and Welch 1992; Hobson et al. 1994) and a scaled TEF approach (Hussey et al. 2014).

Firstly, we consider the inter-specific seabird and marine mammal trophic relations at the present day, using the contemporary stable C and N isotope data (Fig. 1). No IN overlap exists between the seabird and marine mammal species, while within each group competition for resources seems to occur. Three trophic groups among the seabird species can be observed. Common eider (TP=2.56) and little auk (TP=2.82) feed without competition within the lowest group, while an intermediate group was composed by black-legged kittiwake (TP=3.09), black guillemot (TP=3.20) and Brünnich's guillemot (TP=3.15), of which

North Water (2013-2015) versus North Water (1998)

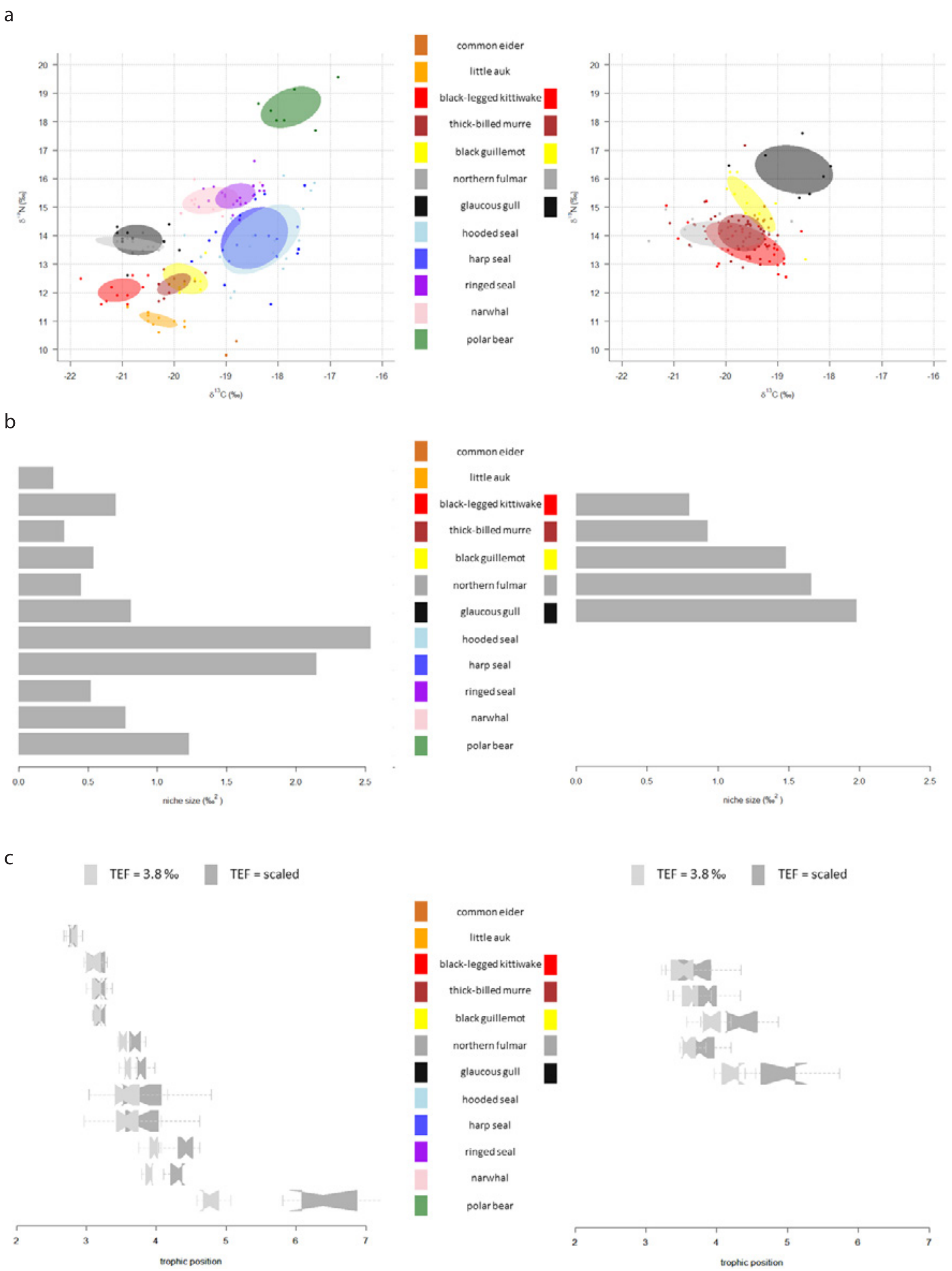


Figure 1. a: Comparison of stable isotope niche topography of selected seabird and marine mammal species sampled in the NOW during 2013-2015 (left) versus in 1998 (right). b and c: stable isotope niche sizes and estimated trophic positions for selected seabird species in the NOW during 2013-2015 (Left) versus in 1998 (right). The 1998 data was published by Hobson et al. 2002.

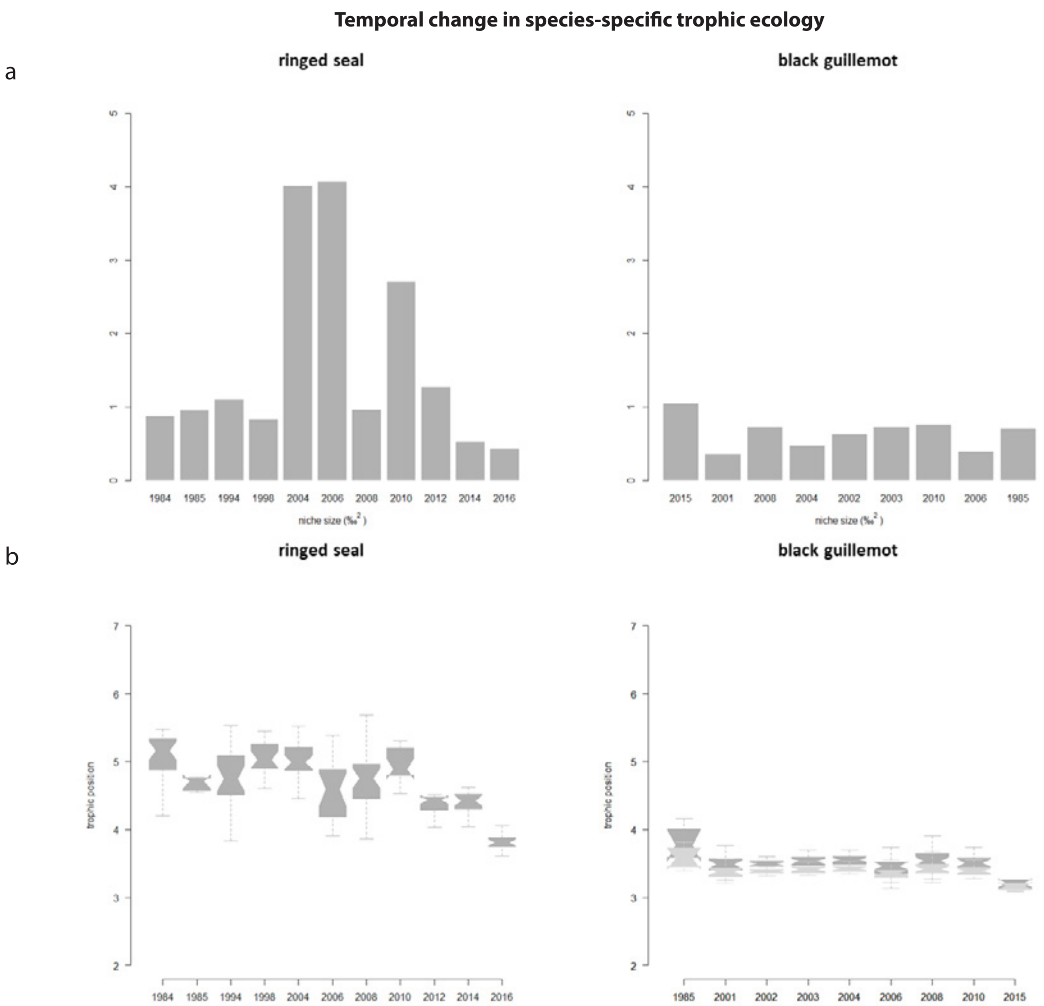
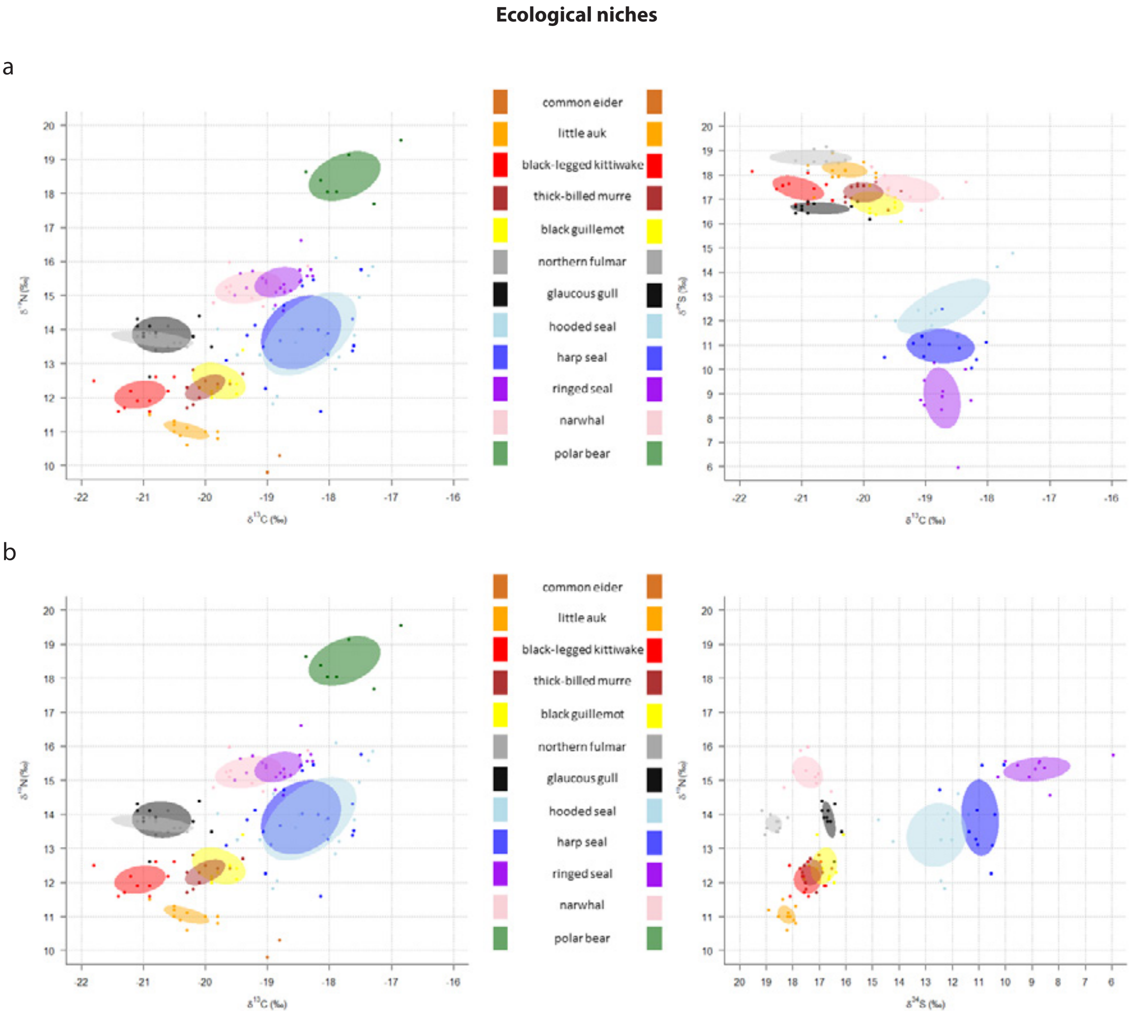


Figure 2. a: temporal variation in stable isotope niche size of NOW ringed seal and black guillemot. b: temporal variation in estimated trophic positions of NOW ringed seal and black guillemot.

the latter two show considerable IN overlap. Similarly, glaucous gull (TP=3.56) and northern fulmar (TP=3.53) show considerable IN overlap, together constituting the highest trophic seabird group. Positioned at the same TP as glaucous gull and northern fulmar, though dependent on marine carbon sources only, harp (TP=3.58) and hooded seal (TP=3.56) show significant IN overlap, while ringed seal (TP=4.00) and narwhal feed higher up the food web (TP=3.92).

Secondly, we consider the data for inter-specific trophic relations for certain seabird species, i.e. black-legged kittiwake, thick-billed murre, black guillemot, northern fulmar and glaucous gull, at the present day compared to published data for the same species in 1998 (Hobson et al. 2002), using the contemporary stable C and N isotope data (Fig. 1).

This temporal comparison shows clearly that these seabird species interacted very differently 15 years ago. The northern fulmar back in 1998 overlapped in IN with the black-legged kittiwake as well as the thick-billed murre, rather than with the glaucous gull as observed for the present day. In fact, in 1998 the glaucous gull and the black guille-



mot were the only two species whoms IN did not overlap with the other seabird species, suggesting higher dietary competition in 1998. However, all species' IN sizes, except those of black-legged kittiwakes, are currently significantly smaller (Fig.1b), possibly indicating a higher degree of prey specialisation. Confirming this is the observation that all species except the northern fulmar and glaucous gull feed at the present day an entire trophic position lower than in 1998 (Fig. 1c). When considering stable C and N isotope muscle data for ringed seal and black guillemot it is again clear that the TP of these species has been declining gradually since the onset of sampling in the early 1980s (Fig. 2b) and may be a result of foraging on lower TP prey. Nonetheless, no clear gradual decline in IN size is apparent despite considerable inter-annual variation (Fig. 2a). This apparent Increasing dietary specialisation and foraging on lower TP prey may indicate a decreasing species diversity and carrying capacity due to the observed decreasing primary production in the northern Baffin Bay and NOW (Bergeron and Tremblay 2014), and may in fact also be another message of the Altantification of the Arctic (Vihtakari et al. 2018).

Figure 3. Comparison of a C on N biplot with a C on S biplot (a) and an S on N biplot (b).

Finally, considering the additional stable S isotope data in the same recent muscle samples shows that the additional analysis for these stable isotope allows discrimination where the seal species are grouped together separately from the other species (Fig. 3a), possibly indicating different spatial foraging, and hence allows for an overall better IN discrimination (Fig. 3b). Nonetheless, more prey species stable isotope signatures are required to fully interpret the true applicability of this triple isotope method.

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Evidence for increasingly rapid destabilization of coastal arctic foodwebs

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Abstract

Understanding the complex dynamics of environmental change in northern latitudes is particularly critical for arctic avian communities, which are integral components that maintain biological connections between the mid- and northern latitudes. We report on studies done in 2010 – 2015 in Northwest Greenland as part of a larger effort focused on understanding the population dynamics of High Arctic marine bird communities. We use several data sources and analysis techniques, including diet data, stable isotopes, and Bayesian inference, to identify the potential relationships between ecological response of coastal marine birds and rapid environmental change such as increased freshwater runoff from glacier melt, inshore oceanographic change, and cascading trophic perturbations. Our preliminary results indicate that community-wide spatial and temporal dynamics of this high Arctic marine bird community are far greater during our study period than was evident in past decades. We also find that the magnitude of change is greater here in the high Arctic (eg., 78 °N) compared to low Arctic coastal marine ecosystems (eg., western Aleutian Islands, 53 °N). In particular, we show that the ecological patterns observed within such widespread arctic species as Dovekie (*Alle alle*), Thick-billed Murres (*Uria lomvia*), and Black-legged Kittiwakes (*Rissa tridactyla*) indicate diets are strongly perturbed from a decade earlier. Moreover, we find that the variance in environmental and ecological parameters is increasing over relatively small temporal and spatial scales. We hypothesize that these fine-scale changes are related to oceanographic and trophic-level responses to increased freshwater injection into coastal waters, in addition to larger- scale perturbations possibly related to a cascade of climate-related factors.

Introduction

It seems now indisputable that the Arctic is undergoing dramatic changes in climate, accompanied by a cascade of effects associated with warming temperatures and consequent environmental change. Coastal arctic ecosystems are particularly vulnerable given that they are at the interface of marine and terrestrial environments of the Arctic, and recent evidence suggests that change is accelerating in these regions compared to coastal systems outside of the Arctic. Coastal marine ecosystems are strongly influenced by fluxes of freshwater, nutrients, and organic matter from river inputs, a factor particularly important in the Arctic (Fig. 1).

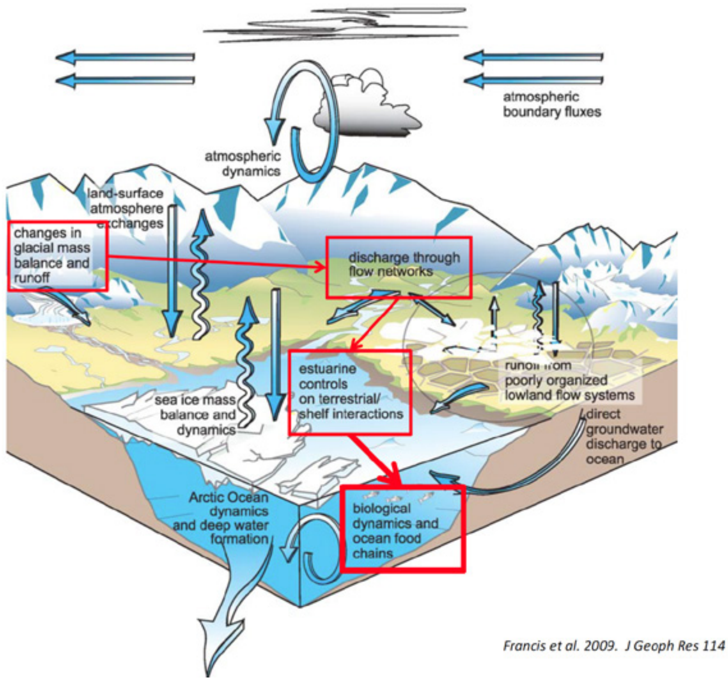


Figure 1. Interconnection of hydrology and oceanography in coastal Arctic systems.

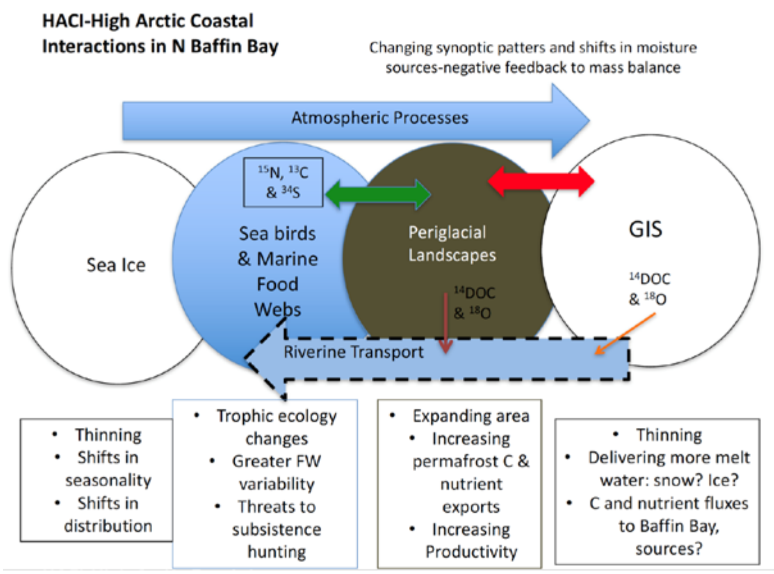


Figure 2. Dynamic interactions among coastal hydrographic systems and food webs.

Overall, the Arctic Ocean receives about 10% of the global river discharge but only comprises about 1% of the global ocean volume. Consequently, Arctic coastal ecosystems are strongly influenced by the terrestrial environment, which often imparts estuarine features at large and small scales (Fig. 2).

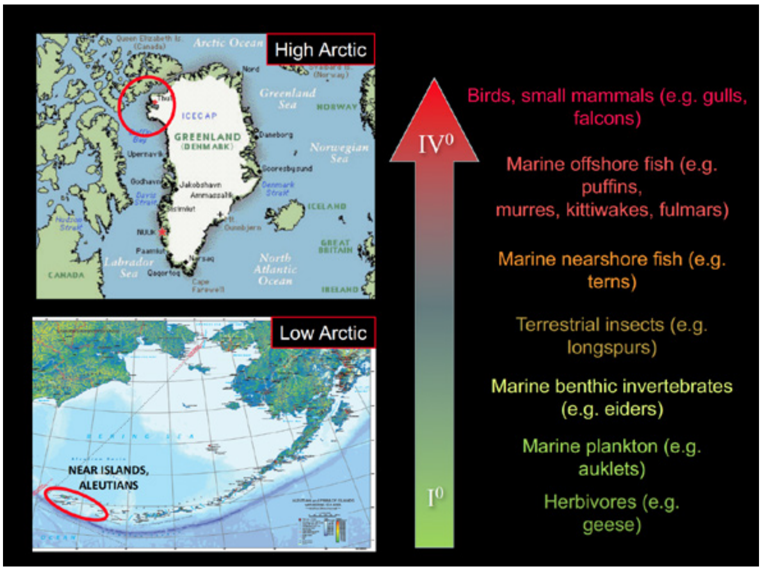


Figure 3. Trophic levels of marine birds in coastal Low Arctic and High Arctic regions.

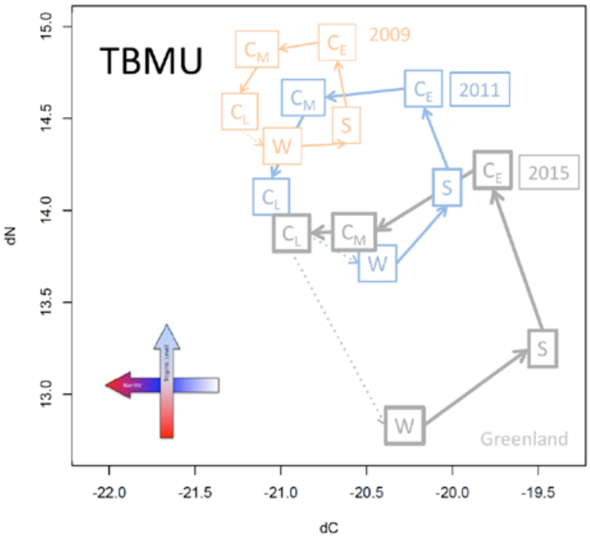
Marine food webs are strongly influenced by physical oceanographic factors as described above, and it is well known that primary and secondary productivity in Arctic shelves are often controlled by these changes, with consequent cascading effects upward into upper trophic levels (Fig. 3.)

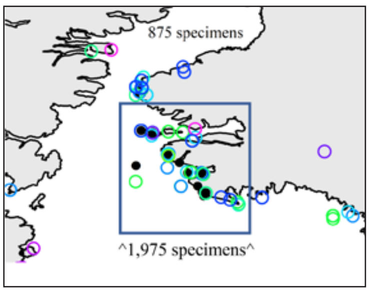
In order to better understand Arctic foodweb dynamics on fine temporal and spatial scales, we are utilizing the foraging ecology of breeding seabirds as an indicator of oceanographic conditions and local prey availability in coastal northwest Greenland. Seabirds serve well as indicators of foodweb dynamics because they are accessible during breeding season and their diets span many trophic levels. Different prey species, especially plankton, are adapted to different oceanographic conditions, and the strong link between distribution/abundance and hydrography can help inform us on the complexity of food web dynamics. We are utilizing changes in the proportion of stable isotopes of carbon $\delta^{13}C$ and nitrogen $\delta^{15}N$ as proxy indicators of diet. We are particularly interested in understanding how stochasticity and variability in climate through hydrography may affect food web stability and dynamics.

Results

Stable isotope values from whole blood and feathers collected from Thick-billed Murres in the central region of the NOW area are shown in Figure 4. The centroids of the temporal range of stable isotope values of Carbon and Nitrogen vary seasonally, but the key aspect shown here is the decreasing nitrogen ratios (indicating feeding at lower trophic levels) and the increasing variance in values.

Figure 4. Stable isotopic biplot of dN and dC obtained from Thick-billed Murres through time. All samples were collected from the Central region of the NOW area. Squares indicate centroids of the 95% confidence ellipses of data values. C_E=Central region, early (July 1-15); C_M=Central region, mid-season (July 1-15); C_L=Central region, Late (July 1-15); S= Spring (~March – May); W = Winter (~ November – February).





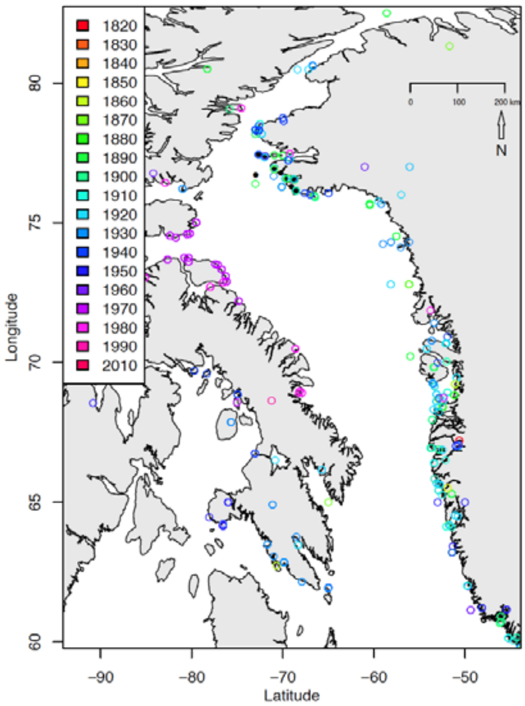


Figure 5. Total number of archival bird specimens since 1820. Specimens are curated throughout the world's natural history museums.

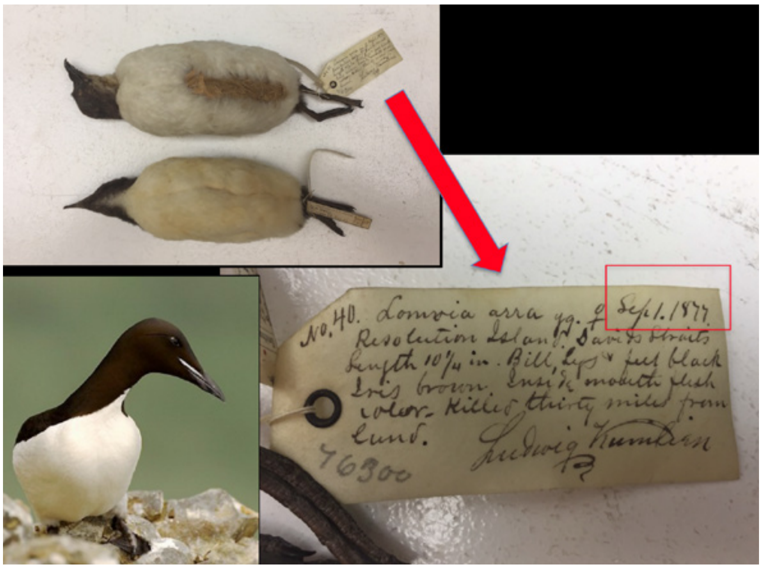


Figure 6. Thick-billed murre specimens collected from Resolution Island, Davis Straits by Leonard Stejneger on September 1, 1877.

