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IDENTIFICATION OF ECOLOGICAL SIGNIFICANCE, KNOWLEDGE GAPS AND CONSERVATION OBJECTIVES FOR THE TUVAIJUITTUQ MARINE PROTECTED AREA

Context

The Tuvaijuittuq Marine Protected Area (MPA; Figure 1) was established by Ministerial Order on August 21, 2019 based on its importance to ice-associated species and in response to increasing accessibility for human activities in the Arctic. Protection via Ministerial Order under the Oceans Act allows the Minister of Fisheries, Oceans and the Canadian Coast Guard ("the Minister") to freeze the footprint of human activities in the area for a period of up to five years while a feasibility assessment is undertaken to determine appropriate the long-term protection tools for the area (e.g., designation as an Oceans Act Marine Protected Area [MPA] by Governor-in-Council and a National Marine Conservation Area under the Canada National Marine Conservation Areas Act).

Figure 1. Current boundaries of the Tuvaijuittuq Marine Protected Area (MPA) in northern Nunavut. Adapted from DFO (2019).

The Government of Canada, in partnership with the Qikiqtani Inuit Association and Government of Nunavut, requires a feasibility assessment for the area. This includes a biophysical and ecological overview of the Tuvaijuittuq MPA, recently published in a report by Charette et al. (2020). The report provides a comprehensive overview of the most current and available information for the area, including information to support the identification of significant ecosystem components (SECs), ecologically significant species and community properties (ESSCPs), and the identification of important areas (Charette et al. 2020). The advice arising from this Science Response Process will inform the decision-making process for establishment of long-term protections in Tuvaijuittuq and will assist in discussions of boundary (and zones if required) and inform the establishment/regulatory approaches. The advice will also inform a future risk analysis for the area, identify priority areas for protection, and refine existing conservation objectives using the most current published information available. This review will also inform subsequent advice on monitoring protocols and strategies, identification of information gaps requiring further research, and the development of a management plan for the area.

This Science Response Report results from the Science Response Process of October 6–7 and October 28, 2020 on the Identification of Key Biophysical and Ecological Features of the Tuvaijuittuq Marine Protected Area (MPA).

Background

Regional Scope

Tuvaijuittuq includes the marine waters off northern Ellesmere, Axel Heiberg and Ellef Ringnes islands, extending to the outward boundary of Canada's Exclusive Economic Zone. The MPA extends from the western edge of Prince Gustav Adolf Sea to the northeastern tip of Ellesmere Island, and south along the western shore of Robeson Channel into Archer Fiord. It includes Nansen Sound and Greely Fiord but excludes those portions of the Ellesmere Island coastline that are part of Quttinirpaaq National Park (DFO 2019; Figure 1).

Habitat within Tuvaijuittuq is a combination of ice shelves occupying small fiords and the continental shelf along the northern shore of Ellesmere Island, extensive cold-season fast ice within the perimeter of the Canadian Arctic Archipelago (CAA), contiguous fast ice along the outer margin of the archipelago and mobile pack ice, across the fiord-coastal-ocean domain. The latter extends in winter from the Canada Basin of the Arctic Ocean to the northern edge of fast ice bordering the Queen Elizabeth Islands (QEI). In summer as fast ice weakens and breaks free of coastal confinement, the pack ice expands to encompass almost the entire MPA. However, fast ice does persist throughout the warm season in some areas (DFO 2011). It provides unique, but poorly studied, habitat for a number of ice-associated species, ranging from ice-adapted microbes and amphipods to higher trophic species, such as seals, walruses and Polar bears (*Ursus maritimus*).

Tuvaijuittuq is located within a larger area of multi-year pack ice in the Arctic Ocean. This ice is delivered by the Transpolar Drift and held against the obstacle of the CAA with its ice-choked channels by wind and current. The multi-year ice (MYI) within Tuvaijuittuq extends hundreds of kilometers offshore, and farther yet to the north-east and south-west along the continental margin. Although the south-western limit of the MPA is the Prince Gustaf Adolf Sea, MYI circulates widely in the Arctic Ocean, spreading: i) north-east to Greenland, Fram Strait and eventually the Greenland Sea; ii) south-east through the Queen Elizabeth Islands to eastern Parry Channel and Baffin Bay, or to western Parry Channel, M'Clure Strait and the Beaufort Sea or to M'Clintock Channel and the mainland coast; iii) south-west to the Beaufort Sea, Amundsen Gulf, the Alaskan Coast, Chukotka and sometimes as far south as Bering Strait. Eventually, the clockwise circulation of the Beaufort Gyre brings some of the south-west drifting ice component back into the MPA from the north-west (DFO 2011, Hibler III 1989, Gerland et al. 2007, O'Brien 2019). Much of the present MYPI area which falls within the Inuvialuit Settlement Region (ISR), can be considered contiguous habitat. In winter, floes of MYPI are fused together by new growing ice to form an immobile cover of land-fast ice that spans almost the entire CAA, and that remains immobile in many areas well into August (Melling 2002, Münchow 2016, CIS 2020). Following break-up, some of this formerly fast ice drifts into Baffin Bay via a number of routes. Although the North Water is hundreds of kilometres south of Tuvaijuittuq, the southward transport of MYPI from Tuvaijuittuq through Nares Strait directly impacts this vital early season open-water habitat (Ingram et al. 2002, Barber et al. 2019).

Tuvaijuittuq is influenced by large-scale oceanic transport in the Arctic Ocean and serves as an important pathway for the export of water and its associated properties (e.g., nutrients), and sea ice, through Nares Strait and the CAA channels. Pacific-derived waters reach Tuvaijuittuq from the Beaufort Sea to the west and spread across the region under the varying influence of the Beaufort gyre. As these nutrient-rich waters circulate in Tuvaijuittuq, they are modified by biological uptake and microbial processes, resulting in declines in nutrient concentrations along the transport pathway from the west to the Lincoln Sea and Nares Strait. Tuvaijuittuq is also influenced by Atlantic waters. The Trans-Polar Drift, which flows directly towards Ellesmere Island from the Russian side, bifurcates within the MPA, so that conditions in the north-east part are less influenced by Pacific-derived waters and more strongly influenced by Atlantic water. The variable influence of the Trans-Polar Drift and the Beaufort Gyre, linked to large scale climate patterns such as Arctic Oscillation, critically impacts ocean properties, productivity and ecosystems in Tuvaijuittuq.

Owing to its location at the gateway to the North Water and Baffin Bay, and at the receiving end of far-field influences from Pacific and Atlantic waters, and sea ice, Tuvaijuittuq plays a key role for the connectivity of the entire Arctic system.

Objectives

The objectives of the peer-review are to:

1. describe and map (where possible) key biophysical and ecological features of the Tuvaijuittuq MPA and adjacent areas (if applicable), possibly including:
    a. predominant and unique physical and biological oceanographic and sea ice characteristics;
    b. predominant, unique, and sensitive habitat features; and
    c. key ecological species, and the abiotic and biotic factors influencing these.
2. identify known sensitivities/vulnerabilities of habitats and key ecological species within the Tuvaijuittuq MPA.
3. identify key uncertainties and knowledge gaps as they pertain to the current understanding of the existing environment and key ecological species within the Tuvaijuittuq MPA, and recommend research to address these gaps, where possible.
4. provide science advice for consideration in the development of conservation objectives and priorities, and boundaries identified for the Tuvaijuittuq MPA.

Analysis and Response

A biophysical and ecological overview was developed for the Tuvaijuittuq region and adjacent areas by Charette et al. (2020), informed by a comprehensive literature review of published scientific documents, reports and peer reviewed journals, as well as known Inuit Qaujimajatuqangit (IQ). The report also identifies currently known or potential stressors to the ecosystem, and highlights where scientific knowledge may be lacking for the region.

