Fisheries and Oceans Canada | Pêches et Océans Canada
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Central and Arctic Region

Canadian Science Advisory Secretariat
Science Advisory Report 2021/052

IDENTIFICATION OF ECOLOGICAL SIGNIFICANCE, KNOWLEDGE GAPS AND STRESSORS FOR THE NORTH WATER AND ADJACENT AREAS

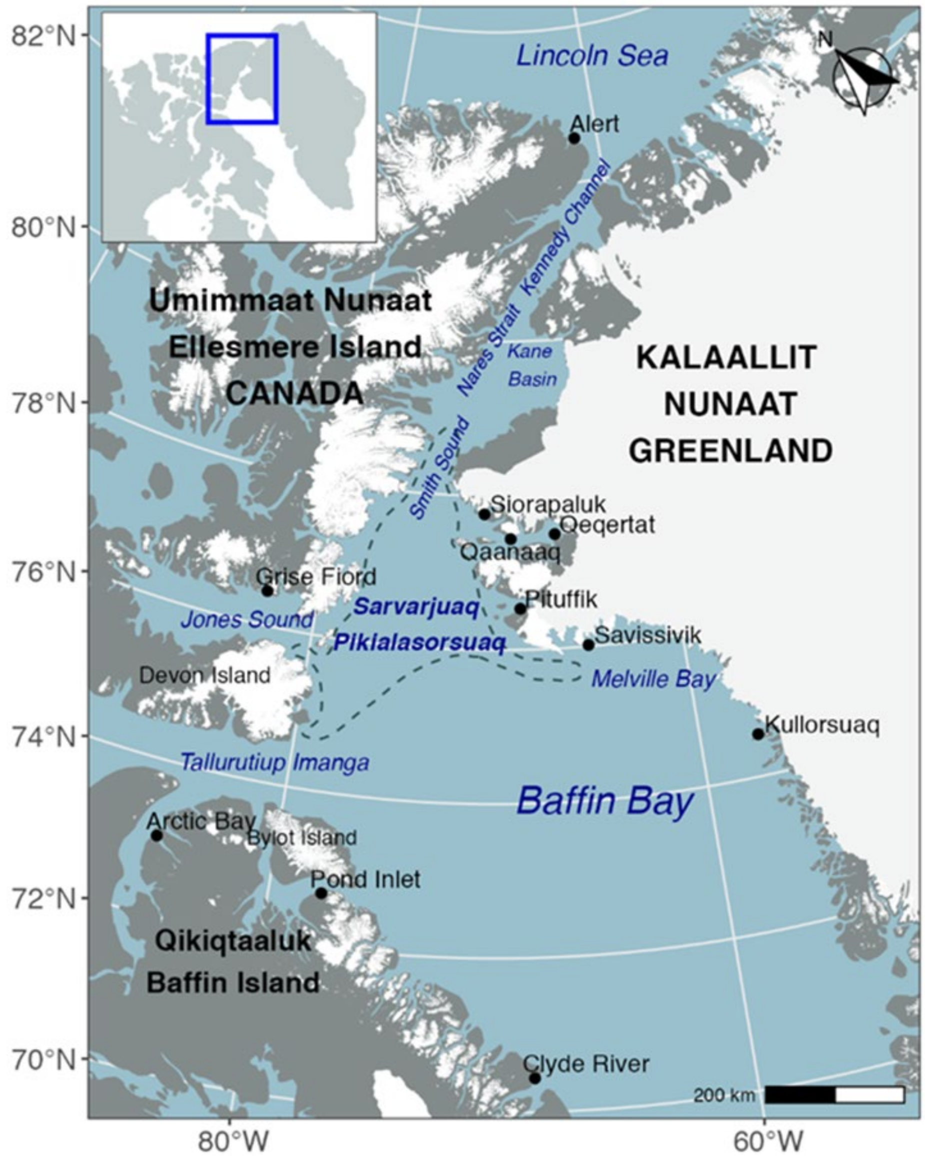

Figure 1. The North Water (Sarvarjuaq/Pikialasorsuaq) region, including adjacent water bodies connected to the study area and connected coastal communities mentioned in this report. A notional polynya boundary (dashed green line) representing the May monthly mean extent, adapted from Dunbar (1969).

December 2021

Context:

The North Water (Sarvarjuaq/Pikialasorsuaq) is a biologically, socioeconomically, and culturally important region located in northern Baffin Bay between Canada and Greenland. This region's biological importance can be attributed to the unique local geography, sea ice cover, oceanographic circulation patterns, and stratification that encourages early (i.e., April-May) and high productivity. The early and predictable phytoplankton blooms in this region support a high diversity of lower trophic feeders, fishes, and Arctic marine mammals (e.g., Bowhead Whales). Known for being one of the largest polynyas in the Arctic, the mechanism and unique formation is primarily driven by strong winds forcing sea ice downwind of a northern ice bridge (or bridges) in Nares Strait and Kane Basin, restricting and reducing ice cover in northern Smith Sound. Marine mammals (Narwhal, Beluga, Bowhead, Polar Bear, Walrus, and Ringed and Bearded seals) utilize this region seasonally, and some species will remain in the open waters of the North Water throughout the winter months. Millions of seabirds (Dovekies, Thick-billed Murres, Kittiwakes, Common Eiders and others) arrive to the North Water in the spring, and use the coastal-fiord regions surrounding the North Water for breeding, foraging and nesting.

In 2011, the Canadian part of the North Water was identified as an Ecologically and Biologically Significant Area (EBSA) by Fisheries and Oceans Canada. Additionally, the North Water has been evaluated as unique through several international processes, including the International Union of Nature Conservation, who in 2017, in collaboration with the UN Organization for Education, Science, Culture and Communication (UNESCO), identified the area as a possible candidate for designation as World Heritage Sites (WHS) based on UNESCO's criteria. Aarhus University and the Greenland Institute of Natural Resources also ranked the Greenland part of the North Water as a highly vulnerable and ecologically significant marine area using the International Maritime Organization (IMO) Particular Sensitive Sea Areas Criteria. These assessments, supported by the Government of Greenland (Naalakkersuisut), are part of a strategic effort to enhance area-based protection of Greenlandic biodiversity.

The North Water is complex and undergoing a high degree of anthropogenic change. In order to establish a comprehensive baseline for ongoing collaborations related to protection of the North Water region, a binational Canadian Science Advisory Secretariat (CSAS) meeting was requested by DFO Strategic Policy and Marine Conservation and Planning sectors, to review the state of knowledge of the North Water. This Science Advisory Report is from the January 22–24, 2020, meeting held at the Canadian Museum for Human Rights in Winnipeg, MB, to review and advise on the Biophysical and Ecological Overview of the North Water and Adjacent Areas. The science advice presented in this report has been developed by meeting participants from Canada, Greenland, and Denmark, and intends to be one resource among many (e.g., future collection of local knowledge, socio-economic assessment, and consideration of terrestrial environment), that can be used to support decision making, and the development of conservation and management policy for the region.

SUMMARY

- The North Water is a distinctive geographic and oceanographic region in northern Baffin Bay, characterized by one of the largest recurring polynyas in the Arctic. The importance of the region is attributed to:
  - Patterns of atmospheric and oceanic circulation producing dominant north winds and ocean currents pushing sea ice from the Arctic Ocean south through Baffin Bay;
  - Narrow channels that promote the formation of ice bridges in Nares Strait, Kane Basin, and Smith Sound, preventing the southward movement of sea ice, and leading to reduced sea ice cover south of Smith Sound;

- Nutrient rich waters that originate from both the Arctic (cold Pacific Water via the Bering Sea) and the North Atlantic (warm water via Davis Strait flowing north along west Greenland);
- Ocean circulation patterns and wind dynamics that encourage the upwelling or upward mixing of the nutrients imported at depth with the Pacific and Atlantic waters; and,
- Extended ice-free (or reduced ice cover) season that promotes a long productive period.

- Glaciers are important features in the vicinity of the North Water and meltwater from glaciers and ice caps likely comprise the greatest source of local freshwater runoff into the region. The mechanisms and overall input of freshwater by glaciers and ice caps into coastal/fiord environments are currently understudied, especially on the Canadian side of the North Water.
- The North Water is a highly biologically productive area, and the magnitude and timing of productivity is dependent on complex physical and biogeochemical controls (e.g., timing of the polynya formation, stratification and mixing, influence of different water masses), which vary across the region. The consequences of the magnitude and duration of productivity in the North Water are further enhanced by efficient energy transfers to the food web.
- The early phytoplankton blooms are supported by the reduced sea ice cover compared to surrounding areas, and the tight coupling between primary productivity and zooplankton provide early food for filter feeders, such as benthic species, and is fundamental in supporting fishes and birds.
- The North Water is an important site for gas exchange; this region is considered a sink for anthropogenic CO_2, the magnitude of which is strongly impacted by regional forcing, including freshwater input, seawater properties (e.g., temperature), sea ice conditions, and biological processes, in particular photosynthesis and respiration.
- The North Water can be characterized by high regional biodiversity. Specifically, the Canadian side of the North Water is considered a hotspot for benthic community biodiversity. Functional diversity of the benthic community in the North Water is among the highest in the Canadian Arctic.
- Arctic Cod (*Boreogadus saida*) is a key species for the entire food web and potential changes in its abundance and/or distribution would result in cascading effects on the energetics of higher trophic levels.
- Two commercially important fish species in the Arctic are Northern Shrimp (*Pandalus borealis*) and Greenland Halibut (*Reinhardtius hippoglossoides*), yet there is limited information on their distribution and abundance in the North Water. Possible range expansion of a commercial trawl and longline fishery for these species represents both an opportunity for northern communities and a potential threat to the ecosystem (i.e., overfishing or bycatch).
- The North Water is a ‘hotspot’ for marine mammals in all seasons, and nine species occur regularly in the region. Endemic Arctic whales (i.e., Beluga [*Delphinapterus leucas*], Narwhal [*Monodon Monoceros*], and Bowhead Whale [*Balaena mysticetus*]) use the region for calving, foraging, and migration; the surrounding sea ice (floe edge) is important habitat for Walrus (*Odobenus rosmarus*), Ringed Seals (*Pusa hispida*), Bearded Seals (*Erignathus barbatus*), and Polar Bear (*Ursus maritimus*).
- The North Water is a vital feeding and nesting site for millions of migratory seabirds. Coburg Island (Nirjutiqavvik National Wildlife Area) is one of the most important seabird nesting

areas in the Canadian Arctic. The Greenland side of the North Water hosts the world's largest aggregation of Dovekie/Little Auk (*Alle alle*), and Greenland's largest colonies of Thick-billed Murres (*Uria lomvia*) and Black-legged Kittiwakes (*Rissa tridactyla*). Other important colonies of birds include Common Eiders (*Somateria mollissima*), King Eiders (*Somateria spectabilis*), and Sabine's Gull (*Xema sabini*).

- The last Canadian nesting site for the endangered Ivory Gull (*Pagophila eburnean*) is found on Ellesmere Island, close to the North Water. The Ivory Gull and Sabine's Gull are particularly important species to monitor and protect, since both species have very small populations in Canada and Greenland.
- Coastal areas (i.e., river mouths, cliffs, fiords, and glacier edges) and the floe edge environment near communities are especially important for local hunting of subsistence species, such as Narwhal, Walrus, Ringed Seal, Polar Bear, and various seabirds. Arctic Char (*Salvelinus alpinus*) is an important subsistence species, and several rivers surrounding the North Water have stocks that utilize the marine environment during the summer months (July-September).
- It is anticipated that the most significant impacts on the North Water ecosystem will be from climate change. Local changes are already being observed, notably extreme weather events, a transition towards a thinner and mechanically weaker ice cover in Nares Strait (increasing sea ice movement through this region), less predictable polynya formation, changes to location and duration of phytoplankton blooms, melting glaciers, and increased water levels (shoreline erosion).