Next Steps

We plan to continue investigations into using stable isotopes as indicators of temporal changes in diet using archival specimens collected from the 19th and 20th centuries (Fig. 5). Data from these early specimens can provide insights into the dynamics of change during periods of relative stability by comparison to the present times. Scientific specimens are relatively free of contaminating substances, and distinguished by an abundance of collection data relevant to identify locality, dates, and ecological correlates (Fig. 6.)

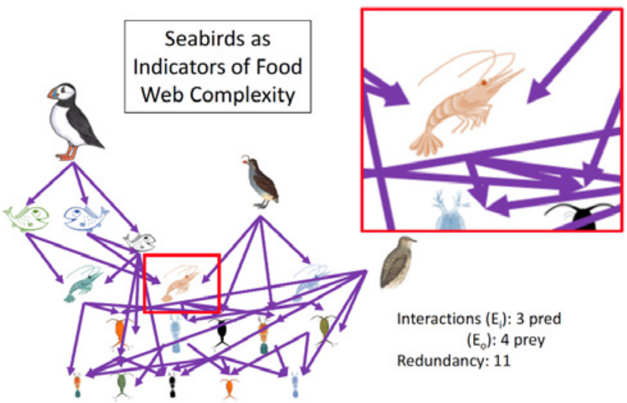
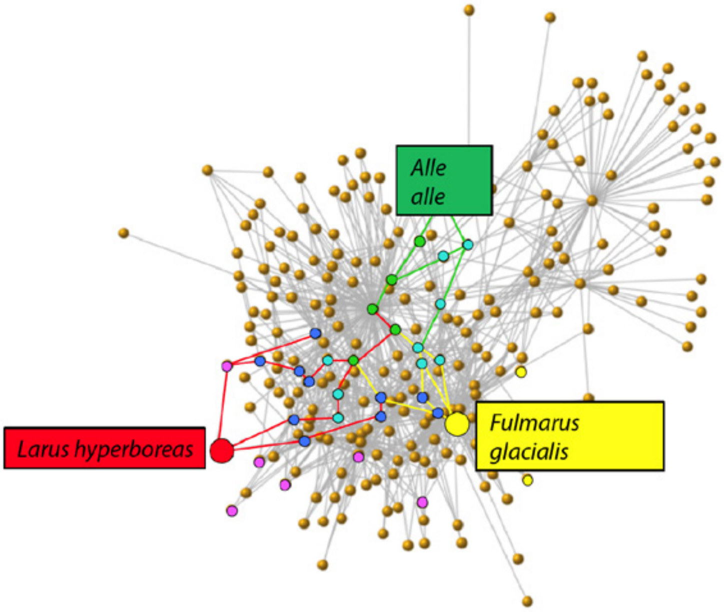


Figure 7. Diagram of the interconnectivity of seabird diet items in a localized foodweb.

Figure 8. Conceptualized network diagram of the NOW region of Northwest Greenland.



These data, combined with correlative information relating to abundance and distribution, are particularly useful for utilizing seabirds as indicators of food web complexity. Natural history data on seabird diets, obtained by many researchers over time and space, provide fairly comprehensive lists of prey items. All the marine species are interconnected through localized food webs, which means that seabirds feeding at the top of the foodwebs are ultimately connected through lower trophic levels. This feature means that patterns observed in one seabird species is simultaneous reinforced by patterns in other seabirds by their interconnection (Fig. 7).

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Why is the North Water Polynya Region such an important breeding area for little auks (*Alle alle*)?

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The North Water Polynya Region (NOW) in Smith Sound and the Northern Baffin Bay is a highly productive area with great importance to many seabirds and marine mammals. Among them are the little auk, the most abundant seabird in the North Atlantic. Approximately 33 million pairs, or > 80 % of the global population, breed within a range of 325 km along the Greenlandic shores within the NOW. In this presentation, we discuss what makes NOW such an important area. We base the discussion on data on oceanography, little auk abundance and their zooplankton prey along the west Greenland coast between 73 and 78.5°N in August 2015 as well as other available data on zooplankton abundance along the west coast of Greenland. Furthermore, we include investigations of little auk chick meals and evaluate the potential impact of little auk foraging on the zooplankton community. Our analyses emphasize the tight linkage between the little auks and *Calanus* zooplankton during the chick-rearing period. In NOW, little auks were mainly feeding their chicks *Calanus* 3 to 5 mm long, *C. hyperboreus* in particular (Fig. 1). As a consequence of the large little auk breeding population, the potential mortality of the older stages of *Calanus* caused by their foraging was significant. The distribution of little auks during the breeding season depends on suitable nesting sites and access to adequate prey, both when the birds first arrive to the breeding area, and later when they feed their chicks (Fig. 2). All of which, under current climate conditions make the northern Baffin Bay the major little auk breeding area.

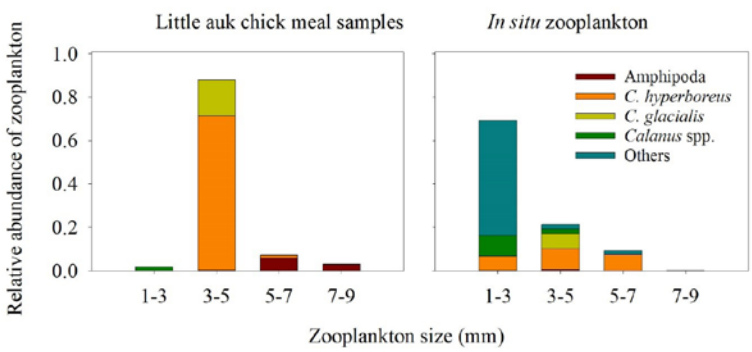
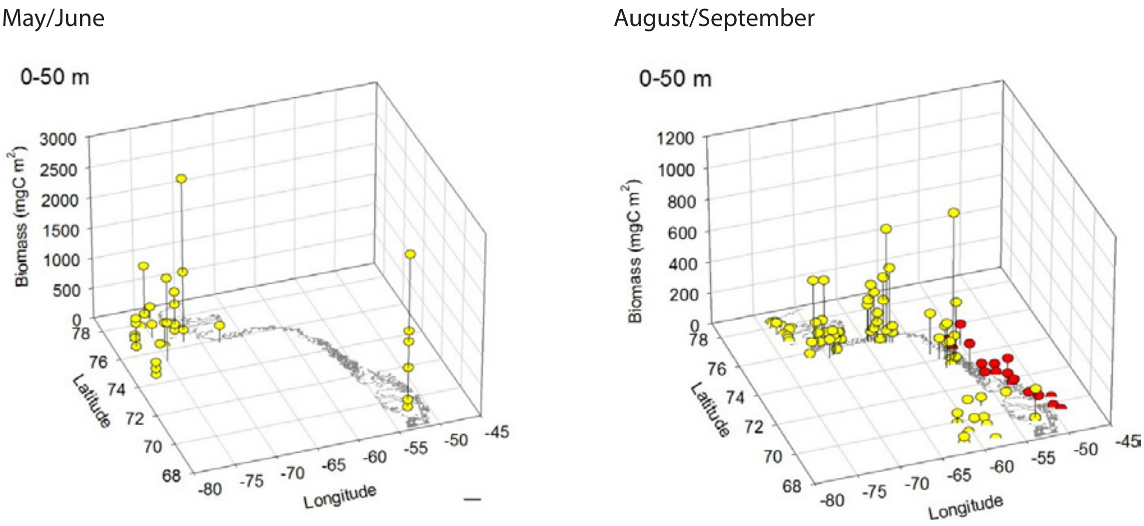


Figure 1. Prey selected by little auk for feeding their chicks in the Annikitsoq colony and the in situ zooplankton size composition.



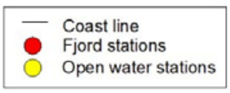


Figure 2. The biomass of the preferred prey (Calanus hyperboreus) of little auks along the west coast of Greenland from Disko Bay in south to North Water Polynya Region in north.

The North Water Polynya: A true biological hotspot for polar cod *Boreogadus saida* recruitment?

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The North Water (NOW) is one of the largest polynyas in the world and has for a long time been considered as an important oasis for arctic marine life. According to recent studies, the productivity in the polynya has potentially been decreasing in the last 20 years. Therefore, the NOW is perhaps no longer the important biological hotspot it used to be.

In arctic marine ecosystems, polar cod (*Boreogadus saida*), the main pelagic prey species, play a key role in transferring energy from zooplankton and primary producers to top predators and, ultimately, to Inuit communities. During the summer season until October, juvenile polar cod are mostly located in the top 100 m near the surface, their survival thus being affected by changes in sea ice concentration and sea-surface temperatures (SST). Bouchard et al. (2017) recently showed that in the last decade an earlier ice breakup and higher SST in different regions of the Canadian Arctic resulted in a higher biomass of juvenile polar cod at the end of the summer and therefore in higher recruitment to the population.

This study addresses two main questions:

1. What processes result in a higher juvenile polar cod biomass in the autumn when the ice breakup is early?
    - Is a larger fall biomass resulting simply from a longer growth season at higher STT enhancing the survival of early hatchers (Bouchard et al. 2017)?
    - Or is an overall more productive summer ecosystem enhancing survival?
2. Is the North Water Polynya a biological hotspot for polar cod recruitment?

To answer these questions, hydroacoustic data were continuously recorded in 10 regions of the Canadian Arctic (including the NOW Polynya) defined by the Canadian Ice Service. The data were recorded in August from 2010 to 2016 on board the CCGS Amundsen and the F/V Frosti using a hull-mounted EK60 multi-frequency echosounder. Pelagic nets were deployed to document the zooplankton and fish assemblages and to validate acoustic echoes. Remote sensing data were used to estimate sea-ice concentration (Canadian Ice Service data) and primary production (Aqua MODIS satellite data). For each region and year, the week during which ice concentration fell below 50% was used as the date of ice breakup. Bloom start date was determined as the day when chlorophyll-a concentration exceeded 20 % of the maximum daily mean chlorophyll-a concentration over the summer.

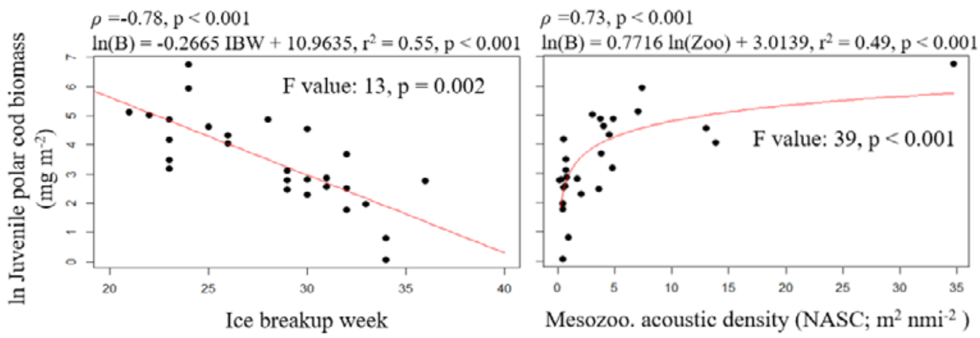

Figure 1. Juvenile polar cod biomass in August in relation to the ice breakup week (left panel) and to the mesozooplankton acoustic density in August (right panel). Red lines are the linear regressions. ρ is the Spearman rank correlation. F values of a two-way ANOVA test are presented.

During the 2010-2016 period, the mean chlorophyll-a concentration over the summer in the different regions was negatively correlated to the ice breakup week ($\rho = -0.49$, $p = 0.004$) whereas the bloom start date was positively correlated to the ice breakup week ($\rho = 0.80$, $p < 0.001$). Hence, the earlier the ice breakup in the different regions, the earlier the phytoplankton bloom and the higher the primary production over summer. Mesozooplankton acoustic density in August was, in turn, positively correlated with the mean chlorophyll-a concentration during the summer ($\rho = 0.53$, $p = 0.003$), and negatively correlated with the bloom start date ($\rho = -0.71$, $p < 0.001$) and with the ice breakup week ($\rho = -0.58$, $p < 0.001$).

Juvenile polar cod biomass in August was strongly negatively correlated with ice breakup week and positively correlated with mesozooplankton density (Fig. 1). Mesozooplankton density explained 3 times more variability in polar cod biomass than did ice breakup week (ratio of the F statistics in the two-way ANOVA). Hence, we conclude that environmental conditions are important for the survival and recruitment of juvenile polar cod, but the productivity of the ecosystem and the resulting density of their mesozooplankton prey is likely more important.

The NOW shared by Canada and Greenland was among the most productive areas of the survey region from 2010 to 2016 (represented by the NWBB and Lancaster Sound regions in Figure 2). Juvenile polar cod biomass, mesozooplankton acoustic density and chlorophyll-a concentration in the polynya were among the highest during the study period. However, other regions such as the Mackenzie Shelf in the Beaufort Sea and Western Baffin Bay (WBB) were as or more productive than the NOW. Other regions of the Canadian Arctic Archipelago (Coronation-Maud, Larsen-Victoria and Peel Sound) presented low productivities. We conclude that the NOW is still a biological hotspot for polar cod recruitment, but maybe not the hottest spot in the Canadian-Greenlandic Arctic.

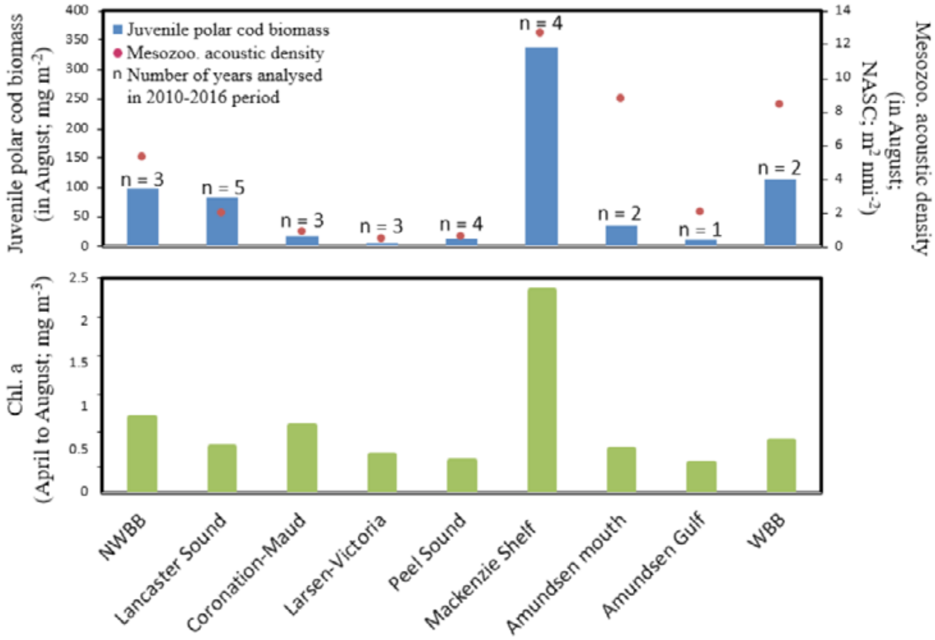

Figure 2. Mean values of juvenile polar cod biomass in August, mesozooplankton acoustic density in August, and chlorophyll-a concentration during summer from 2010 to 2016 in different regions of the Canadian Arctic.

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Identifying climatic drivers of range expansion of a boreal species into the North Water

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Ongoing climate change impacts abundances and redistribute species, resulting in local biodiversity loss, species extinction or introductions and regime shifts. While such climate impacts are well studied in many regions, the consequence of climate change in the Arctic, and particular Greenland, remains understudied, despite the region experiences warming at elevated rates. The warming of the Arctic affects the biota. Increasing temperatures diminishes the sea ice extent, which negatively impact Arctic species associated with sea ice ecosystems. However, Arctic warming may benefit other more exotic species as new habitats become available, hereby facilitating increased abundance and local biodiversity and expand poleward geographical ranges.

Current knowledge on the distribution, genetic structure and population dynamics of temperate species in Greenland are limited. Therefore, we study blue mussels (*Mytilus* spp.) living in the intertidal zone of Greenland. Blue mussels are foundation species in the marine environment where they play a central ecological role and provide ecosystem services. For instance, blue mussels create hard substrates increasing the abundance of other species as they are able to form mussel beds providing complex microhabitats and food. Climate-induced changes in blue mussel abundance and distribution can, therefore, affect community structure of the coastal ecosystem.

Traditionally, it was believed that only one blue mussel (*Mytilus edulis*) species was found in the Arctic. However, we show that two species of blue mussels are commonly found in West Greenland, and three blue mussel species are found across the Arctic (Fig. 1; Mathiesen et al. (2017)). These results show, that the common blue mussel *M. edulis* currently reside on the southern side of the North Water Polynia (NOW). Being a temperate species, *M. edulis* could respond to a warmer climate by expanding into the NOW, and increase their abundance, growth rates and fitness, which may have cascading effects on the NOW ecosystem.

According to a common hypothesis, the northernmost distribution limit of marine invertebrates will be controlled by low water temperatures. However, *M. edulis* show no physiological limitations in cold waters (See Thyrring et al. (2015)). Thus, low water temperature per se does not constrain the survival and distribution of this species in the NOW region. Instead, exposure time to air is central for the survival of intertidal species. The lower thermal limit of blue mussels is -13°C.

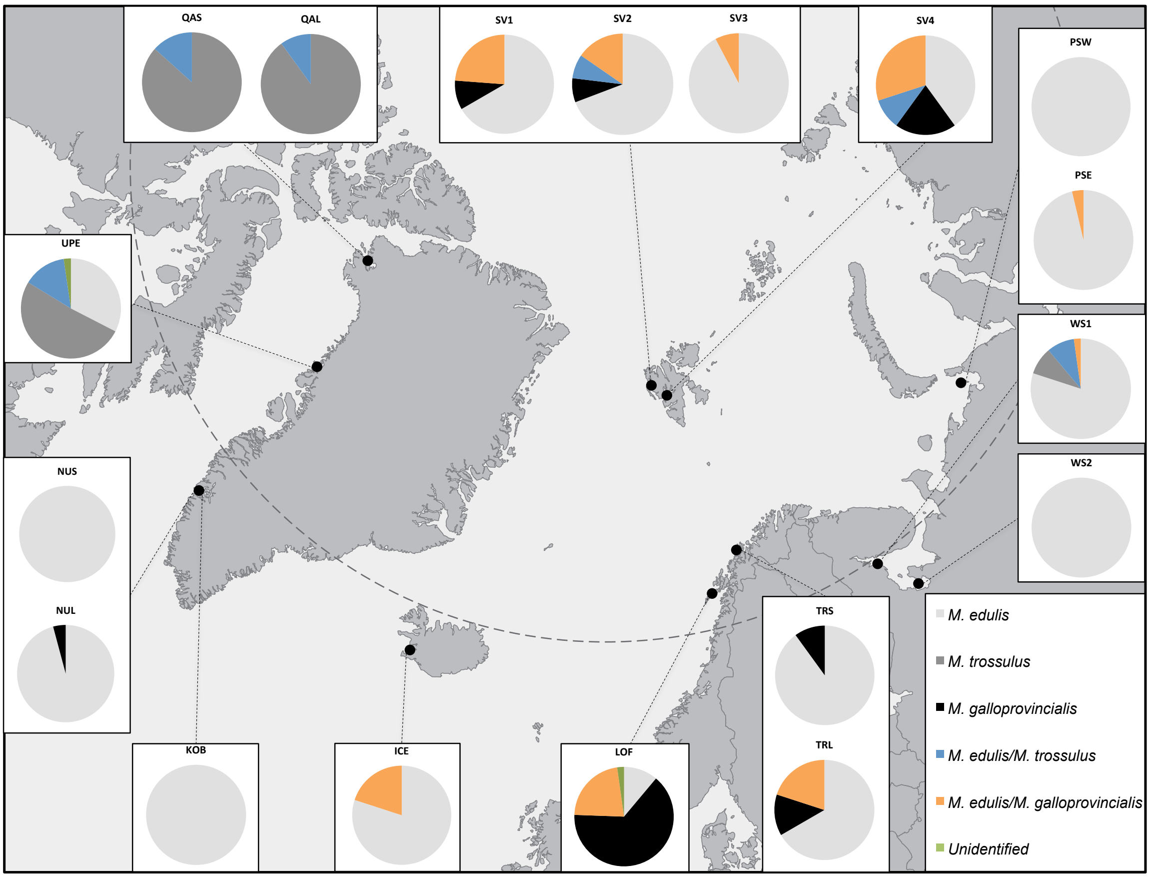

Figure 1. Map showing the different sampling locations and the proportion of three different Mytilus *species and inferred hybrids at each location across the Arctic. Source: (Mathiesen et al. 2017).*

Low air temperatures explain why blue mussels in northwest Greenland were only found in the lowest intertidal zone or in microhabitats between boulders, in crevices or underneath macroalgae boulders; here they are protected from lethal sub-zero temperatures during low tide (Fig. 2; Thyrring et al. (2017)). Since the 1990s, the number of days with temperatures below -13°C has fallen by up to 57 per cent in Greenland. Since cold days are the limiting factor for mussel survival in the Arctic, we expect that blue mussels will increase their abundance and vertical distribution into the NOW as the region warms and become more ice-free. Because blue mussels are key species providing habitats, future potential expansions will have cascading effects on the coastal ecology in this sensitive region.

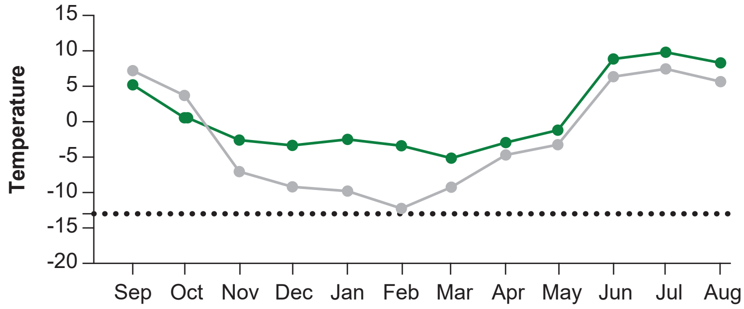

Figure 2. Gaps between stones in the tidal zone create a protected environment for mussels. Here, temperatures (green line) are many degrees warmer than the surrounding air (grey line) in winter. Source: (Thyrring et al. 2017).

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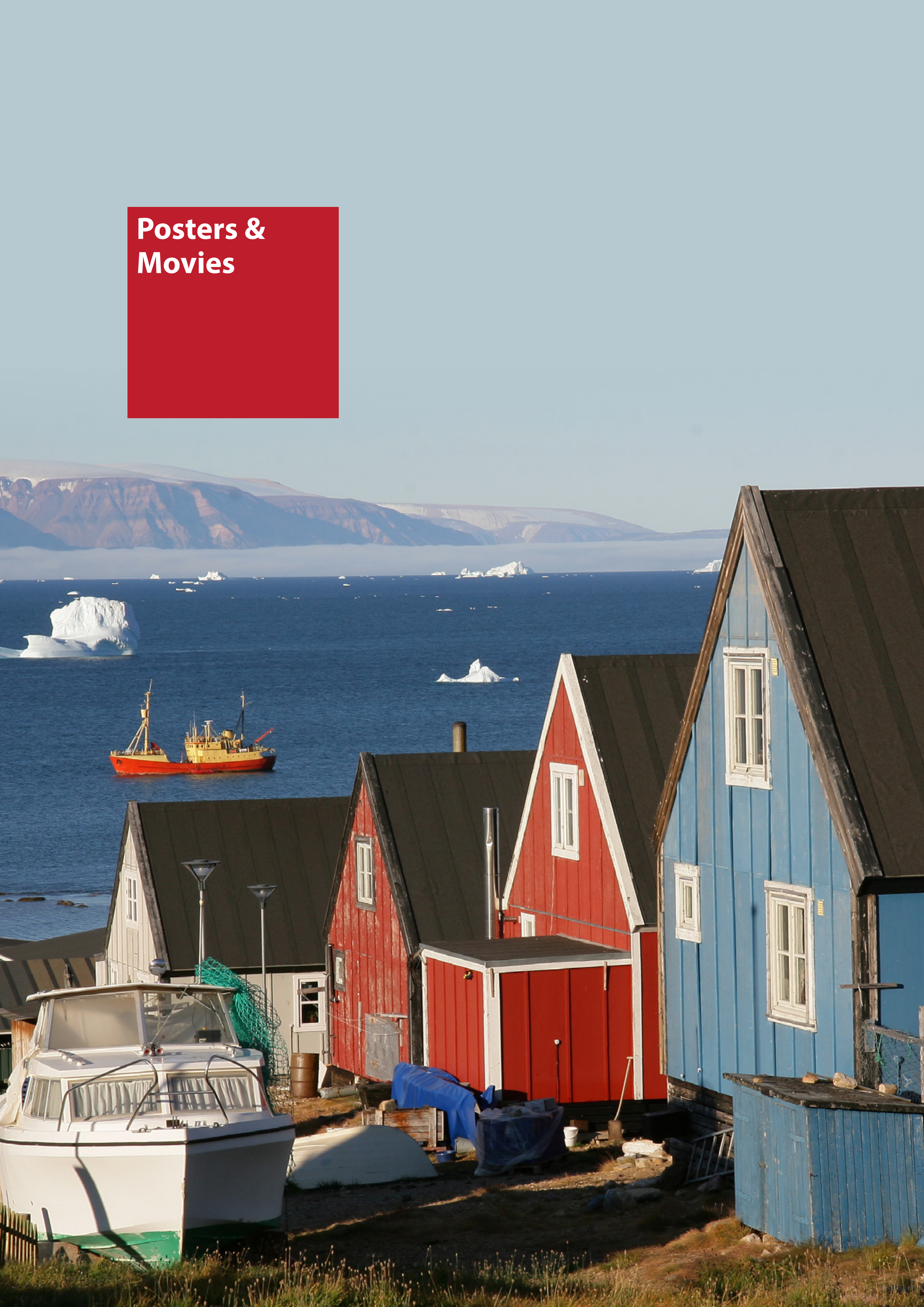
Posters & Movies



Sentinel-2 Image Mosaic of Greenland

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The utilization of satellite images (Fig. 1) of the surface of the Earth is growing ever popular in many different fields of commercial and scientific activities such as within research on the cryosphere, vegetation, wetlands, wildfires, urban development, sea ice and geology. The images cover large areas and they hold a number of internal layers, 'bands', each covering different parts of the spectrum of light visible or not visible to the human eye, but however providing extended possibilities of analysis not achievable with a standard photo only.

The Landsat and Sentinel imaging satellites

The European Union and the United States of America maintain two closely identical satellite programmes for observation of the Earth using optical image sensors. In the USA, the National Aeronautics and Space Administration (NASA) and the US Geological Survey (USGS) develop and run the Landsat series program, most recently with the Landsat-8 in orbit around the Earth since 2013. The Landsat programme is the most elongated series of missions imaging the Earth since 1972.

In contrast, the Copernicus programme of the European Commission and European Space Agency is quite recent with the first launches of the Sentinel series commencing since 2014. Both the data from Landsat and Sentinel are continuously released to the public domain to be applied to any purpose, scientifically as well as commercially.

Since the satellites cover parallel strips of the Earth in the widths of respectively 185 and 290 km and revisit the same area with 16 and 5-7 days interval, it is possible to produce a complete mosaic over a greater region within few months – depending on the weather conditions. Although the satellites have near-polar orbits, they have a maximum extent of c. 81° latitude, so for the northernmost areas of Greenland other satellite data must be included.

Landsat-8 has a detail of one size of a cell (pixel) covering a square of 30 m on the ground, or 15 m in the panchromatic (greyscale) band; and for Sentinel-2, the minimum cell size cover 10 m on the ground.