While the Tuvaijuittuq region has been intermittently visited and studied over the years, there exists an overwhelming number of knowledge gaps, largely attributed to the highly remote nature of the area and difficulty of access due to the presence of thick multi-year sea ice. Superimposed on the general lack of knowledge of the area, there is a high degree of connectivity and complexity within the system (e.g., influence of sea ice, near-field and far-field climate and oceanographic forcings) as it connects the Beaufort Sea to the North Water and downstream ecosystems of Baffin Bay and the Labrador Sea. There are widespread knowledge gaps for all ecosystem components (e.g., unique ice habitats, benthic invertebrates, fishes, birds, marine mammals), or in other cases the data available are spatially and temporally limited and further study is required to determine status and/or trends. Even fundamental structural ecological features such as bathymetry hitherto suffer from extremely poor data coverage, with soundings at every 20 km or so in some areas and none in the fiords of Tuvaijuittuq (see map of bathymetric soundings in Charette et al. [2020]).

To address these knowledge gaps and in an effort to support Canada's commitments to the Convention on Biological Diversity, a research program was undertaken by DFO to initiate ecosystem data collection within the Tuvaijuittuq region, in partnership with other federal agencies (Environment and Climate Change Canada [ECCC], Department of National Defense [DND], Defense Research and Development Canada [DRDC]), and in consultation with communities that are the closest to Tuvaijuittuq (e.g., Grise Fiord, Resolute Bay, and Arctic Bay). The Multidisciplinary Arctic Program (MAP) – Last Ice constitutes an initial effort towards the collection of baseline ecosystem-based knowledge in Tuvaijuittuq. The program investigates the unique MYI ecosystem of the region, on the basis of an ecosystem approach that integrates physical, chemical and biological ecosystem components, including marine mammal surveys (Loewen et al. 2018, Michel and Lange 2018, Michel et al. 2019). New scientific knowledge on the species that inhabit the region and habitat usage is emerging, for example the presence of numerous Atlantic walruses (*Odobenus rosmarus rosmarus*) and narwhals (*Monodon monoceros*) in Archer Fiord, farther north than their known distribution range (Yurkowski et al. 2019, C. Carlyle, DFO, pers. comm.). Most results are still under analysis and have not yet been published in peer-reviewed scientific literature. A Special Issue in the scientific Journal Elementa Science of the Anthropocene will be published over the next months and will provide a compilation of results and original findings from this ecosystem research. Highlights of new findings, presented during community meetings, include observations of abundant and diverse benthos under MYI-covered areas, a finding that would not have been possible without the use of new technology (underwater remotely operated vehicle).

In addition to the background ecosystem overview document (Charette et al. 2020), first-hand observations and knowledge from experts who have been in the region conducting field work and research will provide insights into our knowledge and understanding of the ecosystem to support the recommendations and advice for Tuvaijuittuq.

Tuvaijuittuq is located at the northernmost boundary of the CAA and is remote from northern communities. However, the ecological and cultural footprint of Tuvaijuittuq ranges much further than its boundaries. In particular, Tuvaijuittuq is the upstream region for the export of sea ice and ocean properties into channels of the CAA, and the North Water at its eastern boundary in the Lincoln Sea. The export of sea ice and the physical, chemical and biological properties of the waters in Tuvaijuittuq influence processes in Baffin Bay and even as far as the Labrador Sea. The ocean/sea ice and biological connectivity between Tuvaijuittuq and adjacent regions (e.g., CAA, including Lancaster Sound) is ecologically and culturally important for Inuit communities living beyond its boundaries.

Ecological Significance and Key Knowledge Gaps

Multi-year Ice

Tuvaijuittuq is a unique region of persistent MYI. Since the beginning of the satellite record in 1979, Arctic summer sea ice extent has declined more than 30% (Meier et al. 2014, Perovich et al. 2019). Old MYI (> 4 years), which represented 33% of the Arctic Ocean ice pack in March 1985, made up only 1.2% in March 2019. The remaining oldest and thickest ice is largely confined to the Tuvaijuittuq region (Tilling et al. 2018, Perovich et al. 2019).

Ice fields are composed of two main ice types: first-year ice (FYI) and MYI. FYI forms when crystals of frazil ice, that are the first result of freezing seawater, aggregate and bond together to form pancakes or nilas (NSIDC 2018). FYI is the ice type that in winter dominates those Arctic seas from which all or most ice clears or melts in summer. It is not so common within most of Tuvaijuittuq where much of the sea surface is already occupied by ice at the end of the thaw season. However, FYI does form during the freezing season in the leads that continually open in pack ice, and in fiords and embayments. MYI is FYI that has lost thickness over the summer, and has begun to accumulate new ice on its under-surface (Barber et al. 2010, NSIDC 2018). First-and multi-year ice have distinct physical and morphological properties that distinguish them from one another (Johnston 2017). Moreover, there are important differences between MYI formed largely via thermodynamic processes and hummocked MYI which is derived from pressure ridges. Multi-year ice is the dominating ice type in Tuvaijuittuq but FYI is also present, and it is dominant locally in Nansen Sound and the fiords of western Ellesmere Island (CIS 2016a, 2016b). Multi-year ice in Tuvaijuittuq is characterized by heavy ridging, accumulated during many years at sea and augmented locally through the action of high compressive and shearing forces. Indeed, the dominance of MYI is precisely the reason for creating this MPA.

All ice types decrease in strength during the melt season, but the decrease is smallest in MYI, especially the hummocked types that are abundant in Tuvaijuittuq (Johnston 2017). Ridging is a very important factor in the ice regime of Tuvaijuittuq because of high ice pressure. It dramatically and rapidly increases ice thickness all along the outer coast from Fram Strait to M’Clure Strait (Bourke and Garrett 1987).

Thick MYI accumulates in Tuvaijuittuq as a result of persistent wind and ocean currents that push the sea ice up against, and into, the QEI and northern Greenland (Howell et al. 2008, Moore et al. 2019). Tuvaijuittuq is also a source of MYI that is transported south into the QEI and into Baffin Bay via Nares Strait (Howell et al. 2008, Rasmussen et al. 2011). Southward transport of ice into the QEI occurs in summer but halts in autumn and winter as floating pack ice blocks the straits of the QEI connected to Tuvaijuittuq by forming arches (Melling 2002). In most years, MYI flowing south from the Lincoln Sea (eastern region of Tuvaijuittuq), to Baffin Bay via Nares Strait is obstructed by a seasonal ice arch that forms during winter at the north end of Smith Sound, until spring break-up when the southward flow of ice into Baffin Bay resumes (Dumont et al. 2009, Ryan and Münchow 2017). Ice arches in Smith Sound and Amundsen Gulf are the best known and most precarious of the QEI ice arches. Their widely varying dates of formation from year to year are an indication of their inherent fragility; in some years they do not form. An analysis of the date of break-up of the ice arch in Nares Strait, north of Smith Sound, for the period 1968-2014 show that the ice arch consistently formed until 1990, after which it failed to form on multiple occasions, influencing sea ice and biological conditions in the North Water (Barber and Massom 2007, Blais et al. 2017).

However, the apparently more reliable arches across other channels cannot necessarily be taken for granted in a changing climate. Should they not form in the future, channels such as Sverdrup Channel, Peary Channel, Prince Gustaf Adolf Sea, and Ballantyne Strait, with a combined width of 275 km – comparable to the East Greenland Ice Stream – might possibly move a similar area of ice (1 M sq km) annually out of Tuvaijuittuq. Such a leaky ice barrier could have serious consequences for Tuvaijuittuq.