BACKGROUND

In 2011, the Canadian part of the North Water was designated as an Ecologically and Biologically Significant Area (EBSA) by Fisheries and Oceans Canada (DFO) (DFO 2011, 2015). This region has also been evaluated through other international processes led by Greenland and Denmark, emphasizing its unique cultural and ecological value. For instance, the North Water achieved the highest score and highest priority on the basis of the International Maritime Organization's *(*IMO) criteria for identifying 'Particularly Sensitive Sea Areas' (PSSA) in a national assessment of important and vulnerable marine areas in Greenland (Christensen et al. 2012, 2017). In another strategic effort to enhance area-based protection of Greenlandic biodiversity, an overview of areas of ecological and biological significance in West and South-East Greenland was prepared using the EBSA and other international criteria, to identify important areas in Greenland. The report identified 23 areas, including three within the North Water (Christensen et al. 2016).

For millennia, Inuit have regarded the North Water as a place of great cultural and spiritual significance, relying on the ecosystem for movement, food, and resources for tools and clothing. Sarvarjuaq ("place that never freezes") is the North Qikiqtaaluk/Baffin Island name for an area of year-round open water and surrounding ice, and Pikialasorsuaq is the Kalaallisut, West Greenlandic name for the North Water, meaning "great upwelling" (QIA 2020). The close relationship between the polynya and communities across the North Water, and the recognition of Inuit as part of the North Water ecosystem, were key drivers of the establishment of the Pikialasorsuaq Commission by the Inuit Circumpolar Council (ICC) in 2016. The Commission's subsequent consultations in Canada and Greenland from 2016–2017 were the basis for the report "*People of the Ice Bridge: The Future of Pikialasorsuaq*", which contained recommendations for the region (ICCC 2017).

DFO, under the authority of the *Oceans Act*, is working with Indigenous partners to establish a national system of Marine Protected Areas (MPAs) in order to maintain ecological integrity, and to conserve and protect Canada's marine areas. In March 2019, the Prime Minister of Canada, Justin Trudeau, released a joint statement with Canadian Inuit leaders that committed to working in partnership with the Governments of Denmark and Greenland to advance sustainable marine management and environmental protection for the North Water region. Since the release of that statement, DFO, on behalf of the Government of Canada, has been actively engaged with the Qikiqtani Inuit Association (QIA), and relevant ministries in Greenland and Denmark, to work towards a joint management regime for the North Water region. To further this commitment, DFO Strategic Policy and Marine Conservation and Planning (formally Oceans Management) requested a binational Canadian Science Advisory Secretariat (CSAS) meeting, to summarize and review the state of knowledge of the North Water and surrounding area (DFO 2021).

The planning for this process involved a multi-national, multi-stakeholder steering committee, where Terms of Reference were developed in partnership with the Government of Canada and Greenland, and attendance by government officials and researchers from Canada, Greenland and Denmark. An Ecological and Biological Overview Report (EOR) titled *'Biophysical and Ecological Overview of the North Water and Adjacent Areas'* was developed by DFO Science (see Hornby et al. 2021) and provided the foundation of information for the CSAS peer-review meeting. Both this Science Advisory Report and Hornby et al (2021) will now serve as resources for future consultations and development of management plans for the North Water region. Although there may be fundamental biological, oceanographic, and cultural differences between the two sides of the North Water region and across the jurisdictions of Canada, Greenland, and Denmark, this document is intended to provide information and advice applicable to the whole region, and can be considered a resource for decision making either jointly or within each jurisdiction.

ASSESSMENT

The EOR developed for the North Water region and adjacent areas was prepared from a comprehensive literature review of published scientific documents, reports and peer reviewed journals, as well as any documented Inuit Qaujimajatuqangit (IQ) and hunter/user knowledge that was available for the region. The review also identifies current known or potential stressors to the ecosystem, and highlights where knowledge may be outdated, incomplete, or lacking. Further, the EOR includes summarized published descriptions and spatial information on the most important biological areas in the North Water, provided by Aarhus University and the Greenland Institute of Natural Resources (Christensen et al. 2017).

Similar to the EOR, this report is structured around four core ecological themes that were evaluated at the CSAS meeting by experts from Canada, Denmark, and Greenland:

1. Climate, ice, ocean and atmosphere,
2. Productivity and biogeochemistry,
3. Benthic community, zooplankton and fishes, and
4. Marine mammals and birds.

Within each theme, key features, including representative coastal and marine ecosystems, and other key physical oceanographic and habitat features were identified and are summarized below in subsequent sections. Key data and knowledge gaps related to each ecosystem component are also summarized at the end of each theme. For more detailed information on these topics, including specific references used in this Science Advisory Report, please refer to Hornby et al. (2021).

Geography and scope of review

The North Water is a dynamic region, loosely defined as an area of open water in early spring (March-June) confined on the west and east by coastal landfast sea ice along Ellesmere and Devon Islands and Greenland, and extending north into Kane Basin and south into Baffin Bay to a line spanning from the east coast of Devon Island to Cape York (Figure 1, 2). The polynya area is one of the largest in the Arctic (maximum of 80,000 km^2), and is delineated by fast ice on two, sometimes three sides. Historically, the ice bridge (or ice arch) in Nares Strait provided a transportation route between Canada and Greenland, connecting Umimmaat Nunaat (Ellesmere Island) and Avanersuaq (Northwest Greenland). Today, the landfast sea ice and floe edge environment along Ellesmere Island and Greenland are key features for Inuit travel and hunting, and the North Water remains important to the surrounding communities of Aujuittuq (Grise Fiord), Siorapaluk, Qaanaaq, and Pituffik. Although not directly in the vicinity of the North Water, the communities of Qausuittuq (Resolute Bay), Ikpiarjuk (Arctic Bay), Mittimatalik (Pond Inlet), Kangiqtugaapik (Clyde River), Qikiqtarjuaq, Savissivik, and Kullorsuaq all harvest wildlife (i.e., Ringed Seals [*Pusa hispida*], Beluga [*Delphinapterus leucas*], and possibly Narwhal [*Monodon Monoceros*]) that move between Tallurutiup Imanga (Lancaster Sound) and the North Water seasonally (Figure 1).

The importance of the North Water is due, in large part, to its geophysical location and the regional topography of surrounding land masses (i.e., steep mountains, glaciers, icecaps, narrow fiords). The local geography, along with regional atmospheric pressure patterns, push strong winds through key constriction points (Smith Sound, Kane Basin, and Nares Strait), which are essential for the formation of a polynya in this region. The resultant wind-driven ocean circulation, and convergence of Arctic and Atlantic water masses in this region, are influenced by seafloor topography, including broad continental shelves incised by deep troughs, and a series of narrow sills (e.g., Nares Strait, Jones Sound, Inglefield Bredning) that constrain ocean currents (Figures 2, 3). It is the convergence and upwelling of nutrient-rich Arctic and Atlantic water masses that supports the immense biology and diversity of this region.

It is understood that the ecological and cultural footprint of the region is much larger than the physical bounds of the polynya, and is often viewed as a region of cultural continuity, ignoring international borders, and connecting people and resources. As such, the geographic scope of this review (Figure 1) was not restricted to just the polynya feature/boundary, and specifically includes a review of the physical and oceanographic features connected to the North Water on all sides (e.g., influences from the Lincoln Sea and water mass transport from the Bering Sea and North Atlantic), highlighting the biological connectivity from adjacent areas.

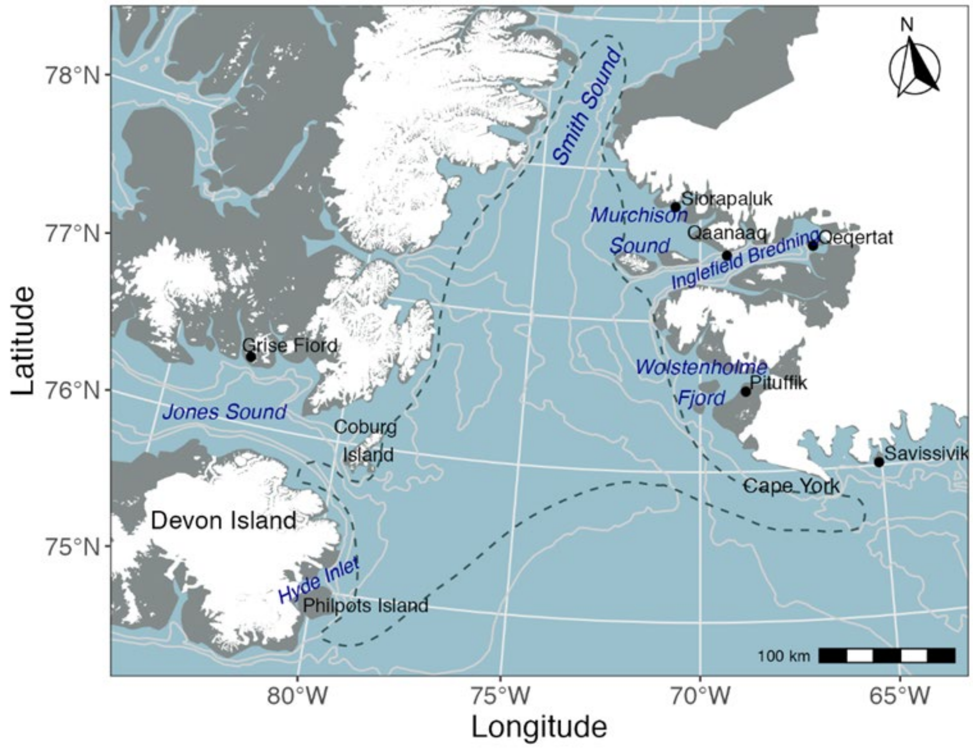

Figure 2. A close up of the North Water (Sarvarjuaq/Pikialasorsuaq), including 200-500 meter bathymetry contour lines (source: Natural Resources Canada), and important coastal fiords, islands, and water bodies mentioned in this report.

Theme 1. Climate, ice, ocean and atmosphere

Sea ice and formation of the North Water polynya

Fundamental to the productivity of the North Water is the presence of sea ice cover, or ice-edges (glacier and sea ice), and the vertical circulation processes that develop as a result of changes in the environment (i.e., light penetration, brine rejection, and wind-stirring). The circulation and movement of sea ice through the North Water is complex, but tends to follow the prevalent counterclockwise motion of the currents and/or prevailing winds. This region is unusually windy and the dominant wind comes from the north-east, converging into Nares Strait and increasing in speed as it is constrained by the steep topography of Greenland and Ellesmere Island. For the majority of the cold season (December to March) the North Water is largely covered with new and young sea ice, with first year-ice (FYI) not developing until March. The Lincoln Sea, located where Nares Strait meets the Arctic Ocean, is often called a ‘switch gate’, as large-scale atmospheric patterns either transport thick multiyear ice (MYI) to the coastline of northern Greenland, or out of the Arctic via Fram Strait, influencing the ice types found in Nares Strait. This sea ice transport is most common during late summer-fall, prior to ice bridge formation, and halts once the ice bridge(s) form across Nares Strait and the polynya starts to take shape.