Mapping Greenland with satellite images

For the land and ice area of Greenland, a couple of mosaics already exist. The Greenland Ice Sheet Mapping Project (GIMP) of the Byrd Polar and Climate Research Center, Ohio State University, has produced an

Figure 1. Map poster displaying the nationwide coverage of the Sentinel Image Mosaic of Greenland. Illustration by Alexandra Højgaard Wood, imagery of ESA Copernicus Programme.

image mosaic (GIMP 2000 Imagery Mosaic) from Landsat-7 and RADARSAT-1 data from the years 1999 to 2002 (Howat et al. 2014). However, the mosaic are kept divided into the individual spectral bands much usable for analysis, but more complicated to visually display in natural colours.

The College of Global Change and Earth System Science at Beijing Normal University and Greenland Institute of Natural Resources in Nuuk have produced a more recent data set based on Landsat-8 images from mainly 2015, composed into a true colour mosaic (Chen et al. in prep). The mosaic does not utilize the possibilities of sharpening the image data from the 30 m to 15 m using the panchromatic band, so the result is consequently less detailed and more difficult to interpret; however, the colour balancing of the mosaic is harmonious and colourful.

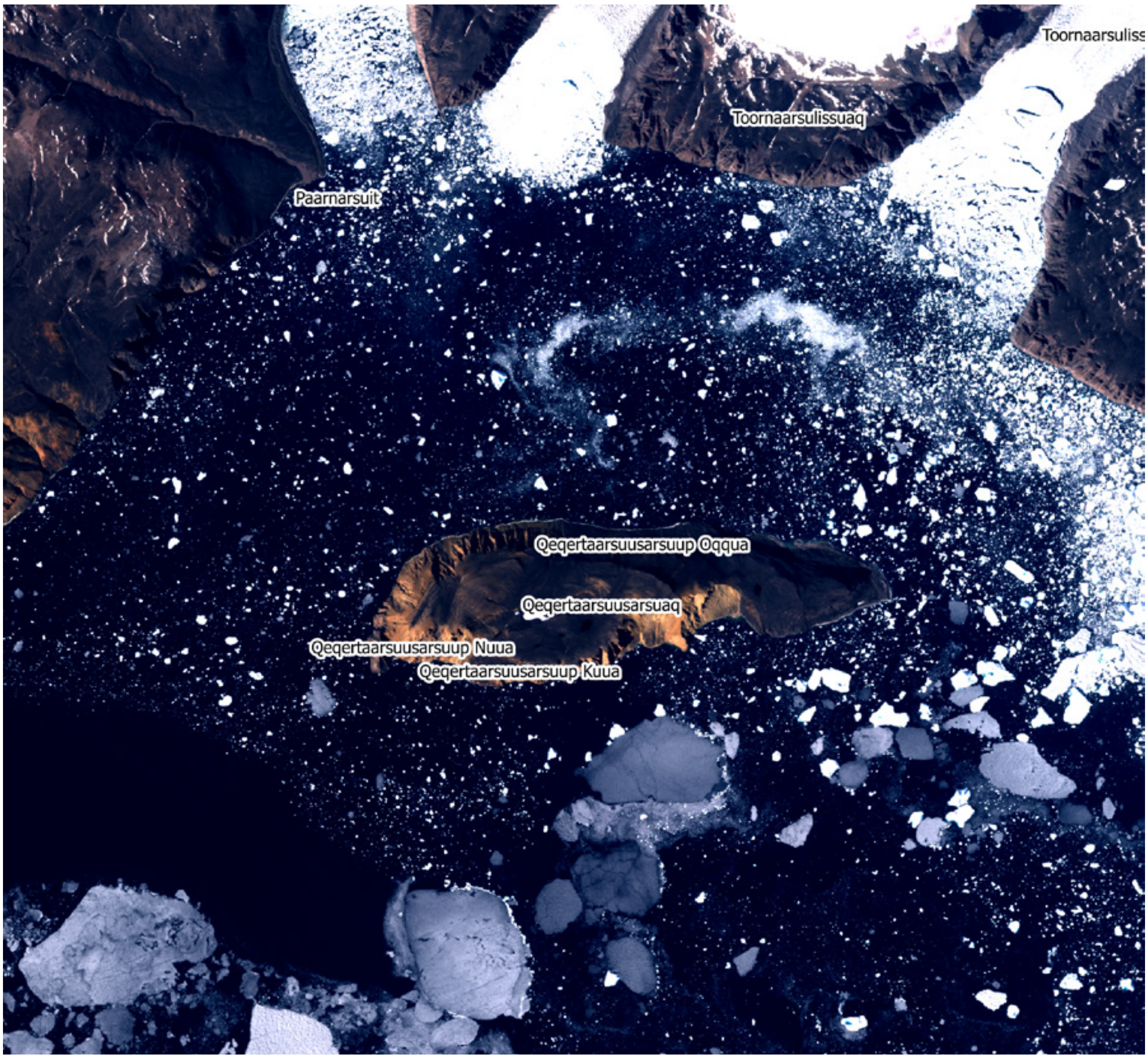

Figure 2. Detail of the Sentinel-2 Image Mosaic of Greenland displaying the Qeqertaarsuusarsuaq Island in the Kangerlussuaq Fjord near the town Qaanaaq and the hamlet Qeqertat. Imagery of ESA Copernicus Programme.

Selecting the data for a new satellite image mosaic of Greenland

Compared to Landsat-8, the Sentinel-2 A and B pair of satellites has the most frequent revisit schedule of 5 days over Greenland, the broadest geographical coverage (swath), and also the greatest level of detail. The release of the Sentinel data into the public domain has initiated commercial online services (sentinel-hub), which makes download and data management convenient to the users. Accordingly, we chose to use Sentinel-2A/B data to build the mosaic.

The optical satellites cannot penetrate covers of clouds, smoke or haze. However, the metadata hold information on the percentage of cloud cover for each image scene, so they can be filtered accordingly. The scenes were selected to being mostly cloud free, below 20 %, and of minimal snow and ice cover using scenes from the months July, August, and September, also being the periods of the highest sun elevation minimizing shadows from mountains and steep slopes. The selected scenes are of the summer 2017, although scenes of the summer 2016 are applied to fill in minor gaps.

Because the satellite constellation hover 180 degrees apart, Sentinel-2 does not reach the northernmost area of Greenland, so to fill in this gap and create a coherent map, images from the MODIS/Terra Corrected Reflectance (True Color) data of 250 m ground resolution has been chosen to cover area with no data. Scenes covering the Greenland Ice Sheet were not included in the mosaic to lower the digital disk space required.

The Sentinel-2 Image Mosaic of Greenland 2017

We have combined all the different images together into a full-cover image mosaic covering Greenland in the summer season 2017 (Fig. 2 and 3). The format is in GeoTIFF, which can be downloaded from ftp://ftp.natur.gl/gis and opened and analyzed in GIS software. Likewise, a graphically edited and visually appealing PDF poster for printing is available (Fig. 1). The GIS version of the mosaic will be included in the national online repository of base maps covering Greenland, with the remote hope to be able to create an updated version within 5 year.

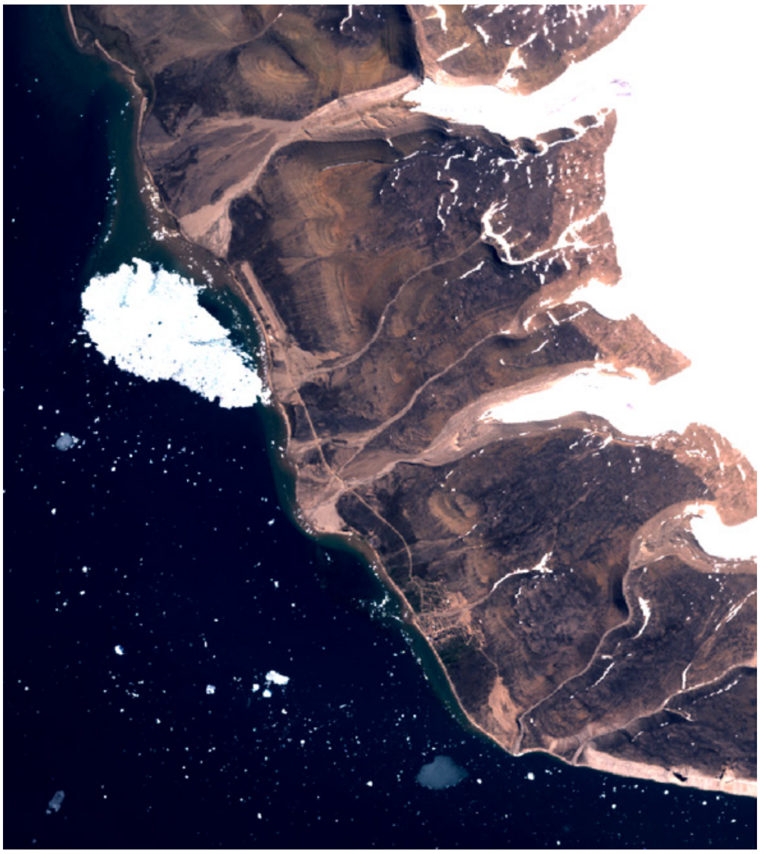

Figure 3. Detail of the Sentinel-2 Image Mosaic of Greenland displaying the town of Qaanaaq. Visible is the man-made landing strip and roads as well as natural features such as glaciers, river valleys, and sea ice, while relatively smaller features such as houses are not clearly visible.

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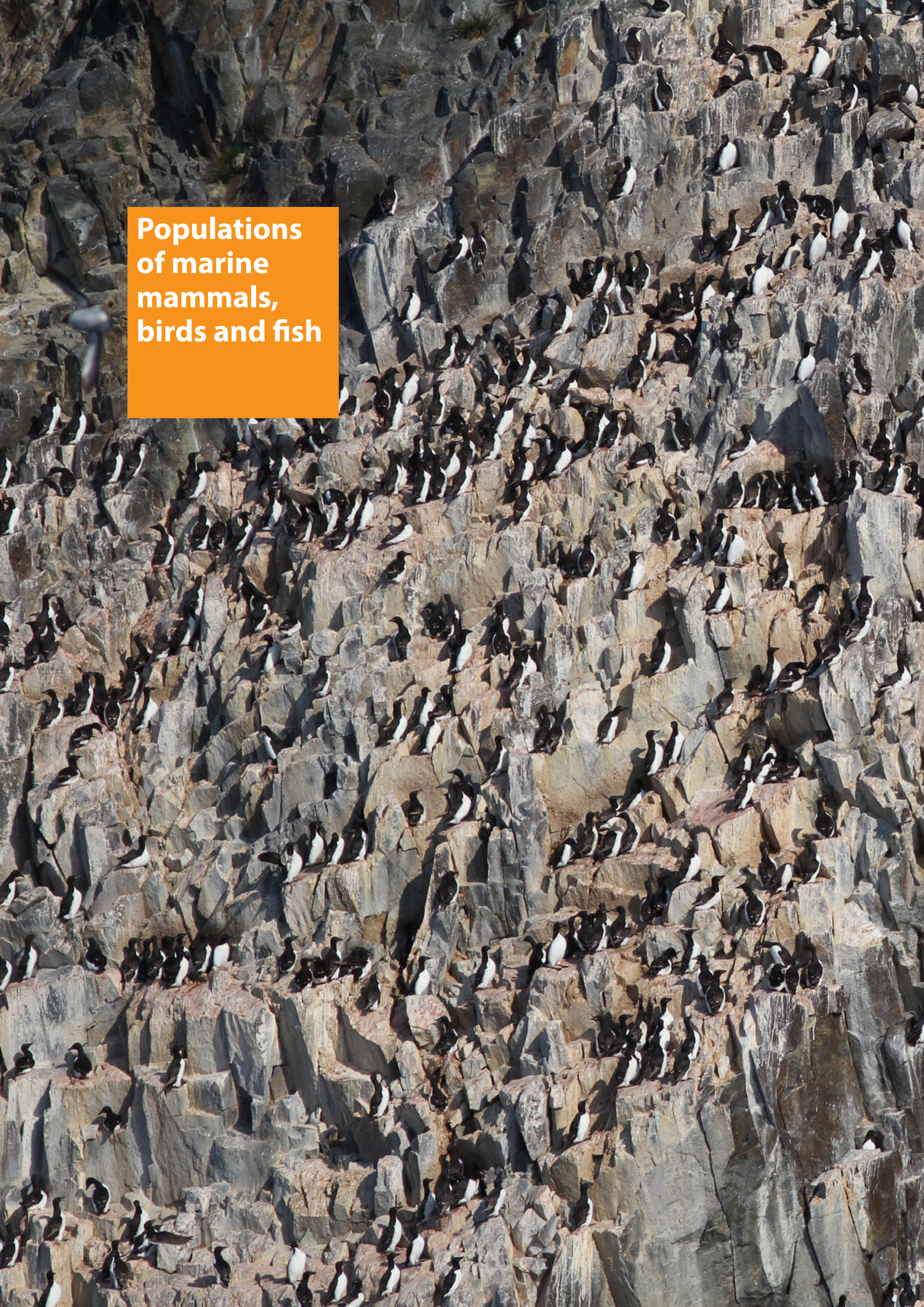
https://www.sentinel-hub.com/

https://apps.sentinel-hub.com/eo-browser/

Populations of marine mammals, birds and fish



Keynote talk

Populations of marine mammals, birds and fish in the North Water

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The North Water/Smith Sound is known for its conspicuous numbers of marine mammals and sea birds. Four species of seals, the walrus, the polar bear and three species of whales represent the regular inhabitants of marine mammals in the North Water and its summer extension in Smith Sound (Fig. 1). In addition, 2-3 boreal whale species occasionally visit Smith Sound in summer.

Beluga whales occur in large numbers in the eastern part of Smith Sound from fall through spring with scattered individuals in coastal areas during summer. Most belugas move to the Canadian Arctic Archipelago for summering in estuaries around Somerset Island. A large southbound migration along eastern Smith Sound and Baffin Bay takes place in September-October where a segment of the population moves south to coastal wintering grounds in West Greenland. This population has been surveyed regularly since 1981 and although it is still depleted it is increasing and is managed at a level that allow for continued increase. Catches in Qaanaaq are at level of <20 whales per year on average.

Three stocks of narwhal occur in the North Water/Smith Sound and they are named after their summering grounds; Jones Sound, Smith Sound and Inglefield Bredning. It is believed that the southern parts of Smith Sound are the primary wintering grounds for these whales. Abundance of the Inglefield Bredning stock has been estimated at 8000 whales and recently large abundance estimates has been obtained for Smith Sound (16,000) and Jones Sound (13,000) stocks. These two stocks have not been surveyed before and the estimates of abundance are surprisingly large. The largest catches of narwhals are taken in Qaanaaq and it is assessed that the current catch level of about 100 whales per year is sustainable. Catches from the Jones Sound stock are stable (<30 per year) but low and highly fluctuating from the Smith Sound stock (<10 per year).

The bowhead whale is not hunted in the Smith Sound region and only few individuals from the Davis Strait-Baffin Bay population are occasionally seen in spring at the ice edge in Qaanaaq. A few individuals may overwinter in the North Water. However, historically bowhead whales may have been of importance for early inhabitants of the Smith Sound region.

The walrus is an important game animal in Smith Sound and it is hunted at a low scale in Canada (5-10 per year) and at larger scale in Greenland (50-100 per year). The population is estimated to be about 2500 animals and recommended catch levels are set to allow the population to increase. Walruses can be found throughout the Smith Sound region

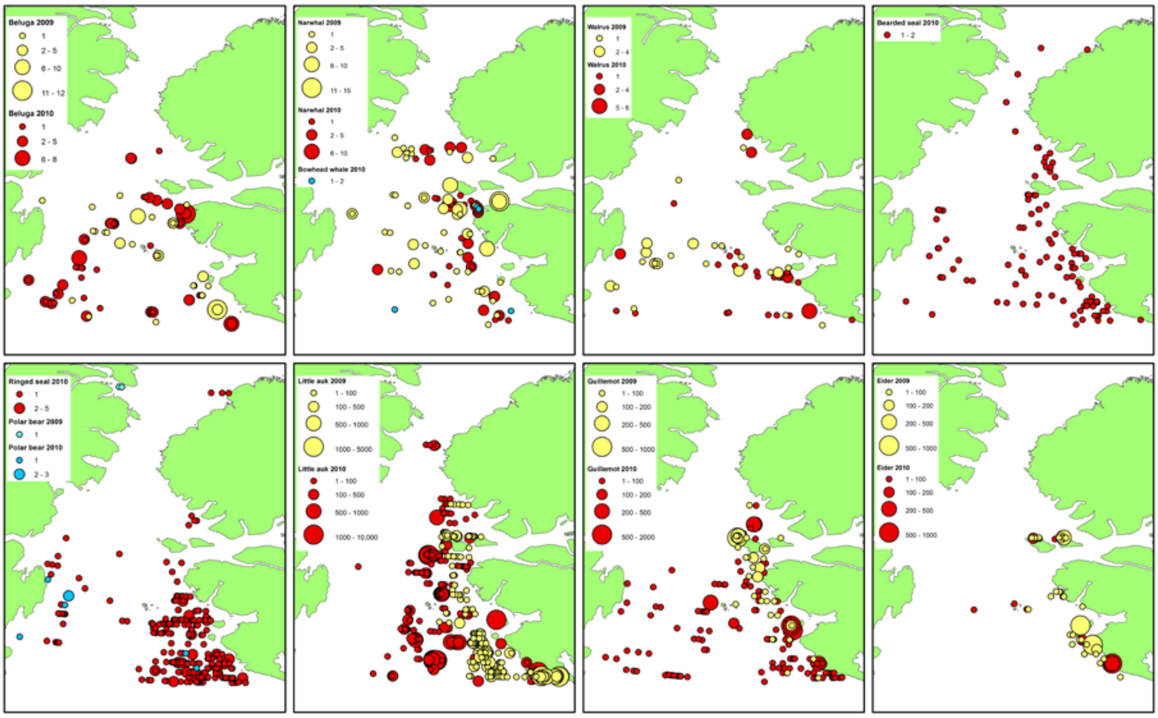

Figure 1. Distribution and group size of a number of species in the NOW as observed during aerial line transect surveys conducted in 2009 and 2010. Originally published in Heide-Jørgensen, M.P., R.G. Hansen, N.H. Nielsen, M. Rasmussen. 2013. The significance of the North Water to Arctic marine mammals. Ambio 42: 596-610.

but particular large concentrations are found on shallow banks on the Greenlandic side from October through June. The walrus abandons the eastern part of Smith Sound and move into the Canadian Arctic Archipelago in summer where they can be found in shallow waters along Ellesmere Island, in Lancaster and Jones sounds.

Ringed seal is a ubiquitous animal in Smith Sound and they inhabit both the fast ice and the moving pack ice. Their abundance is unknown and the movement data of tracked seals show that they move widely in Baffin Bay and have a large degree of flexibility in movement patterns. Catches are highest on the Greenlandic side where between 3000 and 14,000 seals were taken annually between 1993 and 2015.

Two stocks of polar bears share the Smith Sound region. In the northern part is the Kane Basin stock estimated at 360 bears with a recommended annual harvest of 6 that are primarily taken in Greenland. Polar bears in the southern part of Smith Sound are believed to be part of the Baffin Bay stock that numbers about 2800 with a harvest of 18 in the southern settlement of the Greenlandic side of the North Water.

Bearded seal occurs over most of Smith Sound. They are taken in low numbers in Greenland (100-400 per year) and the abundance is at least 6000 seals.

Sea birds in the form of two alcidae are breeding in large numbers on cliffs adjacent to the North Water and 3 species of ducks, 6 species of sea gulls, fulmars and Arctic tern breed on islands and promontories around the North Water. With an abundance estimated at 30 million pairs the little auk is by far the most abundant of the bird species. The little auks are breeding along the outer coast of the eastern side of Smith Sound and they are primarily feeding in waters along the Greenland coast. They are migratory and move south in winter to offshore areas of southern Davis Strait and Labrador Sea. Reported catches of little auks have declined from approx. 100,000 birds in 1993 to less than 40,000 in recent years. The guillemot is the 2nd most important species for the hunt of birds and they are breeding mainly on the eastern side of Smith Sound and at the entrance to Jones Sound. The southbound migration in winter brings the guillemots down to the Labrador Sea and Newfoundland. The estimated abundance is about 350,000 pairs and the population is believed to be stable with a decline in catches from more than 3000 in 1993 to less than a thousand per year after 2000.

The fish fauna is less well studied but includes important species like polar and arctic cod and Greenland halibut, but also capelin, sculpins and lump suckers are known from the area. Recently an ice-based long-line fishery for Greenland halibut has provided landings of more 100 tons in Qaanaaq.

Economically the most important species are the ringed seals, the polar bear, the narwhal and the walrus, of which the latter two species are presently the most important. Exploitation of Greenland halibut has only recently become of economic importance. Data on population size are trends are only available for four species of marine mammals and two species of birds. Some changes in the marine fauna, likely as a consequence of warming in the Arctic and reduction in sea ice, have been observed in recent decades; including summer presence of minke whales and humpback whales, increased abundance of narwhals on the western and northern parts of Smith Sound, increased catches of Greenland halibut in the eastern part, and scattered occurrence of capelin. Abundance and availability of marine mammals and sea birds in the North Water/Smith Sound seems, however, more predictable with lower annual fluctuations than observed in communities in South-west Greenland.

A comparison of the abundance and distribution of marine mammals wintering in the North Water Polynya and the North East Water Polynya

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Polynyas are known to be an important summering and wintering area for marine mammals and the North Water Polynya (NOW) in Northwest Greenland is known to be the most biologically productive polynya in the Arctic. The internal factors accounting for the temporal and spatial disposition of the polynya are unambiguous like the timing and force of the wind arriving from the west and the ice bridge that stretches over Kane Basin. Whilst the NOW has been a reliably recurrent and high-production ecosystem for recorded history, the Northeast Water Polynya (NEW), which forms each spring over the continental shelf of Northeast Greenland, is recurring in different sizes between years (Table 1). A northward coastal current interacts with a persistent shelf ice barrier under which water can flow but that retains ice floes and therefore protects the NEW area from ice advection.

Table 1. Key parameters for comparing the NOW Polynya in northwest Greenland and the NEW Polynya in northeast Greenland.

	NOW	NEW
Polynya	Stable	Variable
Productivity	High	Low
Stratum area	16,000 km^2	39,000 km^2
Transects on effort	1400 km	4500 km
Walrus	2500	1400?
Bowhead whale	Few	100?
Narwhal	3000	Few
Beluga	2300	No

We investigate the abundance and spatial distribution of marine mammals wintering in the NOW and NEW. To determine the abundance of marine mammals in the two polynyas we conducted aerial surveys in April 2014 (NOW) and April 2017 (NEW). Visual aerial surveys involving double observer platforms were conducted over the eastern part of the North Water Polynya in April 2014. Four species of marine mammals were included in strip-census estimation of abundance. Perception bias was addressed using a double-platform survey protocol, a Chapman mark–recapture estimator for whales, seals and walruses (*Odobenus rosmarus*) on ice and a mark–recapture distance sampling estimation technique for walruses in water. Availability bias was addressed by correcting abundance estimates by the percentage of time animals detected in water that were available for detection at the surface. The resulting estimates suggested that 2544 walruses (95 % CI 1513–4279), 6005 bearded seals (*Erignathus barbatus*, 95 % CI 4070–8858), 2324 belugas (*Delphinapterus leucas*, 95 % CI 968–5575) and 3059 narwhals (*Monodon monoceros*, 95 % CI 1760–5316) wintered in the eastern part of the North Water Polynya in April 2014. Visual aerial surveys involving double observer platforms were conducted over the Northeast Water

Polynya in April 2017. Two species of marine mammals will be included in strip-census estimation of abundance and abundance estimates of walrus and bowhead whales (*Balaena mysticetus*) are currently being developed. Marine mammals in high numbers were observed in the NOW whereas the abundance of marine mammals in the NEW were low (Fig. 1 and 2).

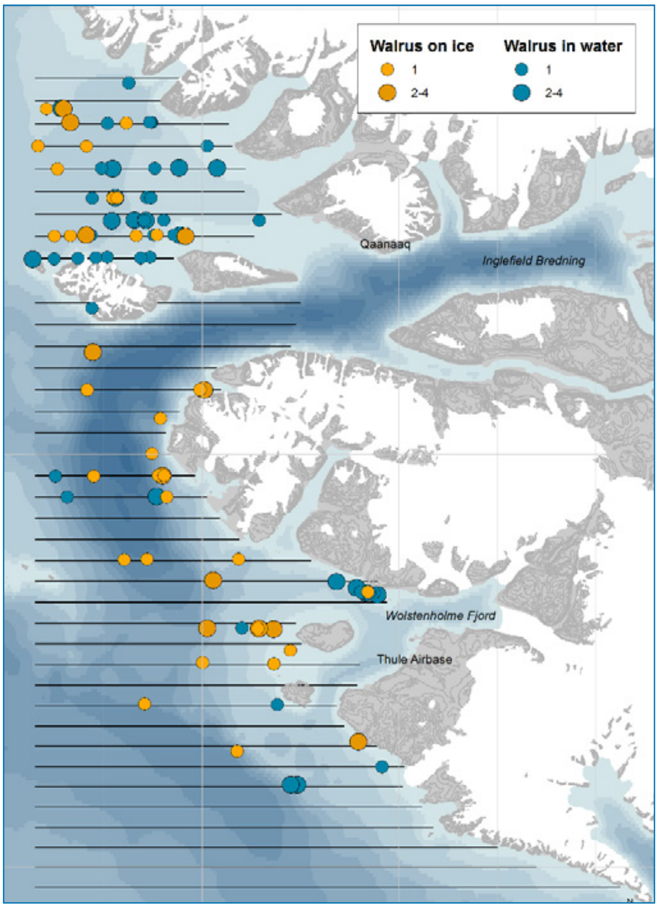

Figure 1. Distribution of walrus in the North Water Polynya.

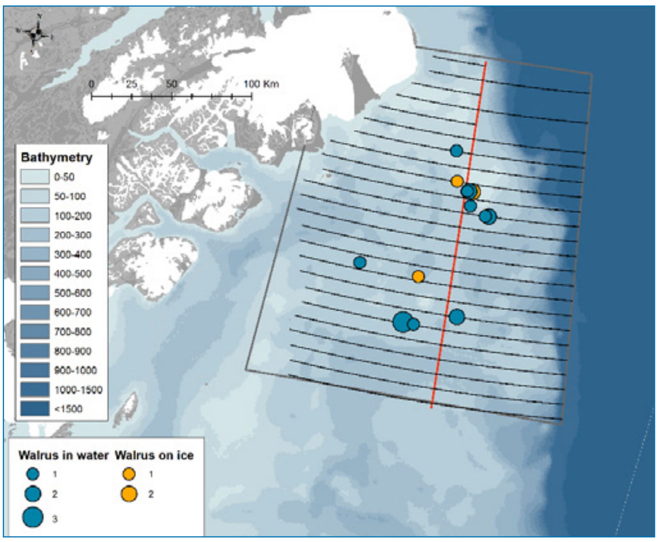

Figure 2. Distribution of walrus in the Northeast Water Polynya.