Tuvaijuittuq means “the place where the ice never melts” in Inuktitut, as MYI is present there at concentrations of 9 to 10 tenths year-round (CIS 2020). In winter, its mobile component (pack ice) can be at varying distances offshore, but it is separated from the outer coastlines of the High Arctic islands by a zone of land-fast (10/10) ice, containing a dense aggregation of MYI floes within a matrix of FYI (Melling 2002). Episodic wind-driven movements of the pack ice away from the edge of fast ice repeatedly open a flaw lead (part of the circumpolar flaw lead system) along this edge. The lead sometimes extends 2000 km from Amundsen Gulf to the northern tip of Ellesmere Island (Stirling and Cleator 1981, Fissel et al. 1984a,1984b, Smith Jr. and Barber 2007). Under frigid winter conditions, the opening flaw lead becomes quickly covered by thin FYI. In summer, the same events expose the sea surface that remains ice-free. Flaw leads can represent areas of enhanced marine productivity at multiple trophic levels in spring and summer (Barber et al. 2010). However, their importance to the marine ecosystem of Tuvaijuittuq remains unknown.

Knowledge Gaps

- Multi-year and first-year ice concentration data based on RADARSAT synthetic aperture radar (SAR) imagery are available from the Canadian Ice Service Archive, and two recent studies evaluate sea ice trends in parts of Tuvaijuittuq (Howell and Brady 2019, Moore et al. 2019). However, there is an urgent need to characterize sea ice properties and dynamics in the region, particularly MYI thickness and trends which are necessary to improve baseline knowledge and help constrain future climate change predictions.
- Fast ice between the Queen Elizabeth Islands, which stops ice from drifting south-east out of Tuvaijuittuq for most of the year, is a critical factor in the existence of a notional last ice area. The seasonal formation and collapse of ice arches is readily observed but not understood. This lack of understanding precludes reliable foresight into the future of Tuviajuittuq under climate change.
- A flaw lead polynya opens up periodically between November and May in the Lincoln Sea, but little is known about the timing and mechanisms of formation, its productivity, or the biota it supports.

The Ellesmere Island Ice Shelves

Ellesmere Island, which is directly adjacent to Tuvaijuittuq, is the only location in Canada where ice shelves are found (Dowdeswell and Jeffries 2017, Mueller et al. 2017). These shelves are remnants of a larger, more contiguous shelf (8,900 km^2) that fringed the entire northern coast of Ellesmere Island from up to 5,500 years ago until the early 20th century (Vincent et al. 2001, England et al. 2008, Mueller et al 2017). Since then, thinning ice and major calving events, usually coinciding with warmer than usual summers, have resulted in continual ice shelf decline (Braun 2017). From 1906 to 2015, the areal coverage of the Ellesmere ice shelves decreased from 8,597 to 535 km^2 resulting in 4 major (Ward Hunt, Ward Hunt East, Milne, and Petersen) and 9 minor (< 10 km^2) (Ward Hunt Northwest, Ward Hunt North, M'Clintock, Petersen North, Wooton, Wooton East, Ayles East, Serson, and Serson East) ice shelves (Mueller et al. 2017). The largest remaining shelf is the Ward Hunt Ice Shelf (224 km^2, Figure 2) which, together with the Ward Hunt East Ice Shelf and three minor ice shelves, are currently part of Quttinirpaaq National Park (Parks Canada 2009, Mueller et al. 2017). The other ice shelves to the west of M'Clintock Inlet are all located in Tuvaijuittuq (Figure 2).

The Ellesmere Island ice shelves within Tuvaijuittuq also host microbial mats dominated by cyanobacteria (Vincent et al. 2004, Jungblut et al. 2017). The microbial mats standing stock of the Ellesmere Island ice shelves in 2001–2002 was estimated at 34 Gg of organic material (Mueller et al. 2006) and the Ward Hunt Ice Shelf annual primary production was determined to be 108 g C m^{-2} y^{-1} (Mueller et al. 2005). Moreover, in 2001, the two best-studied ice shelves, Ward Hunt and the now extinct Markham, had respectively 10% and 44% of their surfaces potentially suitable for microbial mat communities (Mueller et al. 2006). The vast majority of this prime ice shelf habitat was lost due to calving over 2008–2012 (Mueller et al. 2008, Vincent et al. 2011, Mueller et al. 2017).

The Ellesmere Island ice shelves are habitat for the Endangered Ivory Gull (*Pagophila eburnea*), a Species at Risk in Canada. This species is also identified by northern communities (Resolute Bay and Grise Fiord) as declining. Ivory gulls nest on nunataks above the Ellesmere Island ice shelves and feed exclusively in the marine environment adjacent to the ice shelves (J. Provencher, ECCC, pers. comm.).

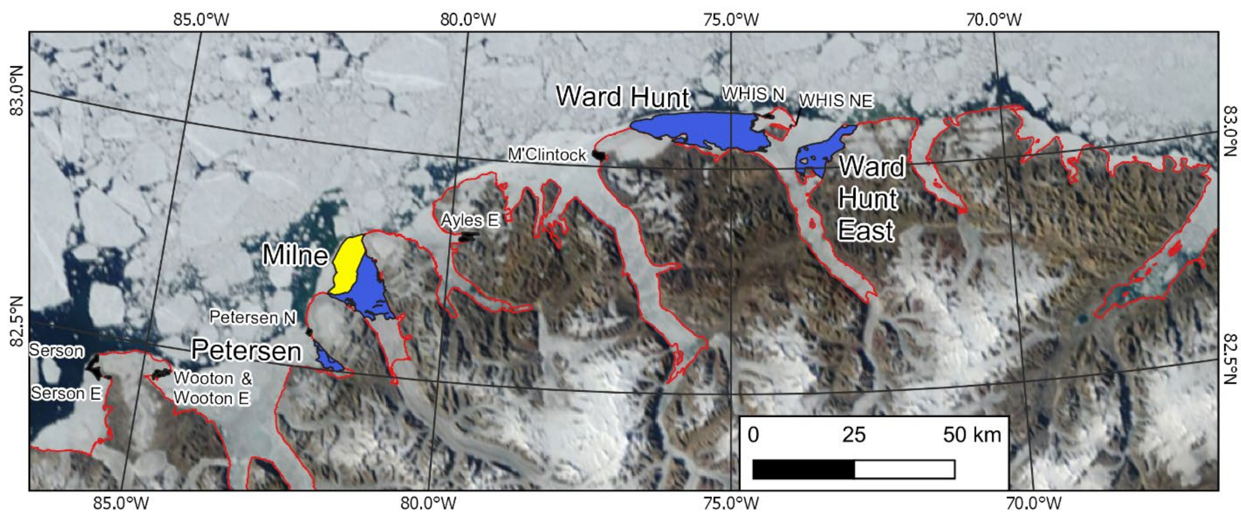

Figure 2. Location of the four major (>10 km^2; in blue) and 9 minor (<10 km^2; in black) Ellesmere Island ice shelves as of 2015 (Mueller et al. 2017). The area that calved from the Milne Ice Shelf at the end of July 2020 is shown in yellow. The July 26, 2020 MODIS image in the background is courtesy of NASA. WHIS: Ward Hunt Ice Shelf.

Knowledge Gaps

- The habitat use of the Ellesmere Island ice shelves by birds species, in particular the Ivory Gull, a Species at Risk in Canada, is poorly documented. There are complete knowledge gaps in regard to their abundance, distribution, and life history dependency on a marine diet in coastal waters near Ellesmere Island.

- Further study of the rapidly changing ice shelves, their unique biota, and their connectivity to the coastal ecosystem of Tuvaijuittuq is required in order to better understand the changing physical conditions of the shelf-ocean system and their influence on the diversity, distribution and abundance of biota.