The scientific community defines a polynya as a persistent oceanographic feature (or region) of thin ice and open water that occurs at a location where, climatologically, thick ice would be expected. In the North Water, the primary driving mechanism responsible for opening and maintaining the polynya is wind-forced advection of sea ice downwind of a series of ice bridges (or arches) that can form in Nares Strait, Kane Basin, and Smith Sound. The first northern ice bridge generally forms across, or north of Nares Strait from December to February, sometimes as late as March, and lasts into June or July. This is often, but not always, followed by a southern ice bridge in Kane Basin/Smith Sound a few days to weeks later. It is the formation of multiple ice bridges that influences the polynya's extent, duration and robustness. New ice formation slows or halts as winter transitions to spring, and the polynya expands southward into Baffin Bay, reaching its maximum extent (estimated at 80,000 km^2) in late June or early July. Break-up of the ice bridge has typically begun in July, initiating the dissolution of the polynya. Melt first occurs on the Greenland side of the ice bridge due to differences in surface temperature, ice thickness, currents, and air patterns. Open water generally extends from Smith Sound to Devon Island by the third week of June and merges with the open water of Baffin Bay in June or July.

This interdependency makes the region sensitive to climate driven changes in pressure patterns. In the last 15 years, these ice bridges have become less recurrent, tending towards delayed polynya formation and earlier breakup. In the spring of 2007, possibly for the first time in recorded history (since the 1970s), the ice bridge across Nares Strait did not form at all; it also failed to form in 2009, 2010, 2017, and 2019 (Vincent 2019). The formation of ice bridges in the Nares Strait region is an important function in preventing and reducing the southward movement of MYI from the Arctic Basin into Baffin Bay. In addition to changes in the timing of formation, the average position of the ice bridge has moved northward since 2007, resulting in the eastern edge being further from land and more susceptible to breakage.

Circulation, stratification, and nutrients

The bathymetry of the North Water is characterized by a fairly deep (700 m), centrally located channel that extends from northern Baffin Bay to the north end of Smith Sound (Figure 3), surrounded by broad, shallow (<200 m) continental shelves incised by a few deep troughs leading into glacial fiords. Circulation within Baffin Bay is baroclinic, which means that the location and strength of currents are shaped by the differences in temperature and salinity across the bay at each depth, and the general movement of seawater around Baffin Bay is counter-clockwise. Sills (similar to mountain passes but on the seabed) and shoals are present at most of the potential entrances to northern Baffin Bay, which influences the movement and properties of water that enter the North Water (Figure 3).

Sources of water in the North Water system have their own distinct physical properties (salinity, temperature, density) and the interaction of these water masses is an important factor for nutrient availability, productivity, and biogeochemical coupling. There are four main water types in the North Water:

1. Arctic outflow water (from Arctic surface water, at depths of ~0-50 m) of relatively low salinity close to freezing temperature for much of the year, but as much as 7°C warmer for 2–3 months in summer;
2. Arctic outflow water (from Pacific water, at depths of ~50-300 m;) of higher salinity, above its freezing temperature but cooler than 0°C, and rich in dissolved nutrients,
3. Atlantic inflow (via the West Greenland Current, at depths <200 m), warmer (up to 2°C) and yet more saline, also referred to as the Atlantic Intermediate Water; and,
4. Baffin Bay deep water, below about 1200 m depth, with salinity comparable to the Atlantic inflow, but with temperatures below 0°C.

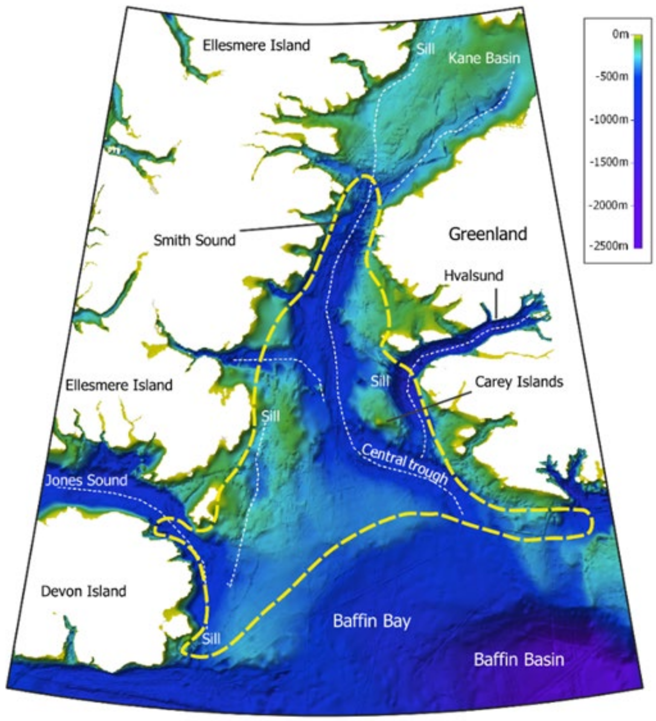

Figure 3. Seabed topography (in meters) of the North Water region. The deep troughs are marked with white dashed lines and the locations of sills are indicated (data from the International Bathymetric Chart of the Arctic Ocean (IBCAO) ver. 4).

The strong north wind that opens the polynya and pushes the sea ice southward on the western side of the North Water also contributes to upwelling along the Greenland coast. Important nutrients (i.e., nitrate, silicate and phosphate) flow into the region from Arctic waters entering Smith Sound (after a long Arctic transit) and Atlantic waters from northern Baffin Bay. Near-field and far-field connections influence nutrient inventories and fluxes in the North Water, thereby impacting primary producers and the food web. For example, source waters from the Pacific Ocean are nutrient rich, but highly susceptible to change during their transit, as well as through climatic and oceanic influences (e.g., changes in the strength and direction of the Beaufort Gyre), and therefore are not constant in the system. Recent evidence also suggests there are strong seasonal and inter-annual variations in the properties and distribution of Atlantic Water flowing into the North Water via the West Greenland Current, which are linked to large-scale atmospheric and oceanic shifts in the North Atlantic. Stratification and mixing of the water column, which primarily depends on freshwater/sea ice and wind influences, is a key process for primary production in the North Water, as in other Arctic regions.

Glaciers and coastal processes

At present, there is an extensive glacial cover on northwestern Greenland and the eastern Queen Elizabeth Islands, with many marine-terminating glaciers flowing into the North Water. Since the 2000s, glacial retreat rates have sharply increased across the Greenland Ice Sheet and along Ellesmere Island, driven both by atmospheric and oceanic warming. Calving glaciers produce icebergs and large tabular ice islands which typically drift southward through Nares Strait and into Baffin Bay, but can also drift northward with the West Greenland Current to recirculate south of the North Water. The presence of these large ice features, if grounded, can slow down sea ice motion and promote consolidation of the pack ice, with potential to impact the formation and breakup of the ice bridge. Increased runoff from surface melting of glaciers and ice caps into the North Water has resulted in a strong freshening of the upper water column of surrounding ocean basins in recent decades. Locally however, meltwater that discharges at the base of tidewater glaciers (subglacial discharge) rises as plumes near the glacier front, entraining ambient water, and causing buoyancy-driven currents, which can have significant effects on fiord-scale stratification and circulation.

When subglacial discharge occurs at deeply grounded tidewater glaciers, the upwelling of deep, nutrient rich water can play a key role in the availability of nutrients to primary producers, boosting marine productivity in coastal regions that are important for fish species, such as Arctic Cod *(Boreogadus saida)* and Greenland Halibut (*Reinhardtius hippoglossoides*). Recently, some widespread changes in the diets of seabirds in coastal northwest Greenland have been observed, and it has been hypothesized that increased freshwater input from melting glaciers, and associated oceanographic changes, have played a role in the observed ecological shifts. Optimum conditions for maximum upwelling likely vary for each glacier, but most of Greenland's tidewater glaciers will see diminishing nutrient fluxes, as they retreat out of deep, nutrient-rich water (likely in the next decade). Overall, the mechanisms and overall discharge of freshwater from glaciers and ice caps are understudied, especially on the Canadian side of the North Water.

Key data and knowledge gaps

- There is a lack of precipitation data (e.g., rain, snowfall on surrounding lands, ice caps, ocean surface and sea ice) and of corresponding data on evaporation especially over the marine environment. More information is needed on precipitation type, accumulation of precipitation over the marine environment and on glaciers.
- Bathymetry is poorly known for many coastal environments (within ~ 30 km from shore), including the grounding depth of many glaciers on the Canadian side, and is still to be mapped for many areas of the North Water. These data are critical to interpreting ocean observations and modeling ocean circulation.
- Floe edge and coastal processes (marine and terrestrial) are relatively unknown and understudied in Greenland and Canada. Specifically, there is limited knowledge of glacial fiord dynamics, including spatial and temporal variability in meltwater discharge from adjacent glaciers at surface and depth, influence on the near-ice circulation and mixing of water masses in fiords, as well as processes that influence primary production and biogeochemical coupling.
- The effects of increased runoff from the Greenland and Canadian glaciers on stratification, circulation, and biological productivity are uncertain.
- It is poorly understood how the large scale (hemispheric) changes in atmospheric circulation and ocean currents are affecting the formation and stability of the ice bridge(s) in the North Water. Further, links between the regional dynamics of the North Water, and global climate change and variability are unknown, which limits our ability to accurately model and predict interactions, (e.g., simulate polynya formation and break-up); therefore, future conditions of the North Water and surrounding area are uncertain.

Theme 2. Productivity and biogeochemistry

High productivity

The North Water is a highly productive area, characterized by high overall phytoplankton biomass and production.The magnitude, distribution, and development of phytoplankton within the North Water are influenced by light availability (e.g., long open water season, timing of polynya formation), coupled with water mass distribution and dynamics, the pool of available nutrients and circulation patterns. The nutrient inflow from the Arctic Ocean to the North Water through Smith Sound is important for productivity, and can be variable since these influences are linked to the biochemical processes in the Lincoln Sea and far-field influences (e.g., Beaufort Gyre). On the Greenland side, the influence of Atlantic water is fundamental to the seasonal dynamics of the production cycle. Much of our knowledge on phytoplankton blooms, community and size structure, and ice algae in the North Water is based on the International North Water Polynya Study, conducted in 1997–99. The intense diatom bloom of species *Chaetoceros socialis* observed in the North Water is followed by production of resting spores, and is tightly connected to seasonal patterns of sedimentation at depth. Ice algae also contribute to primary production in the North Water but their contribution is poorly quantified. The biomass of ice algae accumulated during their growth period is efficiently transferred to water column grazers. Efficient transfers to the pelagic ecosystem support the productive marine food web (see Theme 3: Efficient energy transfer).

Early timing and extent/duration of bloom

An important distinction of the North Water compared to other Arctic regions is not only the high phytoplankton biomass and production, but the early timing (e.g., April–May), and duration of the bloom. The early opening of the North Water allows for the development of a phytoplankton bloom up to 6–8 weeks earlier (Figure 4) than in nearby ice-covered waters of the Canadian Archipelago. The bloom typically begins on the Greenland side of the North Water, which is influenced by warm Atlantic waters, and then spreads to the northwest. Remote sensing analysis shows that the bloom tends to start earlier and last longer during years with less sea ice cover (i.e., longer open-water period), and that cloud cover may also play an important role for bloom conditions through light availability. Recent changes in the bloom dynamics, linked to the changing sea ice conditions in the North Water, point to important impacts of the changing sea ice to the productivity across the region. A recent time-series analysis of remote sensing estimates of phytoplankton biomass in the North Water over the past two decades (1998–2014) shows a significant decline in the amplitude of the bloom, despite inter-annual variability in the observational series (Marchese et al. 2017).