The Atlantic walrus in Smith Sound – movements, diving and consumption

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Investigations of diving behavior of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the high Arctic Greenland and Canada are important for understanding behavioral adaptations and area utilization of this Arctic benthic feeder. Furthermore, such information along with estimations of annual consumption and carrying capacity of walruses can be used in management decisions of this harvested species. The walruses in Smith Sound belong to the Baffin Bay walrus stock with a population size estimated at 2500 walruses (95 % CI 1513–4279). Currently, there is an annual hunting quota of 86 walruses for this population. A recent study has shown that the walruses from the Baffin Bay stock leave Northwest Greenland during May-June to summer in shallow water bays, inlets and coastal areas in Northeast Canada during July through September (Heide-Jørgensen et al. 2017). In October most of the walruses are back in NW Greenland. In particular, in Murchison Sound and Wolstenholme Fjord large aggregations of walruses are found in winter. This seasonal rhythm of walrus movements across Smith Sound probably reflects the regional patterns in the formation and decay of annual sea ice. The study also showed that 12 walruses crossed two putative stock boundaries and it was proposed that these three stocks should be considered as one and managed accordingly (Heide-Jørgensen et al. 2017).

In this study, satellite-linked transmitters (mk10 tags) were deployed on 27 walruses from 2010 to 2013, which provided data on diving (Garde et al. 2018). Biologists collaborated with Greenland walrus hunters from Qaanaaq to locate the walruses and deploy the tags (Fig. 1). Objectives of this study were to: 1) Determine the characteristics of the diving behavior and estimate consumption rates, 2) Identify most important feeding areas for walruses during summer, and 3) Estimate the carrying capacity of walruses in Smith Sound. Data were divided into three pre-defined main areas: NW Greenland, Smith Sound and NE Canada. Sub-areas within each main area were also compared. Depth of dives, dive rates, time at depth of dives, haul-out periods and vertical speeds were estimated. Majority of dives targeted depths from 10 to 100 m, which corresponds to the distribution of the preferred food items of walruses. Four dives to depths > 500 m occurred and are the deepest ever documented for a walrus. These deep dives were observed in the offshore areas of Smith Sound, an area where the tracked walruses spent little time. Dive rates and time at depth of dives were significantly different between sub-areas ($p < 0.0001$), whereas haul-out periods were not ($p = 0.072$). Mean vertical speeds to destination depths ranged from 1.0 m s^{-1} (95% CI: 0.8–1.2) to 1.8 m s^{-1} (95% CI: 1.0–2.6). Based on dive rates, time at depth, haul-out and percentage of feeding dives and considering the results on walrus movements from Heide-Jørgensen et al. (2017) at least the Alexandra Fjord complex and Princess Mary Bay in NE Canada were identified as important areas for walrus feeding

Figure 1. Walrus tagging in NW Greenland 2013.
Foto by Carsten Egevang, Greenland Institute of Natural Resources.

during summer. The Carey Islands in Smith Sound is potentially also an important feeding and 'stop-over' area for walruses migrating from NW Greenland to NE Canada in June. Talbot Inlet/Goding Bay could possibly also be of major importance as feeding grounds during summer. Investigations of bivalve distribution and biomass and walrus stomach content are, however, necessary to fully determine which areas are more important for walrus feeding.

The walruses in NW Greenland consume annually approximately 17,500 tons of bivalves (shell-free wet weight) based on consumption rates (4.2-6.2 % of walrus body mass, Fay 1982), body mass (Knutsen and Born, 1994), current population size (Heide-Jørgensen et al. 2016) and annual occurrence in NW Greenland (Heide-Jørgensen et al. 2017). This corresponds to ~28 kg per walrus day^{-1}. Walrus predation on the standing bivalve biomass in NW Greenland (within 5–100 m of depth) was estimated at 3.2 % annually based on assessments of mean biomass of walrus preferred prey items, which is in the same range as found in two other studies of walruses in East Greenland and in Beringia.

A rough estimation of the carrying capacity of walruses in the Smith Sound region was done based on walrus pre-exploitation population sizes and available shallow water habitat. Although highly variable densities and productivity of benthic prey can be expected in the different walrus populations, there seems to be a simple relationship between available habitat and historical abundance. Compared with other walrus populations the population in the Smith Sound region has a relatively small shallow water area feasible for benthic feeding. It seems unlikely, given the size of the available habitat, that the carrying capacity in the Smith Sound region exceeds 5000 walruses, also considering that for at least six months of the year the walrus habitat is reduced due to the extensive ice coverage.

Today, there are no known terrestrial haul-out sites on the Greenland side of Smith Sound; The abandoned terrestrial haul-out sites have not been used by walruses after 1900 (Heide-Jørgensen et al. 2017). There are also no known terrestrial haul-out sites on the northeastern part of Ellesmere Island. Walruses are, in the absence of terrestrial haul-out sites, dependent on fast-ice or drifting ice pans for hauling out (Heide-Jørgensen et al. 2017). Sea ice extent fluctuates widely in the region, but coastal areas along the western side of Smith Sound usually have enough summer sea ice to provide haul-outs for the walruses. However, any declines in sea ice formation will render Smith Sound less suitable for the walrus. The first documented haul-out site in recent times is an observation of 2–3 walruses on Haa Island in Hayes Fiord off Buchanan Bay in August 2013 (Heide-Jørgensen et al. 2017). This recent observation may suggest that the walrus could shift from ice to land haul-outs in the future with decreasing sea ice coverage. It may however have the effect that walruses will have to commute from their terrestrial haul-out to the offshore feeding grounds. Joint walrus assessments between Greenland and Canada are needed not only to manage the hunt, but also to evaluate effects of climate changes and anthropogenic disturbances.

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Little auk and thick-billed murre in the NOW Polynya

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Introduction

The NOW Polynya marine ecosystem is home to the largest seabird breeding populations in Greenland and the East Canadian High Arctic, and the area has a diverse seabird assemblage with 14 regular breeding species. The little auk (*Alle alle*) and the thick-billed murre (*Uria lomvia*) are by far the most abundant of the seabird species in the NOW, and the ones with the largest biomass (Fig. 1). Here, we briefly describe the ecological linkages of the little auk and thick-billed murre populations in the NOW region, and discuss current population status and potential future trends based on comparison with breeding areas elsewhere in the Arctic with different oceanographic conditions and prey availability. We conclude by proposing use of the little auk and thick-billed murre as indicator species for monitoring future changes in the NOW marine ecosystem.

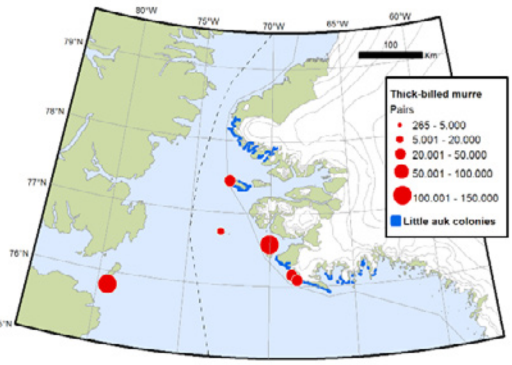

Figure 1. The distribution of little auk and thick-billed murre breeding colonies in the NOW region.

Little auk

While the thick-billed murre has a widespread breeding distribution across the Arctic, large little auk colonies occur only in the High Arctic near polynyas or other highly productive marine areas. Although associated with large uncertainty, the size of the little auk breeding population in the NOW region has been estimated to 33 million pairs, which amounts to more than 80 % of the global population of the species (Boertmann and Mosbech 1998; Egevang et al. 2003). Each year, these huge numbers of birds transport > 3500 tons of nitrogen from the marine to the terrestrial environment in the form of guano. In that process, > 200 km^2 of the otherwise quite barren coastal foreland has been transformed into lush vegetated areas to the benefit of grazers like muskoxen and geese (Gonzalez-Bergonzoni et al. 2017; Mosbech et al. 2018). The little auks of NOW raise their chicks on large lipid-rich High Arctic copepods, in particular *Calanus hyperboreus* (Fig. 2; Frandsen et al. 2014), which they catch at foraging grounds up to 100 km from the

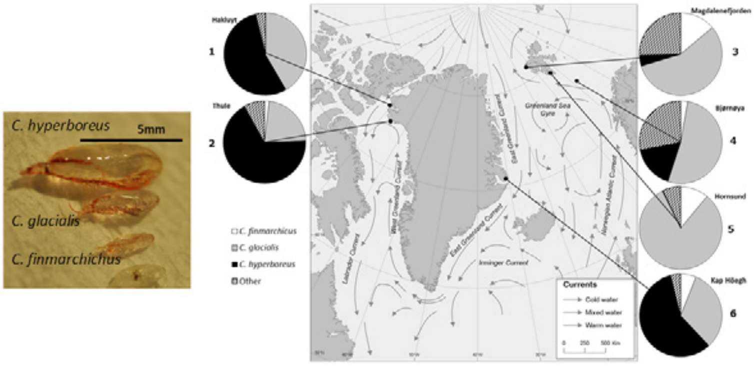

Figure 2. Little auks bring food to their chicks in a small sub-lingual pocket (gular pouch), the contents of which can be easily sampled by catching the birds and gently extracting the prey items. Right: Species composition of chick meals at different colonies throughout the little auk breeding range compiled by Frandsen et al. (2014). The little auks of NOW seem to be privileged as the large, lipid-rich copepod Calanus hyperboreus dominates the chick meals here. Left: C. hyperboreus is significantly larger and more lipid-rich than the other Calanus species available to the little auks (photo: Sanne Kjellerup).

colonies and at up to 50 m depth. During late chick rearing, each chick receives approx. nine meals of ~850 copepods per day, which the parents bring to the colony in a small sub-lingual pocket (Friis-Møller et al. this volume; Mosbech et al. 2017). The adults also to some extend feed on copepods, supplemented with larger zooplankton (Karnovsky et al. 2008). The high abundance of large *Calanus* copepods in the upper water column throughout the little auk breeding season, and in particular during chick rearing from mid-July to mid-August, is most likely the main reason for the extraordinary abundance of little auks in the NOW area (Friis-Møller et al. this volume). Climate change could potentially affect copepod abundance, community composition and accessibility in the future and cause declines in the little auk population (Stempniewicz et al. 2007). However, studies around the Greenland Sea suggest that little auks are able to cope with quite variable zooplankton communities and sea ice conditions without impact on their breeding success (Gremillet et al. 2012; Amélineau et al. 2016). The largest potential threat to the little auk populations of NOW in the future might well be the northwards expansion of other zooplankton predators, in particular fish species like capelin (*Mallotus villosus*). The modest human harvest of little auks in the NOW region today is considered sustainable, and is not likely to pose any population level threat in the future either (Mosbech et al. 2018). However, the trend of the little auk breeding population of NOW is unknown.

Thick-billed murre

The thick-billed murre colonies in the Greenlandic part of NOW hold about 362,000 birds and account for about 2/3 of the Greenland breeding population (Fig. 1 and 3; Merkel et al. 2014). Another ~300,000 murres breed on Coburg Island in the Canadian part of NOW, and >500,000 birds breed in adjacent Lancaster Sound (Gaston and Hipfner 2000), into which the NOW Polynya also extends seasonally. This makes the NOW region a globally important breeding area for the thick-billed murre. The summer diet of adult birds is dominated by the pelagic amphipod *Parathemisto libellula* and arctic cod (*Boreogadus saida*), supplemented with other invertebrates and fish (Gaston and Hipfner 2000; Karnovsky et al. 2008). In contrast to the little auk, the murre is a so-called "single prey loader", capable of bringing home only one food item at a time to feed its chick. This renders prey items smaller than fish energetically unsuitable for raising the chick, and makes the murre dependent on availability of forage fish during the breeding season. Tracking of chick-rearing murres from Saunders Island shows that they frequently visit foraging grounds up to 110 km from the colony and perform pursuit dives down to 150 m depth (Frederiksen et al. 2017). Foraging effort of adults and growth curves of chicks from NOW are within range of other murre breeding areas (Frederiksen & Merkel 2017), and suggest that foraging conditions are favourable during the breeding season. NOW is the only region within Greenland where the thick-billed murre breeding population is not in decline (Fig. 3; Merkel et al. 2014). The population trend in NOW thus appears to resemble the stable development also observed for colonies in the Eastern Canadian Arctic, whereas breeding populations in the rest of Greenland, Iceland and Svalbard are declining at an alarming rate. Historically, spring hunting near colonies has had a strong negative impact on West Greenland colonies south of Upernavik (Kampp et al. 1994), whereas hunting pressure in the NOW area has been much lower. In recent decades, the harvest of thick-billed murres in the North Atlantic has dropped significantly due to a combination of management regulations and occupational changes (Merkel & Barry 2008; Merkel et al. 2018), and evidence is accumulating that the continued decline of many murre populations is linked to large-scale climatic and ecosystem changes in the wintering areas of the birds (Irons et al. 2008; Descamps et al. 2013; Frederiksen et al. 2013; Fluhr et al. 2017). The thick-billed murres from the NOW area primarily winter off Newfoundland, where conditions seems to be relatively favourable compared to the Southwest Greenland Open Water Area and the Central/Western North Atlantic, where many of the declining murre populations spend the winter (Frederiksen et al. 2016).

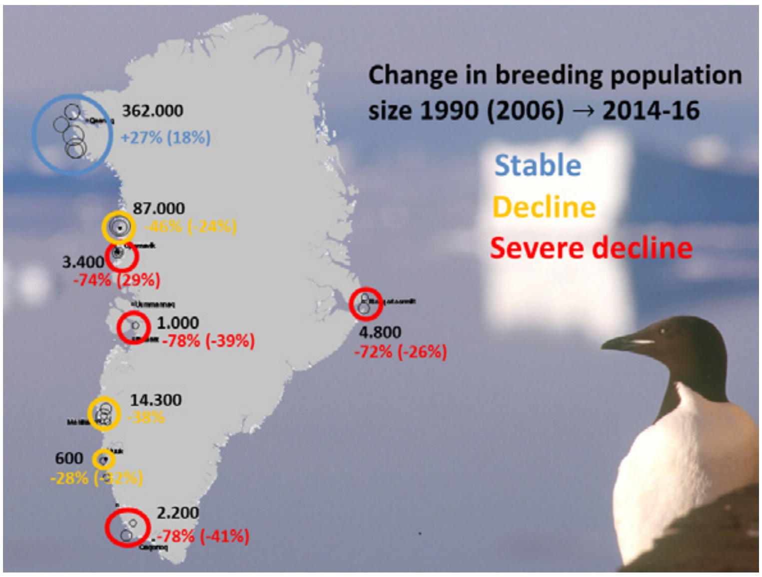

Figure 3. Current status and trend of thick-billed murre breeding populations in Greenland compiled by Carsten Egevang and Flemming Ravn Merkel, Greenland Institute of Natural Resources. Numbers are primarily based on Merkel et al. (2014) with addition of a few more recent counts.

Future monitoring

With their tight ecological linkages to NOW, and their special status in the area, we argue that the little auk and the thick-billed murre may serve as important monitoring organisms of changes in the NOW marine ecosystem in the future. A cost-efficient monitoring program could be developed by extensive use of automated photo monitoring in key breeding colonies (Huffeldt and Merkel 2013; Merkel et al. 2016), and by involvement of local communities in different monitoring tasks such as servicing of equipment, collection of samples, download of data, analysis of photos and providing logistics during short visits. In Table 1, we have listed a number of parameters, which could form part of such a monitoring program.

Table 1. Key parameters which could form part of a cost-efficient, and partly community-based, monitoring program for thick-billed murres and little auks in the NOW ecosystem.

Species	Parameters	Methods
Little auk	Chick diet	Extraction of zooplankton samples from gular pouches of chick-rearing little auks (Frandsen et al. 2014). Can be undertaken by locals in connection with their harvest of little auks.
	Breeding phenology, colony attendance pattern, relative numbers	Installation of solar-powered, automated time-lapse photo monitoring boxes in study plots in key breeding colonies (Merkel et al. 2016) combined with local observations.
	Breeding density	Video recording of study plots during the fledging period (Mosbech et al. 2017).
Thick-billed murre	Colony census counts	Complete photo coverage of breeding colonies, or predefined parts of breeding colonies (study plots), on an annual basis. Already partly undertaken by Greenland Institute of Natural Resources.
	Breeding phenology, colony attendance pattern, breeding success	Installation of solar-powered, automated time-lapse photo monitoring boxes in study plots in key breeding colonies (Huffeldt et al. 2013; Merkel et al. 2016), combined with local observations.

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Status of Peregrine Falcon and Gyrfalcon populations in Northwest Greenland

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Recent changes in climate have led to latitudinal range shifts in avian species throughout many areas of the world (Gibbons & Wotton 1996, Thomas & Lennon 1999, Hitch & Leburg 2006). In the Arctic, similar patterns have begun to emerge, with species once occurring only in the Low Arctic now becoming regular visitors or breeders in the High Arctic. Brommer et al. (2012) documented a northern range shift of 0.81 km year^{-1} for northern boreal and Arctic nesting species in Finland from 1989 to 2006. In the High Arctic of northwest Greenland, Burnham et al. (2014) suggested that a lengthened breeding window has led to an increase in the number of both new and rare waterfowl species. As a result, species which occupy overlapping niches are now competing for both nesting sites and prey.

For over 650 years Gyrfalcons *Falco rusticolus* have been regular breeders in the High Arctic of northwest Greenland (Burnham et al. 2009). More recently (within the past 75 years), Peregrine Falcons *F. peregrinus tundrius* have extended their breeding range northward into this same area and now breed on an annual basis. Based on research on both falcon species between 1993 and 2005, Burnham et al. (2012) suggested that the recent expansion of Peregrines into northwest Greenland was likely the result of a lengthened breeding window as a result of climate change, and that over the next several decades the population would continue to increase in size.

Here we provide results of continued surveys for both species which took place from 2006 to 2017 over approximately 750 km of coastline in the North Water Polynya near Thule Air Base (77 °N, 68 °W) in northwest Greenland. Results presented in figures are for the period 2000 onward, when the formal survey area was established. For more information on the study area and survey methods see Burnham et al. 2012.

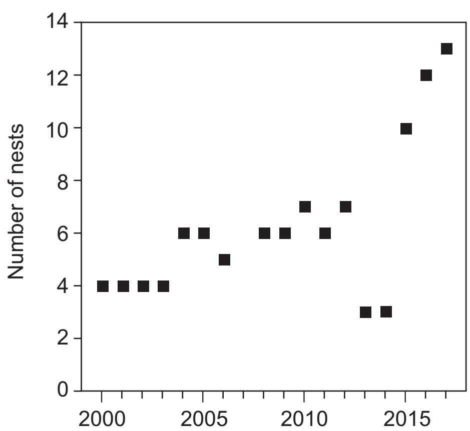


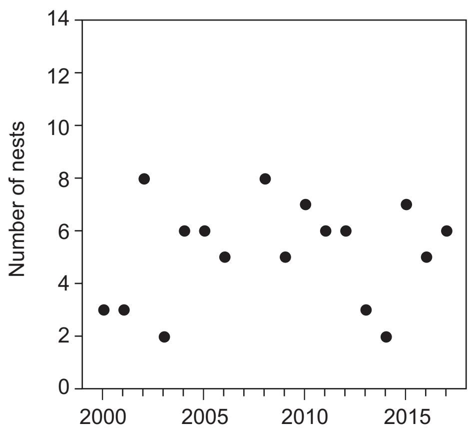
Figure 1. Number of nest sites occupied by Peregrine Falcons from 2000 to 2017 in northwest Greenland. Low numbers in 2013-14 are the result of minimal surveys rather than a lack of birds observed.

From 1993 to 2017 Peregrine Falcons made 118 nesting attempts at 15 different territories. The number of occupied sites varied annually, with the population doubling over the past six years. In particular, the increase has been most dramatic from 2015 onward, with a record high of thirteen occupied sites in 2017 (Fig. 1). Nesting pairs of Peregrines were found only in the northern half of the study area and only lone, non-breeding individuals were observed in the southern half of the study area, where large Little Auk (*Alle alle*) colonies occur. As the number of pairs of Peregrines increased they predominantly colonized vacant cliffs between occupied sites, with the annual inter-nest distance decreasing throughout the study period. Peregrines primarily preyed upon Little Auks, although passerine remains were also commonly found and at some sites as the predominant prey, as reported by Burnham et al. (2012).

Gyrfalcons made 104 nesting attempts at 20 different territories from 1994 to 2017. Although the number of occupied sites varied annually, with a high of 8 in both 2002 and 2008 (Fig. 2), the population appears to be stable. In contrast to Peregrines, Gyrfalcons were found nesting relatively evenly spaced throughout the study area, including nesting in areas with a high abundance of seabirds. However, it appeared that annual movements between territories was much greater for Gyrfalcons than Peregrines. Primary prey species were Little Auks, although Rock Ptarmigan (*Lagopus muta*), Arctic Hares (*Lepus arcticus*), and other seabirds also contributed significantly to their diet, again similar to as reported by Burnham & Burnham (2011).

With both species nesting on similar cliffs and relying heavily on Little Auks for prey, competition between Peregrines and Gyrfalcons in northwest Greenland appears to be frequent. Of the 20 different territories/cliffs where Gyrfalcons have been found nesting, five have recently been used by Peregrines. In the few years when both species have bred at the same cliff, Peregrines have always appeared to be dominant over Gyrfalcons, aggressively stooping the Gyrfalcons whenever they take flight. In one instance a recently fledged Gyrfalcon chick was found with

Figure 2. Number of nest sites occupied by Gyrfalcons from 2000 to 2017 in northwest Greenland. Low numbers in 2013-14 are the result of minimal surveys rather than a lack of birds.



a broken wing in the talus below a nest, possibly a result of being struck and driven into the rocks by the nesting Peregrines at the same cliff. Although both species are heavily dependent upon Little Auks for prey, an estimated 33 million pairs nest in northwest Greenland (Egevang et al. 2003), providing a virtually unlimited food supply and likely limiting the amount of direct competition between falcon species.

Peregrines have generally been shown to be highly adaptable, occurring on all continents except Antarctica, and successfully breeding from the most remote areas to urban city centers. In contrast, Gyrfalcons are unique to the Arctic, and have evolved over millennia to occupy this very specific niche, and thus are most likely less adaptable to a changing climate. As temperatures in the High Arctic continue to ameliorate as a result of climate change, and the breeding window continues to expand, it seems highly probably that the number of Peregrines will not only continue to increase, but that the population will also expand to even more northern areas in Greenland. Should the Peregrine population continue to grow at the current rate there is little doubt that increased interspecific competition for limited nest sites will occur. This increased competition, in addition to the likely inability of Gyrfalcons to adapt to a rapidly changing climate, may well lead to a possible decrease in the Gyrfalcon population in northwest Greenland.

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Fisheries in the northern Baffin Bay and its future potential

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Exploitation of fishery resources within and around the North Water Polynia in the northern Baffin Bay is presently scarce and mainly limited to local coastal small scale fisheries and most large scale fisheries are located more southerly. Changes in the physical environment are assumed to lead to changes in the distribution and migration patterns of fishing resources. Yet, little information on these parameters is available for the northern Baffin Bay and the North Water. However, by focusing on changes in fishery and environment further south in the Baffin Bay and the Davis Strait, it is possible to extend likely future scenarios into the North Water area.

Present fisheries in the Baffin Bay includes fisheries for Northern shrimp and Greenland halibut. Both are bottom trawl fisheries at relatively deep waters; shrimp fisheries at the shelf and slopes at about 200-500 m while Greenland halibut mostly at the slopes at depth of about 200-1000 m. The offshore shrimp fishery has since its beginning in the 1980s fluctuated in a north-south direction; with a period in the late 1990s extending south nearly to Nuuk (Fig. 1). In the recent years, however, fishery as far north as off Upernavik has developed. The Greenland halibut fishery has been conducted from the 1960s in the Davis Strait, but in the early 2000s the fishery expanded north into the southern/eastern slope of Baffin Bay. Within this northerly area there seems to be s a slight northward movement in the recent five years (Fig. 2). For both the fisheries there is therefore no significant northward movement along with the warming of the West Greenland current as observed from the Fylla Bank section, but some tendencies that fisheries gradually move northward. Some scientific Greenland and Canadian surveys seems to confirm the existence of relative unexploited resources north of the traditional fishing grounds. Greenland halibut is presently target for

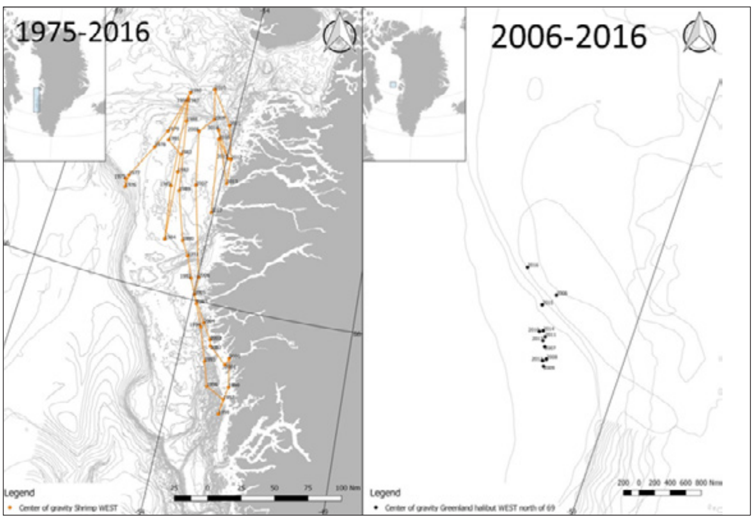

Figure 1. Center of gravity for the Greenland shrimp fishery (left) and Greenland halibut fishery (right).

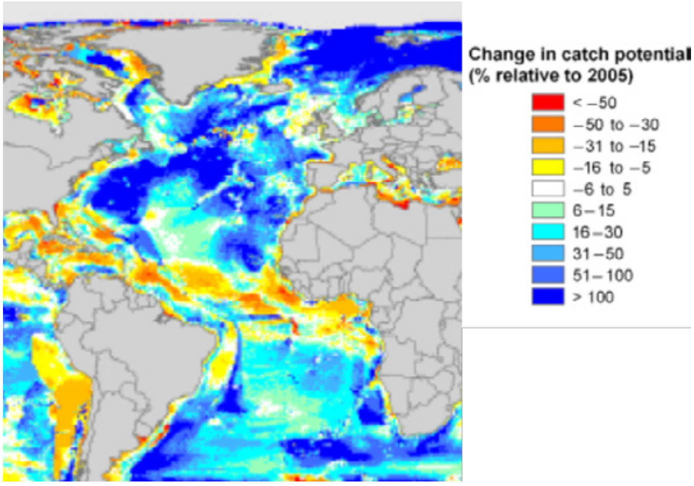

Figure 2. Change in maximum catch potential (10-year average) from 2005 to 2055 under most likely climate change scenario adapted from Cheung et al. (2010).

a smaller coastal fishery in the Qaanaq area and the limitation for this fishery is most likely effort and storage logistics.

In a future scenario with an increased temperature regime in the northern waters of Baffin Bay new fishing resources might be available; Atlantic cod in West Greenland is at its northern border, most likely affected by low temperatures. However, in the recent 4-5 years cod fishery has increased its distribution and now includes Disko Bay and Uummannaq, and is even caught in Upernavik. The species was widely abundant in the last warming period in West Greenland in the years 1920-60 with annual catches up to 400,000 t. Pelagic species such as squids and Polar cod might also be potential fishing resources in a warmer climate further north in West Greenland.

Climate change models, however, do not necessarily forecast warming in all regions but rather mixed scenarios where some areas might experience colder climate although the net global trend is warming. Forecast scenarios for areas close to each other might therefore differ significantly in future fisheries potential.