Tuvaijuittuq Fiords

Northern Ellesmere Island Fiords

The landward side of Tuvaijuittuq is distinguished by a large number of bays, inlets and fiords. Several of the fiords and inlets extend more than 50 km inland into northern Ellesmere Island, including Clements Markham Inlet, Markham Fiord, Disraeli Fiord, McClintock Inlet, Yelverton Inlet and Philipps Inlet, and some contain or have recently contained, the Ellesmere ice shelves and associated ecosystems. Despite their large collective expanse and diversity of forms and size, little is known about most of these coastal features, and even the most basic knowledge about their bathymetry – the shape of the seabed and the depth of the water – is sparse or completely lacking (see Charette et al. 2020).

A small number of sites have been explored as part of specific research projects, and these studies have identified unusual environments and ecosystems. For example, Taconite Inlet contains a well stratified, water column, with an unusual thermal profile and anoxic bottom waters (Ludlum 1996). Disraeli Fiord contained an epishelf lake with freshwater zooplankton (Van Hove et al. 2001) but this drained through a crack in the Ward Hunt Ice Shelf in 2002–2003 (Mueller et al. 2003). With the break-up of the Ward Hunt Ice Shelf, recorded by automated camera in 2011–2012 (NEIGE 2020), this is now a vast glacier-fed fiord ecosystem, newly opened to the Arctic Ocean, with remnant land-fast sections of the Ward Hunt Ice Shelf.

There is ongoing research in Milne Fiord that is focused on the Milne Ice Shelf, the associated epishelf lake, the Milne Glacier and, most recently, the surrounding watershed. The water column in this fiord is heavily modified by the presence of the Milne Ice Shelf, which is responsible for creating the sharp halocline which demarcates the bottom of the epishelf lake at a depth of approximately 10 m (Hamilton 2016, Veillette et al. 2008, Thaler et al. 2017). Fiord water is distinct from ambient water offshore to a depth of 50 m (the mean draft of the Milne Ice Shelf) and below 260 m depth, which was used to infer the presence of a sill under the ice shelf. Milne Ice Shelf and Milne Glacier ice tongue are not in contact with relatively warm Atlantic water (< 200 m depth) and this has acted to preserve these cryospheric features from rapid melt (Hamilton 2016). An ice-tethered oceanographic mooring located in the middle of Milne Fiord and numerous CTD profiles have demonstrated the importance of terrestrial-marine processes within this fiord environment. The epishelf lake deepens seasonally in response to meltwater input from the surrounding catchment (Hamilton et al. 2017). This, and the discovery of an outflow channel beneath the Milne Ice Shelf has led to modelling efforts to better understand mixing within the fiord over the winter season (Bonneau 2020) and watershed-scale modeling of runoff is now underway to better constrain the relationships between climate and fiord oceanography. The atmosphere has warmed substantially in this region over in the last 50 years (White and Copland 2019) and will continue to do so which will have profound implications on runoff to fiord systems and ecosystems, whether they contain ice shelves or not.

All of these coastal features should be considered a component part of Tuvaijuittuq in that they contain or are strongly influenced by the multi-year sea ice along the coast, and provide diverse habitats for marine life in the region. These also constitute the interface between land and sea, and act as conduits for the transfer of snow and ice meltwaters from Ellesmere Island to the Arctic Ocean, along with organic carbon, nutrients and biota such as microbes and fish.

The numerous fiords of this region are also a reminder that sea and land are intimately connected in this region, including along the northern coast of Quttinirpaaq National Park. The thick ice in Tuvaijuittuq is pushed up against and accumulates along the land barrier of Ellesmere Island, and the landscapes, climate and ecosystems of these northern lands are strongly influenced by the persistent sea ice. There are numerous lakes along this coastline that interact with the sea to varying extents, including many that drain to the sea (such as the Taconite Inlet lakes, Ludlam 1996; Ward Hunt Lake, Bégin et al. 2020), some that contain Arctic Char that likely migrate between marine and freshwater habitats (Veillette et al. 2012), and several that are derived by uplift from the coastal Arctic Ocean over the last few thousand years, with ancient seawater still trapped within their basins (Hattersley-Smith et al. 1970).

Nansen Sound/Greely Fiord Complex

In addition to the protection of key features identified within Tuvaijuittuq during preliminary studies, and identified above, the Nansen Sound/Greely Fiord region is also considered a key region for conservation. The fiord provides a pathway for the run-off of the Ellesmere Island ice caps to the coastal ecosystem of Tuvaijuittuq, and likely can be characterized by a suite of unique oceanographic and biogeophysical conditions resulting from these influences. This region is adjacent to two important features of Tuvaijuittuq that are recommended for protection (the multi-year ice pack and the ice shelves of Ellesmere Island), is somewhat easier to access compared to the rest of Tuvaijuittuq, and it has important baseline climate data available from the neighbouring ECCC Station at Eureka. Potential nesting habitat for seabirds has been identified as an important feature of the region (eBird 2017). During engagement and consultation meetings, the area was identified by community members as important habitat for travel across sea ice by the High Arctic population of Peary Caribou (*Rangifer tarandus pearyi*), classified as Endangered under the *Species At Risk Act* (R. Eagleson, Parks Canada Agency, pers. comm.).

Lady Franklin Bay/Archer Fiord Marine Mammal Habitat

Ringed seals (*Pusa hispida*), Bearded seals (*Erignathus barbatus*) and Polar bears are present in Tuvaijuittuq, however their abundance, distribution and ecological interactions in this area are largely unknown (COSEWIC 2008, Stephenson and Hartwig 2010). Information on marine mammal sightings in the Tuvaijuittuq area has been primarily based on opportunistic sightings from explorer records in the late 18th and early 19th centuries that included observations of Atlantic walrus and narwhal (Greely 1886, Peary 1910).

The first systematic marine mammal aerial survey in Tuvaijuittuq, carried out in 2018 in the region north and northeast of Ellesmere Island, revealed the presence of walruses in Archer Fiord, much farther north than their known distribution range (Yurkowski et al. 2019). These sightings were confirmed in a subsequent survey in 2019, which also showed the presence of narwhals including a yearling, in the same region near the head of Archer Fiord (C. Carlyle, DFO, pers. comm.). Overall, 36 Atlantic walrus, 29 narwhal, 34 Ringed seals and two Bearded seals were observed. This indicates that Archer Fiord may be a location where numerous individuals of several marine mammal species congregate (e.g., Altantic walrus, narwhal, Bearded seals and Ringed seals), possibly due to enhanced productivity relative to surrounding areas. As Nares Strait opens up during summer sea ice break-up, the area becomes accessible to marine mammals who can travel northwards from the North Water, as well as between Greenland and Canadian waters.

Knowledge Gaps

- Fundamental knowledge gaps exists with respect to the oceanography and ecology of the Tuvaijuittuq fiords, including sparse or absent bathymetric soundings.
- The fiords constitute a zone of connectivity between the terrestrial, ice shelves, and ocean domains. The loading and cycling of materials in the fiords, exchanges with the coastal ocean, and responses to climate change require dedicated sampling and monitoring at key locations. The rapid changes and recent collapse of ice shelves (e.g., Milne ice shelf in summer 2020) calls for immediate attention.
- Marine mammal distribution and habitat use within Tuvaijuittuq is not well known. Atlantic walruses and narwhal have only been observed in Archer Fiord within Tuvaijuittuq, along with Ringed seals, Bearded seals and Polar bears which have also been observed in the remainder of the MPA. However, marine mammal surveys conducted in Tuvaijuittuq are limited in space and time and the seasonal use of, and behaviour of these marine mammal species in the region, are largely unknown.