The recent decline in phytoplankton biomass and production is also documented by in situ measurements (Blais et al. 2017), attributed to delayed formation or absence of the ice bridge in Nares Strait. During recent years, when the Nares Strait ice bridge did not form, or persisted for only short periods, increased ice drift in the North Water had a negative impact on primary production in the region. Despite decreasing sea ice cover in many regions of the Arctic Ocean, the North Water has seen some increases in sea ice cover due to the increased Arctic sea ice export when the ice bridge does not form (Michel et al. 2015).

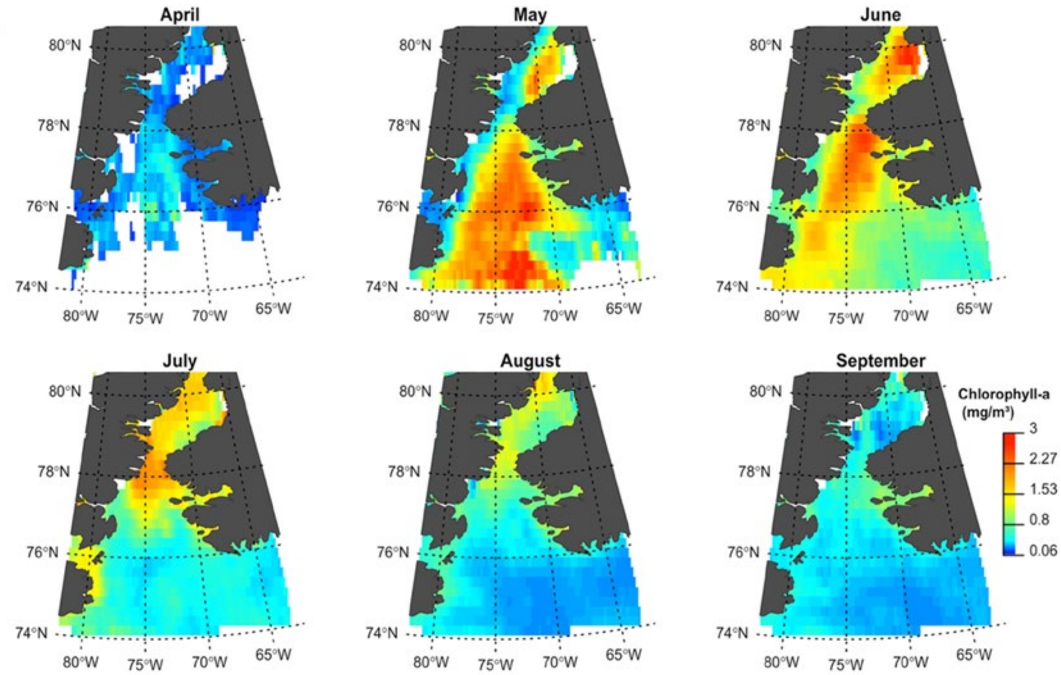

Figure 4. Seasonal progression of the phytoplankton bloom in the North Water region, based on remote-sensing estimates of chlorophyll a concentration. The colors indicate different chlorophyll a concentrations (red = highest concentration which indicated peak bloom in May in the central part of the study area). These maps likely underestimate the total magnitude of primary production, since it only shows chlorophyll a in the surface layer and does not reflect subsurface chlorophyll a maxima or ice associated production. Our knowledge of chlorophyll a in the water column is yet very limited (Source: Marchese et al. 2017).

Site for air-sea gas exchange

Whether an Arctic region is an overall source (releases more than it absorbs) or sink (absorbs more than it releases) of greenhouse and other climatically-active gases depends on water mass properties near to the sea surface, including water biogeochemistry, temperature, the distribution of freshwater, and biological processes. Collectively, these water properties and processes can impact the local biogeochemical system that moderates the gas exchange at the water's surface. It is not known to any degree of confidence whether the North Water is an important site for air-sea exchange of the climatically-active gases. Only a few studies have been conducted in this region, and our knowledge is largely based on observations from discrete research cruises over the open water season and assumptions of wintertime processes. Measurements in the North Water region reveal a strong degree of regional, seasonal, and interannual variation in air-sea CO_2 exchange. While there is not an annual CO_2 budget, it is thought that early springtime outgassing would likely be limited by ice cover and that the region may be a net annual sink for atmospheric CO_2. The supply of freshwater from fiord systems in Greenland is increasing, and case studies suggest glacial meltwater promotes CO_2 uptake within fiords and adjacent coastal waters. It is therefore expected that continued meltwater freshening will impact the CO_2 source/sink status of the region, although wide occurrence of this phenomena has yet to be confirmed. Increases in dissolved CO_2 cause decreases in pH, known as ocean acidification (OA). Indices of OA have been measured in the region, but the effects on the ecosystem remain unknown. Additionally, the North Water is expected to be a source of CH_4 to the atmosphere, though perhaps not a strong source.

However, this is based on only a few studies examining dissolved CH_4 in the eastern Canadian Arctic and none in the North Water region. The North Water could be a strong source of other biogenic gases (those produced by living organisms, such as phytoplankton), like dimethyl sulphide (DMS), but, again, we lack a strong observational base specific to the North Water region. Evidence comes from recent studies conducted in the Canadian Arctic Archipelago during summer, which revealed high concentrations of DMS in open waters and in the overlying atmosphere, with the highest values found in association with localized peaks of chlorophyll *a*, a proxy of phytoplankton biomass.

Key data and knowledge gaps

- Species diversity of primary producers is relatively unexplored across the North Water region. Since most in situ data collected on phytoplankton is from the late-1990s, many knowledge gaps exist, including the current spatial and seasonal distribution of primary producers (particularly in coastal areas), their seasonality (e.g., development of sub-surface phytoplankton bloom), and productivity and coupling to pelagic and benthic grazers.
- Data on phytoplankton production during ice-covered periods is generally lacking, and there is very limited knowledge of ice-associated algae and the magnitude of ice algae production in the North Water.
- Additional monitoring is required, particularly in the winter season, in order to better understand the role of the North Water as a sink or source of greenhouse gases.
- Factors that influence primary production, how they are changing with climate change, and overall impact on primary production, remain an important knowledge gap. For example, the influence of the changing sea ice dynamics, ocean circulation patterns upstream and within the polynya, and changing seasonality and their impact on primary production and ecosystem processes remain poorly understood.
- It is unclear how productivity will be impacted by changing local conditions (e.g., changing sea ice conditions and increased cloud cover), including adaptability of species and possible cascading consequences throughout the ecosystem.
- It remains unknown if the recent decline in surface productivity in the North Water, and its northward shift is reflective of a long-term trend or a transient phenomenon. Better spatial and temporal coverage for system observations is needed in order to establish long-term trends, and define spatial variability and controls.

Theme 3. Benthic community, zooplankton and fishes

High regional benthic biodiversity

Benthic organisms play an important role in carbon cycling by decomposing organic matter on the seafloor and returning nutrients to the water column through remineralisation. They serve as a food source for fish, marine mammals, and seabirds, provide structure and habitat for other macrobenthic organisms (e.g., corals and sponges), and may be harvested commercially (e.g., scallops, crabs, shrimp, mussels, sea urchins, and sea cucumbers). Macrobenthic abundance and diversity is very high near the center of the North Water and lowest on the east side, where concentrations of organic carbon and nitrogen are highest. The benthic community on the west side of the North Water is considered a hotspot of biodiversity. Importantly, functional diversity, a component of biodiversity that addresses the range of niches within an ecosystem, is among the highest known in the Canadian Arctic. Interestingly, Jabr et al. (2018) recently discovered and described a benthic species (Torquaratorid acorn worms, *Allapasus fuscus* sp.) unknown to the North Water. There are limited studies on the Greenlandic side of the North Water, but investigations further south in Baffin Bay suggest that this area is species-rich, with high densities of organisms. The high occurrences of Walruses and eiders in the region, species whose primary food is shellfish, also indicates a rich benthic fauna, at least at the depths they normally forage (eiders to about 25 m, Walrus to 100 m). The North Water region also has a unique and rich microbial community. Similar to warmer marine environments, bacteria are important in the recycling of carbon and other nutrients within the pelagic zone of the North Water.

Efficient energy transfer (pelagic-benthic coupling)

The productivity of the North Water is further enhanced by the efficient transfer of energy to the pelagic and benthic ecosystems. Studies of pelagic-benthic coupling (the cycling of carbon and transfer to pelagic and benthic grazers) have shown that the long production season in the North Water provides a long period over which the benthos receives inputs of organic carbon from the pelagic zone. A large increase in carbon input to the benthos was observed in the 2010s, likely due to either local changes in sea ice conditions, mediated through bottom-up regulation exerted by sea ice on phytoplankton production, or to a mismatch between the timing of peak production and zooplankton grazing. The latter a result of earlier blooms, production shifting northwards, and/or seafloor nutrient deliveries (current-transported) shifting into Smith Sound from northern Baffin Bay. Both possibilities allow a more regular and greater flux of phytoplankton-derived carbon to the sea floor.

High levels of algal primary production provide the basis for a very diverse community of zooplankton grazing on the algae. The zooplankton standing stock in the North Water is similar to that in the southern Beaufort Sea and higher than the rest of the Canadian Arctic. Large Arctic *Calanus* copepods form an important link in the transfer of nutrients from algae to higher trophic levels such as fishes and seabirds. Changes in the zooplankton community is concurrent with variability in algal production (i.e., timing and availability) in the North Water. Arctic copepods may also experience greater competition and/or predation pressure as new species invade from the south. Of particular concern is a potential shift towards smaller species that are less rich in lipids than the High Arctic species, a shift already occurring further south in Baffin Bay and the Labrador Sea. Such a shift could have negative effects on the energetics of zooplanktivorous fauna (fish, some seabirds, and baleen whales).

Fishes and Fisheries

There is very limited information available on the fish community of the North Water and surrounding waterbodies. Coad and Reist (2018) identified 21 fish species likely found within the region, though the actual fish community is expected to be more diverse. For example, The Conservation of Arctic Flora and Fauna (CAFF) assessment on marine fishes reported at least 50 species of Arctic fishes in and near the North Water (Mecklenburg et al. 2018). Sculpins, flounders, eelpouts, Arctic Cod, Polar Cod (*Arctogadus glacialis*), Greenland Halibut, Arctic Skate (*Amblyraja hyperborea*), and Greenland Shark (*Somniosus microcephalus*) have all been reported from Canadian coastal areas, specifically in Jones Sound near the community of Grise Fiord. Arctic Char (*Salvelinus alpinus*), an important Arctic subsistence species to Inuit, can be found in several rivers near communities and utilizes the marine environment during the summer months. Capelin (*Mallotus villosus*), an abundant species in other areas, such as Atlantic Canada and the southern Arctic, is now observed near Grise Fiord, Coburg Island, Pond Inlet, and the western coast of Greenland; its importance to the local food web is unknown. Arctic Cod is considered a key species in the North Water food web and is the main link between phytoplankton and higher-level consumers in the Arctic (i.e., Belugas, seals, birds).

Because of this important role in the ecosystem, Arctic Cod is thought to be an ideal target species for biodiversity monitoring in the North Water.