Based on assumptions on climate changes, global models can predict the change in marine biological productivity and consequently the catch potential by rather accurate resolution. Overall these models show that high-latitude regions might increase in catch potential while the tropics will experience a decrease. Based on a higher resolution this picture gets more heterogeneous, and for the Baffin Bay area the central basin is forecasted to increase the catch potential to more than 100 % while some coastal areas in Baffin Bay are predicted to loose catch potential (Fig. 2). Overall Greenland is predicted to increase its catch potential by 25 % from 2005 to 2055. Species predictive models can also be used to evaluate the impact of climate changes with respect to temperature, oxygen contents and acidification a.o. on specific fish species based on their biology. Greenland halibut has a relatively high risk of impact in the Baffin Bay area according to this modelling.

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The Piniariarneq Project: Inughuit hunters map their important hunting areas

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Introduction

Presently, Greenland is the scene of an extensive mapping of key habitats of important plants and animals, biodiversity hotspots, and ecosystem functioning, the results of which are to inform spatial planning processes to mitigate the effects of climate change and an anticipated increased industrialization of the Arctic in the near future (e.g. Christensen et al. 2016; 2017). Mapping of important resource areas of local communities has also been conducted on numerous occasions, but has generally received less attention, and results of such efforts are often difficult to integrate in analyses with spatial biological data. We give a short presentation of the so-called Piniariarneq project, in which occupational hunters from the NOW area used hand-held GPS devices to map their hunting activities through a full year (Andersen et al. 2017; Flora et al. 2018). We argue that an approach like this has the potential to contribute to a better integration of local communities and locally important areas in spatial planning processes.

Methods

Piniarianeq means "hunting trip" and was a sub-project of the NOW project (Hastrup et al. 2018). It was an interdisciplinary, collaborative effort involving two anthropologists, two biologists, a GIS specialist and 17 occupational hunters from the NOW region. On an overall level, the project sought to map human use of living resources in the landscape. However, each discipline, including the hunters, entered the collaboration with their own aims and motives. New aims were also developed along the way, especially by the hunters who gradually took ownership and found their own purposes for collecting data (Flora and Andersen 2018). Thus, in many ways, Piniarianeq can be seen as an experiment in collaboration across traditional disciplinary divides, the collaboration being centered on the use of a particular GPS-based data recording technology. This was a custom-made app, designed by the researchers and installed on hand-held GPSes, which the hunters in turn agreed to use to document their hunting trips during a full year (Fig. 1). The app allowed the hunters to record detailed information on individual trips, which beyond the route itself included means of transportation, composition of the hunting party, catches and observations of animals, as well as anything else the hunter found relevant to document through geotagged written notes, photographs, and video footage. Database administrators, appointed locally, handled data download from the GPSes.

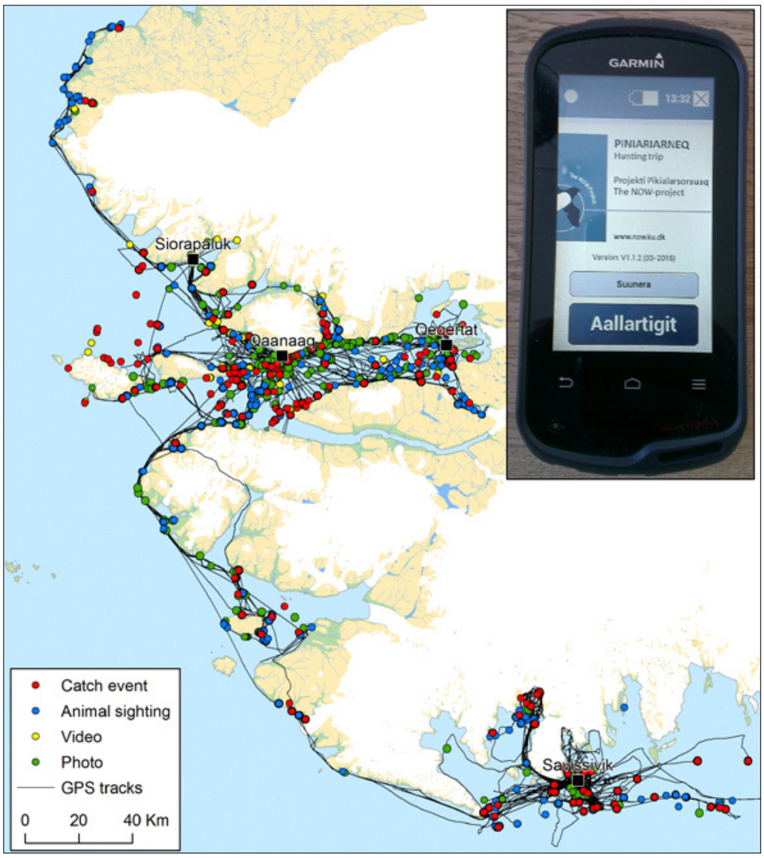

Figure 1. Plot of all data collected during the Piniariarneq study. The top-right insert shows the GPS and custom-made app used by the hunters to document their hunting trips.

Results

15 hunters from Qaanaaq and 2 hunters from Savissivik collected data for approx. 13 months from mid-May 2015 to late-June 2016. In total, almost 20,000 km of tracks from hunting trips was recorded. 433 catch events and 422 animal sighting events were documented, spanning 33 different species. In addition, the participants took almost 2700 geotagged photographs, and made more than 200 geotagged video recordings (Fig. 1). Thus, the hunters have provided an absolute wealth of information on their activities and observations in the landscape.

We observed marked spatial dynamics in the resource use of the hunters across the seasons of the year.

During April – June, the participants were primarily engaged in hunting along edges of the land-fast ice in proximity to their hometowns. The hunting bag was large and characterized by considerable species diversity. The onset of the open water season (July – September) was associated with a complete shift in the land use of hunters. By means of fast motor boats, they now travelled deep into the fjords, and although a variety of species were caught, the recordings were mainly concentrated on narwhals.

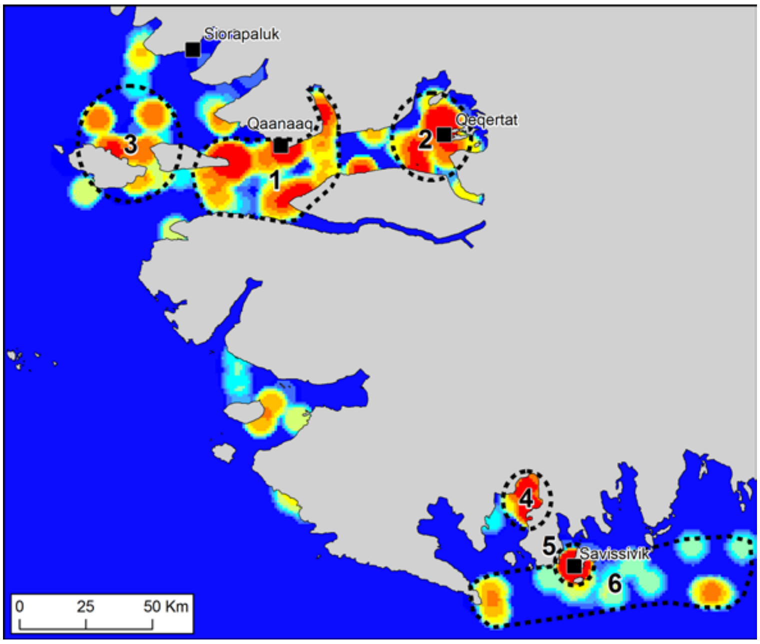

Figure 2. The spatial distribution of the total biomass of catches (kg km⁻²) recorded during the Piniariarneq study on a color scale from blue (low) to red (high). Hotspots of resource extraction described in the text are indicated with dashed outline and numbered 1-6.

During October – December, the hunters' range and mobility decreased markedly due to the slow formation of sea ice, rendering both motor boat and dog sledge traffic difficult. In Savissivik, activities were focused on netting of seals just outside town. In October, Qaanaaq hunters still embarked on a few longer trips (in pursuit of walrus), but towards the end of the period their activities were concentrated on Greenland halibut fishery close to town.

In January – March we saw a re-expansion in the movement of the hunters in the form of dog sledge traffic on the land-fast ice, but we also observed significant regional differences in the hunters' activities. Qaanaaq hunters were mainly preoccupied with long-line fishery for Greenland halibut from semi-permanent fishing camps established several places on the fast-ice in Inglefield Bredning, primarily outside Qeqertat and Qaanaaq. In Savissivik, netting of ringed seals close to town seems to have constituted an important activity throughout the winter, combined with long-range hunting trips targeting polar bear.

By mapping the spatial distribution of the total biomass of catches recorded during the tracking period, we may point to a number of hotspots of "living resource extraction" with high importance for the local communities in the NOW area (Fig. 2). Within a range of approx. 35 km from Qaanaaq, several hotspots are apparent, mainly resulting from the multi-species ice edge hunt during spring, but also partly from Greenland halibut fishery during winter (Fig. 2, no. 1). However, due to the proximity to town, catches were recorded in this area throughout the year. The large hotspot close to Qeqertat is a combined result of the summer narwhal hunt and the winter fishing for Greenland halibut (Fig. 2, no 2). The walrus hunt Murchison Sound during spring and autumn is also clearly visible (Fig. 2, no. 3). The recordings made by Savissivik hunters mainly resulted in two hotspots: one in Sidebrinksfjord, corresponding to the summer narwhal hunt in 2015 (Fig. 2, no. 4), and one centered on the town of Savissivik, mainly relating to seal netting during autumn and winter, but with catches recorded throughout the year (Fig. 2, no. 5). A string of smaller hotspots is also apparent along the edge of the fast-ice south of Savissivik, resulting both from the multi-species spring ice edge hunt, and from the winter hunt for polar bear (Fig. 2, no. 5). With exception one exception (Fig. 2, no. 4), the identified hotspots are to our knowledge more or less recurrent from year to year.

While it may be easy to identify important areas in terms of kg biomass harvested, there is clearly a lot more going on in the landscape than just meat extraction. The rich photo and video material, which the hunters have captured with their GPSes, testifies to landscape which has meaning and value far beyond hunting, and which ties into every aspect of life in the local communities (Fig. 3). This is not something easily quantified, but now we can at least plot the many geotagged notes, photographs and video sequences on a map and get a sense of the multiple aspects of life that unfolds in different parts of the landscape. And we can try to keep this rich, qualitative material in mind for a more informed discussion of what constitutes locally important areas.

Figure 3. The participating hunters took almost 2700 geotagged photographs with their GPSes, documenting the multiple aspects of life that unfolds in different parts of the landscape.

Conclusions

Piniariarneq ran for one year only in a region characterized by large year-to-year variation, and in that sense, it was a pilot project. However, with more years and more participants, and with the results subjected to dialogues in forums of hunters and supported by other study approaches, we believe that robust knowledge of locally important areas can be attained. As method, Piniariarneq results in quantitative data, which are in many respects compatible with spatial biological data, e.g. animal tracking data. This improves the possibilities for making integrated analyses and assessments of important areas, as well as it provides a representation of the hunters' use of the landscape, which is perhaps more directly useable in spatial planning processes than textual accounts. It puts humans on the map, both in a quantitative and a qualitative sense. Last, but not least, an important aspect of the approach is that it may contribute to a better rooting of knowledge production in the local communities. Through recording their actions in the landscape, it is the hunters themselves that collect data on their important areas.

Acknowledgements

Piniariarneq was part of the NOW Project, funded by the Carlsberg Foundation and the Velux Foundations. We wish to thank KNAPP Qaanaaq and KNAPP Savissivik for supporting the project, and Qillaq Danielsen, Kristian Eipe, Markus Hansen, Ole Kristensen, Mads Ole Kristiansen, Mamarut Kristiansen, Najmanngitsoq Kristiansen, Kúlutana Kvist, Minik Larsen, Niels Miunge, Storm Odaq, Avigiaq Petersen, Aaqqiunnguaq Qaerngaaq, Ilannguaq Qaerngaaq, Thomas Qujaukitsoq, Tobias Simigaq and Odaq Tivnaaq for participating.

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Interactive atlas of Inuit knowledge on the Pikialasorsuaq ecosystem, and past and present use of living resources

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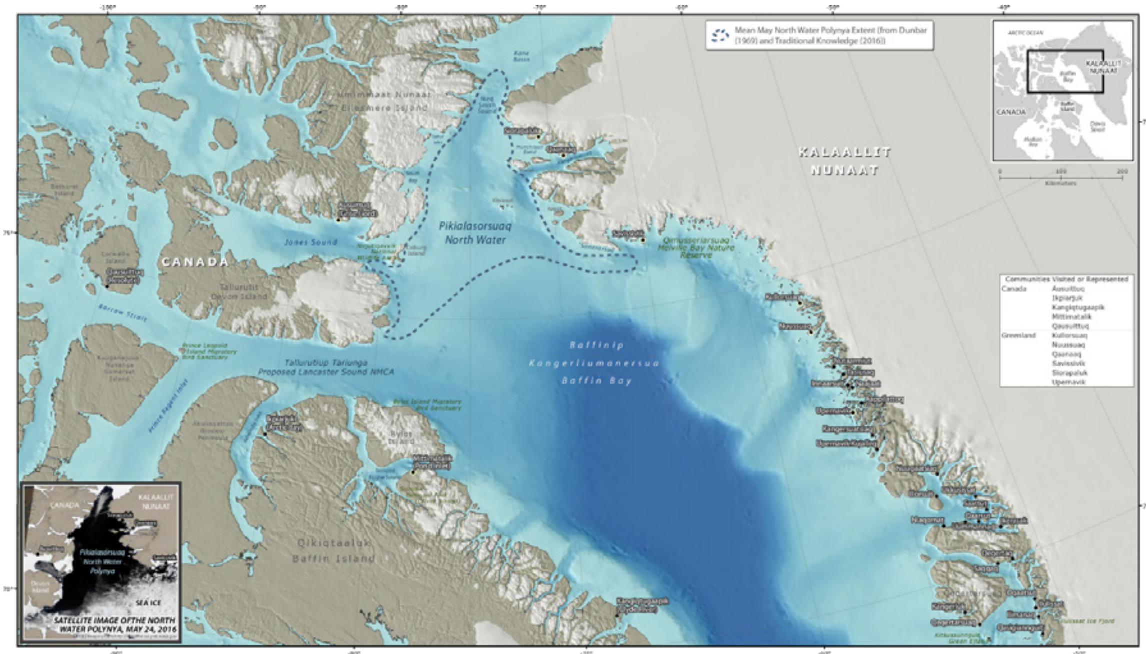
Background for the atlas

The Pikialasorsuaq Commission was established in January 2016 by the Inuit Circumpolar Council (ICC) Greenland and Canada regional offices. Kuupik Vandersee Kleist (former Greenland Premier) was chosen as the Greenlandic Commissioner, Eva Aariak (former Premier of Nunavut) as the Canadian Commissioner, and Okalik Eegeesiak (ICC International Chair) as the International Commissioner. The mandate of the Pikialasorsuaq Commission is to conduct consultations with communities surrounding North Water Polynya (Pikialasorsuaq), and to recommend strategies for safeguarding and monitoring health of Pikialasorsuaq for future generations.

The Commission undertook consultations with Inuit communities in Nunavut in April 2016 with following communities visited or represented: Ausuittuq (Grise Fiord), Ikpiarjuk (Arctic Bay), Kangiqtugaapik (Clyde River), Mittimattalik (Pond Inlet) and Qausuittuq (Resolute). The Commission undertook similar consultations with communities in Northwest Greenland in September 2016 with following communities visited or represented: Siorapaluk, Qaanaaq, Savissivik, Kullorsuaq, Nuussuaq and Upernavik. The location of the polynya and surrounding Inuit communities can be seen in Figure 1.

Figure 1. Map of Pikialasorsuaq (North Water Polynya) including surrounding Inuit communities. Source: Oceans North Canada.



The atlas

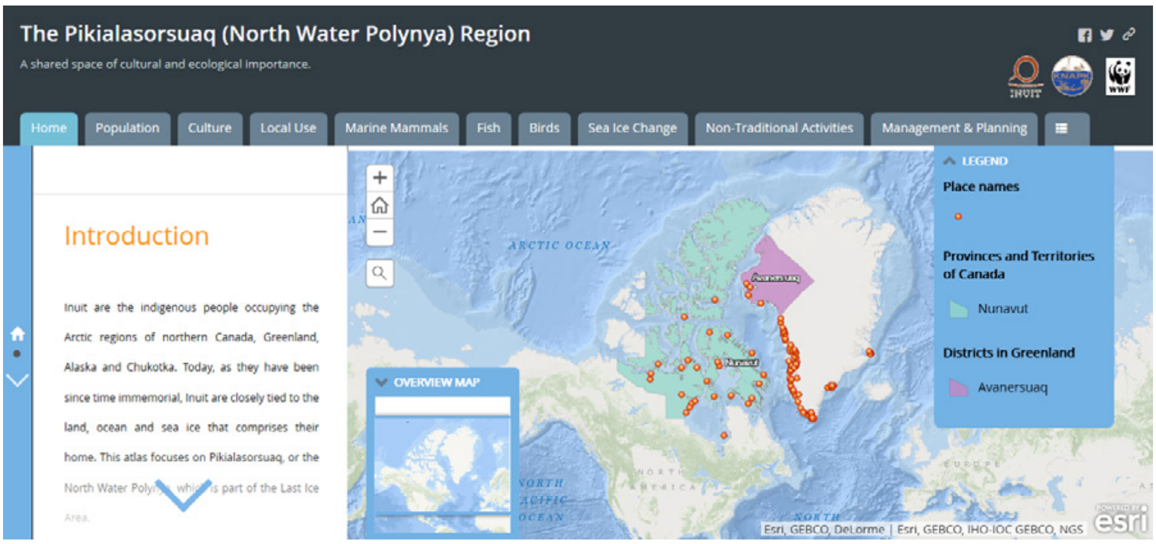
The Commission conducted interviews with several members from each community on their Traditional knowledge of the Pikialasorsuaq and surrounding habitats, the ecosystem, and their past and present use of the living resources. In collaboration with ICC, KNAPK (The Association of Hunters and Fishermen in Greenland) and WWF (as part of their Last Ice Area project) the results have been incorporated into an online, interactive atlas with several GIS layers featuring both indigenous knowledge and scientific knowledge. The interactive atlas is displayed directly from Esri's cloud through WWF's account, and is publically available. The address is:

https://panda.maps.arcgis.com/apps/MapSeries/index.html?appid=-8c2ab42be1ad4bab961d7fe88b279456

The atlas features tabs with specific chapters (Fig. 2). The left side panel contains text and links, and the main panel shows maps and data. There are further functions like legend box, zoom buttons and a search tool. On some of the maps, the data is interactive and clicking on it reveals pop-up windows with more information. There are social media icons for sharing.

The Population tab shows information on population sizes for the Inuit communities surrounding the North Water Polynya. The Culture tab shows information on cultural and archaeological sites, settlements and homes, tent rings, burial sites, and traditional Inuit place names. The Local Use tab shows information on Inuit travel routes and fishing areas, and contains data from the Inuit Land Use and Occupancy Project in Canada and the Piniariarneq project in Greenland. The Marine Mammals tab, the Fish tab and the Birds tab shows Arctic species distribution data. The Sea Ice Change shows information on the WWF's Last Ice

Figure 2. Screenshot of the home page of the interactive online atlas.



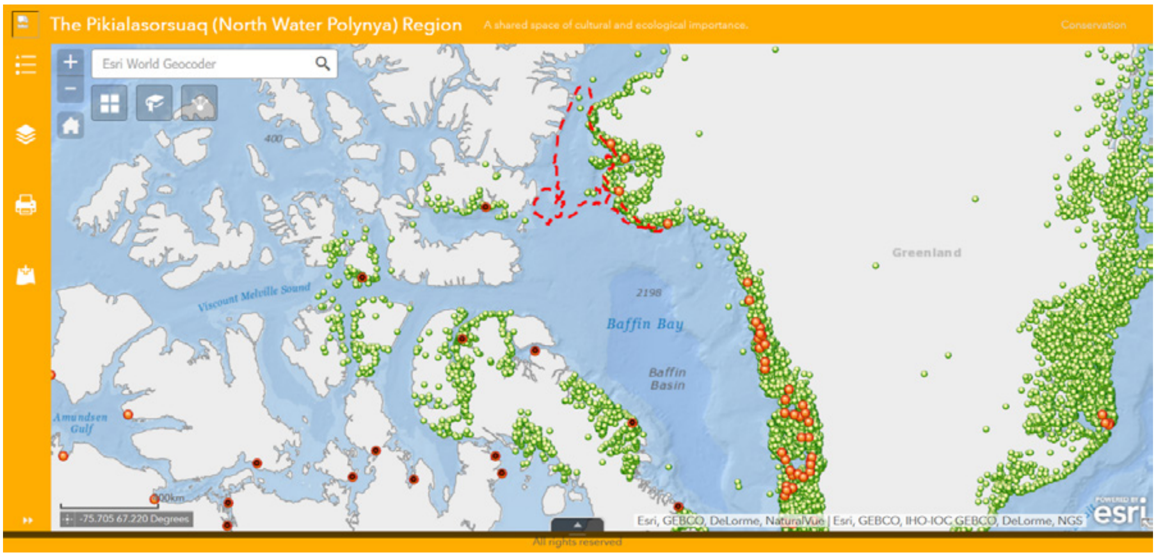


Figure 3. Screenshot of the online planning tool.

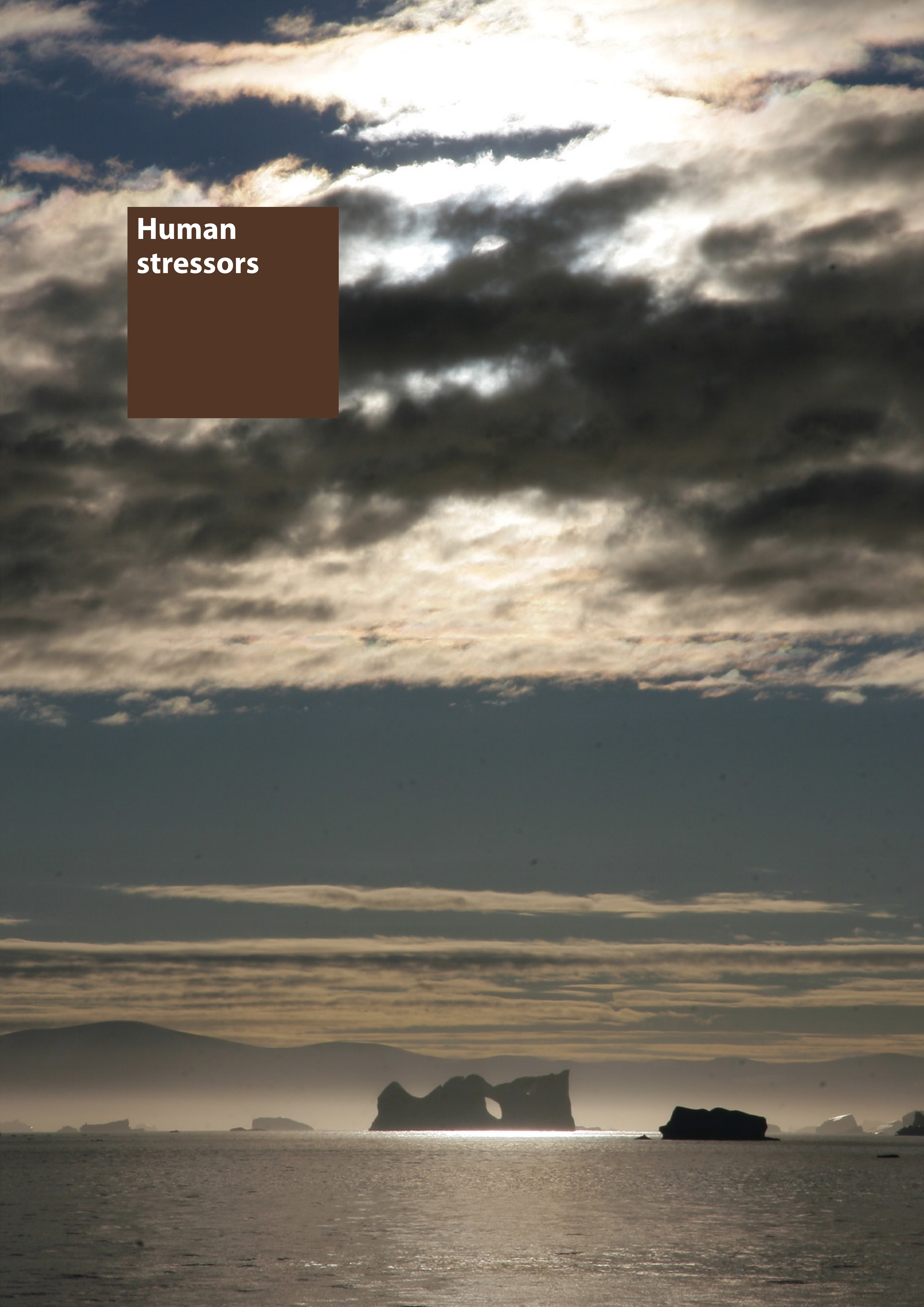
Area project. The Non-Traditional Activities tab shows data on shipping routes related to cargo, tankers, icebreakers, fishing, research, passenger etc. as well as non-renewable resources. The Management & Planning tab shows national parks, protected areas onshore and offshore, Ramsar sites etc. and mentions future planning for special management areas.

There is also an Online planning tool (Fig. 3) that allows you to explore how different activities and resources may overlap and interact (for example how exploration activities may affect marine mammal habitat, or local land use like hunting trails when considering mining activities). The planning tool is located within the far right tab, and can also be viewed on this address:

https://panda.maps.arcgis.com/apps/webappviewer/index.html?id=35081265064a460da83e89d43c041f5c

You can read more about the work of the Pikialasorsuaq Commission on the following links:

www.pikialasorsuaq.org
www.northwaterpolynya.org



Human stressors

Keynote talk

Anthropogenic stressors in the NOW – today and in the future

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Here we provide an overview of present day's anthropogenic stressors acting in the North Water Polynya (NOW), where only about 1000 people live and less than 5000 if we include the settlements next to the NOW-area. Figure 1 shows the stressors as of today.

The most significant stressor is hunting and fishing, which induce direct mortality to the stocks and populations of fish, shellfish, seabirds and marine mammals (Fig. 2). Hunting moreover, increases the natural shyness of hunted seabirds and marine mammals, making them more vulnerable to other disturbing activities.

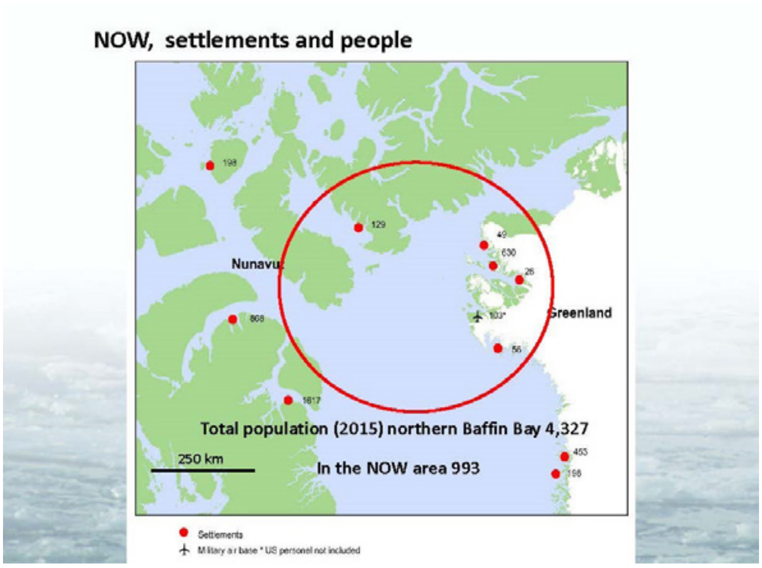

Figure 1. Distribution of the human population in and near NOW. The red circle show the NOW-area, and figures at the signatures for settlements the number of people living there by 2015.