Sea ice-associated Communities

Multi-year sea ice provides a unique, yet poorly studied, habitat for a number of ice-associated species ranging from ice-adapted microbes and amphipods to seabirds and Polar bears. Older MYI, particularly the thick ridges and hummocks found in Tuvaijuittuq, are considered important habitat for ice-dependent biota such as key zooplankton species *Gammarus wilkitzkii* (Hop and Pavlova 2008, Gradinger et al. 2010). The thin snow cover associated with hummocks would increase light transmittance compared to surrounding areas of higher snow cover, thereby offering suitable habitat for ice algal communities (Lange et al. 2017). Although MYI is typically considered less productive than FYI, ice cores collected from MYI hummocks in the Lincoln Sea were found to have significantly higher mean chlorophyll *a* biomass than thinner (i.e., non-hummocked) MYI (Lange et al. 2015, 2017). Ice algae are an essential component at the base of Arctic marine food webs, supporting plankton, benthic invertebrates, and under-ice fauna, through processes such as ice-pelagic-benthic coupling, which is an important transfer pathway for ice-associated production to the food web.

To date, several species of algae, bacteria, viruses and other microbes have been identified in Tuvaijuittuq as part of MAP – Last Ice (Charette et al. 2020), contributing to the overall diversity of the Arctic marine ecosystem. There is evidence of different lipid signatures (Kohlbach et al. 2020) and different ice algal community composition between MYI and FYI in Tuvaijuittuq (J. Charette, DFO, pers. comm.) and in other areas of the Arctic Ocean (Hop et al. 2020). Multi-year ice also has a higher diversity of ice-associated flora and fauna compared to FYI (Melnikov et al. 2002, Hop et al. 2011, 2020)

Invertebrates act as the link in Arctic marine food webs, making the energy from primary producers available to higher trophic levels such as fish (e.g., Michaud et al. 1996), whales (e.g., Lowry et al. 2004, Pomerleau et al. 2011), seals (e.g., Harwood et al. 2015), and birds (e.g., Jakubas et al. 2017). Ice associated invertebrates can be divided into two categories: species that are obligate ice users throughout their life cycle and therefore dependent on MYI (referred to as autochtonous), and species that facultatively use the sea ice and can thrive in seasonal ice environments (referred to as allochtonous; Gulliksen and Lønne 1991, Barber et al. 2015). Ice-associated fauna and zooplankton consume ice algae from under the ice either *in situ* or as the algae sinks through the water column (Michel et al. 1996, 2002), with a shift from ice-associated to phytoplankton sources as the season progress (Brown and Belt 2012). Uptake and storage of large quantities of lipids during ice algae and phytoplankton blooms is essential to the survival of these Arctic zooplankton (Søreide et al. 2010, Record et al. 2018). Ice-associated zooplankton species *Calanus hyperboreus* and *C. glacialis,* synchronize their reproductive cycles with the ice algal bloom to take advantage of high quality polyunsaturated fatty acids produced by ice diatoms, which are important for reproduction and to build reserves for the diapause during the winter months (Falk-Petersen et al. 2009, Record et al. 2018).

The different species have different life cycles and association with sea ice, which are further described in Charette et al. (2020). *G. wilkitzkii,* an autochtonous species not commonly observed in FYI-covered areas of the CAA, was observed attached to the sea ice in Tuvaijuittuq (C. Michel and S. Duerksen, DFO, pers. comm.). This species has been found in areas of seasonal ice, but at 10–100 times lower biomass than in those of MYI; furthermore, the growth rates of individuals in FYI areas were also lower than in MYI regions indicating that FYI is a low quality habitat for these amphipods (Beuchel and Lønne 2002).

Arctic Cod (*Boreogadus saida*) are circumpolar, highly dependent on sea ice (Welch et al. 1993, Mecklenburg et al. 2011) and are ecologically pivotal as both predator and prey in pelagic and benthic food webs of Arctic marine systems (e.g., Crawford et al. 2012, David et al. 2016, Kohlbach et al. 2017, Coad and Reist 2018). Despite being an ecologically and biologically important species, little is known regarding the ecology and movement of Arctic Cod, particularly in areas with high concentrations of MYI. Arctic Cod likely spawn under the ice and their eggs float to the surface and hatch near the ice-water interface (Bain et al. 1977). Arctic Cod larvae use the subsurface of the ice and its brine channels and wedges for feeding and predator avoidance (Bain et al. 1977, Gradinger and Bluhm 2004). Adult Arctic Cod are strongly associated with sea ice and, in the central Arctic Ocean, higher abundances were linked with thick ice cover and higher densities of the amphipod *Apherusa glacialis* (David et al. 2016). Arctic Cod diet consists mainly of ice-associated species such as calanoid copepods, amphipods and mysids (David et al. 2016, Kohlbach et al. 2017). Arctic Cod, in turn, are important in the diets of other fishes, marine mammals, and seabirds, all of which concentrate at floe edges to feed (Bradstreet and Cross 1982, Welch et al. 1993, Kovacs et al. 2011), and they represent a key link between Arctic primary production and higher trophic levels.

MYI loss in the Arctic Ocean will likely have complex effects on Arctic Cod populations: it may reduce the availability of critical shelter from predators and/or reduce the availability of foraging habitat by dispersion over a larger area (Gradinger and Bluhm 2004, Marz 2010, Meier et al. 2014). There is, however, evidence that earlier break-up of sea ice will increase recruitment success of juvenile Arctic Cod due to longer growing seasons (LeBlanc et al. 2019). Arctic Cod are unlikely to be replaced by southern species in Tuvaijuittuq, and the persistence of sea ice in the region can offer refuge for cod populations.

Sea ice-pelagic-benthic coupling is a key process through which sea ice associated production is linked and transferred to the pelagic and benthic food webs. The tight coupling between sea ice and the pelagic and benthic food webs has been investigated during seasonal studies (e.g., Michel et al. 1996, 2006) and using biomarkers that revealed the importance of sea ice primary producers for pelagic grazers and benthos (Søreide et al. 2010, Kohlbach et al. 2019). The evidence of rapid sinking export of ice algae at depths > 4000 m in the central Arctic Ocean emphasizes the important role of sea ice-benthic coupling in Arctic food webs (Boetius et al. 2013).

The distribution of large marine mammals and their use of the sea ice habitat in Tuvaijuittuq is poorly known. Ringed seals, Bearded seals, and Polar bears frequent the region but quantitative assessments are lacking. Recent aerial surveys also showed the presence of numerous walruses and narwhals in Archer Fiord (see previous section).

Knowledge Gaps

- There are only a handful of studies on primary producers and ecological processes in Tuvaijuittuq, providing very limited baseline information for the region. In addition, these studies are very constrained in time and space, thereby leaving wide knowledge gaps for the vast majority of the region, and most of the year. There is limited evidence that ridged and hummocky MYI provides a unique habitat for ice-associated communities but additional studies are required to understand diversity and productivity patterns. There are currently no published data on ice-associated or open water marine productivity in Tuvaijuittuq. The seasonality, spatial distribution, and adaptive capacity of primary producers and zooplankton to changes in sea ice are all unknown for the region.
- There are no published studies on the composition and abundance of ice-associated invertebrate communities in Tuvaijuittuq. Baseline information on the distribution, species composition, abundance, and ecosystem relationships for ice-associated and open water species is required.
- Ice-pelagic-benthic coupling has been identified as an important carbon cycling and food web transfer mechanism in many Arctic ice-covered areas, but this essential information is lacking for Tuvaijuittuq. Similarly, there is no quantitative assessment of benthic communities that depend on this coupling in Tuvaijuittuq.
- The role of MYI as a habitat for ice-associated biological communities, their productivity and the connections with higher trophic levels is still poorly understood.
- Overall, there are wide knowledge gaps for baseline knowledge on primary and secondary producers and their coupling, locally, regionally, and seasonally.
- Polar bears from the Arctic Basin subpopulation are considered data deficient throughout their range, including Tuvaijuittuq. Baseline data regarding Polar Bear use of Tuvaijuittuq and adjacent areas of multi-year ice is necessary in order to monitor changes in distribution and habitat use over time as sea ice patterns in the Arctic continue to change.