There is a large Canadian commercial fishery for Greenland Halibut in Baffin Bay (2019 Total Allowable Catch 9,592.5 tonnes) and most ship-based commercial fishing (longline or gillnet) is conducted at depths of approximately 800–1,500 m as far north as 73°N (DFO 2014), just south of the North Water. Based on the success of the longline fishery for Greenland Halibut near Pangnirtung, Nunavut, several communities, including Grise Fiord, have expressed interest in the development of nearshore fisheries for Greenland Halibut and have conducted exploratory fisheries over the years (see DFO 2019). On the Greenland side of the North Water, there is a small (about 200 t per year) but increasing commercial longline fishery in Qaanaaq, with a plan to start direct export of high quality products to restaurants in Denmark. The possible expansion of fisheries into the North Water represents an opportunity for northern communities, but could introduce threats to the ecosystem, such as increased bycatch of other non-subsistence species or species interactions with fishing gear. It is recognized that more work is needed to understand the stock delineation of Greenland Halibut and the connectivity between the coastal and offshore populations, which are both important for Narwhal.

Key data and knowledge gaps

- Overall, there is a lack of information on the life history of most benthic species, zooplankton, and fish over the annual cycle in North Water.
- Marine macrophytes and macroalgae (i.e., kelp) serve as food for higher trophic levels and create habitat sheltered from predators, waves, and currents, but information on their spatial distribution and abundance is limited.
- There is limited knowledge on assemblage and seasonal migrations of zooplankton and fish in the North Water (and the Arctic in general). Specifically, there is a lack of knowledge on the spatial distribution (horizontal and vertical) of zooplankton, and the difference between the east and west side of the North Water region.
- The distribution and abundance of macrophytes, benthic species, fish, and zooplankton in coastal-fiord systems surrounding the North Water is also largely unknown. Suspended matter and dissolved matter in these areas is particularly important and knowledge related to changes to this area is very limited.
- There is limited information on the spatial migrations, including the connectivity between coastal and offshore populations, of Greenland Halibut in Canada and Greenland. There is also very limited information on the ecology and distribution of Northern Shrimp (*Pandalus borealis*) in the North Water, preventing science-based management of future fisheries in the area.
- The changes brought about by the expansion of boreal species (such as Capelin and Sand Lance) are unknown.

Theme 4. Marine mammals and birds

Seasonally important habitat for marine mammals

To identify the core biodiversity areas and particularly sensitive areas within the North Water, Christensen et al. (2017) conducted a GIS-based overlay analysis of 57 seasonal distribution maps of 24 key species (marine mammals and birds), habitat types, and ecosystem components. The overlay analysis involved both a differential weighting of the different species/ecosystem components (based on the criteria used in Christensen et al. 2017) and of different parts of the seasonal distribution of the individual species/ecosystem components (based on best available knowledge). The resulting maps described below (Figures 5–8) are colour-shaded in 5% percentiles (20 colour shades) on a scale from dark blue (low values), over yellow, to dark red (high values). The darkest red shading identifies the 5% of the area with the highest overlay score at the date indicated in the legend. Dark red tends to highlight areas where many different species overlap (high biodiversity) or areas where important individual species have an extremely high relative abundance. The maps are relative and cannot be directly compared across seasons (i.e., dark red areas in summer tend to have higher abundance and diversity than dark red areas in winter). This approach offers a powerful tool for identifying core areas of biodiversity, specifically highlighting potential sensitive areas within the North Water region. It is important to note that these maps primarily focus on seasonal productivity (algal blooms), and abundance and distributions of seabirds and marine mammals. The analysis does not include layers with zooplankton and fish distributions, as there is currently not enough data to provide detailed maps for these groups.

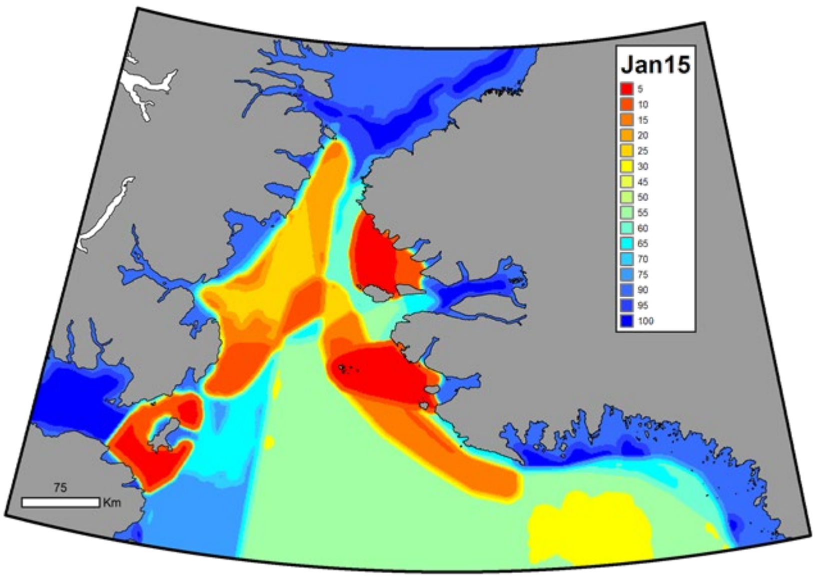

Figure 5. Map of biologically important areas in mid-January, as indicated by a GIS overlay analysis of the distribution of important species (marine mammals and birds) and ecosystem components. The map is colour-shaded in 5% percentiles on a scale from dark blue (lowest values), over yellow, to dark red (highest values). This map is characteristic of much of the winter period, from the early December to early March. During this period, the most important areas in red are the three main wintering areas for Walrus in Murchison Sound, west of Wolstenholme Fjord and around Coburg Island (see Figure 2). The dark orange area along the Greenland shelf-break results primarily from overlapping distributions of Narwhal, Walrus, Beluga, and Bearded seal. In the northwest part of North Water (Canadian coast), the orange area reflects the main winter distribution of Beluga Whales (Source: Christensen et al. 2017).

Winter

During winter (December to early March), seaward advance of landfast sea ice affects the spatial distribution of marine mammal species. At this time, the most important areas within the North Water are the three main wintering areas for Walrus (Figure 5, red zones) in Murchison Sound, west of Wolstenholme Fjord, and the entrance to Jones Sound at Coburg Island (Figure 2). The Baffin Bay (BB), Lancaster Sound (LS), and Kane Basin (KB) subpopulations of Polar Bear (*Ursus maritimus*) also use all portions of the North Water and adjacent areas during the winter, especially to the south, west and north of the polynya. Residents of Grise Fiord confirm Polar Bear occurrence throughout Jones Sound, particularly during winter.

Narwhals, Beluga Whales, and Bearded Seals (*Erignathus barbatus*) also frequent the North Water in winter, occupying the open water regions and leads (Figure 5, overlap of species seen in dark orange). Narwhals arrive in late November, and overwinter in central parts of the North Water and northern Baffin Bay. The use of these regions is thought to be driven by high densities of their preferred prey, Greenland Halibut, although their winter feeding ecology remains a knowledge gap. Critical wintering habitat for the Eastern High Arctic-Baffin Bay Beluga stock can be found on the Canadian side of the North Water (Figure 5, orange-red). Approximately 15% of the Somerset Island Beluga Whale population is estimated to migrate through the North Water to wintering areas along the west Greenland coast.

Spring

By early spring, the Greenland side of the North Water has more open water and Belugas are observed in greater numbers off the northwest coast of Greenland and into the central part of the North Water. Walrus still occur both on the Greenlandic and Canadian side, where the mouth of Jones Sound remains important (Figure 6A). The early and enhanced productivity influences large schools of Arctic Cod, as well as squid and crustaceans. In Canada, the entrance to Jones Sound and south shore of Devon Island have also been identified as calving and feeding habitat for Belugas, and an east-west spring migration route for both Beluga Whales and Narwhal. IQ from Grise Fiord indicates that Narwhal follow the floe edge in eastern Jones Sound, mating at the entrance to Jones Sound, and feeding along the coasts and fiords during late spring and summer. Narwhal numbers also increase on the Greenland side of the North Water in the spring, especially at the entrance to Inglefield Bredning.

Later in the spring, Walruses from Greenland begin to migrate to nearshore haul-out areas on the Canadian side of the North Water (they are largely absent from the Greenland side during the open water season; Figure 6B). At this point, the terrestrial environment becomes more important, as they spend the summer along the coasts and within the fiords of Ellesmere Island. Polar Bears remain in all sea ice areas surrounding the open waters of the polynya, and utilize this habitat primarily for mating and hunting.

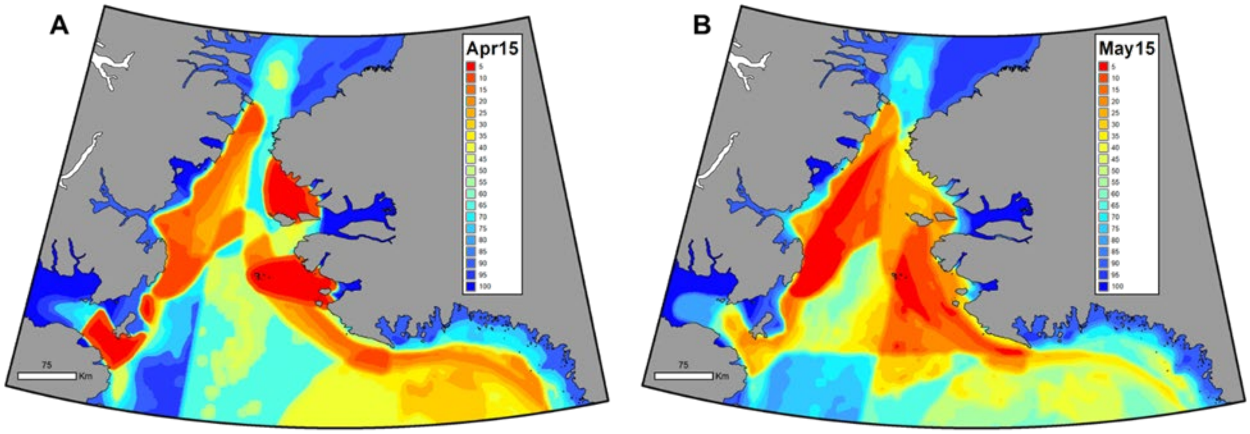

Figure 6. Map of biologically important areas in spring (April 15/May 15) as indicated by a GIS overlay analysis of the distribution of important species (marine mammals and birds) and ecosystem components. The map is colour-shaded in 5% percentiles on a scale from dark blue (lowest values), over yellow, to dark red (highest values). A) In mid-April, the Walrus wintering areas still dominate the map (red areas), as does the main Beluga wintering area in orange in the Canadian part of the North Water. However, the general biodiversity related to the fast-ice edges of the polynya begins to show up (in orange), as does the emerging spring algae bloom in the centre of the polynya (light yellow shades). B) By mid-May, a triangular area in the Greenlandic part of the North Water is highlighted as important (red/dark orange). This is driven by overlapping spring distributions of Walrus, Narwhal, Beluga, and Bowhead Whale. The elongated important area off the Canadian coast highlights overlapping distributions of Beluga, Walrus, Narwhal, and Polar Bear, and the colour shades in the central parts of the North Water reflects the spring algae bloom. Note: Large species distribution shifts occur in May, and the important areas in map B should therefore be seen only as a snapshot in the middle of a dynamic transition period. Also note that millions of seabirds arrive to the area in April-May, but as there is no knowledge of particular pre-breeding concentration areas, they have no influence of the spatial configuration of import areas yet (Source: Christensen et al. 2017).