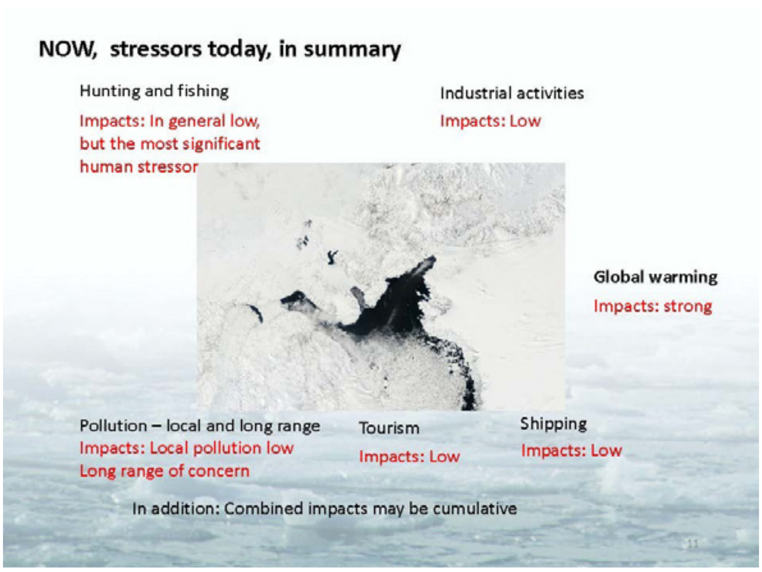

Figure 2. Overview of anthropogenic stressors and global warming acting in the NOW-area today.

Figure 3. Overview of anthropogenic stressors (and global warming) in the now areas in the future

The future will be influenced by the climatic changes, which will reduce the sea ice cover in both time and space (Fig. 3). In this region the reduction in sea ice, however is predicted to be slow until about the middle of the present century, and hereafter accelerate. This means that shipping, at least until then, will not increase significantly. Moreover, the most efficient sailing routes between the North Atlantic and the Bering Sea will be along the Northeast Passage and far from the NOW-area.

Therefore, the expected changes in anthropogenic stressors most likely will be small within a foreseeable future. However, for some sectors there is a potential for increase governed by factors outside the NOW-area, such as mining and hydrocarbon development, which are more dependent on world market issues than on local climatic conditions. Another sector, which has a potential to increase, is the tourism.

Regarding pollution, there are some potential sources, which may be mobilized, for example by increased melt of the Greenland ice sheet. Among these are the nuclear powered US base 'Camp Century', which was a subsurface establishment in the Greenland ice sheet, abandoned in 1966 and just left without any remediation or decontamination. Another potential source of contamination is the remains of four nuclear bombs crushed and today imbedded in the seafloor, when a US bomber crashed on the sea ice in January 1968. After the presentation, a further source of pollution was mentioned from the audience: Russian rocket launches have resulted in the crash of used stages with remains of the highly toxic fuel hydrazine in the waters of northern Baffin Bay in recent years.

Fishery and hunting will probably undergo some changes, as the fauna will respond to the climatic changes, but no significant changes in hunting pressure or fishery activities are expected, except perhaps from an increased bottom trawl fishery for northern shrimp in the Melville Bay just to the south of the NOW-area (but see the abstract of Jesper Boje, this volume).

The climate changes also induce a challenge to nature conservation in the NOW-area, as distribution of species changes and important and sensitive areas may loose their significance and/or be accessible and exposed to human stressors.

Monitoring programs and eco-system based management should be applied to adapt to and mitigate these changes.

Keynote talk

How the traditional lifestyle and diet in the North Water region is challenged by long-range pollution

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Despite the remoteness of the North Water, Northwest Greenland, the local Inughuit population are affected by global anthropogenic pollution and climate change (Dietz et al. 2018). Using a cross-disciplinary approach combining Mercury (Hg) analysis, catch information, historical and anthropological perspectives a recent article by Dietz et al. (2018) elucidates how the traditional diet is compromised by Hg pollution originating from lower latitudes. Here we show in a new approach how the Inughuits in Avanersuaq (North Greenland) are subjects to high Hg exposure from the hunted traditional food, consisting of mainly seabirds and marine mammals. Violation of the Provisional Tolerably Yearly Intake of Hg, on average by a factor of 11 (range: 7-15) over the last 20 years as well as violation of the Provisional Tolerably Monthly Intake by a factor of 6 (range: 2-16), raises health concerns (Fig. 1 and 2). The surplus of Selenium (Se) in wildlife tissues including narwhals, *Monodon monoceros* showed Se:Hg molar ratios of 1.5, 2.3 and 16.7 in muscle, liver and mattak, respectively, likely to provide some protection against the high Hg exposure. Our findings are in agreement with previous health assessments performed under the Arctic Monitoring and Assessment Programme (AMAP). The high human exposure are in particular important as historical samples have revealed that the Hg concentrations have increased almost 20-fold since the beginning of the industrialization around 1850 (Dietz et al. 2009, 2011). The onset and increase of Hg pollution was further supported by similar trends found in the lake sediment of the study by Davidson et al. (2018). The seasonal pattern with the highest exposure during late summer (Fig. 2), where the majority of the narwhals are hunted, was further supported by a pilot study on seasonal exposure of the Inughuit population based on weekly samples of facial hair from local inhabitants with different occupation and from different parts of Avanersuaq (Dietz et al. 2017; in prep). These results likewise show a higher load during summer, beginning to increase in June and peaking in August-September after which the exposure declines due to reduced narwhal consumption and consequent Hg excretion. One of the occupational hunters analysed showed up to 100-times higher Hg concentrations than reference persons, transgressing up to 45-times the US Environmental Protection Agency guideline value for acceptable Hg concentrations in human hair. Traditional Arctic food however, contains valuable nutrients and vitamins and has also proven to be healthier than certain Western food products.

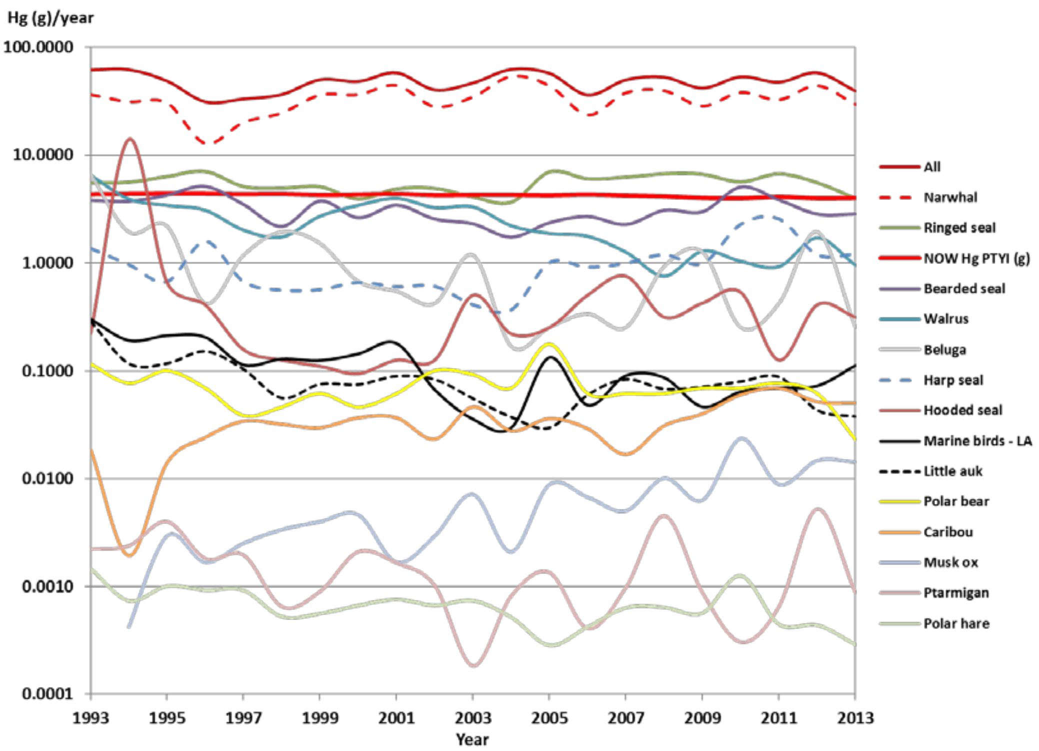

Figure 1. Temporal Hg load in the hunted game of Avanersuaq based on average hunt from 1993 to 2013 (Piniarneq 2016) and average Hg loads in muscle tissue from published and unpublished contaminant studies in Greenland (see Dietz et al. 2018 for further information).

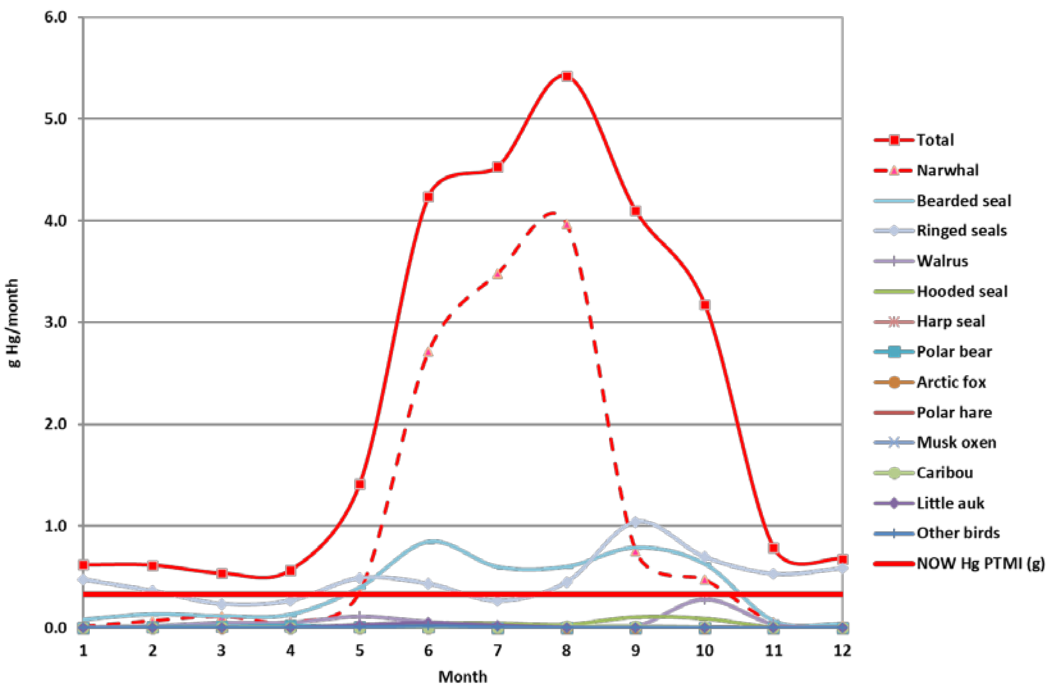

Figure 2. Seasonal Hg load in the hunted game of Avanersuaq based on average hunt from 1994 to 2014 (Piniarneq 2016) and average Hg loads in muscle tissue from the present study and published and unpublished contaminant studies in Greenland (see Dietz et al. 2018 for further information).

The AMAP Human Health Assessment (AMAP 2009) hence concluded and confirmed the 'Arctic Dilemma' described first in the second AMAP Human Health Assessment in the Arctic (AMAP 2003). Reducing human exposure to Hg in the Arctic will depend both on global action to reduce anthropogenic Hg entering the environment as well as local dietary choices (Minamata Convention 2017).

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Modelling oil spill trajectories in Melville Bay and the North Water Polynya

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While major oil platform blowouts are rare, the risk of a blowout happening at any future Arctic off-shore oil development must be considered before development proceeds, to mitigate risks to wildlife and people dependent on the North Water Polynya. Although no exploration activities are currently underway in the North Water Polynya region, adjacent areas have been licensed for offshore oil and gas exploration.

WWF Canada and WWF Denmark have explored the potential trajectory of two hypothetical blowout scenarios to determine the potential consequences for ecologically important areas in the region: the Melville Bay nature reserve and the adjacent North Water Polynya.

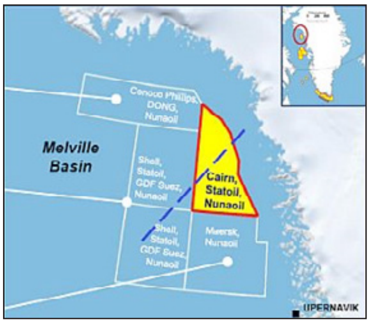

Figure 1. Map of Baffin Bay with the five exploration license areas shown. The yellow area is Pitu – the area for which oil spills were modeled in this study.

The spill site selected for the hypothetical well blowout in Melville Bay was located at 75.231740°N, 60.645321°W. The selected site was within the exploration license area referred to as PITU block. PITU block was one of 5 license areas in Northern Baffin Bay granted by the Government of Greenland in 2012. The PITU block lease was granted to Cairn Energy, who had already completed a series of test drillings in West Greenland in 2010 and 2011, in a joint venture with Statoil and Nunaoil (Fig. 1). The five leases have all been returned to the Government of Greenland.

In the Northern Greenland communities, Upernavik and Qaanaaq, there were widespread concerns about the consequences of hydrocarbon development, including concerns about the impacts of seismic activities on marine mammals and concerns about the risk of and consequences of an oil spill.

WWF contracted Shoal Edge Consulting to model trajectories of oil from a hypothetical blowout in PITU block. Our research questions included the risk of oiling of the Melville Bay Nature Reserve/Qimusseriarsuaq and the adjacent North Water Polynya/Pikialasorsuaq, impacts of oil wildlife and the likely effect of response mechanisms.

For the modelling consequence thresholds were used (Table 1). For shoreline modelling a value of 100 g m^{-2} as used to identify areas where oiling may affect shoreline life. For impact of oiling on the water surface

Table 1. Stochastic scenario input parameters for scenarios 1A and 1B.

ID #	Spill type	Location	Release depth (m)	Oil type	Spill rate (m^3 day^{-1})	Spill duration (days)	Total volume (m^3)	Season	Simulation duration (days)
1A	Subsurface blowout	75.231740 °N 60.645321 °W	808	Medium crude	3340	1	3340	July to October	46
1B	Subsurface blowout	75.231740 °N 60.645321 °W	808	Medium crude	3340	34	113,560	July to October	79

a threshold for fisheries were set to 0.01 g m^{-2} (the socio-economic threshold) while a higher threshold of 10 g m^{-2} was used to identify where surface oiling could mortally impact birds and other wildlife associated with the water surface (the ecological threshold).

Two different scenarios were modelled in Melville Bay (Fig. 2 and 3). The most likely scenario is a 1-day spill of 3340 m^3 medium crude oil. The flow of oil is stopped by natural bridging. Studies indicate that in about 84% of all well blowouts the flow of oil is stopped naturally in 0.5 – 5 days as sediments fill the wellbore. In 16% of all well blowouts intervention is needed to stop the flowing oil. In the worst-case scenario modelled the spill flows for 34 days before a relief well is drilled. No contingency plans were available for the PITU block, but the 34-day response was used by Cairn Energy in the contingency plan for their operations in West Greenland.

The worst-case scenario modelled is a very large spill. With a total volume of 113,560 m^3 medium crude oil spilled it is nearly three times the size of the devesting spill caused by the Exxon Valdez oil tanker grounding in Prince William Sound, Alaska. The modelled spill would be the largest ever seen in the Arctic and even a large spill on a global scale, but would not compare to the Deep Water Horizon blowout in the Gulf of Mexico where an estimated 780,000 m^3 oil spilled remains a catastrophe for the marine environment.

A B

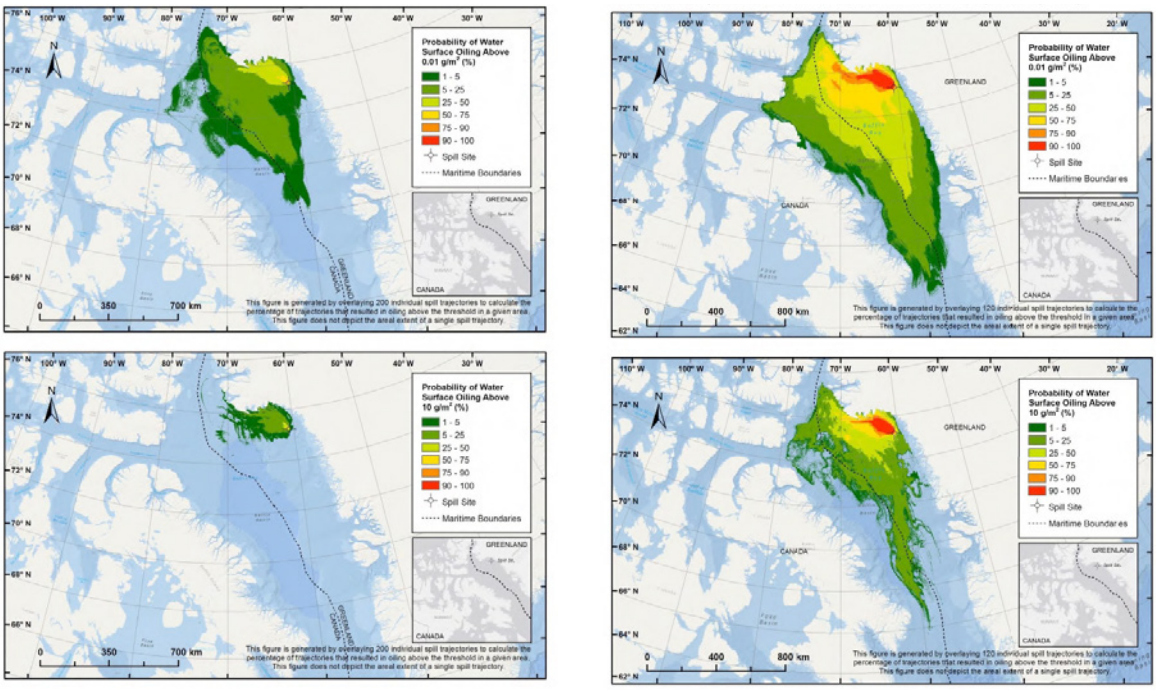

Figure 2. Probability of water surface oiling about the socioeconomic threshold (0.01 g m^{-2}) (top) and the ecological threshold (10 g m^{-2}) (bottom). A) Most likely scenario (1-day spill). B) Worst case scenario (34-day spill). Shoal Edge Consulting for WWF (2016), p. 39-45.

Stochastic modelling – results

Modeling is based on a daily flow rate of 3340 m^3 crude oil. The blowout is presumed to be during open water season (July through October) when drilling operations would take place. A most likely scenario (1-day spill) as well as a worst-case scenario (34-day spill) is modeled (Fig. 2). Areas with the highest probabilities of oiling of the water surface are immediately north of the spill site with consequences for the community of Savissivik.

Deterministic modelling – results

Based on a blowout scenario modeled to have occurred on August 27, 2012, the spill trajectory initially heads to the west of the spill site before turning north and oiling sections of the coast of Melville Bay Nature Reserve 12.6 days into the simulation (Fig. 3). The trajectory continues to travel northwest along the coast and into the North Water Polynya area, oiling additional shoreline areas including along the settlement of Savissivik, Kap York, Kap Atholl, Kap Parry, and Carey Islands.

Floating oil not retained on shore continues to travel westward and southwestward. After 65 days, most of the remaining surface oil is bound in sea ice and moving with the ice currents. At the end of the 120-day simulation, 17,583.2 m^3 of oil (about 15% of the volume spilled) remains on the water surface in Baffin Bay, mostly bound in sea ice.

The model is based on estimated capacity of response: near-shore mechanical recovery is estimated at 30 m^2 oil day^{-1}, off-shore mechanical recovery at 90 m^2 day^{-1} and in-situ burning and use of dispersant at near 900 m^2 day^{-1}. Response operation starts 48 hours after the flow of oil has begun and operations run 12 hours a day.

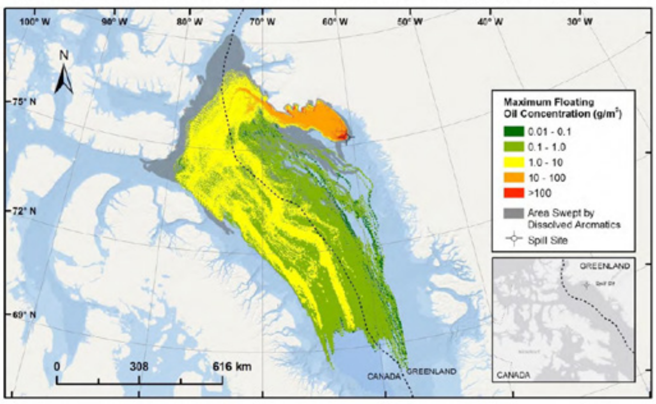

Figure 3. Worst-case (95th percentile) trajectory for water surface area oiled above 10 g m^{-2} within the North Water Polynya, with spill response (surface dispersant, mechanical containment/recovery, and in situ burning) – Maximum concentration (g m^{-2}) of floating oil that passed by a given area during the simulation and the subsurface area swept by dissolved aromatics. Shoal Edge Consulting for WWF (2016), p. 45-51).

Discussion

The trajectory modelling illustrates that a large oil spill in Melville Bay, here PITU block, will flow north form the spill site and impact the northern sections of Melville Bay Nature Reserve, parts of the Greenland section of the North Water Polynya. From here oil will spread towards Canadian waters and southbound into parts of central Baffin Bay. Birds and other wildlife linked to the water surface will likely be impacted in Northern Baffin Bay challenging the livelihoods of people in Savissivik. Oil will not flow into Inglefield Bredning, but the sections of the North Water Polynya home to walrus, narwhal and beluga whale will be oiled. The trajectories illustrates the huge risks associated with hydrocarbon development and the challenges with response in areas difficult to work in.

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Seismic surveys and the Greenland regulation

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Introduction

The early tens saw a growing interest in search for hydrocarbon deposits in offshore Greenland Waters. Deeper Arctic waters have propagation conditions and a marine mammal fauna different from better-studied temperate or shallow-water regions, and there are therefore many unknowns when it comes to impacts on marine mammals during seismic surveys in Greenland. In response to the increasing interest in the offshore Greenland crust the Greenland Environmental Agency for Mineral Resource Activities (EAMRA) established a rather precautionary regulation of seismic surveys to protect marine mammals during seismic surveys (EAMRA, 2015).

Marine mammals and noise

Marine mammals spend the majority of their time in the sea and for cetaceans, all of their life functions takes place in the water. In the sea light is limited, especially in the Arctic winter, and marine mammals have therefore evolved to depend on acoustic cues for orientation, prey localization, finding mates end more. Toothed whales have evolved echolocation and depend strictly on acoustic cues for all of their life functions. To enable use of acoustic cues, marine mammals have very sensitive ears and hears well over a wide range of frequencies. Seismic surveys are problematic for marine mammals because very high sound levels are emitted when an airgun array blast towards the seafloor in search for hydrocarbon deposits. An airgun array typically consists of two sub-arrays of around 30 airguns each. The airguns of each sub-array is fired simultaneously emitting a primarily low frequency blast with a source level of up to $L_{peak\text{-}peak}$ 265 dB re 1 μPa for conventional commercial airgun arrays (NunaPlan-A/S and Golder-Associates, 2012). Such high source level impulse sounds may give hearing damages to marine mammals, if they are close (within a few hundreds of meters) by the airguns or remain nearby (few kilometers) for longer periods of time (hours). However, more importantly may be the behavioral changes that seismic surveys may cause as airgun blasts can be heard thousands of kilometers from the seismic vessels (Nieukirk et al. 2004). Typical reactions within closer ranges of less than 100 km are for example avoidance and changed migration route (Richardson et al. 1999), changes to vocal activity (Blackwell et al. 2015), changes to respiration and foraging activity (Pirotta et al. 2014) as well as other effects (Gordon et al. 2004; Nowacek et al. 2007). It was therefore assessed important by the EAMRA to make a rather strict regulation of seismic surveys to protect marine mammals in Greenland waters.

Regulation of seismic activities

The Greenland regulation of seismic surveys is built on four pillars; 1) an annual application cycle, 2) modeling of noise emissions in the application, 3) time-closure areas for vulnerable species and 3) a requirement of noise monitoring during seismic surveys.

In the annual application cycle, all companies must apply to perform seismic surveys in December the year before the intended survey. All applications can therefore be evaluated together, which is necessary as it is required that each applying company models its own expected noise emission, as well as the cumulative noise resulting from all concurrent activities in a given area and period. The results of the noise modeling is then submitted as part of the environmental impact assessments (EIA). The EIAs with results of the cumulative noise modeling are then evaluated and subject to a public hearing process and a review by expert advisors at Aarhus University and at Greenland Institute of Natural Resources. The results of the noise modeling are evaluated with respect to protection areas, or so called time-closure areas designated for vulnerable marine mammal species: Bowhead whales, narwhals, beluga whales and walruses. There are two types of time-closure areas: Areas of concern and Closed areas. Closed areas are off limit for seismic surveys during specific periods where they constitute important habitats for the focal species. Areas of concern are important areas that are subject to certain conditions for seismic surveys during specific periods. Once a company has obtained permission to conduct a seismic survey the company is required to monitor its noise pollution during the survey and to submit recordings as well as a report of analyzed noise recordings to EAMRA. This report shall relate the actual noise levels to the results of the pre-season modeling.

The purpose of the Greenland regulation is to ensure that uncertainties with respect to effects on the environment are reduced for every permission given. In other words, for every year the EIAs provided in the application cycle should build on a better understanding of the impacts on the marine environment, based on results of previous years' permissions. This type of regulation increases the possibilities and potential for proper mitigation over time. To meet this purpose the hydrocarbon companies are further asked to sponsor research or monitoring activities to increase the knowledge and reduce the uncertainties.

Case study – Baffin Bay 2012

In December 2011 applications were received to perform four simultaneous seismic surveys in the Baffin Bay; three 3D surveys and one 2D survey. The surveys were all planned for the ice-free period August to November. The companies therefore submitted a joint cumulative noise model and were eventually granted permission to carry out the applied surveys, however, in a reduced period due to time-closure areas in Baffin Bay.

Both narwhals and belugas are highly sensitive to human activity, and these species were the main concern of the seismic surveys. It was not known how the species would react to seismic activity in the Melville Bay, but there were, due to reactions observed in response to distant ice-breakers, reasons to believe that narwhals would avoid the seismic vessels and perhaps even abandon the area (Finley et al. 1990). Narwhals have strict migratory schedules and apparently maintain isolation of summer resident populations and they will therefore have few or no alternative summer residencies to the Melville Bay, the quality of which is unknown (Heide-Jørgensen et al. 2012). During summer no contact between Melville Bay and those in Inglefield Bredning, the only other summering stock in West Greenland, has been documented. It was therefore not known if the narwhals would remain in the bay or move offshore during a period with seismic activity. The migrating belugas would most likely continue their migration but try to escape the sound source, very likely by choosing a route few meters from land as is often observed as a danger response among belugas (Heide-Jørgensen 1994).

The Greenland authorities requested three studies to fill knowledge gabs: 1) A large airgun noise propagation study that replaced the requirement for the companies to monitor their own noise emissions (Wisniewska et al. 2014). 2) Aerial surveys for narwhals in the Melville Bay to examine if the distribution or density changed (Hansen et al. 2015), and 3) a hunter interview study as narwhals constitute an important catch for hunters in the region and it was important to understand whether the seismic surveys would change the hunt (Heide-Jørgensen et al. 2013).