Biodiversity

Despite its far northern location, Tuvaijuittuq contains a remarkable diversity of habitat types. In addition to the vast multi-year sea ice ecosystem, the region includes many other ice-dominated habitats including annual sea ice, the Ellesmere Ice Shelves and associated environments, fiords and inlets (see section above), leads of varying size and duration in the pack ice, and coastal lagoons including some cut off from the sea only a few thousand years ago and still retaining ancient seawater from the coastal ocean. Inshore, where landfast ice forms and melts, marine macrophytes (seaweeds) and inshore vertebrate and invertebrate communities are also shaped by ice dynamics. The multi-year sea ice ecosystem includes not only habitats on, within and immediately under the ice, but also the underlying water column which is connected to the sea ice through exchanges of dissolved (e.g., nutrients) and particulate materials (e.g., incorporation of organisms from the water into the ice and export from the ice), as well as properties such as heat or brine that further influence ocean dynamics. Modifications of ocean properties in the ice-covered ocean or in open leads further influence downstream ecosystems. Ocean properties also depend on upstream processes. In Tuvaijuittuq, dominant forcings are the large-scale circulation of Pacific and Atlantic waters influenced by the Beaufort Gyre and Trans-Polar Drift, which also shape biodiversity. These forcings are subject to variability associated with climate oscillations (i.e., the Arctic Oscillation), superimposed with climate change (e.g., increasing freshwater content in the Beaufort Gyre), with anticipated but unknown cascading impacts on the structure and diversity of Tuvaijuittuq ecosystems.

Given this diversity of habitats, Tuvaijuittuq is likely to support diverse biological communities, yet little is known about the abundance, productivity or species composition within the region. The recent discovery of animals living within cavities inside the Milne Ice Shelf (WIRL 2020) suggests that there will be other surprises ahead in exploring and mapping the biological richness of this region. During the MAP- Last Ice expeditions, direct observations of under ice zooplankton and fishes, as well as benthic communities, were made possible by the use of a remotely operated underwater vehicle (ROV) equipped with a camera (S. Duerksen, DFO, pers. comm., Charette et al. 2020). Swarms of amphipods (*A. glacialis*) were observed swimming directly under the ice and numerous *G. wilkitzkii* were seen attached to the bottom of the sea ice. Arctic Cod were observed under MYI. ROV dives also revealed diverse assemblages of benthic organisms underneath the ice-covered ocean. Crinoid congregations, brittle stars and basket stars (Ophiuroidea), star fish (Asteroidea), beds of scallops, glass sponges, soft corals, sea fans, anemones, and sea snails were commonly observed. Several species of benthic fish, including sculpins (Cottoidea) and fish doctors (*Gymnelus* spp.) as well as cuttlefish (*Sepia* spp.) and octopus (*Bathypolypus arcticus*) were also detected. Numerous types of sea spiders (Pycnogonida) were very abundant and one individual was observed carrying a brood of young.

Traditional collection methods, i.e., zooplankton nets, revealed an abundance of large calanoid copepods (*C. hyperboreus and C. glacialis)*, as well as *Paraeuchata norvegica, Metridia longa*, and *Themisto spp.,* the pteropod *Clione limacina,* and gelatinous zooplankton such as *Mertensia ovum* and *Beroe spp.* A large siphonophore (*Marrus orthocana)*, measuring approximately 2 m in length, was observed under the ice in 2019.

Classic techniques of collecting and identifying biodiversity at the lower trophic levels are now being augmented using molecular microbiological techniques that can reveal the rich diversity of microbial species in all domains of life. For example, unusual species assemblages dominated by chlorophytes were found in the epishelf lake associated with the Milne Ice Shelf (Thaler et al. 2017), and photosynthetic bacteria were found to dominate the ancient seawater of coastal lakes along northern Ellesmere Island (e.g., Labbé et al. 2020). Analyses of ice islands calved from the ice shelves indicate that they contain an unusual biota, and new species of cold-loving yeast have been described from these Tuvaijuittuq habitats (Tsuji et al. 2018). These studies, however, are only in their infancy and the ongoing development of molecular methods is opening up new opportunities for assessing the taxonomic and functional diversity of these northern habitats. Records of bird species along the coast (e.g., Table 2 in Vincent et al. 2011) and fish species are mostly anecdotal; for example the report of a 1 m long halibut in Disraeli Fiord (G. Hattersley-Smith, DND, pers. comm.), and Ivory gulls flying over the Milne Ice Shelf (D. Mueller, Carleton University, pers. comm.).

There is very little information about fish diversity and abundance in Tuvaijuittuq and the surrounding areas. Notably, Polar Cod (*Arctogadus glacialis)*, Arctic Cod, Arctic Char (*Salvelinus alpinus*), Fourhorn Sculpin (*Myoxocephalus quadricornus*) and Greenland Halibut (*Reinhardtius hippoglossoides*) have been confirmed above 83 °N, within the boundaries of the Tuvaijuittuq (see Table 6 in Charette et al. 2020). The International Union for the Conservation of Nature (IUCN) includes portions of Tuvaijuittuq for the range of Greenland Shark (*Somniosus microcephalus)* (IUCN 2020). Nansen Sound also hosts many fish species, especially *Cottidae*, and Glacial Eelpout (*Lycodes frigidus*) was recorded in the Canada Basin, in the deep water just outside Tuvaijuittuq (see Table 6 in Charette et al. 2020). Predicted water depths in Tuvaijuittuq are appropriate for Greenland Halibut, and this species is often found under sea ice so their presence is likely, but no direct observations have been made (Coad and Riest 2018, K. Hedges, DFO, pers. comm.).

Within Tuvaijuittuq, Arctic Char have been observed off the northern tip of Ellesmere Island and in Nansen Sound and Greely Fiord (Coad and Reist 2004, 2018). No significant rivers are present in Tuvaijuittuq, however, some lakes that drain to the sea contain Arctic Char that likely migrate between marine and freshwater habitats (Veillette et al. 2012). While Arctic Char is the most commonly harvested fish species in Nunavut, there are no commercial or subsistence fisheries within or near Tuvaijuittuq (Nunavut 2016). Existing exploratory licenses operating in Nunavut also do not include Tuvaijuittuq (Nunavut 2016).

Seabirds frequent Tuvaijuittuq but are not as abundant when compared with regions to the south, possibly due to a lesser contribution of open water productive areas (e.g., polynyas, floe edges) that typically support nesting colonies. Tuvaijuittuq is used by several nationally and internationally important species (CAFF 2013). Ivory gulls and Ross's gulls (*Rhodosterhia rosea*), classified as Endangered in Canada (COSEWIC 2006) have been observed in Tuvaijuittuq, but their abundance, distribution and habitat use within the MPA is unknown. While the only known colony of Ross's gulls is south of the region, this species has been tracked using loggers utilizing the area within Tuvaijuittuq (J. Provencher, ECCC, pers. comm.). Arctic Tern (*Sterna paradisaea*) and Glaucous Gull (*Larus hyperboreus*) are both species that are not listed under the Species at Risk Act, but have declining populations in Canada. They are both ice-associated species and nest south of Tuvaijuittuq (Mallory et al. 2020), therefore these ice-associated species are likely to rely more heavily on the habitat in this region in the coming decades.

The Tuvaijuittuq ecosystem is contiguous with the coastal lands, and with ice-dominated regions to the east and west. In particular the northern Greenland coast with its thick ice zone, fiords and polar desert landscapes, closely resembles that of Tuvaijuittuq, and is part of the same overall ecosystem.