Summer-Fall

In the summer-fall, Walruses and Narwhals are the primary marine mammals in the North Water, and Beluga distribution has shifted away from the North Water to core summering areas in Somerset Island, Lancaster Sound (and adjacent waterbodies), and Jones Sound. In the summer of 2019 and 2020, unusually large numbers of Arctic Cod were seen near the community of Grise Fiord, and with it, an increase in the observed numbers of Belugas, Narwhals, and Harp Seals *(Pagophilus groenlandicus)* (L. Audlaluk, Hamlet of Grise Fiord, pers. comm.).

In Greenland, Melville Bay and Inglefield Bredning are thought to be important foraging and breeding areas for Narwhal (Figure 7B, orange area). In general, preferred summer habitat for Narwhal includes deep, steep-sided inlets with partial ice cover, possibly to provide protection from Killer Whales (*Orcinus orca*), although, Killer Whales are rarely seen along the west and east sides of the North Water. Bowhead Whales (*Balaena mysticetus*) are present in the North Water region from April through September, followed by a western migration. In recent years, Minke Whales (*Balaenoptera acutorostrata*) have also been observed or caught by Greenland hunters several times during the summer.

Terrestrial Walrus haul-out sites in Canada are critically important during summer and early fall periods of sea-ice minima. Harp Seals, Hooded Seals (*Cystophora cristata*), and Ringed Seals are also common summer residents throughout the region. Hunters from Qaanaaq indicate that Walruses are seldom seen on the Greenland side during the summer, which is also confirmed by satellite tracking data. However, the first sign of a terrestrial haul-out sites in Wolstenholme Fjord was observed recently, after a more than 50 year absence. Important areas for Polar Bears have primarily shifted to the coast of Ellesmere Island during this time period, but include the Greenland side of Kane Basin, and any available sea ice habitat in the northern portion of the North Water. The north coast of Devon Island has been described as an important area for Polar Bear denning, as well as summer retreat habitat around Hyde Inlet and Philpots Island off eastern Devon Island (see Figure 2).

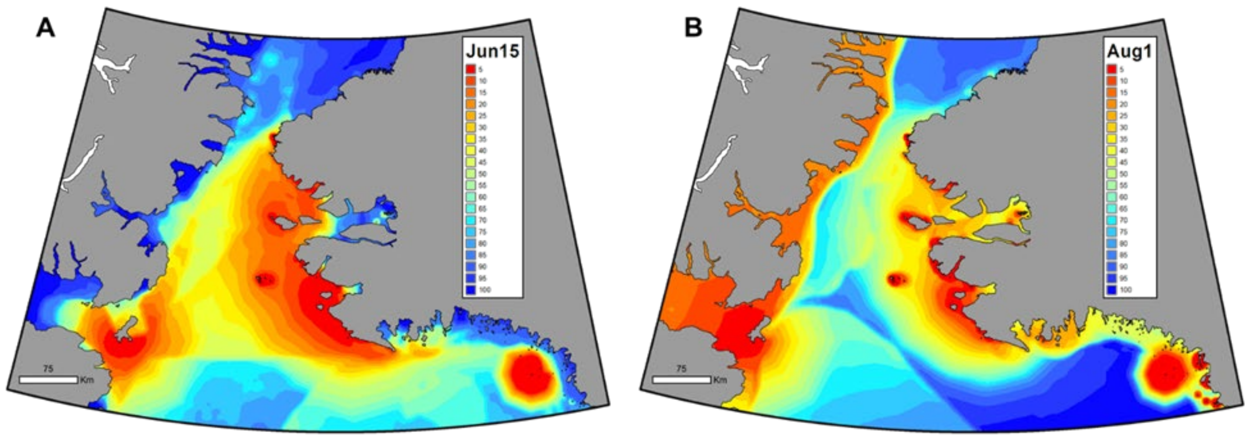

Figure 7. Map of biologically important areas in summer (June 15/August 1) as indicated by a GIS overlay analysis of the distribution of important species (marine mammals and birds) and ecosystem components. The map is colour-shaded in 5% percentiles on a scale from dark blue (lowest values), over yellow, to dark red (highest values). A) By mid-June, millions of seabirds are actively breeding in large colonies around the North Water, and the foraging ranges around these colonies, where many birds are concentrated and now dominate the relative distribution of important areas. The large red areas are primarily driven by Thick-billed Murre, Dovekie/Little Auk, and Common Eider colonies. The large red dot in Melville Bay reflects a large and unique Sabine's Gull (and Arctic Tern) colony. B) In early August, the foraging habitats around large seabird colonies are still highlighted as the most important areas (in red), as are Common and King Eider moulting areas along Greenland coasts. However, compared to map A, much of the relative weight/importance has shifted to the Canadian coast, where Narwhal, Walrus and Polar Bear now concentrate (large orange area). Inglefield Bredning and Melville Bay also have higher relative importance due to Narwhal, and Narwhal and Polar Bear concentrations, respectively (Source: Christensen et al. 2017).

Summer breeding, feeding and nesting site for seabirds

By the summer, millions of seabirds arrive to areas surrounding the North Water to breed and feed (Figures 7A, red zones). There are 14 species of seabirds that regularly use the region for breeding and the most abundant is the Dovekie/Little Auk (*Alle alle*), with more than 30 million breeding pairs. In addition, five colonies of Thick-billed Murres (*Uria lomvia*) are found in the area (with more than 308,000 breeding pairs) and tens of thousands of Common Eider (*Somateria molissima*). Seabird 'hotspots' in the North Water tend to be more concentrated/localized during the summer, and directly related to large breeding colonies of Thick-billed Murres, Dovekies (absent from Canada), Sabine's Gulls (*Xema sabini*) and Arctic Terns (*Sterna paradisaea*) (Figure 7A). In late summer/early autumn moulting areas for Common and King Eider (*Somateria spectabilis*), which are more common along the coast of Greenland, also represent important concentration areas (Figure 7B, 8A).

Coburg Island (Nirjutiqavvik National Wildlife Area) is one of the most important seabird nesting areas in the Canadian Arctic, specifically for the Black Guillemot (*Cepphus grylle*), Black-legged

Kittiwake (*Rissa tridactyla*), Northern Fulmar (*Fulmarus glacialis*), and Thick-billed Murre. Ivory Gulls (*Pagophila eburnea*), endangered in Canada (COSEWIC 2006), have undergone a range contraction in recent years, such that their only remaining Canadian nesting area is on Ellesmere Island, Nunavut.

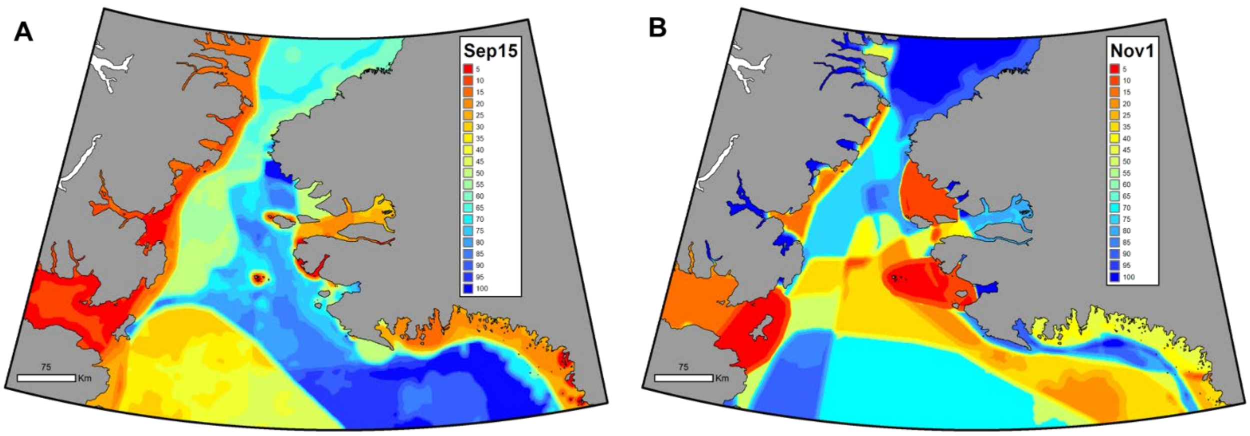

Figure 8. Map of biologically important areas in fall (September 15/November 1) as indicated by a GIS overlay analysis of the distribution of important species (marine mammals and birds) and ecosystem components. The map is colour-shaded in 5% percentiles on a scale from dark blue (lowest values), over yellow, to dark red (highest value). A) By mid-September, the seabird breeding season is over and most birds have left the area. However, Common and King Eider moulting areas along Greenland coasts are still highlighted as important. The Canadian coastal areas are very important due to overlapping distributions of Walrus, Polar Bear and Narwhal. Inglefield Bredning and Melville Bay also have relatively high importance due to Narwhal and Narwhal + Polar Bear concentrations, respectively. B) By late October/early-November, Walruses start to concentrate in their wintering areas (the three red areas). Narwhals gradually move from their coastal summering areas (along the Canadian coast, in Inglefield Bredning and Melville Bay) to winter in the central parts of the North Water. Here they overlap with the Beluga fall migration and Polar Bears which gradually disperse from the Canadian coasts and Melville Bay as sea ice expands. Note: Large species distribution shifts occur during fall, and the important areas in maps should therefore be seen only as snapshots in a dynamic transition period (Source: Christensen et al. 2017).

Coastal habitat vital for subsistence species

Coastal rivers, shallow coastlines, and fast ice edges surrounding the North Water are important habitats for commonly harvested species such as Beluga Whales, Narwhal, Walrus, Polar Bear, Ringed Seal, Arctic Char, Greenland Halibut, and various seabirds. However, for many species in the North Water, there remains limited knowledge of seasonal habitat use in the many coastal fiords and inlets. Arctic Char has historically been a valuable subsistence species for the local Thule people of Greenland, and is similarly harvested in coastal marine habitats near the community of Grise Fiord. Evidence to date suggests rapid change in kelp forests in coastal Arctic environments as the oceans warm and sea ice retreats. As such, there is the possibility of expansion of kelp forests in the North Water, which would provide new habitats for fish and other marine organisms.

The Dovekie, Thick-billed Murre, Black Guillemot, Glaucous Gull (*Larus hyperboreus*), Ivory Gull, Black-legged Kittiwake, Common Eider, Northern Fulmar, and the Long-tailed Duck (*Clangula hyemalis*), have all been historically harvested by communities near the North Water. Seabird habitat in the North Water, specifically for nesting and breeding, is most common on islands (e.g., Coburg Island) and along the sides of fiords, coastal mountains, and the cliffs of

Greenland and Ellesmere Island, where open water is consistently available throughout the summer season. Coastal sea ice also plays an important role in the distribution of some birds in the North Water, as the presence of sea ice along coastal areas may force the birds to feed further offshore. Marine mammals are most often hunted near communities, in the coastal ice-free environment or along the floe edge surrounding the polynya in the winter. Due to the disappearance of offshore and archipelago summertime ice, Polar Bear habitat appears to be shifting to lower sea-ice concentrations and has resulted in bears remaining closer to land, with predicted increases in the use of coastal-terrestrial habitats in the future.