The monitoring studies were conducted by Aarhus University and Greenland Institute of Natural Resources, in collaboration with the companies conducting the seismic surveys: Shell, ConocoPhillips and Mærsk. However the analysis and the conclusions were exclusively and independently produced by the research institutions.

Airgun propagation study

The noise contributions from the four concurrent seismic surveys in Baffin Bay was measured with 31 calibrated sound recorders deployed at eleven stations in and around the seismic areas (Fig. 1). Ten of the dataloggers were deployed by Shell inside their license areas and included in the noise analysis (Wisniewska et al. 2014). The impact was cumulative as the noise level rose in response to the onset of each

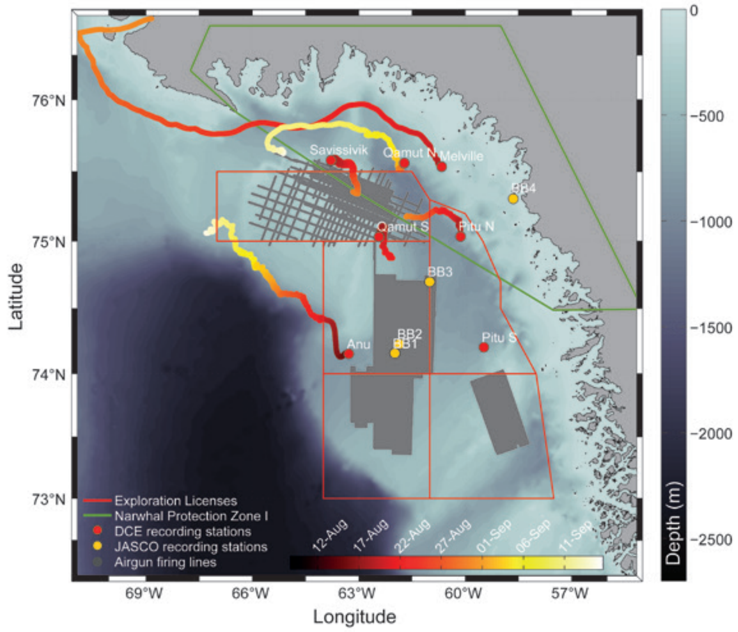

Figure 1. Position of recording stations and seismic surveys in the Baffin Bay 2012. The green line signify a narwhal protection zone in the Melville Bay, where the Melville Bay narwhal population is during summer. Some of the moorings broke loose and their positions are shown as tracks as they drifted in the bay.

survey: On a minute-by-minute scale the sound exposure levels (LE,1 min) varied with up to 70 dB (20 dB on average) (Fig. 2), depending on range to the seismic vessel, local bathymetry effects and interference patterns, showing a significant variability in the auditory scene for marine mammals. The measured values matched well with the pre-season modeling submitted in the EIAs, emphasizing the value of noise modeling in impact assessments, especially if species-specific responses of focal marine mammals are known. During the seismic surveys, the background noise level was constantly elevated, as one airgun pulse would not fade out before the arrival of the next pulse (Fig. 3a). Furthermore, with several concurrent seismic surveys undertaken in the same area, multiple pulses were constantly apparent at various levels (Fig. 3b). This general rise in background noise may cause the airgun sounds to mask other sounds in the frequency range of 1-10 kHz, including sounds of importance to marine animals, especially at close ranges to the airgun array. The airgun signals in the close-up recordings contained significant energy above ambient noise up to, and possibly beyond, 50 kHz at close ranges. This result stresses the importance of including higher frequencies in assessments of potential effects of seismic surveys on marine organisms, especially when considering Odontocetes, which have exceptionally good high-frequency hearing. One datalogger (BB4) was positioned close to shore and inside the narwhal habitat. The airgun sound levels recorded here were low and often the signals were masked in the very high ambient noise level at this station. The lower received levels reflects both the greater distance from the seismic sources, but also the complex conditions for sound propagation with melting ice, moving icebergs and uneven bathymetry near the coast changing the ambient noise from that of the open bay. It is therefore likely that most of the airgun signals were masked in the high ambient noise level at this position.

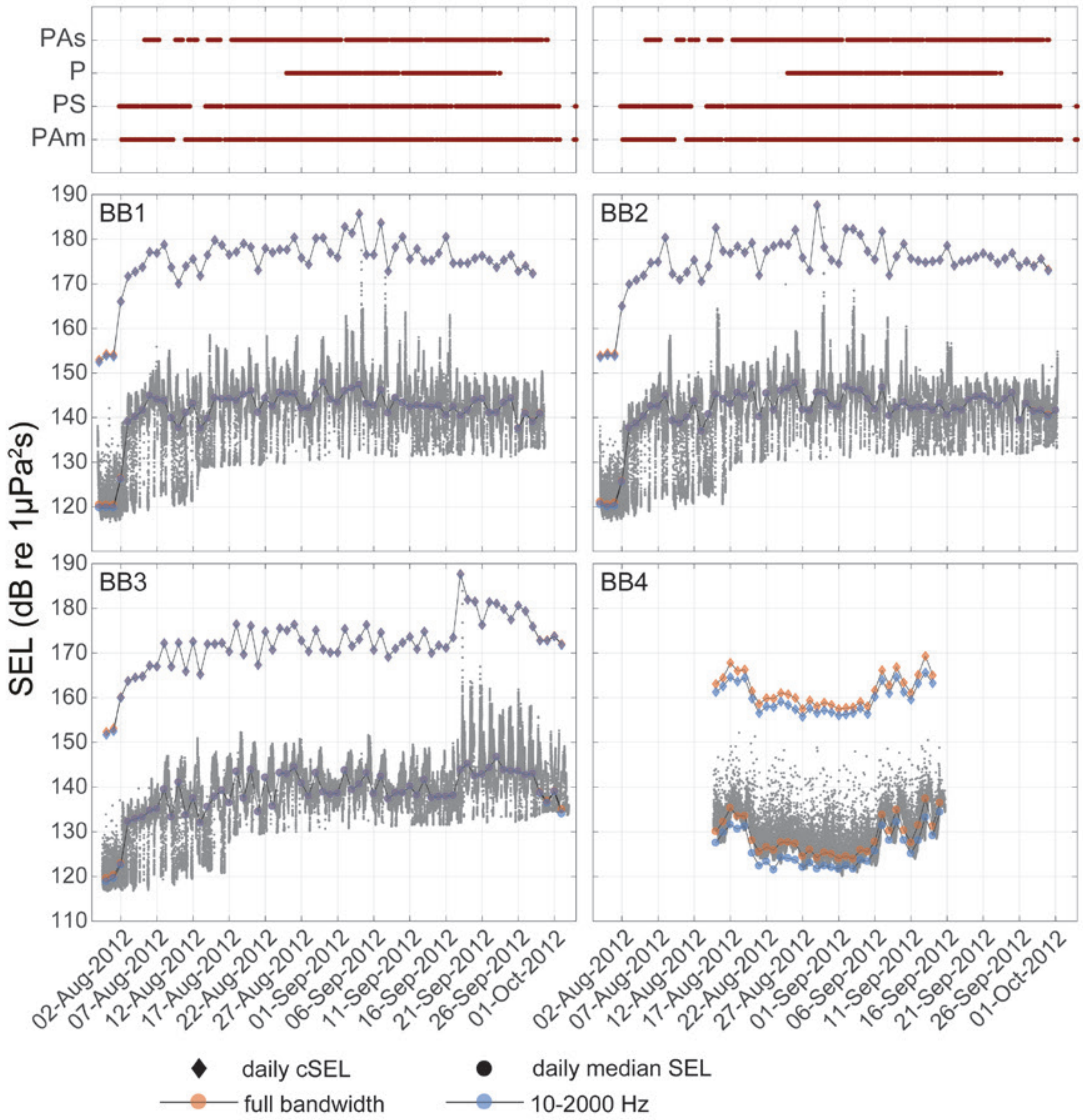

Figure 2. 1-minute full bandwidth (10–32000 Hz) sound exposure levels (LE,1 min; i.e. energy flux density computed for 1-minute long time periods) at the shallow (100 m for BB1-4) hydrophones at Shell's recording stations. Red circles mark daily median LE,p, black circles denote cumulative sound exposure levels, SELCUM, over 24 hours. Top panel shows time of operation of the seismic vessels (PAs = R/V Polarcus Amani (Shell), PS = R/V Polarcus Samur (Shell), P= M/V Princess (ConocoPhillips), Pam= R/V Polarcus Asima (Maersk). For BB4 values are shown as full bandwidth (orange dots) and 10-2000Hz (blue dots). Please note that these energy values are calculated over 1 minute. For estimates over a time window of 1 s, subtract 18 dB (10log10(60)).

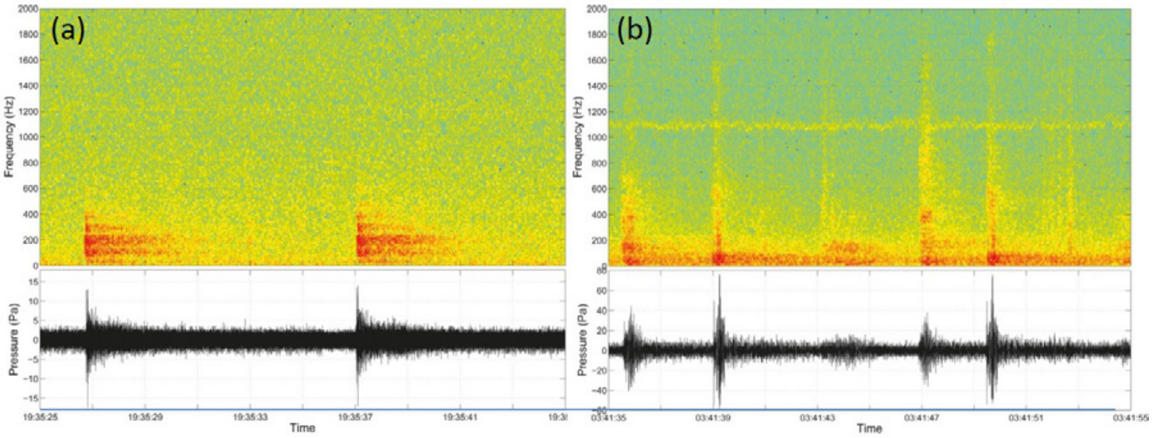

Figure 3. Spectrogram and time series of a typical sound recording of airgun pulses received at a) the bottom hydrophone at the Savissivik station on 27 August 2012. b) shows overlapping airgun pulses from three seismic vessels (most likely M/V Princess (ConocoPhillps), R/V Polarcus Samur (Shell) and R/V Polarcus Amani (Shell)) received at the middle hydrophone (150 m deep) at the Qamut N station on 11 September 2012. From Wisniewska et al. 2012.

Aerial surveys

Three aerial surveys were planned in 2012 in the Innermost part of the Baffin Bay, the Melville Bay, which is the prime habitat of the Melville Bay narwhal stock in summer. Unfortunately, the weather delayed conductance of the first aerial survey and it was therefore performed at the same time as the seismic surveys commenced, rather than before, as planned, to obtain the natural distribution (Hansen et al. 2015). The same transect lines were used in the three aerial surveys, the second and third survey was also during the seismic surveys. Compared with the results of an aerial survey conducted in the same area in mid-August 2007 (Heide-Jørgensen et al. 2010), the narwhal observations from surveys 2 and 3 were significantly closer to the coast. The distribution of narwhals from the 2007-survey was, in comparison with the two first surveys in 2012, intermediate in relation to the distance to the coast. In terms of timing the 2007-survey was also intermediate between survey 1 and 2 in 2012.

Generally, narwhals were more dispersed in a north–south direction in 2007 (Heide-Jørgensen et al. 2010), while they were distributed in a narrow part of the central area of Melville Bay in 2012 (Hansen et al. 2015). In 2012, the distance between the different narwhal groups was significantly shorter during all three surveys than during the 2007-survey. In conclusion, the distribution of narwhals in 2012 was more clumped and concentrated in a smaller section of the coast than in 2007 (Hansen et al. 2015). However, aerial surveys conducted in 2014, where there were no seismic surveys, confirmed the 2012 pattern, and the clumped pattern seen in 2012 and 2014 may therefore be caused by other factors.

The acoustic datalogger located closest to the area favoured by the narwhals in 2012 was placed approximately 40 kilometres from the Melville coast. The highest noise levels recorded here were approximately L_{eq} 110–124 dB re 1 µPa (Wisniewska et al. 2014). Another datalogger located further north in Melville Bay, about 125 kilometres from the coast had the highest noise levels at approximately L_{eq} 130–155 dB re 1 µPa. Both dataloggers were deployed outside the area surveyed visually, but within the area shown by satellite telemetry to be used by narwhals in

August-September (Dietz and Heide-Jørgensen 1995; Heide-Jørgensen et al. 2013). As recordings from the BB4 datalogger showed low received levels of airgun signals, the inshore areas may to a great extend have been sheltered from airgun noise resulting in low received levels in the narwhal habitat. However, this should be studied in a monitoring study focusing on the near shore habitat.

Behavioural changes have been observed in narwhals at Leq levels from 94 to 105 dB re 1 µPa (between 20 and 1000 Hz) from both passive and actively ice-breaking vessels, i.e. at a frequency range and noise level similar to the seismic noise encountered in Baffin Bay in 2012 (Wisniewska et al. 2014) but of a different 'nature'. This means that airgun pulses travelling from the off-shore seismic areas to the acoustic loggers closest to the narwhal area in Melville Bay were high enough to potentially cause behavioural changes there. Shell's coastal datalogger however demonstrated masking of airgun pulses due to the naturally occurring high background noise level near the coast, and therefore a reduced likelihood of behavioural effects on narwhals there.

Hunter interview study

Interviews with the hunters showed that 58 % of the 79 narwhals caught in northern Baffin Bay in 2012 were caught before the seismic surveys began, while the rest were caught during the period with seismic activities (Heide-Jørgensen et al. 2013). Of these 42 % the hunters reported no changes in catch locations or difficulties in the hunt compared with other years. However, when compared with catch reports from 2007–2009, the catches in 2012 were concentrated more in the central and protected part of the Melville Bay, consistent with the distribution of narwhals observed in the aerial surveys. The catch survey also showed that most of the narwhals were caught from kayaks (Heide-Jørgensen et al. 2013).

Narwhals were caught very close to shore and noise measurements from one catch area showed very decreased levels of received airgun pulses, and that the airgun pulses were masked in noise from glacier ice moving around in the bay.

Conclusion

The measured noise levels at the stations closest to the Melville Bay were high enough to potentially cause behavioural changes of narwhals. It is possible that the seismic noise caused the narwhals to prefer the central part of Melville Bay in 2012, where they were more clumped in the central part of the bay than observed in 2007. However, the results from the aerial survey in 2014 suggest that the clumping of narwhals in the inner part of the Melville Bay may be a long-term trend un-related to seismic exploration. Continued monitoring of the relatively small population of narwhals in the bay will presumably provide a better understanding of their distribution over time.

The next step towards greater understanding of the impact of seismic noise on narwhals – both individually and at population level – is to conduct targeted effect studies of behavioural and physiological effects on individual narwhals during controlled exposure to noise from airgun arrays. The long-term impact of seismic noise on distribution, migration patterns and population size should be documented by annual aerial surveys preferably prior to the onset of seismic surveys and in the years following seismic exposure and where the level of hunting pressure is known (e.g. Melville Bay).

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Status of blood mercury concentration in twenty-four bird species in Northwest Greenland

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Birds are useful bioindicators of environmental contamination around the globe, but avian studies in the high Arctic have been primarily limited to a few abundant species. Previous Hg studies of Arctic avian species have focused largely on marine seabird species that occur in high abundance (e.g. Thick-billed Murres (*Uria lomvia*) and Black-legged Kittiwakes (*Rissa tridylacta*)). Tissues such as liver, kidney, and muscle have largely been used for analysis (e.g. Dietz et al. 1997; Riget et al. 1997, 2004), acquisition of which is lethal to sampled birds. Non-destructive techniques have predominantly focused on sampling whole eggs (e.g. Braune et al. 2016; Akearok et al. 2010) or feathers (e.g. Bond and Diamond 2009; Fort et al. 2014). Quantification of Hg using these tissue types provides measures of long-term Hg exposure (AMAP 2011). Whole blood sampling has recently become more common which allows for non-destructive sample collection. Blood is considered the best tissue for evaluating short-term dietary uptake of Hg, and can provide insight into Hg exposure during specific life-history stages or geographic locations at time of sampling (i.e. breeding or wintering grounds) (Evers et al. 2005; Wayland and Scheuhammer 2011). Furthermore, using non-destructive blood samples allows for sampling of rare and threatened species, for which little to no information on Hg exists (Boertmann 2007; Eisler 2010). Studies of blood Hg concentrations for Arctic bird species during the breeding season are relatively uncommon, and recent research has highlighted the overall lack of knowledge of Hg exposure on the breeding grounds of Arctic birds, particularly post egg laying (Braune et al. 2016; Mallory and Braune 2017).

The aim of our study was to establish baseline measurements of avian blood Hg during the post-egg laying period in northwest Greenland and examine differences across passerine, shorebird, waterfowl, seabird, and bird of prey species, many of which represent knowledge gaps in contamination studies (Mallory and Braune 2012). Twenty-four migratory avian species (n = 625) were sampled over a three year period (2010–2012) along 750 km of coastline near Thule Air Base (77° N, 68° W). Whole blood samples were analyzed for total Hg along with $\delta^{13}C$ and $\delta^{15}N$ to estimate food web position. Similar to Hg, stable isotopes measured from the blood reflect short-term dietary intake (Hobson and Clark 1992).

Adult mean blood Hg concentrations ranged from 11.4 ng g^{-1} in Hoary Redpoll to 1164.85 ng g^{-1} wet weight in Peregrine Falcon (*Falco peregrinus*) (Fig. 1). Birds of prey had the highest Hg concentration (Least Squares mean = 1164.85 ± 368 ng g^{-1}) followed by seabirds (413.87 ± 97 ng g^{-1}), shorebirds (359.68 ± 152 ng g^{-1}), waterfowl (86.85 ± 29 ng g^{-1}), and passerines (35.25 ± 30 ng g^{-1}).

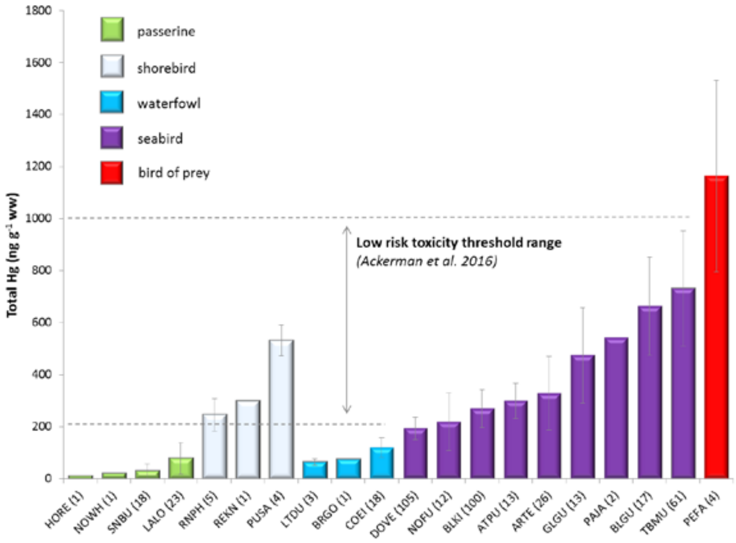

Figure 1. Whole blood total mercury (±SD) for adult birds ranked by mean Hg concentration grouped by bird type. Species not included had juvenile only samples.

Concentrations of Hg in blood of marine and terrestrial species were positively correlated with $\delta^{15}N$ ($r^2 = 0.51$, p = 0.004, slope = 0.089, n = 346) (Fig. 2). Thick-billed Murres (pelagic and benthic fish-feeding seabird) had the highest Hg concentration (mean = 731.35 ± 223 ng g^{-1}) and second highest trophic level (Peregrine Falcons had highest overall Hg concentrations, but isotopic data not available for comparison). The highest trophic position for Glaucous Gulls (coastal scavenger and predator) corresponded to the fifth highest Hg concentration.

Our study documents low to moderately high levels of Hg in bird populations in northwest Greenland. Although there are relatively few comparative blood Hg studies of the same Arctic species on breeding ground, our compared mean Hg results were mixed. Concentrations of blood Hg in Arctic Terns (*Sterna paradisaea*) and Atlantic Puffins (*Fratercula arctica*) measured in our study were 2× higher than breeding birds

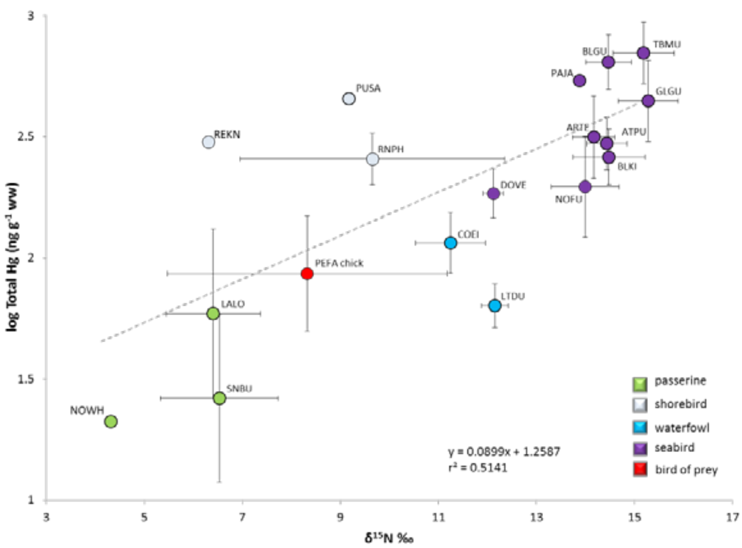

Figure 2. Mean and standard deviation for $\delta^{15}N$ and Hg in all adult birds. Higher $\delta^{15}N$ values indicate higher trophic positions. Data shown are only for samples run for both Hg and isotopes. Hatch year Peregrine Falcons (PEFA chicks) shown, but not included in linear regression statistic.

reported at a more southern latitude (New Brunswick, Canada, 44° N) (Bond and Diamond 2009). Studies of Black-legged Kittiwakes nesting in Svalbard (similar latitude) reported both lower and slightly higher mean Hg levels than were found in our study (Goutte et al. 2015; Tartu et al. 2015; respectively). Dovekies nesting farther south in east Greenland had a lower Hg concentration (Fort et al. 2014). These results are similar to those found by Braune et al. (2002, 2006, 2014), who suggested that Hg concentration in Arctic seabird populations increase with latitude (although blood samples were not the method of comparison). Among non-seabird species only Common Eiders and Red-necked Phalarope had comparable blood Hg data published. Wayland et al. (2001) and Provencher et al. (2016) studied Common Eiders nesting farther south in eastern Canada and reported mean Hg concentrations nearly 2× higher than in our study, which is similar to the decreasing latitudinal pattern reported for Common Eider in the eastern Canadian Arctic by Mallory et al. (2004; not blood samples). A single Red-necked Phalarope sample in coastal northern Alaska was substantially higher (1210 ng g^{-1}; Perkins et al. 2014) than our reported values (246 ng g^{-1}). While concentrations of Hg in other tissue types have been published for a number of the species studied here, useful comparisons with blood tissue are challenging due to differences in heavy metal retention between tissue types and demethylation rates between tissue type and species (Eagles-Smith et al. 2008).

Broadly speaking across latitudes and species, total Hg concentrations of 200–1000 ng g^{-1}have been observed to pose low fitness risks, 1000–3000 ng g^{-1} moderate risks, and values exceeding 3000 ng g^{-1} pose high and severe risks (Ackerman et al. 2016). The mean Hg concentration of all but one of our studied species falls at or below the low toxicity impact level. The Peregrine Falcon was the only species with mean Hg concentrations > 1000 ng g^{-1}indicating moderate risk from Hg exposure (mean = 1164 ± 368 ng g^{-1}). However, 8 of 61 (13.1%) Thick-billed Murres and 1 of 17 (5.9%) Black Guillemots had Hg concentrations > 1000 ng g^{-1} suggesting that all three species may warrant further investigation concerning its potential fitness effects. Eleven species had mean concentrations associated with low risk of Hg toxicity (including Thick-billed Murres and Black Guillemots) while an additional four species had individuals in this range. Avian species of concern listed in Greenland's Red List (Boertmann 2007) as vulnerable (Common Eider, Thick-billed Murre, and Black-legged Kittiwake) and near threatened (Atlantic Puffin, Gyrfalcon (*Falco rusticolus*), and Arctic Tern) may also warrant special attention and continued monitoring. Special attention may also be warranted for three species designated by The Arctic Council Working Group, Conservation of Arctic Flora and Fauna (CAFF), as species of circumpolar concern: Long-tailed Duck, Dunlin, and a Red Knot subspecies (*C. c. islandica*) (Johnston et al. 2015).

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Tools for marine conservation planning in the Eastern Canadian arctic

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World Wildlife Fund-Canada's Arctic program offers an environmental perspective to northern issues and seeks to promote sustainable development with minimal impact to wildlife in the Canadian Arctic. As an NGO, WWF cannot decide on the allocation of resources in or management of the Pikialasorsuaq. However, WWF can provide tools to inform that management by supporting and communicating both bio-physical information and traditional knowledge. Two recently developed tools include an interactive digital atlas of the Pikialasorsuaq, and a map of a proposed marine protected areas network for the Eastern Canadian Arctic.

The Pikialasorsuaq Atlas and Interactive Planning Tool (Fig. 1) has been developed through a collaboration between WWF, KNAPK (the Association of Fishers and Hunters in Greenland) Inuit Circumpolar Council (ICC) Canada and ICC Greenland, with support from Dalhousie University. The atlas consists of a digital atlas cataloguing human uses and ecological information from both the Canadian and Greenlandic sides of the polynya, and an interactive planning tool to allow users to combine data to suit their needs. The atlas is a visualization of existing information about the region and includes indigenous knowledge collected during the spring 2016 Pikialasorsuaq Commission consultations in Arctic communities. Data layers span a broad range of social and ecological components of the Pikialasorsuaq, including Arctic species distribution data, Inuit travel routes and fishing areas, cultural and archaeological sites, sea ice changes, and non-traditional activities (e.g. marine tourism, shipping routes, non-renewable resource exploration and development). The Interactive Planning Tool can be used for a variety of purposes, including management decision-making and research planning. The Atlas can also be updated with new research or spatial information as it becomes available if researchers submit GIS data layers to the database manager through WWF. The Atlas is hosted on WWF's web server.

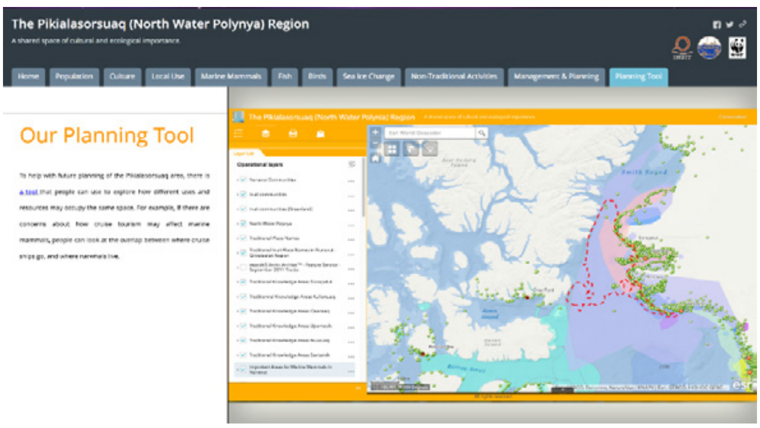


Figure 1. Pikialasorsuaq Interactive Planning Tool homepage.