Knowledge gaps

- Fish communities have not been studied in Tuvaijuittuq. Arctic Cod is an ice-associated species and an important link between lower and higher trophic levels in Arctic marine food webs. There is a complete knowledge gap for Arctic Cod and other fish species in Tuvaijuittuq. There are no significant rivers in Tuvaijuittuq; it is therefore unlikely that this region would offer suitable habitat for important populations of anadromous Arctic Char.
- Bird species distribution and habitat use for the bird species observed in Tuvaijuittuq is largely unknown, including for Ivory Gull and Ross's Gull, both classified as Endangered species (COSEWIC 2006).
- The exploratory ROV dives during MAP — Last Ice revealed a diversity of benthic organisms, including slow growing glass sponges. There is a complete knowledge gap regarding the diversity, abundance and distribution of benthic species in Tuvaijuittuq, as well as their connectivity with sea ice and ocean productivity and their role in the diet marine mammals and birds.
- Our current knowledge of Tuvaijuittuq is based on sparse observations rather than dedicated ecosystem-based surveys and sustained ecosystem monitoring. The uniqueness and diversity of habitats within Tuvaijuittuq suggests potential high biodiversity. However, these unique habitats or ecosystem types are not yet inventoried nor adequately characterized.

Other Considerations

- Tuvaijuittuq is one of the least studied ecosystems of the Arctic. This is a unique ecosystem where multi-year sea ice is projected to remain while it is rapidly disappearing from large expanses of the Arctic Ocean. Tuvaijuittuq can offer a refuge for ice-associated species as Arctic sea ice continues to decline.
- There are widespread knowledge gaps for Tuvaijuittuq, including ecosystem components and function, near- and far-field ocean and sea ice processes, connectivity to other ecosystems (e.g., North Water, Beaufort Gyre), and seasonality. Our knowledge is also spatially limited in this vast region.
- The documented presence of numerous Atlantic walruses and narwhals in Archer Fiord, farther north than their previously documented distributional range, shows how little we know about the distribution of species within Tuvaijuittuq, and their use of habitat. Recent indications of diverse and unexpectedly abundant benthic species in the region also point to the likely importance of sea ice-pelagic-benthic coupling on the shelf, and further highlight our limited knowledge of this remote ecosystem.
- Continued ecosystem assessments and monitoring of ecosystem change will provide the scientific basis required to support management considerations for Tuvaijuittuq. Consistent long-term ecosystem-based studies at key locations are necessary to fulfill ecosystem knowledge gaps in Tuvaijuittuq, in order to characterize baseline conditions, on-going changes, and to better predict future conditions in this unique ecosystem.
- The connectivity of Tuvaijuittuq to the wider multi-year ice ecosystem and to coastal and large-scale ocean features calls for liaison with conservation activities to the west via Northwest Territories and the Inuvialuit Settlement Region, to the south with Quttinirpaaq National Park, Nunavut), and to the east, via the Arctic Council, for the development of a network of MPAs, as well as with conservation activities in northern Greenland such as the Northeast Greenland Biosphere Reserve (UNESCO 2014).

Sources of uncertainty

The main uncertainty for Tuvaijuittuq is the lack of data, across all ecosystem components in the region. The only ecosystem study of Tuvaijuittuq is the recent DFO Program MAP – Last Ice, with field campaigns near Canadian Forces Station (CFS) Alert during spring 2018 and 2019 (2020 field program cancelled due to COVID-19 pandemic; Michel and Lange 2018, Michel et al. 2019). Results from this program are, however, localized in space and time (e.g., Lange et al. 2019, Kohlbach et al. 2020), except for aerial marine mammal surveys that extended across the shelf and into Nares Strait and Archer Fiord to the south (Yurkowski et al. 2019).

Overall, only a very small area of the marine environment of Tuvaijuittuq has been studied, and only during spring and summer. The extremely rapid changes associated with climate change, for example, the dramatic loss of ice shelves and epishelf lakes, requires immediate mobilisation to establish the rapidly changing baseline.

Stressors and Vulnerabilities

Climate Change

Climate change represents a significant threat to Tuvaijuittuq. Overall extent and thickness of Arctic sea ice, particularly during summer, have significantly declined over the past decades as MYI is replaced with thinner FYI in vast expenses of the Arctic Ocean (AMAP 2017, Perovich et al. 2019). During the past decades, the older ice has become less common (Perovich et al. 2019), so that by 2019, Arctic MYI > 3 years covered only 0.9 M km^2 compared to 3.5 M km^2 in 1985. Tuvaijuittuq now appears to harbour most of the oldest ice in the Arctic and a sizeable fraction of the remaining MYI (Perovich et al. 2019). Recent important ice shelf calving events include the complete disappearance of the Ayles and Markham ice shelves in 2005 and 2008, respectively (Copland et al. 2007, Mueller et al. 2008, White et al. 2015) and large losses from the Ward Hunt, Petersen, Serson and Milne ice shelves (White et al. 2015, Copland et al. 2018, WIRL 2020). Most of the periods of extensive calving and break-up of ice shelves have coincided with warmer than usual summers in northern Ellesmere Island (White et al. 2015, Braun 2017).

Changes to sea ice composition (e.g., MYI versus FYI), as well as spatial and seasonal extent affect all components of the ecosystem, including physical, chemical, and biological processes at various scales (for review, see AMAP 2017). The composition, location, timing and magnitude of ice algal and phytoplankton blooms (the foundation of Arctic marine ecosystems) are already impacted by climate and sea ice changes in the Arctic (e.g., Comeau et al. 2011, Leu et al. 2011, Ardyna et al. 2014). In turn, these changes have cascading effects on the diversity and abundance of higher trophic levels, the nature of energy transfer within the food web, carbon and elemental cycling, and overall ecosystem structure and function (e.g., Meier et al. 2014, Michel et al. 2015, Underwood et al. 2019). For example, the decline in MYI in the Canada Basin has been linked to a decrease in the abundance of the ice-associated zooplankton species *G. wilkitzkii* (Melnikov et al. 2002). This ecologically-important species was found in large aggregations under the MYI in Tuvaijuittuq (S. Duerksen, DFO, pers. comm., Charette et al. 2020). Lipid-rich large copepod species such as *G. wilkitzkii* provide an essential food source for higher trophic levels, and changes in their abundance and the composition of zooplankton communities therefore have cascading impacts across the food web.

Bayesian modeling also shows the importance of Tuvaijuittuq as an ice-covered refugium for ice-associated species such as Polar bears as the climate continues to warm and sea ice cover declines in other regions (Atwood et al. 2016). These species are particularly sensitive to climate change and sea ice loss (e.g., Laidre et al. 2008).

Analysis of long-term (60-years) temperature datasets from the Canadian Arctic has revealed relatively large and often significant increases in mean annual air temperature, with Eureka experiencing one of the largest increases (van Wijngaarden 2015). Climate model simulations suggest an increase in precipitation for the Tuvaijuittuq area by the end of the century (Šeparović et al. 2013). Increased rate of glacier melt on Ellesmere Island due to climate change is anticipated to augment the discharge of glacier melt freshwater and its constituents to the nearshore region of Tuvaijuittuq.

Additionally, climate variability and change influences the position of the front separating Pacific and Atlantic waters in the central Arctic Ocean, and therefore the signature of these water masses in Tuvaijuittuq. The response of these far-field ocean forcings to climate change and their influence on the marine ecosystem of Tuvaijuittuq is unknown.