Key data and knowledge gaps

- Data collection on stock structure, spatial distribution, movements, numbers, and ecology of seabird and marine mammal species that occur in the North Water region is often incomplete or outdated.
- Little is known about the behaviour, movement, migration, feeding, and overwintering location of the Jones Sound, Smith Sound, and the Inglefield Bredning Narwhal stocks. Specifically, researchers still do not know where the ~3,600 Narwhals that spend winter in the North Water go during summer, nor where the ~24,000 Narwhals from Smith Sound and Inglefield Bredning migrate during winter. In general, there is lack of knowledge of marine mammal use of coastal fiords systems.
- As the sea water temperature increases, the cold-water dependent Bowhead Whales might change their behaviour and move more northwards. It is important to monitor this species in relation to the predicted warming of the North Water, as they might alter their migration route.
- Walrus have been absent from historical terrestrial haul-out sites in West Greenland for the last 50 years. However, in 2018 the first sign of a terrestrial Walrus haul-out was found near the Thule Air Base/ Pituffik. This occurrence requires further study, as it may be a response to the North Water sea ice becoming thinner and providing Walrus with less opportunities to find suitable sea ice habitat/haul-outs.
- Very little in know about the population development and key factors influencing the Dovekie population in Greenland, specifically how changes in the North Water food web will influence the species productivity in their most important breeding area.

Stressors

Climate Change

The North Water is a system highly sensitive to changes in the physical environment, driven by natural fluctuations and climatic influences. Since this area is prone to extremely strong winds, it is highly sensitive to climate driven changes in pressure patterns. Communities in the region have emphasized that winds throughout Baffin Bay are now stronger, more erratic, and less predictable than they have been in the past. The community of Grise Fiord has also documented more rain in the region, and different kinds of precipitation (L. Audlaluk, Hamlet of Grise Fiord, pers. Comm.), which can be an important indicator of climate driven changes. The most northern part of Nares Strait (close to the Lincoln Sea) may be transitioning from an area with large amounts of multiyear ice to a seasonally ice-free area during the summer. The transition towards a thinner and mechanically weaker ice cover has reduced the duration of ice bridging and increased ice flux through Nares Strait. As such, the recurrent nature of the polynya appears to be weakening. Communities of northwest Greenland also equate changes to sea ice conditions with the increasing instability of the ice bridge. Recent ocean and sea-ice modelling simulations (1981–2070) carried out for the North Water and northern Baffin Bay (Myers et al. 2019) show a strong future reduction in sea-ice concentration and thickness, significant upper-ocean warming, and changes in salinity (highly dependent on the size of the estimated future runoff from Greenland). These changes ultimately lead to scenarios with more, or less, stratification in the region, potentially leading to large impacts on the productivity in the region.

In the North Water, high inter-annual variability can be attributed to differences in year-to-year ice cover, and a balance between oceanographic (i.e., ocean currents and temperature) and climatic forcings, with longer and shorter blooms during years of low and high ice cover, respectively. However, despite inter-annual variability, the North Water has been impacted by climate change over the past decade, specifically a decline in the recurrent and predictable productivity from the past (Niemi et al. 2019). Declines in productivity across the Arctic are suggested to be a product of changing conditions that have resulted in physical changes to the environment (e.g., increased stratification and reduced mixing and/or upwelling). In the North Water, it is largely attributed to changing sea-ice conditions and delayed formation, or absence, of the ice bridge in Nares Strait. Shrinking pack ice can also have a significant impact on the benthic ecosystem, specifically changes in the amount, quality, timing, or source of carbon to the benthos.

The future impact on the North Water from melting glaciers, from both atmospheric and oceanic warming, could be substantial. Calving events are expected to increase as the climate warms, resulting in more icebergs and ice islands moving through Nares Strait. Large ice features, when grounded, promote consolidation of pack ice and slow down ice flow, which may impact the ice bridge, thus affecting the formation of the polynya. Additionally, glacial meltwater from Greenland and Ellesmere Island has significantly increased in recent decades, resulting in a strong freshening of the surrounding waters. The increased freshwater flux (both surface and subglacial), and its impacts on stratification, nutrient and biogeochemical cycling (e.g., inhibiting vertical heat and nutrient transfer from deeper waters), ocean circulation, sea ice cover, and general ecology are going to be important drivers of change in the North Water.

Changes and variability in sea ice conditions (i.e., reductions in sea ice, loss of the perennial ice cover) are having impacts on habitat availability, diet, competition and predation leading to shifts in migration and distribution of many Arctic species, primarily in the eastern Canadian Arctic. Comparisons from the 1990’s to the 2010’s show that the large subpopulation of Polar Bears in Baffin Bay, at the southern edge of the North Water, is showing clear signs of stress, while the small subpopulation of Kane Basin, at the north side of the North Water is experiencing potentially improved habitat conditions. The Kane Basin area, directly north of the North Water, is already shifting from a habitat with abundant multiyear ice to more seasonal ice cover, resulting in shifts of productivity that affect the ecosystem at several levels.

Possible colonization by invasive aquatic species into the region could have varied impacts on the North Water system. For example, the Blue Mussel (*Mytilus edulis*), a largely temperate species currently found at the southern boundary of the North Water, could expand throughout the North Water in response to a warmer climate. Mussels create hard substrates that increase the abundance of other biota; their presence could have a noticeable impact on the community structure within the North Water. For resident and migratory marine mammal and seabird populations, some species are more vulnerable to these ecosystem changes than others. One of particular concern is the Thick-billed Murre, which is known as a so-called “single prey loader”, capable of bringing back only one food item at a time to feed it’s chick, and thus highly sensitive to changes in availability of big food items and changes in the North Water food web.

Transboundary and pervasive stressors

The issue of pollutants and other anthropogenic stressors from outside the Arctic resulting in significant impacts within the region is not a recent phenomenon. Within the North Water region anthropogenic pollution and contaminants, such as Persistent Organic Pollutants (POPs) and trace metals, have been found in high concentrations. As a result of biomagnification in the ecosystem, some bird species that are known scavengers, such as Ivory Gulls, are susceptible to bio-accumulating contaminants, putting them at increased risk of adverse toxic effects. Plastics (macro and micro) are another form of contamination across the Arctic that can cause toxic effects and physical injury to biota, such as fishes, marine mammals, and seabirds, as a result of ingestion, entanglement, and other negative interactions. The issue of plastic pollution is one of increasing concern within the Arctic, and should be considered as an additional transboundary stressor on the North Water ecosystem.

The North Water is an important site for the exchange of gases between the atmosphere and ocean. During the winter/spring, the open waters of the polynya facilitates the flux of carbon dioxide from the atmosphere to the ocean, which acts as an atmospheric carbon sink. The increase in dissolved carbon dioxide results in a decrease in the pH of the seawater, leading to ocean acidification that can negatively impact the marine life of the region. The potential effect of ocean acidification within the North Water region is an added stressor which will need to be taken into consideration when assessing future conservation measures.

A recent transboundary issue has also been noted in regards to the release of residual hydrazine fuel contained in Russian rocket stages that regularly come down in Baffin Bay and the North Water region. The potential impacts from hydrazine within the North Water are unclear and volatility of hydrazine in cold water is also unknown. The effects on the North Water ecosystem which could result from the continued releases of rocket stages in the region is of concern.

Potential/future impacts related to local resource development

Largely due to its remoteness, the North Water region is one which has historically been free from commercial activities. Ships rarely go so far north, except to resupply communities. Commercial fishing activities do occur in the waters south of the North Water and have the potential to impact biodiversity in the North Water. For example, there is a high bycatch rate of Greenland shark from longlining fishing practices in other regions and the possibility of sensitive benthic habitats being damaged from bottom trawling. Increases in large-scale shipping (e.g., inshore mine activities) and tourism activities in the North Water region are also possible future stressors and would result in increased disturbance for sensitive fish, seabird and marine mammal habitats (i.e., noise and physical disturbance).

Currently, mineral extraction and hydrocarbon activities in the North Water region are low compared to other Arctic regions, yet there is some potential for mineral and hydrocarbon activities to increase in the future. Specifically, localized shipping and year-round extraction is expected to increase as mining projects in west Greenland are approved. Potential risks from any resource extraction activity in or near to the North Water include construction impacts, large spills (including hydrocarbon), and underwater noise from shipping and seismic activity during oil and gas exploration.

The human population density is low around the North Water, and therefore subsistence hunting is generally considered sustainable in the region. However, the hunting pressure on Narwhals (Heide-Jørgensen et al. 2020) and Walruses can be high on the Greenland side of the North Water, and catches have been at times higher than the scientific advice from the North Atlantic

Marine Mammal Commission (NAMMCO) and Joint Commission on Narwhal and Beluga (JCNB).

Future Monitoring and Research

In Canada, the National Inuit Strategy on Research (NISR) sets a new standard for how research should be conducted in Inuit Nunangat. The strategy emphasizes the need to respect Inuit self-determination in research and outlines priority areas related to Inuit governance of research (i.e., conservation economy, research ethics, alignment of funding with Inuit priorities, access, ownership and control of data and information, and capacity building). It also highlights the need for a partnership approach to research resulting in enhanced benefits for Inuit communities and society at large. In Greenland, there remains good collaboration between managers, researchers and locals, and these collaborations are being strengthened as new projects are designed. For example, usable platforms (e.g., apps, web atlases) to integrate the different knowledge systems into a future monitoring paradigm that can help inform future management of the North Water region.

Continued monitoring of seabird colonies and marine mammal populations in the North Water, offers opportunities to detect trends in the marine environment and to assess how species are adapting to rapidly changing environmental conditions. It is very important to continue the collection of species specific data (i.e., population surveys, telemetry-movement studies) and any already established monitoring (short or long-term) programs. In Greenland, long-term research and monitoring activities in the North Water are already occurring on more or less regular intervals. Most common are seabird and marine mammal monitoring programs, conducted by the Greenland Institute of Natural Resources (GINR). According to the Greenland seabird monitoring plan, surveys in the North Water are conducted every 5-10 years for murres and Kittiwakes. Monitoring of marine mammals in Greenland follows a plan designed to provide stock assessment and management advice for Walrus, Beluga, and Narwhal, with emphasis on aerial surveys being carried out at least once every 5-10 years. This monitoring plan is similar in Canada, however the last High Arctic Cetacean Survey (2013) only assessed Narwhal and Bowhead populations, and most Walrus and Beluga populations using the North Water region have not been surveyed for over 10 years. Both the Kane Basin (north of the North Water) and Baffin Bay (south of the North Water) Polar Bear subpopulations were surveyed in a joint Canada/Greenland effort in 1992–1997, and again in 2011–2014 (SWG 2016). The Scientific Working Group of the Canada/Greenland Joint Commission on Polar Bear (JCPB) recommend that a new population assessment should be carried out in the mid 2020's, and would likely be a joint effort and ideally, coordinated by the JCPB at the start of the 2020's. The Lancaster Sound Polar Bear subpopulation, located to the east of the North Water, is scheduled for a population inventory starting in the spring of 2021.

Following the principles of NISR, future research and monitoring needs in the North Water will most effectively be done through knowledge co-production, whereby researchers and local knowledge holders work in partnership to develop and co-lead monitoring and research programs that exploit the strengths of both knowledge systems. In Greenland, there is an ambition to include 'user knowledge' in this process, including knowledge from hunters, fishermen and other local users. A new research strategy is aimed to be approved by the Greenland Government and published in 2021. Much of the knowledge specifically pertaining to the North Water remains with local knowledge holders. It is expected that future integration of both IQ, and local and hunter knowledge, together with scientific knowledge, will lead to a holistic understanding of the North Water system that addresses priorities of mutual importance. Inuit and local users of the region have an intimate connection and knowledge of the area and wildlife, including a historical understanding of the local system changes. As such, local communities are uniquely positioned to carry out year-round, sustained monitoring of the North Water (e.g., through Inuit Stewardship programs, QIA 2020), which among other things, can lead to an understanding of seasonality and long-term ecosystem change that is not achievable through occasional short-term studies. As more local information is shared, new features or stressors within the North Water may be identified, helping to inform future co-design of research and monitoring programs. It is important for governments and the science/research community to co-develop research initiatives, in order to ensure that the research being done has direct benefit for the communities.