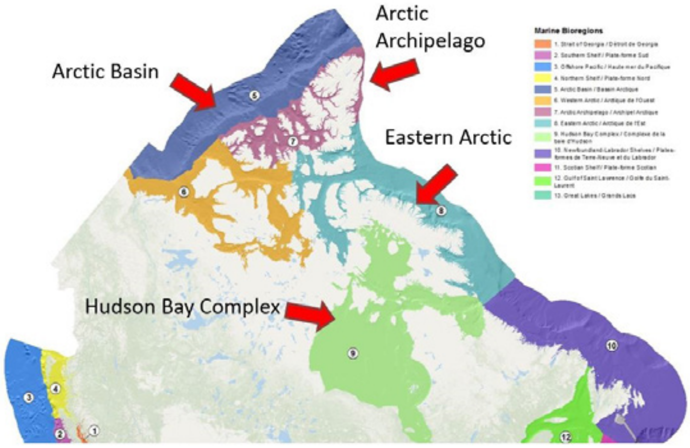


Figure 2. Canadian Arctic Marine Bioregions included in MECCEA analysis.

The second tool will be the final product of the ongoing WWF "Marine Ecological Conservation for the Canadian Eastern Arctic (MECCEA) project", expected to be completed in December 2018. WWF-Canada is advocating that the Canadian federal government undertake marine protected areas (MPAs) network planning in the marine bioregions of the Eastern Canadian Arctic, beyond their ongoing process to establish standalone MPAs. To support this advocacy, WWF-Canada has undertaken a project to identify and map an ideal MPA network based on ecological information for four of the five identified Canadian Arctic marine bioregions (the Arctic Basin, Arctic Archipelago, Eastern Arctic, and Hudson Bay Complex; Fig. 2). The Western Arctic bioregion has been excluded from WWF's analysis because MPA network planning is already underway in that region.

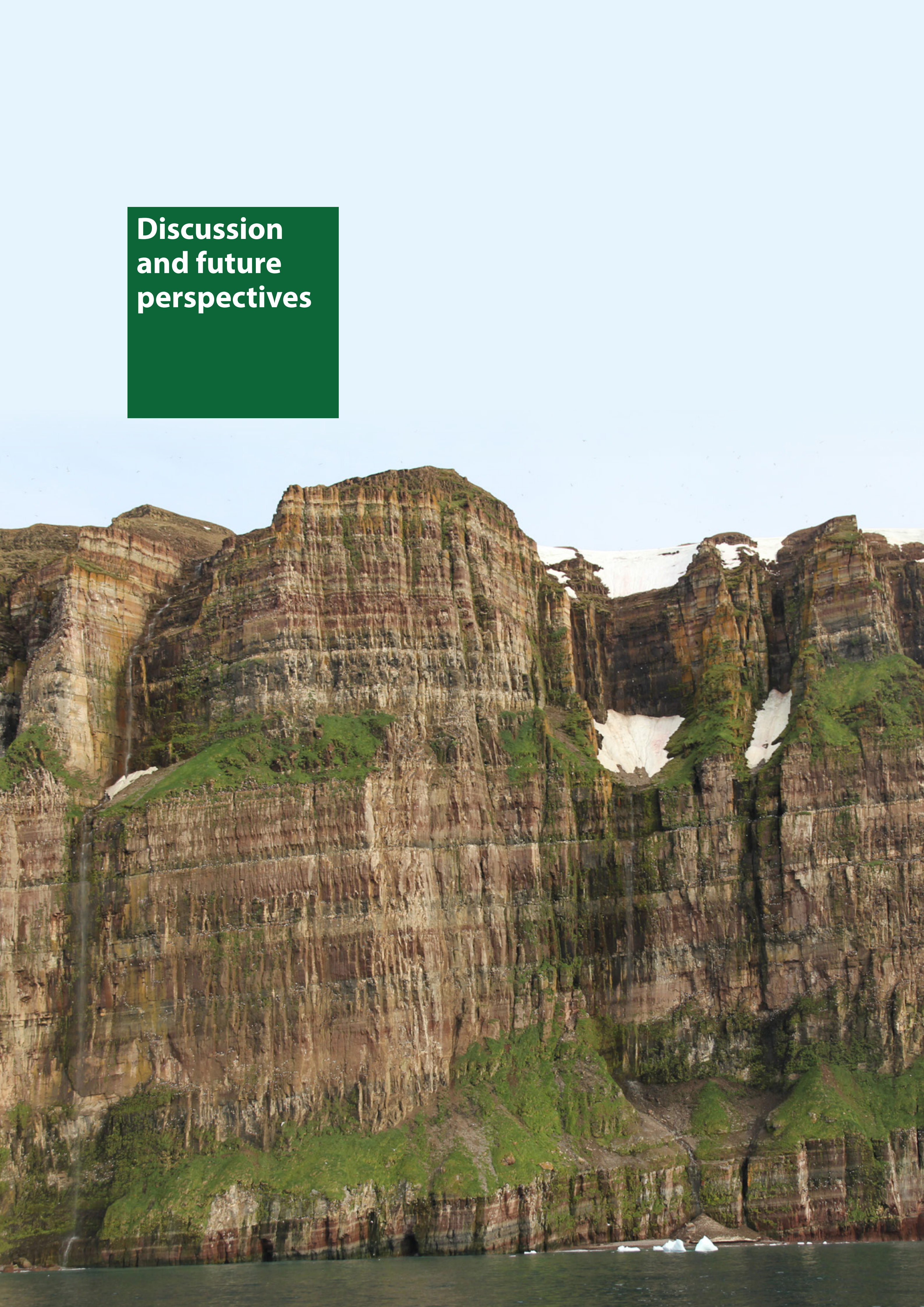
The strategic objectives guiding the network design include:

1. Distinctiveness: protect distinctive, unique, special, rare, and sensitive ecological features in the four bioregions
2. Representativeness: protect representative examples of identified ecosystems and habitat types in the four bioregions
3. Ecosystem Resilience: maintain ecosystem structures, functions, and resilience within the four bioregions

The map will be developed using Marxan analysis, integrating spatial scientific information (wildlife distributions, habitat, benthic data, geophysical data, etc.) and traditional and local knowledge (significant cultural areas, hunting areas, etc.) to capture the maximum number of identifiable components of marine biodiversity and culturally significant areas embedded in potential candidate MPAs. This tool can contribute to MPA network development in the Eastern Arctic and inform the development of the future pan-Arctic MPA network. Following the Marxan analysis, maps of human uses in the bioregions (economic activities and areas of socio-cultural significance) will be overlaid with the

Marxan scenarios to refine the MPA network, and a connectivity analysis will be applied to ensure that the proposed network incorporates connectivity between identified candidate MPAs. The well-established significance of the Pikialasorsuaq suggest that this area will be identified in the analysis, but the analytical framework will contextualize it in a circumpolar frame and provide insights into connectivity between the Pikialasorsuaq and other ecologically significant areas in the Canadian Arctic.

Discussion and future perspectives



Round table discussion

A panel of users, stakeholders and managers of the NOW was invited to provide questions for the scientific community

Line A. Kyhn
Kasper Lambert Johansen
Anders Mosbech

The second day of the conference concluded with a round table discussion with a panel of users, stakeholders and managers of the North Water Polynya that was invited to ask key questions to the scientific expert community on the NOW to begin a discussion on future research needs in the area, as well as to put their expert knowledge into play for the wider community. This text is a distill of the raised main questions and the discussion that took place at the round table discussion. We have answered some of the questions in the introduction to this report (Link) and in the Friday morning discussion on future research needs (Link). While some questions remain for the future to be responded to.

The individual presentations and questions posed by the panel participants may be re-visited here.

Panel participants

Kuupik Kleist	– *Pikialasorsuaq Commission*
Lisbeth Ølgaard	– *Ministry of Environment and Food, Denmark*
Inge Thaulov	– *Ministry of Nature and Environment, Naalakkersuisut, Greenland*
Vicki Sahanatien	– *Nunavut Wildlife Management Board*
David Lee	– *Nunavut Tunngavit Inc.*
Joel Ingram	– *Oceans Program Central and Arctic Region, Fisheries and Oceans, Canada*
Mads Ole Kristiansen	– *Association of Fishers and Hunters in Greenland, Qaanaaq*

Hunters and locals request to be involved from the planning stage of research projects

High Arctic scientists depend heavily on hunters of the NOW region to carry out research projects. As it is, the hunters sometimes do not know who, when and why the scientists arrive, what the purpose of their research is or what the results mean. This means that they cannot anticipate their arrival or plan their own hunting activities if they are to assist the arriving scientists. In some places, for example Qaanaaq, there are many foreign researchers carrying out research and acquiring assistance every year. Hunters assist with dog sledges, boats, game or labor depending on season and research activities. Hunters appeal to be involved from the planning stage in order to be able to participate in the research activities and make money, and at the same time being able to conduct their own cyclic and strictly regulated hunting activities. It was put forward as important that hunters get an equal chance to be involved and that there is equality in salary and working conditions across projects and between hunters. Hunters argued further for research activities to be coordinated at some level for example with the Hunter's Association, KNAPP, in Greenland. Another possibility discussed was the installment of local research hubs in for example Qaanaaq. Such hubs could offer to provide logistics, storage and contact with hunters, standard contracts & working conditions as well as collection of monitoring data and assist with an information flow from scientists and back to the hunters and the local community. There was general consent among the NOW experts to improve collaboration at all stages with the hunters and to provide more feedback with the results of their research. However, the short funding scheme for many research projects puts limits to establishing long-term commitments and it was certainly welcomed if a research hub could be established and provide contact and continuity.

Managers need to see the full picture to provide the correct advice to decision makers

Managers emphasized that they need to see the full multifaceted picture to provide decision makers with the best available knowledge to base their decisions on. It is therefore important that the Science Community make their knowledge readily available for the Greenland and Canadian managers in order for their authorities/politicians to take well-informed decisions. It was further noted that Canada and Greenland has a challenge managing their shared stocks, especially within the context of climate change and for some species there are important information needs. It was mentioned as a wish from locals that both scientific and local knowledge is included in Strategic Environmental Impact Assessments and other assessments.

In the discussion it was asked what the key system and socioeconomic management objectives are for the NOW polynya? While this is mainly a political question beyond the scientific community it was relevant in the discussion of what information is needed to support the management in achieving the objectives and what adaptation tools may be required for adaptation and sustainable management. It was obvious that while some research questions on the ecological dynamic of the NOW system are straight forward there are other questions which tie into the management regime and the setting of management objectives for NOW socio-ecological system. One important question is what the financial and societal impacts of new protection measures will be?

It seems that there is a need for establishing a process for Greenland, Denmark and Canada to involve locals and collaborate on identifying and addressing a) management objectives, b) an integrated monitoring program for the socio-ecological system and c) the most urgent research questions for the NOW polynya.

Monitoring the NOW

How will stressors affect the biodiversity of the North Water? How will anthropogenic stressors affect the ecosystem and species in the most important areas now and in the future? How do these anthropogenic stressors affect the ecosystem together with climate change? Do we know the cumulative effects of all that is going on right now? Some of these questions may be resolved by monitoring. Monitoring in the NOW was brought up several times: What in the NOW is most important to monitor in the future and how can sustained monitoring be assured? How can the existing Arctic Council Platforms including their advice, recommendations and protocols be used in a potential monitoring/observation system in the NOW? These questions were addressed in several of the presentations and eagerly discussed in the workshop Friday morning. One possibility was argued to be the Nunavut Agreement monitoring that (harvested) species are sustainable. See summary of the workshop (p. xx) and presentation by Barber and colleagues (p. XX) as well as by Fortier and colleagues (p. xx), Mosbech and colleagues (p. xx) and Boertmann and colleagues in (p. xx).

How is the NOW ecosystem changing and which protection measures can be installed?

We need an improved understanding of the changing environmental conditions within the NOW ecosystem: Which environmental conditions and anthropogenic stressors are changing and how are they impacting productivity of the region and transfers through the food webs to birds, fish and marine mammals? How can the changes in habitat within the NOW region impact the distribution of fish and marine mammals and the potential to sustain traditional and commercial fisheries? Some of these questions are addressed by Rysgaard (p. xx), Casey and colleagues (p. xx), Fortier and colleagues (p. xx), Le Blanc and colleague (p. xx), Thyrring and colleagues (p. xx) and Boertmann and colleagues (p. xx).

Concluding workshop: Needs for research coordination and planning

Anders Mosbech
Tom Christensen

All conference participants were invited to half a days' follow up workshop, to share plans and ideas for future projects. A main purpose was to discuss potentials for research coordination and scientific and logistic synergy in the North Water Polynya (NOW) at large. The workshop used previous days' presentations and round table discussions as a set off, including the stakeholder/ user needs and questions that was presented at day 2.

Key messages from the discussion of research coordination and planning

There are many on-going research and monitoring activities in the NOW and there is an immediate potential for synergy from collaboration and data sharing among research groups. Contacts were established and initiatives discussed during the conference.

Effects of drivers and anthropogenic stressors on the changing ecosystem in NOW are key questions. How does climate change together with other existing and new emerging anthropogenic stressors (including fisheries, oil and gas exploration, shipping, noise, tourism, contaminants, changes in marine litter) affect the ecosystem? Answers to this question will be important for people living in the NOW area, as well as managers, for planning adaptation to changes in ecosystem service conditions and to manage the area.

It was a general opinion that there is a potential for a large multidisciplinary research initiative encompassing ongoing and new activities and involving locals, to inform local climate adaptation as well as gaining insight into regional and global processes.

A large research initiative should cover disciplines from physics (ice, oceanography etc.) over ecology to social science.

One of the next steps in such an initiative is to engage with relevant stakeholders and users of research results related to the NOW. In this regard the link between research, monitoring and political relevance should be a key issue; including dialogue and collaboration with Greenland agencies, Canadian agencies, local people, organizations and other stakeholders.

In the discussions a number of research questions and priorities were proposed, and it appeared that if a large coordinated research initiative should take off, discussions at a next meeting should be based on a clear straw-man proposal for a proposed initiative.

Whether or not a large coordinated project will take off, future research and monitoring will be a multitude of studies and activities. It was therefore also proposed to create of a Research Coordination Network involving researchers from Canada, Greenland, Denmark, US and others and also with strong participation and dialogue with local Greenlandic and Canadian people.

Synergy and collaboration

Mark Mallory made a presentation on "Synergy From Collaboration", showing how open sharing of data has led to new interpretations and scientific insights into marine biodiversity in the Canadian Arctic. He provided examples of how shared tracking data from top predators has revealed clear "hotspots" and "cold spots" for multiple species in Canada – information that would be extremely difficult to generate by means of other than a single analysis with pooled data. In the North Water Polynya Conference presentations, there were several cases where it appeared that pooling of data among researchers could lead to both new research opportunities, but also to better assessment of chemical and biological patterns in the Polynya. For example, there are clearly multiple datasets from different locations in and around the Polynya on stable isotopes (notably N and C) of different components of the marine food web, and the preliminary information suggests species-specific differences in temporal patterns in those data (e.g., stability of fulmar signals and variation in guillemot signals). Other presentations looked at using chemical proxies of past environmental conditions in the Polynya (e.g., sea floor cores), and it seems clear that bringing together a suite of proxies through time, both from the marine and terrestrial environment (e.g., cores from nearby freshwater lakes in the little auk flight path) may provide additional support for concepts. Finally, there were different presentations that provided data on current and past human use of the Polynya, and others that looked at wildlife use of the Polynya – pooling these spatial and temporal data would yield better answers to existing questions about the importance of this area. Collectively, pooling data in an open and collaborative approach, with careful thought on assessment techniques, provides multiple opportunities for new research and assessments/papers, while still allowing individual researchers to publish their own independent work. Ultimately, an open approach will allow for more robust and sound results, as well as stronger support for funding applications.

Examples of ongoing activities

See also the extended abstracts from the presentations

Jean-Eric Tremblay:
As part of ArcticNet and following the detailed investigation conducted during the International North Water Polynya Study, the Canadian team has been maintaining an annual survey of the east-west transect located at ca. 76.3°N (+ additional stations up North when ice conditions permitted) since 2005. Funding for the current phase of ArcticNet is ending in March 2017, but they were able to sample once more in 2018. Sampling activities at the survey stations include physical (CTD, currents, met) and chemical (nutrients, carbonate system, pH, pCO_2, DMS, contaminants) measurements, primary production, benthic diversity and O_2 demand, microbial diversity, diversity and abundance of zooplankton and fish larvae, acoustics etc. (this is not a comprehensive list). These activities could be complemented by bird and marine mammal surveys, which have not been systematically performed until now.

Flemming Merkel:
As part of the monitoring program for seabirds, the Greenland Institute of Natural Resources (GINR) conducts breeding bird surveys in the NOW area every 5-10 years (last survey in 2014/15). The surveys are focused on murres and kittiwakes, of which there are five large colonies, and total counts are conducted from photos. Where possible, total count numbers are corrected for diurnal variation in numbers by means of time-lapse cameras. In two colonies (Saunders Island and Parker Snow Bay), time-lapse cameras have been put out on a permanent basis (taking pictures throughout the breeding season) with the purpose of documenting breeding phenology and quantifying breeding success. Monitoring activity is often coordinated with short-term research projects, and in 2007-08 and 2012-15 migration patterns and foraging behavior of the murres were studied at Parker Snow Bay, Saunders Island and on the Carey Islands by means of geo-dataloggers and GPS devices. In addition, studies on the impact of human disturbances were conducted on Saunders Island and the Carey Islands in 2015.

Information about seabird performance in the NOW area can be an important reference for other seabird colonies in West Greenland. This is especially the case with murres as they are declining heavily in most of West Greenland, but not in the NOW area. For this reason the GINR wants to intensify monitoring in the NOW area, including the use of time-lapse cameras and geo-dataloggers. This is perhaps possible to achieve if the costs and logistics can be shared with other institutions working in the NOW.

Rune Dietz:
Ringed seals have been sampled on regular basis for more than 30 years in Avanersuaq prior to and as part of the AMAP program since 1984. Studies of stable isotopes, amino acids and fatty acids could provide information on the ecosystem and changes over this period as we have previously done in East Greenland based on polar bear samples. There are a number of options and ongoing projects on temporal and geographical trends in marine birds, belugas, narwhals on top of what has already been done on ringed seals and polar bears. Diseases and effect studies are underway on narwhals and ringed seals.

Burnhams:
During 2018 they worked again out of Thule Air Base and surveyed approximately 750 km of coastline by small boat. Surveys was primarily for nesting Gyrfalcon, Peregrine Falcon, Arctic Tern, and Glaucous Gull. Samples was also collected from Black-legged Kittiwake, Thick-billed Murre, Common Eider, Black Guillemot, and Northern Fulmar as part of a collaborative study with researchers working in eastern Canada. In total, they have worked with approximately 25 different avian species and are more than happy to collect samples for other researchers or help out in any other way possible.

Thoughts on developing a new research initiative

Jean-Eric Tremblay:
Future sampling plan/programs should, at a minimum, strive to maintain the Canadian/ArcticNet time series (see description above). The rationale is that we have documented a high variability in nutrient supply and primary production in the area, with a strong decrease for the period 1998-2011. Productivity levels seem to be increasing again, suggesting the possibility that transient or cyclic phenomena linked to larger-scale atmospheric dynamics or climate oscillations are influencing the area. Assessing or anticipating the relative contributions of these components of variability versus the impact of directional climate change on the ecological status of the NOW and its significance for local communities requires that we extend the temporal and spatial scope of the time series.

The timing of opening as well as physical conditions and biological productivity in the NOW are strongly tied to the formation of the ice arch, ice dynamics in the Lincoln Sea and the supply/storage of freshwater and nutrients from the Beaufort Gyre. It is therefore desirable that a future program aiming to evaluate the present ecological status of the NOW should integrate this connectivity. A second element of this connectivity is the large storage of nutrients and especially silicate in the deep waters of Baffin Bay. We have evidence that this storage is fueled by the oblique sinking and remineralization of diatoms produced in the NOW, its extension in Lancaster Sound and possibly productive areas along the western Greenland shelf. These extraordinary high inventories of nutrients have a strong potential to retroact on biological productivity in the NOW, depending on the extent to which deep Baffin Bay water ventilate upward and northward (poorly understood). A third crucial element of this connectivity is the ecological and economic impact that biogeochemical fluxes in the NOW/Lancaster Sound/Deep Baffin Bay complex have on the southward transport (via the Labrador current) of nutrients, carbon and contaminants toward the nexus of deep water formation in the Labrador Sea and the fishing grounds of the northwest Atlantic off Canada and the US. These can be used as selling arguments for a program focused on northern Baffin Bay and the NOW.

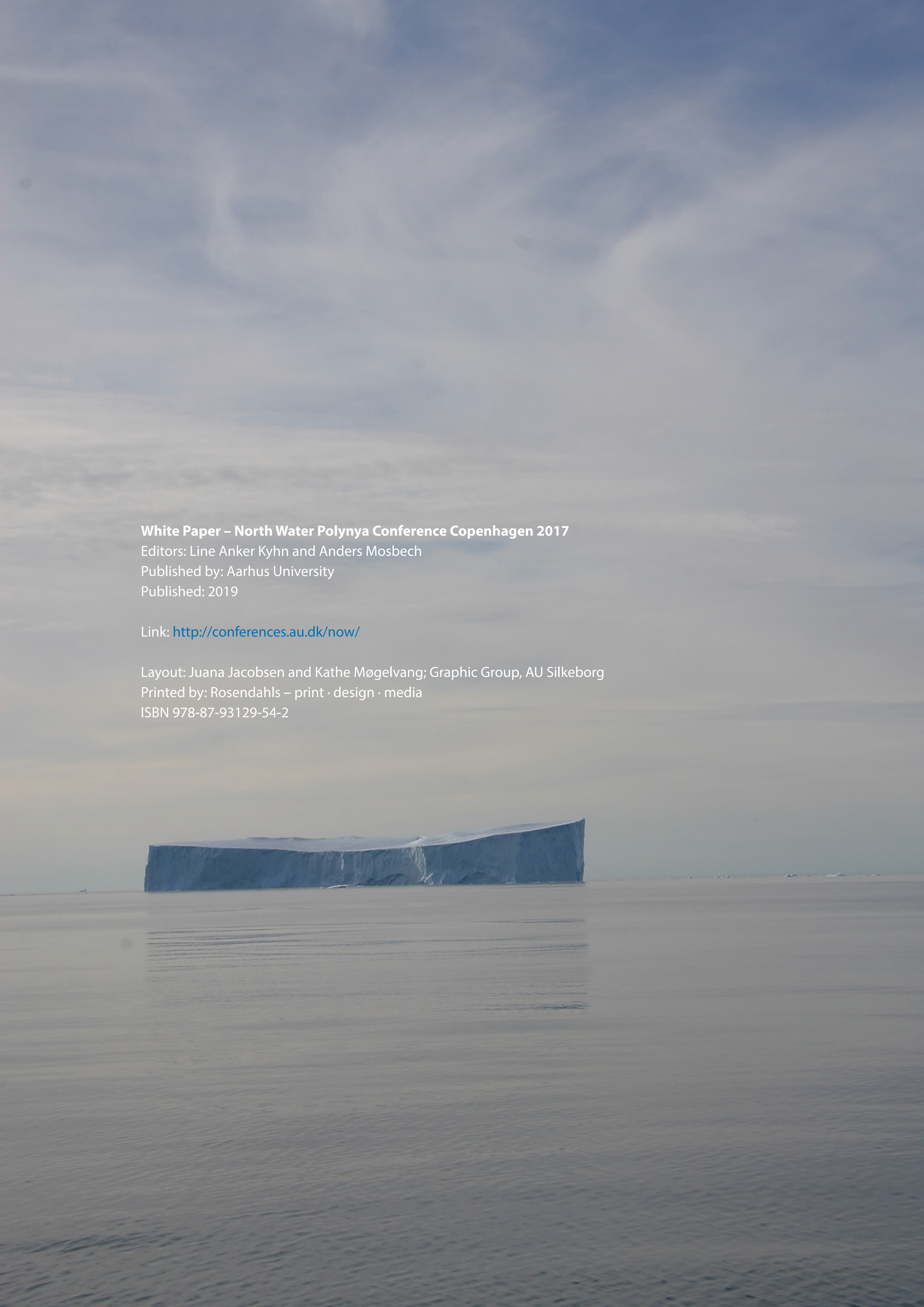
Finally it seems that a future program focused on the NOW should incorporate winter sampling, which is necessary to assess the environmental pre-conditioning of the growth season in terms of nutrients, stratification and ice conditions. Winter sampling is also necessary to validate the techniques that we have developed to assess annual productivity from point sampling in late summer and fall (assessed by difference from late-winter properties). An extension of sampling into Kane Basin would also be useful, since we have evidence that mixing/ice dynamics and biological productivity over the shallow sill there have a strong impact on downstream nutrient supply into the western part of the NOW.

Louis Fortier:
A multinational icebreaker expedition to revisit the North Water in the coming years would enable us to inventory the marine ecosystems of the North Water to buttress the proposal to 1) make the Pikialasorsuaq a Marine Protected Area (including Lancaster Sound); (2) to assess how climate change has affected the regional sea-ice regime and ecosystems relative to our last study of the area in the late 1990's; and (3) to document how the ecosystem services provided to Canadian and Greenland Inuit communities will be affected by on-going changes. An overwintering or partial overwintering would be particularly useful to document the winter ecosystem.

Søren Rysgaard:
The Baffin Bay Observing System (BBOS) is a unique 'big science' idea building on a strong collaboration between national and international Universities, Inuit organizations, communities on both sides of Baffin Bay, government ministries and agencies, defense, shipping and marine based companies, various technology providers, industry, coastal and offshore fisheries and colleges, all focused around a single collaborative world-class-bay-wide observatory.

Challenges and ideas related to logistic and science support

- DMI (Danish Meteorological Institute; Steffen Olsen and Till Soya Rasmussen) has facilities and equipment in Qaanaaq (workshop) and a small hut on the Carey Islands. DMI is open for cooperation and for a discussion on setting up a joint science hub in Qaanaaq.
- In relation to the DMI "Participatory climate ocean monitoring programme" there may be a potential to include a DMI building in Qaanaaq in relation to other research activities. However, the house is not rented out, since this will compete with local housing and income possibilities. There is a person employed year-round to service the house and instruments.
- There is a potential to use Thule Airbase and logistics as a science platform ("hub"). However, it was mentioned that research facilities at the airbase are expensive to use, and that the lack of boats is a problem.
- Thule Airbase may likely increase the focus on servicing scientists in the future.
- There are strong linkages between NOW projects and national and international programs (such CBMP and AMAP), which help promote the relevance of projects. Further steps would be to include guidelines, advice and protocols from AMAP, CBMP, GEM and others in future applications, work and in a potential monitoring/ observing system in NOW.
- EU Horizon 2020 was mentioned as a potential for kick start future research and monitoring activities.
- There is a potential to use US logistics and science support (incl. National Science Foundation – NSF) to conduct research in the area when there is a US partner.
- In relation to NSF and Canadian funding systems it will promote the application if US/ Canadian applicants are mentioned as partners in e.g. EU funding applications.
- Bellmount Forum was mentioned as a funding opportunity. However Denmark and Greenland are not part of Bellmount Forum.



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