Vessel Traffic/Resource Development

A summary of recent vessel transits in Tuvaijuittuq is presented in Charette et al. (2020; Table 8). Potential resource development and associated vessel traffic in Tuvaijuittuq and adjacent areas of multi-year pack ice are considered high-risk and high-cost activities due, in part, to its remoteness and the dangers presented by operation in an area of thick MYI cover. As such, the overall potential for development in the area is limited (Gavrilchuk and Lesage 2014). Extraction of oil and gas deposits within the Sverdrup Basin of the QEI (Adams 2014, Gavrilchuk and

Lesage 2014), while unlikely until more of the MYI disappears, could result in direct and indirect negative effects to key features and biota. In addition, increase in trans-Arctic vessel traffic as shipping routes open up with the decline in sea ice may be a stressor for the northern part of the MPA.

While interest in cruise ship tourism in Tuvaijuittuq may grow as MYI declines, this type of activity is currently minimal due to accessibility issues and dangerous ice conditions. An analysis of vessel traffic by Maerospace Corp. (2019) revealed that between 2012 and 2019, only one passenger vessel (the Kapitan Khlebnikov, in September 2016) entered Tuvaijuittuq at Greely Fiord through Eureka Sound. With the exception of this vessel, the only confirmed tracks identified in Tuvaijuittuq during this period were those of four icebreakers, including three Canadian (Canadian Coast Guard Ship [CCGS] Des Groseilliers, CCGS Henry Larsen and CCGS Amundsen) and one Swedish (Oden) (Amundsen Science 2019, Maerospace Corp. 2019) vessel. The vessels were present only in two regions, Greely Fiord or Hall Basin and Robeson Channel.

Environmental concerns of commercial development and increased vessel traffic in the area include, but are not limited to, damage to habitat and disturbance/injury to biota as a result of noise, oil spills and release of other contaminants, ice breaking, movement underway (e.g., ship strikes), grounding/foundering, and discharge (e.g., bilge/grey water, garbage, ballast) (Adams 2014, DFO 2020).

Fisheries and Subsistence Activities

Subsistence and commercial harvests are not currently conducted in Tuvaijuittuq due to its remoteness, dense MYI cover, high costs of harvesting, and hazardous travel conditions (DFO 2019, Maerospace Corp. 2019). The nearest communities with natural resource harvesters, Grise Fiord and Resolute Bay, are over 600 km away from Tuvaijuittuq; however, the area represents one of cultural importance to these, and other communities within the Qikiqtani Region. The distribution and abundance of potential commercial species such as Arctic Char, Greenland Halibut, and Northern Shrimp (*Pandalus borealis*) are largely unknown for the area, however, general oceanographic conditions in Tuvaijuittuq indicate the region may not be suitable for fisheries for these species (Charette et al. 2020). There is also a lack of knowledge on marine mammal distribution and use of habitat in Tuvaijuittuq despite observations of Ringed seals, Bearded seals, Polar bears, Atlantic Walrus and narwhal in Archer Fiord in recent summers (Yurkowski et al. 2019, C. Carlyle, DFO, pers. comm.). However, for Atlantic Walrus and narwhal it is unknown which populations and stocks they represent and the level of harvesting pressure they may experience during migrations to and from the MPA.

While interest in commercial fishing within Tuvaijuittuq may arise in the future, this activity is highly unlikely to occur due to sea ice and oceanographic conditions. An assessment of the productive capacity of Tuvaijuittuq is the first step towards an evaluation of fisheries potential.

Range Expansions

There is accumulating evidence of poleward expansions of sub-arctic pelagic species, from phytoplankton to fishes, in the Arctic gateways of the Pacific and European Arctic (Fossheim et al. 2015, Eriksen et al. 2017, Spies et al. 2020), largely attributed to advection (Oziel et al. 2020). Tuvaijuittuq is not directly connected to these gateways as it is located far downstream of the Atlantic or Pacific water influences, also acting a transit route of waters from the Beaufort Sea/Arctic Basin en route to their export through the narrow conduit of Nares Strait. Waters from Tuvaijuittuq are upstream of those from Baffin Bay, which means that Arctic waters from Tuvaijuittuq are transported into the North Water and further south to Baffin Bay whereas

Atlantic waters of the west Greenland current do not reach Tuvaijuittuq. Therefore, Tuvaijuittuq is not exposed to the direct influence of range expansion via advection of sub-Arctic species, i.e., advection of planktonic species or larval stages of benthic and pelagic species. Northward range expansions in Tuvaijuittuq are anticipated for highly mobile species such as marine mammals and seabirds, including gulls and terns, that can migrate to Tuvaijuittuq, either opportunistically or based on learned/adaptive behaviour, as climate and sea ice conditions are changing. Increasing abundance and distribution of these species would impact food webs via top-down effects of predation as well as competition. For example, increased predation on potentially slow-growing benthic species in Tuvaijuittuq by accrued numbers of benthic feeders, such as walruses, could disproportionally impact benthic communities. Range expansions of fish species into the eastern region of Tuvaijuittuq is possible depending on ocean conditions.

Long-range Pollutants

Like other areas of the Arctic, Tuvaijuittuq is considered a receiving environment for global pollutants, including persistent organic pollutants (POPs), mercury and microplastics. High trophic level species of interest for Tuvaijuittuq, such as Polar Bear and Ivory Gull can accumulate high enough concentrations of POPs and mercury to put them at high risk of adverse reproductive and other health effects (AMAP 2018). Future monitoring and assessment of ecosystem and wildlife health for the area should consider the effects of global pollutants in combination with other current and anticipated stressors.

Conclusions

Two unique and vulnerable habitat types, the multi-year sea ice and Ellesmere Island ice shelves are identified as predominant, unique and sensitive features within the Tuvaijuittuq region. In addition, there is a diversity of ecosystems and habitat types across the offshore, coastal, and the ice shelf-fiord domains. Ice-associated communities within the region are key species groups of interest influenced by the physical and oceanographic drivers in the region, as they define trophic pathways from zooplankton and benthos up to birds and marine mammals. Fiords connecting the ice shelves to the marine domain represent key areas of change, impacting ecosystem processes at multiple scales from microbial diversity to mixing and stratification processes. The Nansen Sound/Greely Fiord is also considered a potential key area due to the connectivity associated with important habitat types. Recent discoveries of the use of Lady Franklin Bay and Archer Fiord by several marine mammal species (e.g., Atlantic Walrus, narwhals) suggests that these areas are important habitat within the Tuvaijuittuq region. Large areas of Tuvaijuittuq have not been explored yet and, as such, we currently lack critical baseline information to understand the region's biodiversity, species distribution and habitat use, and how these are being altered as a result of climate change.

Conservation Objectives

Recognizing the unique ecological features of the marine waters north of Ellesmere Island, adjacent fiords and coastal ecosystems, Conservation Objectives for the Tuvaijuittuq MPA are as follows:

- **Multi-year ice, Ellesmere ice shelves and fiords**
    - Protect a large area of multi-year ice-covered ocean in the Canadian High Arctic, associated coastal areas, inlets and fiords and remaining Ellesmere ice shelves from potentially harmful human activities.
    - Document and monitor the physical and biological characteristics of sea ice, ocean waters, and Ellesmere ice shelves along with their associated ecosystems, to detect change and predict resulting impacts.
- **Ice-associated communities and biodiversity**
    - Document and conserve the diversity of species and ecosystems across the offshore, coastal, and the ice shelf-fiord domains.
    - Map the biogeography of Tuvaijuittuq, including seabed surveys and the characterization of unexplored areas.
    - Monitor sea ice communities and food webs to evaluate their sensitivity to climate forcings.
    - Document and investigate marine mammal distribution and habitat use in Lady Franklin Bay and Archer Fiord, and throughout Tuvaijuittuq, and the ecological processes that support these species.
    - Document and protect Species at Risk in Tuvaijuittuq, and support recovery and action plans where they exist.
    - Document ecological features and ecological connectivity, food webs and species habitat use, from sea ice, ocean processes and primary productivity to top consumers.

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