Some of the major uncertainties and knowledge gaps outlined in this report should inform future research priorities for the North Water region and facilitate informed future policy decisions. However, these research priorities will require longer timelines to properly account for any meaningful change in this complex system. It will also require coordinated efforts between Canada and Greenland for the development of a comprehensive multidisciplinary ecosystem research and monitoring plan. Canada, Greenland, and Denmark already prioritize the work and collaboration within the Arctic Council. Scientists, as well as experts from ICC, are active in monitoring and assessment programs under CAFFand the Arctic Monitoring and Assessments Programme (AMAP). This includes the network established under the Circumpolar Biodiversity Monitoring Programme (CBMP), and AMAP Contaminant Programme, and the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) assessment (AMAP 2017). Furthermore, the Arctic Council Working group, Protection of Arctic Marine Environment (PAME), has established expert groups, and guidelines and tools for advancing Ecosystem Based Management and for the development of Marine Protected Area Networks in the circumpolar context. For example, it will be important to consider management in the context of potential connected networks (e.g., Tallurutiup Imanga National Marine Conservation Area and Tuvaijuittuq in Canada). Consideration should be given to these existing networks and tools when developing future, international joint management and/or monitoring for the North Water region.

Research considerations

1. Continual and long-term collection of ecosystem data will help to broaden the knowledge needed for future decision making in the North Water region. It has been recommended to establish year-round monitoring (i.e., in-situ) sites throughout the region to examine the ocean, sea ice, and atmospheric properties, as these are essential to the understanding of the physical, biological, and chemical processes, and the variability and change in the North Water. Specifically, local community-level climatic observations can help identify and fill wider regional climate/weather knowledge gaps.
2. As future management of this region is considered, monitoring sea ice (e.g., observations of the ice export, both sea ice and glaciers, through Nares Strait, and formation and melt of the ice bridge) in the North Water region will be critical for increasing our understanding on how reductions in sea ice are likely to influence the duration of the polynya, primary productivity, as well as the availability of habitat for sea ice dependent species. In addition, it will be important to understand the relationships between the glacier and fiord dynamics, and the role they play in primary production in the North Water.
3. Continued monitoring and research efforts are needed to identify indicators of change in the North Water system. For example, the northward movement of southern species such as Blue Mussels, Capelin, and Sandlance, may be indicators of change in the North Water. Birds and marine mammals may also be good indicators of ecosystem change as they congregate at areas of increased productivity and can be used to identify hotspots, as well

as offer further insight through changes in migration and utilization of areas from year-to-year.

4. The Dovekie and Thick-billed Murre are both highly sensitive to changes in the food web, and the two most important populations to monitor (e.g., population development, availability of food items, diet of chicks, and reproduction success).
5. In general, monitoring and sampling of harvested species is an efficient way to detect changes in the environment. This is logistically difficult in these often remote areas of the North Water, but nonetheless of great value when looking at large-scale changes
6. Updated information on changes occurring within the North Water ecosystem is needed, including those resulting from human activities and stressors. This is required to support effective species conservation and ensure the sustainability of subsistence and commercial harvests within or adjacent to the North Water region.
7. The continued development of spatial mapping exercises/databases and hotspots analyses for the North Water are important tools in providing baseline measures to help guide future discussion of important and vulnerable areas, and can easily be expanded on in the future (i.e., updated layers, sources of information). In addition, shared open-access data portals can provide better harmonization and access to relevant datasets across countries.

Sources of Uncertainty

While the North Water region has been intermittently studied over the years since 1867, many knowledge gaps exist and present challenges when evaluating long-term trends for the region. As described above, there are a number of themes that are lacking significantly in data (e.g., ice-associated algae, unique ice habitats, fiord/coastal interactions, and climatic projections). This can be attributed, in part, to the highly remote location of the North Water, high degree of connectivity and complexity within the system, and at times, jurisdictional challenges. As a result, sporadic research programs and varied sampling effort between Canada and Greenland, have resulted in short time-series and uncertainty in terms of the comparability of datasets, as technology and collection methods have evolved. Additionally, collection methods and availability of published knowledge (Indigenous/local and scientific) can vary between Canada and Greenland, resulting in different recommendations and/or monitoring actions by each country. It has been acknowledged that some historical scientific data may not be useful for our current thinking of the North Water ecosystem and its long-term health, and these data may be more appropriate when considering episodic impacts or short-term changes in the system.

CONCLUSIONS

Sarvarjuaq/Pikialasorsuaq is one system stretching across an international border (QIA 2020). It is a place of great ecological, cultural, economic, and political importance, connecting communities with rich resources and wildlife. This interconnectivity is physically supported by the presence of a polynya, ice bridges, and surrounding coastal regions and landfast ice, which are key habitats and migration corridors for many important Arctic species. In the winter and spring, the North Water offers open water and important ice edge habitat for marine mammals. By the summer, millions of seabirds migrate to the North Water to feed and nest on the many coastal cliffs and fiords. The majority of the fiords and coastal regions (i.e., river mouths, cliffs, glaciers edges) surrounding the North Water are underexplored and understudied by science, yet these unique ice and productive habitats (marine and terrestrial) are vital for local hunting of subsistence species, such as Arctic Char, Beluga, and seabirds. In addition, some migratory species, such Narwhal, are harvested by Canadian and Greenlandic Inuit as far as Kullorsuaq and Qikiqtarjuaq.

The North Water has historically been judged one of the most biologically productive regions in the Arctic, defined by early and predictable phytoplankton blooms, uniquely dependent on many complex physical and biogeochemical controls. Although these characteristics remain true, the magnitude, location, and timing of productivity in the region is changing. There are strong signals that climate change is impacting the seasonality and timing of each physical and oceanographic process in the North Water, and has ultimately resulted in a disconnect between primary production and the upper food web. The timing and consistency of these processes are critical for supporting forage species for resident and migratory species throughout the year. The ice bridges are becoming increasingly unstable and variable, as are the fast-ice edges around the periphery of the North Water, which has increased the quantity of drifting ice through the region, and resulting in cascading impacts further south in Baffin Bay.

As our understanding of the overall changing Arctic system continues to expand, so must our understanding of the links between regional dynamics, and global climate change and variability. It is important to document and understand the changes that are already occurring, as the future of the North Water is uncertain. As mentioned, future programs and research efforts must continue to be co-developed by communities and researchers on both sides of the North Water, with the goal of better understanding and predicting how future conditions and activities across the region will impact the communities and marine ecosystem. This continued collaboration among international partners and stakeholders will be the key to advancing the protection of Sarvarjuaq/Pikialasorsuaq. At the CSAS meeting, it was decided that no boundaries be included on the study area map. This signifies an understanding that processes and changes occurring in the North Water system do not follow international boundaries, and underpins the necessity of working together to answer large and complex problems. Focusing on improving our common understanding of the North Water ecosystem is the next step in supporting conservation and protection of the region, as well as ensuring that Inuit harvesting and food security is sustainable into the future.

LIST OF MEETING PARTICIPANTS

All participants at this science peer review meeting are expected to participate as objective and knowledgeable individuals on the subject matter under review; not advocates or representatives of any interest group.

Name	Organization/Affiliation
Jason Stow (Co-Chair)	DFO – Science, Ontario and Prairie Region
Tom Christensen (Co-Chair)	Aarhus University, Denmark
Claire Hornby (Science lead)	DFO – Science, Ontario and Prairie Region
Kevin Scharffenberg (Rapporteur)	DFO – Science, Ontario and Prairie Region
Elizabeth Worden (Rapporteur)	University of Manitoba, Canada
Bethany Schroeder	DFO - Marine Planning and Conservation, Arctic Region
Glenn Benoy	DFO – Science, National Capital Region
Steve Ferguson	DFO – Science, Ontario and Prairie Region
Cory Matthews	DFO – Science, Ontario and Prairie Region

Name	Organization/Affiliation
Humfrey Melling	DFO – Science, Pacific Region
Maya Gold	DFO – International Oceans Policy, National Capital Region
Garry Stenson (Contributor)	DFO – Science, Newfoundland and Labrador Region
Christine Michel	DFO – Science, Ontario and Prairie Region
Monika Pućko	DFO – Science, Ontario and Prairie Region
David Murray	Parks Canada Agency
Grant Gilchrist	Environment Climate Change Canada
Evan Richardson	Environment Climate Change Canada
Bjarne Lyberth	Department of Nature and Environment, Gov. of Greenland
Inge Thaulow	Department of Nature and Environment, Gov. of Greenland
Andres Mosbech	Aarhus University, Denmark
Søren Rysgaard	Aarhus University, Denmark
Paul Myers	University of Alberta, Canada
Andrew Hamilton	University of Alberta, Canada
Luke Copland	University of Ottawa, Canada
Lauren Candlish	University of Manitoba, Canada
David Barber	University of Manitoba, Canada
Tim Papakyriakou	University of Manitoba, Canada
Dorthe Dahl-Jensen	University of Manitoba/University of Copenhagen, Denmark
Connie Lovejoy	Laval University, Canada
Philippe Archambault	Laval University, Canada
Jean-Éric Tremblay	Laval University, Canada
Maxime Geoffroy	Memorial University, Canada
Larry Audlaluk	Hamlet of Grise Fiord, Canada
Stephanie Meakin	Inuit Circumpolar Council, Canada
Chris Debicki	Oceans North Canada
Annie Eastwood	Oceans North Canada
Erin Keenan	World Wildlife Fund, Canada
Nynne Hjort Nielsen	Greenland Institute of Natural Resources, Greenland
Fernando Ugarte	Greenland Institute of Natural Resources, Greenland
Andrew Randall	Qikiqtani Inuit Association, Canada
Andrew Bresnahan	Qikatani Inuit Association, Canada

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Telephone: 204-983-5131
E-Mail: xcna-csa-cas@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-41247-4 Cat. No. Fs70-6/2021-052E-PDF

Correct Citation for this Publication:

DFO. 2021. Identification of Ecological Significance, Knowledge Gaps and Stressors for the North Water and Adjacent Areas. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/052.

Aussi disponible en français :

MPO. 2021. Détermination de l'importance écologique, des lacunes dans les connaissances et des agents de stress pour les eaux du nord et les zones adjacentes. Secr. can. de consult. sci. du MPO. Avis sci. 2021/052.

Inuktitut Atuinnaummijuq:

ᐃᖃᓗᓕᕆᔨᒃᑯᑦ 2021. ᓇᓗᓇᐃᖅᓯᓂᖅ ᐱᕈᖅᐸᓪᓕᐊᔪᓕᕆᓂᕐᒧᑦ ᐅᔾᔨᕐᓇᖅᑐᓂᒃ, ᖃᐅᔨᒪᓂᕆᔭᐅᔪᑦ ᐱᓚᖃᖕᖏᑦᑐᑦ ᐊᒻᒪᓗ ᖃᐅᔨᔾᔪᑕᐅᔪᑦ ᐅᑭᐅᖅᑕᖅᑐᒥᑦ ᐃᒪᕐᒧᑦ ᐊᒻᒪᓗ ᐊᑭᐊᓂᑦ ᐃᓂᐅᔪᑦ. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/052.

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Kalaallisut aamma atuarneqarsinnaavoq :

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